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Standard Army HVAC Control Systems

Standard Single-Loop Digital Controllers for HVAC Systems

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Heating, ventilating, and air-conditioning (HVAC) control systems are uniquely designed for individual Army facilities. Since each facility has a *different control system design and nonstandard* hardware, Army Directorate of Engineering and Housing (DEH) personnel have a very difficult time operating and maintaining the systems correctly. DEHs need standard control systems that are simply designed and are constructed of reliable, interchangeable control hardware.

The objectives of this research were to: (1) evaluate single-loop digital controller (SLDC) technology to see if the SLDC is the optimum controller to be used in the standard control panel, (2) develop detailed product specifications, and (3) develop application guidance.

Although SLDCs have typically been used only by the process control industries, they are suitable *for us in HVAC control applications*. Despite the fact that SLDCs are somewhat more expensive than other alternatives, they are simple, flexible, reliable, and maintainable, making them well suited for use in Army facilities. They are ideal for PID, reset, and economizer applications. Product specifications developed during this research were submitted to Huntsville Division for inclusion in documentation on HVAC control systems.

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STANDARD SINGLE-LOOP DIGITAL CONTROLLERS FOR HVAC SYSTEMS

1 INTRODUCTION

Background

Typical Army heating, ventilating, and air-conditioning (HVAC) systems waste energy and cause discomfort for building occupants. This usually results from poorly designed HVAC control systems, improperly operating control equipment, and inadequate control system maintenance[1]. The HVAC control system for a typical Army facility is uniquely designed for that facility and uses complex control strategies and hardware. The systems generally use commercial grade pneumatic hardware that has a very low initial cost but very high operation and maintenance costs. Since each Army facility has a different control system design and nonstandard hardware, installation Directorate of Engineering and Housing (DEH) personnel have a very difficult time operating and maintaining the systems correctly. These problems indicate the need for standard control systems that are simply designed and are constructed of reliable, interchangeable control hardware.

Recent research[2] discovered that the controller industry had developed on inexpensive single-loop digital controller (SLDC) that might prove to be more interchangeable and reliable in standard control panels than an electronic analog controller.

Objectives

The objectives of this research were to (1) evaluate current single-loop digital controller technology to see if the SLDC is the optimum controller for a standard control panel, (2) develop detailed product specifications suitable for inclusion in a guide specification and technical manual on control systems, and (3) develop application guidance for using the controller in the standard control system designs.

Approach

1. Available state-of-the-art electronic controllers were evaluated for their applicability to the HVAC control process requirements.

2. The SLDC controller was evaluated to determine its optimal configuration for cost effective application to the Corps' standard HVAC control system designs.

3. A product specification for the controller was developed.

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[1] Douglas C. Hittle and David L. Johnson, *New Control Design Principles Based on Measured Performance and Energy Analysis of HVAC Systems*, Interim Technical Report E-85/02/ADA151708 (U.S. Army Construction Engineering Research Laboratory [USACERL], January 1985).

[2] Kling-Lindquist Partnership, *State-of-the-Art Technologies for HVAC Control Systems*, prepared for Huntsville Division, U.S. Army Corps of Engineers (August 1986).

4. Guidance for application of the controller to the Corps' standard system designs was developed.

Mode of Technology Transfer

The information in this report has been transferred to Huntsville Division, U.S. Army Corps of Engineers and has been incorporated in Corps of Engineers Guide Specification (CEGS) 15950, *Heating, Ventilating and Air Conditioning HVAC Control Systems*, and Technical Manual (TM) 5-815-3, *Heating, Ventilating and Air Conditioning HVAC Control Systems.*

2 HISTORY OF CONTROLLER RESEARCH

Research performed by the U.S. Army Construction Engineering Research Laboratory (USACERL) in the early 1980's led to the recommendation that the Army and Air Force adopt the use of standardized control systems composed of electronic control hardware assembled in standard control panels.[3] USACERL developed proposed standard system designs for 14 HVAC systems typically used by the Army and the Air Force and developed a proposed standard control panel for each standard control system. Based on the available control hardware in the early 1980's, USACERL proposed using industrial grade electronic analog controllers in the standard control panels. Although these controllers were not truly interchangeable between manufacturers or function, they were highly reliable and were the most cost-effective choice available at the time.

USACERL found that using standard HVAC control systems streamlined design and design review procedures; reduced operation and maintenance costs, operator training requirements, and system energy consumption; and improved the comfort of facility occupants. Additionally, the recommended standard control systems use simple, well defined control logic instead of the complicated control schemes used in typical Army and Air Force control system designs.

Elements of standardization that can help when designing maintainable control systems are identified in an Air Force Engineering Technical Letter[4] and are defined more fully as the need for:

- Easy access to control devices,
- Provision for test points,
- Component identifiers,
- Detailed design drawings that can serve as maintenance documentation,
- Fully labeled control diagrams that show setpoints, proportional bands, reset rates, device actuation ranges, etc.,
- Fully labeled electrical ladder diagrams,
- A sequence of control including system start-up, operation and shutdown, and
- A functional description of each control component describing its operation, and a design review process that includes a maintainability review by those who will be operating the system[5].

Change 1 to ETL 83-1[6] implemented the use of the standard control system designs and electronic analog-based control panels proposed by USACERL for all new Air Force construction projects. The U.S. Army Corps of Engineers also accepted USACERL's recommendation to standardize HVAC control systems, and, in 1986, the Huntsville Division of the Corps of Engineers in conjunction with their contractor, Kling-Lindquist Partnership, began to develop a new guide specification and technical manual for HVAC controls based on the concepts outlined by USACERL.

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[3] Douglas C. Hittle and David L. Johnson.

[4] Engineering Technical Letter (ETL) 83-1, *Design of Control Systems for HVAC* (Headquarters USAF/LEEEU, Washington, DC 20330, 16 February 1983).

[5] S.T. Tom, "Maintainable Control Systems," *ASHRAE Journal* (September 1985), pp 38-40.

[6] ETL 83-1, Change 1, *U.S. Air Force Standard Heating, Ventilating and Air Conditioning (HVAC) Control Systems* (Headquarters USAF/LEEEU, Washington, DC 20330, 22 July 1987).

3 SINGLE-LOOP DIGITAL CONTROLLER

Controller Alternatives

The standard controller selected by the Corps must complement and support the standardization objectives stated in ETL 83-1. Alternatives in controller technology include pneumatic controllers, commercial grade analog electronic controllers, industrial grade analog electronic controllers, industrial grade single-loop digital controllers, and commercial grade multiple-loop digital controllers.

Standardization is the key element of Change 1 to ETL 83-1. The SLDC is the only alternative that supports standardization in that it is fully interchangeable not only between manufacturers, but also between applications. This is due in part to the size of the controller. SLDCs are available in a standard size, which corresponds to a panel cutout size of 3.62 by 3.62 in.* One version of the controller available from a variety of manufacturers can be used in any of the standard control applications. SLDCs that have 4 to 20 milliampere (mA) input and output (I/O) signals are readily available, allowing the Army to establish this as the control standard and to obtain units compatible with existing Energy Monitoring and Control Systems (EMCS).

SLDC Features

Although predominantly used by the process control industries, the SLDC is suitable for use in a variety of HVAC control applications. Because it is an interchangeable component, the SLDC lends itself well to the Army's standard HVAC control applications. Other advantages of the SLDC include: state-of-the-art features, its industrial grade, reliability, and ease of use.

Various function keys or push buttons on the front panel of the controller (Figure 1) allow the user to operate it. It has one or two displays to show the controller setpoint, the controlled process, the magnitude of the output signal, and other operating parameters. The controller also has various indicators to show the status of the relay contact outputs, automatic or manual operation mode, and remote or local setpoint mode.

The two basic types of SLDCs are either process controllers or temperature controllers. Both can perform proportional (P), proportional plus integral (PI), and proportional plus integral plus derivative (PID) control. The process controller is the standard because it can control a variety of processes including temperature, pressure, flow, and humidity. The process controller accepts either a milliampere or voltage input from a sensor/transmitter assembly. This differs from the temperature controller that is restricted to controlling only temperatures and accepts either a resistance temperature device (RTD) or thermocouple sensor input. Unlike the process controller, the temperature controller's sensor range usually is fixed at the factory and cannot be readily altered by the user.

The standard controller receives one 4 to 20 mA analog input from the controlled process and provides one 4 to 20 mA analog output. A second 4 to 20 mA input is available to remotely change or reset the controller setpoint. There are also two dry contact outputs, sometimes referred to as alarms. The process contact output activates if the process (controlled) variable rises above or falls below the contact

* A metric conversion table is provided on p 42.

setpoint. The deviation contact output activates if the process variable deviates a given number of units from the control setpoint. The magnitude of this deviation is selected by the user.

SLDCs are available in a standard size, which corresponds to a panel cutout size of 3.62 in. by 3.62 in. The standard panel cutout size allows easy SLDC replacement. The lengths of the controller vary between manufacturers. The average length of an SLDC is about 7 in. The depth of the control panel limits the maximum length of a standard controller. The controller is mounted on the inner door of a standard size control panel. Additional hardware is mounted at the back of the control panel. This limits controller length to about 10 in. but depends on dimensions of the hardware mounted on the back panel and the distance between the inner door and the front of the panel.

SLDCs are accurate and reliable. The rated accuracy of most of these devices is ± 0.25 percent or better. This is more than sufficient for HVAC control applications. One-year warranties are common.

The SLDC is a microprocessor-based device. Its primary components include a central processing unit (CPU), an I/O board, random access memory (RAM), and read only memory (ROM). The SLDC uses an algorithm stored in a fixed firmware program to execute its control functions. The algorithm, stored in ROM, cannot be altered by the user. Flexibility in applying the controller to the various standard applications is available to the user via the keypad. Application-specific control parameters are either keyed (or configured) into the controller. These configuration parameters change the execution of the controller's fixed program. The configuration parameters reside in long term memory. This may be either programmable read only memory (PROM) or battery backup RAM. Memory storage life of the configuration parameters typically will exceed 5 years. Supplemental hardware configuration of the controller may be required by setting dip switches or jumpers inside the controller.

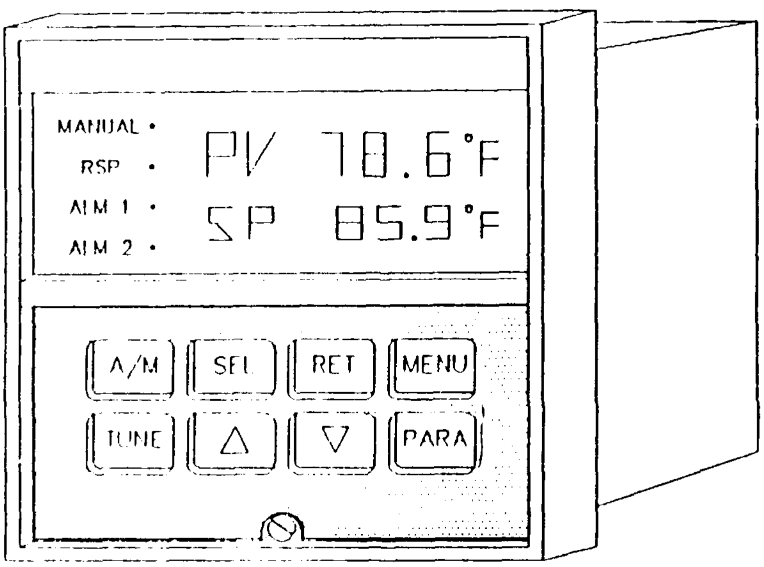

Figure 1. Front view of a typical single loop digital controller.

The standard controller can accommodate a communications interface board. This interface may be either Recommended Standard (RS) 422 or RS 485. The Army is not currently using this feature.

Other features of the standard controller include; self-tuning capability, user-selectable process input range, user-selectable maximum and minimum setpoints and output signals, user-selectable reverse or direct control action, and auto/manual control. These features are discussed in more detail later.

SLDCs range in cost from about $300 to over $1000. The retail cost of a standard SLDC is about $550. The cost has been decreasing as integrated circuitry design and manufacturing techniques improve. Because of its numerous features, the SLDC reduces the amount of control hardware that might otherwise be needed if similar commercial grade hardware were used.

Table 1 lists the features of several SLDCs. A short description of each feature is included. Features marked with an asterisk are not required of the standard controller. Some available features are not included in the table because they are not commonly available or are of little interest.

Terminology and Definitions

Because the single-loop controller has found use primarily in process control applications, some terminology may differ from that used by the commercial HVAC control industry. Many terms are the same or very similar. For completeness, all significant terms pertaining to SLDCs are described.

Configuration parameters are the controller settings that prepare the controller for a given application. The user keys in the values from the front panel of the controller. Example configuration parameters include the PID mode constants, controller setpoint, type of setpoint (local or remote), maximum and minimum allowable setpoints, and the span of process variable input signal.

Process variable (PV) input is the controlled variable. In the standard HVAC applications, the types of PV inputs include air and water temperatures, duct static pressure, air flow rate, and humidity. The controller accepts a PV input in the range of 4 to 20 mA.

The controller converts (or scales) the 4 to 20 mA process variable input signal to match the span of the process variable transmitter. For example, in a hot water temperature control application, the PV transmitter range will be 100 °F to 250 °F. Once the user configures the controller for this range, the controller scales the 4 to 20 mA signal to recognize 4 mA as 100 °F and 20 mA as 250 °F. The relationship is linear between these extremes. This 100 °F to 250 °F range is sometimes called the span of the controller. Setting the span of the controller is done as part of the configuration process.

Field scalable means that the range of the controller PV input can be scaled in the field (onsite) by the user as part of the configuration process. By definition, process controllers have this capability.

The control setpoint is the value of the process variable that the controller is to maintain while operating in the automatic control mode. The control setpoint is set either locally from the keypad, or remotely.

Control point adjustment (CPA) is the act of remotely setting, or adjusting, the control setpoint from an external device. The controller receives the 4 to 20 mA CPA signal at the controller remote setpoint (RSP) input and scales the signal to correspond to the same range as the process variable.

