POLYIMIDE CAPACITIVE HUMIDITY SENSORS

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ABSTRACT

The need for a full-range, low cost humidity sensor has led Honeywell to develop a capacitive relative humidity (RH) sensor with resistance to environmental contaminants. The sensor is used in a bridge circuit to give either a voltage or a current output. In our application, the bridge circuit also has a temperature sensor and is used to sense the enthalpy of outdoor air for an economizer cooling cycle.

INTRODUCTION

In recent years, concerns about efficient use of energy, new data about how people are affected by their environment and advancements in electronic control technology have combined to generate new interest in finding better ways to control indoor humidity. This need recently prompted Honeywell, long involved in humidity control, to embark on a project to develop a new humidity sensor. The challenge was to develop a cost effective sensor that was accurate, rugged and easy to make. The polyimide capacitive humidity sensor described in this paper was the result.

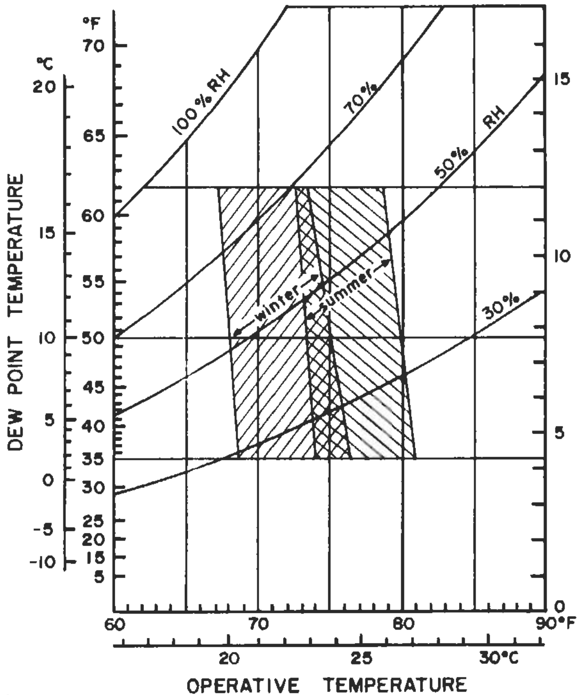
HUMIDITY CONTROL FOR COMFORT AND HEALTH

It wasn't long after the introduction of central heat and central air conditioning that attention turned to controlling the humidity as well as the temperature. Many studies were performed to develop a comfort standard based on the most comfortable combinations of temperature and relative humidity.

ASHRAE Standard 55-1981 (1) is one such standard. This standard defines the relative humidities that offer acceptable comfort at a range of temperatures. These can be displayed as a zone on a standard psychrometric chart, as shown in Fig. 1 (1). Generally, as the air temperature goes up, the acceptable maximum relative humidity drops. The relative humidity range in this traditional model is rather broad, however, so that at a space temperature of 75 F, for example, relative humidity can be anywhere between 25 and 65 percent and still result in acceptable comfort.

A recent summer comfort study done at Honeywell indicated that, in homes with mechanical air conditioning, changes as small as 5 percent relative humidity can be noticed, particularly at higher RH levels.

Also, there apparently is a relationship between relative humidity and the effect of various air contaminants on health. According to a report in the 1985 ASHRAE Transactions (2), the optimum relative humidity range for health is between 40 and 60 percent. In this zone, living contaminants like bacteria are least active, and the effects of upper respiratory problems seem to be less severe. See Fig. 2.



ASHRAE STANDARD 55-1981

Fig. 1 Parameters of the traditional "comfort zone".

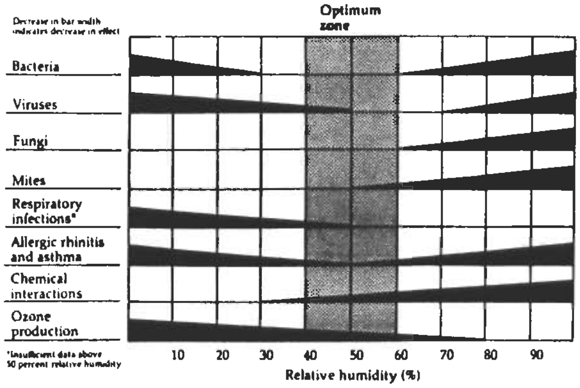


Fig. 2 Optimum relative humidity levels when air contaminants are considered.

