ENTHALPY COMPARATOR LOOP

PNEUMATIC CONTROL

APS
(905) 640-2333
analystsofpneumatic@bellnet.ca

CONTENTS

DEFINITIONS

DRY BULB TEMPERATURE

A measurement of sensible heat, usually expressed in degrees Fahrenheit or degrees Celsius, measured with a thermometer.

WET BULB TEMPERATURE

The lowest temperature that evaporation of water causes, measured using a thermometer with a wet wick over its bulb.

RELATIVE HUMIDITY

The percentage of moisture contained in air relative to the air saturated at that dry bulb temperature.

ENTHALPY

The total heat content of air, considering the dry bulb temperature and the relative humidity. (Every pound of evaporated water contains 970 BTU of latent heat, as well as its sensible heat.)

PREFACE

Enthalpy comparison in HVAC systems presents a significant opportunity in control logic, where society may reduce electrical consumption. This applies to mechanical cooling systems with outdoor air, return air and exhaust air dampers, where the controls alter the dampers from full outdoor air to minimum ventilation, based on calculations that the outdoor air will consume more cooling energy than the return air of the building.

Air at 70°F and 100% RH contains 34 BTU/lb of dry air and at 70°F and 15% RH contains 19 BTU/lb of dry air. (Environment Canada, last year, reported that Calgary experienced 100% RH as the outdoor high and 15% RH as the outdoor low during the mechanical cooling season.) These conditions present a 78.9% BTU increase from the low to the high regarding air at 70°F. Return air 75°F at 40% RH contains 26 BTU/lb of dry air, which is midpoint considering the high and low, Altering the damper position to minimum ventilation, based only on a temperature of 70°F, which occurs in many systems, would be a bad idea if the outdoor relative humidity is at the lowest recorded value and a good idea if the outdoor relative humidity is at the highest recorded value. The system must know the relative humidity level of both air sources and calculate the actual enthalpy of each to make a proper decision.

This report illustrates our control circuit that calculates the enthalpy of both the return air and outdoor air. The circuit compares the two enthalpy values and selects the lower value as the air stream passing through the mechanical cooling coil. We believe that installation and set up can be accomplished by a pneumatics technician with average ability.

A couple of scenarios where enthalpy logic may not apply are:

-1- Some chillers will create an artificial load, internally matching a lessening load from the fan systems. The chiller's energy consumption will not change at low load levels.

-2- A unit with Freon coils controlled from the space may tend to run the compressors more frequently under certain conditions with enthalpy comparison logic.

For example:

The conflict is that the dampers are positioned based on enthalpy comparison and the mechanical cooling is based only on space dry bulb temperature.

If the outdoor air is 80°F at 15% RH, the enthalpy is 23 BTU/lb of dry air and if the return air is 73°F and 40% RH the enthalpy will be 25 BTU/lb of dry air. The enthalpy comparator will select the outdoor as the air stream passing through the cooling coil.

When the mechanical cooling is active, the outdoor 80°F at 15%RH containing 23 BTU/lb of dry air is the more efficient air stream passing through the cooling coil; however, when the mechanical cooling is not active, the outdoor air will raise the room temperature restarting the cooling in a shorter time than the cooler return air.

Consider allowing enthalpy selection when the mechanical cooling is active and use the air stream with the cooler sensible dry bulb temperature during periods when the mechanical cooling is inactive.

The only other pneumatic logic circuit, currently commercially available, to my knowledge, is the Johnson Control N9000 Logic Center. We tested this device's performance and our data and Johnson Control's specification sheet indicate that the N9000 is not a true enthalpy comparator as per pages nine and ten in this report.