Table 1

Controller Features

	SLDC A	SLDC B	SLDC C	SLDC D
Meets all Specs:	Yes	Yes	Yes	No
Self-Tune:	Yes	Yes	Yes	Yes
Process Input:				
4-20 mA/*Isolated	Yes/Yes	Yes/Option	Yes/Yes	Yes/Yes
Field Scaleable	Yes	Yes	Yes	Yes
Input Resistance	250 ohms	50 ohms	100 ohms	
Output:				
4-20 mA/*Isolated	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes
Resistance (ohms)	0 to 1000	0 to 1000	0 to 750	0 to 900
Max Limit	105%, selectable	100%, selectable	110%, selectable	100%, selectable
Min Limit	-5%, selectable	0%, selectable	10%, selectable	0%, NOT selectable
PV Retransmission	Yes	Yes	Yes	Yes
Remote Setpoint:				
4-20 mA/*Isolated	Yes/Yes	Yes/No	Yes/No	Yes/Yes
Max/Min Setpoint	Yes	Yes	Yes	Yes
* Field Scaleable	Yes	No	Yes	No
Ratio	-20 to 20	-99 to 99	0 to 99.99	No
Bias	-9999 to 9999	-999 to 9999	-999 to 9999	No
Power up in RSP	Yes	Yes	Yes (note 1)	Yes
LSP/RSP Selectable	Yes	Yes	Yes	Yes
Control:				
PID	Yes	Yes	Yes	Yes
Direct/Rev Acting	Yes	Yes	Yes	Yes
Auto/Manual	Yes	Yes	Yes	Yes
* Bumpless Transfer	Yes	Yes	Yes	Yes
Power up into Auto	Yes	Yes	Yes	Yes
Prop Band Width	0.1 to 9999%	0.1 to 999%	0.1 to 999.9%	0.1 to 999.9%
Manual Reset	0 to 100	0 to 100	(note 2)	0 to 100
Integral Range	0.08 - 50 rpt/min	1 to 3600 sec/rpt	0.3-999.9 sec/rpt	1 to 9999 sec/rpt
I Disable	Set to 0 or off	Yes	Yes	Yes
Derivative Range	0.02 - 50 rpt/min	0 to 600 sec	0 to 999.9 sec	0.1 to 999.9 sec
D Disable	Set to 0.02	Yes	Yes	Yes
Alarms:				
Separate PV Alarm	Yes	Yes	Yes, high/low	Yes
Separate Dev Alarm	Yes	Yes	Yes, high/low	Yes
SPDT Relay	Yes	Yes	Yes	Yes
* Selectable NO/NC	Yes, jumper	Yes, wiring	Yes, wiring	Yes
* Select High/Low	Yes	Yes	Yes	No
Hysteresis	0.0 to 5.0%	1 to 50 units	0 to 1000 units	0.1 to 10.0%
Other Specs:				
3.62" x 3.62"	Yes	Yes	Yes	Yes
Accuracy	0.2%	0.25%	0.2%	0.25%
Anti-reset Windup	Yes	Yes	Yes	Yes
>100dB @60 Hz CMRR	Yes	Yes	Yes	Yes
>60dB @60 Hz NMRR	Yes	Yes	Yes	Yes
Primary Display	6 digit VF	4 digit LED	4 digit LED	4.5 digit LED
* Secondary Display	8 digit VF	4 digit LED	4 digit LED	4.5 digit LED
* Int Power Supply	No	Yes	Yes	No
Data Retension	EEPROM	Batt, 5 yrs	Batt, 10 yrs	PROM
Power Consumption	9 watts	15 watts	20 watts	8.5 watts
* Communications	RS 422/485	RS 485	RS 422	RS 485/422
Warranty	3 yrs	1 yr	2 yrs	2 yrs
* **Base Price:**	$445	$540	$465	$800
* **Total Price:**	$545	$584	$615	$1075
* **Options Breakdown:**				
2nd Alarm	$50	$37	$150 opt module	$75.00
4-20 mA Output	Included	Included	Included	Included
Remote Setpoint	$50	Included	Incl w/2nd Alarm	$200 (analog comm)
PV Retrans	$95	Included	Included	$170.00
Communications	$225	$185	$147	$225.00

*** Indicates that feature is NOT required to meet the current Guide Specifications.**

Note 1: If the RSP signal is lost, this controller will automatically revert to LSP. This is an optional feature with E1 and E2.
Note 2: Manual reset for SLDC C cannot be set through a menu option. The manual reset setting must be adjusted in manual mode, and then the controller must be switched into auto when the corresponding process variable and setpoint values are correct.

Table 1 (Cont'd)

	SLDC E1	SLDC E2	SLDC F	SLDC G
Meets all Specs:	Yes	Yes	No	No
Self-Tune:	Yes	Yes	Yes	Yes
Process Input:				
4-20 mA/*Isolated	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes
Field Scaleable	Yes	Yes	Yes	Yes
Input resistance	250 ohms	250 ohms		
Output:				
4-20 mA/*Isolated	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes
Resistance (ohms)	0 to 600	0 to 600	0 to 500	0 to 750
Max Limit	105%	105%	100%	105%
Min Limit	5%	5%	0%	0%
PV Retransmission	Yes	Yes	No	Yes
Remote Setpoint:				
4-20 mA/*Isolated	Yes/No	Yes/No	No	Yes/Yes
Max/Min Setpoint	Yes	Yes		
* Field Scaleable	No	No	No	Yes
Ratio	Yes	Yes	No	Yes
Bias	Yes	Yes	No	Yes
Power up in RSP	Yes (note 1)	Yes (note 1)	No	Yes
LSP/RSP Selectable	Yes	Yes	No	No
Control:				
PID	Yes	Yes	Yes	Yes
Direct/Rev Acting	Yes	Yes	Yes	Yes
Auto/Manual	Yes	Yes	Yes	Yes
* Bumpless Transfer	Yes	Yes	Yes	Yes
Power up into Auto	Yes	Yes	Yes	Yes
Prop Band Width	0.1 to 999.9%	0.1 to 999.9%	1 to 400 (gain)	0.0 to 999.9%
Manual Reset	-5.0 to 105.0	-5.0 to 105.0	No	No
Integral Range	1 to 6000 sec	1 to 6000 sec	0 to 250 sec	1 to 9999 sec
I Disable	Set to 1	Set to 1	Set to 1	Set to 1
Derivative Range	1 to 6000 sec	1 to 6000 sec	0 to 250 sec	0 to 9999 sec
D Disable	Set to 1	Set to 1	Set to 0	Set to 0
Alarms:				
Separate PV Alarm	Yes	Yes	No	Yes
Separate Dev Alarm	Yes	Yes	No	Yes
SPDT Relay	Yes	Yes	Yes (option)	No, transistor
* Selectable NO/NC	Yes	Yes	Yes	No
* Select High/Low	Yes	Yes	Yes	Yes
Hysteresis	0 to 5%	0 to 5%	No	0.0 to 99.99
Other Specs:				
3.62" x 3.62"	Yes	Yes	Yes	Yes
Accuracy	0.2%	0.1%	0.2%	0.1%
Anti-reset Windup	Yes	Yes	Yes	Yes
>100dB @60 Hz CMRR	Yes, > 140 dB	Yes, > 140 dB	Yes, > 120 dB	Yes, > 130 db
>60dB @60 Hz NMRR	Yes	Yes	Yes, > 80 dB	No, > 50 db
Primary Display	4 digit LED	4 digit VFD	4 digit LED	4 digit LED
* Secondary Display	4 digit LED	4 digit LED	4 digit LED	4 digit LED
* Int Power Supply	No	No	No	No
Data Retension	Batt, 10 yrs	Batt, 10 yrs	EROM, 10 yrs	EPROM, 10 yrs
Power Consumption	9 watts	9 watts	6 watts	12 watts
* Communications	RS 422	RS 422	RS 232C, 485	RS 232C, 422A
Warranty	2 yrs	2 yrs	2 yrs	1 yr
Cost:				
* Base Price	$425	$695	$730	$550 (w/10% discnt)
* Total Price	$520	$790	$785	$810 (w/10% discnt)
* Options Breakdown:				
2nd Alarm	Included	Included	$55.00	Included
4-20 mA Output	$45.00	$45.00	Included	Included
Remote Setpoint	Included	Included	Not Available	$260.00
PV Retrans	$125.00	$125.00	Not Available	$360.00
Communications	$195.00	$195.00	$119.00	$160.00
Other	$50.00 (note 3)	$50.00 (note 3)		

*** Indicates that feature is NOT required to meet the current Guide Specifications.**

Note 1: If the RSP signal is lost, this controller will automatically revert to LSP. This is an optional feature with E1 and E2.
Note 3: E1 and E2 have an additional $50.00 charge for ratio and bias.

Table 1 (Cont'd)

	SLDC H1	SLDC H2	SLDC I	SLDC J
Meets all Specs:	No	No	No	No
Self-Tune:	No	Yes	Yes	No
Process Input:				
4-20 mA/*Isolated	Yes/No	Yes/No	Yes/Yes	Yes/No
Field Scaleable	Yes	Yes	Yes	Yes
Output:				
4-20 mA/*Isolated	Yes/Option	Yes/Option	Yes/Yes	Yes/Option
Resistance (ohms)	0 to 1000	0 to 1000	0 to 600	0 to 1000
Max Limit	100% (not adj)	100% (not adjustable)	100%	100%
Min Limit	0% (not adj)	0% (not adjustable)	0%	0%
PV Retransmission	Yes	Yes	No	Yes
Remote Setpoint:				
4-20 mA/*Isolated	Yes/No	Yes/No	Yes/No	Yes/Option
Max/Min Setpoint				
* Field Scaleable	No	No	No	Yes
Ratio	No	No	No	No
Bias	No	No	No	No
Power up in RSP	Yes	Yes	No	Yes (note 1)
LSP/RSP Selectable	Yes	Yes	Yes	Yes
Control:				
PID	Yes	Yes	Yes	Yes
Direct/Rev Acting	Yes	Yes	Yes	Yes
Auto/Manual	No	Yes	Yes	Yes
* Bumpless Transfer	Yes	Yes	Yes	Yes
Power up into Auto	Yes	Yes	Yes	Yes
Prop Band Width	1 to 200%	1 to 200%	0.1 to 200.0%	0 to 1000 units
Manual Reset	Yes	Yes	No	Yes
Integral Range	0.01 to 20 rpt/min	0.01 to 20 rpt/min	1 to 3600 sec	0.1 to 99.9 min
I Disable	Set to 0.01	Set to 0.01	No	Yes
Derivative Range	0.01 to 5 min	0.01 to 5 min	0 to 2000 sec	0.1 to 99.9 min
D Disable	Set to 0.01	Set to 0.01	No	Yes
Alarms:				
Separate PV Alarm	Only 1 alarm	Only 1 alarm	Yes	No
Separate Dev Alarm	Only 1 alarm	Only 1 alarm	Yes	Yes
SPDT Relay	Yes	Yes	Yes	Yes
* Selectable NO/NC	Yes	Yes	N/O only (Dev)	Yes
Select High/Low	Yes	Yes	Yes (Dev)	Yes
Hysteresis	.25, .5, 1%	.25, .5, 1%	No	0-300 units
Other Specs:				
3.62" x 3.62"	Yes	Yes	Yes	Yes
Accuracy	0.2%	0.2%	0.3%	0.25%
Anti-reset Windup	Yes	Yes	Yes	Yes
>100dB @60 Hz CMRR	Yes, 140 db	Yes, 140 db	Yes, 120 db	Yes, 140 db
>60dB @60 Hz NMRR	Yes, 65 db	Yes, 65 db	Yes	Yes, 65 db
Primary Display	8 digit VFD	8 digit VFD	4 digit LED	4 digit LED
* Secondary Display	8 digit VFD	8 digit VFD	none	4 digit LED
* Int Power Supply	No	No	No	Yes/option
Data Retension	Batt, 10 yrs	Batt, 10 yrs	Batt, 5 yrs	Batt, 5 yrs
Power Consumption	8 watts	8 watts	10 watts	10 watts
* Communications	No	RS232C, RS422	No	RS 485
Warranty	1 yr	1 yr	1 yr	3 yrs
Cost:				
* Base Price	$395.00	$395.00	$470.00	$670.00
* Total Price	$650.00	$650.00	$470.00	$790.00
* Options Breakdown:				
2nd Alarm	$25.00 (1st alm)	$25.00 (1st alm)	Included	Included
4-20 mA Output	$60.00 isolated	$60.00 isolated	Included	Included
Remote Setpoint	$50.00	$50.00	Included	$95.00
PV Retrans	$30.00	$30.00	Not Available	$75.00
Communications	$145.00	$145.00	Not available	$150.00
Other	$120.00 (note 4)	$120.00 (note 4)		$25 (note 5)

*** Indicates that feature is NOT required to meet the current Guide Specifications.**

Note 1: If the RSP signal is lost, this controller will automatically revert to LSP mode. This feature is optional with E1 and E2.

Note 4: SLDCs H1 AND H2 have an additonal $120.00 charge for a 4-20 mA input.

