Night Setback/Setup System— Web Centric DDC Framework

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ABSTRACT

Significant savings can be realized by implementing a night HVAC management program during the unoccupied time when the temperature in the facility is set below or above the normal comfort temperature for the heating and cooling months respectively. Conventional means of achieving this often proved to be non-functional due to a host of reasons like difficulty to program, inaccessibility of the system, lack of a user friendly interface, etc. The goal of this article is to develop a conceptual framework for a night setback/setup system leveraging state-of-the-art technologies to address some of the problems that current night setback systems face. This work describes a web-centric DDC system that can be easily programmed from any computer connected to the network using a combination of software and hardware components.

INTRODUCTION

Significant savings can be realized using night mode during the heating and cooling months where the temperature in the facility is set below or above the normal comfort temperature. After normal working hours, the facility is set to operate in an "unoccupied mode" where it is allowed to operate at a temperature different than the normal condition to conserve energy.

Traditional methods, comparatively inexpensive, using night setback/setup thermostats and time clocks have proven impractical. These devices operate in a rigid fashion without any knowledge about holidays, leap years, daylight savings time, and employee overtime. After a year or less, traditional time clocks and night setback stats are usually disconnected, set permanently on "manual override," or otherwise defeated. The energy use goes back up.

The combination of low cost, high performance microcomputers together with the emergence of high-speed communication networks has produced explosive growth in the use of web-based technology for various control applications. These technologies can be leveraged in developing more intelligent and easy-to-use night setback/setup systems. The goal of this article is to provide a description of the principles, operation, and components of such a conceptual web-centric system.

BACKGROUND

The process of controlling a system involves three steps. These steps include first measuring data (sensor), then processing the data with other information (controller), and finally causing a control action (controlled device) [1]. These three functions make up what is known as a control loop. The process of controlling an HVAC system involves three components, shown in Figure 1, interacting to control the air temperature [2]. Figure 1 could be an example of a pneumatic or electronic control system, where the controller is a separate and distinct piece of hardware. In a DDC system, the controller "function" takes place in software, as shown in Figure 2. Sometimes, the control can be achieved by a combination of software and hardware, depending upon the application.

Common HVAC *sensors* are used to measure temperature, pressure, relative humidity, airflow state, and carbon dioxide. Other variables may also be measured that impact the controller logic. Examples include other temperatures, time of day, or the current demand condition. Additional input information (sensed data) that influences the control logic may include the status of other parameters (airflow, water flow, current) or safety (fire, smoke, high/low temperature limit, or any number of other physical parameters). Sensors are an extremely important part of the control system and can be the first, as well as a major, weak link in the chain of control. The signal from a sensor is either analog or digital. An analog signal is a continuously variable signal which bears a known relationship to the value of the measured variable. A thermocouple measures temperature and emits a signal in the form of

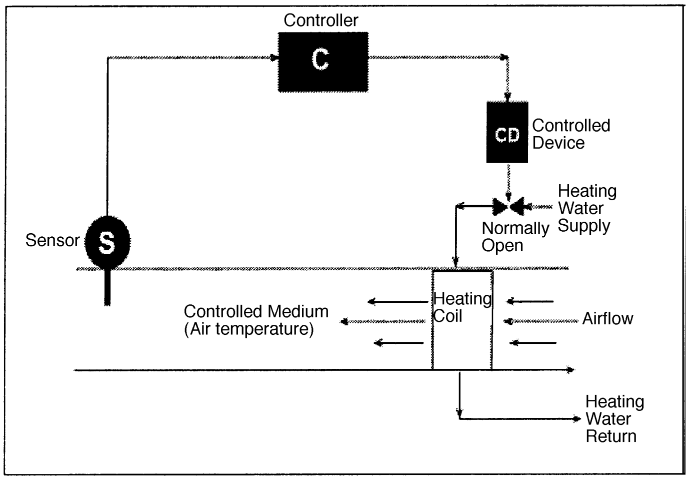

Figure 1. Basic Loop To Control Air Temperature.

