Building Management System

Part 2

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BMS Architecture

Figure 1 shows the architecture of a typical BMS for automating an HVAC system. In actual use this comprises of many hundreds of equipment and devices, in a large number of communication loops. *Figure 2* shows a simplified version of the same architecture for easy understanding.

At the very top of *Figure 2* is the Tier-1 element, User Interface (UI). The user is able to monitor, operate and control the entire facility from here. This is facilitated by realistic and simple graphics for the user to monitor different equipment and also by live trending of actual real-time data from all the mapped equipment. In large facilities with numerous equipment and devices, data size becomes large, necessitating the use of application data servers.

The heart of the BMS is the next tier (Tier-2), consisting of Supervisory Controllers, which are Network Engines that connect a variety of field controller networks into a single seamless system. They perform functions such as scheduling, trending, alarm detection and facility-wide custom programmed applications.

Moving below the Supervisory Controllers, the BMS has Field Controllers (Tier-3). These are intelligent stand-alone devices (Direct Digital Controllers – DDC) that are connected to and control the various mechanical and electrical systems throughout the facility with sensors, relays, actuators, etc. (Tier-4). Field Controllers report their current values to and receive supervisory commands from the Network Engines.

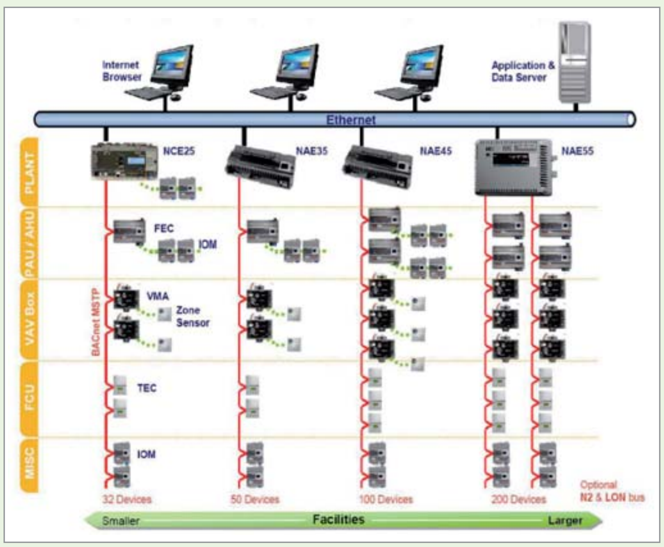

Figure 1: BMS architecture - exploded view for typical HVAC system

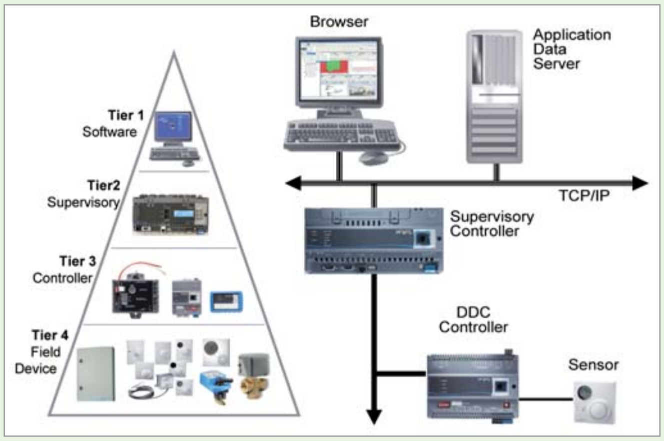

Figure 2: BMS architecture - a simplified view

Some examples of Field Devices (Tier-4) that we see in a typical HVAC plant are the temperature sensors in chillers, AHUs and FCUs, the CO_2 sensors used in AHU rooms or in the occupied space, RH sensors, occupancy sensors, the motorized ball valves or butterfly valves used with chillers, AHUs and FCUs, water flow switches, differential pressure sensors for air/water, VFDs, flow meters, energy meters, power meters, damper actuators, etc. The BMS designer decides as to which Field Devices are required, at which location and in what quantity, to meet site requirements.

The sensors and field devices continuously measure and monitor the required variable parameter and continuously communicate to the Field Controllers or DDC. DDCs have their own microprocessors and pre-defined application programs to ensure correct operation of individual equipment, e.g. Chiller controller, AHU controller, Roof Top AC controller and VAV Box controller. DDCs continuously command and control the field devices suitably to make this happen.

In a BMS, tons of data and information flow around, and many controller and automation engines share data and network together. This requires a *Communication Protocol* to define the communication behavior of each component in the network. These rules define the content and format of messages to be exchanged, error detection and recovery, addressing, when a

About the Author

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device may transmit a message, electrical signaling characteristics and details of the communication medium such as wire type and pin connections. Some common BMS Communication protocols used are BACnet, Modbus and LonTalk.

