Pacific Gas and Electric Company

Emerging Technologies Program
Application Assessment Report #0620

Field Evaluation of Wireless HVAC Air Distribution Controls
Jordan Hall Annex, Stanford University

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Executive Summary

Project Objectives

PG&E's Emerging Technologies Program commissioned this application assessment of Federspiel Controls' Discharge Air Regulation Technique (DART) control system. DART is a controls retrofit for existing Constant Air Volume (CAV) commercial building HVAC systems. In a previous study, DART provided significant and cost-effective savings in fan energy, heating energy, and cooling energy

The objective of this study was to assess all aspects of the DART retrofit in a typical commercial building and measure kW, kWh, and therm savings. This study aims to quantify the energy savings, and to suggest a method of estimating the savings to be expected in future installations in PG&E service territory. This study documents the customer experience during and after the DART installation. This study also assesses the commercial readiness of DART, the potential market acceptance of this technology, and the potential savings in PG&E service territory. The goal is to determine if DART is a cost-effective, widely-accepted HVAC retrofit strategy that provides significant savings.

Project Results

The DART control system was successfully installed in Stanford University's Jordan Hall Annex and the energy savings were documented. On an estimated annual basis, DART reduced fan energy by 33%, cooling energy by 39%, and heating energy by 26%. This study shows that the energy savings are indeed significant and cost-effective. DART had negligible adverse effect on temperatures in the demonstration building. There were no reports of occupant discomfort, and no indication that building occupants were aware of any change to the HVAC system. The savings were well within the cost-effectiveness criteria of the customer. The simple payback of this DART installation before utility incentives is 1.7 years, and 0.5 years when including the incentive provided by PG&E's Non-Residential Retrofit Program.

The DART system vendor, Federspiel Controls, has a strong core business team and a business model capable of meeting increasing demand. DART fills an important market niche and does not have significant competition from any comparable product. When surveyed, potential DART customers indicated that the cost and benefits of DART make it an attractive, easily-implemented retrofit. DART HVAC retrofit projects are attractive to commercial customers and can create a considerable savings impact in the current program year.

Key Findings

ENERGY SAVINGS

A *Measurement and Verification Report* was prepared by Adam Fernandez of PG&E's Applied Technology Services (ATS). The findings on energy savings are presented in

Table 1. Two other case studies confirm the significant energy savings realized in this study.[1]

1. California Energy Commission's Public Interest Energy Research Program (PIER), *Discharge Air Regulation Technique (DART) Draft Case Study*, 2008; and Federspiel Controls, *Discharge Air Regulation Technique (DART)*; both attached to PG&E DART Market Opportunity Assessment Report.

Table 1: DART Savings Results for Jordan Hall Annex

Jordan Hall Annex Baseline Annual Usage Estimates						
Supply Fan Usage (kWh)	Return Fan Usage (kWh)	Est Cooling Usage (kWh)	Est Heating Usage (therms)	Pk Coincident Cooling Demand (kW)	Pk Coincident Fan Demand (kW)	Fan Load Factor
167,000	87,900	144,000	34,600	34.0	29.1	0.93

Jordan Hall Annex Post-DART Annual Energy Estimates						
Supply Fan Usage (kWh)	Return Fan Usage (kWh)	Est Cooling Usage (kWh)	Est Heating Usage (therms)	Pk Coincident Cooling Demand (kW)	Pk Coincident Fan Demand (kW)	Fan Load Factor
111,000	58,700	88,300	19,800	34.0	29.1	0.62

Jordan Hall Annex Post-DART Annual Energy Savings Estimates					
Supply Fan Savings (kWh)	Return Fan Savings (kWh)	Est Cooling Savings (kWh)	Est Heating Savings (therms)	Pk Coincident Cooling Demand (kW)	Pk Coincident Fan Demand (kW)
55,600	29,300	55,500	8,900	0.0	0.0

MEASURED TEMPERATURE CONTROL

Temperature control of building zones was measured by PG&E ATS both before and after activating DART control. This data relied on the sensors installed as part of the DART system, as the existing pneumatic thermostats provided no data. According to the ATS report, DART control had a negligible effect on zone temperatures.

1. The standard deviation of the 37 measured zone temperatures decreased very slightly with DART, from 0.87 °F to 0.86 °F on average.
2. The maximum daily temperature swing for the measured zones increased by 2.5°F for the worst case, zone 60.

Either change could have been affected by occupants changing thermostats or leaving windows open during the monitoring period.

OCCUPANT COMFORT

According to the facility manager of the demonstration building, there was not a single occupant complaint regarding temperature or air quality during the two months following the activation of DART control, which included the beginning of winter. In the view of the facility manager, the installation was not at all disruptive, and he believes occupants have not noticed any change at all.

CUSTOMER SATISFACTION

Energy savings from the DART system, as measured by PG&E's ATS, were modestly higher than pre-installation estimates. Stanford's demand-side energy manager is very satisfied with the savings, and the payback period of less than a year is far below their requirements for projects less than $50,000. Stanford has plans to expand DART to the rest of Jordan Hall, a further two air handling units, and evaluate it for campus-wide use.

DART's temperature data is an important benefit for facilities staff, allowing them to monitor HVAC performance and consider changes meant to reduce energy use. This measurement capability is not available with pneumatic thermostats.

MARKET OPPORTUNITY

Federspiel Controls appears to have assembled an expert team and a good business model. Their technology clearly adds value to the existing HVAC retrofit market. Federspiel Controls' market positioning is advantageous.

DART is applicable to a large number of existing buildings. Interviews suggest this will be an economically-attractive, energy-savings measure. We believe it is well suited for utility promotion.

Project Background

Wireless sensor systems are just entering the marketplace for use in building systems control and communications. They have substantial potential to decrease costs of HVAC and lighting controls and provide a basis for the expansion and improvement of controls in buildings and industrial processes. Federspiel Controls has used wireless technology in conjunction with innovative software applications to develop a new class of HVAC controls. These offer an increased level of control over systems that would be prohibitively expensive to achieve in a standard HVAC retrofit. Simply put, in many cases, this approach allows a CAV system to mimic the flow dynamics of a variable air volume (VAV) system. Given the large number of CAV systems in the building inventory, the potential of wireless retrofits, and this approach in particular, merit evaluation. This project evaluated the energy efficiency and demand-response potential of these types of retrofits in existing buildings using wireless sensor networks and the Federspiel control algorithm.

Project Purpose

The core of this project was to not only demonstrate the wireless HVAC control technology, but also evaluate the technology's fit as a programmatic PG&E promotion for a leading-edge application of combined energy-efficiency and demand response. This project investigated the issues surrounding the DART technology and its deployment in existing buildings.

Project Summary

Under this project titled *Emerging Technologies Demonstration: Field Evaluation of Wireless HVAC Air Distribution Controls*, PG&E and its consultant team, Energy Solutions and Federspiel Controls, Inc., planned and implemented an assessment of DART wireless controls for CAV-to-VAV conversion. The DART project was structured with six primary tasks:

Task 1: Project Planning and Management
Task 2: Site Selection
Task 3: Performance Monitoring & Installation
Task 4: Customer Satisfaction Assessment
Task 5: Market Opportunity Assessment
Task 6: Analysis of Results and Recommendations Report

The project called for installing the DART system in a single air-handling unit at a demonstration site. After determining appropriate site parameters, a demonstration building on the campus of Stanford University was selected. Federspiel Controls installed the DART system at the same time as ATS placed the temporary energy-monitoring equipment. The DART sensors and monitoring equipment gathered data for more than a month, with the DART control system disengaged. The fan controls were then turned on and data was recorded for two weeks. The facility manager of the demonstration building and Stanford's demand-side energy manager were interviewed before and after DART operation began—to record their expectations and responses to the retrofit. ATS analyzed the resulting monitored data and determined energy savings and systems performance under Task 3.