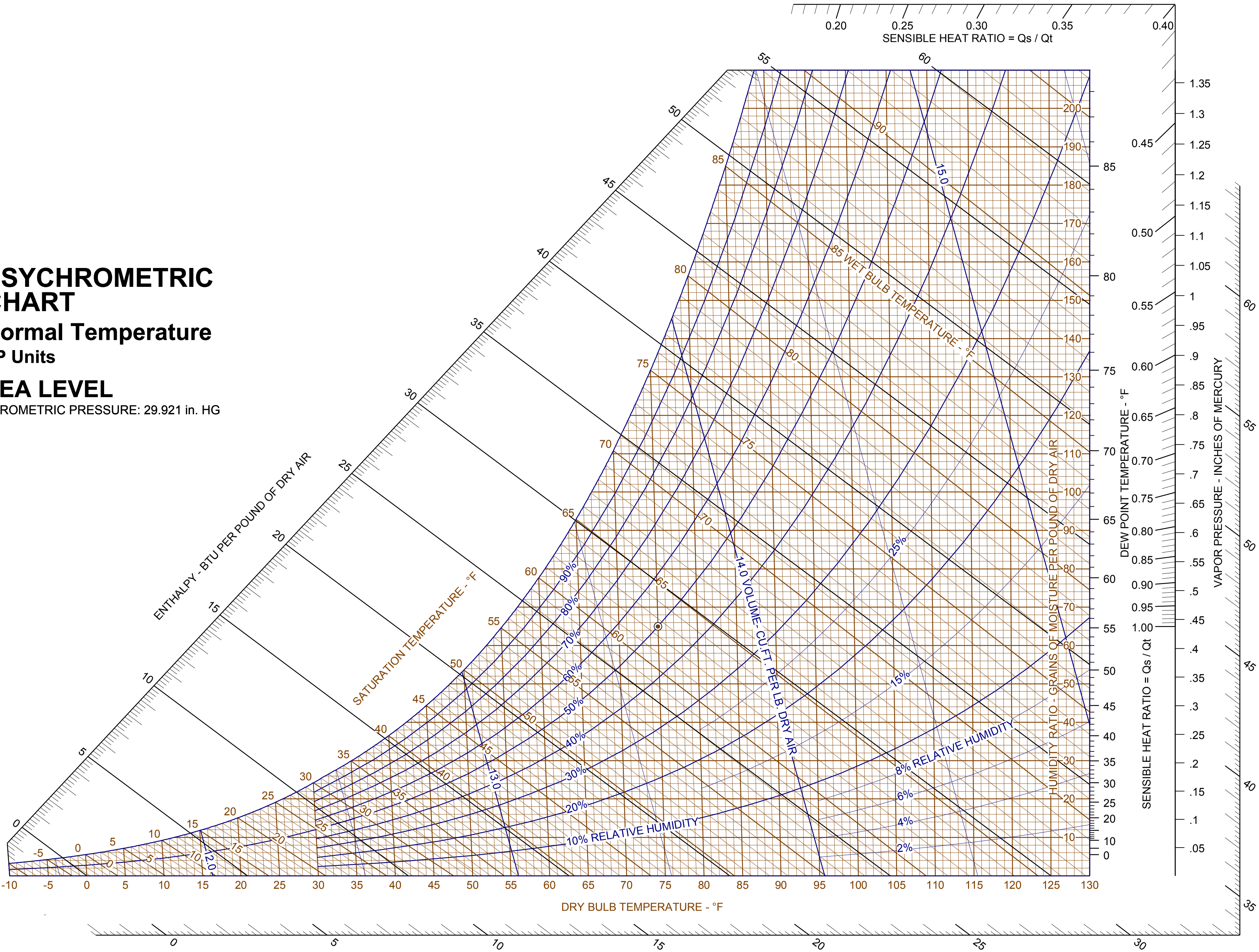
PSYCHROMETRIC CHART

Normal Temperature

I-P Units

SEA LEVEL

BAROMETRIC PRESSURE: 29.921 in. HG



ISSUE

Many systems revert the mixing dampers back to minimum ventilation when the outside air exceeds 70 ^{o}F dry bulb temperature, attempting to reduce the cooling load at the cooling equipment. Environment Canada information records the average lowest Toronto outdoor relative humidity at 32.5% RH for June, July, August and September 2010. They record the average high at 100% RH and the average mean at 73.61% RH for those months during 2010, in Toronto.

Air 70 ^{o}F at 32.5% RH contains 22.32 BTU/lb of dry air while air 70 ^{o}F at 100% RH contains 34.08 BTU/lb of dry air. Air 70 ^{o}F at 100% RH (average high) contains 52.7% more heat energy than air 70 ^{o}F at 32.5% RH (average low). Switching from free cooling to no free cooling, based only on temperature is often an incorrect decision.

The relative humidity, as well as the dry bulb temperature must both be considered for both the return air as well as the outdoor air when determining the lesser cooling load. This combination of humidity and temperature is called enthalpy. The psychrometric chart on page two illustrates this relationship.

EXAMPLE: Pick the point where the temperature and relative humidity of your air stream intersect and follow a line diagonally up to the left, parallel with the other lines, to the enthalpy line that presents values from 0 BTU/lb of dry air to 60 BTU/lb of dry air. The point you cross presents the BTU's/lb of dry air your air stream contains.

GOAL

Use the least amount of mechanical cooling in the HVAC system, while satisfying the requirements of the occupied space.

REQUIREMENTS

-1-Psychrometric chart.

-2- Transmitters for sensing both the return air and the outdoor air relative humidity and dry bulb temperatures.

-3- Two reset receiver controllers producing two pneumatic, varying signals, ranging from 3 PSIG to 15 PSIG, representing a change in enthalpy from 21 BTU/lb of dry air to 39 BTU/lb of dry air for both the outdoor air and return air.

-4- Custom make two overlays for 3# to 15# transmission gauges, ranging from 21 BTU/lb of dry air to 39 BTU/lb of dry air. (A CD/DVD labeling program can be used.)

-5- A relay to subtract the return air enthalpy signal from the outdoor air enthalpy signal.

-6- A snap acting air switching valve or receiver controller acting as the determining point to select the air stream with the lesser BTU content.

-7- Install components as per drawing.

CALIBRATION PROCEDURE

-1- Calibrate all transmission gauges to be accurate at nine PSIG with a certified test gauge or one tested as accurate.

-2- Calibrate the temperature and relative humidity transmitters to be accurate relative to their respective transmission gauges.

-3- Temporarily install gradual switches allowing simulation of varying temperature and relative humidity values for both return and outdoor air.

-4- For each of the two direct acting, reset receiver controllers, tube the temperature signal into the primary port and the relative humidity into the reset port with direct re-adjustment. (This means that an increase on either port signal will cause an increase in the receiver controllers' out put signals.)

-5- -a- Take one receiver controller and set the relative humidity value at 40% RH with your manual gradual switch and leave it at 40% RH, while you address the temperature side of the receiver controller.

-b- Find the proportional band (sensitivity or gain) setting that causes an output signal change from 23.70 BTU/# of dry air to 29.10 BTU/#of dry air on your enthalpy indication gauge as you change the temperature from 70 ^{o}F to 80 ^{o}F.

-c- Set the temperature gauge to 70 ^{o}F and leave the proportional band at the setting determined in "b".

-d- Find the authority (reset) setting that causes an output signal change from 23.70 Btu/lb of dry air to 28.10 BTU/lb of dry air on your enthalpy indication gauge when you change the relative humidity from 40% RH to 60% RH.

-e- Check the enthalpy values at the extremes on the chart and several points in the middle. You can use the psychrometric chart as well.

-6- Remove your manual simulation gradual switches and re-connect the temperature and relative humidity transmitters as required.

We did not expect the system values to be exactly the same as the psychrometric chart, as we are blending a linear signal (temperature) with a non-linear signal (relative humidity) into one signal. As you should see during checking the system values produced are plus or minus one BTU/lb of dry air.

