The Direct Digital Control Crisis in Oregon Public Schools: Offering Solutions Through Trouble-Shooting Services, Construction Specifications and DDC Circuit Rider Services

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ABSTRACT

Oregon school districts are experiencing problems with direct digital controls (DDC) in new and existing schools. Errors in the design, installation and operation of DDC systems cause occupant discomfort (thermal and IAQ), are time consuming to fix and waste energy. Schools that fix their DDC problems can save substantially on energy costs. One new school that fixed its controls is saving $10,000 annually or 13 percent of its energy budget.

The Oregon Office of Energy implemented a systematic approach to address DDC problems. A broad service delivery strategy is required because many schools have multiple DDC systems and school construction is booming. The office uses three key components in its systematic approach.

First, office staff uses trouble-shooting tools to identify DDC problems and suggest solutions for installed systems.

Second, the office developed construction bid specification guidelines for DDC systems. They include an explicitly stated sequence of operations, accountability for system deficiencies by trade, and a detailed training agenda. Anticipated results include consistent bids from multiple vendors, reduced contractor callbacks, appropriate system design, energy efficient operation, and a functional DDC system.

Third, the office is developing a DDC circuit rider program because individual school districts can not afford control experts and local control vendors often do not provide adequate service. Under the program, the school system employs control experts who circulate among school districts to provide trouble-shooting, repair, and general operation and maintenance services.

Introduction

Direct digital control systems have been in vogue for several years as **the** method for controlling heating, ventilation and air conditioning (HVAC) within a building (Alduino & Mumma 1995). The term "direct digital control" – or "DDC" for short – refers to the system's ability to electronically monitor and control HVAC components. Engineered, installed, and used correctly, a DDC system offers precision control of equipment to provide building comfort with energy efficiency. In addition, a DDC system can be modified and expanded more easily than the once-standard pneumatic (compressed air) systems.

However, in its work with schools, the Oregon Office of Energy has discovered that a DDC system sometimes brings a school more problems than benefits. For example:

- To maintain stable temperatures in 60 percent of its classrooms, a new middle school had to manually operate its malfunctioning DDC system. Maintenance staff members bypassed the $144,000 automated controls to modulate the supply air temperature. They manually opened the heating valve in the air handler and adjusted the outside air damper.
- A new elementary school's $77,500 DDC system caused the building's heating and ventilation system to run around the clock, even on weekends. The building's air pressure was so high that doors could not close automatically, and several rooms were always too hot or cold.
- An elementary school built 20 years ago spent $100,000 on an energy efficiency retrofit that included new steam actuators, new damper actuators, T8 lighting, an 80-gallon water heater to replace boiler water heater operation in the summer, and a DDC system that served only as a glorified time clock. The result was a utility bill that increased from $11,000 a year to $17,000 a year.

We estimate that about 200 or one-sixth of Oregon K-12 schools have dysfunctional DDC systems. By fixing DDC design, installation and user errors, these schools could save an estimated 11.5 million kWh and nearly one million therms of natural gas. They would cut their energy costs by a total of more than $1 million per year. They also would increase building comfort and reduce the amount of staff time spent on jerry-rigging the DDC and HVAC systems to work correctly.

This paper explores the reasons behind the DDC problem in schools and discusses three solutions the Oregon Office of Energy has developed: trouble-shooting services to identify control errors, construction bid specifications to reduce errors in the design and installation process, and a program designed to hire DDC experts to maintain and repair systems for multiple school districts.

Working DDC Systems Equal Savings of Energy, Time and Money

A working DDC system has many benefits for schools. A working system means that equipment operates within acceptable tolerances (that will help avoid premature equipment failure). A working system also means a school isn't wasting money on its heating and ventilation. Of more importance to schools, though, are the system's stable temperatures and good indoor air quality that help make a school's occupants comfortable.

While saving energy usually isn't the highest priority for schools wanting to correct their malfunctioning DDC systems, the potential for saving energy is nonetheless high precisely because the system's first goal is temperature stability — even if energy is wasted to achieve this goal. On the other hand, a fixed DDC provides comfort with minimal energy use. For example, stopping the DDC system from continuous operation at one Oregon school saved $6,300 a year or 24 percent of the school's energy budget without reducing occupant comfort levels during the school day. At another school, the control contractor and the vendor for the air handling unit established communication between the DDC system and the rooftop unit saving the school $10,000 a year or 13 percent of its energy budget. This fix resulted in improved comfort while saving energy.