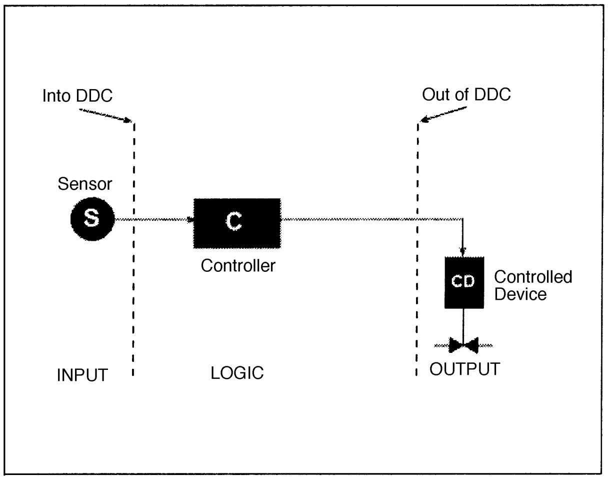

Figure 2. DDC Based Control Loop (*Source: http://www.ddc-online.*

a voltage. A resistance temperature detector measures temperature and provides a signal in the form of an electrical resistance. Analog signals must be converted to digital before a computer can process them. A digital signal is an input signal that can be in either open or closed position.

The *controller* processes data that are input from the sensor, applies the logic of control, and causes an output action to be generated. This signal may be sent directly to the controlled device or to other logical control functions and ultimately to the controlled device. The controller's function is to compare its input (from the sensor) with a set of instructions such as setpoint, throttling range, and action, and then produce an appropriate output signal. It usually consists of a control response along with other logical decisions that are unique to the specific control application. A controlled device or an actuator (usually pneumatic or electronic) is a device that responds to the signal from the controller and changes the condition of the controlled medium or the state of the end device based on the control logic. These devices include valve operators, damper operators, electric relays, fans, pumps, compressors, and variable speed drives for fan and pump applications.

Direct Digital Control (DDC)

DDC control consists of microprocessor-based controllers with the control logic performed by software. Analog-to-digital (A/D) converters transform analog values into digital signals that a microprocessor can use [3]. Most systems download the software to remote controllers to eliminate the need for continuous communication capability (stand-alone). Complex strategies and energy management functions are readily available at the lowest level in the system architecture. If pneumatic actuation is required, it is accomplished with electronic to pneumatic transducers. The central programmable capabilities are a significant asset that reduces the redundancy of the data and greatly eases programming of the system, making them intuitive and user-friendly.

The benefit of direct digital control is its improved control effectiveness and control efficiency. DDC provides more effective control of HVAC systems by providing the potential for more accurately sensed data. Since the logic of a control loop is software based, this can be readily changed, making DDC far more flexible. This flexibility makes DDC ideal for changing reset schedules, setpoints, and the overall control logic. It is also ideal for applying more complex strategies that implement energy saving features and optimize system performance, since there is less cost associated with these changes than there would be when the logic is distributed to individual components.

CASE STUDY

During a visit to the plant, an observation was made that even though the offices in the manufacturing plant operate only 40 hrs per week, they were air-conditioned 24 hours per day, 7 days a week. The yearly gas consumption profile for the plant is shown in Figure 3. Significant savings could be realized if they were to implement a night setback program in the office area of the plant. By reducing the heating requirements after working hours, a significant amount of energy, in terms of natural gas consumed, could be saved.

The calculations for determining the savings from the proposed recommendation involves using the bin weather data on outside temperatures and with the required inside temperature thermostat settings. After normal working hours, the system goes into "night setback mode" and maintains a range of 55 degrees Fahrenheit. Table 1 and Table 2 show the savings from implementing a night setback and setup for 1 and 2 shifts based on the bin data for Tinker AFB, OK. Figure 5 summarizes the realizable savings for night setbacks for different geographical conditions.

Office heating load (Figure 3)

$$= [(\text{Total gas use in the plant}) - (\text{Base Load})(\text{mo/yr})](1\text{x}10^6\ \text{Btu/MCF})/(\text{Total plant area})$$

$$= [(1{,}326\ \text{MCF}) - (50\ \text{MCF Base Load/mo})(12\ \text{mo/yr})](1\text{x}10^6\ \text{Btu/MCF})/(10{,}000\ \text{ft}^2)$$

$$= 102{,}600\ \text{Btu/ft}^2\text{-yr}$$

From the nomograph in Figure 4 [4], for the present energy heating consumption of 102,600 Btu/ft^2-yr and for a setback temperature of 15 degrees, the energy savings that can be realized are 40,000 Btu/ft^2-yr. These projected savings, from the nomograph, are close to the percentage obtained from calculations using the bin data (Table 1 & 2). The percentage from the nomograph presents a more accurate number, as it takes into account the heat generated from various internal sources.

