Information Resources for Better Building Controls

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ABSTRACT

Sustainability is a driving force in the building industry today and energy efficiency is one of the core components of sustainable design. While it is clear that sustainability cannot be achieved unless it is addressed in the design process, it is equally clear that addressing energy efficiency at design is not sufficient to actually achieve it. If the building industry aspires to the high ideals of sustainability, more attention must be paid to ensuring that the building control system actually delivers the energy efficiency envisioned at design. DDC Online and the National Building Controls Information Program (NBCIP) are resources that are aimed at increasing the building industry's understanding of the actual performance and capabilities of control systems, a necessary first step toward improving energy efficiency through better building controls.

DDC Online is a web-based catalog of product lines of the leading manufacturers of building direct digital control (DDC) systems presented using a generic architecture and common terminology, thereby simplifying the task of comparing products of different manufacturers. NBCIP was established to provide manufacturer-specific performance information as well as broad-based best-practice information on building controls based on research, testing, and sound engineering practice. The paper provides overviews of DDC Online and NBCIP and highlights three NBCIP projects.

Introduction

Sustainability is a driving force in the building industry today and energy efficiency is one of the core components of sustainable design. While it is clear that sustainability cannot be achieved unless it is addressed in the design process, it is equally clear that addressing energy efficiency at design is not sufficient to actually achieve it. Whether or not a building was designed using sustainability principles, energy efficiency is closely linked to building operations and control. Furthermore, there are numerous studies in the literature that support the belief that control problems leading to significant energy waste are common in buildings (e.g., Ardehali et al. 2003). A recent study that assessed the cost-effectiveness of commercial-building commissioning reported median whole-building energy savings of 15 percent in 150 existing buildings (Mills et al. 2004). The same study reported that the most common correctional measures dealt with operations and control. And, although centralized energy management and control systems (EMCS) serve only about 30% of the floor space in commercial buildings, most commercial buildings likely have some degree of control functionality commonly found in an EMCS (Roth et al. 2005). Thus, if the building industry aspires to the high ideals of sustainability, more attention must be paid to ensuring that the building control system actually delivers the energy efficiency envisioned at design.

Recognizing the critical role that building controls play in achieving energy efficiency, the Iowa Energy Center has created two resources that provide credible third-party information about building control systems, namely, DDC Online and the National Building Controls

Information Program (NBCIP). DDC Online is a web-based catalog of product lines of the leading manufacturers of building direct digital control (DDC) systems presented using a generic architecture and common terminology, thereby simplifying the task of comparing products of different manufacturers (IEC 2006a). NBCIP provides manufacturer-specific performance data and broad-based best-practice information on building controls based on research, testing, and sound engineering practice (IEC 2006b). The product information provided by DDC Online and NBCIP is unique to the building controls industry and fills a significant void between claims made in manufacturer literature and the individual experiences of those who design, specify, install, commission, and operate building control systems. The information itself does not lead to improved energy efficiency any more than commissioning guides do; however, knowledge obtained from resources such as these can lead to better decisions concerning building controls that can have a significant impact on energy efficiency.