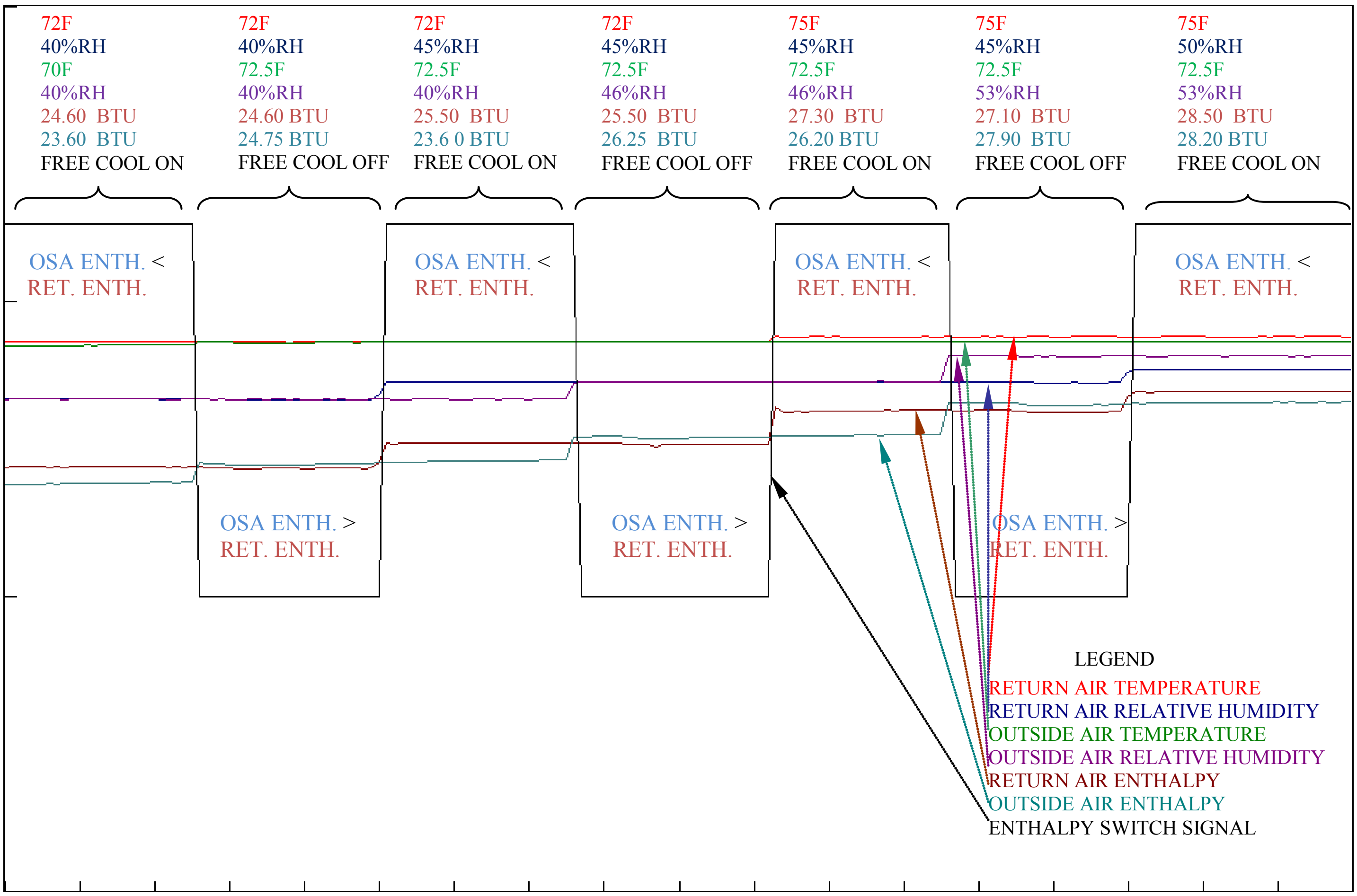
ENTHALPY VALUES

(PSYCHROMETRIC CHART IN BLACK. (BTU/LB DRY AIR)
(VALUES PRODUCED VIA CONTROL LOOP IN BLUE. BTU/LB DRY AIR)

TEMP. °F		BTU	BTU	BTU	BTU	BTU		
80 (10.20#)		28.79 29.10	30.00 29.90	31.23 31.10	32.45 32.30	33.68 33.80		
79 (9.96#)		28.23 28.40	29.41 29.60	30.59 30.70	31.77 32.30	32.96 33.30		
78 (9.72#)		27.68 27.40	28.82 28.80	29.96 30.00	31.10 31.10	32.25 32.30		
77 (9.48#)		27.14 27.30	28.24 28.20	29.34 29.60	30.45 30.60	31.56 32.00		
76 (9.24#)		26.61 26.60	27.67 27.90	28.74 29.10	29.81 30.40	30.88 30.00		
75 (9.00#)		26.09 26.00	27.12 27.10	28.15 28.30	29.18 29.50	30.21 30.00		
74 (8.76#)		25.58 25.50	26.57 27.20	27.56 27.80	28.56 29.20	29.56 30.50		
73 (8.52#)		25.07 25.70	26.03 26.40	26.99 27.70	27.95 28.70	28.92 30.00		
72 (8.28#)		24.58 24.60	25.50 25.80	26.43 27.10	27.36 28.10	28.29 29.20		
71 (8.04#)		24.09 24.20	24.98 25.20	25.87 26.30	26.77 27.30	27.67 28.40		
70 (7.80#)		23.61 23.70	24.47 24.60	25.87 25.90	26.20 27.10	27.06 28.10		
	RH%	40%	45%	50%	55%	60%		

Temperature transmitter is 0°F to 100°F.
Humidity transmitter is Robertshaw 0% RH to 100% RH.
Branch signal is 21 BTU/lb dry air (3 PSIG) to 39 BTU/lb dry air (15 PSIG).
Note: As the dry bulb temperature drops and the relative humidity rises, the BTU values remain within one percent variation. There are more BTU's in the air at 71° F than at 76° F.