Energy Solutions (ES) assessed the commercial readiness of the Federspiel Controls DART technology based on an assessment of the DART technology from several perspectives. ES evaluated Federspiel Controls, Inc.'s business model, their core team, and the intellectual-property issues relating to the DART technology with its key components.

ES assessed the potential market acceptance of the DART technology as an energy-efficiency measure in Northern California and the potential for inclusion in PG&E's incentive portfolio. ES completed a brief literature review for studies of the deployment of related HVAC measures. ES then conducted a limited number of interviews with executives and facilities managers for medium and large real estate holdings to assess market interest in DART. The interview responses are reported in detail in the Task 5 *Market Opportunity Assessment*. Based on these findings— together with consideration of DART performance to-date and an assessment of the market potential for CAV-to-VAV projects—ES identified opportunities and issues surrounding inclusion of the DART technology in future PG&E deemed and calculated-incentive programs.

This report summarizes the results of the work and recommends inclusion of DART in PG&E programs.

Size of the Market

There are many potential sites for DART retrofits in California commercial buildings. The highest concentrations of existing CAV systems are in large offices and colleges, so we concentrated our attention on those building types. The report titled *Efficient Thermal Energy Distribution in Commercial Buildings*—completed by Modera et al. at Lawrence Berkeley National Laboratory (LBNL) for the California Institute for Energy Efficiency—presents the following breakdown of HVAC systems. Large office HVAC distribution systems include 36% constant volume (single zone and multiple zones), 5% dual duct, and 26% multi-zone air distributors. University and college HVAC distribution systems include 80% constant volume (single zone and multiple zones), 6% dual duct, and 2% multi-zone air distribution systems.[2] Based on several studies, we conservatively estimate that 58% of all large commercial and college building types are served by CAV multiple zone systems and therefore are potential sites DART retrofit projects (see Task 5 for the complete analysis).

According to the 2006 Commercial End-Use Survey, California has about 4.9 billion square feet of commercial space. Of this, about 1.9 billion square feet of commercial space falls in PG&E electric service territory. Large offices (>30,000 sq ft) and colleges represent 300.5 million square feet and 80.6 million square feet, respectively. By

2. Modera, M . et al., "Efficient Thermal Energy Distribution in Commercial Buildings" 1994, Revised 1999.

applying this estimate, 58% of this square footage total is served by CAV systems. Thus, we estimate that the existing stock of CAV systems—174 million square feet in the large office sector and 47 million square feet in the college sector—are potential sites for DART retrofit.

State of the Market

The current state of the market summarized here is described in detail in the Task 5 *Market Opportunity Assessment*. CAV HVAC systems were installed commonly through the 1970s and less-commonly as the 1980s progressed. In 1990, CAV systems represented 22% of new construction in California.[3] Existing CAV systems are estimated to be widespread in most buildings dating from before 1980 and in a portion of later building vintages; the highest concentration is in the Large Office and College/University market sectors (see *Size of the Market*).

The LBNL report documents the occurrence of CAV and VAV systems in new construction from 1955 to 1990.[4] Its estimate of the percentage of CAV systems in existing stock was developed from extensive year-by-year research. This body of research also documents the opportunity and potential for converting CAV systems to VAV systems.

Very few CAV systems have been converted to VAV, primarily because of the extraordinarily-high installation cost associated with installing VAV boxes. Modera et al. document the difficulty of converting CAV systems to fully functional VAV systems:

> "Converting existing constant-air-volume systems to variable air volume can be an involved, yet possible, retrofit activity. The conversion includes modifying or replacing the CAV fan and motor controls for variable speed duty, installing terminal boxes at each sub-zone and running control wiring from the new or modified central controller to the terminal boxes. Due to the extent of the VAV retrofit process, we have assumed that 5% of the existing central air distribution systems might be converted to VAV systems. Based on the DOE-2 analyses of central distribution systems, the savings potential for VAV systems over that of CAV systems could be 50% of both fan and cooling energy. Due to the extent of the VAV retrofit process, only 5% of the existing CAV distribution systems might be converted to traditional VAV systems.[5]"

The major factors in the difficulty of full CAV-to-VAV retrofits are the cost, the disruption of opening up ceilings and walls, and, in many cases, the need for asbestos abatement or removal.

While CAV-to-VAV retrofits are possible, they are difficult enough to be likely implemented in only a small fraction of buildings. The size of the opportunity for DART is primarily defined by the number of CAV systems in existence. Modera's detailed analysis, without considering DART, concluded that traditional VAV retrofits could

3. Modera et al.., 1999.

4. Modera et al.., 1999.

5. Modera et al.., 1999.

capture an eventual 5% of the market. We expect DART to present a more-attractive opportunity than traditional CAV-to-VAV retrofits; the size of its potential market is greater than 95%, and 95% can be considered a conservative estimate.

RELEVANT ALTERNATIVE TECHNOLOGIES

Market research for this project identified several related controls products, which do not provide the functionality of VAV systems. DART emulates the functionality of a CAV-to-VAV retrofit, and is closest to VAV functionality of all alternatives identified in this study. The benefits and limitations of three types of retrofits—traditional VAV, DART, and the two other controls products discussed below—are compared in Table 2.

Table 2: Summary of DART and Alternatives

	VAV-to-CAV retrofit	DART	Other Controls Products
Heating and Cooling Savings	Yes	Yes	Less savings: no airflow reduction
Fan Savings	Yes	Yes	No
Disruption	Very disruptive	Minimal	Minimal, or moderate if wiring needed
Cost	Very high	Low cost	Low cost

A full VAV terminal retrofit with Direct Digital Controls (DDC) is the solution that offers the most control over building HVAC systems. While DDC requires significant electrical components and wiring in addition to a VAV retrofit, it offers the highest standard of building automation control and output. A DDC system is an optional addition to a full VAV retrofit, and the additional expense will limit this solution to less than the 5% of CAV systems that may be retrofitted to VAV.

Neither DART nor the other control products supply the full functionality of a VAV system, but DART offers a significant advantage in fan control. DART controls fan speed but does not control diffusers individually. For the most part, the other control products are building control or thermostat systems and do not control HVAC fan speeds or diffusers. We present below the two most notable of these systems for comparison.

Honeywell's OpenViewNet is a system for buildings with Honeywell building control systems in the Excel5000 product line. OpenViewNet enables these controllers to operate over an intranet or the Internet. OpenViewNet is a general-purpose, field-programmable platform, whereas DART is application-specific (focused on supervisory control of air-handlers with pneumatic zone control) and web-configurable, but not field-programmable. The benefit of an application-specific and web-configurable controls system is that most HVAC contractors can perform installation and configuration. Honeywell doesn't appear to use wireless communications, though there may be a wireless capability that can be added to the OpenViewNet-Excel5000 system.

Cypress Envirosystems (CE) has a control and monitoring solution designed to save energy in older buildings. CE markets easy-to-install, non-invasive solutions to upgrade pneumatic thermostats in minutes with payback in under a year. CE's new technologies enable older sites to adopt the latest automation technologies at an affordable cost and with minimal disruption to existing occupants, processes, and staff. These products use components from CE's corporate parent, Cypress Semiconductor Corp., including 2.4-GHz wireless radios and intelligent, programmable systems-on-chip (PSoC). The product is easy to install and typically provides payback within 12 months. CE's patent pending Wireless Pneumatic Thermostat (WPT) retrofits existing pneumatic thermostats to deliver DDC-like functionality. Compared with a cost of $2,000 or more per zone for implementing DDC systems, the WPT costs less than $400 per zone and may be installed in under 20 minutes with minimal disruption of occupants. WPT enables: remote temperature sensing and control of set points, programmable zone control and night setback, automatic self-calibration, BACnet integration with existing automation systems, and enables use with utility demand response programs.

