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A Survey of Electronic Environmental Controllers

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A SURVEY OF ELECTRONIC ENVIRONMENTAL CONTROLLERS

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ABSTRACT

Sixteen commercially available electronic environmental controllers were evaluated. The units were classified according to enclosure type, analog versus microprocessor based control, power supply, sensors, alarms, control relays and triac output, interval timers, outside temperature feedback, and retail price. An assessment of these controllers indicated several critical limitations in the application of this technology.

The use of integrated controllers for animal production has the potential for substantial improvements in production efficiencies. If the limitations observed in the present controller technology, as represented by this sample, are addressed, industry acceptance of the technology can be accelerated. A uniform standard to address this technology is recommended and specific suggestions are provided for what the standard should address. **KEYWORDS.** Environment, Control, Animal production, Electronics.

INTRODUCTION

Intensive animal production industries rely almost completely on multiple thermostats and timers to maintain interior environmental conditions. These systems are complex to manage and troubleshoot for several reasons, particularly as their size and the number of buildings per site increase. Users may not understand the complex interactions between different control components. The production environment can be deleterious to individual components, and components can fail without management's knowledge. The wide variety of mechanical control components often found in a facility after several years of use, make maintenance difficult.

Consequently, managers of intensive animal production systems are beginning to adopt more sophisticated electronic environmental controllers to manage the interior environment. The controller is placed in or near the facility or zone to be controlled, and it collects information and makes decisions regarding equipment actuation. Measurements made by the controller can include dry-bulb temperature, relative humidity (or wet-bulb temperature), ammonia concentration, water flow or pressure, and various other analog or digital sensors. Control connections can include analog or digital output to secondary control devices such as power relays or fan speed controllers, which operate the primary control devices (fans, heaters, etc.)

Widespread adoption of this technology has the potential for dramatic improvement in production efficiencies through lower management costs, energy savings and improved feed conversion efficiencies. A significant benefit from electronic environmental controllers is their superior control resolution compared with conventional multiple-thermostat mechanical systems. This superior performance is most noticeable in newer, larger-scale production facilities, where correct and timely adjustments of multiple thermostats can be tedious and confusing and is often ignored.

Electronic environmental controllers can be divided into analog and microprocessor based technologies. In many respects their basic environmental control functions are similar. However, microprocessor based systems have the potential for more sophisticated management interactions (such as data logging, or remote adjustments of set points). This added flexibility comes with additional risk, because microprocessors are susceptible to loss of memory from transient overvoltages. There is also risk inherent to the centralization of environment control into a single unit, whether it contains a microprocessor or not. Traditional systems utilizing multiple thermostats are in a sense distributed control systems; if one thermostat fails it is unlikely to create a life-threatening situation for the livestock. Despite these risks, the integration of many control functions into one device can substantially reduce errors due to improperly set thermostats and timers and simplify the task of making periodic adjustments to the interior environment. The inherent risks of these centralized controllers can be safely managed with appropriate mechanical backup systems and alarms (Gates et al., 1992a, 1991). However, there is no standard by ASAE or other societies to address items such as minimum functionality, failure conditions, or other issues useful to both designers and end-users.

This work was done in conjunction with a project to evaluate the transient overvoltage suppression capabilities of these same controllers (Gates et al., 1992b). In that study, these controllers were subjected to a standard transient overvoltage waveform (ANSI, 1980) at both their power supplies and at a temperature sensor circuit. It was determined that all units evaluated were capable of withstanding repeated transients of up to 770 V on the

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TABLE 1. Overview of controllers evaluated