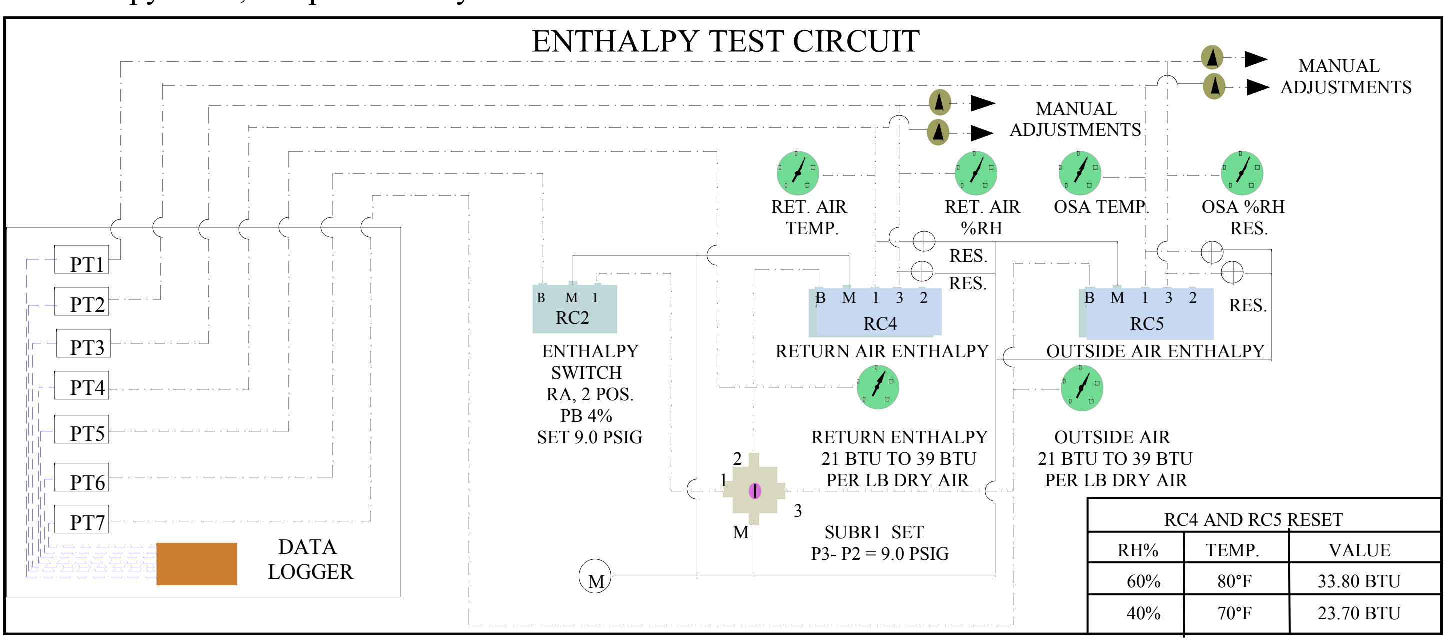
ENTHALPY COMPARATOR PERFORMANCE GRAPH



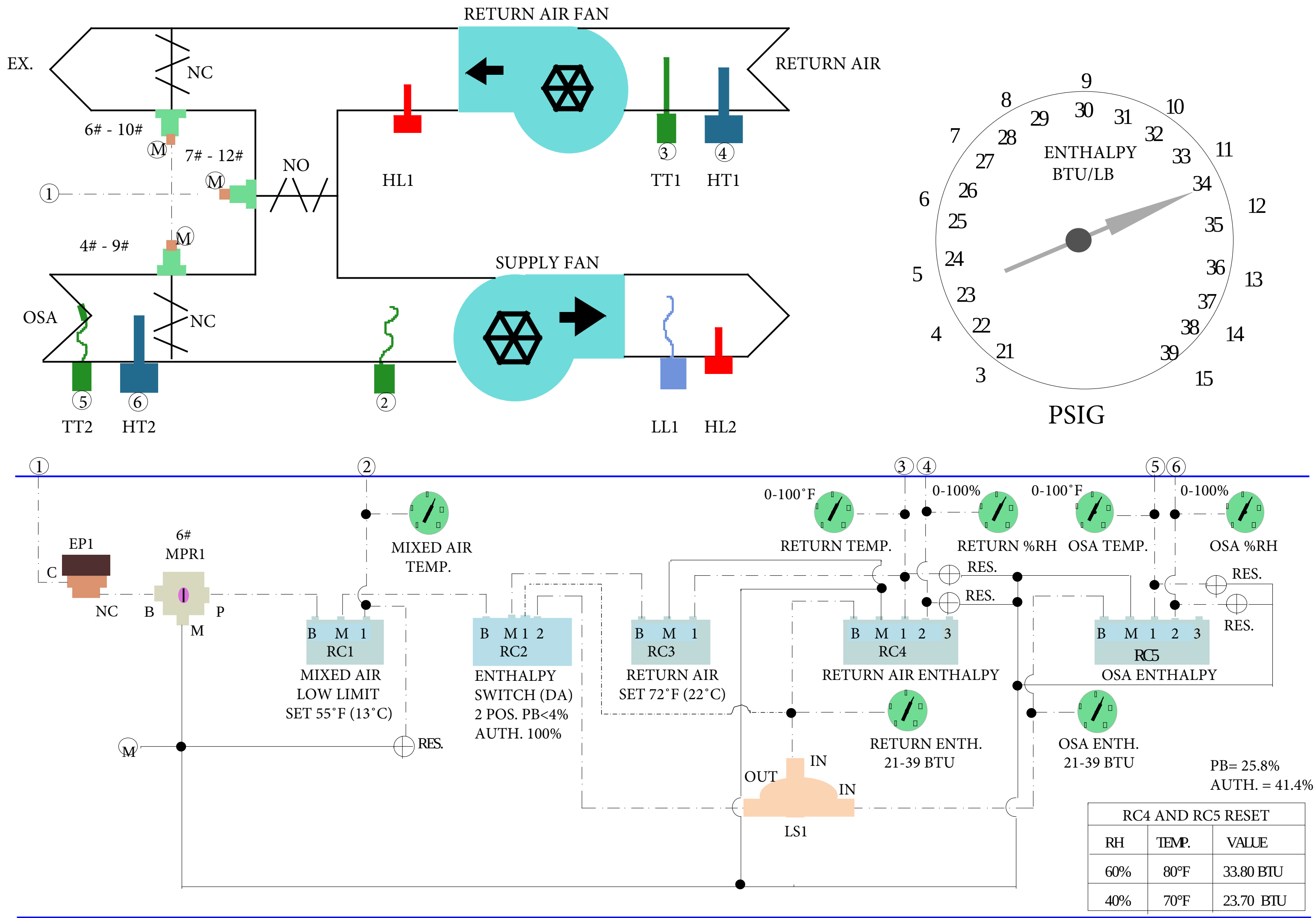
The graph illustrated above presents the values regarding temperature, relative humidity and enthalpy with the presented test values colour matched to the graph colours.