CE's WPTs offer part of the solution when compared to DART. They do not, however, reduce fan speed, so no fan savings are achieved. They can achieve some heating and cooling savings, but not all of the heating and cooling savings that DART achieves by reducing supply airflow. Without these savings, CE's WPTs do not achieved most of the savings potential in a CAV system.

Potential for Reducing Energy Usage and Demand

As previously described, DART is an easy-to-install and low-cost solution that allows a CAV system to emulate VAV operation. Previous studies have shown energy usage reductions of one-half to one-third of heating, cooling, and fan energies.

Prior research included DART case studies in buildings at the Iowa Energy Center and University of California at Santa Barbara (UCSB). A DART demonstration project was conducted at Iowa Energy Center's Energy Resource Station (ERS). ERS's case study reports savings of 51% of fan energy, 32% of heating energy, and 38% of cooling energy. The Public Interest Research Program (PIER) and Architectural Energy Corporation (AEC), in conjunction with a utility partnership program, conducted a demonstration project at UCSB. The case study from this installation in two high-rise buildings reports savings of 50% of fan energy, 35% of cooling energy, and 35% of heating energy. [6]

Based on the derived market size and the savings percentages from the UCSB demonstration, we estimate annual potential cooling savings of 196 GWh, annual potential ventilation savings of 544 GWh, and annual potential heating savings of 16 million therms. The complete derivation and assumptions for these estimates of total market potential are documented in detail under the *Market Opportunity Assessment* section. While significant <u>peak</u> demand reduction impacts not expected, DART is estimated to deliver aggregate average cooling demand reductions of 41.6 MW and ventilation demand reductions of 116 MW. We believe that our potential savings estimates are very conservative for a number of reasons. Additional CAV systems exist in the retail, school, food store, health care, and the very large miscellaneous sectors.

POTENTIAL FOR DEMAND REDUCTION

From the completed case studies, DART has not yet been shown to reduce electric demand (PG&E monitoring results are pending). The supervisory control system for DART can incorporate demand response functionality under a separate control algorithm, Demand Response Integrated Feedback Technique (DRIFT™)

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6. PIER, *Discharge Air Regulation Technique (DART) Draft Case Study.*

DRIFT is the FACS™ (Federspiel Advance Control System) application; it is designed to automatically shed HVAC system electric load in response to a signal from a demand-response server. DRIFT can be integrated with other FACS applications such as DART, so that the system saves energy by emulating a VAV and sheds additional load when an event is in effect. When a demand-response event is initiated, FACS stops executing the energy-efficiency algorithm and starts executing DRIFT. The DRIFT application reduces HVAC system fan speeds until the highest zone temperature—as measured by the wireless temperature sensors—is close to a high-temperature set point.

The set points can be different from zone to zone, and they can be determined by DRIFT automatically or specified by the operator using the web interface of FACS. Reducing fan speeds reduces the energy consumed by those fans, and reduces the amount of air cooled by the chiller.

DRIFT can communicate with the Demand Response Automation Server (DRAS); this is a real-time price server originally designed by LBNL and now being used by the investor-owned utilities (IOUs) in California. A diagram of the DRIFT system, using a supervisory controller potentially shared with a DART system, is shown in Figure 1.

A recent study with LBNL demonstrated that DRIFT can shed 1.5 W per design CFM of supply air on a design day in a hot climate such as Sacramento. The scoping study also demonstrated that DRIFT can significantly reduce utility costs. For an HVAC system that delivers 1.5 CFM/sf, DRIFT can reduce electric energy costs by as much as \$0.095 ft^2/yr. The savings from any particular installation will depend on the amount that temperatures are allowed to drift, the design of the HVAC system, and the number and duration of demand-response events.[7]

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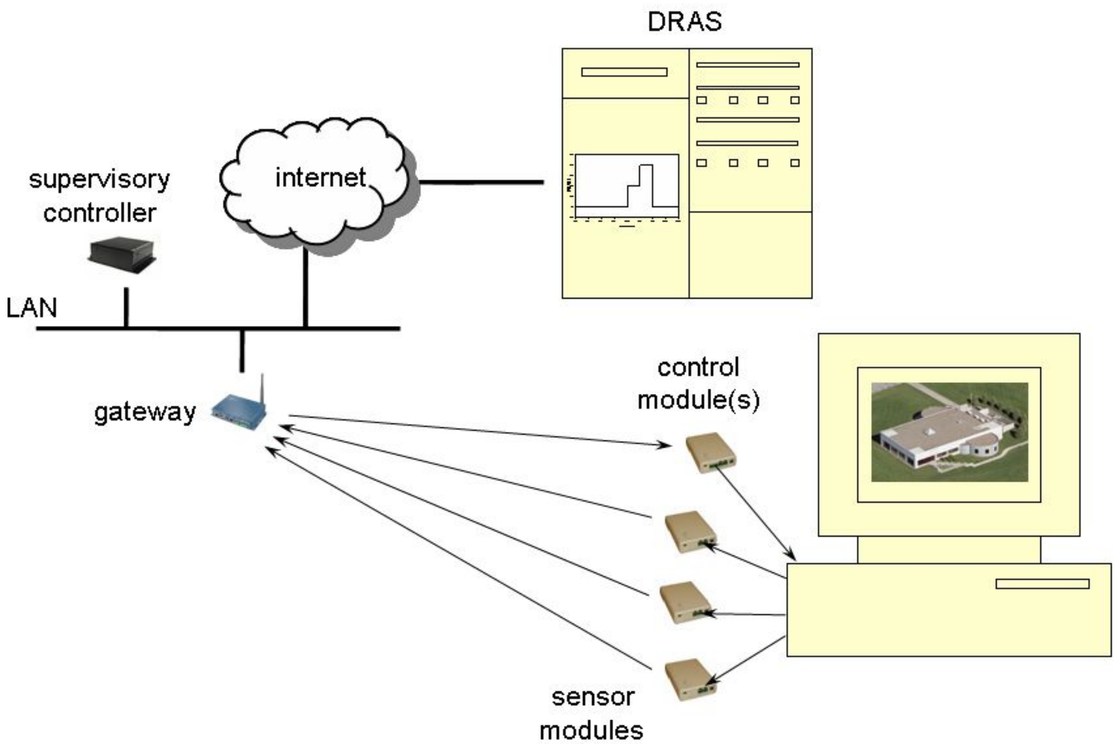
7. PIER, *Wireless Demand Response Controls for HVAC Systems*, Aug 2007.

Figure 1: Drift System Diagram



Project Objectives

PG&E's Emerging Technologies Program designed this study to gain more information about DART in use at a PG&E-served building and to measure kW, kWh, and therm savings. This study aimed to determine whether DART is a cost-effective, widely-accepted HVAC retrofit strategy and provide significant savings impacts in PG&E service territory. PG&E's objectives in this study were as follows.