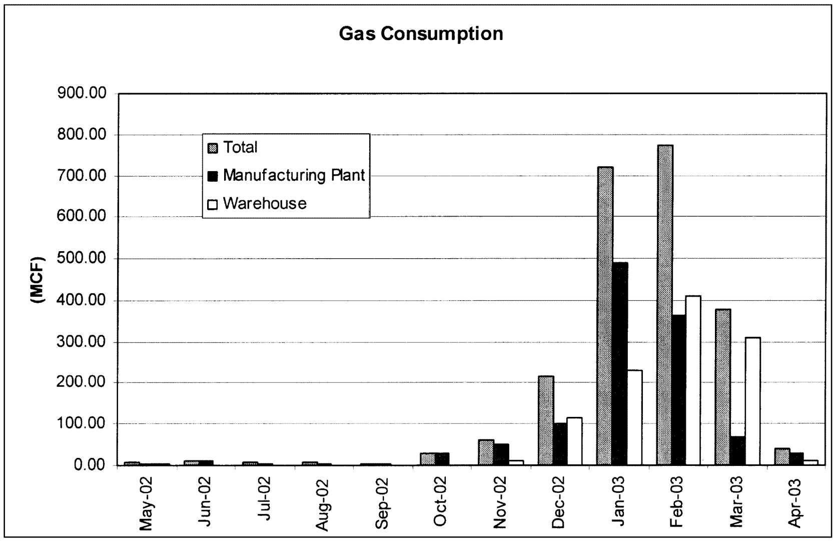

Figure 3. Annual gas consumption profile

CONCEPTUAL FRAMEWORK FOR THE NIGHT SETBACK SYSTEM

Control Unit Hardware

Universal Processor Unit

A schematic of the network-based night setback control system is shown in Figure 6. The brain of the system is the universal processor unit, which continuously monitors the current room comfort parameters (temperature and humidity), checks them against the setpoints, and initiates appropriate actions when necessary. This universal processor unit contains the control logic and programs the application. Because the zones are distributed across different areas, distributed I/O modules (FieldPoint) are used for the remote data acquisition and control. A PC running a LabVIEW application [5] can provide the user interface that allows the operator to set up the different cycle profiles and temperature conditions and also view the status of all the zones. Using LabVIEW Real-Time, data logging, control, and measurement can be done by using a networked computer.

Range	Midpoint	Desired	Temp	Shift 1		Temp	Shift 2		Temp	Shift 3		Temp	Total	Without	With Setback	
		Temp	Diff	01:00-08:00	Setpoint	Diff	09.00-16:00	Setpoint	Diff	17.00-24.00	Setpoint	Diff	Hours	Setback	for 1 Shift	for 2 Shifts
	F	F	F	(No of Obser)	F	F	(No of Obser)	F	F	(No of Obser)	F	F		(FHrs)	(FHrs)	(FHrs)
55-59	57	70	13	59	55	-2	121	70	13	104	70	13	284	3,692	2,807	1,247
50-54	52	70	18	83	55	3	153	70	18	0	70	18	236	4,248	3,003	3,003
45-49	47	70	23	221	55	8	180	70	23	207	70	23	608	13,984	10,669	7,564
40-44	42	70	28	222	55	13	167	70	28	203	70	28	592	16,576	13,246	10,201
35-39	37	70	33	225	55	18	143	70	33	169	70	33	537	17,721	14,346	11,811
30-34	32	70	38	210	55	23	108	70	38	128	70	38	446	16,948	13,798	11,878
25-29	27	70	43	137	55	28	66	70	43	79	70	43	282	12,126	10,071	8,886
20-24	22	70	48	87	55	33	41	70	48	46	70	48	174	8,352	7,047	6,357
15-19	17	70	53	40	55	38	21	70	53	24	70	53	85	4,505	3,905	3,545
10;14	12	70	58	26	55	43	12	70	58	11	70	58	49	2,842	2,452	2,287
5.;9	7	70	63	9	55	48	3	70	63	4	70	63	16	1,008	873	813
0.;4	2	70	68	7	55	53	1	70	68	1	70	68	9	612	507	492
														102,614	82,724	68,084
				Night Setback Shift 1						Night Setback Shift 2						