The control circuit illustrated below allowed simulation of various relative humidity and temperature values, causing variations in the enthalpy values regarding both the return air and the outside air. The values were recorded via pressure transducers and collected through a data logger.

The conclusion of the enthalpy comparison, allowing selection of the air stream with the lesser enthalpy value, is represented by the black line.



The Kreuter subtraction relay became obsolete; therefore, this circuit was developed allowing enthalpy comparison.



RC4 AND RC5 RESET		
RH	TEMP.	VALUE
60%	80°F	33.80 BTU
40%	70°F	23.70 BTU

SEQUENCE OF OPERATION

When the fan is off, solenoid valve (EP1) is de-energized. The outside air and exhaust air dampers close and the return air damper opens.

Receiver controller (RC5) senses the outside air humidity and temperature via transmitters (HT2) and (TT2) respectively. RC5 produces a signal representing the outside enthalpy as the humidity and temperature vary according to the reset schedule. RC4 senses the return air humidity and temperature via transmitters (HT1) and (TT1). RC4 produces a signal representing the return air enthalpy as the humidity and temperature varies according to the reset schedule. Both RC4 and RC5 send their signals to low selctor (LS1). RC4 also sends its signal to RC2.

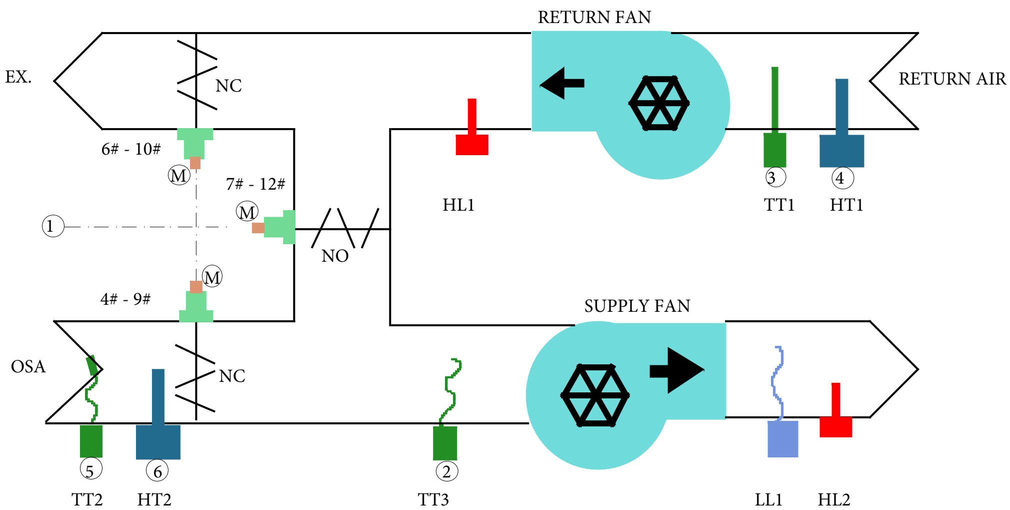
RC2 receives its main air from receiver controller (RC3), which senses the return air temperature via TT1.

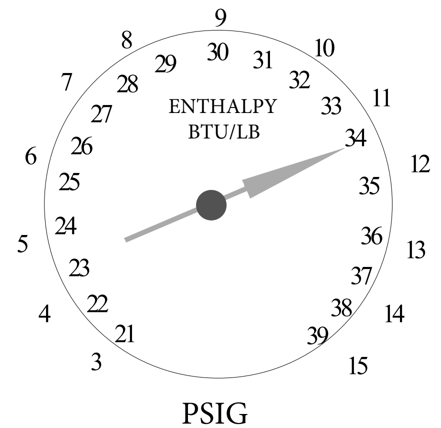
RC2's signal provides the main air for receiver controller (RC1) which senses the mixed air temperature via transmitter (TT3). RC1 sends its signal to minimum positioning relay (MPR1), which sends its signal through EP1 to modulate the mixing dampers.