These studies indicate that the optimum relative humidity range may be smaller than indicated by the traditional temperature vs air moisture model. They also indicate a need for closer control of relative humidity than has been available with traditional mechanical sensors.

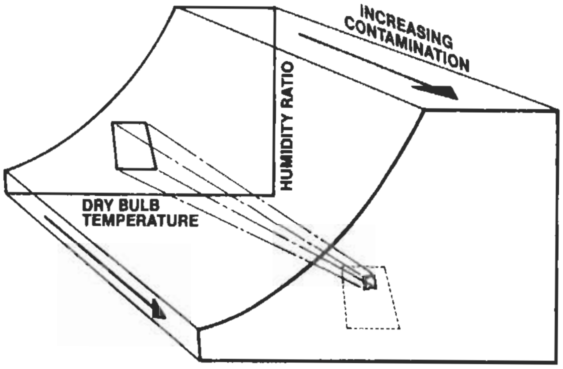


Fig. 3 The "comfort zone" may be much smaller than previous studies would indicate.

HUMIDITY SENSING FOR ENERGY EFFICIENCY

Energy efficiency of an air conditioning system can be improved by use of an economizer cycle that uses outdoor air whenever possible for cooling. But the outdoor air must not only be cool, it must be within the desired parameters for relative humidity. Since systems that use an economizer cycle are usually sophisticated electronic systems, the need arises for an electronic humidity sensor. Also, since many of these controls are installed in ductwork where they aren't readily available for maintenance, the sensor must be sturdy and relatively troublefree.

METHODS OF SENSING HUMIDITY

Traditional mechanical humidity sensors depend on the fact that many materials are hygroscopic. As humidity increases, they absorb moisture and expand (or lengthen), and as the humidity drops, they release moisture and contract (or shorten). In a humidity controller, this characteristic is used to operate a switch that turns the equipment on and off.

Humidity controllers that use the dimensional change of hygroscopic sensors to activate a switch are still widely used in residential applications. These humidity controllers are reliable and troublefree, but cannot be considered precision controls because of variations in materials and in manufacturing tolerances. In applications like basement dehumidifiers they provide adequate control as long as the chosen setting keeps the humidity below 60-70 percent RH, which is a threshold level for mold and fungus growth.

A variety of other sensors have been developed for large commercial and industrial applications. Electrical sensors like our "Gold Grid" resistive relative humidity sensor and the "Dewprobe" self-heating dewpoint sensor operate from the hygroscopic response of lithium chloride. Very sharp resistance changes within their operating range lead to precise control. However, lithium chloride based sensors are relatively easily damaged by exposure to heavy condensation or atmospheric contaminants like sodium chloride. As a result, electrical sensors have been too costly and not rugged enough to use in homes and small commercial buildings.

Electronic environmental control systems require a sensor that is more accurate than traditional mechanical sensors and more durable than the electrical type. A capacitive sensor best meets these requirements.

DESCRIPTION OF A CAPACITIVE RELATIVE HUMIDITY SENSOR

A capacitive relative humidity sensor is a special form of a capacitor. It consists of a humidity-sensitive film between two electrodes. When the electrodes are connected in a circuit, the capacitance change can be used as an input to the control system.

After investigating a number of humidity-sensitive polymer films, we used polyimide because it was the most chemically resistant and because it has a suitable dielectric response to water. In addition, long exposures to saturated conditions do not degrade the film, and it is not affected by the atmospheric contaminants usually found in the outdoor air intake of an air conditioning system.

Polyimide film is widely used in the electronics industry as a dielectric layer, so it is readily available in thicknesses suitable for our sensor.

The sensor is formed from a strip of polyimide by screen printing a layer of conductor material on both sides of the film. Then the printed film is heat-cured, cut to size and mounted in a housing containing externally accessible metal contacts. The resulting capacitive sensor can be mounted on a circuit board. The sensor is shown in Figure 4.