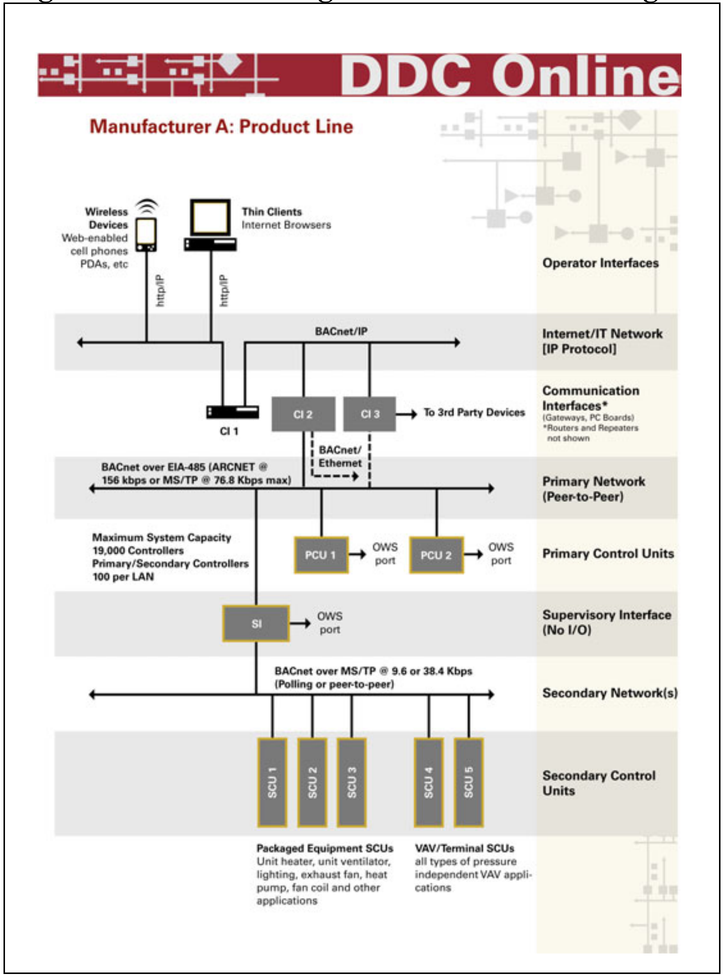
The objective of this paper is to provide an overview of DDC Online and NBCIP in order to draw attention to the information on building controls provided by these resources. The overview of DDC Online includes a discussion of manufacturer product information and fundamentals of direct digital control. The overview of NBCIP includes summaries of three projects, one that was recently completed and two that are ongoing. The first project is product testing of duct-mounted relative humidity transmitters, which was completed in 2005. The second project is the development of an application guideline on return fan capacity control strategies. This project will conclude in the summer of 2006. The third project that will be described is product testing of wall-mounted carbon dioxide transmitters. This project was recently initiated and will be carried out over a two-year period.

DDC Online

Comparing the merits of different DDC systems is one of the biggest challenges specifying engineers face today. DDC systems are complex and their capabilities evolve quickly, particularly in the area of communications. To further complicate matters, manufacturers naturally strive to differentiate their products from those of their competitors. Product capabilities and the terminology used to describe these capabilities are two of the ways this is done. DDC Online is a web-based catalog that was created to simplify the task of comparing products from different manufacturers by stripping away the artificial differences (the terminology differences) so that functional differences (product capabilities) become more evident. This "standardization" of the presentation of DDC product lines was initially introduced to the industry at the 2000 ASHRAE Winter Meeting and has since grown to include 25 manufacturers of DDC systems. The ability to readily compare product lines from different manufacturers is so valuable that at least one designer now requires that a product be listed on DDC Online to prequalify on large campus master specifications (Hydeman 2006).

Figure 1 shows the generic architecture diagram used to present the product lines of each manufacturer listed on DDC Online. A quick screening of the architecture diagram of various product lines can identify those lines with an appropriate level of sophistication for the application of interest. The labels on the right side of Figure 1 correspond to eight layers of the architecture. Manufacturers commonly provide their own architecture diagrams with their product literature; however, they lack uniformity between manufacturers and therefore are difficult to compare. For each manufacturer listed on DDC Online, the layers are populated with appropriate devices and/or communication information based on technical specifications

Figure 1. DDC Online generic architecture diagram



Source: IEC 2006a

provided in the manufacturer literature. Manufacturers are given the opportunity to review material pertaining to their product line before it is posted on DDC Online.

Additional information lies below each architecture diagram. Clicking on a controller such as the primary controller PCU 1 in Figure 1 allows users to view more detailed information about that particular controller. Templates are used to present this information so that the same information can be readily located for a primary controller from another manufacturer. Plans are underway to enhance the information on DDC Online by adding a software template that will list all the software packages required for each product line.

In addition to product information, DDC Online presents introductory material on DDC systems that aids in the understanding of the product descriptions. Topics range from the elements of a control loop to types of control responses and various types of network topologies. There are also descriptions of various control devices, explanations of the different approaches for programming control logic, and an overview of communication issues. Another section of DDC Online describes a wide range of input and output devices and the terminology (e.g., accuracy, repeatability, hysteresis) used to characterize the performance of these devices. Controls experts indicate they frequently refer students to this introductory material (Sellers 2005, Hydeman 2006).

