Compensation Reset

Sometimes it is desirable to change the set point of the process variable based on the value of a second variable. In other words, we use two seemingly unrelated variables to determine final controller output. This concept is known as compensation reset. This strategy is used in such cases as:

1) Hot water reset based on outdoor air temperature
2) Hot deck reset based on outdoor air temperature
3) Discharge air reset based on space air temperature

As with control action, reset action may be either direct or reverse. Reset action is direct acting when a rise in reset signal received by the controller causes a rise in the controller **output signal**. Reset action is reverse acting when a rise in the controller received reset signal causes a fall in the controller's output signal.

Reset Performance is defined as the change in the controlled variable's controller set point occurring from a change in the reset signal. If the controller's **set point** increases with an increase in the received reset signal, the reset performance is "direct". If the controller set point increases upon receiving a decrease in reset signal, the reset performance is "reverse".

The four combinations of control action, reset action and reset performance are shown in Table 1.

CONTROL ACTION	RESET ACTION	RESET PERFORMANCE
Direct	Direct	Reverse
Reverse	Reverse	Reverse
Direct	Reverse	Direct
Reverse	Direct	Direct

Table 1 Determining reset performance

Notice when control action and reset action are the same, the result is reverse reset performance. When control and reset action differ, the result is direct reset performance. Do not confuse reset performance with reset action. They are two different concepts. Some examples are:

1) Direct acting controller with direct acting reset (Reverse Reset Performance):

Control of discharge air temperature via a N.O. heating valve with discharge air reset based on outdoor air. Assume a dual-input controller operates at bias condition. The controller must close the valve (increase control signal) with an increase in discharge air temperature (direct action). We also want a *decrease* in discharge air set point with an *increase* in outdoor air temperature (reverse reset performance). When outdoor air temperature does increase, the outdoor air sensor increases its signal to the controller's reset port. This has a *tendency* to increase controller output (direct acting reset). This increase in controller output causes the valve to close decreasing the value of the controlled variable. The primary sensor senses this and signals the controller to compensate by reducing its output. This effectively shifts bias signal to a point lower than it was. In other words, set point is effectively decreased with an increase in reset signal (reverse reset performance).

2) Reverse acting controller with reverse acting reset (Reverse Reset Performance):

Control of discharge air temperature via a NC heating valve with discharge air reset based on outdoor air. Assume a dual-input controller operates at bias condition. The controller must close the valve (decrease control signal) with an increase in discharge air temperature (reverse action). We also want a decrease in discharge air set point with an increase in outdoor air temperature (reverse reset performance). When outdoor air temperature does increase, the outdoor air sensor increases its signal to the controller's reset port. This has a tendency to decrease controller output (reverse acting reset). This decrease in controller output causes the valve to close decreasing the value of the controlled variable. The primary sensor senses this and signals the controller to compensate by increasing output. This effectively shifts the bias signal to a point lower than it was. In other words, set point is effectively decreased with an increase in reset signal (reverse reset performance).

3) Direct acting controller with reverse acting reset (Direct Reset Performance):

Control of space humidification via a N.O. water valve with humidity reset based on outdoor air. Assume a dual-input controller operates at bias condition. The controller must close the valve (increase control signal) with an increase in space humidity conditions (direct action). We also want a decrease in space humidity set point with a decrease in outdoor air temperature (direct reset performance). When outdoor air temperature does decrease, the outdoor air sensor decreases its signal to the controller's reset port. This has a tendency to increase controller output (reverse acting reset). This increase in controller output causes the valve to close decreasing the value of the controlled variable. The primary sensor senses this and signals the controller to compensate by decreasing output. This effectively shifts bias signal to a point lower than it was. In other words, set point is effectively decreased with a decrease in reset pressure (direct reset performance).

