Building Management System

Part 6

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Control and Performance Optimization of HVAC System through BMS

Introduction

In this Classroom series on BMS, we have limited our discussions to only HVAC systems and equipment in a building. The very reason for installing an HVAC system in a building is to deliver thermal comfort and indoor air quality (IAQ) to the occupants of the building. The higher level of concern, obligation and commitment towards energy and environment from all stakeholders involved in a building design, make it essential to optimize the HVAC system performance and control techniques. The BMS is a key tool, which enables and delivers these key results.

Let us understand the concepts of thermal comfort and IAQ and various control strategies for chillers and air side equipment to optimize the HVAC system's thermal and energy performance.

Thermal Comfort

ASHRAE Standard 55 – 2005 defines Thermal Comfort as the condition of mind that expresses satisfaction with the thermal environment. Comfort also includes behavioral actions initiated by the conscious mind and guided by thermal and moisture sensations to reduce discomfort. Comfort is not a directly measurable parameter, the way temperature or RH is. ASHRAE Standard 55 also stipulates that at least 80% of the occupants shall be satisfied with the comfort conditions.

Based on research, PMV (Predicted Mean Vote) is considered as a true indicator of the comfort of occupants. As per ISO 7730: 2005, PMV is a derivative of analyzing six components: (i) metabolic rate of occupants, (ii) clothing insulation of occupants, (iii) dry bulb temperature, (iv) moisture content, (v) wind speed, and (vi) mean radiant temperature. The average scale of PMV is described over a scale of (-)0.5 to (+)0.5. A negative value implies it is too cold, and a positive PMV value indicates it is warm.

Though the PMV sensors (*Figure 1*) were developed and demonstrated two decades ago, they are not practical to use and designers prefer to measure dry bulb temperature and RH in the occupied space as a measure of comfort, than PMV. Space temperature in the Indian context is usually monitored near the false ceiling, say for a VAV box control, or in the return air plenum above false ceiling for an AHU. These measurements could be indicative of approximate space temperature, but many times do not reflect the actual occupied space conditions in different zones, especially the perimeter zones. Measuring space temperature

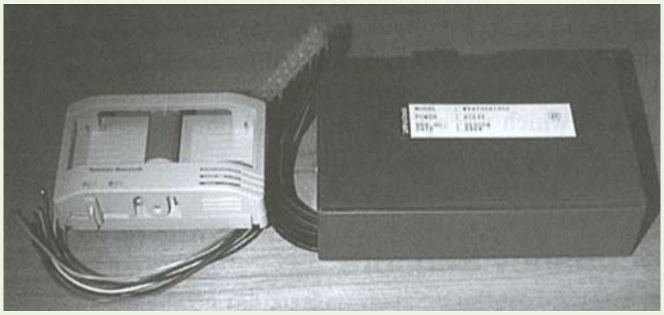

Figure 1: PMV sensor

at different locations in an occupied space could let the facility managers understand any issues in uniform air distribution and to keep track of temperature trends. If this tracking is done, it will also enable improving air distribution in the space and evaluating the possibility of increasing the set point suitably for energy conservation.

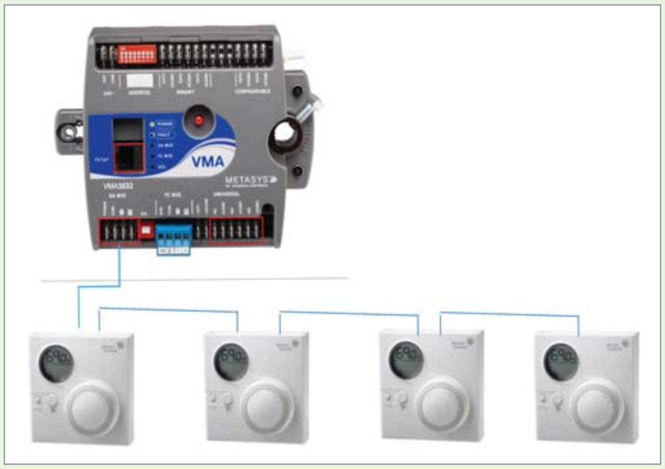

Figure 2: Networking type temperature sensor

The networking type temperature sensors that are available with VAV boxes facilitate use of multiple temperature sensors (*Figure 2*), and their controllers could be set to either carry out temperature averaging of different sensors or to go with polling.

About the Author

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Indoor Air Quality

In modern buildings, indoor air is increasingly becoming more hazardous than the outdoor air. ASHRAE Standard 62 specifies IAQ norms widely referred by the HVAC industry. IAQ could be expressed in terms of the following parameters:

1. Room temperature, RH and air movement.
2. Different types of gases that are found in nature, but excessive for human consumption in offices – like carbon dioxide, carbon monoxide, radon, ozone and formaldehyde.
3. Volatile organic compounds (VOC) like benzene, chloroform and xylene found in paints, carpets, curtains, office furniture, etc.
4. Microbial contaminants (mold, bacteria) and suspended particulates in the air.