National Building Controls Information Program

NBCIP was created in 2001 on the premise that properly functioning control systems are a significant contributor to energy efficiency, and problems associated with building controls and operation are a primary cause of inefficient energy usage (Barwig et al. 2002). NBCIP was established to facilitate the adoption of energy efficient control products and strategies through testing, demonstration, education and dissemination of information on building controls. NBCIP information is targeted at the building professionals who design, specify, install, commission and operate building control systems and takes the following forms:

- Product Testing Reports: NBCIP product testing provides performance results obtained by testing comparable products from leading manufacturers. Product testing projects are conducted using a rigorous process wherein a method of test is developed and reviewed by experts external to the program. Products are purchased anonymously in an effort to ensure they are representative of what typical customers would receive.[1] Testing is then conducted in accordance with the method of test and a peer-reviewed report is published that details the testing and results. The reports include manufacturer names so readers can use the information to make informed choices concerning the products they specify and use. A project to test the performance of duct-mounted relative humidity transmitters was the first NBCIP product-testing project and was completed in 2005 (Corsi & House 2004, Corsi & House 2005). A second project has recently been initiated to test wall-mounted carbon dioxide transmitters. Both projects are highlighted later in this section.
- Application Guidelines: Application guidelines are intended to provide guidance to designers, installers and operators concerning the proper application of control system devices and strategies. A guideline comparing five strategies used for return fan capacity control is under development and is highlighted later in this section.
- Best-Practice Control Strategies: Best-practice control strategies are established through comparisons of control strategies/algorithms using the matched systems at the Iowa Energy Center Energy Resource Station (IEC 2006c). A project to compare energy efficient supply fan control strategies, such as static pressure reset, with a conventional strategy that controls the supply fan to a fixed static pressure will be initiated by NBCIP in spring 2006.
- Building Operation Tutorials: Building operation tutorials provide guidance to contractors, commissioning providers, and building operators explaining "how" typical installation, operation and maintenance tasks, such as installing and calibrating sensors, are performed.

The ensuing sections describe three NBCIP projects; one which was recently completed, one that is nearing completion, and one that was recently initiated.

Product Testing of Duct-Mounted Relative Humidity Transmitters

The first product testing project undertaken by NBCIP evaluated the performance of HVAC grade duct-mounted relative humidity transmitters. The performance of relative humidity

[1] NBCIP does not accept funding from manufacturers or manufacturer associations.

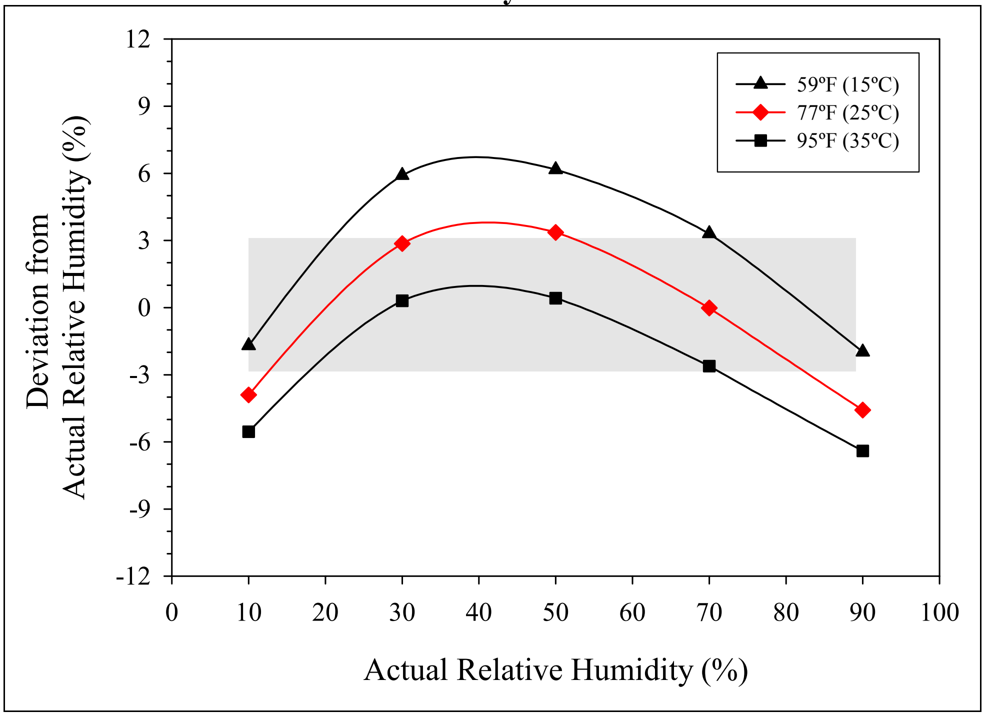
transmitters has significant impact on energy use in buildings. As an example, enthalpy-based economizers utilize relative humidity and temperature measurements in the outdoor and return air streams to determine when it is appropriate to enable free cooling using outdoor air. Inaccurate relative humidity measurements can produce energy penalties due to inadequate or excessive use of outdoor air. Poor humidity control in supermarkets caused by inaccurate relative humidity readings can result in excessive load on display cases and the necessity to operate anti-sweat door heaters and defrost cycles more frequently.