Correcting DDC problems isn't always inexpensive or easy, however. If pressured, a control contractor may provide some DDC repairs free of charge. Others, however, can be costly. One Oregon school had to pay $15,000 to reprogram its DDC system to design specifications only three years after installation. In addition, fixing a DDC system is a time-consuming process that may require the participation of the facility manager, business manager and even the superintendent. Repetitious meetings with the architect, engineer, controls contractor, test-and-balancing firm and air handler vendor can result in little productive gain and lots of finger pointing.

Badly engineered, installed and operated DDC systems waste energy, time and money. Helping schools minimize their DDC headaches has become a priority for the Oregon Office of Energy.

Problems with Direct Digital Controls in Schools

DDC problems in schools commonly start at the design stage, snowball through the installation phase and become further magnified by maintenance staff or other end users who introduce operational errors.

Design Stage Errors

Errors during the design stage of a school's DDC system often result from an engineer's unfamiliarity with the electronic controls. The change from pneumatic to DDC systems represents a huge leap for engineers in the number of choices they must make and the complexity of those choices (Bynum 1991). Many engineers do not understand that even simple operations may require complex programming and inclusion of additional equipment - such as sensors.

This failure to include sufficient points, such as sensors, and/or failing to develop detailed control logic is a common problem at the design stage. For example, a school's request to routinely cool a building at night using 100 percent outside air – called night purge – requires several actions to avoid wasting energy or causing water damage. First, the control system must monitor the inside and outside temperature to avoid running a fan without actually cooling the space. Second, a humidity sensor must be included in the system to avoid bringing cool, saturated air into the ducts. Examples of design-stage problems encountered at Oregon schools include:

- Engineering plans for one new school lacked start-and-stop points for each of the stages for a four-stage heater.
- Plans for another new school failed to include a sequence of operation (control logic) for the designated evaporative cooler.
- At another new school, DDC engineering specs called for indoor air quality control, but they did not specify whether a volatile organic compounds (VOCs) or carbon dioxide sensor should be used for monitoring indoor air quality. The specs also lacked any sequence of operation instructions to indicate when the air quality was compromised or how the HVAC system was to respond.
- At a 30-year-old school, the HVAC design engineer did not notice that the unit's ventilators lacked full modulating damper actuators. The result was that

the new control system did not provide energy-efficient damper control because its existing damper configuration could only control the damper to fully open and fully closed.

Besides the engineer's unfamiliarity with DDC systems, another problem at the design stage is that fee structures for engineering a school's DDC system that do not allow engineers time to educate themselves on how to specify controls for a specific project and system (Alduino & Mumma 1995). Many engineers use generic specifications provided by the control contractor (a cut and paste approach) and they rely on the control contractor to design and install a proper DDC system (a free reign approach).

Installation Errors

Many of the problems start with a school's vague or ambiguous construction bid specifications. For example, CO_2 demand controlled ventilation is requested but the spec provides no detail on how to implement this control. Thus, the control logic for the CO_2 demand controlled ventilation feature is determined by the programmer and not the engineer who designed the system (Solberg 1988). This programming code is usually undocumented and may or may not conform with the engineer's design intent. Another common ambiguous specification states that a DDC system must be capable of night purge but few require the implementation of this capability. The engineer and the owner may assume that they will receive the feature since it's in the specs but they fail to realize that the feature is not adequately defined and will not be installed unless the feature is written more explicitly.

In addition, many computer programmers who excel at their craft but do not understand HVAC systems can also cause DDC installation problems. For example, they can program the fan and steam humidifier systems to turn on and off, but they do not understand that the fan should be turned on before turning on the steam humidifier. Also, the programmer who starts the project is replaced in the middle of the job. The result is that two different sequence of operations are used for different sets of air handlers that can cause difficulty while trouble-shooting the DDC system. Finally, some third-party contractors new to DDC work lack the detailed knowledge required to install a correctly operating DDC system.

Examples of installation-stage problems encountered at Oregon schools include:

- A DDC system did not communicate successfully with a school's rooftop unit (manufactured by a leading firm). This lack of communication resulted in large temperature swings in the classrooms and offices.
- A programmer did not tie boiler operation to outside air temperature. As a result, the boiler was on when it was 80°F outside.
- A control panel was mounted on a school's wall, but no wires were attached.
- Programming errors at one school led to around-the-clock operation for all HVAC systems and temperature swings of ±5°F every minute in the supply air.