The facility's IT infrastructure forms the backbone of the BMS architecture. Automation Engines and Application Servers connect to the facility's existing ethernet network. User access to BMS is provided by PCs with web browsers, either directly connected to the network or remotely connected via the Internet. The same firewalls and other security provisions used to protect the enterprise software apply to the BMS network.

We will discuss and understand each of the 4-tiers of the BMS architecture, including the Communication protocols and IT infrastructure.

Field Devices

Field devices include many type of sensors, motorized valves, motorized dampers, actuators, VFDs and metering devices (*Figure 3*). Let us look at their types, operating principles and currently used types.

Figure 3: Field devices

Introduction to Sensors and Transmitters

Sensor is a device which converts a physical property (e.g. temperature or humidity) or quantity (e.g. flow rate) into a conveniently measurable effect or signal (e.g. current, voltage or number). For HVAC, sensors can be grouped into the following types:

- i) Temperature and humidity (enthalpy);
- ii) Pressure;
- iii) Flow rate;
- iv) Comfort;
- v) Indoor air quality.

A sensor is not just the sensing element. It can be considered to have three basic elements of a measurement system, as shown in *Figure 4*.

1. Transducer or sensing element, which produces a signal that is related to the quantity being measured. It converts the raw, measured signal into a 'convenient' signal (usually electrical).
2. Signal conditioner or transmitter, which ensures that the raw signal is converted to a scalable electrical signal, which can be calibrated with the raw measured signal and displayed. It takes the output of a sensor and converts the signal to an industry-standard signal type (e.g. 4–20 mA, 0–10 V, network protocol).
3. Display or indicating element, where the value from the measuring system is displayed.

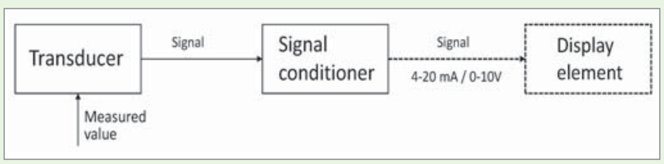

Figure 4: General form of measurement system

In a BMS, the sensors are chosen with or without display of the value being measured, at the point of application of sensors, as per requirement. For example, the differential pressure switch across the AHU filter or pump or a few temperature probes in fresh air/return air plenum need not have display at the point of sensing, as these are centrally displayed in the User Interface terminals. FCUs and VAV boxes may use a thermostat with LCD screen display, as the set point of these devices could be adjusted by the user.

Recent and future generations of sensors have an additional feature, 'intelligence', where a built-in microprocessor enables data to be reported and analyzed alongside pure measurement. Comfort and enthalpy 'sensors' fall into this category.

General Specifications of a Sensor

Performance-based factors

- i) *Range*: Gives the limits between which values can be measured.
- ii) *Accuracy*: The degree to which the measured output matches with some known benchmark.
- iii) *Repeatability*: The ability to consistently reproduce the same output from the same measured value.
- iv) *Sensitivity*: The smallest detectable change in measured value that results in output change by the sensor.
- v) *Drift*: The degree to which the sensor fails to give a consistent performance throughout its stated life.
- vi) *Linearity*: Closeness to linear proportionality between output and measured value across the range.
- vii) *Response Time*: The time to elapse to get an output value response whenever input changes (often expressed as lag).
- vii) *Noise or Interference*. Unwanted signals from unrelated electrical circuits and fields that may be picked up by the measurement device and interfere with the signal being measured.

Practical and Economic Factors

- i) *Cost*: The cost should include power supply, transducer, signal conditioner and the connecting cables. Very often, the cost to install the sensor consumes a significant portion of the overall cost.
- ii) *Maintenance*: Any special maintenance and re-calibration requirements involving additional labor and expenses.
- iii) *Compatibility*: Interoperability and interchangeability with other components and standards.
- iv) *Environment*: The ability to withstand harsh or hazardous environments.

Overview of Sensors used in HVAC applications

The most commonly used types of sensors are temperature sensors, pressure sensors, flow sensors, humidity sensors, comfort sensors, Indoor Air Quality sensors (CO_2, etc.) and occupancy sensors. Brief descriptions of various sensors installed in HVAC systems are given below. For more detailed information, relevant books may be referred.