Testing was performed on comparable products from six different manufacturers. All the transmitters had manufacturer stated accuracies of ± 3% RH. Three transmitters of the same model were purchased from each manufacturer. Manufacturers were not involved in any aspect of the planning or performance of the testing. The testing performed is summarized below:

- Newly purchased relative humidity transmitters were tested over a range of relative humidity values and temperatures in a two-pressure humidity generator that has a small environmental chamber that can be controlled to tolerances of ± 0.5 % RH and ± 0.06ºC (Thunder Scientific Corporation 2006). Testing evaluated overall accuracy as well as linearity, repeatability and hysteresis.
- Two of the three transmitters from each manufacturer were installed in the outdoor air duct of an air-handling unit for one year. Every four months, the transmitters were retested in the humidity generator. Data were also collected while the transmitters were installed in the outdoor air duct. This ageing test was intended to evaluate the drift of the transmitters when they are exposed to typical HVAC environmental conditions over a period of time.
- The third transmitter from each manufacturer was tested to determine the device response time. The response time of the transmitter can be important when trying to control a humidification process, such as direct steam injection.
- The third transmitter was then subjected to a battery of stress tests aimed at evaluating the robustness of the devices. The transmitters were first cycled between low and high humidities and low and high temperatures. The transmitters were then installed in a dry environment where the relative humidity was nearly 0%. Following this the transmitters were installed in a saturated environment where the relative humidity was nearly 100%. Testing in the dry and saturated environments was termed the desiccation and saturation test. Finally, the sensing component of the transmitters was submerged under water. After each stage of testing, the transmitters were retested in the humidity generator.

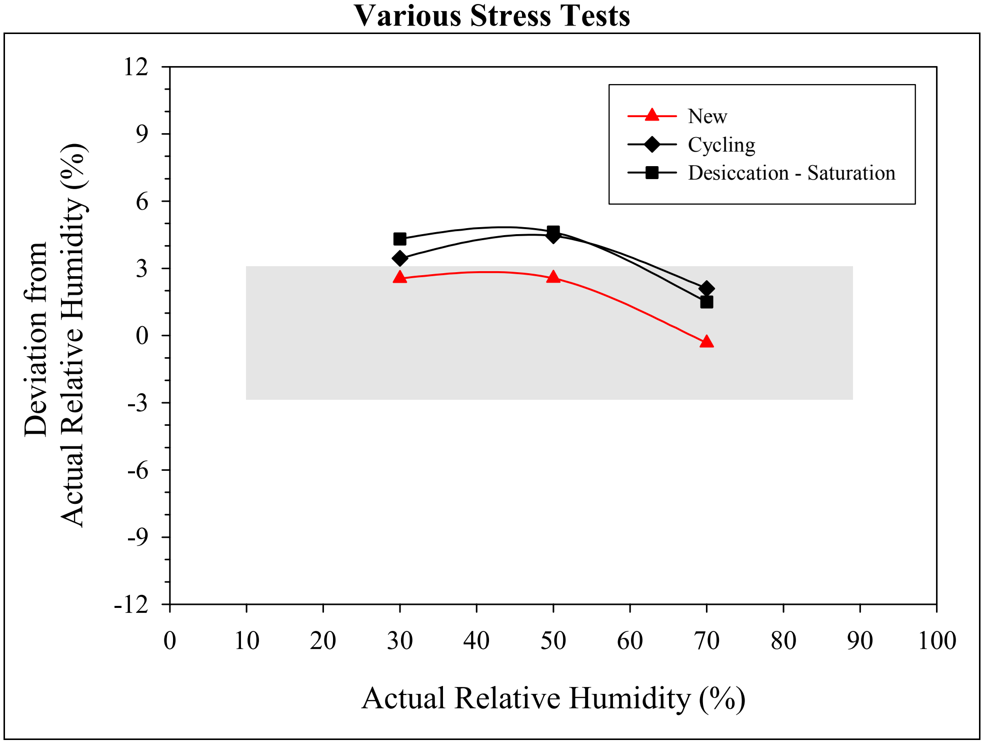
Results obtained for the product of one manufacturer are shown in Figures 2 through 5. In each figure, the actual relative humidity is shown on the x-axis and the deviation of the sensor measurement from the actual relative humidity ($RH_{measured} - RH_{actual}$) is shown on the y-axis. In Figures 2 through 4, the actual relative humidity corresponds to the condition in the humidity