It should be noted that while DDC and HVAC errors are usually attributed to the control contractor, other vendors such as air handlers, test-and-balance firms, plumbers, electricians, and boiler installers (to name a few) also introduce control related errors.

Operational Errors

Of the people involved in the installation of a school's DDC system, the actual operators may be the least educated about the controls. The biggest problem facing school staff is that the DDC system can seem prohibitively complex, especially when compared with a much more intuitive pneumatic system (Chamberlain 1988). Staff members often are not adequately trained to use the system and thus have little understanding of its full potential. They usually aren't capable of collecting the data the system can provide (regarding equipment and energy use trends) or analyzing the data once it is collected. As a result, operators often either play with temperature setpoints (via the DDC software) or mechanically bypass the electronic system in part or completely to achieve occupancy comfort.

Examples of operational-stage problems encountered at Oregon schools include:

- In many older buildings, the DDC system often is in complete override mode. Operators use the software or mechanically disconnect the system to produce 24-hour operation that results in perfect space temperatures during both occupied and unoccupied periods.
- Because of an undersized heating coil, staff at one school disconnected the outside air damper linkages in the winter to maintain a higher mixed air temperature in the air handler and thus a higher space temperature. The result was that half the dampers were permanently closed.
- A school district's staff manually set the heating valve for the air handler each day and throughout the day changed the amount of outside air to maintain internal temperature setpoints.

These examples also show the staff's inability to utilize the DDC system to diagnose HVAC and DDC problems as well as use the DDC system to fix problems rather than manually overriding HVAC and DDC systems.

A Systematic Approach for Addressing DDC Problems

The Oregon Office of Energy determined that reducing the DDC crisis in Oregon schools required a strategy for delivering broad and systematic DDC services. The three key components in its systematic approach are:

- Trouble-shooting tools to identify DDC problems for installed systems and suggest solutions
- Construction bid specification guidelines for DDC systems for a typical 80,000+ square-foot school
- Development of a shared controls expert – dubbed a DDC circuit rider – hired by school districts to fix and maintain control systems

The three approaches evolved as a way to address school needs. The trouble-shooting approach was born as field energy studies evolved from identifying traditional energy savings measures to assisting schools with immediate DDC problems that wasted energy and caused comfort problems. School staff limitations, a boom in school building construction, and trouble-shooting services that addressed symptoms rather than causes led to the development of construction bid specifications that address key causes of poor

DDC systems. Finally, the DDC circuit rider concept, now under development, is a result of school staff limitations, the role of the Oregon Office of Energy as an identifier rather than repairer of DDC problems, and widespread DDC problems in existing schools.

Trouble-Shooting Approach

Evolution of trouble-shooting approach. Only one Oregon Office of Energy staff member is dedicated to schools, but there are more than 1,200 schools in Oregon. As a result, a process became critical for identifying schools to receive the office's assistance package of an energy study, indoor air quality ventilation study, and operator training. Typically, we collect a year’s worth of energy use data for every school within a school district. We then convert fuel use to BTUs and divide by the building's square footage to determine the Energy Usage Index (EUI). Schools with an EUI above the normal range – typically schools at 150 percent of normal – are contacted and offered help to reduce their energy use.

Initially, our target was existing schools with high (150 percent of normal) energy use and not the new, modern schools that used energy at about 125 percent or less of normal. However, as we met with school district personnel, they often seemed more concerned with the comfort, air quality and energy use of newly built schools. This situation occurred so many times that the Oregon Office of Energy’s focus on energy study assistance for schools evolved from energy studies (identifying cost-effective energy efficiency projects) into DDC trouble-shooting assistance.

Trouble-shooting assistance process. Trouble-shooting assistance is rather like retro-commissioning. We collect a copy of the construction bid specifications and as-built documentation. We then compare these documents to actual equipment and software programming to determine if the school district received what it paid for. Next, we collect and analyze data for a system variable or point over a period of time using the system's trend logs. The trend logs are, unfortunately, rarely set-up by the control contractor and need to be set-up by Oregon Office of Energy staff. Once trending is established, an analysis is conducted to determine if the control logic is correct (i.e., does the economizer work). A key component of the process is judging whether the DDC system’s electronic inputs and outputs are consistent with observed events. For example, the DDC system may show a signal that the dampers are open while they are observed to be partially or fully closed at the air handling unit. We collect additional data using portable temperature probes, static pressure probes and other equipment to compare control data to observed events.