1. To quantify the savings of fan energy, cooling energy, and heating energy provided by DART, and the corresponding reductions in electric consumption, electric demand, and natural-gas consumption.
2. To evaluate customer satisfaction with DART, including: the ease of use of the interface, ease of installation, and any temperature or air-quality effects of DART control on building occupants.
3. To determine the size of the potential market for DART and the potential market acceptance of DART compared with other HVAC alternatives.
4. To identify the cost-effectiveness criteria of customers considering HVAC retrofits.
5. To quantify the costs of DART and of alternative HVAC retrofits.
6. To understand the limitations of the DART system, including the building types and occupancy for which it is best suited.
7. To recommend an appropriate program channel for DART utility rebates.
8. To provide the starting point for estimating savings from DART in future installations across PG&E service territory.

Methodology

Host Site Description

Jordan Hall Annex is a five-story annex attached to Jordan Hall in the main quadrangle at Stanford University. The Annex abuts Jordan Hall to the north, and has exterior sandstone walls with exposure to the east, south, and west. The upper four floors of the Jordan Hall Annex are used primarily for offices and study rooms. The occupants are mainly graduate students and professors. The lower level, which is partly below grade, consists of shop space, a few small offices and the retail portion of a small cafeteria that is open for lunch. Cafeteria food preparation occurs in a different part of Jordan Hall. The total Annex is area is 15,608 ft^2, approximately 3,120 ft^2 on each of the 5 floors. According to current drawings, the design occupancy is 178 people. The building's windows are double-hung, wood framed and operable. Windows were regularly found open during site visits and facilities staff indicates they are often left open when offices are unoccupied. Design supply airflow is 22,460 CFM. Design ventilation airflow is 2,720 CFM and is based on design occupancy.

Heating energy, in the form of steam, and cooling energy, in the form of chilled water, used in Jordan Hall is supplied by a central plant located offsite in Stanford's central energy facility. Data on heating and cooling energy supplied to Jordan Hall and Annex is measured and trended by Stanford's Utilities Division.

The HVAC system in the Annex is a CAV, single-duct system with terminal steam reheat. Zone temperatures are controlled locally with pneumatic thermostats. The system serves a total of 96 zones. The air-handling unit serving the Annex, AH3, is a built-up system located in a penthouse mechanical room in Jordan Hall Annex. AH3 has separate supply and return fan systems which were retrofitted with HUNTAIR FanWall Technology® systems eight months prior to this study.

Figure 2: Jordan Hall, Stanford University

Measurement Methodology

MEASURED DATA POINTS

Energy consumption for Jordan Hall Annex was monitored using a combination of data available from Stanford's Utilities Division and from the DART system's sensors. DART sensors provided supply and return airflow, zone temperatures, and discharge air temperatures. Stanford's data included chilled water and steam flow to the entire Jordan Hall. Flow data for just the Annex was not available.

FAN ENERGY

PG&E's ATS placed data loggers in the air-handling unit to measure fan power. Data was collected as 10-minute averages. Fan energy-savings results were calculated by multiplying the pre and post-DART kW averages with the annual operating hours for the Annex—8,760 hours per year.

PG&E's ATS measured fan speeds across the range of temperatures during the monitoring period, and from that data extrapolated energy savings over a full year of weather. Energy savings occur only during those periods when DART can maintain reduced fan speeds. At the Jordan Hall Annex this is estimated to be during periods when outdoor temperatures are between 54°F and 69°F, or approximately 4,400 hours per year.

HEATING AND COOLING ENERGY

Heating and cooling energy consumption for the DART installation were estimated in two ways. The first was from trended 10-minute data samples of flow rates and temperatures of chilled water and heating steam, all supplied by Stanford's Utilities Division. For the second method, zone discharge air temperatures and a single supply duct temperature, as measured by DART, were trended; these were used along with a calculation of supply air flow to estimate heating and cooling energy at the zone level. Additionally, 10-minute average data of AH3 mixed air temperature and supply air duct temperatures were provided by Stanford's Utilities Division, to be used in the calculation of zone-level savings.

The calculation of supply air flow was made after calibrating the fan VFD speed to supply air CFM using the HUNTAIR air flow station's output readings. The DART system was used to record data of the VFD fan speed percentages during the monitoring period.

VENTILATION

Code requires a minimum amount of outside ventilation air be delivered to all occupied zones. In CAV systems, because the supply flow rate of air is fixed, the outside air damper minimum position is a single fixed setting regardless of building loads. When converting a CAV system to VAV the minimum damper position required for maintaining adequate ventilation must be increased for periods when the fan speeds are reduced. For energy efficiency, a building's control system should "reset" the outside air damper's minimum position as a function of fan speed. Simply setting the minimum damper position to maintain ventilation at minimum fan speed would lead to increased outside air flows and increased cooling and heating loads during periods when fans are at high speed.

To develop the reset sequence for the dampers, measurements of outside air flow were made while varying the fan speeds and damper positions. A new damper sequence was implemented to reset the minimum allowable outside air damper position linearly as a function of the fan VFD speed. The damper position reset strategy maintains approximately 3,170 CFM of ventilation air at maximum and minimum fan speeds. The reset strategy is linear at fan speeds between 50% and 100%.

DART INSTALLATION

Across 96 zones, 37 pairs of DART sensors were installed. Each of the 37 pairs included one temperature sensor located in the discharge air stream and one wall-mounted zone temperature sensor. Wall-mounted temperature sensors were placed near existing thermostats when possible. The supply and return fans were controlled by DART with the same speed signal. This method of fan control may be considered inadequate by modern standards for VAV systems with VAV boxes; dissimilar fans (supply and return) may not deliver proportional amounts of air at developed pressures. For Jordan Hall Annex, however, this control method was found to be adequate as building pressurization was an unlikely issue due to the age and construction of the building envelope.

Project Timeline

Table 3: Project Installation Timeline

Date	Event	Conducted By
November 2007	First site visit is conducted at three CAV buildings on Stanford campus.	Energy Solutions, PG&E Applied Technical Services, Federspiel Controls
December 2007	In a separate project, a variable speed HuntAir FanWall® Technology system is installed in the Jordan Hall Annex AHU.	Stanford & HVAC contractor
February 2008	Project Summary is provided to Stanford, with savings and cost estimates.	Energy Solutions & Federspiel Controls
July 2008	Stanford approves project and issues purchase order.	Stanford University
August 2008	Installation of DART sensors is completed in two days; fans remain uncontrolled. Installation of monitoring equipment leads to discovery of malfunctioning economizer dampers.	Federspiel Controls PG&E ATS
October 2008	Economizer dampers are fixed.	HVAC contractor, unrelated to DART
October 14, 2008 – October 21, 2008	Pre-monitoring period; HVAC system operates uncontrolled by DART.	PG&E ATS
October 21, 2008 – November 13, 2008	Post-monitoring period; DART begins controlling HVAC fan speed.	PG&E ATS
November 5, 2008	Site visit to Stanford is completed.	PG&E TAS, CEE, ATS, Federspiel Controls, Energy Solutions

Project Results

Annual Demand, Energy, and Natural Gas Savings

DART savings based on PG&E's Applied Technology Services monitoring activity is listed in Table 4. Actual fan energy was reduced by 67% in the monitoring period. Estimating on an annual basis, DART is expected to reduce fan energy by 33%, cooling energy by 39%, and heating energy by 26%.

Annual electric and gas cost savings were estimated at $26,700. The installed cost of DART was $44,200. The simple payback on DART technology is 1.7 years before utility incentives, and 0.5 years when including the incentive provided by PG&E's Non-Residential Retrofit Program.