Difference in FHrs (without and with seback for 1 shift)	19,890
Difference in FHrs (without and with seback for 2 shifts)	34,530
Percentage Savings from implementing night setback for 1 shift	19.38%
Percentage Savings from implementing night setback for 2 shifts	33.65%
Heating Degree Days (without setback)	4275.583
Heating Degree Days (with 1 shift setback)	3446.833
Heating Degree Days (with 2 shift setback)	2836.833

Based on Bin data for AFB - Tinker

Table 1: Table showing the night setback calculations for 1 and 2 shifts based on Tinker AFB, OK bin data.

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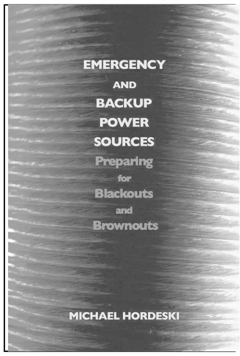

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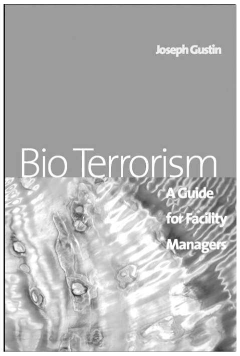

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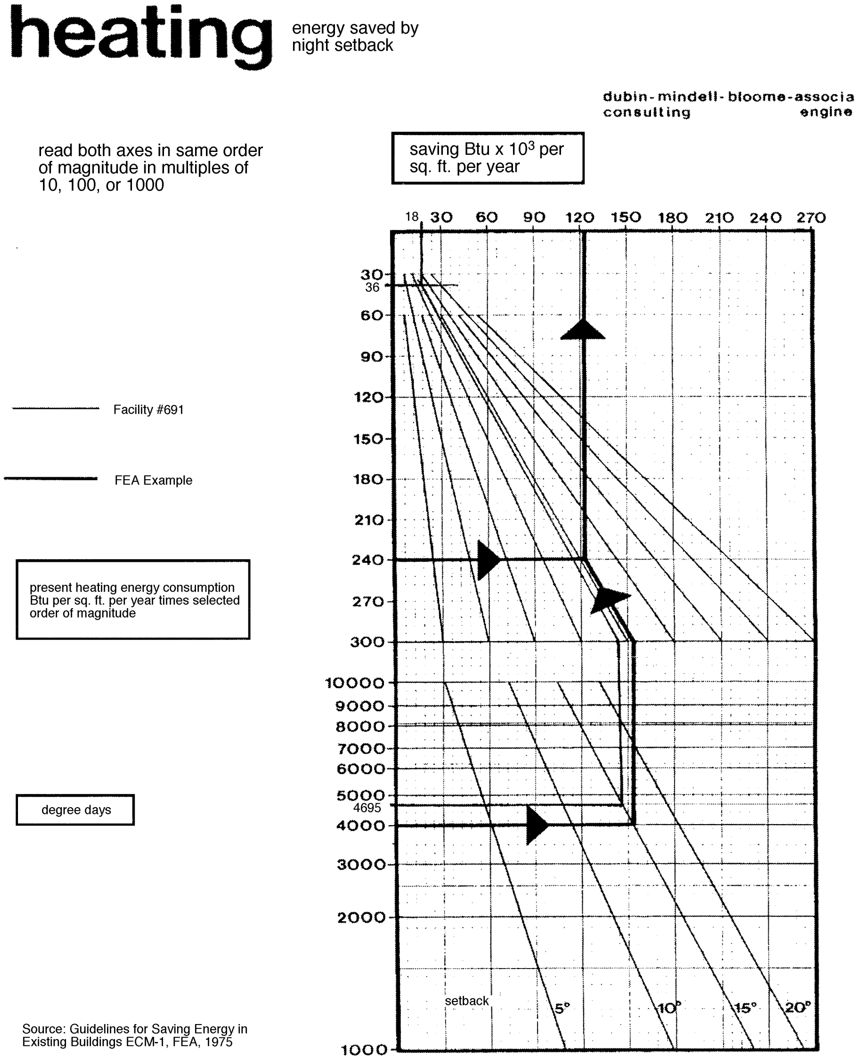
Range	Midpoint	Desired	Temp	Shift 1		Shift 2		Shift 3		Total	Without	With Setup	
		Temp	Diff	01:00-08:00	Setpoint	09.00-16.00	Setpoint	17.00-24.00	Setpoint	Hours	Setup	for 1 Shift	for 2 Shifts
	F	F	F	(No of Obser)	F	(No of Obser)	F	(No of Obser)	F		(FHrs)	(FHrs)	(FHrs)
100/104	102	70	32	0	85	13	70	4	70	17	544	544	484
95/99	97	70	27	0	85	68	70	26	70	94	2,538	2,538	2,148
90/94	92	70	22	0	85	164	70	75	70	239	5,258	5,258	4,133
85/89	87	70	17	4	85	236	70	145	70	385	6,545	6,485	4,310
80/84	82	70	12	57	85	268	70	252	70	577	6,924	6,240	3,216
75/79	77	70	7	238	85	240	70	284	70	762	5,334	3,668	1,680
70/74	72	70	2	376	85	179	70	249	70	804	1,608	856	358
											28,751	25,589	16,329
				Night Setback Shift 1				Night Setback Shift 2					