SENSOR OPERATION

When the relative humidity increases, the polyimide film absorbs water, which changes the film's dielectric constant. At 100 percent relative humidity, the film has gained about 3 percent of its dry weight in water. Because the dielectric constant of water is much greater than the polymer, even small amounts of moisture make a substantial change. The capacitance of the sensor changes from 400 picofarads at 0 percent relative humidity to about 500 picofarads at 100 percent relative humidity. This amount of signal change is ample to operate a bridge circuit for full range voltage output.

SENSOR PERFORMANCE

For small changes from 50 percent RH, the sensor response is almost linear. However, when exposed to humidities above 90 percent, the capacitance response becomes somewhat nonlinear, increasing faster than the increase in RH. As the

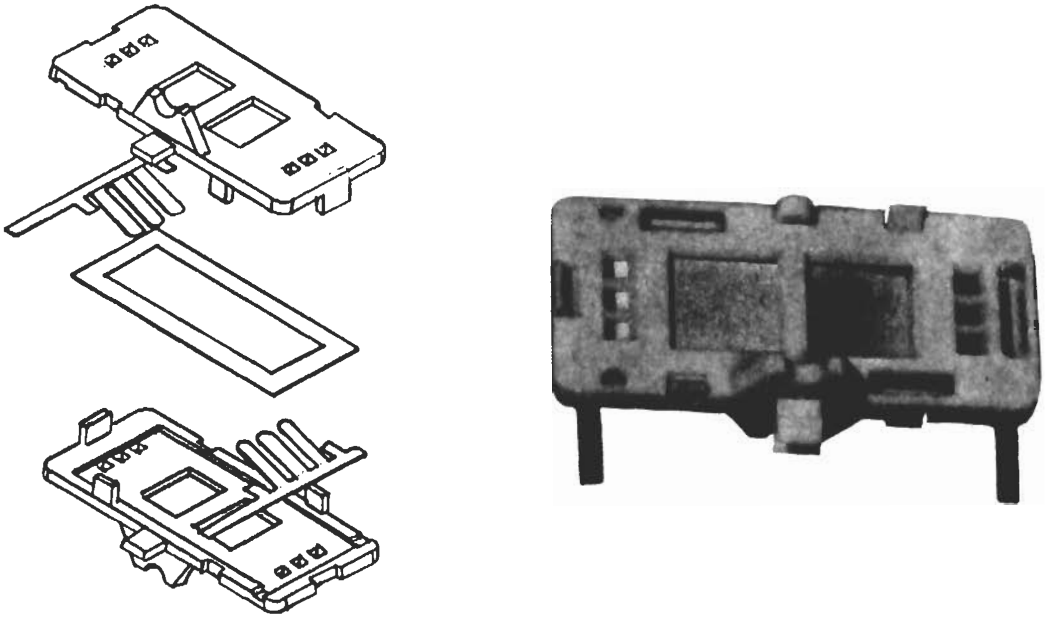


Fig. 4 The sensor consists of the housing, external contacts and the polyimide-electrode film.

relative humidity drops, the sensor can develop a small amount of hysteresis. However, as humidity continues to drop below 50 percent, the response becomes essentially linear again.

During normal use, the sensor will be accurate to within 2 percent relative humidity. However, accuracy claims for the sensor must be limited to about 5 percent because of its response to a saturated atmosphere. When the sensor is exposed for a prolonged period to a saturated atmosphere, the capacitance drifts slowly upward for some time because the film takes on additional water and swells beyond its normal range. Then, the down curve has greater hysteresis than normal, although the sensor recovers its initial values after a short time at lower humidity levels. The response curve is shown in Fig. 5 and the performance characteristics are listed in Table 1.

The sensor can be made with a response time of less than one minute or about 5 minutes to suit the application.