4) Reverse acting controller with direct acting reset (Direct Reset Performance)

Control of space humidification via a N.C. water valve with humidity reset based on outdoor air. Assume a dual-input controller operates at bias condition. The controller must close the valve (decrease control signal) with an increase in space humidity condition (reverse action). We also want a decrease in space humidity set point with a decrease in outdoor air temperature (direct reset performance). When outdoor air temperature does decrease, the outdoor air sensor decreases its signal to the controller's reset port. This has a tendency to decrease controller output (direct acting reset). This decrease in controller output causes the valve to close decreasing the value of the controlled variable. The primary sensor senses this and signals the controller to compensate by increasing output. This effectively shifts bias signal to a point lower than it was. In other words, set point is effectively decreased with a decrease in reset pressure (direct reset performance).

Although a situation may occur requiring a fail-safe condition as described in examples two and three, these examples are generally an improper application of N.C. and N.O. water valves. As such, the examples are illustrative only.

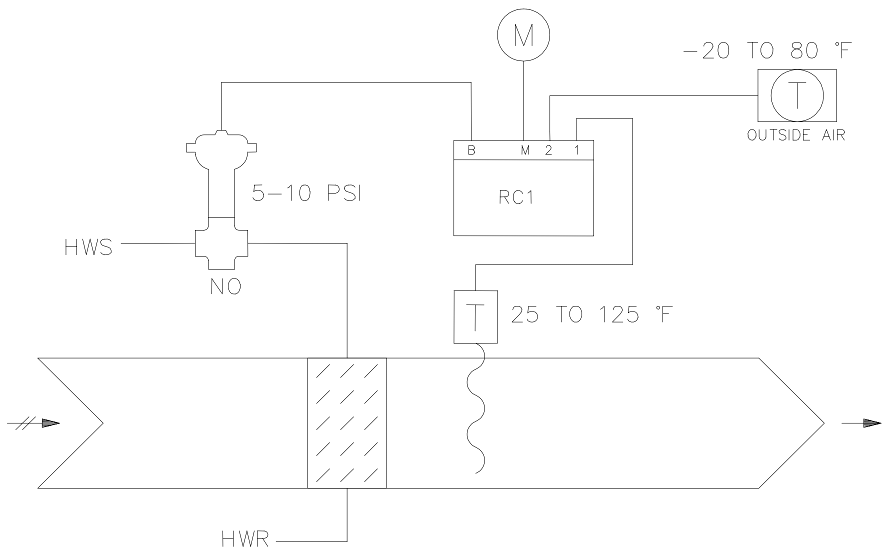
Reset may be accomplished two ways. These are:

- Reset using dual sensor input
- Reset using Master/Submaster systems

Reset with dual sensor input

Reset using dual sensor input is perhaps the most common reset strategy. Figure 1 shows a typical reset system. In this case, the reset of discharge air temperature based on outside air temperature via a hot water control valve feeding a hot water coil. The system is under pneumatic control. To properly setup a controller for reset action, one must set the controller percent proportional band or gain, and the controller percent authority.

Using the schematic in Figure 1, note the primary sensor has a range of 25 ^{o}F-125 ^{o}F, the outdoor sensor has a range of -20 ^{o}F-80 ^{o}F. In each case, the sensor outputs a 3-15 psi signal to the controller over its sensing range. The control valve is normally open with a spring range of 5-10 psi. The first step is to establish the reset schedule also shown in Figure 1.



CONDITION	DISCHARGE AIR SETPOINT	O.A. TEMP (RESET)
1	100 °F	0 °F
2	70 °F	60 °F

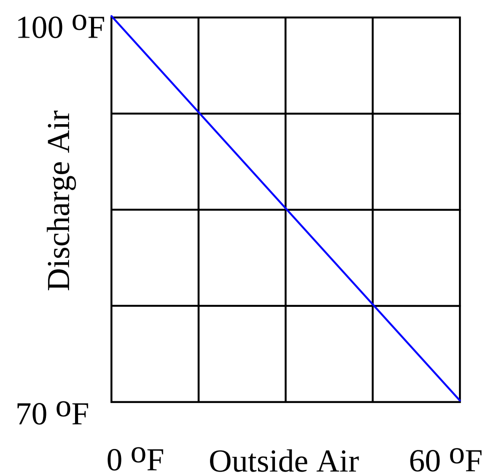


Figure 1 A pneumatically controlled discharge air system with reset

The reset schedule can be developed as either a table or as a graph. The reset table is set up to provide the endpoint conditions of the reset schedule. Namely, when the outdoor air temperature drops to 0 °F, we wish the discharge temperature to be 100 °F. Also, when the outdoor temperature rises to 60 °F, we wish discharge temperature to be 70 °F. This can also be plotted as a graph as shown. The graph is a convenient way to show a reset schedule since it allows one to determine the desired set point given any outdoor temperature.