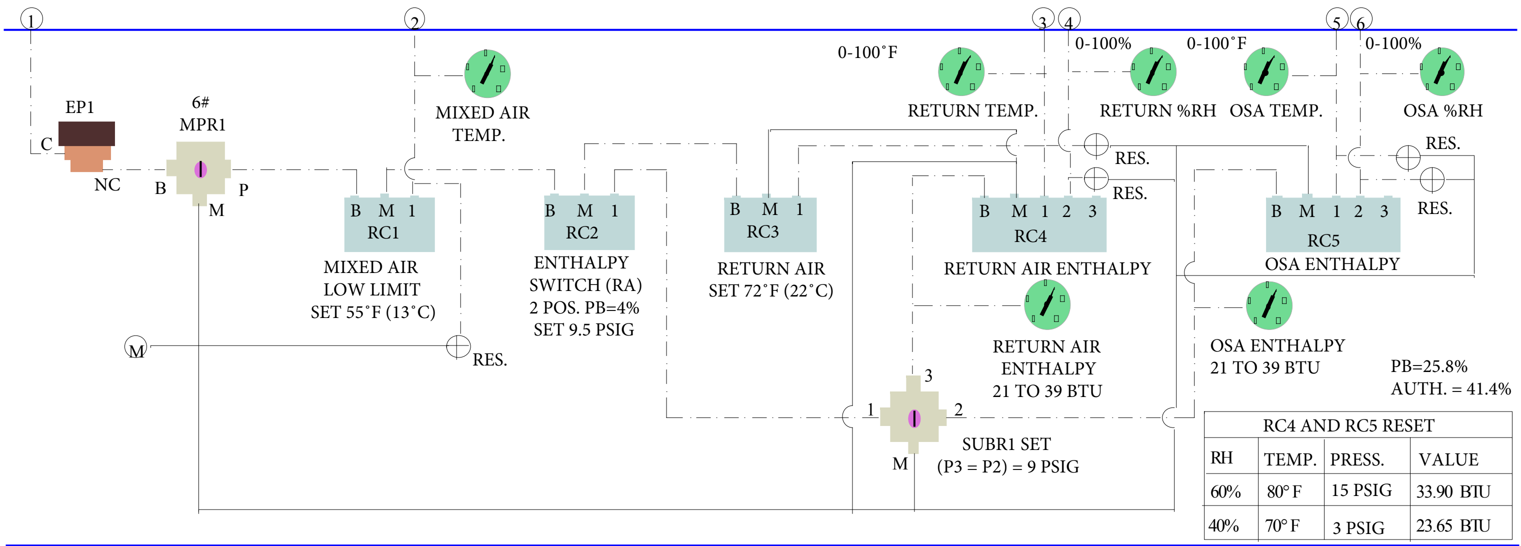
The safeties will shut down the fan when the temperature exceeds their set points.

NOTE: The proportional band and authority may have different values, depending on the controller manufacturer.

Alternate relay to achieve circuit intent.







RC4 AND RC5 RESET

RH	TEMP.	PRESS.	VALUE
60%	80° F	15 PSIG	33.90 BTU
40%	70° F	3 PSIG	23.65 BTU

SEQUENCE OF OPERATION

When the fan is off, solenoid valve (EP1) is de-energized. The outside air and exhaust air dampers close and the return air damper opens.

Receiver controller (RC5) senses the outside air humidity and temperature via transmitters (HT2) and (TT2) respectively. RC5 produces a signal representing the outside enthalpy as the humidity and temperature vary according to the reset schedule. RC4 senses the return air humidity and temperature via transmitters (HT1) and (TT1). RC4 produces a signal representing the return air enthalpy as the humidity and temperature varies according to the reset schedule. Both RC4 and RC5 send their signals to subtraction relay (SUBR1). SUBR1 subtracts the return air enthalpy signal from the outside air enthalpy signal. SUB1's output signal is 9 PSIG when both input signals are equal. If the outside air enthalpy is greater than the return air enthalpy SUB1's output signal will start to rise by the difference that RC5's signal is greater than RC4's signal indicating that the outside enthalpy is greater than the return air enthalpy.

SUB1's signal goes to receiver controller (RC2), which prevents free cooling when the outside air enthalpy is greater than the return air enthalpy.