Temperature Sensors

Temperature is an important controlled parameter inside an air-conditioned environment because it is closely related to human comfort level. Thermocouples, resistance temperature detectors

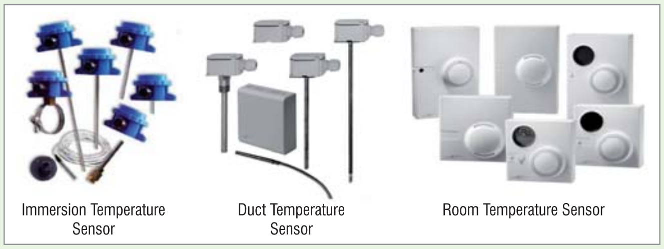

Figure 5: Different types of temperature sensors

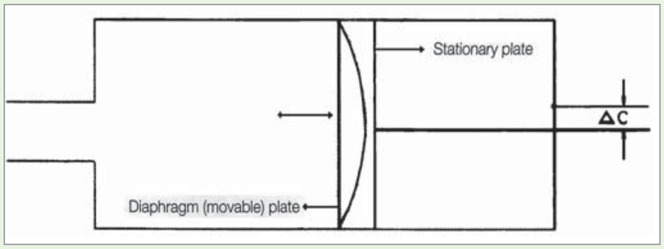

Figure 7: Capacitive pressure transducer ((Figure 2.2 from the book)

(RTDs) and thermistors are the three types of temperature sensors which are most commonly used in HVAC systems (*Figure 5*) for measuring room, duct, water and surface temperature.

Thermocouples

Thermocouples make use of the current flowing in a circuit, consisting of two dissimilar metals which are joined at different temperatures – a reference temperature and the measured temperature. They are robust but not sensitive, and are normally used for high temperature measurement.

Resistance Temperature Detectors

RTDs make use of the variation in electrical resistance of a metal with respect to temperature changes. Platinum is the most commonly used metal in RTDs. The main drawback is its relatively high cost compared to copper, tungsten, nickel-iron alloys, etc.

Thermistors

Their working principle is similar to that of RTDs; they use the temperature-resistance relationship of a semiconductor, which exhibits a negative temperature coefficient of resistance. Typically, oxides of metals such as nickel, manganese, cobalt, copper and iron are employed. They are highly sensitive compared to RTDs. Also, they are relatively inexpensive. Because of these advantages, they are widely used in closed-loop control of air-conditioning devices and chilled water plant control.

Pressure Sensors

In HVAC application, capacitive, inductive and Piezo-electric pressure sensors are commonly used (*Figure 6*).

Figure 6: Different types of pressure sensors

Capacitive Pressure Sensors

A metallic diaphragm for one capacitor plate with the other plate positioned alongside of the diaphragm is shown in *Figure 7*. They are small in size with high frequency response, can operate under high temperature and allow both static and dynamic measurements. Typically, the range of measurement is from 69 Pa (0.01 psi) to 68,900 kPa (10,000 psi), with an error of 0.25%. Some products accurate up to 0.05% are also available. They are usually applied to measure differential pressure of ventilation filter and VAV system fan control.

Inductive Pressure Sensors

The mechanism is based on the relative motion of a core and the inductive coil. Inductive pressure sensors sense the pressure by moving a mechanical member which is used, in turn, to change its inductance. A motion of about 0.08 mm produces an output voltage of 100 mV for this kind of sensor. Therefore, these sensors produce a high output, responding to both static and dynamic measurements, providing continuous resolution and having a high signal/noise ratio. They are usually employed in relatively low-pressure applications of ventilation systems.

Piezo-electric Pressure Sensors

When a crystal is stretched or squashed, it results in the opposite faces of the crystal getting positively and negatively charged. This leads to a potential difference across the crystal, which is referred as piezo-electric effect. This type of sensor is used for widely fluctuating pressures.

Flow Rate Sensors

In HVAC control, measurements of air flow rate and chilled water flow rate are very important as their accuracy directly affects the performance of control actions. There are several flow-rate sensors available and each of them serves some specific purposes, for example, pitot tubes, orifice plates, venturi meters, hot wire anemometers and turbine flow meters.

Pitot Tubes

They are essentially for in-duct ventilation applications and are based on two open ended tubes; one mounted to face the air stream and the other being perpendicular to the air stream. Refer *Figure 8*. The difference in pressure measured between the two tubes can indicate an air velocity based on the Bernoulli equation. This method is common and highly robust. Accuracy depends very much on the

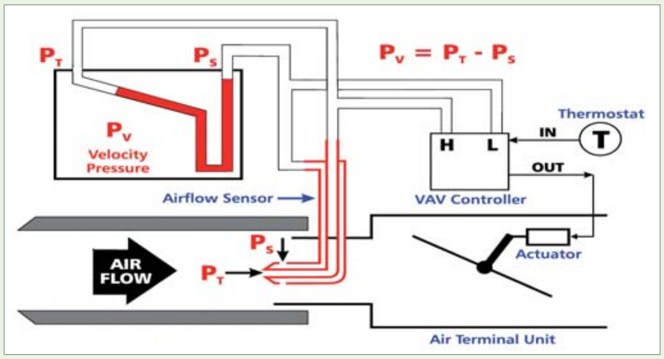

Figure 8: Pitot tube used for flow measurement in VAV box

number of sampling measurements taken across the duct, and upon the instrument for differential pressure measurement.