Note 5: *SLDC J has an additional $25.00 charge for auto mode output.*

Table 1 (Cont'd)

	SLDC K	SLDC L	SLDC M	SLDC N
Meets all Specs:	No	No	No	No
Self-Tune:	Yes	Yes	No	Yes
Process Input:				
4-20 mA/*Isolated	Yes/No	Yes/Yes	No	No
Field Scaleable	Yes	Yes	Yes	Yes
Output:				
4-20 mA/*Isolated	Yes/No	Yes/Yes	Yes/Yes	Yes/Yes
Resistance (ohms)	0 to 300	0 to 800	0 to 650	0 to 650
Max Limit	100%	100%	100%	100%
Min Limit	0%	0%	0%	0%
PV Retransmission	Yes	Yes	Yes	Yes
Remote Setpoint:				
4-20 mA/*Isolated	Yes/No	Yes/No	Yes/No	Yes/No
Max/Min Setpoint				
* Field Scaleable	No	Yes	Yes	Yes
Ratio	No	Yes	No	No
Bias	No	Yes	No	No
Power up in RSP	Yes	Yes	Yes	Yes
LSP/RSP Selectable	Yes	Yes	Yes	Yes
Control:				
PID	No	Yes	Yes	Yes
Direct/Rev Acting	Yes	Yes	Yes	Yes
Auto/Manual	Yes	Yes	Yes	Yes
* Bumpless Transfer	Yes	Yes	Yes	Yes
Power up into Auto	Yes	Yes	Yes	Yes
Prop Band Width	1 to 199%	0.8 to 400.0%	1 to 3000 units	1 to 3000 units
Manual Reset	No	0 to 100	-1500 to 1500	-1500 to 1500
Integral Range	1 to 6000 sec	1 sec to 99 min	0 to 100 rpt/min	0 to 100 rpt/min
I Disable	Set to 1	Yes, off option	Set to 0	Set to 0
Derivative Range	0 to 1200 sec	0 to 99 min	0.0 to 10.0 min	0.0 to 10.0 min
D Disable	Set to 0	Set to 0	Set to 0	Set to 0
Alarms:				
Separate PV Alarm	Only 1 alm	Yes	Yes	Yes
Separate Dev Alarm	Only 1 alm	Yes	Yes	Yes
SPDT Relay	Yes	Yes	Yes	Yes
* Selectable NO/NC	No	Yes	Yes	Yes
* Select High/Low	Yes (only 1 alm)	Yes	Yes	Yes
Hysteresis	0.2 or 2%	No	0 to 300 units	0 to 300 units
Other Specs:				
3.62" x 3.62"	Yes	Yes	Yes	Yes
Accuracy	0.3%	0.25%	0.25%	0.25%
Anti-reset Windup	Yes	Yes	Yes	Yes
100 dB @60 Hz CMRR	Yes	Yes	Yes, > 90 db	Yes, > 90 dB
60 dB @60 Hz NMRR	Yes	Yes	Yes, > 85 db	Yes, > 85 dB
Primary Display	4 digit LED	4 digit LED	4 digit LED	4 digit LED
* Secondary Display	3 digit LED	4 digit LED	4 digit LED	4 digit LED
* Int Power Supply	No	Yes (option)	No	No
Data Retension	Batt, 10 yrs	Batt, 5 yrs	Batt, 5 yrs	Batt, 5 yrs
Power Consumption	8 watts	15 watts	15 watts	15 watts
* Communications	No	Rs 422, 485	RS 422	RS 422
Warranty	1 yr	2 yrs	3 yrs	3 yrs
Cost:				
* Base Price	$529.00	$797.00	$325.00	$420.00
* Total Price	$579.00	$917.00	$375.00	$490.00
* Options Breakdown:				
2nd Alarm	Not Available	$94.00	$30.00	$30.00
4-20 mA Output	$50.00	$26.00	$40.00	$40.00
Remote Setpoint	Included	Included	Included	Included
PV Retrans	Included	$131.00	Included	Included
Communications	Not Available	$131.00	$125.00	$125.00
Other		$79 (note 6)		

*** Indicates that feature is NOT required to meet the current Guide Specifications.**

Note 6: SLDC L has an additional $79.00 charge for an optional internal power supply that can be used to power it's PV input loop.

DESCRIPTION OF CONTROLLER FEATURES

Meets All Specs: Indicates whether or not the controller meets all of the specifications given in the U.S. Army Corps of Engineers Guide Specification for HVAC Control Systems (CEGS 15950, July 1990). These include features in this matrix that do NOT have an asterisk by them.

Self-Tune: Indicates if controller has a built-in tuning function, which selects the PID values for the given application.

Process Input:
4 to 20 mA/Isolated. Indicates if controller can accept a 4 to 20 mA input signal. Isolated refers to a process variable input ground electrically isolated from other inputs and outputs. Isolation is not a guide spec requirement.

Field Scalable. Controller's PV span. Can be configured onsite (i.e., 0 ° - 100 °F, 0.0" - 2.5", etc).

Input resistance. This is the controller input resistance as measured across the process variable input terminals.

Output:
4 to 20 mA/Isolated. Indicates if the controller can supply a 4 to 20 mA output signal. Isolated refers to an output ground electrically isolated from other controller inputs and outputs.

Resistance:
Max Limit. Maximum control signal output setting. "Selectable" means that it can be selected by the user in the field.

Min Limit. Minimum control signal output setting. "Selectable" means that it can be selected by the user in the field.

PV Retransmission. 4 to 20 mA output signal identical to the 4 to 20 mA PV input. The advantage of PV retransmission is that it is electrically or optically isolated from the process variable input. This means that any device, such as an Energy Monitoring and Control System (EMCS) interface or similar peripheral, connected to the controller will not interfere with the PV input signal, and vice versa. This is desirable because there is generally noise on the input signal that a recorder or the like would pick up if simply wired in series with the input loop. By using a separate PV retransmission signal, this noise is eliminated and a cleaner signal is obtained.

Remote Setpoint:
4 to 20 mA/Isolated. Indicates if controller can accept a 4 to 20 mA input signal to remotely control its setpoint. Isolated refers to a remote setpoint (RSP) input ground electrically isolated from other inputs and outputs.

Field Scalable. Indicates if setpoint span can be configured onsite to a span different than the PV span.

Ratio. Range of values for ratio function. The RSP signal is multiplied by the ratio value. (i.e. if ratio is 1.2, incoming signal of 100 °F is seen as 120 °F, 750 cfm is seen as 900 cfm, etc).

Bias. Range of values for bias function. The bias value is added to the RSP signal. (i.e. if bias is 10, incoming signal of 100 °F is seen as 110 °F, 750 cfm is seen as 760 cfm, etc).

Power up in LSP/RSP. Indicates if controller can be configured by the user onsite to power up (default) into local or remote setpoint.

LSP/RSP Selectable. Indicates if setpoint can be configured by the user onsite as either local (LSP) or remote setpoint (RSP).

Control:
PID. Indicates whether or not controller uses proportional - integral - derivative control.

Direct/Rev Acting. Indicates whether or not controller can be configured by the user onsite for reverse or direct acting control action.

Auto/Manual. Indicates if controller has operator selectable auto and manual modes of output. In manual the output can be controlled by the operator, in auto the controller operates in closed-loop PID control mode.

Bumpless Transfer. There are a variety of definitions. Most common definition is when the controller is switched from auto to manual mode or vice-versa, the controller output does not immediately jump from one signal level to another - the transition is smooth.

Power up into Auto. Indicates if controller can be configured onsite to power up (after power loss) directly into automatic output mode (see auto/manual above).

Prop Band Width. Limits of the proportional band setting.

Manual Reset. Indicates if the controller manual reset function can be configured onsite.

Integral Range. Limits of the integral range. The reset adjustment is measured as the number of times proportional action is repeated per minute. Units are provided: sec = seconds per repeat, min = minutes per repeat, rpt/min = repeats per minute.

I Disable. Indicates if integral can be turned off for either P or PD control.

Derivative Range. Limits of the derivative range. The rate is based on how fast the input is changing. Units are provided: min = rate in minutes, sec = rate in seconds.

D Disable. Indicates if derivative can be turned off for either P or PI control.

Alarms:
Separate PV Alarm. Indicates if controller has a process variable alarm/contact output that acts independently of other contacts and output. A PV alarm relay is triggered when PV goes either above or below the given alarm setting (see selectable high/low).

Separate DEV Alarm. Indicates if controller has a deviation alarm/contact output that acts independently of other contacts and output. A deviation alarm relay is triggered when PV deviates a given amount above or below setpoint (see selectable high/low).

SPDT Relay. Indicates if alarm/contacts are mechanical single-pole, double-throw type.

Selectable NO/NC. Indicates if alarms/contacts can be configured as normally open or normally closed when power to controller is off.

Select High/Low. Indicates if alarms can be configured as high or low. The PV high alarm relay will energize when PV goes above the PV alarm setpoint, PV low alarm will energize when PV goes below alarm setpoint. Similarly, the DEV high alarm will energize when PV is a given amount above the controller setpoint, while DEV low alarm energizes for a PV a given amount below the controller SP.

Hysteresis. Limits of contact output/alarm hysteresis (deadband). Hysteresis is a deadband around the contact setpoint. This prevents relay "chattering".

Other Specs: German standard defining 1/4 DIN. Standard controller size, chassis is 3.62 in. by 3.62 in. Permits mounting in standard size panel opening.

Accuracy. Input to output accuracy of controller.

Antireset Windup. Prevents integral (I) reset contribution to PID output from saturating the output signal beyond the range of the controller output.

>100 db @60 Hz CMRR. Common mode rejection ratio.

>60 db @60 Hz NMRR. Normal mode rejection ratio.

Primary Display. Indicates type of display (LED = light-emitting diode, LCD = liquid crystal display, VFD = vacuum florescent display) and number of digits shown. Secondary Display. Indicates type of display (LED = light-emitting diode, LCD = liquid crystal display, VFD = vacuum florescent display) and number of digits shown.

Secondary Display.

Internal Power Supply. Controller has an internal power supply that may be used to power the PV input loop.

Data Retention. Method of data retention and maximum shelf life of configured parameters.

Power Consumption. Nominal power rating.

Communications. Types of digital communications options.

Warranty: Period of warranty.

Cost:

Base Price. Retail base price of the unit before prices of options necessary to meet specifications are added.

Total Price. Retail total price including base price and prices of all options required by the Guide Specification.

Options Breakdown:
2nd Alarm. Cost of second alarm/contact if it is an option.

4 to 20 mA Output. Cost of 4 to 20 mA output option if this is not included as a standard feature.

Remote Setpoint. Cost for adding the remote setpoint option if not a standard feature.

PV Retrans. Cost for 4 to 20 mA PV retransmission if not a standard feature.

Communications. Added cost for communications feature.

Other. Includes any option costs not shown above.

Some controllers permit scaling of the RSP to a range different from that of the PV. This feature is not necessary for the standard applications described in TM 5-815-3.

The ratio is used with the remote setpoint input signal. The controller multiplies the scaled RSP signal by the value of the ratio. For example, assume the 4 to 20 mA RSP input to the controller is from an airflow transmitter that has a span of 0 to 1,000 feet per minute (fpm). The cross-sectional area of the duct at the transmitter location is 10 sq ft. Therefore, the resulting range of the volumetric airflow for this application is 0 to 10,000 cubic feet per minute (cfm). The user configures the controller to scale the 4 to 20 mA signal to this 0 to 10,000 cfm range. Assuming you want to ratio this scaled signal by 1.2, configure the controller for this ratio value. When the RSP input is 20 mA, with the ratio set to 1.2, the resulting setpoint of the controller will be:

Setpoint = Scaled signal x ratio
= 10,000 cfm x 1.2
= 12,000 cfm

Table 2 shows other inputs with the ratio set to 1.2

Table 2

Ratio Examples

Sensed Flow (fpm)	RSP Input (mA)	Scaled Signal (cfm)	Ratioed Signal (cfm)
0	4	0	0
500	12	5000	6000
1000	20	10,000	12,000

Bias, like ratio, is also used with the remote setpoint input to offset (add or subtract) a portion of the scaled RSP signal. The controller first scales the signal, ratios it, then biases it. Expanding on the above ratio example, assume the RSP input is from an airflow transmitter that has a span of 0 to 1000 fpm. This span corresponds to a volumetric flow of 0 to 10,000 cfm in a 10 sq ft duct. Referring to Table 2, when the flow is 1000 fpm, the scaled signal is 10,000, and the ratioed signal is 12,000 cfm (assuming the ratio is 1.2). With the bias set to be -3000, the resulting setpoint of the controller will be 12,000 cfm - 3000 cfm = 9000 cfm (Table 3).

Analog output (OUT) is a 4 to 20 mA control signal used to modulate the controlled device. Its upper and lower limits are user-selectable. OUT is displayable on the front panel of the controller in units of percent, where 0 percent equals 4 mA and 100 percent equals 20 mA.

Manual Reset (MR) or Adjustable Bias can be defined as the value of the analog output from the controller when the controlled variable equals the control setpoint (Error = 0) while the controller is operating in the proportional only mode. Manual reset is often used as a final tuning adjustment in the application of a proportional only controller to get the controlled variable to equal the setpoint. It is also useful in setpoint reset applications. This is discussed later.

Although MR is commonly used when the controller is operating in the proportional only mode, it also applies to the PI and PID control modes. Mathematically, MR is a constant in the PID control equation that is added to the output signal and is shown below in the generic PID algorithm:

$$OUT = MR + PG \times (Error) + IG \times (Sum\ of\ Errors) + DG \times (Del\ Error)$$

where PG = Proportional gain
Error = Difference between setpoint and controlled variable
IG = Integral gain
Sum of Errors = Integration of error over time
DG = Derivative gain
Del Error = Difference between present and previous error.

Reduced to a proportional only algorithm:

$$OUT = MR + PG \times (Error)$$

Table 3

Ratio and Bias Example

Sensed Flow (fpm)	RSP Input (mA)	Scaled Signal (cfm)	Ratioed Signal (cfm)	Biased Signal (cfm)
0	4	0	0	0
500	12	5000	6000	3000
1000	20	10,000	12,000	9000

MR is input into the controller in percent during the configuration process. Do not confuse MR with the bias associated with the RSP; they are not the same.

Auto/manual are the two control modes that the controller can operate in. When in the automatic mode, the controller operates in a closed loop as it attempts to keep the process variable at the control setpoint. In the manual mode, the controller operates in an open loop with the output signal at a value (or level) selectable by the operator.

Bumpless transfer is when the operator switches the controller from auto to manual mode or vice-versa, and the controller output does not immediately jump from one signal level to another. The transition is smooth.

Antireset windup is a controller feature that stops the integration of the error signal when the controller output signal reaches its minimum or maximum value.