Figure 2. Average Accuracy of Three Identical Relative Humidity Transmitters Tested Shortly After Purchase



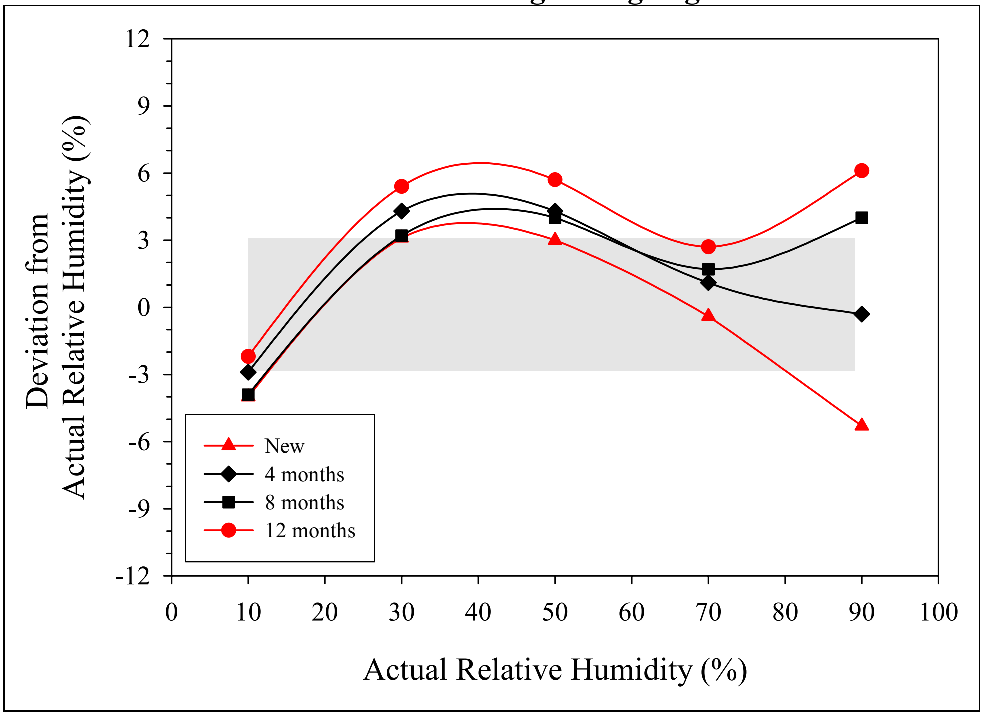
Source: Corsi & House 2004

Figure 3. Accuracy of a Single Relative Humidity Transmitter After Various Stress Tests