Orifice Plates

These are based on a pressure difference across the pipe or duct by the actions of throttling the flow through an orifice and measuring the pressure difference. They are simple but prone to wear when used with liquids, especially those carrying small particles of dirt. They were used extensively in the past for piped liquids. Usually, HVAC retrofit projects employ most of them for existing installations due to their simple construction.

Venturi Meters

They have a similar working principle as the orifice plate except that they have a gradual reduction in the pipe or duct bore forming a throat section, instead of an abrupt orifice, and there is gradual enlargement to full bore downstream. Thus, pressure loss at the contraction is almost entirely regained. One distinctive advantage is that a venturi meter is not prone to wear. However, it tends to be large and expensive.

Hot Wire Anemometers

These are essentially for ventilation airflow measurements. The hot-wire anemometer is sensitive enough to detect flow at a very low speed, making it suitable for free air movement measurement as well as in-duct flow measurement. It can be used over a large range of flows, from very low (e.g. 0.03 m/s) to supersonic and is able to measure unsteady flows. For in-duct flow measurement, it is less robust than the pitot method.

Turbine Flow Meters

They are used mainly in liquid-in-pipe applications and are susceptible to wear and clogging, and are unsuitable for dirty flow streams. Until relatively recently, these meters were the predominant choice for BTU meter applications in hot water and chilled water systems.

Humidity Sensors

These sensors fall into four categories – hygrometers, psychrometers, electronic humidity sensors and dew point sensors. Refer *Figure 9*. Humidity measurement has long been problematical because electromechanical hygrometers have suffered from serious non-linearity and there is a tendency to drift, whilst the more recently developed electronic sensors are prone to contamination in the air stream. Nevertheless, certain electronic sensors are steadily improving in terms of accuracy, long-term stability and tolerance to contaminants.

Figure 9: Different types of pressure sensors

Hygrometers

They are based on the earliest developed method by using naturally found materials, which change dimensionally with moisture absorption and desorption. They are highly nonlinear and prone to drift. They have now been replaced by electronic devices.

Psychrometers

Placing a distilled water-wetted wick around a conventional temperature sensor (e.g. RTD) results in the reduction of wet-bulb temperature, which can be related to the relative humidity. This is robust and potentially accurate. The difficulty is that the speed of air passing the wick must be high enough, which makes it not so suitable for HVAC control.

Resistive and Capacitive Sensors

These are probably the most widespread, commercially available electronic sensors used today and modern devices have improved sensitivity, up to 2% in relative humidity. Another advantage is that this type of sensor tends to have better immunity to contaminated air streams than other electronic types. However, this family of sensors suffers easily from impairment and, in some cases, the damage may be irreparable if operated for a significant period of time at a humidity level higher than 90% - a frequent requirement for in-duct measurement and fresh air measurement.

Dew Point Sensors

There are generally two types on the market, i.e. the chilled mirror sensor and the saturated salt solution device. The chilled mirror sensor has been popular for dew-point and humidity measurement for a long time and is capable of detecting dew-point with accuracy up to 1K. It has a mirror whose temperature is controlled until dew starts to form on its surface. Then, the relativity humidity can be estimated. The saturated salt solution device consists of an RTD surrounded by a wick, which is impregnated with lithium chloride solution. A heating element is used to control the temperature of the wick until a stable condition is achieved and the power from the heating element is just enough to supply the latent heat from the wick. At this point, the temperature measured by the RTD is equal to the dew-point temperature (*Figure 10*).