Once the reset schedule is established, we need to calculate the percent authority for the controller. Percent authority is defined as the ratio of the effect of the reset sensor relative to the effect of the primary sensor. To calculate:

$$\%Authority = \frac{Change\,in\,setpoint\,signal}{Change\,in\,reset\,signal}$$

The change in set point signal is the difference in the primary sensor signal at the extremes of the reset set point. The following calculations determine this signal differential.

Sensor sensitivity

$$\frac{(15-3)\,psi}{(125-25)\,^{o}F} = 0.12\frac{psi}{^{o}F}$$

Transmitter output at 100 °F

$$0.12\frac{psi}{^{o}F}\times(100-25)^{o}F + 3\,psi = 12\,psi$$

Transmitter output at 70 °F

$$0.12\frac{psi}{^{o}F}\times(70-25)^{o}F + 3\,psi = 8.4\,psi$$

Change in set point signal

$$12.0 - 8.4 = 3.6\,psi$$

Similarly, we can determine the change in the outdoor air sensor signal over the reset range as follows:

Sensor sensitivity

$$\frac{(15-3)\,psi}{\left[80-(-20)\right]\,^{o}F} = 0.12\frac{psi}{^{o}F}$$

Transmitter output at 0 °F

$$0.12\frac{psi}{^{o}F}\times\left[0-(-20)\right]\,^{o}F + 3\,psi = 5.4\,psi$$

Transmitter output at 60 °F

$$0.12\frac{psi}{^oF}\times\left[60-\left(-20\right)\right]{}^oF+3psi=12.6\,psi$$

Change in reset signal

$$12.6-5.4=7.2\,psi$$

Calculate percent authority as:

$$\%Authority=\frac{3.6\,psi}{7.2\,psi}=50\%$$

Let’s assume the controller in Figure 1 has a throttling range of 8 °F. Since this is a pneumatic controller, let’s also assume it has a standard output of 5 psi. Then:

$$\%PB=\frac{8^oF}{100^oF}\times\frac{5\,psi}{5\,psi}=0.08=8\%$$

-or-

$$Gain=\frac{\left(10-5\right)psi}{8^oF\times 0.12\,{}^{psi}\!/_{^oF}}=5.2$$

We can now enter these values into our controller per manufacturer’s instructions. A reset controller can have any set point between the limits established in the reset