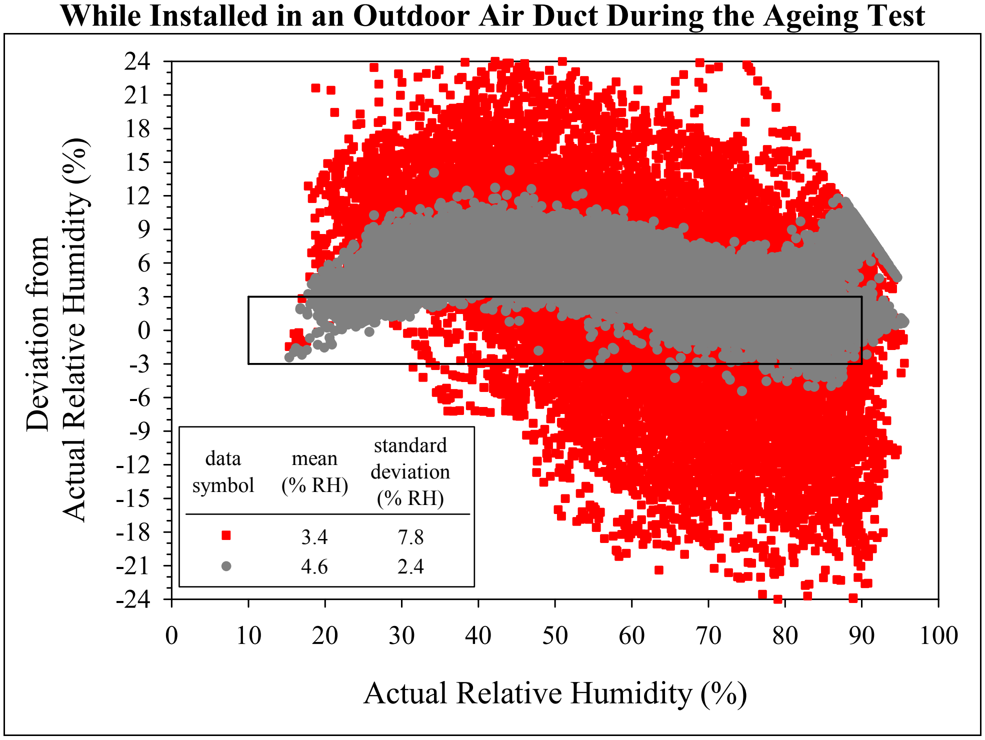
Source: Corsi & House 2005

Figure 4. Accuracy of a Single Relative Humidity Transmitter at Four-Month Intervals During the Ageing Test



Source: Corsi & House 2005

Figure 5. Accuracy of Two Identical Relative Humidity Transmitters While Installed in an Outdoor Air Duct During the Ageing Test



Source: Corsi & House 2005

generator, while in Figure 5 the actual relative humidity was taken to be the value measured by a precision duct-mounted relative humidity transmitter installed in the outdoor air duct in close proximity to the transmitters tested by NBCIP.

The curves in Figure 2 reveal the accuracy of the newly-purchased transmitters and were obtained by averaging the results from three transmitters. According to the manufacturer's stated accuracy, all the points on the curve corresponding to 77ºF should fall within the gray box. Note that the accuracy of this particular transmitter has strong temperature and relative humidity dependencies.

The curves in Figure 3 correspond to a single transmitter that underwent the battery of stress tests. The curves correspond to the accuracy of the new transmitter, the accuracy after the cycling test, and the accuracy after the combined desiccation and saturation test. The accuracy after the submergence test is not shown because the transmitter was not operational following this test. The curves indicate only a slight degradation in performance as the tests were carried out. Several of the transmitters were not operational after the submergence test; however, products from two manufacturers were operational and their accuracies did not suffer from the test.

Figure 4 shows the performance of a single transmitter that was subjected to the ageing tests. The individual curves show the performance of the new transmitter and subsequently at four month intervals during the ageing test. The drift of the transmitter is noticeable over the full range of relative humidity; however, it is especially dramatic at 90% RH.

Figure 5 shows ageing data collected for two transmitters while they were installed in the outdoor air duct. The mean and standard deviation of the two data sets are also provided in the plot. The first data set has a significantly wider scatter, indicated by the fact that its standard deviation is more than three times that of the second data set. Measurement errors of the magnitude found with the first transmitter lead directly to control errors and, for economizer applications, can lead to significant energy waste.

Testing methods and results for all manufacturers are provided in comprehensive reports that include manufacturer names (Corsi & House 2004, 2005). To date, a combined total of more than 900 copies of the two reports have been downloaded from the NBCIP web site.

Application Guideline: Return Fan Capacity Control via Speed Control

The control of the return fan speed affects the pressure within the HVAC system and the spaces it serves, the intake of outdoor air, and ultimately system energy consumption and building indoor air quality. There are numerous strategies in use today for controlling return fans; however, there is little guidance available concerning how and when (what building types and applications) the individual strategies should be applied. NBCIP is partnering with Portland Energy Conservation, Inc. in the development of an application guideline on return fan capacity control strategies that will: 1) provide a comparison of five existing return fan control strategies, and 2) provide design engineers, installers and building operators with guidelines on selecting, implementing, and troubleshooting the strategies to ensure energy efficiency and proper building pressurization. The return fan control strategies addressed in the guide are: 1) speed tracking control, 2) flow tracking control, 3) building pressure control, 4) discharge pressure control, and 5) mixed air plenum pressure control.