Once we analyze the data, we generate a report describing any deficiencies. The deficiencies are divided into two sections:

- Section 15900 bid specifications deficiencies describe the items the school district is entitled to as specified in Section 15900 of the bid/contract document. The items are listed by section number and sub-headings for easy reference for the school district, engineer and controls contractor.
- The DDC system deficiency section describes the problems associated with the actual operation of the DDC system. Such problems may include unstable temperature control at the classroom or at the air handler, inability of the DDC

system to communicate with the air handlers, and 24-hour operation of the system.

The report is typically routed from the school district to the engineer and control contractor. Sometimes control contractors fix the DDC related problems for free, and sometimes they charge $90 or more an hour for repairs. If asked, the Oregon Office of Energy will help the school district develop a scope of services for the control contractor.

Future. The next step in our trouble-shooting process will be to use an automatic trend log diagnostic program. The diagnostic software would analyze sensors and other point data within the DDC system to determine when equipment fails or if a sequence of operation is incorrect. For example, the software would determine if a leak exists in a heating or cooling coil valve or if the economizer is operating incorrectly. Diagnostic software is in development at a U.S. Department of Energy laboratory and at a private engineering firm specializing in HVAC/DDC commissioning.

Construction Bid Specification Guidelines for DDC Systems

Since the introduction of DDC systems, many people in the construction industry have called for more precise and clear construction bid specifications. ASHRAE papers in the late 1980s and early 1990s called for better communication between the engineer, control contractor, and the owner (Bynum 1991, Hadden 1988; Haines 1985; Hardin 1988; Solberg 1988). But by 1995, documentation for DDC systems had not improved. A study by Alduino & Mumma (1995) indicated that documents from the engineer are only 70% complete according to control contractors. This lack of precision and clarity in DDC specifications is evident in construction bid documents for Oregon schools.

In response to this lack of precise and clear documentation, we developed (during the summer of 1999) construction bid specification guidelines for DDC systems to reduce or eliminate the problems we have discovered with existing DDC systems at schools as well as those ideas and issues mentioned in many of the ASHRAE papers (Bynum 1991, Hardin 1988, Kohlhoff 1988). While the typical bid specification is 20 pages long, usually general in its requirements and vague about the system's sequence of operation, our specifications range from 78 to 95 pages long and are specific so as to reduce any ambiguity for the control contractor about the DDC’s requirements and functionality.

The purpose of the specification is to:

- Require control contractors to design the system before they arrive on-site
- Ask for documentation that control contractors should or would normally generate during their design of a DDC system
- Obtain complete system documentation
- Acquire detailed description of sequence of operations
- Reduce "I didn't know I was suppose to do that" by control contractor and other trades
- Easily determine who is responsible for system deficiencies and reduce finger pointing among construction trades
- Reduce problems associated with system start-up
- Obtain reliable equipment
- Obtain and retain the best programmer

- Obtain quality training for school staff
- Tailor the control system to staff needs
- Provide a quality check by having the mechanical design engineer commission the DDC system
- Level the bidding playing field among vendors

Because the specification is large and complex, this paper will describe only two of the above features.

Obtain and retain the best programmer. Often control contractors send less experienced programmers and/or they cycle through several programmers during system installation at Oregon schools. The specifications require a programmer with 5+ years of installation experience with a high level of HVAC knowledge. In addition, the required list of installations within the past 12 months is used for checking their performance. If unsuitable, the spec allows the school district to choose another programmer. These requirements hopefully will obtain the best programmer for the school district. Once at the site, other specification language requires the same programmer to complete the entire job. The programmer can only be replaced with the school district's written permission.

Acquire detailed description of sequence of operations. We have found that most DDC bid specifications feature brief and general discussions of the system's sequence of operations. For example, one engineer specified carbon dioxide control of the outside air dampers. The specification read, in essence, adjust outside air dampers as set by heating and cooling CFM that is calculated based on CO_2 (Figure 1). What is not defined in the specs is 1) the definition or equation for determining heating and cooling CFM or 2) the control algorithm to adjust outside air dampers based on the heating/cooling CFM. Thus, the control contractor has free rein to program as they think the system should react to changes in CO_2 readings (even if they understand only DDCs and do not understand the HVAC processes). The Oregon Office of Energy spec guidelines have two (2) pages describing the exact method for changing outside air damper position based on CO_2 readings.