Mode constants are the PID values. These are the gain values used by the controller while it is in the automatic closed-loop control mode. The classical definition of the integral gain term is not often used by the digital controls industry. The term seconds per repeat is more often used than reset time constant. The exact form of the SLDC PI alorithm using these units is:

$$OUT = \frac{MR + 100^2 \times Error}{SS \times PB} + \frac{Tup \times 100^2 \times (Sum\ of\ Errors)}{PB \times SS \times I_c}$$

where	MR	=	Manual reset in percent x 100
	Error	=	Difference between setpoint and controlled variable
	SS	=	Sensor Span, appropriate units (i.e., degrees F)
	PB	=	Proportional band mode constant in percent x 100
	Tup	=	The rate at which the controller updates the value of OUT
	Sum of Errors	=	Integration of error over time
	I_c	=	Integral mode constant, seconds per repeat

Notice that the proportional band mode constant affects both the P and the I portions of the algorithm. This algorithm has been found to be specific to controllers B, C, E1 and E2 shown in Table 1. The algorithm of SLDC A differs in that I_c has units of repeats per minutes. For this controller, the above equation applies with the following exception:

$$I_c = 60 \times 1/(\text{repeats per minute})$$

The controller's action is either Direct (DIR) or Reverse (REV) acting. Direct-acting output will increase as the process variable rises above the control setpoint, and will decrease as it drops below. Likewise, reverse-acting output will decrease as the process variable rises above the control setpoint and will increase as it drops below.

Self-tuning is the process that the controller goes through to automatically select its PID control mode constants.

The PV contact is a contact closure output that is open or closed, depending on the value of the process variable. The PV contact is often called a process variable alarm by SLDC vendors. User-selectable parameters associated with the PV contact are: PV contact setpoint, normally open or normally closed, and direct acting or reverse acting. A normally open, direct acting PV contact will close if the PV rises above the PV contact setpoint. A normally closed, direct acting PV contact will open if the PV rises above the PV contact setpoint. A normally open, reverse acting PV contact will close if the PV drops below the PV contact setpoint. A normally closed, reverse acting PV contact will open if the PV drops below the PV contact setpoint.

Hysteresis is a lagging effect that creates a small deadband on both sides of a contact setpoint. It prevents rapid opening and closing (chattering) of the contact output when the condition required to activate the contact is very close to its setpoint. The size of the hysteresis is a user-selectable parameter. A hysteresis setting of two units establishes a deadband that extends one unit above and one unit below the contact setpoint.

The deviation (DEV) contact is a contact closure output that is open or closed, depending on the size of the deviation between the process variable and the control setpoint. The DEV contact is often called a deviation alarm by SLDC vendors. This contact has a user-selectable setpoint equal to the desired deviation between the process variable and the control setpoint. Note that the control setpoint, as described previously, is different from the contact setpoint; the contact setpoint may be positive or negative. And as with the PV contact described above, the user selects the relay contact output to be normally open or closed. Direct and reverse action are not user-selectable for this contact, although the same effect is achieved depending on whether the magnitude of the setpoint is positive or negative. Table 4 illustrates the response of the controller contact output when the DEV setpoint is +8, the hysteresis is 2, and the contact is normally open. The example assumes the setpoint (SP) is being varied remotely via a remote setpoint (RSP) input to the controller. At a PV of 70 and SP of 63 the deviation is +7. This is less than the contact setpoint, therefore the contact is in its normally open state. When the SP drops to 62, the deviation is equal to the DEV contact setpoint but the controller contact does not change because of the hysteresis setting. The contact closes when the SP drops to 61, resulting in a deviation of 9. The contact remains closed until the SP rises to 63, a deviation of 7.

Table 4

Deviation Contact Example

PV	SP	Deviation	Contact status
70	63	+7	Open
70	62	+8	Open
70	61	+9	Closed
70	62	+8	Closed
70	63	+7	Open

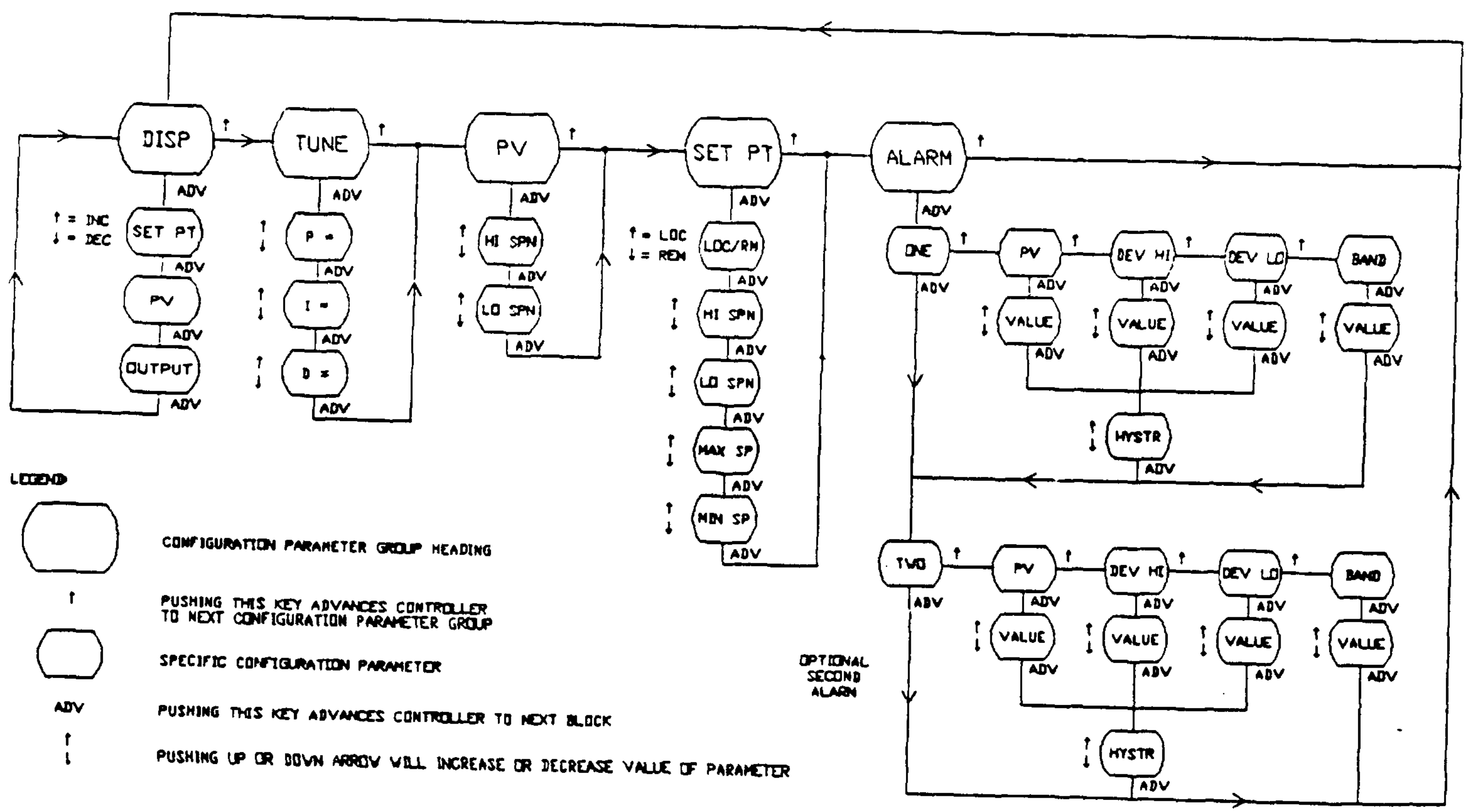

Figure 2. Typical SLDC configuration flow chart.

Controller Configuration

Configuring the SLDC prepares the device to control a given process. SLDC manufacturers provide step-by-step instructions. Although the procedure is not simple, it is straightforward and, given a little time and/or instruction, it can be performed quickly and easily. Many SLDC instruction booklets illustrate the configuration procedure in a flow chart (Figure 2) that simplifies the process.

The front keypad of the controller is used to select the various control options by manually keying in the proper parameters. One key is used to scroll through the main menu headings, including: Control, Input, Output, and Alarm/Contact settings. Another key is used to scroll through the individual parameters under each main menu heading. Change the individual parameters using the arrow keys. Some of the parameters are: P, I, and D values, control setpoint, upper and lower scale ranges for the input signals, direct or reverse control action, maximum and minimum output signal, alarm/contact definition, and alarm/contact setpoints. Some controllers require additional configuration (setting dip switches or placing jumper pins).

For each application, the designer calculates and selects some of the controller configuration parameters. An example application is where the controller is designed to reset the setpoint of another controller. The designer must calculate the configuration parameters of the reset controller that will result in the desired reset schedule. Another example is an economizer application where the designer calculates the relay/contact setpoints. These calculations are described later.

For the Army standard systems, the designer includes the selected configuration parameters on the equipment schedule drawing. The contractor records these and any additional parameters, as determined necessary by the contractor, on a controller configuration check sheet developed by the contractor. The contractor uses the configuration check sheet during system commissioning. The checksheet also provides operation and maintenance personnel with a permanent record of the controller configuration.

Operation and Maintenance

Operation of the controller is relatively simple. The displays show the controller setpoint and process variable (temperature, pressure, flow, etc.). The displays can also show the controller output signal (in percent) and other parameters of interest such as contact or alarm setpoints and the PID mode constants. The user can operate the controller in the manual mode. In manual, the arrow keys set the level of the output signal.

The single-loop concept can help maintenance personnel locate and diagnose suspected problems. Each SLDC readily displays its control setpoint, process variable, and output value. It requires little effort to view each of these values, making the first step of diagnosis a straightforward process. If a controller becomes defective, it is easily replaced by a controller of the same or different manufacturer.

Self-Tuning

Self-tuning is a process that automatically selects optimal PID control mode constants. Two basic types of self-tuning controllers are available: the operator-initiated, self-tuning controller that self-tunes upon command from an operator, and the automatic self-tuning controller that automatically self-tunes either continuously or when it determines the process needs tuning. Automatic self-tuning controllers (sometimes called adaptive controllers) are not recommended for use in the standard HVAC control applications because they are not readily available and because their performance is questionable and needs further study. An exception to this is a continuously self-tuning controller with a self-tuning function that the user can disable after self-tuning is complete.

The self-tuning algorithms used by most SLDCs follow either: the Pattern Recognition method or the Process Identification method[7]. The Pattern Recognition method is described here by comparing it to the Ziegler Nichols Process Reaction Curve (PRC) Method[8]. The Ziegler Nichols PRC method is a common method of manually tuning a control loop. In the PRC method, the controller "bumps" the process by changing its output control signal to a fixed level as shown in Figure 3. It then monitors the change in the process variable in response to this disturbance. This is done while the controller is operating in an open loop (no attempt to control). The controller calculates PID parameters based on measurements of the process variable such as the dead time, time constant, and gain.

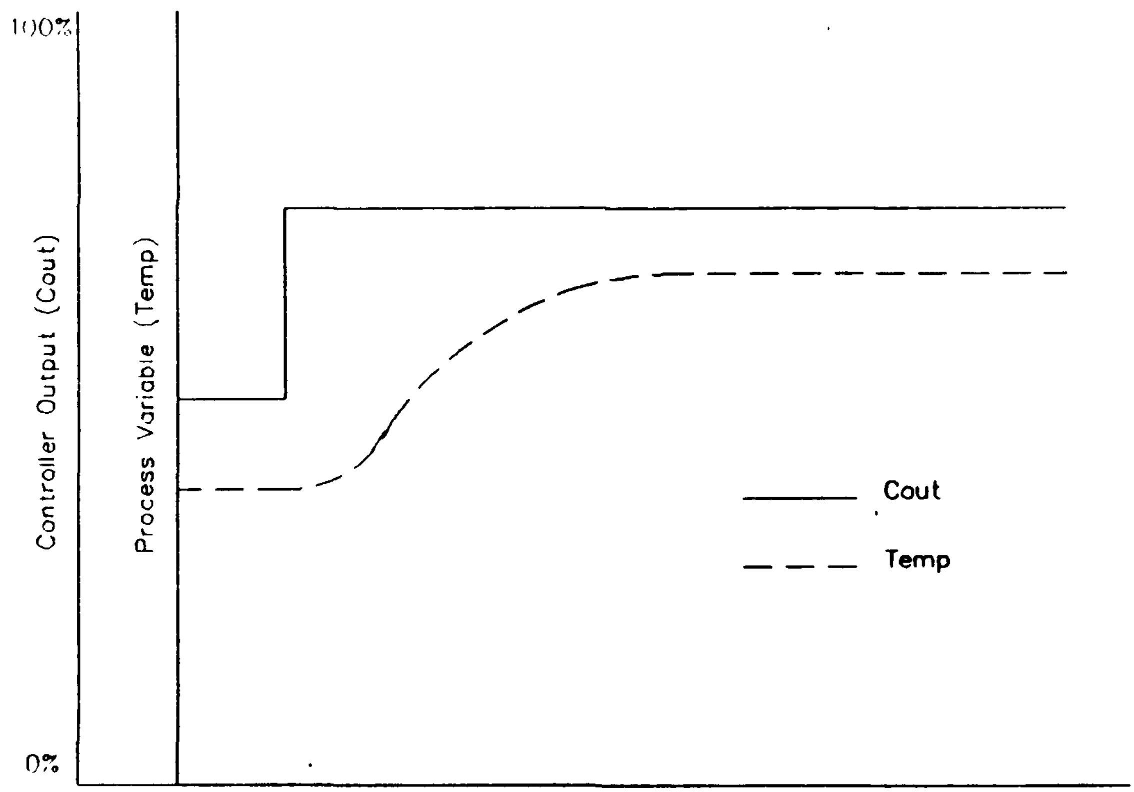

Figure 3. Process reaction curve.

[7] P.R.J. de la Nougerde, *What is Self-tuning?* Technical Note TN2071-1 (Gulton Industries).

[8] J.B. Ziegler and N.B. Nichols., "Optimum Settings for Automatic Controllers," *Transactions of the A.S.M.E.* (November 1942), pp 759-768.