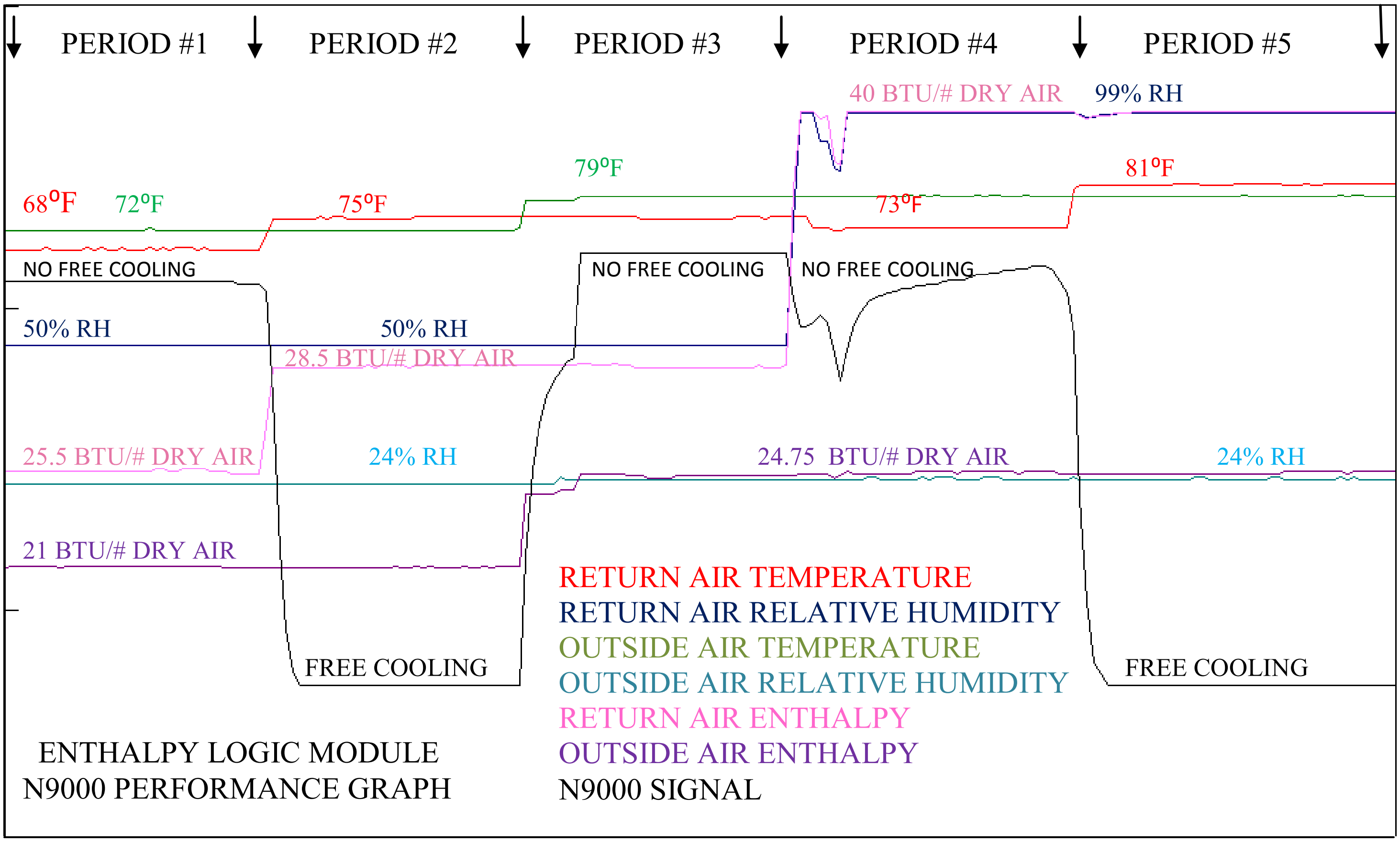
RC2 receives its main air from receiver controller (RC3) which senses the return air temperature via TT1.

RC2's signal provides the main air for receiver controller (RC1) which senses the mixed air temperature via transmitter (TT3). RC1 sends its signal to minimum positioning relay (MPR1), which sends its signal through EP1 to modulate the mixing dampers.

The safeties will shut down the fan when the temperature exceeds their set points.

NOTE: The proportional band and authority may have different values, depending on the controller manufacturer.
The subtraction relay may be obtained from Kreuter Marketing (RCC-1508).
Kreuter Marketing manufactures the receiver controllers used in the testing. (CCC-1002)

JOHNSON CONTROL N9000 ENTHALPY CENTRE



The Johnson Control N-9000 Enthalpy Logic Centre’s specification sheet states:

-1- “The N9000 imposes the lowest cooling load on the mechanical cooling equipment.”

-2- “When outside air enthalpy is greater than return air enthalpy or when the outside air temperature is greater than the return air temperature, the N9000 provides a maximum output signal of 10 PSIG or greater. This signal returns the outside air damper to its minimum position. Note: If the outside air temperature is greater than the return air temperature, the output signal is at maximum and will not be reduced by a change in the humidity signal.

When outside enthalpy is less than return air enthalpy *and* the outside air temperature is less than the return air temperature, the N9000 provides a 0 PSIG output signal. This signal places the dampers under control of the system controller to obtain free cooling.”

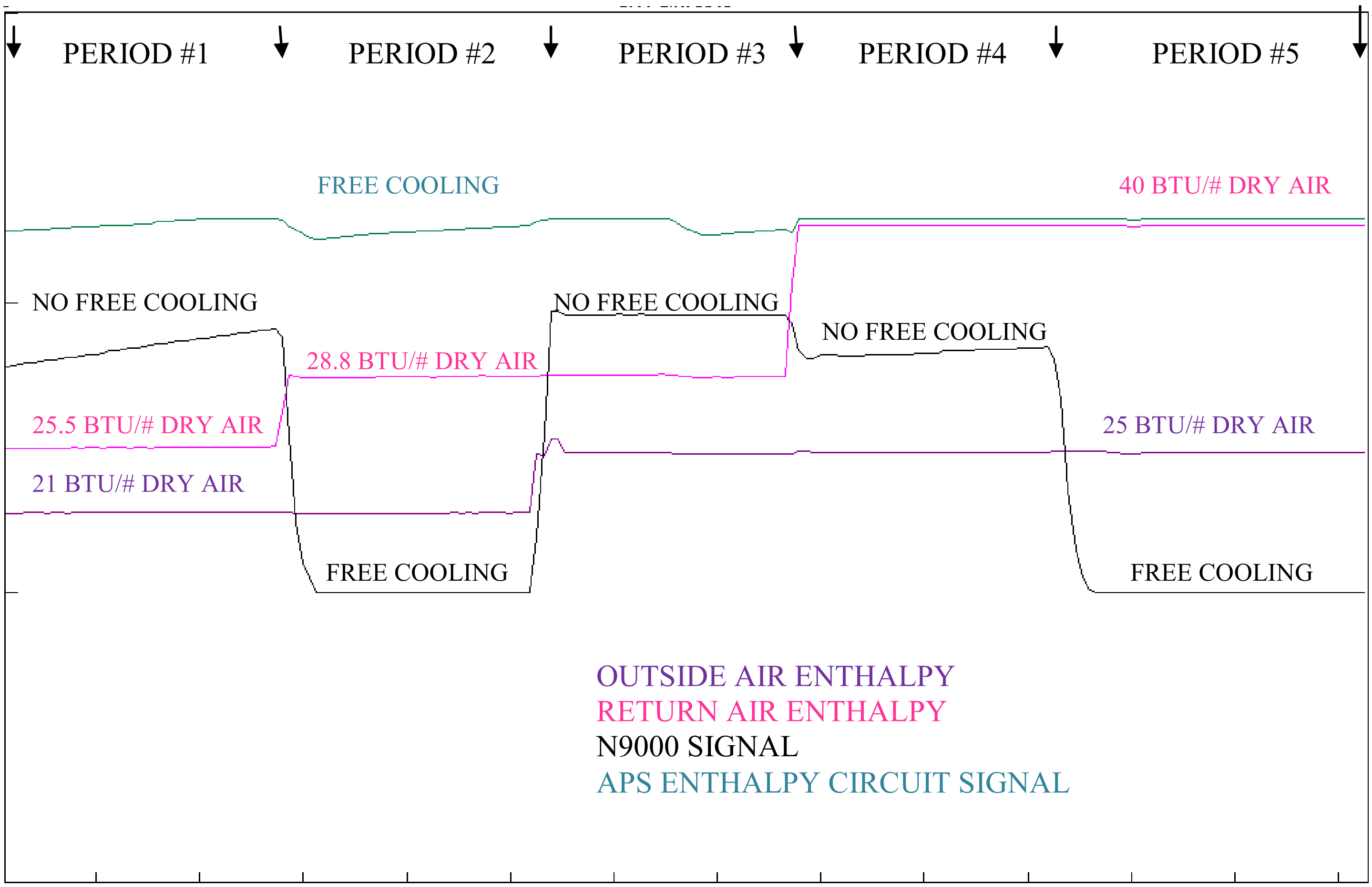
-3- “By enthalpy and sensible heat comparison of both outside and return air conditions, the N9000 provides the most efficient use of free cooling and thus true economizer operation.”