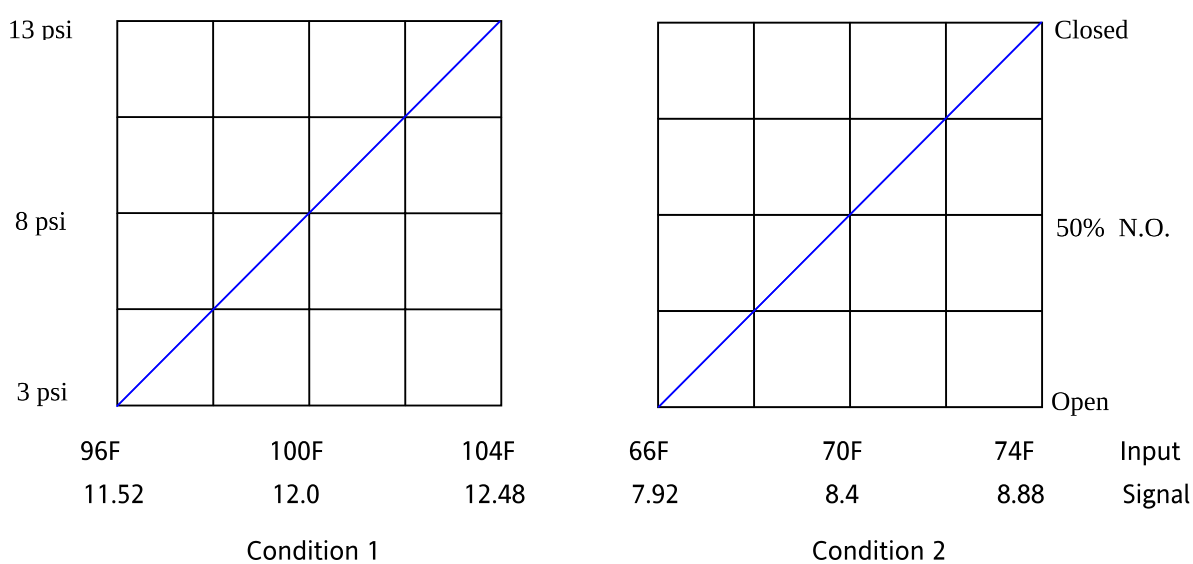


Figure 2 Controller action diagrams for reset example

schedule. This means that the control action diagram will also vary between these limits. It is of interest to study these diagrams at the two end conditions of the reset schedule as shown in Figure 2. Notice that as the set point is varied due to a change in the outdoor air temperature, the controller throttling range remains constant, controller bias remains constant, and the effective output range of the controller remains constant. The only property that varies is the set point.

Reset using Master/Submaster systems

Reset may also be accomplished using the master/submaster strategy, also referred to as master/slave. The difference between dual sensor strategy and master/submaster strategy is the source of the reset signal. In dual sensor strategy, the reset signal is from a second sensor as indicated above. In the master/submaster strategy, the reset signal is from another source. This source may be an energy management and control system (EMCS), another controller, or perhaps a high/low selector or other adaptor. An example of this is shown in Figure 3. This example is similar to the example used above, except the outdoor air sensor sends its signal to a master controller. The master controller must be setup with a set point and a controller gain. The resulting output signal is sent to the slave controller and effectively changes the set point of the slave. The slave controller must also be configured with a set point, a value of gain, and a value of controller authority.

Much like a single input controller, we can predict the output of a reset controller by using the following controller equation.

$$output=bias\pm\left[\left(\frac{pv\text{-}sp1}{TR1}\right)\pm\left(\frac{rv\text{-}sp2}{TR2}\right)\right]\times SR$$

where:

$bias=\text{controller output at calibration point}$

$pv=\text{engineering value of controlled variable}$

$rv=\text{engineering value of reset variable}$

$sp1=\text{set point of primary (slave) controller}$

$sp2=\text{set point of reset (master) controller}$

$SR1=\text{actuator range in units of controller output}$

$SR2=\text{Change in setpoint pressure}$

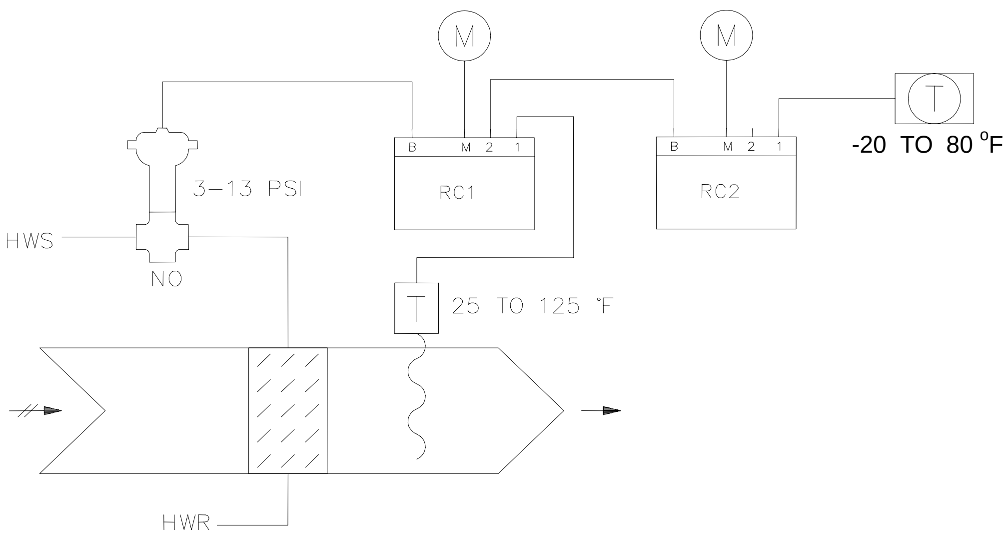
$TR1=\text{throttling range of primary (slave) controller}$