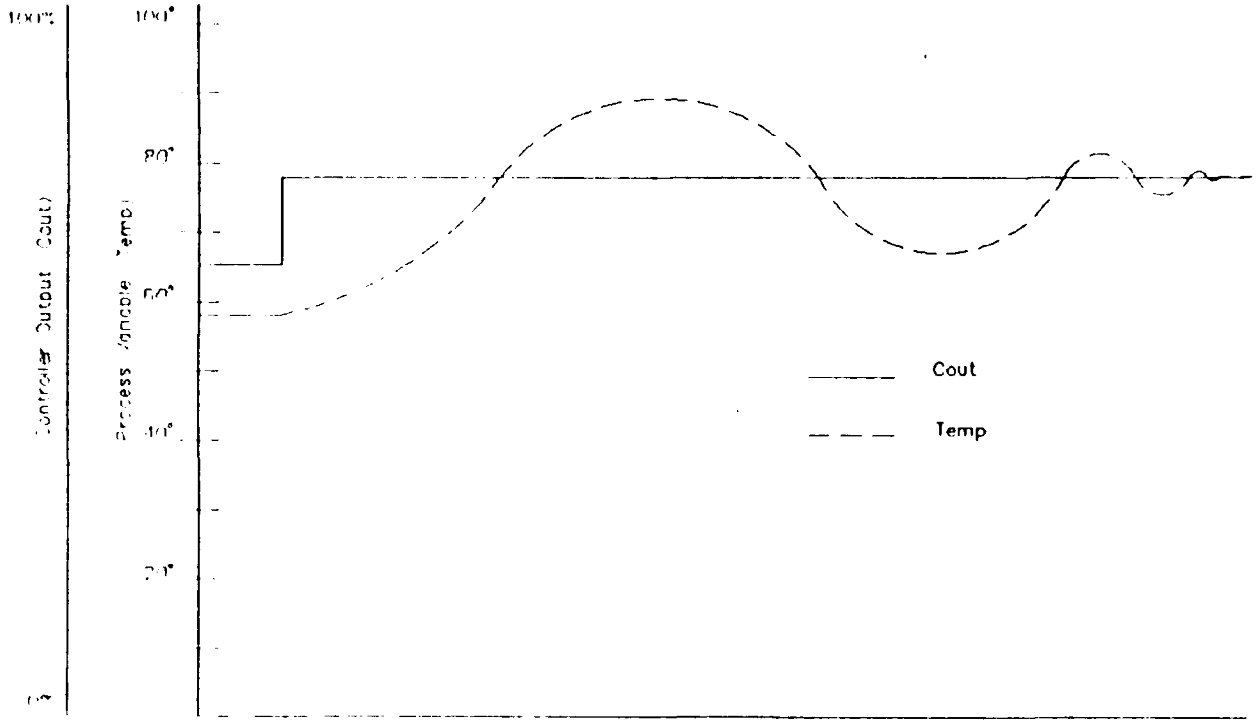

Figure 4. Quarter-wave damped response.

Using the Ziegler Nichols method, the calculated PID parameters result in a quarter-wave damped response to a closed loop setpoint change (Figure 4). At 1 second, the controller setpoint is changed from about 60 °F to 80 °F. The process variable overshoots the setpoint as it begins to settle out. Observe that the peak-to-peak height of the second oscillation of the process variable is one-quarter of the peak-to-peak height of the first oscillation. The advantage of this type of response is that the time from the initial setpoint change until the process finally settles is minimal compared to other types of responses. The disadvantage of this type of response is that it is less stable than a nonoscillatory response. Changes, over time, of the process dynamics may result in an unstable system.

Pattern recognition self-tuning controllers use an algorithm to replicate the tuning procedure. The exact nature of the algorithm varies among vendors. Because of variations in the algorithm, the calculated PID values using different vendors' controllers might be different for an identical control loop. For example, one vendor's algorithm might calculate PID values that provide a quarter-wave damped response while another vendor's algorithm might provide a critically damped response (no overshoot of the setpoint).

An SLDC using the Process Identification method monitors the process variable input and controller output signal while the controller is operating in the closed loop mode. It uses this information to create a mathematical model of the controlled process. Based on this model, the controller calculates either an appropriate control output signal directly or appropriate PID values for optimal control.[9] The Process Identification method is sometimes referred to as adaptive control because it attempts to continuously optimize controller performance.

In one laboratory test on USACERL's HVAC test facility, an operator-initiated, Pattern Recognition self-tuning controller was used to tune a hot deck discharge air temperature control system. As shown in Figure 5, the self-tuning controller calculated PID values to yield better control than those selected manually via an hour-long trial-and-error attempt at tuning the loop.

In another laboratory test using the test facility, three different operator initiated, Pattern Recognition self-tuning controllers were used to tune a duct static pressure control loop. Each controller successfully self-tuned the loop in less than 1 minute. Figure 6 illustrates the self-tuning process of one of the controllers. At 33 seconds, self-tuning begins. At 50 seconds, self-tuning is complete. During this short interval, the controller monitors the duct static pressure in response to the output signal cycling between 0 percent and 100 percent. Figure 7 shows the controller response to setpoint step changes using the PID constants calculated by the controller. Both resemble a quarter-wave damped response.

Other testing on a variable air volume system at Fort Leonard Wood, MO, showed that each controller successfully self-tuned its loop. In some instances, the resulting closed loop response was not ideal, but required little effort to correct the response to achieve good control.

Self-tuning SLDCs are designed and developed primarily for use by the process control industries. This may limit the self-tuning functionality of these devices and they may not always work in HVAC applications. For example, one SLDC requires a large error signal between the setpoint and process variable before it will self-tune. The size of the error for this controller is too large for HVAC applications.

Variations in self-tuning algorithms indicate that the tuning process is not a generic procedure. One algorithm may work better than another in a given application. Preliminary testing performed at USACERL showed that two of three SLDCs could not self-tune to yield satisfactory control of a fan static pressure control system which had a very short time constant.

Exercise caution in using the self-tune feature. Do not self-tune proportional only controllers, including the setpoint reset controller. Proportional only controllers have a proportional band selected by the designer and are not designed to use the I and D mode constants that would be calculated by the self-tuning algorithm. Also, do not self-tune an economizer controller; it does not use PID control.

In PID applications, do not assume that the controller will always self-tune successfully. Generally, if a controller cannot be manually tuned, it cannot be self-tuned. Some processes may not lend themselves well to self-tuning. An example is mixed air (MA) temperature control. The outdoor air must be cool enough, when mixed with the return air, to cause a fairly significant decrease in the mixed air temperature. If the decrease is not significant, the control loop cannot be manually or self-tuned. To illustrate this, assume that the MA loop is tuned under conditions where the outdoor air is 60 °F and the return air is 70 °F. The difference between the two temperatures is 10 degrees. This approximates the throttling range

[9] S.G. Brandt, "Adaptive Control Implementation Issues," *ASHRAE Transactions*, Vol 82, Pt 2 (1985), pp 211-218.

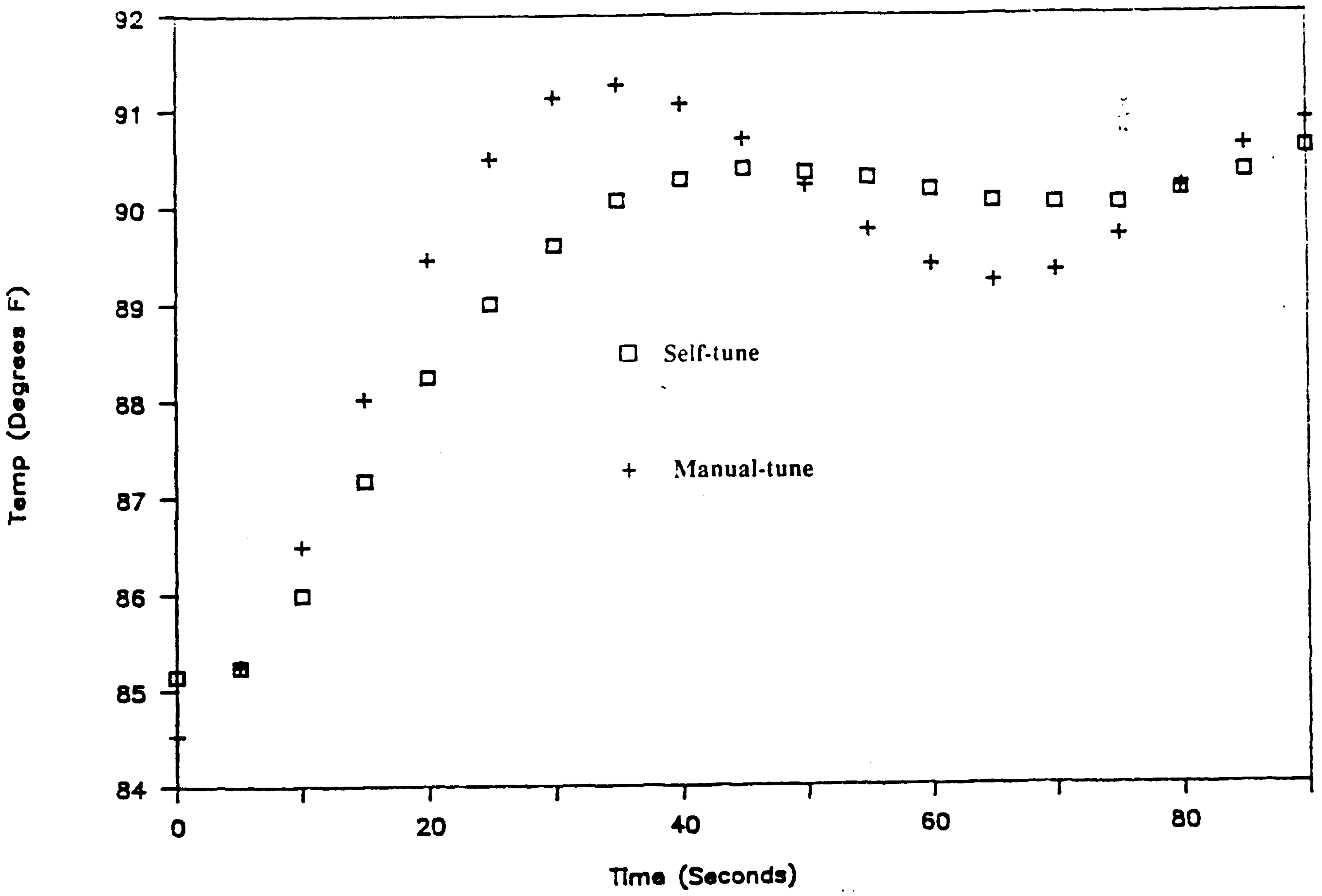

Figure 5. Hot deck temperature response to a setpoint change.

of the process, which means that when the controller output moves from minimum to maximum, the process changes 10 degrees. At a later time, the outdoor air temperature may change to 50 °F. The new throttling range, assuming the return air is still 70 °F, is now about 20 degrees. Since the controller was originally tuned for a 10 degree throttling range, it will be unstable under the new set of conditions. A small movement of the outdoor air damper will cause a greater change in the mixed air temperature than it would if the outdoor air were only 10 degrees less than the return air temperature. Therefore, the gain of the process is higher under the new condition. Always tune control loops under high gain conditions. If tuned under low gain conditions, the loop may be unstable when the system conditions are such that the gain is high.

Another example of an application where the self-tuning controller will not tune successfully is in a heat exchanger application where there is no load on the system. USACERL witnessed the commissioning of a control system where a self-tuning controller failed to self-tune because there was essentially no call for heating from the HVAC system that the heat exchanger supplied.

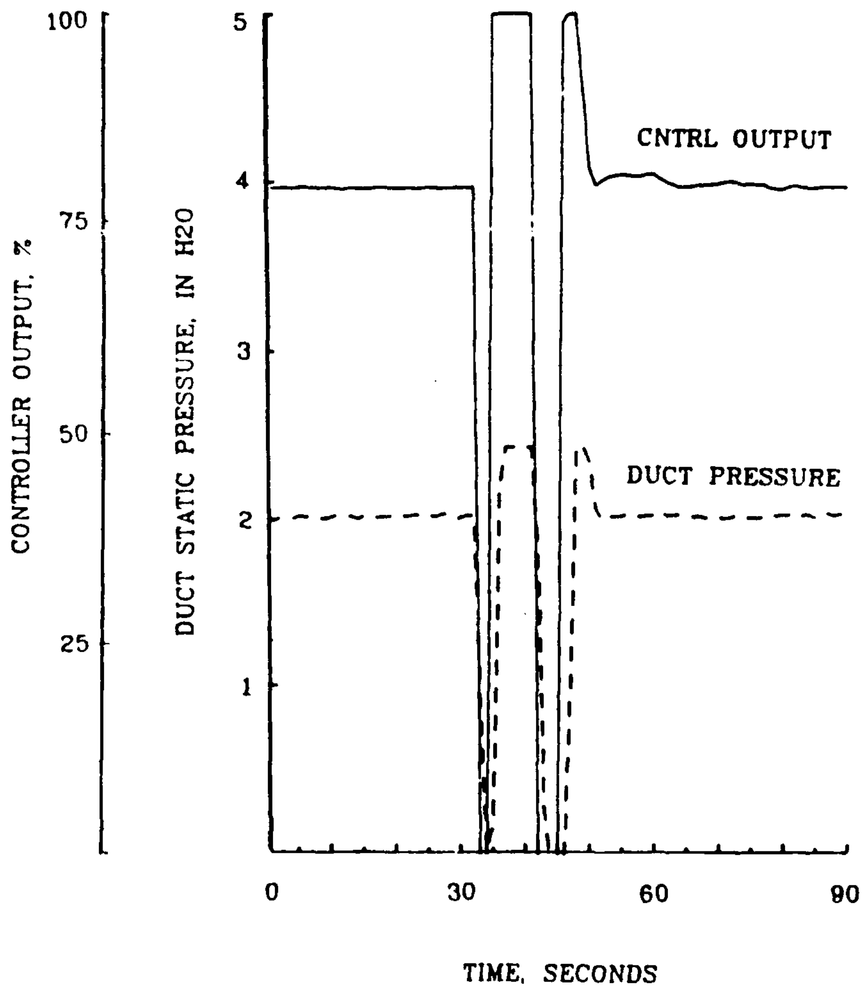

Figure 6. Self-tune of duct static pressure.

The previous examples illustrate that a self-tuning controller is not a remedy for processes that exhibit dramatic changes in control characteristics nor will the controller self-tune successfully if there is not a sufficient load on the system.

Some controllers may require additional configuration information to self-tune successfully. This additional information may include: (1) the magnitude of the output signal used to bump the process and (2) an indication of whether the process is fast or slow. Read the operator's manual before selecting self-tune parameters. If unsure about the settings, assume a fast process. Also, set the maximum output to 100 percent. If there is a minimum output, set it to 0 percent. An exception to this is a controller that repeatedly cycles its output during self-tune. Cycling between 0 percent and 100 percent is excessive and may take longer than necessary or may damage the equipment.

