

Advanced Automated HVAC Fault Detection and Diagnostics Commercialization Program

Final Technical Transfer Plan

CONSULTANT REPORT

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Table of Contents

Introduction	5
Product Overview.....	5
Business Case	6
Market Analysis.....	9
Product Development Status and Needs	15
Technology Transfer Actions	17

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Notes on Using this Technology Transfer Plan Template:

- This template is provided to help you produce a good and quick Technology Transfer Plan. Complete what you can, indicate your current thoughts on other items, and insert any comments or questions that would help refine the template itself.
- The first section focuses on making the business case for the product BEFORE describing the plan for its commercial introduction. This first “action item” is essential. It provides the rationale for arguments to move the product past the barriers in the path to market. An economic justification should be possible even if assumptions (clearly identified) are needed for some key variables.
- It is important that project managers think broadly about their product’s benefits. Sometimes the key determinants of value have little or nothing to do with energy efficiency; some users may value an FDD product for its O&M cost saving properties, worker safety, productivity enhancement, or status as an innovator.
- Most FDD products are only components of larger products or systems. In such cases only the most general economic case can be made—but the attempt should be made, including clearly identified assumptions for the unknowns.
- This template suggests the main types of tech transfer activities needed to capture the current views of the product developers for the consideration of manufacturers and other key actors. The intent here is to encourage the developer to think through the process and to develop a full vision of the product’s necessary path to the market. You are not expected to know all the specific policy interventions, media, messages, channels, timing, expenditures, and division of responsibilities but where these details can be described now, they should be.
- The template is a work product of the FDD Market Connection Project under management of the New Buildings Institute. Please contact • . Please contact Mark Cherniack at New Buildings Institute (509-493-4468x17, markc@newbuildings.org) with any questions or comments.

Technology Transfer Plan

Fault Detection and Diagnostics Commercialization Program

For Project 3

AHU and VAV Box Diagnostics

Introduction

This is one of a series of Technology Transfer Plans in the PIER Advanced Automated HVAC Fault Detection and Diagnostics Commercialization Program (FDD). In the FDD, “technology transfer” is defined broadly to mean everything needed to move the product from its current developmental state to successful market introduction. Each of the FDD’s technology transfer plans addresses one of the FDD’s technology or protocol products, and provides an overview of the product’s development status, markets, and business case. Most importantly, it identifies specific actions recommended to encourage the product’s production and successful market introduction in California.

The template contains five sections:

- Product Overview
- Business Case
- Market Analysis
- Product Development Status and Needs
- Technology Transfer Actions

The Business Case section is to be completed along with the accompanying spreadsheet.

The template is a work product of the FDD Market Connection Project. The project manager is Mark Cherniack, New Buildings Institute. Additional staff support was provided by Cathy Higgins and Jeff Johnson.

Product Overview

Product Description

What is this product, in a single sentence? And is it a complete end-use product or system, a separate component for the OEM market, a protocol or standard, or something else?

(Include a photo and/or diagram if readily available)

The National Institute of Standards and Technology (NIST), the subcontractor for this project, has developed FDD algorithms, suitable for embedding in commercial air handling unit (AHU) and variable air volume (VAV) box controllers, which can detect and diagnose faults including stuck or leaking dampers and control valves, sensor failure or drift, and improper control sequencing. These algorithms are executed by the equipment controller as a component of the

control logic, therefore they are not complete end-use products, but software enhancements for control application programs.

Function and Features

What HVAC function does this product serve? For what general markets and uses? If it's a component, what ultimate products will incorporate it, and for what purposes? What are its main features?

There are two separate FDD algorithms: AHU Performance Assessment Rules (APAR) evaluates knowledge-based rules to detect faults in single duct VAV and constant volume AHUs with airside economizers, while VAV box Performance Assessment Control Charts (VPACC) implements a statistical quality control method to detect faults in most VAV box types. Both algorithms are intended to be written into manufacturer-specific control application programs along with the actual equipment control logic. Each AHU or VAV box will be monitored by an algorithm running in its local controller. The results of the algorithm are reported to the building operator through the alarm and event handling features of the building automation system (BAS).