		Controller Features						Control Features						Retail
		Analog (A) vs. Micro-processor	Power Supply			Sensor Features			Control		Variable	Interval	Outside	Price
			Input	Step Down	Loca-	Temperature		Alarm ‡	Relays	Stages§	Speed	Timers	Temperature	Approx.
ID #	Enclosure*	(M)	(VAC)	(VAC)	tion†	In	Out	Feature	(#)	(#)	Control	(#)	Feedback	($)
1	P Nema-4X	M	120	12	I	1	1	D	7	7	No	2	Yes	600
2	P Nema-4X	M	240	12	I	1-4	1	R,D	5	8	Yes	0	Yes	1800
3	P Nema-4X	M	240	12	I	1-2	1	R,D	4	3	No	0	Yes	1200
4	P Nema-4X	A	120	12	E	1	0	-	12	7	No	1	No	650
5	M N/A	A	120	12	I	1-2	0	-	2-7	2-7	No	0	No	<650
6	P Nema-4X	M	120	12	I	1	0	R,D	N/A	N/A	No	0	?	1200
7	P Nema-4X	A	120	24	E	1		R,D	12	11	No	1	Yes	700
8	P N/A	M	120	12	I	1	0	-	4	4	No	0	No	320
9	M N/A	M	120	12	I	1	0	-	4	4	No	0	No	360
10	P N/A	M	120	12	I	1	0	-	2	N/A	No	0	No	200
11	P Nema-4X	M	240	12	I	1	0	D	2	2	Yes	0	No	500
12	P Nema-4X	A	120	12	E	1	0	-	2	2	No	0	No	350
13	P Nema-4X	M	120	12	I	1	1	R,D	6	6	Yes	0	Yes	320
14	P Nema-4X	A	240	12	I	1	1	R,D	6	6	No	0	Yes	330
15	P Nema-4X	M	120	12	I	2	1	R,D	6	6	Yes	0	Yes	2200
16	P Nema-4X	A	120	12	I	1	0	D	6	6	No	0	No	800

*   Plastic (P) versus Metal (M).
†   Internal (I), External (E).
‡   Display (D), Relay enabled (R).
§   Number of stages may differ from number of relays output.

power supplies without failure; however, three units failed when smaller magnitude transients (100 V maximum) were supplied to their temperature sensors. Controller action on sensor failure varied — two units would have actuated all ventilation equipment, and the other unit would have actuated all heating equipment.

The objective of this project was to review a sample of sixteen currently available environmental controllers, and to suggest possible actions which could improve their design and utility. All controllers were available commercially. In the transient testing study the concern was adoption of a performance test standard for such controllers; in this article the focus is on other important design aspects, including enclosure types, control methodologies, sensors, calibration, failure modes, user interaction, documentation, and ease of interfacing to a building. After analyzing trends evident in these current designs, it is clear that a substantial range of problems exists. A uniform standard by ASAE that provides criteria for selection and use of this equipment is suggested. Such a standard could benefit both users and designers of these controllers.

DESCRIPTION OF CONTROLLERS

Sixteen different controllers, from fourteen different manufacturers, were evaluated. These models ranged from simple analog stage controllers to sophisticated units with the ability to control multiple modulating devices (such as air inlet vents, variable speed fans, motorized shutters, etc.) simultaneously. An overview of these units is presented in Table 1, and additional unique features of each controller are listed in Table 2. The controllers were categorized based on information from manufacturers, dealers, product literature and our analysis of each individual unit. Features listed in the main categories in Table 1 are described in the following sections.

ENCLOSURE TYPE

With the exception of units 9 and 10, all controllers were advertised to be able to withstand the harsh and corrosive environment of a livestock building. However, several units used mild steel enclosures that would corrode in most facilities. One unit had an aluminum enclosure, but the most prevalent enclosure was plastic of various types.

Concern by the manufacturers regarding sealing of the enclosure, and the use of watertight connectors for any

TABLE 2. Unique feature of controllers evaluated

ID #	Other Factors
1	Two modulating interval timers, multiple relay control programs.
2	Extensive accessories for dampers, modulating control, pulse counters, PC communication.
3	One unit for two zones, PC communications.
4	Switch-selectable relay assignments, use 24 VAC "wet controls". Twelve assignable outputs.
5	Buyer specifies number of stages. Fragile temperature sensor.
6	Relative humidity control, PC communications.
7	Targeted at broiler house.
8	Poor user interface, different models include modulation, requires additional parts to make watertight. No means of calibration.
9	Not designed for harsh environments, different models include modulation. No means of calibration.
10	Additional relays can be plugged in. Not designed for harsh environments.
11	Trigger output to staging device available.
12	Added stages can be connected. External wall pack power supply. Fragile temperature sensor.
13	Adjustable differential between stages.
14	Adjustable differential between stages. Accepts 1, 4, or 9 sensor inputs.
15	Extensive accessories available, PC communications. Fragile temperature sensor.
16	Adjustable differential between stages.

wiring through the enclosure walls, varied considerably. Only one manufacturer clearly labeled the enclosure stipulating that a watertight seal was essential to maintain product warranty; some units came with pre-drilled holes for wiring, but without any connectors. Most, however, came without holes and without connectors. Given the likelihood that a field installation would be provided with similar merchandise when ordered, it is apparent that manufacturers' concerns over maintaining the units' integrity in the field are not strong enough to promote the use of warning labels or the inclusion of watertight connectors, in the majority of units evaluated. One obvious factor involved is that of product liability; yet some warning would be very helpful. This problem could perhaps be blamed on field installation personnel, but directives from the manufacturer clearly stating this concern in the form of labels would be beneficial.