Some controllers can be configured to filter noise from the process variable input signal. In a properly designed and installed system, filtering should not be necessary, therefore, it is not required by the guide specification. If this feature happens to be available, using it may improve self-tuning and control performance.

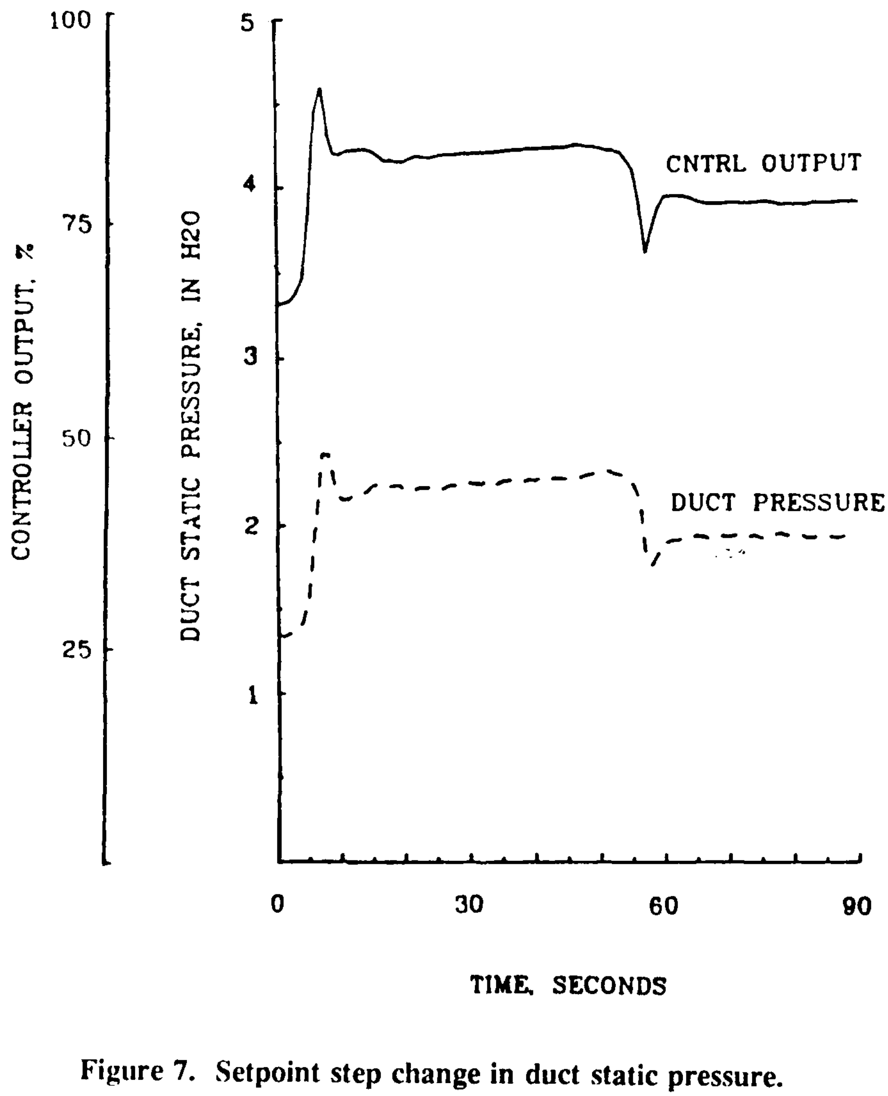

Figure 7. Setpoint step change in duct static pressure.

4 APPLICATION OF SLDCS TO HVAC CONTROL SYSTEMS

The Standard Controller

The standard SLDC can be used in three basic types of HVAC control applications: PID closed loop, setpoint reset, and economizer. In PID applications, the controller is suitable for controlling temperature, humidity, duct static pressure, and airflow. SLDCs are also used in P only control applications. These include humidity limit control, single zone systems, and setpoint reset applications. In an outdoor/return air economizer application, the controller uses only the PV and DEV contact outputs.

The specifications for a standard single-loop controller capable of performing the functions described in this report are included in the Appendix. Still, experience dictates that you exercise caution in selecting a standard controller. It is not always clear from the controller specification sheet that a particular controller will meet the guide specification requirements. The following controller features may not be obvious on a vendor's specification sheet; be cautious about them.

- The controller must be capable of powering up into the automatic control mode as opposed to manual mode. Also, if configured for a remote setpoint application, it must be capable of powering up into the RSP mode rather than local. This will ensure that if power to the control panel is lost, even for a short time, the controller will return to the desired mode of operation.

- The PV and DEV contacts must have separate external connections for wiring.

- There should be two separate contact closure outputs *in addition* to the 4 to 20 mA control output. Do not use the control (or primary) output from the controller as a PV or DEV contact output.

- The controller design should be such that the operator can turn the self-tune feature on and then disable it when finished self-tuning. Do not use a controller that continuously self-tunes.

- The self-tuning SLDC should allow the operator access to the PID values.

- The controller should accept a 4 to 20 mA input. Some SLDCs can accept only thermocouple or RTD inputs, thus restricting their use to temperature control applications.

- The SLDC should allow the user to span (scale) the process variable input.

- The length of a replacement controller cannot exceed the space available to it in the control panel.

PID Control

Most PID applications are relatively simple and straightforward. For example, controlling duct static pressure, discharge air temperature, and mixed air temperature are fairly common HVAC control applications. Typically, each requires only a sensor, transmitter, controller, and an actuation device. The SLDC is ideal for simple, accurate, and maintainable control in these applications.

Return fan control applications are common in Army facilities. The ratio and bias features of the controller are useful in this type of application. The ratio is used to account for differences in the supply and return cross-sectional areas of the ductwork at the location of the flow sensing element. It can also compensate for differences in the ranges of the flow transmitters if the ranges are not identical. The bias feature is used to establish a volumetric flow setpoint less than the flow sensed in the supply duct.

Reset Control

The setpoint of a heating coil controller is often changed or reset in response to the outdoor air temperature. Such a control scheme is shown in Figure 8. Here the proportional only reset controller, operating in the reverse acting mode (REV), accepts its input from a temperature transmitter (TT) in the outside air stream and provides a 4 to 20 mA output to the heating coil temperature controller. The 4 to 20 mA output is the CPA input to the heating coil controller. Adjusting the control point results in the heating coil temperature setpoint being reset in response to outdoor conditions. The PID heating coil temperature controller operating in a direct acting mode (DIR) accepts its input from a temperature transmitter (TT) in the supply air stream and provides a 4 to 20 mA output to a current to pneumatic transducer (IP). The IP provides a pressure signal to a normally open (NO) valve that modulates the rate of water flow through the heating coil (HC). Another similar and common application of reset control is in hydronic applications as shown in Figure 9. Here the heating water temperature is reset based on outdoor temperature. Again the output of the reset controller is the CPA input to the temperature controller. The relationship between the outside air temperature and heating water temperature is called the reset schedule.

There are four reset controller configuration parameters that the designer must calculate to establish the reset schedule: the SLDC setpoint, the proportional band, the maximum controller output signal, and the MR value. Before explaining the configuration parameters, several terms must be defined. The reset schedule is a linear relationship between a process variable and the setpoint. Figure 10 shows a detailed example for a hot water application. The horizontal axis shows the process variable (outside temperature) while the vertical axis shows the reset controller output (heating water setpoint). On the vertical axis, the upper end of the reset schedule line corresponds to a 20 mA output from the reset controller. The lower end of the line corresponds to a 4 mA output. This corresponds to the span of the hot water (HW) temperature controller; at 20 mA its setpoint will be 250 °F and at 4 mA its setpoint will be 100 °F.

The configuration of the reset controller limits its output to a maximum value (Max Out). This establishes the highest setpoint the reset controller will send to the hot water controller. An inverse relationship exists between the reset controller output and the process variable input. An increasing process variable results in a decrease in the controller output. To achieve this relationship, the reset controller must be reverse acting.

By definition, the reset controller setpoint is at the midpoint of the proportional band. This assumes that the value of the MR is 50 percent. Changes in the value of the reset controller setpoint will shift the reset schedule line either right or left.

The proportional band of the reset controller is the range of the process variable over which the controller output will move from minimum to maximum. Figure 11 illustrates this as (OA2 - OA1) / (HW1 - HW2). Another way of defining the proportional band is that it is the inverse of the slope of the reset line. Changing the proportional band will change the slope and length of the line as it rotates about the midpoint (the reset controller setpoint). The values of HW1 and HW2 are fixed in that they correspond to the setpoint (and process variable) range of the hot water controller.

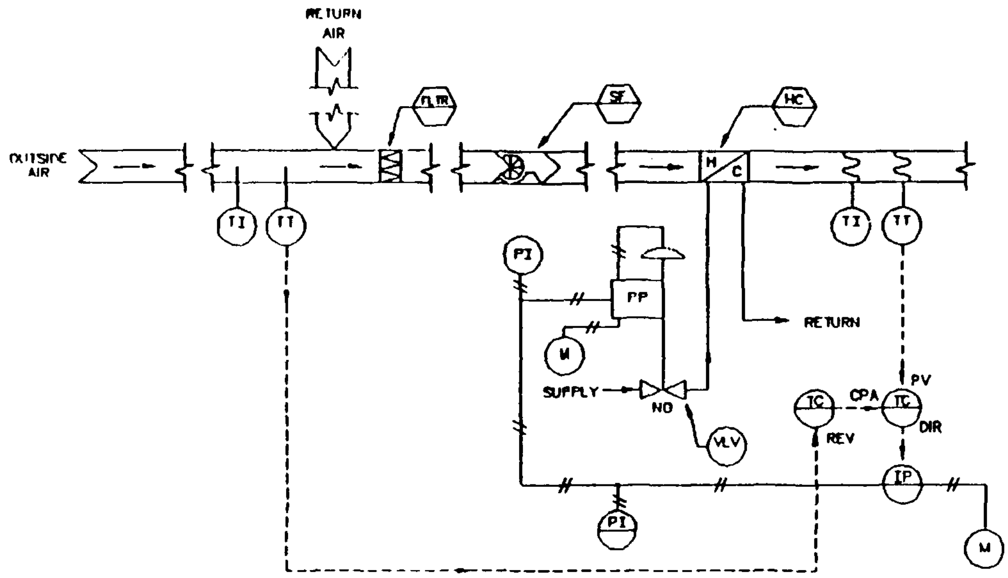

Figure 8. Heating coil with setpoint reset.

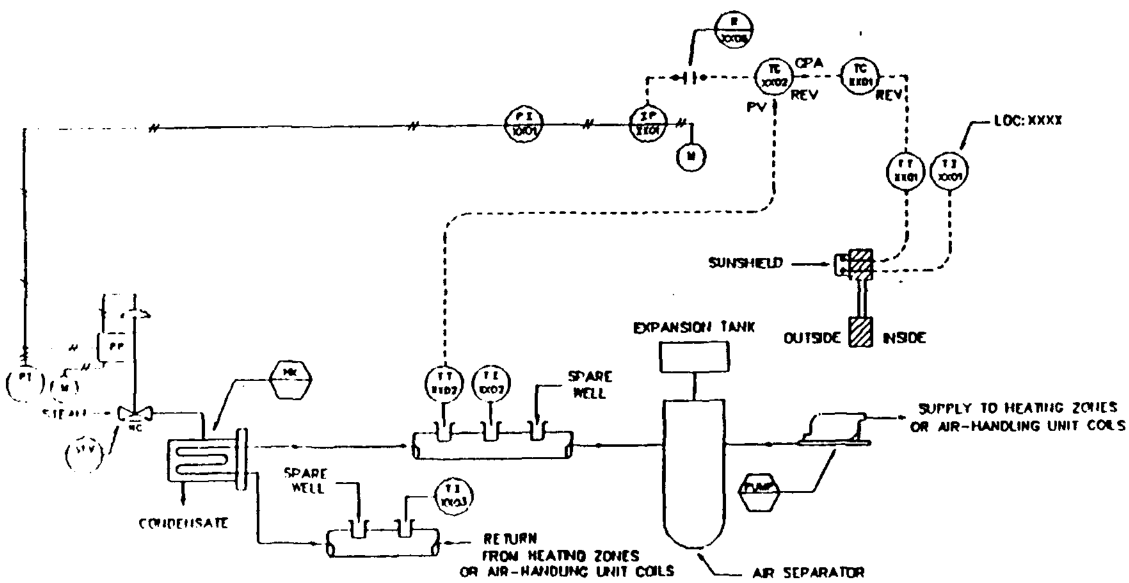

Figure 9. Hydronic application with setpoint reset.

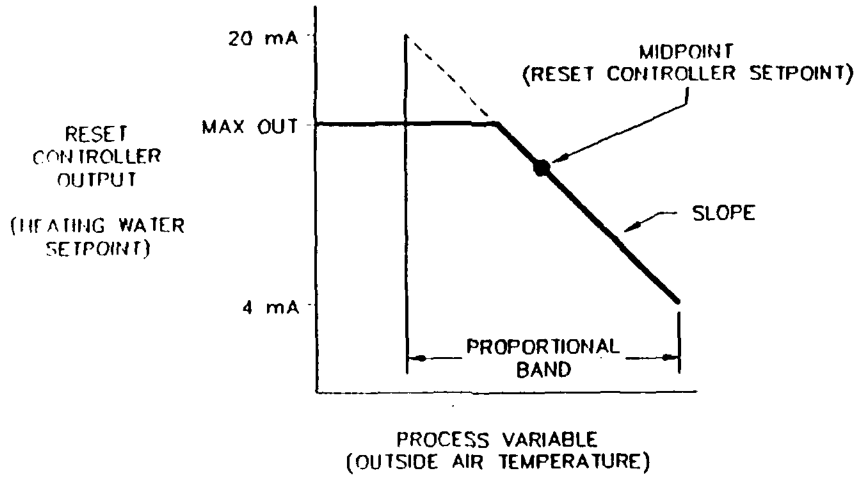

Figure 10. Setpoint reset controller function.