Table 4: Jordan Hall Annex DART Estimated Savings

Jordan Hall Annex Post-DART Annual Energy Estimates						
Supply Fan Usage (kWh)	Return Fan Usage (kWh)	Est Cooling Usage (kWh)	Est Heating Usage (therms)	Pk Coincident Cooling Demand (kW)	Pk Coincident Fan Demand (kW)	Fan Load Factor
111,000	58,700	88,300	19,800	34.0	29.1	0.62

Jordan Hall Annex Post-DART Annual Energy Savings Estimates					
Supply Fan Savings (kWh)	Return Fan Savings (kWh)	Est Cooling Savings (kWh)	Est Heating Savings (therms)	Pk Coincident Cooling Demand (kW)	Pk Coincident Fan Demand (kW)
55,600	29,300	55,500	8,900	0.0	0.0

Jordan Hall Annex Post-DART Annual Energy Savings Estimates (percentages)			
Supply Fan Savings (percent)	Return Fan Savings (percent)	Est Cooling Savings (percent)	Est Heating Savings (percent)
33%	33%	39%	26%

Jordan Hall Annex Post-DART Dollar Savings, PG&E Rebate, and Payback							
Total Electric Savings (kWh)	Total Electric Savings (dollars)	Total Gas Savings (therms)	Total Gas Savings (dollars)	Total DART Installed Cost	Est PG&E Rebate	Simple Payback before Rebate (yrs)	Simple Payback after Rebate (yrs)
140,400	$16,800	8,900	$9,900	$ 44,218.78	$20,100	1.7	0.5

Jordan Hall Annex Post-DART Energy and Cost Savings per square foot						
Supply Fan Savings (kWh/sq. foot)	Return Fan Savings (kWh/sq. foot)	Est Cooling Savings (kWh/sq. foot)	Est Heating Savings (therms/sq. foot)	Electric Savings ($/sq. foot)	Natural Gas Savings ($/sq. foot)	Building Square Footage
3.71	1.95	3.70	0.59	$1.12	$0.66	15,000

PEAK DEMAND SAVINGS

The DART control algorithm, coupled with recorded data, suggests that the installation of DART alone will not provide peak demand savings for this facility. However, because DART collects and responds to zone temperature data, many potential variations of demand response techniques are made easier by a DART installation.

Demand response could be achieved either by modifying the DART control algorithm, or by installing Federspiel Controls' demand response product, DRIFT. The DRIFT system described previously in the *Project Background* section could be added to the FACS supervisory controller installed at the Jordan Hall Annex. The demand savings per CFM—found in the previous DRIFT study—suggests that the demand reduction at Jordan Hall Annex might be 34 kW on a design cooling day, though that study was conducted in warmer climate.

Summary of Customer Satisfaction

OCCUPANT COMFORT

According to the facility manager of Jordan Hall, there was not a single occupant complaint regarding temperature or air quality in the two months following the activation of DART control. This period, from November 6th through January 20th, included periods where a loss of heating capacity would be likely noticed. In the view of the facility manager, the installation was not at all disruptive. The sensors themselves were unobtrusive for building occupants, and did not create complaints even in small offices where the occupants have personal effects. The facility manager believes occupants have not noticed any change at all in the HVAC system.

SATISFACTION WITH DART INTERFACE

Access to DART temperature data is an important benefit for facilities staff. The existing pneumatic thermostats provide no data to the facility manager. Real-time and historical data from the DART sensors, and both zone air temperatures and discharge air temperatures, were made available over the building Ethernet network. The facility manager reports being "thrilled" at having access to this data. He is working with his IT staff to access this data remotely, which will give him a significant new capability in monitoring the building from off-site. The availability of this data over the Internet is a great benefit of the DART system that can allow greater control by building staff. Stanford is planning to install DART in the remaining two air-handling units in Jordan Hall, and is considering DART for use in CAV systems campus-wide.

EQUIPMENT INSTALLATION

Jordan Hall contains asbestos in the ceilings and the mechanical room. The mechanical room had been retrofitted with a protective wall barrier. The ceiling remains unprotected. The DART installation itself was completed without any issues. DART components (web-to-wireless gateways, wireless gateways, supervisory controller, etc.) were successfully installed without disturbing the asbestos. Where necessary, discharge air sensors were mounted outside the diffusers and utilized probes extending into the discharge ducts. Installation was completed in two days and there was no need for ongoing adjustment. The ability to install DART without asbestos disturbance is seen as a primary benefit of the system.

There were issues with the HVAC system that required correction before DART could be engaged. The outside air dampers were jammed and thus not operating properly.

The jamming was likely caused by accelerated corrosion of the nylon bushings in the dampers and actuators. These bushings were replaced with oil-impregnated bushings. Replacing the bushing and remounting the motors resolved the problem and resulted in smooth operation of the dampers and actuators. Baseline data was collected starting after the dampers were repaired.

Market Opportunity Assessment

COMMERCIALIZATION READINESS

The Federspiel Controls team appears well-qualified—with respect to the necessary technology and business aspects—for successful business operations. Federspiel Controls Inc. (FCI) appears to have the production, installation, and maintenance capacity needed to provide DART systems in the face of increasing demand—for example, as might result if PG&E were to support DART technology with rebates.

DART appears to be very competitively positioned with respect to other identified CAV-to-VAV conversion products in price, simplicity, applicability, and performance. DART is a strong candidate for inclusion in the IOU efficiency measure portfolio, which can be a market advantage depending on promotional resources brought to bear by the utilities.

RESULTS OF CUSTOMER INTERVIEWS

ES completed four customer interviews to assess their value of DART. Although we initially contacted and talked with executives, facility engineers, and facility mangers, we were consistently referred to project engineers, project managers, and energy engineers. Our interviews documented strong customer acceptance of this technology. These engineers and managers understood the significant potential savings of DART. Some customers have had projects delayed because of issues with asbestos in their facilities, so DART was attractive in that respect. When the savings potential from previous cases studies was described, customers agreed that DART could be cost effective in their buildings.

Given the low installation cost, an interviewee indicated they could install DART within the expense budget. The customer commented that expense budget projects undergo a much less rigorous and quicker approval process.

In summary, we were surprised with the strong positive response to DART technology as presented in the interviews. Every participant expressed interest in DART technology. DART's relatively low installation cost, compared with the significantly higher cost of VAV system, is clearly the preferred option for most of these customers. Customers also expressed interest in DART because installation is less intrusive than that of a VAV system and does not require asbestos abatement.

Potential Market Acceptance and Penetration

Stanford made the decision to pursue DART because of its low cost and high savings potential. CAV systems are common on Stanford's campus. There were no complaints regarding air quality and the installation was "un-disruptive." The existence of asbestos and the high cost of alternative technologies prevented the installation of VAV boxes. Stanford ranks energy-efficiency projects high on their list of priorities. Project cost is a very big factor when approving such projects however; they must pay for themselves in less than five years.

Our literature search (documented in Task 5) did not uncover any projects that fully compete with DART's functionality. Based on our findings, it's reasonable to assume that DART—with a significant increase in marketing, education, and utility promotion—could have broad success with retrofitting the 95% of the CAV market that will not be converted with VAV boxes. Not all of the 95% market will be converted, as buildings will be torn down or gut rehabbed, but DART retrofits will be widely cost-effective and feasible within that market. While there is no precise forecast as to a potential DART conversion rate or a total percent of the CAV market, all of the factors uncovered in this case study point to a very optimistic estimate of that rate.

DART can retrofit existing CAV systems including single duct with re-heat, dual duct with mixing damper at zone, and multi-zone with mixing damper at supply fan. A literature review of building studies in California allow us to conservatively project that between 58% and 66% of commercial buildings have CAV HVAC distribution systems. The highest percentages of CAV systems are in large offices government, and education buildings.