PROCESSORS, POWER SUPPLIES AND TRANSIENT PROTECTION

Twelve of the units utilized 120 VAC power supplies, though most of these were ordered that way for convenience of testing purposes. In general, a 240 VAC power supply will reduce the magnitude of incoming transients compared with a 120 VAC power supply, assuming an identical secondary voltage (typically 12 V) in either case.

Ten controllers utilized some type of microprocessor. For all of these units, the primary/secondary power supply was housed within the unit's enclosure with varying levels of shielding between the transformer and the processor board. Only three of the analog controllers (units 4, 7, and 12) were designed to utilize an externally mounted power supply. The location of the power supply is an important consideration in the design. Externally mounted supplies may have fewer problems with "flashover" from large transients on the power supply, although a well-designed internal power supply with a high quality transformer can readily accomplish the same task (Standler, 1989).

Visual inspection of the circuit boards of each controller provided insight into the types of transient overvoltage suppression designed into the boards. The most prevalent components were the metal oxide varistor (MOV) and Zener diodes. For most of the microprocessor controllers, these two components were found in several different parts of the board(s), including the power supply, sensor circuits, and output circuits. Other suppression components were claimed to be used by the manufacturers during conversations, but not verified. These included "ferrite beads", "spark gaps", and "transorbs". Surprisingly, not all units had a fused primary supply; most did not have a resident means of disconnecting power to the unit, nor did they have a pre-wired power supply cord.

SENSORS

Temperature sensors utilized for these controllers were typically thermistors, platinum resistive thermal devices (RTD), or solid state linear devices. Transient protection of sensor circuits for the majority of units appeared on the board. One unit with a solid state sensor also had transient protection for the sensor itself. This has clear implications for reliability; the controller circuitry might readily survive a transient overvoltage that destroys the sensor. Yet without a temperature sensor, the controller will not be functional. Several units would actuate and/or display an alarm if the measured temperature was out of some range, and this range could be configured on the more sophisticated units.

The majority of units (eleven of the sixteen) had only one inside temperature sensor. Of the other five, unit 14 had the capacity (as an option) of either four or nine sensors, unit 4 had the capacity for four inside sensors, unit 17 had two inside sensors as standard equipment, and units 3 and 5 could utilize either one or two inside sensors. However, unit 5 was designed to control two different rooms or zones so that effectively it had one sensor per zone.

Seven of the units utilized outside temperature in some fashion. The primary reason given by manufacturers for outside temperature sensors was to accommodate fairly severe and/or rapid changes in outside temperature. This was done by either scaling back or modifying the minimum ventilation setting (both variable speed and interval timer actuated systems used outside sensors), or by changing the hysteresis of certain control functions as outside temperature changes.

Several units had no means for calibrating the temperature sensors. The controllers with microprocessors utilized one of two methods for calibrating the sensors. The simplest method was to adjust one or two potentiometer until the measured temperature matched a reference temperature. The more sophisticated units ran a software calibration which apparently accounted for effects of sensor line resistance; however, these units had no direct means of calibration. Two units in particular (8 and 9) had no means of calibration and were shipped with sensors approximately 8° F high at about 75° F. With the exception of these two units, all other sensors maintained indicated settings of within approximately 5° F of one another over a period of several months of intermittent operation (in still air).

Temperature sensor dynamic response varied tremendously. Several sensors were constructed to have a high thermal mass, and thus dampened response to drafts. Other sensors were housed in a piece of heat-shrink tubing, with very fast response. Some of the microprocessor units apparently utilized some means of digital filtering of the inside sensor measurements for damping.