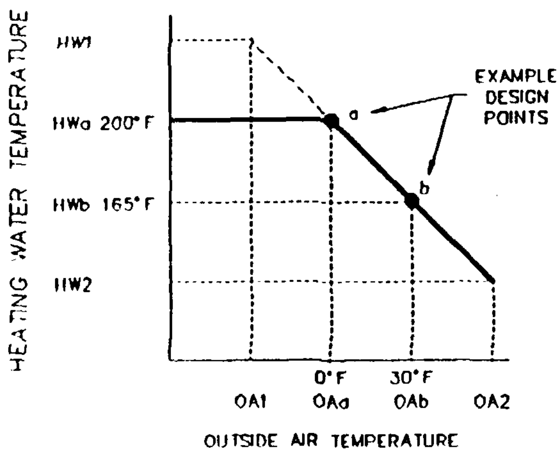

Figure 11. Example reset schedule.

As an example of the calculations necessary to determine the reset controller configuration parameters, consider a typical design where the heating water temperature is 200 °F at an outside design temperature of 0 °F. This is design point "a" in Figure 11. Design calculations indicate that at an outside temperature of 30 °F, a heating water temperature of 165 °F will satisfy the load. This is design point "b." In addition, the design should ensure that the heating water temperature never exceeds 200 °F regardless of the outdoor temperature. The solid line shown in Figure 11 represents these conditions. The configuration parameters for the reset controller are calculated from this information.

The guide specification requires the heating water temperature transmitter to have a PV span of 100 °F to 250 °F. The heating water controller CPA input must also be scaled to this range. (This is an important premise for the following calculations.) Therefore, when the reset controller output is 20 mA, the setpoint of the HW controller will be 250 °F, and when the output is 4 mA, the setpoint will be 100 °F. This span defines the values of HW1 and HW2 in Figure 11.

Given the values of HW1 and HW2 (HW1 = 100 °F and HW2 = 250 °F), their corresponding points on the reset schedule line, OA1 and OA2, are calculated based on the slope of the line. The slope of the line is calculated using the two design points:

$$\text{Slope} = (HWa - HWb)/(OAa - OAb) \qquad \text{[Eq 1]}$$
$$\text{Slope} = (200 - 165)/(0 - 30) = -1.17$$

OA1 corresponding to HW1 is calculated by again using the slope equation, the calculated slope, and one of the design points on the reset schedule line:

$$\text{Slope} = (HW1 - HWa)/(OA1 - OAa)$$

rearranging:

$$OA1 = (HW1 - HWa)/\text{Slope} + OAa \qquad \text{[Eq 2]}$$
$$= (250 - 200)/-1.17 + 0$$
$$OA1 = -42.7\ °F$$

similarly:

$$OA2 = (HW2 - HWa)/\text{Slope} + OAa \qquad \text{[Eq 3]}$$
$$= (100 - 200)/-1.17 + 0$$
$$OA2 = 85.5\ °F$$

The percent proportional band (PB%) for the reset controller is the range of the process variable over which the controller output will move from maximum to minimum (OA2 minus OA1 in example) divided by the span of the setpoint adjustment:

$$PB\% = (OA2 - OA1)/(HW\ Span) \qquad \text{[Eq 4]}$$
$$= (85.47 - -42.74)/(250 - 100)$$
$$PB\% = 0.855 \text{ or } 85.5$$

The reset controller setpoint (SP) is the midpoint of the throttling range:

$$SP = [(OA2 - OA1)/2] + OA1 \qquad \text{[Eq 5]}$$
$$= [(85.47 + 42.74)/2] - 42.74$$
$$SP = 21.4\ °F$$

The procedure described above for calculating the setpoint assumes that the value of the MR is 50 percent.

The reset controller must also limit the setpoint of the temperature controller to 200 °F (Max SP) by limiting the output of the reset controller. This controller feature, sometimes called "Max Output" or "Output High," is expressed as a percentage of the signal output where 0 percent is 4 mA and 100 percent is 20 mA. The HW controller recognizes a 4 mA CPA input as 100 °F (Lo Span) and a 20 mA CPA input as 250 °F (Hi Span). As discussed before, this is the span of the HW controller (HW Span). To calculate the Reset Controller Max output (Max Out):

$$\text{Max Output} = (\text{Max SP} - \text{Lo Span}) / \text{HW Span} \qquad \text{[Eq 6]}$$

The Max Output for the example is:

$$\text{Max Output} = (200 - 100) / (250 - 100)$$
$$\text{Max Output} = 0.67 \text{ or } 67 \text{ percent}$$

With the output of the reset controller limited to 67 percent of its maximum (this equates to 14.7 mA) the heating water setpoint will never be greater than 200 °F.

Economizer Control

Another useful application of the SLDC is as an economizer. An economy cycle is designed to allow the use of outdoor air (OA) to satisfy part or all of a system's cooling load. This is possible during the spring and fall, at night and early morning, on cool summer days, and at high altitudes. An ideal economizer compares the total heat content (enthalpy) of the outdoor air and the return air (RA). During the cooling cycle, the economizer operates whenever the enthalpy of the outdoor air is less than the return air. This results in maximum energy savings.

In practice, accurate and reliable measurement of enthalpy is very difficult[10]. The controls are expensive and require almost constant attention to ensure proper calibration and operation. As an alternative, economizer operation based on a dry bulb comparison between the OA and RA temperatures provides most of the energy savings associated with enthalpy control but without the major disadvantages[11]. This is called an optimized economizer. The controls are relatively inexpensive, are accurate and reliable, and require only normal attention to maintain system calibration and proper operation.

Figure 12 shows an optimized economizer control system. The mixed air temperature controller (TC) modulates the OA, RA, and relief air dampers when the system is in the economizer cycle operation. The minimum position switch (MPS), sets the OA damper minimum position. The output of MPS and TC are compared by the high signal selector (TY). The economizer controller compares the outdoor air dry bulb temperature to the return air dry bulb temperature. It puts the system into economizer operation by energizing a relay external to the controller which closes relay contact (NN).

To perform the economizer function, the controller is wired to accept the OA temperature transmitter signal as its remote setpoint input and the RA temperature transmitter signal as its process variable input.

[10] Douglas C. Hittle, et al., "Theory Meets Practice in a Full Scale HVAC Laboratory", *ASHRAE Journal* (November 1982), pp 36-41.

[11] Dale K. Dickson and Steven T. Tom, "Economizer Control Systems", *ASHRAE Journal* (September 1986), pp 32-36.

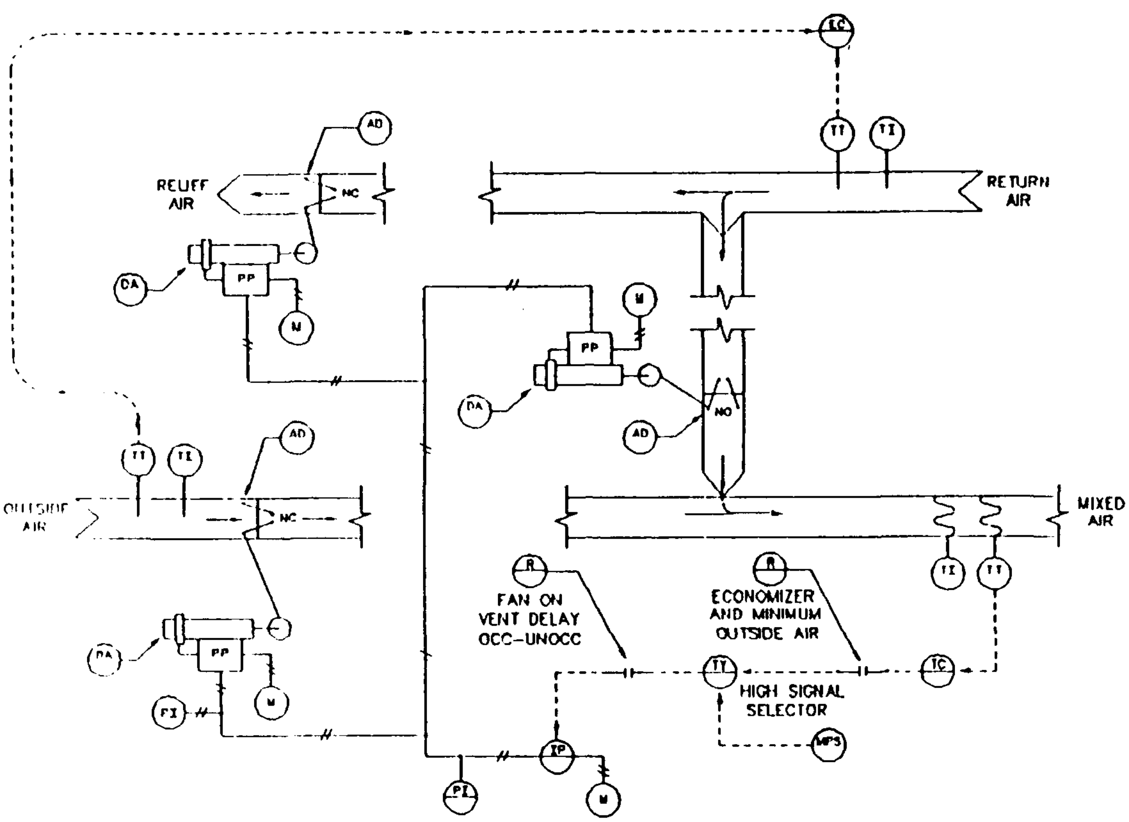

Figure 12. Mixed air and economizer control loop.

The economizer SLDC essentially operates as a switch to allow the mixed air temperature controller to modulate the system dampers when both of two conditions are satisfied.

Economizer Switching Condition 1

This switching condition is based on a measurement of the return air dry bulb temperature. The RA temperature is the PV input to the SLDC. Typically, the RA temperature will be nearly the same as the space temperature. Space temperature is usually controlled from a space thermostat that has a setpoint that is changed from season to season. The setpoint during the winter months might be 68 °F; during the summer months, it might be 78 °F. Select a temperature within this range, say 73 °F, above which there is a need for cooling. This is selected as the setpoint of the process variable (PV) contact output. When the RA is warmer, it exceeds this setpoint, the space has a cooling load and the economizer can operate if the second condition is satisfied. Below the selected RA temperature, the economizer cycle will not operate.

The design parameters that apply to the controller for switching condition 1 are the process variable (PV) contact setpoint and the deadband surrounding the setpoint. With a setpoint of 72 °F and a deadband of 2 degrees, the contact is closed when the return air temperature is 73 °F and open when the temperature is 71 °F. Switching condition 1 is based on the assumption that there is a significant difference between the thermostat setpoints during the heating and cooling seasons (68 °F to 78 °F). If the space thermostat setpoint is reset to a value not consistent with the assumed range, the economizer controller PV contact setpoint may also need to be changed. If the same or essentially the same thermostat setting is used for heating and cooling, the economizer cycle may not function as designed.

Economizer Switching Condition 2

The second condition that must be satisfied for economizer operation is based on a comparison between the return air and the outside air dry bulb temperatures. Local weather data can be used to determine the difference between these two temperatures that, on the average, results in the enthalpy of the outdoor air being less than that of the return air. This difference between the OA and RA temperatures is the DEV contact setpoint of the economizer controller. To calculate the DEV setpoint use a psychrometric chart and:

1. Determine the design return air temperature and relative humidity. For the example assume 78 °F and 50 percent relative humidity.

2. Draw a constant enthalpy line (A to B) through these conditions. Below this line, the total heat content of the outside air is less than the return air.

3. Draw a vertical line (C to D) through the return air condition.

4. Plot the average weather line. A line representative of the annual average outside conditions can be constructed from the data in *Engineering Weather Data.*[12] Each point on the line is the midpoint of the temperature bin and the corresponding mean coincident wet bulb temperature. The line E to F in Figure 13 is a plot of the average conditions for Greenville, South Carolina.

5. Draw a vertical line through the intersection of the constant enthalpy line (A to B) and the average weather line (E to F).

6. The optimum switchover temperature differential is based on the difference between points G and D or 7 degrees. This is the DEV contact setpoint.

The design parameters that apply to the controller for switching condition 2 are the DEV contact setpoint and the deadband surrounding the setpoint. With a setpoint of 7 degrees and a deadband of 2 degrees, the contact is open when the OA temperature is 6 degrees less than the RA temperature. The contact is closed when the OA temperature is 8 degrees less than the RA temperature.

Input/Output Signal Considerations

The process variable input to the standard controller is from a sensor/transmitter assembly. The transmitter is powered by the control panel 24 volts direct current (Vdc) power supply. In practice many controllers receive the 4- to 20-mA signal through a precision dropping resistor placed across the controller input terminals. The resistor converts the 4- to 20-mA signal to a voltage.

Figure 14 illustrates a circuit diagram for a temperature transmitter. In this example, the 4 to 20 mA signal from the temperature transmitter is needed by two different controllers. Ensuring that the temperature transmitter can supply a full 20 mA to its output loop load resistance of the two controllers requires considering electrical characteristics of the transmitter and the total resistance of the loop ($R_1 + R_2$).

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[12] Air Force Manual (AFM) 88-29, TM 5-785, Naval Facilities Engineering Command (NAVFAC) P-89, *Engineering Weather Data* (Departments of the Air Force, Army, and Navy, 1 July 1978).