$TR2=\text{throttling range of reset (master) controller}$

$+=\text{add for direct action}$

$-=\text{subtract for reverse action}$

The set point of the master controller is that value of the reset variable that corresponds to the set point of the slave controller. The throttling range of the master controller is calculated as the specified throttling range of the slave controller multiplied by the ratio of the reset variable range to the set point range. Consider the example shown in



CONDITION	DISCHARGE AIR SETPOINT	O.A. TEMP (RESET)
1	100 °F	0 °F
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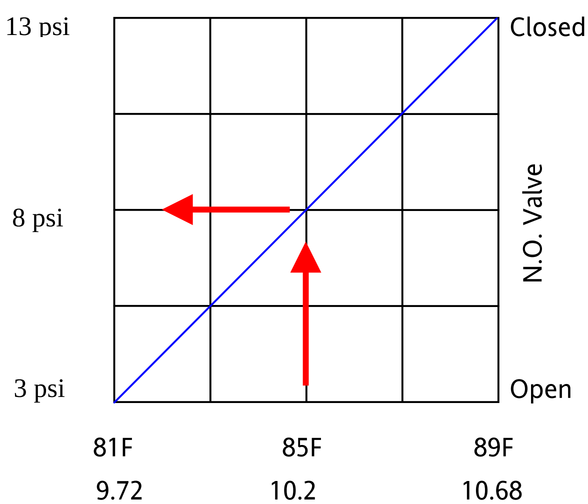
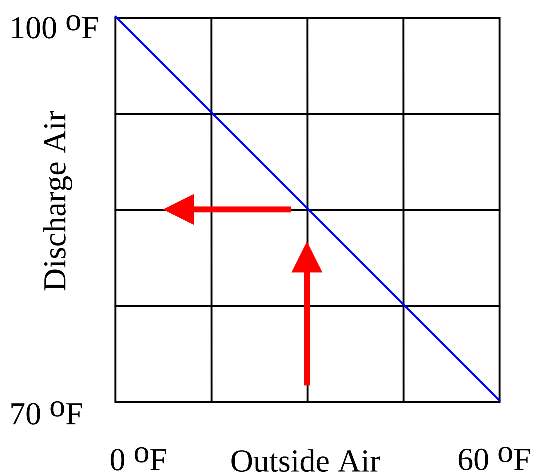


Calibration Condition



Reset Schedule

Figure 3 Reset example using a master/submaster system. This system is calibrated using simulated conditions of 30 °F outside air and an 85 °F set point.

Figure 3. This is a pneumatically controlled discharge air system with a reset schedule and control action diagram as illustrated. In this example we will select a calibration condition of 30 °F O.A.T. and a 50% bias. From the graphs, this results in the following characteristics for each of the two controllers.

$$
\begin{aligned}
&bias\ output=8\ \ psi\\
&sp1=85\ ^{o}F\\
&sp2=30\ ^{o}F\\
&SR1=10\ psi\\
&SR2=3.6\ psi\\
&TR1=8\ ^{o}F\\
&TR2=8\ ^{o}F\times\frac{(60\text{-}0)\ ^{o}F}{(100\text{-}30)\ ^{o}F}=16\,^{o}F\\
&Controller\ \ Action:\ \ Direct\ \ (+)\\
&Reset\ \ \ Action:\ \ Direct\,(+)\\
&Reset\ \ Performance:\ \ Reverse
\end{aligned}
$$