Business Case

The following information is provided in accordance with the RMT conference call on 11/16/04.

Energy Savings from FDD

APAR and VPACC detect mechanical and control faults including stuck or leaking dampers and control valves, sensor failure or drift, and improper control sequencing. Under some conditions, these faults may cause increased energy consumption. The energy saving benefits of the FDD tools come from identifying those faults that cause increased energy consumption. When these faults are corrected by the building maintenance staff or service contractor, the increased energy consumption is eliminated, thus the energy savings.

There have been a number of studies to determine the energy saved as a result of FDD, with somewhat divergent results. In general, the studies reported savings ranging from 10% to 30% of HVAC energy consumption, depending on the age and condition of the equipment, maintenance practices, climate, and building use.^{1,2,3,4} The conservative end of this range, 10%, was used in the proposal for this project. Therefore, the technology has a load reduction potential of 56 MW in the state of California.⁵ Caution must be taken when using this estimate since there is a large variation in the energy savings from one building to the next. The estimate provided here is intended to be used to calculate potential energy savings for a large aggregation of buildings, for example for the state of California, not for application to individual or small numbers of buildings.

References:

1. TIAX. 2002 "Energy Consumption Characteristics of Commercial Building HVAC Systems – Volume III: Energy Savings Potential." Final Report to U.S. DOE, Office of Building Technologies.
2. Piette, M.A., S. Kinney, and P. Haves .2001. "Analysis of an Information Monitoring and Diagnostic System to Improve Building Operations." *Energy and Buildings* 33 (8): 783-791.
3. Westphalen, D. and K.W. Roth. 2003. "System and Component Diagnostics." *ASHRAE Journal* 45(4):58-59.
4. Claridge, D., M. Liu, and W.D. Turner. 1999. Whole Building Diagnostics Workshop. <http://poet.lbl.gov/diagworkshop/proceedings/>.
5. State of California RFP #400-99-401. Volume 2. p 6.2.

Non-Energy Benefits of FDD

There are also significant non-energy benefits of FDD which result from improved operations and maintenance (O&M) and from better control over the environmental conditions in the occupied spaces. APAR and VPACC can improve O&M by identifying minor problems before they become major problems, thus extending the useful service life of equipment. Also, repairs can be scheduled when convenient, rather than causing undesirable downtime and costly overtime work. Depending on the building use, better control of the temperature, humidity, and ventilation rate of the occupied spaces can improve employee productivity, guest/customer comfort, and/or product quality control. In some cases, identifying and repairing faults may make the difference between regulatory compliance and noncompliance.

The non-energy benefits of FDD are clearly substantial, but they are difficult to quantify. Although there has been some research on the effect of thermal comfort on employee productivity, there is no scientific consensus on this issue, nor on the economic effects of

guest/customer comfort. The quality control and regulatory issues are important as well, but the associated cost savings haven't been the subject of anything other than anecdotal study.

Cost of FDD

Each BAS manufacturer provides a library of standard control application programs for use by application engineers. The proposed deployment path for APAR and VPACC is to develop versions of the existing AHU and VAV box control application programs that have been modified to include logic to perform the appropriate FDD calculations. In order to install the FDD tools at a specific site, the BAS dealer/representative would select application programs from the library close to the desired sequences of operation, identify the applicable threshold parameters from tables provided by the manufacturer, and configure alarm or event points for each AHU and VAV box.

The cost to the BAS manufacturer of providing FDD technology consists of the cost of modifying the standard control application programs and the cost of training its dealer/representatives to apply FDD. The cost to the BAS dealer/representative is the time to receive the training and the time to configure the threshold parameters and configure the alarm/event points. It should be noted that labor represents the bulk of the costs to both the manufacturer and to the dealer/representative. It is not yet known how much of the cost of providing FDD will be passed on to the building owner by the manufacturer and to the dealer/representative. There is also a cost to the building owner to commit time to review and follow up on fault reports from FDD.