Only one controller as tested (number 6) came configured with a relative humidity sensor and the ability to simultaneously "control" temperature and humidity. Two other units (2 and 15) had options for wet-bulb sensors and built-in psychrometric routines. The addition of relative humidity "control" is clearly not very prevalent, nor is it clear from these units precisely what is controlled, although they appear to actuate heaters or fans if the relative humidity exceeds specified limits. It is noteworthy that each unit that could in some fashion "control" relative humidity was priced at $1,200 or more.

Failure of the inside temperature sensor resulted in differing responses with the controllers. Unit 1 displayed a message when an error was detected on a temperature sensor; other units activated an alarm condition; most made no special note of a failed sensor. Open circuit sensor conditions represented a "cold" reading in some controllers and a "hot" reading in the rest. This information would be

very beneficial for anyone designing safety backup systems.

ALARM FEATURES

Alarm functions for this sample of controllers ranged from nonexistent (units 4, 5, 8-10 and 12), a simple display feature (units 1, 11, and 16) to some type of alarm relay circuit. Presumably, ASAE Standard S417.1 (1989) applies to all units which utilize an alarm feature. This implies that the units without NEMA-4x enclosures, but with alarm features, are in violation of that standard.

The more elaborate microprocessor controllers were capable of providing information to the user regarding the nature of the alarm condition, and the ability to program thresholds for measured conditions (e.g., temperature) which would trigger the alarm. While such functionality is very convenient, it is unclear whether a completely independent alarm system should be utilized. Clearly, any condition that upsets a microprocessor program can potentially corrupt a portion of the program containing the alarm functions; consequently, it seems likely that an independent alarm system should still be recommended, along with appropriate mechanical backup systems (Gates et al., 1991, 1992a).

CONTROL MODULATION AND STAGING

The majority of these controllers had no capacity for modulating control, such as a triac output to power a variable speed fan. Of the four units with this feature, one or two triac outputs rated at 5 A or 10 A (120 VAC) were provided along with one or more additional low level outputs that could be connected to additional equipment that translated the low level signal to another triac. Output signals for these controllers were analog for units 2 and 15, and a variable frequency "trigger" for units 11 and 15.

All other controllers were configured strictly as stage controllers. These controllers are specialized multistage thermostats, with the ability to control one or more stages of heat, and several stages of cooling. All units, including the modulating control units discussed above had at least two control relays. Six to eight relays were typical for the units evaluated. In all cases but one (unit 5), these multiple stage controllers used small control relays (0.5 to 2 A at 240 VAC) that were supposed to switch current to the coils of larger amperage load relays (not part of the controller). The most prevalent approach was to use "dry contact" control relays so that the installer could utilize whatever voltage the power relay coils required. Unit 4 utilized a 24 VAC system, and two others (5 and 10) used power relays directly which had to be specified when ordering the unit.

Two of the stage controllers had a feature to assign relay functions to various stages. This provides substantial flexibility when determining a building ventilation staging scheme. All other stage controllers could be classified as "sequential", because activating each new stage activates another relay. Adjustments for control of individual stage functions varied from the option to completely specify stage differential and hysteresis, to no adjustment possible.

Three of the units tested (1, 4, and 7) had built-in interval timers for use as a means of minimum ventilation. Two of these units (1 and 7) were specifically targeted at broiler chicken growout facilities. Unit 1 modulated the "on-time", and hence the minimum ventilation, as the inside temperature deviated about the setpoint. In addition, two independent, 10-minute interval timers, configured 5 minutes out of phase, were available with this unit.

DOCUMENTATION

Instructions and manuals for installation varied widely. Both of the most expensive units had very poor documentation and used unconventional wiring schematics. Several units had no instructions except for minimal labelling within the enclosure. While this initially appeared very odd, it was pointed out by several manufacturers that the controllers were typically sold through regional dealers who provide sales, installation, service and technical assistance. Installation is viewed as the distributors' responsibility by these manufacturers.

Generally, this sample of products exhibited poor documentation for installation, interfacing to the building equipment, and operation. Many controllers came with one or two of the above subjects covered; several attempted to cover all three subjects; the majority provided very limited documentation. This points out a clear need for appropriate personnel (such as Cooperative Extensions specialists) to become involved with manufacturers and regional distributors to help provide practical information on the design of environmental control systems, selection of controllers, their use, and related issues including mechanical backup. This information is currently derived by field sales personnel with extremely varied design experience.