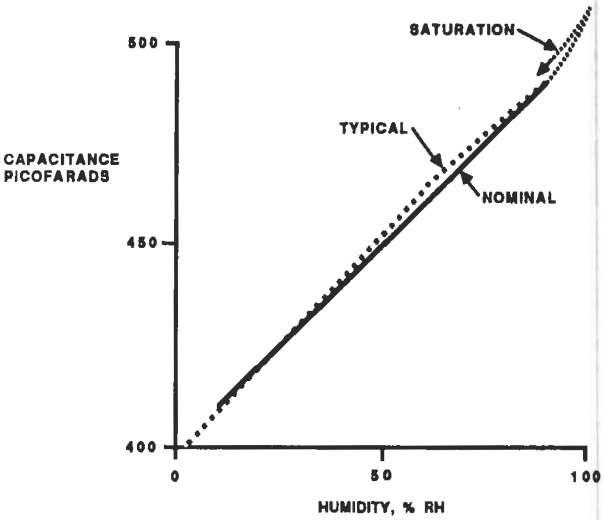


Fig. 5 Response curve for the polyimide sensor.

Table 1, Polyimide Sensor and Circuit Performance Characteristics

PERFORMANCE CHARACTERISTIC	POLYIMIDE CAPACITIVE SENSOR
Operating Range	0 to 100 percent RH
Temperature Range	-1 to +85 °C
Sensitivity	1 pf/percent RH
Repeatability	<±1 percent RH
Time Response	<1 or 5 min., as desired
Temperature Sensitivity	<-0.1 percent RH/°C

STABILITY

The most important characteristic of the sensor is its stability under a variety of environmental conditions. To determine the device's stability, we conducted both cycling tests and field tests.

In the cycling tests, the sensor output changed by less than 5 percent relative humidity when cycled from dry to saturation and from 0 to 65 C for periods of up to 10 weeks. During continuous exposure to 65 C and to near saturation at 40 C, somewhat larger changes were observed. In every case, the sensor stabilized after several weeks of exposure.

In the field tests, the sensor was exposed to the weather at sites across the United States for periods ranging from 6 months to one year. All units remained fully functional throughout the test.

These responses indicate adequate stability for the environments in which it will be used.

SENSOR CIRCUITRY

An AC bridge circuit converts the sensor's capacitance to a usable output. The bridge circuit compares the capacitance to a reference capacitor and converts the difference to a DC voltage output. The circuit is shown in Fig. 6. A calibration potentiometer is used to balance the sensor and reference at a specific condition such as 50 percent relative humidity at 75 F. Other refinements have been added, such as a feedback loop to stabilize the gain of the output amplifier and a temperature-sensing bridge leg to compensate the signal for temperature changes. The output of the circuit to indicate a range of 0 to 100 percent relative humidity can be 0 to 10 Vdc, 2 to 10 Vdc, or the more conventional 4 to 20 MAdc.

SENSOR APPLICATION

The sensor is being used in an enthalpy control for air handling systems in small commercial buildings. To provide enthalpy control, the temperature sensing leg of the bridge was given enough authority to give a signal output which is related to the ambient enthalpy rather than the humidity. An example of the enthalpy controller's response is shown in Fig. 7. It is part of a control system that consists of a power supply and controller, one or two sensors and a damper actuator motor. During the economizer cycle, the damper is positioned based on the output from the sensor(s).

In the single sensor system, the sensor is located in the outdoor air intake duct. The controller is set to an enthalpy level approximating that of the usual return air. The device has four settings, as shown in Fig. 7. When the enthalpy is below the setting line shown in the figure, the outdoor damper modulates in response to a call for cooling. When the outdoor enthalpy moves above the setting line, the damper resets to the minimum air intake position.

The dual sensor system is similar except that a second sensor located in the return air duct measures the operating point condition for the system. The controller is set past the "D" position shown in Fig. 7, so that when the outside air enthalpy is at or below the actual return air enthalpy, the outdoor air damper modulates in response to a call for cooling. When outdoor enthalpy moves above return air enthalpy, the damper resets to the minimum air intake position.