Market Analysis

Market Segmentation, Size and Price Effects

There may be a variety of markets for some FDD products, with increasingly large total sales (and energy savings) at progressively lower prices. If applicable, estimate the market segmentation and sizes for different product price points (graph or table). Consider California, regional, and national or international markets separately as appropriate. Compared against your best estimates of product costs and required margins, how does the price affect the total market size? Could efforts to reduce the product's price significantly increase its market?

Although it is possible to implement FDD on its own, in most cases, it is expected that FDD will be purchased as part of a larger project, either new construction or a BAS upgrade. The benefit is that some costs may be shared, i.e. site visits, familiarization with existing mechanical and control system, and administrative costs. Since the cost of FDD will be small, particularly relative to the cost of the entire project, it is unlikely that initial cost will be a key issue for the buyer. Therefore, efforts to reduce the price aren't likely to significantly affect the market.

Market Size versus Annual Sales

Obviously not everyone in the estimated target market will buy the product. Provide your reasoning on how the market size translates into an annual sales trajectory over at least the first few years. Also estimate the eventual sales based on likely total penetration rate.

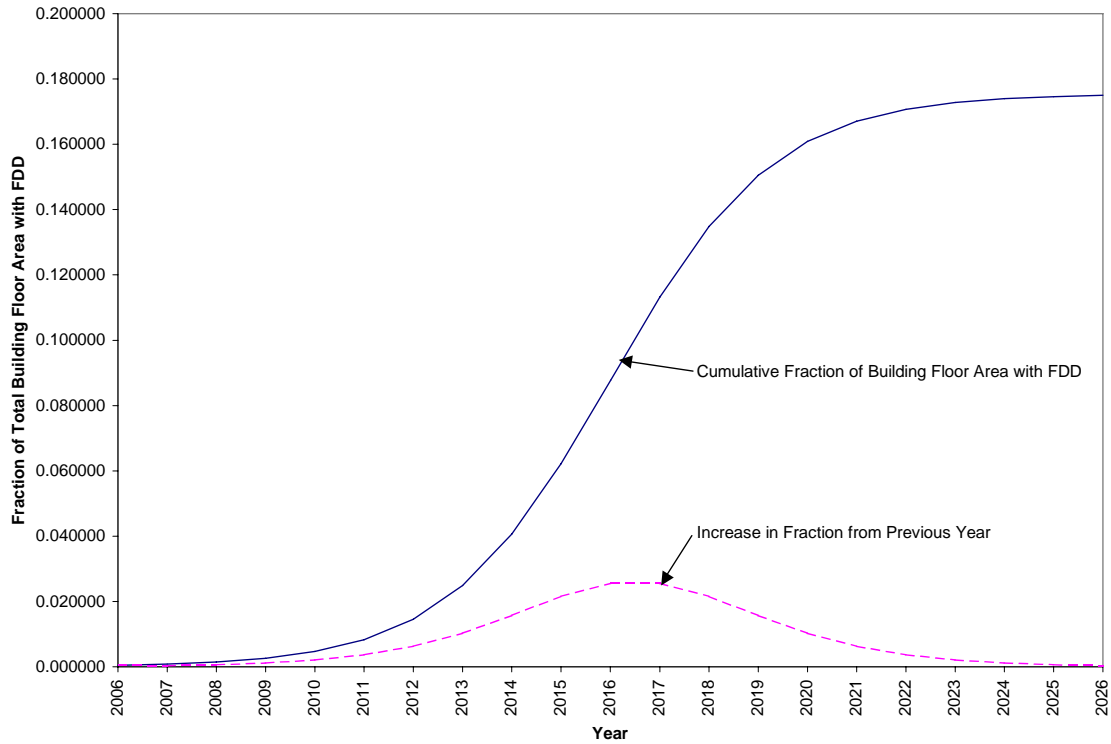
Given the absence of hard data on potential pricing of FDD, along with the significant effect of factors other than price on the buying decision, it is difficult to predict the rate of diffusion of FDD into the market. In order to address the diffusion issue, predictions are presented here based on the Mansfield model¹, which is widely used to study diffusion rates of new technology. The model is expressed as:

$$P_{\eta}(t) = \eta[1 + \exp(\alpha - \beta t)]^{-1}$$

where $P_{\eta}(t)$ is the fraction of the total market using the technology by time t , η is the saturation market diffusion, and α and β are model parameters known as the location and shape parameters, respectively. A well-known study² of several "smart building" technologies, including FDD, uses the following parameters for the average case analysis: $\eta = 0.1754$, $\alpha = 6.0$, $\beta = 0.6$. It is a characteristic of the Mansfield model that the α/β is the time to reach 50% of the saturation market diffusion. In this case, $\alpha/\beta = 6.0/0.6 = 10$ years. The study notes a number of factors contributing to the uncertainty of these parameters related to the decisionmakers' thought process and attitude toward new technology as well as other actors' behavior and external economic conditions. Therefore, the predictions presented here should be used with caution. The model predicts the following diffusion pattern for a 20 year period beginning with introduction of FDD to the market in 2006 (next page):

References:

1. Mansfield, E. 1977 "Innovation, Technology, and the Economy: Selected Essays of Edwin Mansfield." 2 vols. Economists of the Twentieth Century Series. Aldershot, UK. Elgar.
2. Chapman, R.E. 1999. "Benefits and Costs of Research: A Case Study of Cybernetic Building Systems." NISTIR 6303. National Institute of Standards and Technology.



Year	Cumulative Fraction of Building Floor Area with FDD	Increase from Previous Year
2006	0.000434	0.000434
2007	0.000789	0.000355
2008	0.001432	0.000643
2009	0.002591	0.001160
2010	0.004665	0.002074
2011	0.008318	0.003653
2012	0.014588	0.006270
2013	0.024881	0.010292
2014	0.040601	0.015720
2015	0.062152	0.021551
2016	0.087700	0.025548
2017	0.113248	0.025548
2018	0.134799	0.021551
2019	0.150519	0.015720
2020	0.160812	0.010292
2021	0.167082	0.006270
2022	0.170735	0.003653
2023	0.172809	0.002074
2024	0.173968	0.001160
2025	0.174611	0.000643

The Buyer and Other Influencers

Who makes the buying decision for this type of product? Who are the other major influencers?

Depending on the type and size of the organization, the scale of the project, and whether the project is a retrofit or new construction, the buying decision may be made by the building owner; a facilities engineer, maintenance supervisor, or building manager employed by the building owner; or a consulting engineer contracted by the building owner. The decision may also be influenced by representatives of the control system manufacturer or dealer/representative, mechanical contractor, or electric utility.

The most desirable deployment path is for FDD to be included in the manufacturer's standard library of application programs. This will dramatically reduce the cost to provide FDD at a given site in comparison to a custom implementation. The ultimate goal is for FDD to be included "by default" rather than as an extra cost option. In this scenario, there is no extra cost for FDD, it is simply included by the manufacturer to differentiate their own product line from their competitors' products. Since there will still be some cost to the building owner for FDD due to the time to review and follow up on fault reports from FDD, any kind of incentive would have a positive impact on market acceptance.

The Competition

What are the principal competing products, and how does this product have an advantage over that competition? How entrenched is the competition and what are its advantages that must be overcome?