Figure 10: Dew point sensor

Comfort Sensors

Comfort is not a directly measurable parameter. It is based on the Fanger's equation that considers six parameters altogether – metabolic rate of occupants; clothing insulation of occupants; dry bulb temperature; moisture content (in terms of water vapor pressure); wind speed; and mean radiant temperature – to estimate a 'Predicted Mean Vote' (PMV). PMV is believed to be able to model the sense of comfort of most human beings. A negative value of PMV implies a cool feeling while a positive one implies a warm feeling. The PMV criteria have been included as an international standard, ISO 7730. Instruments that measured the four non-human related parameters had been available for decades. The first comfort sensor that was practical for HVAC control and integration with the building automation system was manufactured in Japan more than twelve years ago, as shown in *Figure 11*, consisting of a sensor unit and a processor unit. The sensor detects the perceived temperature consisting of air

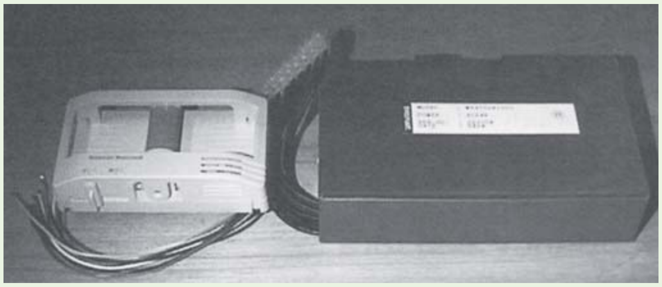

Figure 11: A comfort sensor

temperature, mean radiant temperature and air speed, while the processor unit converts them into an electrical signal. In this sensor, a new PMV equation has been developed by simplifying the original equation, and the new equation is for the building instead of the human occupants. In this way, the comfort level inside a room can be estimated for real-time control purposes.

Indoor Air Quality Sensors

See *Figure 12*. An indoor air quality sensor non-selectively measures the concentration of all oxidizable gases collectively. It consists of a tube coated with a thin film semiconductor, a pair of electrodes and a miniature heating element inside the tube. Maintained at a constant temperature, the semiconductor absorbs the gases emitted from the occupants, resulting in the releasing of electrons, which in turn alters the resistance across the two electrodes to produce a signal. The process is bi-directional. Though the predominant human emission of carbon dioxide is not measured, the sensor measures a combination of gases emitted from human beings and such a combination is proportional to the carbon dioxide content. This instrument is sensitive and has a reasonably fast response time making it quite suitable for IAQ applications in comfort ventilation and air-conditioning applications.

There are electrochemical cells that are liquid-state electrolyte

Figure 12: Different types of CO_2 sensors

sensors; Lambda probes which are solid-state electrolyte sensors; metal oxide sensors, Figaro sensors and conducting polymers, all of which are electronic conductance and capacitance sensors; field effect sensors, pellistors which are calorimetric sensors; infrared cells, fiber optics sensors which are optochemical and photometric sensors; and quartz microbalances which are mass-sensitive sensors.

Occupancy Sensors

See *Figure 13*. For energy conservation, it is essential to detect the occupancy of a room to make sure electrical appliances, such as lighting and air-conditioners, are only turned on when they are required by the occupants. Therefore, occupancy sensors have two main tasks: keeping the lights or air-conditioners on while the room is occupied and, conversely, keeping the lights or air-conditioners off when unoccupied. Commercially, there are two kinds of occupancy sensors, namely ultrasonic motion sensors and infrared motion sensors. Each of them has its own characteristics.

Ultrasonic Motion Sensors

This sensor makes use of the Doppler effect. It fills the room with continuous high frequency (ultrasonic) sound waves. Any movement within the sensor's range causes a shift in the originally emitted frequency due to the Doppler effect. The sensor then identifies any change in frequency of the received sound wave by comparing it with that of the emitted wave. High sensitivity to small movements is the distinctive feature of this sensor. Typical applications include offices, restrooms and small conference rooms where occupants are sitting in place for extended periods of time. However, this kind of sensor is vulnerable to false triggering from air-conditioning currents, corridor activity and the movement of inanimate objects.

Figure 13: Different types of occupancy sensors

Infrared Motion Sensors

By sensing moving infrared heat sources such as people, forklifts or other heat emitting objects, the sensor is able to carry out appropriate switching actions on the lights or air-conditioners in a room. Infrared motion detection gives immunity to false triggering due to air currents or fans, i.e. it is a more reliable motion sensor. However, at greater distances, its sensitivity is rather low. Typical applications for this sensor include work areas, storage areas, store-rooms, indoor garages and rooms with pendant fixtures such as overhead fans.

Subject to the advantages and drawbacks of the two kinds of sensors, it is advisable to use composite dual tech sensing. Using Infrared (IR) (high error immunity) sensing with Ultrasonic (US) (high sensitivity) sensing provides good performance. The signal strengths are added together to form a composite sum. The advantage of this method is that a weak IR signal plus a strong US signal will turn the appliances on because the sum is enough.

References

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Articles and presentations on BMS by Johnson Controls

In Part 3 of this Classroom series, in the January - February 2016 issue of the Journal, we shall continue with other Field Devices and introduce Control Electronics.