The guideline will contain a chapter on fundamentals, a separate chapter for each of the five control strategies, and appendices with supporting material. The fundamentals will address issues such as the interaction of the return fan operation with building pressurization and outdoor air control. It will also contain a summary table such as that shown in Table 1 (Sellers 2006). The summary table will provide a high level description of the control strategies and will compare them based on application complexity, potential for negative indoor environmental quality and energy impacts, potential for integration and interaction problems, first cost, maintenance cost, and energy cost. Table 1 provides the content of the comparison table for two of the five strategies addressed in the guideline. For each of the comparison characteristics, the strategy is given a rating of low, moderate or high, thereby enabling an initial assessment of the strategies relative to one another.

Each strategy chapter begins with a two-page summary of the strategy, including a schematic diagram, general description, advantages, limitations, comparison characteristics (same as Table 1), and key design, installation and operation issues and considerations. The body of the chapter provides more in-depth discussion of the issues highlighted in the summary and also includes a trouble-shooting table, points list, and an example operating sequence.

The application guideline will be available on the NBCIP web site in the fall of 2006.

Product Testing of Wall-Mounted Carbon Dioxide Transmitters

Demand-controlled ventilation (DCV) based on measurements of indoor carbon dioxide levels is becoming a common strategy for achieving HVAC energy savings. In California, for instance, the energy efficiency standard for residential and nonresidential buildings, commonly referred to as Title 24, requires the use of demand-controlled ventilation in certain types of high-

Table 1. Return Fan Speed/Capacity Control Strategy Comparison

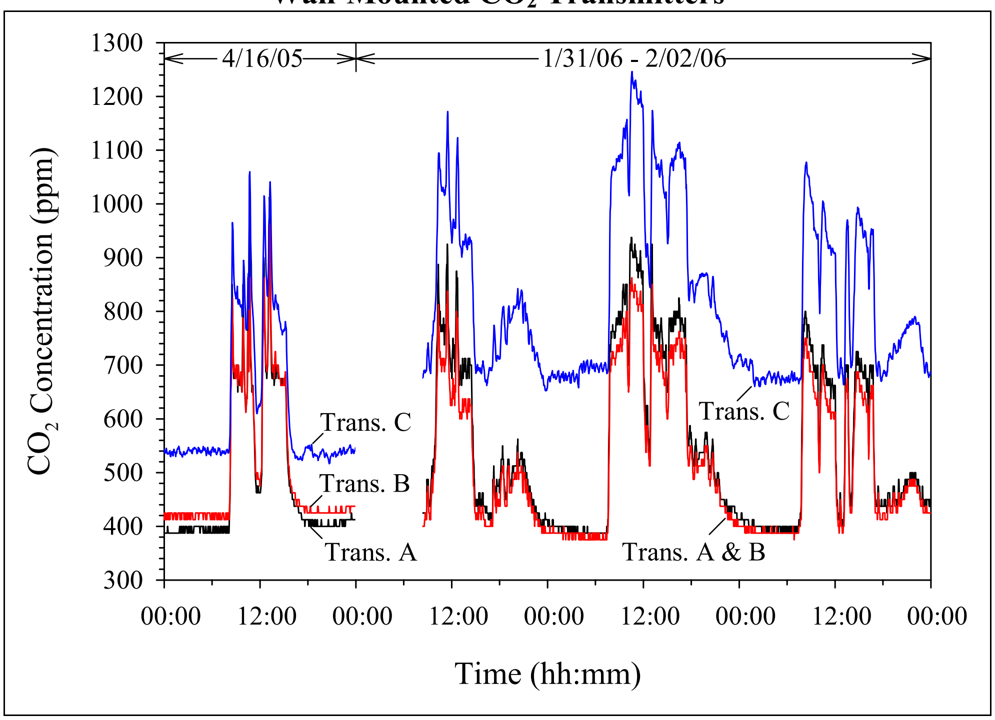
Strategy	Description Fundamental Principle of Operation	Comparison Characteristics	Rating		
			Low	Moderate	High
Speed Tracking Control	Description: Return fan speed is controlled in direct proportion to the supply fan speed or the supply fan speed command. Fundamentals: Once the correct supply to return fan volume ratio has been set and the speeds associated with it have been determined, the desired flow relationship can be maintained by controlling the return fan speed based in proportion to the supply fan speed.	Application Complexity	✓		
		Potential for Negative IEQ Impact			✓
		Potential for Negative Energy Impact			✓
		Potential for Integration and Interaction Problems		✓	
		First Cost	✓		
		Maintenance Cost	✓		
		Energy Cost			✓
Flow Tracking Control	Description: Return fan speed is controlled based on flow measurements to maintain a differential between supply and return flow. Fundamentals: Via conservation of mass, the desired minimum outdoor air flow rate can be maintained by measuring the supply flow rate, subtracting the desired outdoor air flow rate from it, and controlling the return fan to deliver the resulting flow.	Application Complexity			✓
		Potential for Negative IEQ Impact		✓	
		Potential for Negative Energy Impact	✓		
		Potential for Integration and Interaction Problems		✓	
		First Cost			✓
		Maintenance Cost			✓
		Energy Cost	✓		