Difference in FHrs (without and with setup for 1 shift)	3,162	
Difference in FHrs (without and with setup for 2 shifts)	12,422	
Percentage Savings from implementing night setup for 1 shift	11.00%	
Percentage Savings from implementing night setup for 2 shifts	43.21%	
Cooling Degree Days (without setup)		1197.958
Cooling Degree Days (with 1 shift setup)		1066.208
Cooling Degree Days (with 2 shift setup)		680.375

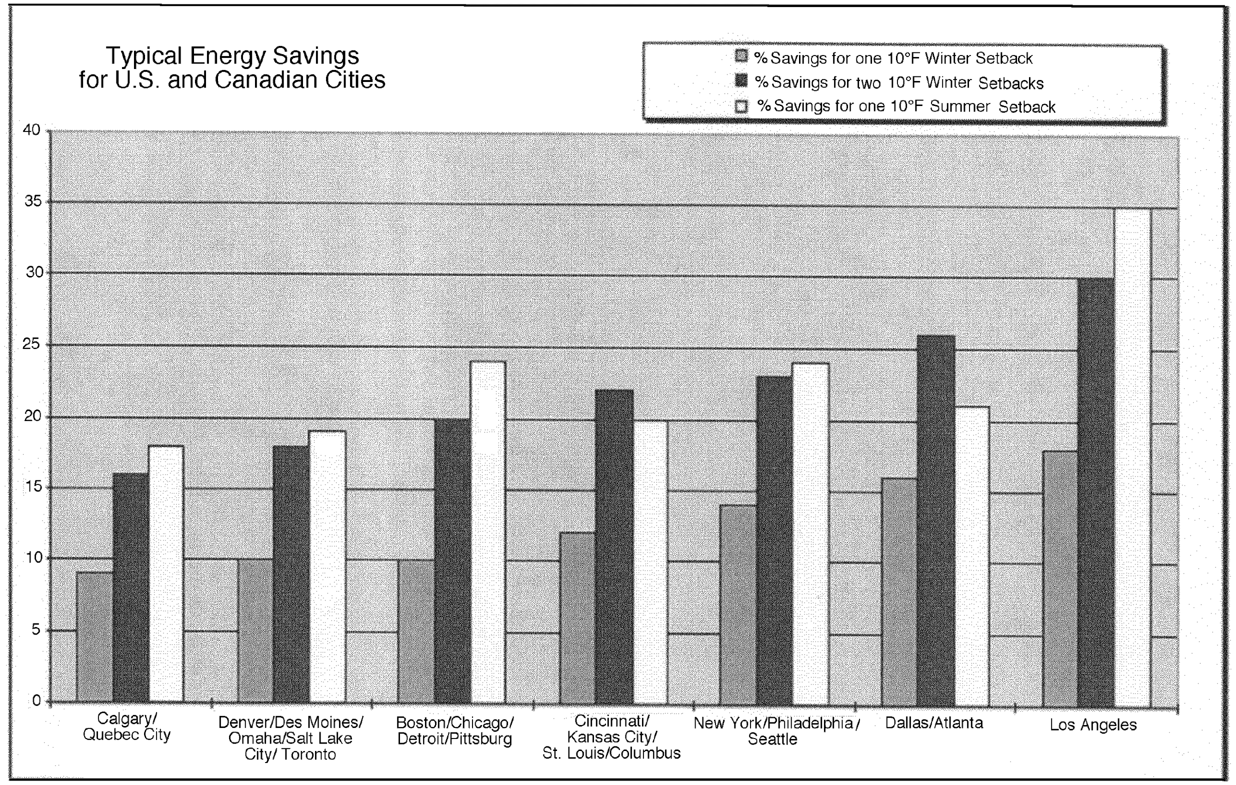
Based on Bin data for AFB - Tinker

Table 2: Table showing the night setup calculations for 1 and 2 shifts based on Tinker AFB, OK bin data.



Source: Guidelines for Saving Energy in Existing Buildings ECM-1, FEA, 1975

Figure 4: Heating Energy Savings Nomograph



Percent of savings will vary depending on equipment, insulation and personal lifestyle.
The chart indicates savings based on typical homes in various cities.
*Data based on U.S. DOE and industry sources.

Figure 5: Plot Showing the Energy Savings That Can Be Realized From Setbacks for Different Locations. *Source: XCI Corporation*

This application can be embedded on an intelligent controller for reliable distributed or stand-alone deployment. The PC also runs a web server that allows the operator to program the night setback system through any client computer connected to the network inside the company's firewall. This also allows the status and trends to be viewed over a secure line over the internet.

Universal Input/output Modules

The data acquisition from different zones and the supervisory control is accomplished using distributed FieldPoint modules. Three banks of FieldPoint modules are used (depicted in figure 5) where each bank consists of a thermocouple module, an analog input module, a digital input module, and a relay module along with an RS485 communications module. These modules are wired to the thermostats in the individual zones and act as inputs and trigger the controller action based on these inputs in comparison to the preset setpoints from the computer. This controller capability can also be extended to other facets of building automation systems based on different control parameters that one wants to control or monitor, for e.g., monitoring the CO_2 level in different zones, triggering the alarms if they reach the predetermined levels, or turning the lights on/off based on the occupancy of a zone.

Control Unit Communications Network

Ethernet is the most widely used local area network (LAN) technology and most widely deployed network technology in the world. The original Ethernet is based on a simple principle of communication over a single cable shared by all devices on the network. Once a device is attached to this cable, it has the ability to communicate with any other attached device. This allows the network to expand to accommodate new devices without requiring any modification to those devices already on the network.

RS485 is a specialized interface that is very common in data acquisition applications. RS232 is the most common interface used to communicate serially, but it has its limitations. Standards have been developed to insure compatibility between units provided by different manufacturers, and to allow for reasonable success in transferring data over specified distances and/or data rates [6]. The Electronics Industry Association (EIA) has produced standards for RS485, RS422, RS232, and RS423 that deal with data communications. RS485 will support 32