The principal competition to VPACC is a performance-index method developed by Johnson Controls. Although the algorithm is different, the implementation approach is similar in that the algorithm is executed by the VAV box controller. Since this method was developed in-house by Johnson Controls, it is highly unlikely that they would adopt VPACC. However, since Johnson Controls' method is proprietary, it is unavailable to other control system manufacturers. In other words, if a Johnson Controls system is selected for a particular project, VPACC will not be used; if a system other than Johnson Controls is selected for a particular project, Johnson Controls' method will not be used – if any VAV box FDD method is used, it will be VPACC. Although Johnson Controls is one of the largest control system manufacturers in term of market share, the market is highly fragmented, so this is not a major concern.

There are a number of AHU FDD tools which are in competition with APAR. These tools are similar to one another, and different from APAR, in that they take the form of stand-alone software products in which either trend data files must be processed off-line, or an interface to the BAS must be developed to enable on-line analysis. This does give these competing tools the advantage of being manufacturer-independent. However, there are a number of advantages to embedding the FDD algorithm in the controller (APAR is the only AHU FDD algorithm that does this):

- APAR doesn't require additional third-party software that must be integrated with the control system.
- APAR scales better since it has local access to the data it needs, eliminating the need to communicate the data needed for FDD calculations via the BAS network.

- APAR is written into a control program once and copied to each AHU controller, so it doesn't have to be configured separately for each AHU.

There are also FDD tools that have been developed for other equipment or for system-level analysis. In general, these tools are similar in operation to the AHU FDD tools described above, in that they are stand-alone products that are not embedded in the BAS. As a result of this project, there may be interest in embedding other FDD algorithms in the BAS. For safety reasons, the controls for central plant equipment such as boilers, chillers, etc., have historically provided by the equipment manufacturer. Some limited communication with the BAS through gateways is possible, but it will be more difficult to implement FDD in this situation. Some equipment manufacturers have begun making BACnet-speaking controls available, which eliminates many of these concerns.

Commissioning services, including retro- and continuous commissioning also may compete with FDD. Since the FDD developed for this project is completely embedded in the BAS, it automatically and continuously monitors the equipment with minimum human involvement. The various forms of commissioning, which can all be very effective, are more labor-intensive and therefore more expensive. In many cases commissioning is a one-time event while FDD runs all the time. Also, commissioning requires conducting a series of functional tests, while FDD runs in the background during normal operation.

Uncertainties

Identify intangible factors such as new-technology risk, warranty protection, buyer support, etc., that could affect the buyer's perception of value.

The purchase of any new technology, such as FDD, is associated with some element of risk. In this case, consulting engineers and building owners/operators are understandably concerned about the risk of FDD interfering with the normal control actions of the system, as well as the risk of flooding the building control network and operator's workstation with false alarm messages. Previous research, as well as the current project, has addressed these concerns, but it is expected that facilities with an "early adopter" approach will be the first commercial users of FDD, with the more conservative facilities waiting to see how the first users fare.

Standalone FDD tools which interface with the BAS can raise concerns about interference with the warranty of the BAS, but APAR and VPACC are provided by the controls manufacturer and dealer/representative, so integration of FDD with the BAS is assured and there are no warranty protection complications.

Consumer Choice Barriers

For this product, what are the principal issues for the buyer and key influencers? (some possibilities: initial cost, O&M costs, energy savings, non-energy features, competition, availability, visibility in market, reliability, longevity, warranty, ease of specification, liability).

The principal issues for the buyer will be the benefits, both energy savings and improved O&M. The buyer will have concerns about reliability and ease-of-use, but these issues either have been addressed by previous work, or will be addressed by the current project.

APAR and VPACC will be offered through BAS manufacturers' regional dealer/representatives, so FDD will be available to potential buyers located in the geographical areas served by those

dealer/representatives. Since availability will be a function of the location of the building, it is not expected to be a key issue for the buyer.

Product Development Status and Needs

Product Development Status

What is the current state of this product's development? Where will it be at the end of this project?

In previous research, standalone software implementations of the APAR and VPACC algorithms have been developed and tested using data collected in simulation, emulation, laboratory, and field studies. APAR and VPACC were embedded in several manufacturers' AHU and VAV box controllers and tested in a laboratory study. For the current project, APAR and VPACC are being embedded in several manufacturers' AHU and VAV box controllers and evaluated at a number of field sites in a technology demonstration.