Source: Sellers 2006

density spaces and also identifies acceptance requirements pertaining to the DCV implementation that must be satisfied before an occupancy permit is granted (CEC 2005). Among the acceptance criteria are requirements that the carbon dioxide transmitter(s) have an accuracy of ±75 ppm and that the transmitters have a calibration interval of at least five years. The five year calibration interval is quite remarkable considering the historical performance of CO_2 transmitters. Traditionally, CO_2 transmitters were susceptible to drift, caused primarily by particle buildup in the sensor and ageing of the light source used in the measurement technology (Schell & Int-Hout 2001). Frequent calibrations were necessary to combat this problem.

More recently, manufacturers have developed self-calibration technologies to address the problem of drift and manufacturer data sheets now indicate there are numerous products on the market that can satisfy the accuracy and calibration requirements in Title 24. However, field experience indicates the actual performance of some products may fall short of these requirements. Field data collected in a classroom from three products with manufacturer stated accuracies that satisfy the Title 24 criteria are shown in Figure 6. The data in Figure 6 were collected over two periods; the first data set, shown on the left, was collected on April 16, 2005 and the second set was collected January 31, 2006 through February 2, 2006. The three CO_2 transmitters were located within 12 inches of one another and all utilize a form of self-calibration, although the technologies on which self-calibration is based differ. Note that the readings from transmitters A and B are in close agreement in both data sets in Figure 6. The mean of the absolute value of the difference between the readings is 23 ppm for the first data set and 28 ppm for the second. Transmitter C, however, has a mean reading that is 126 ppm higher than the mean reading from Transmitters A and B in the first data set. This difference increases to 294 ppm in the second data set. Thus, the difference in the readings between transmitter C and transmitters A and B increased in absolute terms by 168 ppm in less than 10 months.

Figure 6. CO_2 Concentration Measurements from Three Side-by-Side Wall-Mounted CO_2 Transmitters



The implications of the results in Figure 6 depend on which transmitter is correct. A transmitter having a positive offset (i.e., the reading is higher than the true CO_2 concentration) will lead to over ventilation of the space it serves, thereby reducing potential energy savings from DCV. A transmitter with a negative offset will lead to under ventilation of the space it serves, which can produce indoor air quality problems.

The scope of the NBCIP product testing of CO_2 transmitters will be established in a formal method of test that will be peer reviewed by external experts. It is anticipated that testing will evaluate the accuracy of three identical HVAC grade CO_2 transmitters from each of the leading manufacturers through monthly checks using calibration gas. It is also anticipated that a fourth transmitter will be purchased from each manufacturer and used to assess the sensitivity of CO_2 transmitters to humidity. Reports similar to those written for the relative humidity transmitter testing will be produced to document the testing procedures and results.

Summary

This paper described the web-based information resources DDC Online and NBCIP. DDC Online provides "standardized" information on DDC systems that facilitates the comparison of product lines from different manufacturers. NBCIP conducts and reports on product testing that compares the performance of control components from different manufactures. The product information provided by DDC Online and NBCIP is unique to the building controls industry and fills a significant void between claims made in manufacturer literature and the individual experiences of those who design, specify, install, commission, and operate building control systems. NBCIP also develops application guidelines, best-practice control strategies and operator tutorials. Together, DDC Online and NBCIP provide valuable information aimed at improving the energy efficiency of buildings through better building controls.

Acknowledgements

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