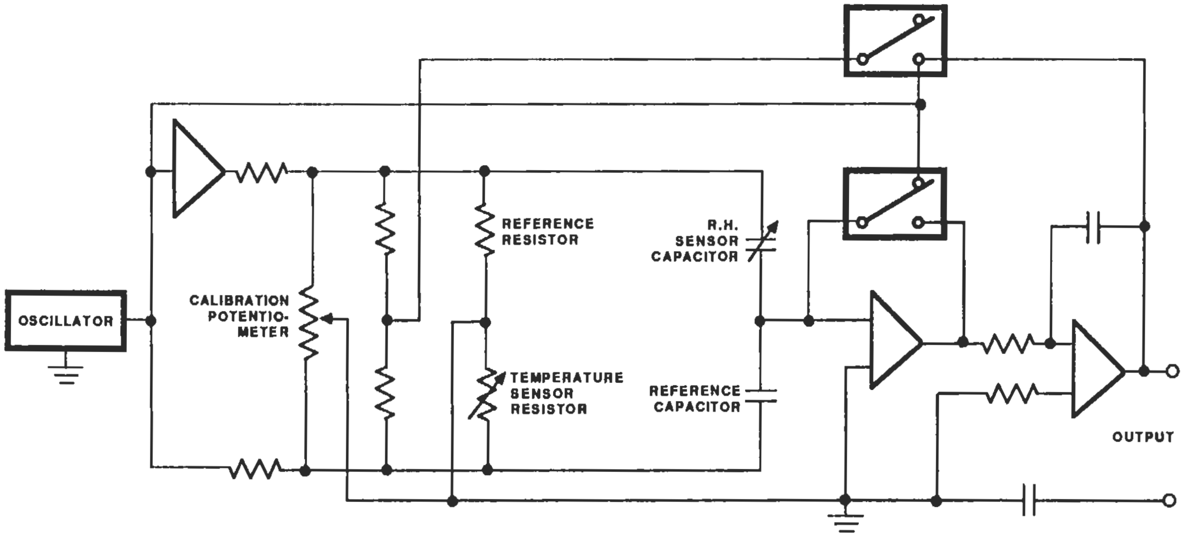
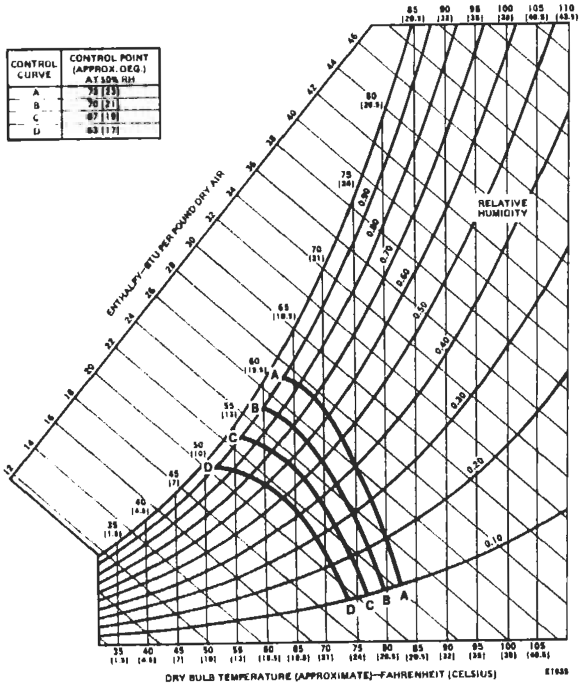


Fig. 6 Circuit for an enthalpy controller using the polyimide sensor.



CONTROL CURVE	CONTROL POINT (APPROX. DEG.) AT 50% RH
A	73 (23)
B	70 (21)
C	67 (19)
D	63 (17)

Fig. 7 Psychrometric chart, showing the control settings for the enthalpy controller.

FUTURE APPLICATIONS

The sensor is currently being evaluated for use as a relative humidity sensor in large building monitoring systems.

Also, it is anticipated that the sensor will be used in other applications where the circuitry can be part of the controller.

REFERENCES

1. ASHRAE Standard 55-1981.

2. Sterling, Arundel and Sterling, "Criteria for Human Exposure to Humidity in Occupied Buildings," ASHRAE Transactions, 1985, Vol. 91, Part 1.

3. Lofgren, H. and Mills, F., "Polyimide Relative-Humidity Sensors," Scientific Honeyweller, Fall 1987.