DART Limitations

With DART, fans are controlled to maintain temperature set points in the worst-case zone, where temperatures are not always typical of the entire building. As a result, fan speeds are not well-correlated to the independent variables of outside air temperature or hour of day. Savings estimates, therefore, need to be based on information about the zones with the largest loads. Savings calculations that rely solely on total building load information will be less accurate and will likely lead to over-estimating savings potential. For example, having accurate sub-metered data for the baseline cooling and heating energy usages would not have ensured accuracy in initial savings estimates. Zone-level information, such as occupancy and infiltration data, would provide improved savings estimates—especially with regard to unusual zones.

ZONE-LEVEL EFFECTS ON SAVINGS

DART saves energy by reducing fan speeds when all zone loads can be met with reduced air flows. It is important to note that with DART, unlike traditional VAV systems with control boxes, any one zone can require the fans to speed up. Also, when DART does increase the airflow, discharge airflow increases evenly across all zones; this is unlike traditional VAV, where control boxes direct more airflow to the requesting zone. In the case of the Jordan Hall Annex, the data suggests that 3 particular zones among the 37 monitored zones are responsible for requiring increased fan speeds. When a single zone requires a particular air flow, all 96 zones are delivered that same air flow. When this happens, temperature conditions are maintained throughout the facility but energy savings are not minimized (see PG&E ATS's *Measurement and Verification Report* for more detail).[8]

To reduce the influence of the controlling zones responsible for DART maintaining high fan speeds, it is important to know the underlying causes of the zones' higher loads. Potential causes in these zones are: high amounts of air infiltration (Jordan Hall Annex

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8. Fernandez, Adam and PG&E ATS, *DART Controls Demonstration Project at Stanford University Jordan Hall Annex: Measurement and Verification Report*, Report 491-09.3, 2009.

has operable windows), too little duct capacity, location within the building, energy/heat sources within the zone, and more frequent use.

One potential partial solution might be to incorporate a zone-occupancy schedule into DART's routine. If DART could ignore data from unoccupied spaces, it should be able to maintain reduced fan speeds a larger percentage of the time. It seems reasonable that DART modules could incorporate an occupancy sensor or other device (switch) that an occupant could use to signal occupancy.

For zones with too little design capacity, a solution would be to increase the system's capacity in those areas—either by modifying the existing duct system, or adding a secondary system. In both cases, if a small number of zones are responsible for keeping fans running at high speed, it may be beneficial to have their influence reduced.

We do not consider controlling zones to be a barrier to DART installations. Most existing HVAC systems will have particular controlling zones, where temperature fluctuations are greatest. It appears that the effects of controlling zones can be reduced by adjusting the control algorithm. Even with three primary controlling zones, the savings from DART installation in the Jordan Hall Annex were substantial.

VENTILATION CONTROL REQUIREMENTS

With all HVAC systems, it is necessary to control the quantity of outdoor ventilation air. A minimum quantity of ventilation air must be delivered to all occupied zones regardless of fan speed to meet building codes for occupant health and safety. Additionally, California's energy code requires an operable outdoor air economizer. Because DART varies the quantity of supply air, it may also have an impact on ventilation airflow and outdoor air economizer operation.

For Jordan Hall Annex, an operating protocol was set up so that the existing control system could maintain proper ventilation and proper economizer operation when fan speeds were reduced. The revised ventilation and economizer sequence of operations must be custom engineered for any particular facility that is installing DART and does not have an established economizer sequence. This requires detailed information on occupancy and zone square footage, and measurement of airflow.

ADDITIONAL EFFECTS ON SAVINGS

Based on the data in the PG&E ATS report, the minimum fan speed of an air-handling unit will have a major impact on savings. In Jordan Hall the fans ran at the minimum fan speed for approximately 65% of the monitored post-DART period. The minimum fan speed of 50% was determined as part of the DART installation for Jordan Hall Annex—based on the pre-existing controls sequences and measurements of the economizer. It is unclear how to best determine this minimum fan speed set point for all buildings. In some installations it will probably be necessary to measure airflows to critical zones at various fan speeds if this is to be optimized.

Building operating hours also have an important effect on savings. The HVAC system in Jordan Hall Annex is operated 24 hours per day, 7 days per week. The HVAC system maintains zone temperature set points continuously. In buildings that are shut down at night or have night time set point changes as part of their control system, DART savings will vary significantly, and can be assessed in future installations.

Costs of DART and Alternatives

The DART cost includes equipment, software, and installation. The cost depends on the number of discharge air and zone temperature sensors (which depend on the number of zones) and the supervisory control and web gateway systems (only one of which are needed per air-handling unit).

The installed cost of DART at Jordan Hall Annex was $44,219 for 96 existing control zones. The engineered design, based on the zone layout and architecture, called for 37 pairs of sensors to monitor those 96 zones. The most accurate figure for estimating DART's installed cost given the dependence on building size is the cost per zone. For this demonstration project, the cost was $460 per zone.

The supply and return fan motor drives in the Jordan Hall Annex had been replaced with Variable Frequency Drives (VFDs) eight months before the DART demonstration. However, most buildings with CAV HVAC systems utilize single-speed drives on HVAC fan motors, and will require a VFD retrofit before the DART retrofit. Based on distributor quotes, VFD costs are estimated at $6,000 for a 30 hp fan system. In order to combine this with DART costs, we estimate VFD cost at $62 per zone. The combined total for DART plus VFD installation is $522 per zone.

The most common alternative to a DART retrofit is to retrofit the CAV HVAC with VAV terminal boxes. The cost to install VAV terminal boxes is estimated at $4,700 per box, based on an estimate provided to PG&E's Livermore Training Center in August 2008. The alternative cost to install 96 VAV terminal boxes in Stanford University's Jordan Hall Annex would be $451,000, an order of magnitude greater than DART.

Product Useful Service Life

Useful battery life in the wireless control modules is an estimated three to eight years and replacement batteries are readily available. DART's software monitors the batteries' remaining life. Industrial computers used in the control system have cooling fans with an estimated life of 50,000 hours, or 6 years. These control computers come installed with backup fans in case one fan fails. The web-to-wireless gateways and the wireless control modules have estimated lives in the range of 15-31 years. Based on the above analysis, it is reasonable to assume a useful life of 15 years for the DART system.

Conclusions

Project Objectives

The objective of this study was to determine whether DART can become a cost-effective, widely-accepted HVAC retrofit strategy and provide significant savings impacts if promoted by PG&E. This study indicates that the energy savings are indeed significant—on the order of one-third of ventilation, heating, and cooling energies. These savings provide cost-effective HVAC retrofit projects that are attractive to commercial customers. DART technology is well-positioned for immediate impact on buildings with CAV HVAC systems. This study suggests that the existing savings model—based on outdoor air temperature—is a good start, but that more data is needed from future projects to provide a more accurate savings prediction across building designs and locations.

Stanford University reported a very positive experience with DART during and after installation. Commercial installations of DART are poised to accelerate greatly in 2009. Anecdotal evidence obtained in conversations with UC Berkeley, leads us to believe a ten-fold increase in completed installations over 2008 levels in 2009 is possible. We recommend PG&E include DART in an incentive offering targeted to commercial building owners, and promote adoption of DART by the office, government, and educational segments.

Market and Impact Potential

FEASIBILITY OF WIDESPREAD IMPLEMENTATION

We estimate that DART—with a significant increase in marketing, education, and utility incentives—could have broad success in retrofitting up to 95% of the CAV market.

POTENTIAL MARKET SIZE AND PENETRATION

We estimate that the existing stock of multiple-zone CAV systems in California (174 million square feet of large office and 46.7 million square feet of college space) are potential DART retrofit projects. These figures are based on 58% of these building types having addressable CAV systems.