Remaining Steps to Market Readiness

What remains to be done before it is market-ready? Describe briefly.

Before the FDD tools are market ready, robust sets of threshold parameters, suitable for use without site-specific configuration, must be tabulated. Determining these sets of parameters is a subtask of the current project.

More work is also needed to complete development of the "user interface" for the FDD tools. The term "user interface" includes changes to the embedded FDD logic to permit disabling portions of the algorithm which may be causing nuisance alarms without disabling FDD entirely, as well as better understanding of the integration of the results of the FDD calculations with the BAS alarm and event handling configuration.

Codes and Standards

Do the product's energy saving and cost advantages depend on any current or scheduled code requirements? Are these code requirements likely to change? Conversely, are any new code requirements needed to encourage the adoption of this product? What needs to be done to promote those requirements, by whom, and are there any critical time deadlines?

The energy savings and O&M benefits of FDD are not dependent on any code requirements. However, changes to any applicable codes or standards to recommend the use of FDD would encourage its adoption. Such a recommendation might take the form of relaxing other code requirements provided FDD was used. Alternatively, a point-based standard could be modified to encourage the adoption of FDD. For example, if LEED Green Building points were awarded for FDD, that would encourage its use.

The following paragraph is copied from the preceding comment [JJ19]:

Acceptance requirements could be implemented by the FDD if VAV box testing was added to CA' acceptance criteria. LEED points could also be awarded through innovation credits or continuous commissioning credits. Finally, LEED EB looks at overall building performance so improving a benchmark score would provide some benefit to the FDD.

Manufactures Status

Who will initially produce and market this product? How firm is their commitment? If there is no current manufacturing partner, what steps have been taken to find one? (see Additional Manufacturer Commitment in the next section for planning to do this, if needed)

What are the crucial criteria to assure the manufacturing partner's continued commitment? What are you committed to do to get an interested or involved manufacturer to go all the way to production of this product? What else must others do?

How soon is the manufacturer likely to introduce this product to the market, after production engineering, costing, tooling, initial production, and distribution and marketing arrangements? What is the expected rollout strategy, if known?

APAR and VPACC will initially be available through two BAS manufacturers, Automated Logic Corporation and Novar Controls. There are currently Cooperative Research and Development Agreements (CRADAs) in place with these two manufacturers. Furthermore, each manufacturer has made its corporate headquarters building available as the first two field test sites for this project. Both of these sites are currently in operation. Several AHU and VAV box faults have already been successfully detected and diagnosed at the Automated Logic corporate headquarters building. Provided that additional field test sites can be identified and utilized, and that the field demonstration is successful, these two manufacturers' continued support seems assured.

Discussions are ongoing with two other BAS manufacturers: Andover Controls and Delta Controls.

Related and/or Competing Products under Development

Many of FDD products will be used directly by manufactures that are currently developing their own FDD capabilities. What are related FDD products under development by manufacturers and what benefit/barriers might exist due to the development of additional FDD type products?

Johnson Controls is developing a VAV box FDD tool that will be embedded in Johnson Controls VAV box controllers. The chief impact of this development is that it is highly unlikely that Johnson Controls would adopt APAR or VPACC. This issue is described further in the "Market Analysis" section under "The Competition."

Technology Transfer Actions

For each of the following paragraphs keep in mind these guidelines: What activities are planned for completing during the FDD contract? After the contract? Who is responsible for completing these tasks? Please also provide a schedule of these activities.

Additional Manufacturer Commitment

If additional manufacturers are required, describe how they will be identified and approached? If known, who are prime candidates? What will be done to encourage their commitment, and by whom? For instance, how will this plan's proposed business case be used? Can other influencers help in convincing manufacturers? Who will approach them and how?