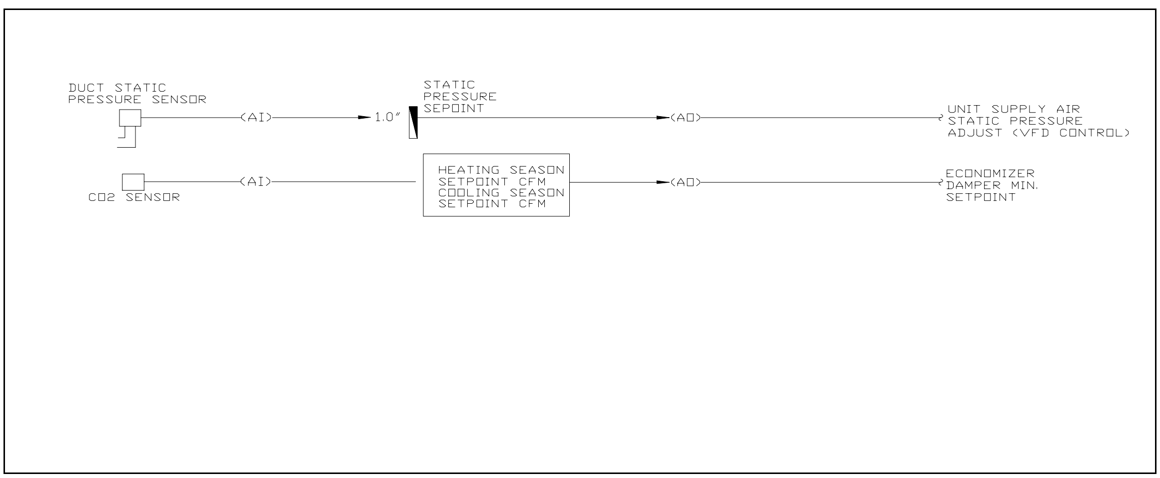

Figure 1. Actual CO_2 Control Specification

Documentation of the sequence of operation installed by the control contractor is critical especially if the engineer provided a vague sequence of operation. Therefore, our specification requires the control contractor to document the as-built sequence of operation in gory detail. Future trouble-shooting will be easier if the sequence of operation is documented in a high level of detail.

Problems with guideline acceptance. While our specification guidelines are thorough, they are not universally transferable. Because staff requirements and building configuration vary for each new building, the specification requires modification before it can be incorporated into final construction documents. Our first specification guideline was developed for a variable air volume system with hot and chilled water and the second for a constant air volume multizone system (with indirect gas heat and DX unit with air-cooled condenser). At this point, it is time consuming for the Oregon Office of Energy to re-write the specs for each construction project. In the future, the engineer could re-write the specs, but this option seems unlikely due to the engineer's unfamiliarity with DDC systems.

The second problem with the office's DDC specifications is getting the engineering firm to adopt them. Engineers may perceive our assistance as an intrusion unless the school provides full support for the use of our specifications. However, school district staffs often do not understand the construction process and their need to be advocates. Often, our DDC specs are not adopted unless a school district recently built a building with DDC problems or it has recently benefited from DDC trouble-shooting assistance. Three school districts are actively using our DDC specs and seven are considering them.

A final problem with our DDC specifications is their enforcement. While we believe all of the items are justifiable and reasonable, a control contractor may believe otherwise. Furthermore, in the school construction environment, a school district often perceives itself as having little control over the project. Therefore, the schools do not force follow-up remediation (e.g., acquiring working control logic) and do not obtain all the features in the bid specification (e.g., complete documentation). At this point, we're still evaluating how effective our DDC specs will be.

Development of DDC Circuit Rider Program

Our circuit rider concept – still under development – has its origins in the history of the electric utility field. Individuals once traveled along the electric grid system (within several utility territories) to provide maintenance and repair services. A DDC circuit rider would be a DDC expert who would travel from school district to school district providing technical assistance.