PERFORMANCE SPECIFICATIONS

Most of the units lacked complete performance specifications. Units 1, 2, 8, 9, 10, and 14 had reasonably complete specifications; however, no information was available for the capacity of the power supply to "ride through" short term outages, nor was there information on minimum and maximum allowable voltages at which the unit would still operate. These data are crucial and should be supplied, because brief power interruptions and sags are quite common in many rural areas.

While several units came with UL and/or CSA approval, there is no consistent standard to address these controllers. Many manufacturers expressed concern over this issue, especially regarding reasonable tests for transient overvoltage protection. Organizations such as the ASAE could assume a leadership role in addressing this issue.

BATTERY BACKUP

It is disturbing to note that none of the controllers tested had any capacity for long term operation without power. Many of the microprocessor units did have battery backup for the RAM, so that settings were not lost when power was removed. However, battery backup of the entire controller, not just RAM, was not provided.

Battery backup was suggested as a helpful accessory by some dealers and manufacturers, but no mention was made in any accompanying literature. For microprocessor based controllers, battery backup is primarily useful to allow the controller to retain settings after brief power interruption of only a few cycles. While battery backup is one method, design and/or selection of a power supply that can

withstand several slipped power cycles may be a viable alternative. For longer term power outages, the consequences of disruptions to the controller is largely a moot point, since the controlled equipment is also inoperable. Stipulation of reset and startup methods, however, should be considered in any proposed standard. For example, power failure during a high ventilation period could be very harmful if, upon power resumption, the controller simultaneously re-actuates all previously running ventilation equipment and subsequently trips the circuit breakers.

DISCUSSION

The need for minimum design specifications and performance standards was stressed by manufacturing representatives and design engineers during our discussions. Features such as alarms, mechanical backup systems, transient protection and battery backup were widely proclaimed to be necessarily optional, rather than required. The major reason given for these features to be options was cost. They view the market to be strongly influenced by the cost of the basic controller, and less sensitive to secondary, but usually essential equipment such as speed controllers, power relays, and transient protection on both the controller and auxiliary to the controller. This attitude appears to have resulted in an industry focus on supplying elements of a basic controller, and leaving the very important details of complete control system specification and design to the agricultural equipment dealers and individual customers. For this reason, important issues such as system integration and mechanical backup systems are often ignored when the controllers are sold and installed.

A standard for these controllers should address critical items that are not consistently followed in controller manufacture, installation, and operation. The following items are suggested as essential elements of such a standard.

- Controller response to transient input applied to both the power and sensor circuits. Both impulsive and oscillatory transients of recommended magnitude and frequency should be used and stated.
- Controller response to short duration power interruptions including the number of ac power cycles that can be slipped without upset, or alternatively, battery backup specifications to allow continued operation.
- Controller response to temporary (2 s to 2 min) and complete power outages, including recovery sequence once power is restored.
- Controller response to power voltage variations, including sags and undervoltage, and swells and overvoltage. These categories refer primarily to duration of the event (0.5 to 30 cycles, and greater than 30 cycles, respectively.)
- Functions to be performed by backup systems in the event of controller failure, and whether an independent alarm system is necessary.
- Precision, accuracy, dynamic response and method of calibration of sensors.

- Specific action (if any) taken by a controller in the event of a sensor failure.
- Adequate documentation to provide sufficient information for routine field installation, maintenance and repair. Topics should include initial configuration of the controller settings, standard operation, implementation with mechanical backup systems and alarm systems, interfacing to typical environment control equipment, sensor calibration and other performance specifications.
- Appropriate methods to disconnect power from the controller and auxiliary equipment.

In addition, the more sophisticated controllers in this study incorporated some type of communications protocol for remote connection to a central computer. ASAE is currently developing a standard for controller communications, and this should also address the needs of this particular industry (Fehr and Gates, 1991).

While not selected for greenhouse environment control consideration, many of the more sophisticated controllers in this study are used in greenhouses. Consequently, recommendations from this study are applicable to this industry as well.

SUMMARY

Several limitations in the sixteen controllers evaluated were noted and are believed to represent the state of technology in electronic environmental controllers. These limitations should be addressed by developing an appropriate standard that provides guidelines for the performance and installation of these controllers. Appropriate organizations such as the ASAE could provide a leadership role in developing such a standard. As the technology evolves, these control systems are becoming more affordable and likely to be used. By addressing the limitations encountered in this study, manufacturers and research and extension specialists have the opportunity to improve this important aspect of animal production.

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