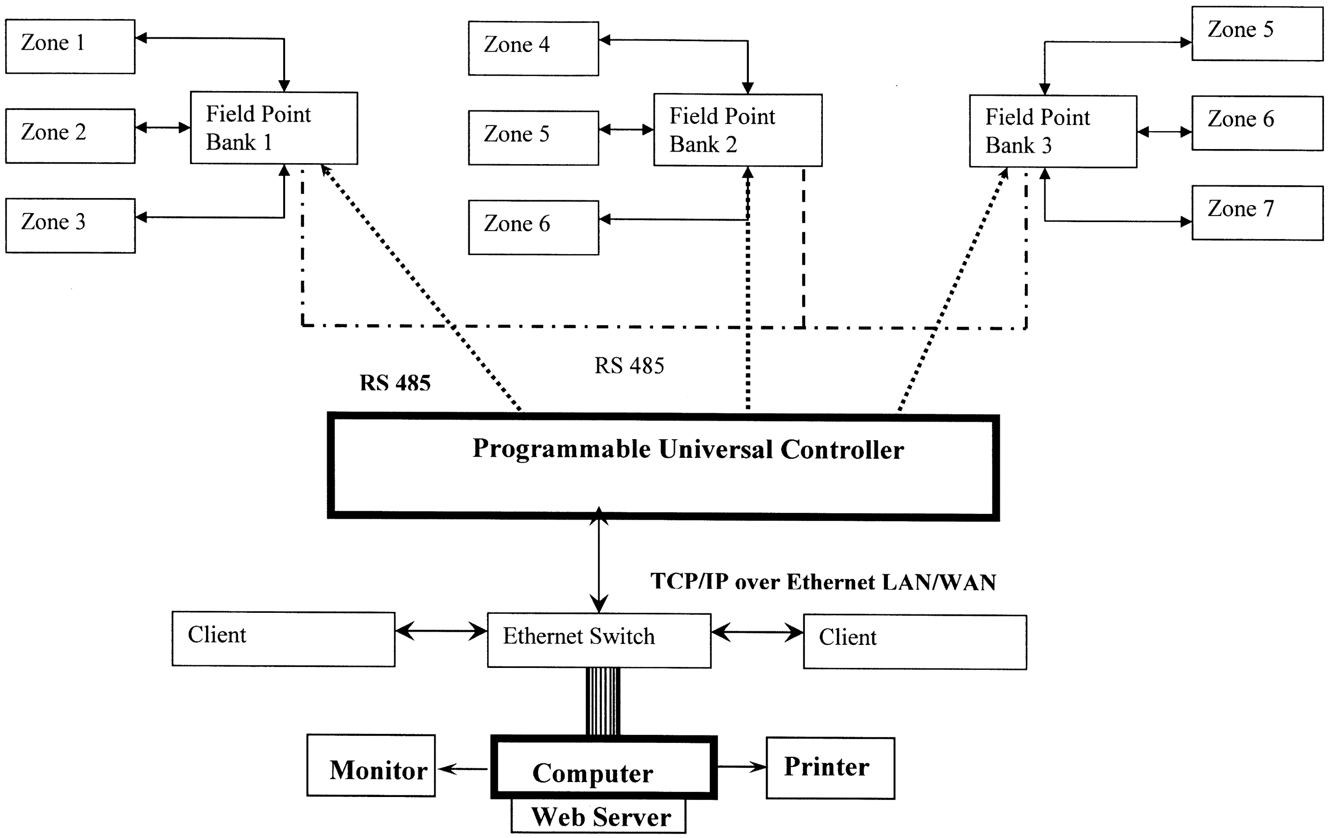


Figure 6. Schematics of network controlled night setback/setup system

drivers and 32 receivers (bi-directional—half duplex—multi-drop communications over a single or dual twisted pair cable). An RS485 network can be connected in a 2 or 4 wire mode. The typical use for RS485 is a single PC connected to several addressable devices that share the same cable. RS232 signals are represented by voltage levels with respect to system common (power ground). This type of signal works well in point-to-point communications at low data transmission rates. RS232 ports on the PC are assigned to a single device. In short, the RS232 port was designed to communicate with local devices, and will support one driver and one receiver.

Control Unit Software

Control Unit Programming

Control units typically contain software that can control output devices to maintain the temperature at a desired temperature based on the time of the day and day of the week. The most commonly used are graphical programming tools like LabVIEW [4]. LabVIEW uses a dataflow programming model that is free from the linear architecture of text-based languages. Because the execution order in LabVIEW is determined by the flow of data between blocks, and not by sequential lines of text, diagrams can be created that have simultaneous operations. These programs, called virtual instruments (VI), are built in logical sequence to implement the data acquisition or to implement a particular control strategy. Front panel user interfaces can be created for interactive control of the software system. On the front panel of VI, the controls and data for the system are displayed by choosing objects from the controls palette, including numeric displays, meters, gauges, thermometers, tanks, LEDs, charts, graphs, and more to control or read various parameters. When the VI is complete, the front panel can used to control the system while the VI is running by clicking a switch, moving a slide, zooming in on a graph, or entering a value from the keyboard. LabVIEW VIs are modular in design, so any VI can run by itself or be used as part of another VI. LabVIEW also has drivers for industrial I/O devices such as PLCs, data loggers, and single-loop controllers. LabVIEW features powerful and comprehensive analysis libraries. These libraries are complete with statistics, evaluations, regressions, linear algebra, signal generation algorithms, time and frequency-domain algorithms, windowing routines, and digital filters.