Table 1: IAQ objectives for office buildings – EPA guidelines

Parameter	Unit	8-hour Average	
		Excellent Class	Good Class
Room Temperature	°C	20 to < 25.5	< 25.5
Relative Humidity	%	40 to < 70	< 70
Air movement	m/s	< 02	< 0.3
Carbon Dioxide (CO_2)	ppmv	< 800	< 1,000
Carbon Monoxide (CO)	$\mu g/m^3$	< 2,000	< 10,000
	ppmv	< 1.7	< 8.7
Respirable Suspended Particulates (PM_{10})	$\mu g/m^3$	< 20	< 180
Nitrogen Dioxide (NO_2)	$\mu g/m^3$	< 40	< 150
	ppbv	< 21	< 80
Ozone (O_2)	$\mu g/m^3$	< 50	< 120
	ppbv	< 25	< 61
Formaldehyde (HCHO)	$\mu g/m^3$	< 30	< 100
	ppbv	< 34	< 81
Total Volatile Organic Compounds (TVOG)	$\mu g/m^3$	< 200	< 600
	ppbv	< 87	< 261
Radon (Rn)	$\mu g/m^3$	< 150	< 200
Airborne Bacteria	cfu/m^3	< 500	< 1,000

Table 1 shows the IAQ objectives for offices and public places published by EPA. The primary methods deployed in improving IAQ in buildings are (i) filtration of air, (ii) using ventilation air to dilute contaminants, and (iii) source control.

Use of nano-Titanium Dioxide (TiO_2) filters in the indoor unit (AHU coil, FCU, DX evaporator, etc.) has resulted in eliminating air-borne pathogens and other pollutants. VOC concentration has been on a decline over the last few years due to increasing customer awareness. IAQ audits are conducted in modern day buildings, which include collecting air samples to detect the presence of harmful gases like radon. From IAQ control point of view, the use of CO and CO_2 sensors is prevalent only in modern day buildings connected to a BMS. CO_2 sensor in the AHU room return air path control the amount of fresh air drawn in, as per the logic built in the BMS. In many commercial buildings, trying to incorporate best IAQ practices and compliance to Green building norms, CO_2 sensors are also used in specific zones like office cabins and conference rooms. These sensors are directly connected to VAV box controllers (*Figure 3*) and have a priority override over the zone temperature in controlling VAV box air flow rate into the served zone. This ensures that these zones get adequate fresh air to keep CO_2 levels lower.

BMS helps to store historical IAQ data on the servers to meet

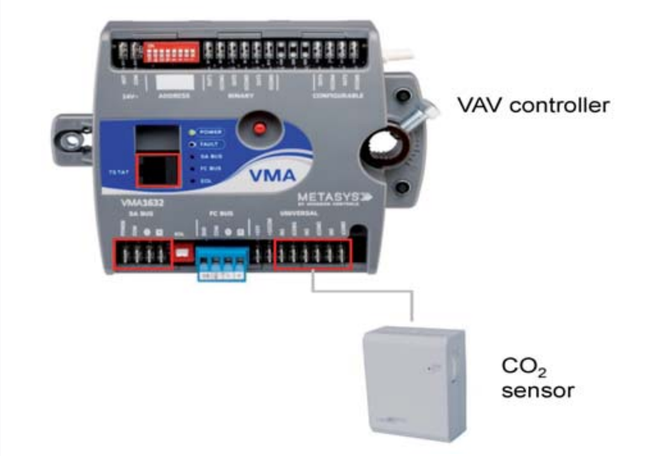

Figure 3: CO_2 sensor direct connection to VAV controller to control IAQ needs

any compliance requirements for the employers (like in the USA), and also facilitates evaluation of suitable energy conservation measures without compromising IAQ levels.

Air Side Control

Air side components can be considered as the interface between the HVAC system and the occupants. AHU and VAV box are the major air side equipment controlled through BMS. A typical AHU room also consists of quite a few field devices connected to the DDC, to perform specific functions:

1. CO_2 sensor in return air plenum, based on whose level the fresh air damper actuator is suitably driven to allow the required fresh air into the AHU room.
2. A smoke detector and fire damper, to shut air supply in the event of smoke and fire, to avoid propagation to more areas.
3. A valve actuator, mostly proportional type, on the chilled water line connected to the AHU chilled water cooling coil.
4. Control panel to drive the AHU blower motor. Whenever VAV boxes are used, the motor is driven by a VSD.
5. A duct static pressure sensor is located outside the AHU room on the main duct run approximately at 1/3rd distance. The exact location of the static pressure sensor for optimum performance is derived from a few iterations. The static pressure sensor input is considered for speeding up or down the VSD.
6. Many times a heat recovery wheel (HRW) is used to recover energy from the cold space air being exhausted and the hot outside fresh air being drawn into the AHU room. BMS can integrate the HRW, fresh air intake/exhaust air operations and also display the status on the UI screen.

The operating principle of VAV box was explained in *Part 1* of this series, and is not repeated here.