At calibration condition, the resulting controller equation for the slave controller is

$$output(psi)=8\,psi+\left[\frac{(pv-85)\ ^{o}F}{8^{o}F}+\frac{(rv-30)\ ^{o}F}{16^{o}F}\right]\times 10\,psi$$

Let's try to get a better feel for how this may work. Assume a step change in outdoor air temperature to 10 °F. Using the controller equation above, this results in a slave output of:

$$output=8\,psi+\left[\frac{(85-85)\ ^{o}F}{8^{o}F}+\frac{(25-30)\ ^{o}F}{16^{o}F}\right]\times 10\,psi=4.875\,psi$$

According to the reset schedule above, a 25 °F outdoor air temperature results in a set point of 87.5 °F. Since the valve is normally open, this reduction in output opens the control valve thus heating the air. When the air stream reaches 87.5 °F, slave controller output should equal:

$$output=8\,psi+\left[\frac{(87.5-85)\ ^{o}F}{8^{o}F}+\frac{(25-30)\ ^{o}F}{16^{o}F}\right]\times 10\,psi=8\,psi$$

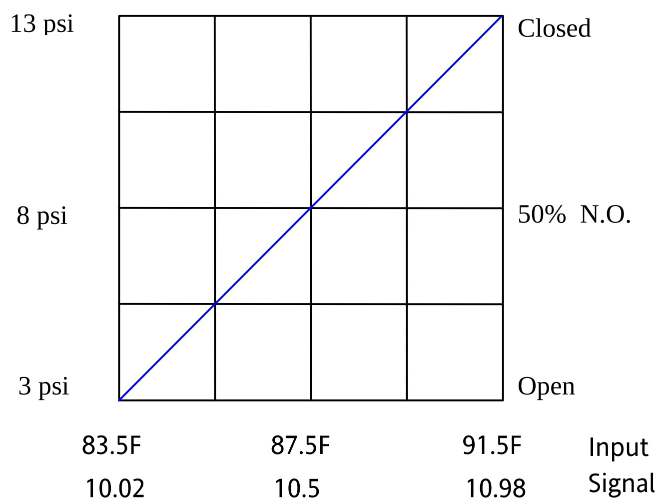


Figure 4 The effective control action diagram corresponding to the reset condition of 25 °F. Note the throttling range or controller output range does not change. There is only a shift in the controller set point.

In other words, the controller will attain a bias condition, but at a different point on the reset schedule. Figure 4 illustrates the new control action diagram for this system under the current conditions of reset.

Figure 5 shows another arrangement of the master/submaster strategy. This system is designed to reset discharge air temperature based upon room temperature. However, instead of using a master controller, the reset signal is derived from a low-select adaptor. This adaptor is designed to accept several control signals as input and pass the lowest signal to the next control loop component. Since discharge air temperature is reset based on room temperature, the space with the lowest temperature will govern.

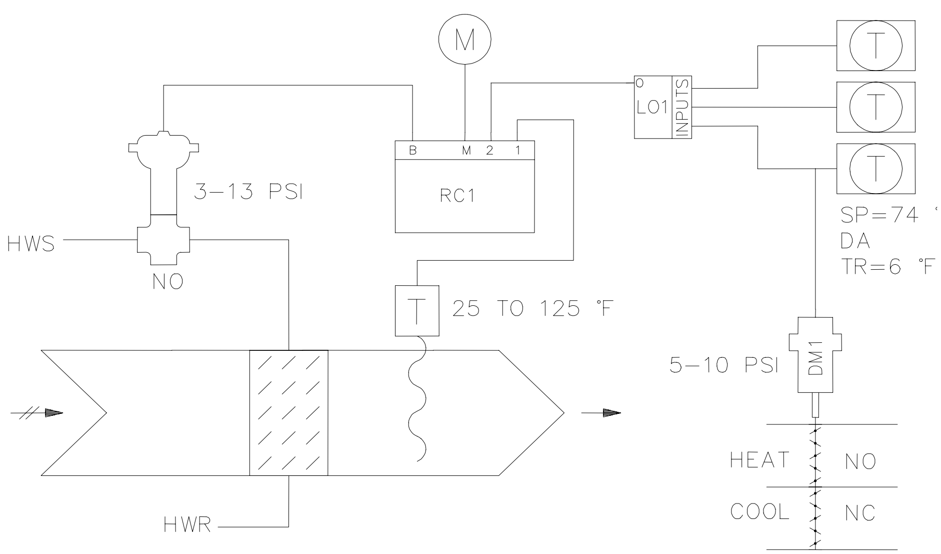


Figure 5 Discharge air reset based upon room temperature. Note that the low select adaptor acts as the master controller. It passes the lowest control signal to