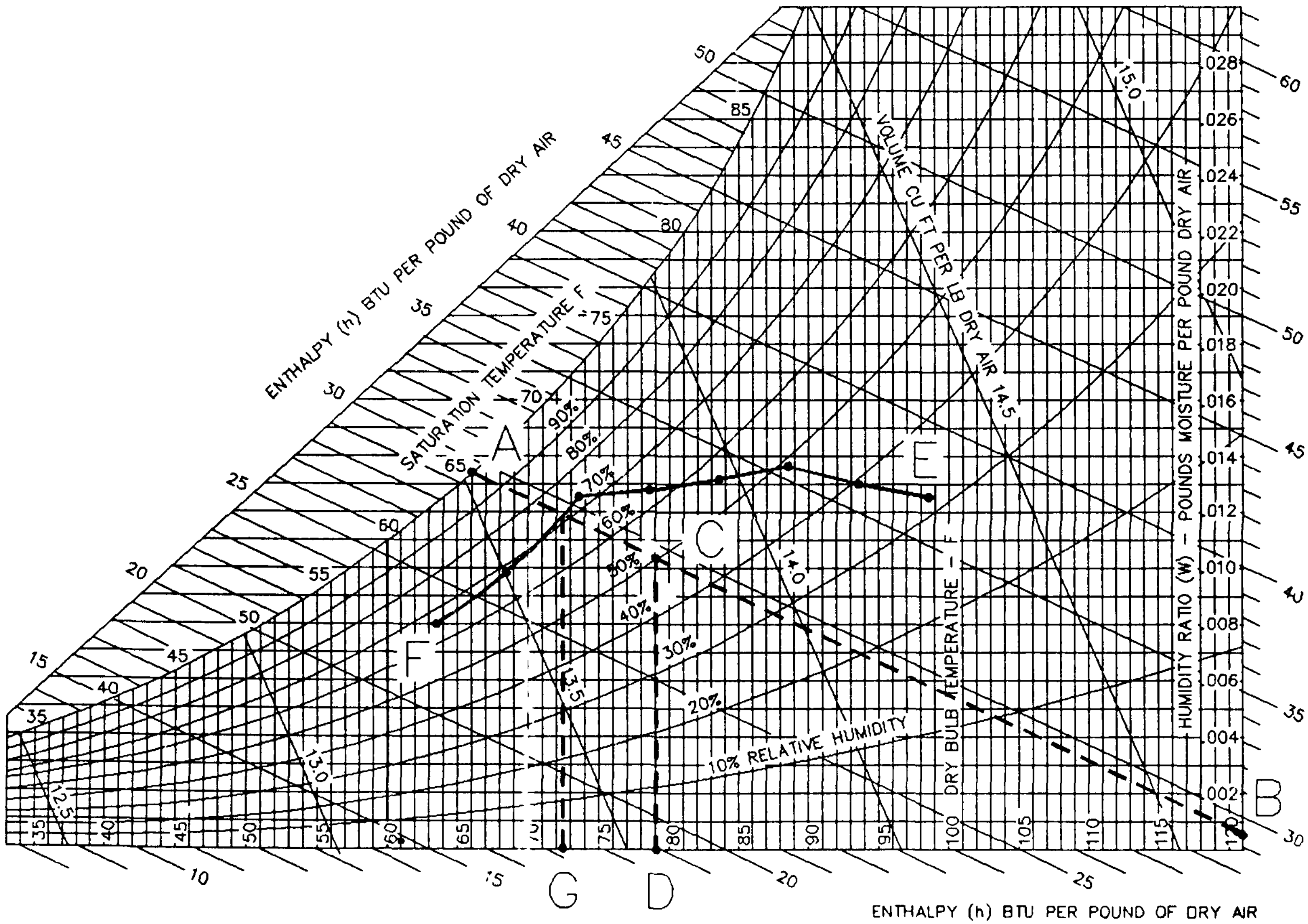

Figure 13. Use of psychrometric chart for determining the deviation (DEV) contact setpoint.

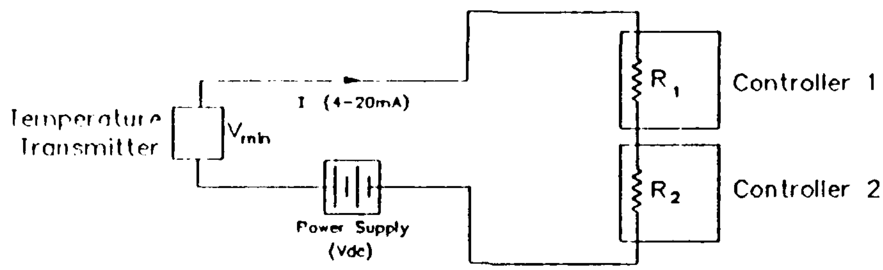

Figure 14. Transmitter loop output load resistance.

The temperature transmitter requires a minimum voltage to operate (V_{min}), referred to as the lift-off voltage, plus an additional voltage that generates the 4- to 20-mA signal. The power supply will provide 24 Vdc (per the guide specification). Assuming that, for a given transmitter, the minimum operating voltage is 12 Vdc, calculate the maximum loop resistance ($R_1 + R_2$) to which the transmitter can supply 20 mA:

$$\text{Power supply} = V_{min} + 0.020 \text{ Amp} \times (R_1 + R_2) \qquad \text{[Eq 7]}$$

Rearranging:

$$R_1 + R_2 = (\text{Power supply} - V_{min}) / .020 \text{ Amp}$$
$$R_1 + R_2 = (24 \text{ Vdc} - 12 \text{ Vdc}) / .020 \text{ Amp}$$
$$R_1 + R_2 = 600 \text{ ohms}$$

If $R_1 = R_2$, the input resistance of each controller cannot exceed 300 ohms.

Equation 7 is usually provided by the temperature transmitter manufacturer in graph form, similar to that shown in Figure 15. The graph illustrates how the maximum output resistance is constrained by the size of the external dc power supply used to power the transmitter. The larger the power supply, the greater the resistance through which the transmitter can provide a full 20 mA. Similar considerations apply to other transmitters including pressure, flow, and humidity transmitters.

The standard controller powers the output loop using an internal power supply to generate a 4- to 20-mA output signal. The controller is rated to be capable of pushing 20 mA through an output load of up to 600 ohms. This means that no more than two devices, at 300 ohms each, should be in the output loop.

Some standard applications may have three devices in the controller output loop. Only one of the devices and a loop isolator are connected directly to the output loop. The other two devices are connected to the loop isolator output. Loop isolators have characteristic input resistances less than 250 ohms and can drive up to 800 ohms.

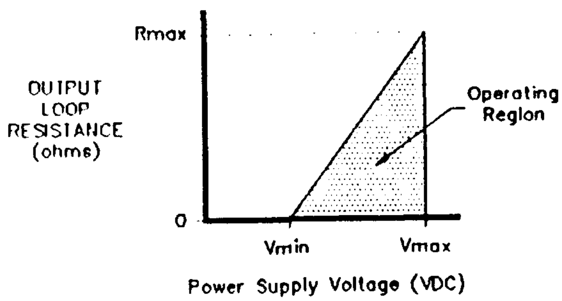

Figure 15. Transmitter range of operation.

Some situations require load resistance checks to be made in a controller output loop. In Figure 16, the controller is driving two current-to-pneumatic transducers (I/Ps). The controller must provide enough output power to produce a full 20-mA signal when the actuators, through the I/Ps, are driven full stroke. In the example, the controller output load resistance rating (R_L) must exceed the series combination of the I/P transducer resistances (R_1 and R_2). This method of computing output resistance differs from the preceding method because the power source used to drive the controller output is internal to the controller.

Potential drawbacks to using SLDCs in HVAC control applications include:

1. Installed first cost. SLDCs are becoming less expensive, but still are more expensive than other alternatives. This drawback is balanced by their simplicity, reliability, and maintainability.

2. Some useful features are not commonly available, thus require signal conditioning hardware in some applications.

3. Interfacing the controller with an energy management system. The interface is accomplished using a dc protocol to provide for monitoring of process variables. SLDCs have the capability to communicate via a digital protocol, but as with multiloop digital controllers, no standard communications protocol is available that will allow controllers of different manufacture to communicate directly with one another or with a common host computer.

4. Lack of familiarity by field personnel and designers.

As mentioned previously, SLDCs can be used in, but are not specifically designed, for HVAC control applications. Some features that the standard controller lacks include:

1. The ability to perform setpoint reset function using only one controller. A single controller could be used if it were capable of inverting the remote setpoint input to provide for a decreasing setpoint as the remote setpoint input increases. Additionally, the single controller would need to be capable of displaying the remote setpoint range in outdoor air temperature units and the corresponding hot water temperature setpoint. Also, a contact output activated by the remote setpoint input signal would be needed.

This contact would be similar, in function, to the process variable contact output (in a reset controller) that is used to turn the hot water circulating pumps on. These features would permit a single controller to perform the setpoint reset function.

2. Capability to span the remote setpoint independent of the process variable span. This feature is available with several controllers, but is not common enough to justify it as a standard controller feature.

3. Capability of the controller to revert to the local (internal) setpoint upon loss of the external remote setpoint input.

4. Square root extraction of both the remote setpoint and process variable inputs. This would be useful in return fan volume control applications.

5. Ramping up of the setpoint over time. This would be useful in the duct static pressure control application.

6. Low power consumption of the controller to minimize heat build-up in the control panel enclosure.

7. Improved self-tuning algorithms that are specifically designed for HVAC control processes.

8. Sufficient digits on the controller display. In a return fan volume control application the duct flow often exceeds 10,000 cfm. A number of controllers display only 4 digits plus polarity sign. One more digit is needed.

Most of these features are available in some combination from one or more manufacturers, but generally are not common features.

A general concern that designers and users should be aware of is that some manufacturers' documentation does not fully explain the capabilities of their controller. Other manufacturers provide a good, comprehensive explanation. Good documentation is a must if SLDCs are to prove functional in the field.

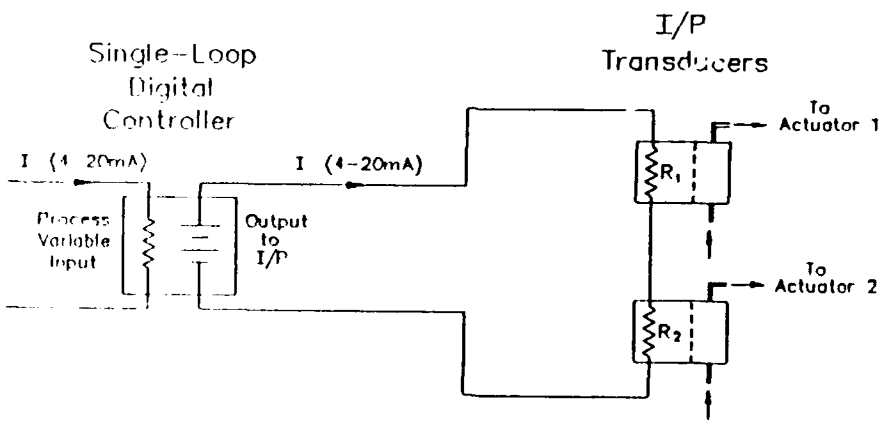

Figure 16. Controller output loop load resistance.

5 CONCLUSIONS AND RECOMMENDATIONS

An evaluation of current single-loop digital controller technology led to the following conclusions:

1. SLDCs, which have typically been only used by the process control industries, are suitable for use in HVAC control applications.

2. SLDCs are accurate and reliable. Although somewhat more expensive than other alternatives, SLDCs offer the user standardization features not available with conventional HVAC controls. They are simple, flexible, reliable, and maintainable, making them ideal for use in Army facilities.

3. The self-tuning feature, available only with SLDCs, should help to reduce maintenance requirements and improve HVAC system performance in typical Army applications.

Detailed product specifications were developed and submitted to Huntsville Division for inclusion in a guide specification and a technical manual on HVAC control systems.

The SLDC is ideal for PID, reset, and economizer applications.

SLDCs should be used as the standard controller for Army and Air Force standard control panels. No other single-loop controller offers the wide range of features and benefits available.

METRIC CONVERSION TABLE

1 cu ft	=	0.028 m^3
1 ft	=	0.305 m
1 in.	=	25.4 mm
1 sq ft	=	0.093 m^2
^0C	=	0.55 (^0F-32)

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APPENDIX:

SINGLE-LOOP CONTROLLERS

Controller Features

The controller shall be a microprocessor-based single-loop device that does not require Contractor-generated software. The controller shall comply with 15 Code of Federal Regulations (CFR) *Commerce and Foreign Trade*. The controller panel cutout shall be 3.62 in. by 3.62 in. The controller shall have field scalable process variable, a remote setpoint analog input and an analog output with adjustable high and low end limits and proportional control manual reset adjustment. The analog output shall result from proportional, integral, and derivative (PID) control. The analog output shall be configurable as direct acting and reverse acting. The controller shall have a keyboard, display, auto/manual selection for control of its analog output, remote setpoint adjustment/local setpoint adjustment selection with adjustable high-end and low-end limits, ratio and bias adjustments on remote setpoint input, operator-initiated self-tune/manual-tune selection, antireset windup feature, and 2 configurable independent single pole, double throw (SPDT) contact outputs with adjustable contact closure setpoints. The controller shall be configurable to power-up in manual with local setpoint control, in automatic with local setpoint control and in automatic with remote setpoint control. Contact closures shall be activated by a process variable and by a process variable deviation from setpoint as configured. The range of hysteresis adjustment shall be not smaller than from 1 to 5 percent of process variable input span. The controller shall power the analog output loop to 20 milliamperes when connected to a load of 600 ohms. The controller shall have a 5-year battery backup to store operating parameters or shall have nonvolatile memory.

Controller-Parameter Input and Display

All control parameters shall be entered and displayed directly, in the correct engineering units, through a series of keystrokes on a front-panel display with a 3-1/2 digit, 7-segment display, with decimal point and polarity indication. The use of this display shall allow manual interrogation of setpoint, mode constants, and values of the process variable and output.

Controller Electrical Requirements

Each controller shall be powered by 120 volts ac. Power consumption shall not be greater than 20 watts. Each controller shall provide electrical noise isolation between the ac power line and the process variable input, remote setpoint input, and output signals and of not less than 100 db at 60 Hz common-mode rejection ratio, and not less than 60 db at 60 Hz normal-mode rejection ratio.

Controller Accuracy

The controller shall have an accuracy of plus or minus 0.30 percent of input span, plus or minus 1 digit.

Controller Self-Tuning

The controller self-tuning operation shall apply proportional, integral, and derivative modes of control and shall modify the mode constants as required. Self-tuning shall only be in operation when selected from the front panel.

Controller Manual-Tuning

The controller manual-tuning operation shall provide proportional, integral, and derivative control modes, or any combination thereof, by means of individual mode constant adjustments. These adjustments shall be set for the appropriate value if a particular control mode action is desired, or to zero if that particular mode is not desired. The proportional-mode constant shall be adjustable from 0 to 200 percent of input signal range, the integral-mode constant shall be adjustable from 0 to 20 repeats per minute, and derivative-mode constant shall be adjustable from 0 to 5 minutes.

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