POTENTIAL ENERGY AND DEMAND REDUCTION

We estimated annual potential cooling savings of 196 GWh, potential ventilation savings of 544 GWh, and potential heating savings of 16 million therms. DART's cooling energy savings potential is 41.6 MW and ventilation energy savings potential is 116 MW. These figures are based on percentage savings from a previous case study and an estimate derived from several surveys that 58% buildings in the large office and college market sectors have addressable HVAC systems.

Incorporating DART in PG&E Rebate Programs

DART's performance and energy savings in this and other studies justify incentivizing DART in a utility rebate program. Utility incentives can help increase DART deployment and acceptance in the marketplace. We recommend including DART in the New Efficiency Options Program (NEO) on a pilot basis so that DART can demonstrate savings across multiple CAV buildings, especially buildings in each of PG&E's climate zones.

DART savings are not yet quantifiable enough for inclusion in the deemed rebate catalog. Savings measurements will be needed in additional projects until the savings range is well understood. PG&E can choose to rebate DART installations through the standard Non-Residential Retrofit incentive offering (NRR, previously known as Standard Performance Contract, or SPC) or through the NEO program that targets large commercial and retail market sectors.

The benefit of using the NRR program is that it would not require additional measure development in order for DART to qualify for incentives. The drawbacks include the complexity of the application process and the lack of support for customers during the NRR technical review and monitoring process. One customer interviewee indicated that, based on previous experience, they would be unlikely to apply for an NRR rebate. The lack of incentive capture support for DART under the NRR program would result in missed opportunities for energy savings.

We recommend including DART in the NEO incentive program; the level of participation and program savings would benefit from the ease of participation and available technical assistance. Potential purchasers of DART systems would be able to consult with a program team to assist with implementation of the technology.

In addition to technical assistance, NEO provides a more proactive approach to marketing. Inclusion in NEO could increase DART installations and achieved savings in 2009 by helping to bring DART to the commercial office building sector where NEO is active. Universities in the UC System are beginning to adopt DART, and utility incentives can help bring this awareness to large offices and other markets.

NEO rebates have heretofore been based on fixed, connected-load energy savings from lighting technology. NEO will have to handle the new challenge of measuring and calculating energy savings. DART will require an evaluation team to get up to speed on savings calculations and measurement protocols. NEO would provide a program framework for these efforts.

Based on DART installations, program staff must compile savings information as it is gathered and determine an overall rebate strategy. The initial 10-30 NEO sites would need to include a performance measurement before final rebate rates can be determined. After that, a refined version of the savings-estimation tool developed by FCI may allow rebates to be paid based on building information such as square footage, design CFM, or fan kW. A program justification can be developed for DART that can equal or exceed the accuracy of the many standard calculations used for measures in the PG&E program portfolio. Given the number of DART retrofits in planning stages, much of the data needed to characterize savings could be gathered in 2009. To assist this effort, program managers should actively pursue DART projects in a variety of climate zones and building types.

Experience with DART

Overall, DART performed very well. In simple terms, DART did save energy and is reliable and cost-effective. It also fills a huge void in cost-effective products for existing CAV systems.

According to the PG&E ATS monitoring report, DART savings were reduced by a few zones that demanded increased fan speeds when the majority of zones were satisfied with minimum airflow. There is only one variable-speed drive per air handling unit, so there can only be one speed setting. The DART system is designed to respond to requests for additional ventilation from one or a few demanding zones. It is ultimately a conservative system; it sacrifices savings for the sake of maintaining comfort. This places a limit on DART savings in buildings with unusual zones—heavily-loaded zones, poorly-sealed zones, or zones with windows left open. Federspiel Controls can account for these zones during system setup. If a particular zone is prone to infiltration and temperature control is not critical, then that zone can be allowed to float below temperature set points. The conservative approach that reduces savings in some cases, is also a strength of DART—facility managers can install DART knowing it will not affect occupant comfort.

DART does not offer an "ultimate solution" for all HVAC issues. DART can be an effective "80% solution" that meets a market need and will quickly gain acceptance with building owners. Most CAV systems are older and unusual zones will be present in many buildings, but this should not impede widespread adoption.

Our survey of facility managers indicates that projects with lower costs—below $50,000 to $100,000—are funded quickly out of maintenance budgets based on less-stringent criteria. Costlier projects require extensive review and funding allocated from capital budgets. DART fits in the first category, and other full CAV-to-VAV retrofits fit in the second category.

DART has the additional benefit of being a great diagnostic tool which can uncover numerous operational deficiencies in HVAC systems and building zones. DART provides data on zone temperatures centrally and electronically, where users had no data before. In our experience in this project, one of the first things that the facility manager noticed was that fans were running all night. The customer quickly changed the building operation schedule to shut down the fans overnight, resulting in considerable energy savings.

Installation of DART might spur commercial building owners to fix long-term issues in their HVAC systems, or to consider a retrofit that appeared too costly before DART demonstrated the energy cost savings possible in the HVAC system. Future rebate programs should track operational and scheduling changes, and equipment repairs (such as valves and dampers) that are made due to data provided by DART.

Recommendations for Future Work

COOLING-SEASON INVESTIGATION AT JORDAN HALL ANNEX

We recommend that PG&E again collect DART data beginning in May 2009, the last month of the academic calendar. PG&E ATS can collect and analyze data files without a trip to the site. We recommend a site visit be coordinated with Federspiel Controls to review the zones already identified as trouble spots. This should occur on or before May 15th so that data could be collected after this investigation, but while classes are still in session. Additional monitoring would provide more accurate savings estimates, especially for cooling.

The monitoring team for this study indicated enthusiasm for returning to the Jordan Hall Annex during the summer to quantify cooling savings. There are three project results that could be further evaluated at that time: assessing savings in the cooling season, providing a better understanding of how a few zones may drive the fan speeds under DART, and developing an improved savings estimation model.

The outside air temperatures during 2008 DART monitoring stayed below 70°F. Chilled water cooling energy was estimated based on the calculated supply air flow and the measured supply duct and mixed air temperatures Additional monitoring would verify the methodology used to calculate cooling savings. DART has achieved greater cooling savings in other case studies, and further study in the 2009 cooling season would indicate whether similar savings occur at this site.

The investigation should consider what causes a few zones to control fan speed through extra ventilation requests. This would provide greater accuracy in estimating DART savings. In the Jordan Hall Annex, the data suggests that 3 of the 37 monitored zones are responsible for requiring increased fan speeds. When a single zone requires design air flow, all 96 zones are delivered that same air flow. When this happens, temperature conditions are maintained throughout the facility but energy savings are not maximized. As said before, DART sacrifices savings to maintain comfort.

This study would try to determine first what causes a single zone to require higher airflow, and second whether this can be mitigated through building changes or control changes (e.g., closing a window or adjusting the control algorithm for looser control at the given zone). To reduce the influence of the few zones responsible for DART maintaining high fan speeds, it is important to know the underlying causes of the zones' higher-than-average flow requirements. Some potential causes may be: high amounts of infiltration (Jordan Hall Annex has operable windows), spaces with too little airflow capacity, spaces that are used more frequently than others, or the location of sensors next to windows or heating loads.

Further study could investigate the problem, fix it, and then monitor the system to determine if greater savings are possible, and how far it is possible and cost-effective to troubleshoot the issue of the controlling zones. It is important to note that even with particular zones increasing the fan speed to 100% at certain times, DART still showed large savings and a payback of 1.7 years without a utility incentive, and 0.5 year with a utility incentive.