These quotes are contradictory, as they state the N9000 will select the air stream with the lesser cooling load. They also state the N9000 will switch based on dry bulb temperature and humidity will have no effect. At times the N9000 positions the dampers solely on a sensible heat comparison and ignores the humidity level, as per quote number two; therefore, ignores the enthalpy levels.

The performance graph above illustrates the N9000’s signal under varying humidity, thermal and enthalpy levels. The enthalpy levels were obtained via the enthalpy circuit which is the subject of this paper. During the five periods of testing, the outside air enthalpy was always lower than the return air enthalpy; however, the N9000 determined that free cooling was appropriate for two periods and no free cooling was appropriate for three periods. A true enthalpy controller would have kept the system on fresh during all five periods, as the outdoor enthalpy was lower than the return air during the five periods.

We suggest that existing N9000 installations be altered to the use the circuit presented in this paper, if enthalpy comparison is a valid feature in those buildings.

JOHNSON CONTROL N9000 AND APS ENTHALPY PERFORMANCES



The above graph compares the performance of the Johnson Control N9000 Enthalpy Logic Module and the APS enthalpy comparison circuit.

The return air enthalpy and outdoor enthalpy values were determined via the APS enthalpy comparison circuit illustrated on pages five and six in this report. The accuracy relative to the standard psychrometric chart on page two is presented on page five.

As illustrated above the outdoor enthalpy was lower than the return air enthalpy during the whole test. The APS enthalpy comparison circuit correctly determined that the system should remain on free cooling from outdoor air. The Johnson Control N9000 Enthalpy Logic Module determined that free cooling was appropriate for two periods and no free cooling was appropriate for three periods.

The APS enthalpy circuit compares enthalpy of the return air and the outdoor and these are the only factors determining the switching point. The Johnson Control N9000 Logic Module literature states " When outside air enthalpy is greater than return air enthalpy or when the outside air temperature is greater than the return air temperature, the N9000 provides a maximum output signal of 10 PSIG (70 kPa) or greater. Note: if the outside air temperature is greater than return air temperature, the output signal is at maximum and will not be reduced by a change in the humidity signal."

SUMMARY

Many systems use only outdoor dry bulb temperature when determining the point when outdoor air requires more mechanical cooling than the return air maintaining comfort in the occupied space. At this point the dampers revert back to mainly return air, with outdoor providing only minimum ventilation. The change-over dry bulb temperature is often seventy degrees Fahrenheit. 70°F air at 100% RH contains 78.9% more heat energy than 70°F air at 15% RH. The system must sense relative humidity and dry bulb temperature in both the return air and the outdoor air and calculate the actual enthalpy in determining which air stream is more economical for mechanical cooling.

SIEMENS' enthalpy transmitter, part number 184-0101 and enthalpy logic module, 243-0043 are no longer available. The Barber Colman enthalpy transmitter, part number HKS8065, and enthalpy logic module, part number AK-52101, are no longer available. We did not test the performance of these components through their whole range, but spot checking them over time, during service, we believe that they functioned properly as enthalpy comparators.

Honeywell made an enthalpy comparator, part number HP973A, which is an obsolete item now. We have never seen one in the field.

Johnson Controls Enthalpy Logic Centre, part number N9000, is still commercially available. We do not consider it a true enthalpy comparison circuit, as the dry bulb temperature can cause the unit to switch from free cooling, while a change in the relative humidity will not affect that decision. Enthalpy is a combination of dry bulb temperature and relative humidity; therefore, both must continually have an impact on the decision to choose return air or outdoor air as the primary component of the air passing through the mechanical cooling equipment.

We suggest that each circuit, whether pneumatic or DDC, claiming enthalpy comparison, be checked with simulated temperatures and relative humidity levels. The operator, using the psychrometric chart on page two, can select various enthalpy values for the return air and the outdoor air commanding particular dry bulb temperatures and relative humidity values. The positioning of the mixed air dampers will demonstrate the true logic of the enthalpy system.