There are two participating manufacturers (Automated Logic and Novar Controls) and two others (Andover Controls and Delta Controls) with whom discussions are ongoing. Discussions were also held with Siemens Building Technologies and Staefa Control Systems. Staefa decided against participating, while Siemens chose a "go slow" approach that will likely take several years before any action is taken with regards to FDD. As mentioned elsewhere in this report, it is highly unlikely that Johnson Controls would participate because of their in-house VAV box FDD tool. Any manufacturer of commercial AHU and VAV box controllers (or AHUs or VAV boxes with packaged controls) could be a viable partner, however there are currently no plans to approach any other manufacturers. It is felt that once FDD capabilities are introduced by one or two BAS manufacturers, competitive pressures will induce many other manufacturers to include FDD in their products as well.

Purchase Incentives

(Refer back to Business Case section for basic cost data) Are rebates or other incentives required to make this product competitive? These include direct incentives as well as mandated codes and industry standards. What is the plan for proposing and achieving such incentives? Who will lead this effort, and how? What timing is possible?

The energy savings and O&M benefits of FDD are not dependent on any code requirements. However, any incentives, whether they take the form of rebates, direct incentives, code recommendations, or points, will increase the appeal of APAR and VPACC, both to potential buyers and manufacturers. Potential incentives are described in the section "Codes and Standards".

Educating HVAC Engineers, Designers and Specifiers

What efforts in product introduction are needed to promote awareness and understanding among HVAC equipment specifiers? Who will be doing it? What type of material (early case-study applications, journal articles, conference presentations, spec sheets, brochures, press announcements, trade ads, education for manufacturing reps and distributors, trade show exhibits, etc.) is needed?

In current practice, HVAC systems are designed by engineers who are largely focused on the mechanical system, and who provide a fairly high-level narrative sequence of operations and specification for the control system. It is necessary to educate these individuals on the existence, general principles, and benefits of FDD. An article on this topic was submitted to the ASHRAE Journal for their July 2005 issue, which will be dedicated to controls-related topics. Case studies of each of the sites in the field test component of this project could be made available, as well.

Other Intermediaries

Who might hold up or advance the success of this product? Are there influential actors who must be encouraged? These might include distributors, manufacturers' agents, and local building code enforcers, for example. For this product, how important are these efforts, how will they be done, and by whom?

The BAS manufacturers' dealer/representatives play a key role in determining the success of the product. They will be the ones who actually install and configure APAR and VPACC at the sites and in most cases they will be the only ones who market the FDD tools to potential buyers. In many cases, they also enter into a service and/or monitoring agreement with the buyer, so that in addition to installing FDD, they will be the end users as well. Furthermore, some manufacturers rely heavily upon their dealer/representatives' assessment of the market interest in FDD when deciding whether to participate in this project. Therefore, they must be convinced of the potential benefits, effectiveness, and ease of installation of APAR and VPACC. A small number of dealer/representatives will be involved in the field demonstration project; these will have direct contact with the researchers. However, most of the dealer/representatives will learn about and be trained on the FDD tools through their respective manufacturer.

Tools: Design and Specification Aids

Are design and specification aids needed, such as computerized or written guides for sizing and energy-cost savings calculations? Are guides needed on integrating the product into different HVAC systems and controls? If so, what is needed and who should develop it for these products? What is it likely to cost, and is this viable? (Note that this information will be helpful in focusing the FDD's own project on design tools.)

The modification of standard AHU and VAV box application programs to include APAR or VPACC, respectively, is part of the "Plan Field Demonstration" subtask of this project. The development of robust sets of configuration is itself a subtask of this project. No other design or specification tools are needed.

Media: Papers, Presentations and Press Releases

What specific papers, presentations and press releases are needed? Describe the overall media approach. List event names and dates to the extent possible.

Paper & presentations on field demonstration results - AC

Other Outreach Actions

What other outreach efforts are needed to speed market adoption? Additional field demonstrations? Implementation of code changes? (etc.)