Finally, further study might allow for improvements in a DART savings-estimation tool. PG&E ATS believes that the existing DART savings estimation tool, developed by Federspiel Controls, uses a reasonable approach by considering HVAC energy as a function of outdoor air temperature. The parameters of this relationship were difficult to determine in the monitoring period for three reasons: the system never entered full cooling mode, three zones seemed to control the fan speed most of the time, and the DART system responded inconsistently to outdoor air temperature (possibly because of open windows). Further measurement of the Jordan Hall Annex DART installation would address the first two factors as stated above, and might be able to address the third by monitoring or closing windows. PG&E needs to work toward an improved model that can be used to estimate savings easily in rebate programs.

Future investigation of DART should consider implementing ongoing improvements in the DART system. Federspiel Controls has plans for enhancements of the control algorithm and improvements in identifying and eliminating fan manipulation by the controlling zones.

MARKET CHARACTERIZATION

A market-characterization study could be conducted to estimate more precisely the number of CAV systems in commercial office buildings, government, and educational buildings. UC Berkeley and Stanford provided anecdotal evidence that a substantial number of CAV systems exist on University of California and California State University campuses. We are not optimistic that exact numbers of DART-amenable CAV systems in large commercial office buildings will be easy to identify in existing survey data; single-zone and multiple-zone CAV systems are often not differentiated in survey questions. DART is not designed to modify single-zone CAV systems. A survey could be conducted in conjunction with PG&E's large office target market team and partnership programs focusing on colleges.

Utility Promotion Information

Based on our recommendation that PG&E implement a utility promotion for DART immediately, we are providing basic information on DART as an energy-efficiency measure. These numbers can be adapted to craft a promotion offering. The information below is based on measurements from the Jordan Hall Annex assessment site. Further evaluation in 2009 by PG&E ATS may refine these figures.

Table 5: Rebate Information

Base Case	Existing Constant Air Volume HVAC systems
Measure Case	Installation of Federspiel Controls' DART control system, including: wireless temperature systems, wireless-to-web gateway, Supervisory Fan Control System, and variable-speed drives on supply and return air handling units
Building Vintage	Most buildings will be older than 1980
Primary Building Types	Large Office, Education: Colleges & Universities, Small Office, Government
Secondary Building Types	Other Education, Retail, Hospital and Healthcare
Climate Zones	All Climate Zones

The following table of expected DART energy savings per CFM was estimated by adjusting the savings found at the demonstration site. The calculations compensate for the number of hours in each climate zone between 7 am and 6 pm where outdoor air temperatures would be between 54°F and 69°F (inclusive). The system was assumed to run at full fan speed from 6 am to 7 am as the building comes up to temperature.

Table 6: Estimated DART Savings by Climate Zone

Climate Zone	For HVAC Systems Operating 24/7		For HVAC Systems Operating 6 am to 6 pm, 5 days per week	
	Expected Annual Electricity Savings per Supply Fan CFM (kWh)	Expected Annual Natural Gas Savings per Supply Fan CFM (therms)	Expected Annual Electricity Savings per Supply Fan CFM (kWh)	Expected Annual Natural Gas Savings per Supply Fan CFM (therms)
1	6.51	0.41	3.18	0.20
2	4.96	0.31	2.43	0.15
3	7.70	0.49	3.32	0.21
4	6.25	0.40	2.84	0.18
5	7.17	0.45	3.28	0.21
11	4.66	0.29	2.19	0.14
12	5.14	0.33	2.33	0.15
13	4.62	0.29	2.15	0.14
16	3.28	0.21	1.61	0.10

RESULTS FROM THE E3 COST-EFFECTIVENESS CALCULATOR

Results from the PG&E ATS's energy savings analysis were entered into the E3 cost-effectiveness calculator, 2009-2011 planning version. Savings and cost data from the Jordan Hall Annex were included on a per-CFM supply airflow basis, and an incentive was based on 2008 Non-Residential Retrofit levels.

Table 7: E3 Cost-Effectiveness Calculator Results

TRC Cost-Benefit Ratio	PAC Cost-Benefit Ratio	PAC Levelized Cost per kWh	PAC Levelized Cost per Therm
4.67	10.25	$0.021 / kWh	$0.11 / therm

These cost-effectiveness values are based on data from the Jordan Hall Annex site with 24 hours-per-day operation in Climate Zone 4. The ATS report indicates that DART reduced energy consumption generally between 54ºF and 69ºF, but DART was designed to deliver savings outside this range. Further study may better clarify the temperature range of savings.

Based on California climate data, climate zones 1, 3, and 5 have more hours per year in this temperature range than climate zone 4 where this assessment was performed; they could expect greater savings for a similar application. Other climate zones in PG&E territory have fewer hours in the given temperature range and could expect less savings.

LIST OF REQUIREMENTS FOR DART INSTALLATION SITES

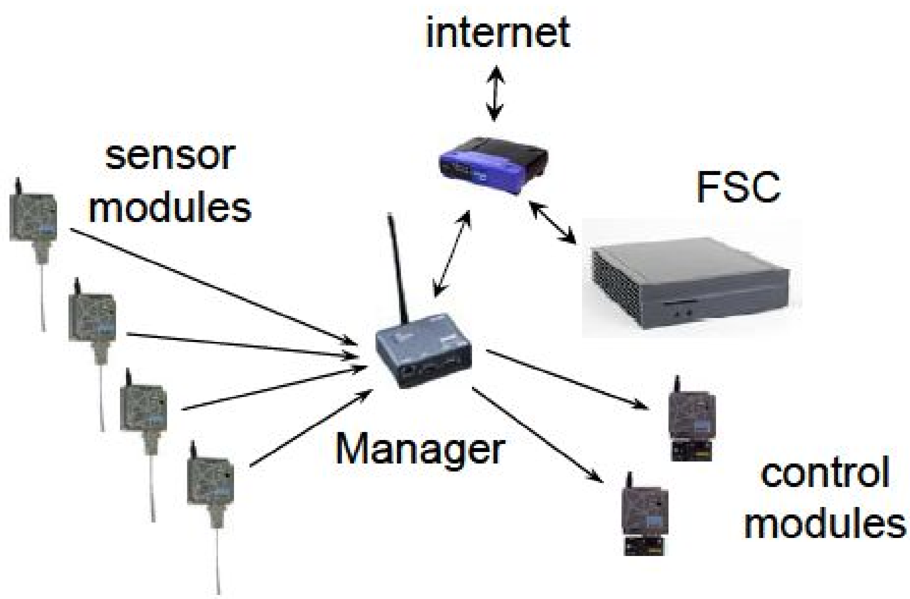
The following table lists requirements and prohibitions for potential DART sites as determined in this assessment. These criteria can be used to educate PG&E program and sales and service managers, and to target customer outreach activities.

Table 8: Requirements for Potential DART Applications

Mandatory	Not Permitted
Constant Air Volume HVAC System is operable, including: cooling and heating valves, thermostats, and air dampers Adequate control of outside air damper(s) Air handler motor drives must be retrofitable with VFDs	Single-zone CAV Baseboard heating Zones that are grossly under-served with HVAC for their existing uses—unless the building manager will permit the HVAC system to ignore temperature requests by those zone(s) Special pressure requirements or static pressure control points CO_2 or other ventilation controls, unless incorporated into the DART control algorithm

Appendix: Diagrams and Photographs of DART System

DART Control System Components



DART Sensor

LOCATED OUTSIDE DIFFUSER FOR CEILINGS WITH ASBESTOS ISSUES

DART Control Modules and VFD