Control Unit Communications Protocol

In the DDC world, there are the three classifications of protocols: closed protocol, open protocol, and standard protocol [1]. A closed protocol is a proprietary protocol used by a specific equipment manufacturer. An open protocol system uses a protocol available to anyone, but not published by a standards organization. A standard protocol system uses a protocol available to anyone. It is created by a standards organization.

BACNET, published by a standards organization (American Society of Heating, Refrigerating and Air-conditioning Engineers or ASHRAE), is the most commonly used standard protocol [9]. It is a specification for a protocol. DDC vendors create a communication protocol that complies with this specification.

LONTALK, an open protocol created by the Echelon Corporation, allows components from different manufacturers to co-exist on the same LAN. The protocol is available to anyone and is called LONTALK. A unique chip is required for any device that uses LON. Standard network variable formats have been established to allow the transfer of data from one device to another regardless of origin. For "small building" environments, it's still typically expensive to use BACNET or LONTALK, as the manufacturers supporting it wrap a lot of extras around it.

The proliferation of internet and its compatibility, the TCP/IP, has become very popular in this DDC area. This protocol, widely used in the IT community, is the internet standard protocol. This protocol helps establish the standardized communication between various devices on the network through a high speed ethernet or LAN. The standard and mature nature of this protocol is drawing more and more vendors to make their device compatible with TCP/IP.

DISCUSSION AND CONCLUSIONS

Significant savings can be realized by implementing a night setback program during the heating months and usual savings are in the range of 35-40 percent. The savings from the night setback, from the nomograph, agrees with calculations using the bin data. The percentage from the nomograph presents a more realistic number, as it takes into account the heat from internal sources. Similarly, a significant percentage of energy savings can be realized by implementing a night setup program during the summer also. Traditional night setback/setup systems are rigid, hard to program, and cannot interface with other systems. Webcentric systems, on the other hand, are intelligent (embedded logic), easy to program with a single user interface on a computer (irrespective of how rooms needed to be programmed), and communicate with other building automation systems. A conceptual framework for webcentric DDC night setback/setup system is designed, and various components of this system are described. The calculations from this proposed system and the existing system are also compared.

Different setpoints are needed for setback and setup operations during winter and summer months to optimize the energy conservation. It is important to note that this night setback mode is only triggered during the winter months, when the outside temperature is cold (i.e., when heating is required). Similarly, during the summer months, savings can be realized from reduced cooling by establishing a higher setpoint (night setup) during the unoccupied hours. The same architecture can be used to implement the night setup program with a different range of setpoints. The additional cooling savings for the office area in the summer months from this program are not quantified in this work. Using this configuration, an intelligent control strategy can be programmed to optimize the performance by taking into account the time needed to start the HVAC system to get the temperature back to normal conditions when employees arrive and the temperature outside rises. An optimal-start strategy utilizes a database and outside temperature measurements to determine when the system should resume heating or cooling. This allows the system to remain in setback until the last possible moment, maximizing the savings from the setback controls.

This DDC system functionality can be extended and allowed to work at a zonal level; this could be programmed by decreasing the requirement for air conditioning on a zone-by-zone basis, depending on the occupancy. This DDC system can be extended and integrated into fire control systems, access/security control systems, lighting control systems, and maintenance management systems. Also, the data can be stored and analyzed for trends in equipment's performance over time and can be used to tune the performance of the system. Making the DDC web-enabled also provides the capability that allows an operator to access the system remotely and diagnose the problems, thereby making it a viable framework for performance contracting.

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ABOUT THE AUTHOR

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