Establishing reset on a programmable controller

The above discussion assumes a single-loop controller with dual inputs and a single output. Although the examples were based upon the use of a pneumatic controller, exactly the same principles apply to an electronic analog controller. The only difference is the control signals are current or voltage signals rather than pressure signals. Most of these controllers still require the calculation and input of some value of authority.

Figure 6 A typical controller designed for HVAC duty. This KMD-5210 controller from KMC Controls can control up to 128 inputs and outputs. This unit is fully programmable. Rather than the classic master/slave arrangement, this controller performs the reset function programmatically. (Courtesy KMC Controls)

However, many controllers for HVAC duty are multiple-input/multiple-output controllers with either predefined or user-defined programs. In order to perform a reset function, the reset schedule must be defined mathematically.

Consider the system shown in Figure 1. Instead of the pneumatics depicted in the figure, assume the controller is microprocessor-based and the temperature transmitters output 2 – 10 V over their sensing range. One must remember that the analog input to a digital controller is a voltage or current. If you need to express this signal in Engineering Units, you must write the equation for the sensor/transmitter. Thus, to establish a reset function, one must define and program the equation for each sensor and the equation for the reset schedule. Typically, the user is able to define his or her own variables for each input, each output, and each user defined property of the controller. Let's define the following variables.

Primary input signal (voltage):	PVV
Primary input value (temperature)	PV
Reset input signal (voltage)	RVV
Reset input value (temperature)	RV
Discharge Air Set Point	DASP

We would then write a program segment establishing the reset function as follows:

```
.
.
.
120  PV = PVV * 12.5 + 0    REM Equation for the primary transmitter
130  RV = RVV * 12.5 - 45   REM Equation for the reset transmitter
140  DASP = RV * 0.5 + 70  REM Equation for the reset schedule
150  if DASP < 70 then DASP = 70              REM Limits low end of set point
160  if DASP > 100 then DASP = 100           REM Limits high end of set point
.
.
.
```

Figure 7 Program segment implementing a reset schedule. Line 140 is the actual reset schedule. Lines 150 and 160 limit the end points of the schedule

In the above segment, line 120 takes the input voltage from the primary variable transmitter and calculates the corresponding temperature. Line 130 does the same thing for the reset variable sensor. Line 140 is the equation for the reset schedule. Using the value of the reset variable as calculated in line 130, this equation calculates the new controller set point and assigns it to variable DASP. Mathematically, the equation in line 140 can result in a set point temperature above 100 ^oF or below 70 ^oF. Lines 150 and 160 limit the value of the reset set point if the calculation does result in such a value.

The program segment shown is written using the programming language currently favored by KMC controls. Language type and syntax is unique to each manufacturer, but the basic concepts illustrated in Figure 7 are the same.

Not all controllers require the development of programming code. Frequently, the controller is a generic controller with basic control algorithms encoded in firmware. If the controller is dedicated to a specific function such as the control of an air-handling unit, the algorithms unique to such control are also encoded. In either case, line coding as illustrated in Figure 7 is unnecessary, perhaps even impossible. In such a case, the manufacturer will establish a menu system within which the user establishes a set of parameters. For example, assume a specific controller allows the input of voltage or current signals. Now assume you wish to connect a 25 ^oF - 125 ^oF sensor with a 2 – 10 V output signal over its sensing range. By paging through the controller menus, you would input the endpoints of the sensing range and the output signal. The controller would calculate the transmitter equation using this information. The input of a reset schedule might be accomplished in the same fashion.