DDC circuit rider technical assistance services will most likely include:

- Emergency repairs
- DDC hardware troubleshooting and repair
- Software troubleshooting and repair (includes control sequence of operation)
- General operations and maintenance
- Training school maintenance and custodial staff in the proper operation and benefits of DDC systems

- DDC specification review for new construction
- DDC quality control for new construction
- DDC installation for new construction

Reason for DDC circuit rider. We believe a DDC circuit rider system would be more effective in Oregon than the existing system of hiring control contractors to provide trouble-shooting, repair, and general operation and maintenance services. The reasons include:

- Control contractors and vendors are unresponsive to schools needs
- Control contractors and vendors are too expensive
- In-house control experts for an individual school district are too costly or not cost-effective for the workload

The circuit rider system has distinct benefits for schools. First, a control expert employed by an association of school districts – or another school organization – would have a vested interest in a school's welfare. Second, the circuit rider system would cost a school district approximately $60 an hour rather than the $90 an hour it would pay for a control contractor. Finally, the cost of the control expert is distributed among several school districts.

While the DDC circuit rider concept has many benefits, it also has some disadvantages. The Office of Energy has initiated the development of a circuit rider service infrastructure to minimize or avoid any disadvantages associated with a DDC circuit rider system.

DDC circuit rider infrastructure. The basic disadvantage with the DDC circuit rider is that schools must share the control expert. Sharing requires defining when and how much of the control expert's time each school district receives and how much each school must pay.

When and how much of the DDC circuit rider's time a school district receives is related to prioritizing the DDC services. Therefore, prioritizing the DDC technical assistance services is a major issue. Each school district, having paid in advance for circuit rider services, may expect service upon demand. Defining what constitutes an emergency or high priority work will be critical to regulating the DDC circuit rider's time among the school districts. Of course, the method for prioritizing must be acceptable to the school districts if the DDC circuit rider is to be successful. Problems may arise if a school buys into the service but rarely sees the circuit rider because its DDC problems are deemed a low priority.

A cost allocation method will also affect the level of DDC circuit rider services the school districts will receive. Cost allocation variables/methods we have identified so far include:

- The number of schools with DDC systems
- Number of students and/or total square footage of buildings
- Complexity of DDC systems
- One-time repair and adjustment service
- Permanent service contracts
- Design and installation of DDC controls for new schools
- Fixed hourly rate

- Annual fee

When the issues of cost allocation and allocation of a DDC circuit rider's time have been resolved, we will develop standardized agreements and contracts among school districts and other paying parties.

Implementation problems. We have encountered two major problems encountered in trying to develop and implement a DDC circuit rider program. First, no single circuit rider will be an expert on all of the DDC systems now manufactured. At the most, a circuit rider may be able to provide full DDC services for one, two, or three DDC manufacturers due to the skills, knowledge base and equipment needed to maintain and diagnosis multiple generations of each manufacturer's software and hardware. In addition, many school districts have DDC systems from multiple manufacturers and would probably require services from more than one circuit rider. We believe both of these situations are best resolved by hiring several control experts to provide services throughout the state (either on-site and/or via modem). Multiple control experts will, however, require more logistical coordination, broader contractual agreements and more accounting.

A second setback has been the lack of school district commitment. Several school districts in Eastern Oregon and their Educational Service District – an organization providing services to multiple school districts – agreed last summer to implement the DDC circuit rider. However, the largest school district with the highest number of DDC systems pulled out and instead signed a service contract with its DDC vendor (partially due to the fear of the, then, anticipated millennium bug). This inability to commit will most likely continue to be a problem until the DDC circuit rider concept is proven.

Circuit rider future. The 1999 Oregon Legislature passed a utility deregulation bill (SB1149) that will provide about $5 million per year for 10 years to schools for energy efficiency projects. The Oregon Office of Energy is helping the schools write the rules for the implementation of the bill. We anticipate some of the money being directed to the funding of a DDC circuit rider system.

Future Efforts

Currently, hand-holding the schools and the engineers through the adoption and implementation of the DDC guidelines requires a huge time commitment. It is hoped that once several schools adopt the guidelines and have successful DDC systems, the Oregon Office of Energy and the school system can market the guidelines on a broad scale rather than on a one-to-one basis. With the implementation of a DDC circuit rider, Oregon Office of Energy trouble-shooting services will be in less demand. By providing specification and circuit rider services, it is hoped that DDC crisis within the school system can be eliminated. Once this is accomplished, local governments and state facilities can be targeted with the same programs.

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