Energy Optimization Strategies

BMS is a very useful tool for collecting raw data, carrying out simple analyses and alerting the operator on abnormal conditions happening in the HVAC system in the facility. All the raw data could be presented in a simple spreadsheet (excel) format, helping the user to analyze, visualize and create the required reports.

The following six energy optimization strategies offer very good potential for energy saving in commercial buildings: (1) day-night mode, (2) occupied/unoccupied mode, (3) optimal start-stop, (4) equipment interlock, (5) duty cycling and (6) demand limiting. Let us understand exactly what measures are deployed to conserve energy. In all these methods, the thermal comfort, IAQ, safety and security of people and premises are always ensured without any compromise.

Day-night Mode

This strategy applies to the entire building, all days of the week. This involves changing the operating mode of the entire building between 'day mode' and 'night mode', to save energy. A few examples are (a) bringing on the exterior light during the night and turning it off during daytime, and (b) keeping the light in an enclosed parking lot at full level during daytime and at half or 3/4th level at night.

The day and night mode setting is not done through the time scheduling feature in the supervisory controller; it is done through a special program in the BMS software, which uses trigonometric, date and time functions to calculate the sunrise and sunset time for each specific day. Refer *Figure 4*. Fixed offsets can then be added so that the building could switch to day mode 30 minutes after sunrise and to night mode 10 minutes before sunset. A daylight sensor is added to the BMS to account for cloudy days in the calculation.

Occupied/Unoccupied Mode

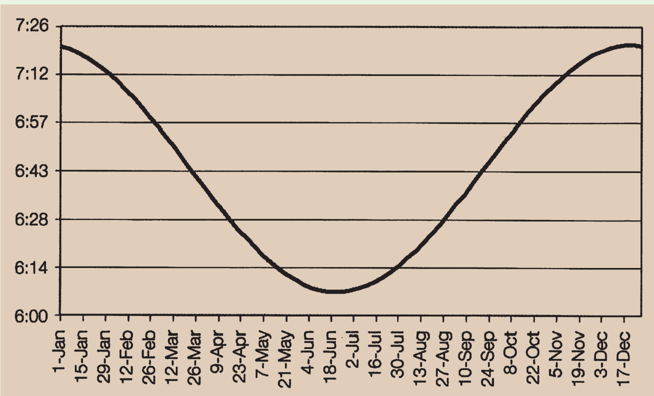

Figure 4: Calculated day-mode switching time

This strategy is applied only for specific zones, and it saves energy because the equipment will use less energy when operating in the 'unoccupied mode' compared to the 'occupied mode'. The level of savings from this measure will depend upon the granularity (detailed study and analysis) of zoning. A large number of zones will allow precise control and larger energy savings.

A few examples of the application of this technique are (a) specific zones conditioned by VAV boxes, like cabins and conference halls, (b) control of individual lighting circuits rather than entire distribution boards, and (c) control of fresh air intake to different areas like office, canteen and gym. A rewarding approach could be defining all the controlled application zones as 'unoccupied' by default, unless the mode is switched to 'occupied'. It is very important to understand that though these measures could be built-in right at the design stage, the real benefits could be leveraged and enhanced only by analyzing actual use data through a BMS. Refer *Figure 5*.

In BMS, switching to occupied mode could be done in several ways, like (i) card access system, (ii) occupancy sensor, (iii) door lock indicator, (iv) telephone request, which deploys a voice prompting system with passwords, (v) web browser with limited and specific access, (vi) e-mail, and (vii) facility booking system.

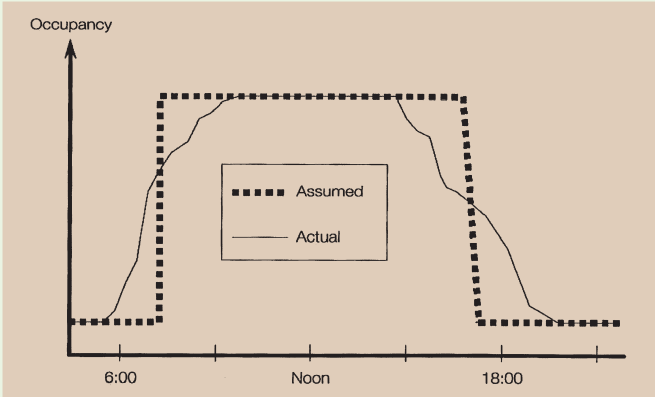

Figure 5: Occupancy pattern 'actual use data' from BMS

Optimal Start-Stop

This strategy is deployed to adjust and optimize the start time and stop time of AHUs so as to reduce daily run time, thereby saving energy. The optimal start measure uses temperature sensors for outdoor air and space air and, depending on the outside weather, suitably adjusts the time duration for 'prior starting of AHU' before the occupants start arriving. The algorithms used in BMS for optimal start are adaptive in nature and learn the characteristic response time for the space to make the required adjustments. Fresh air dampers are kept closed during the start-up time.

The optimal stop method checks the difference between outside temperature and space temperature and suitably turns off the air conditioning before the scheduled office closure time. Instead of turning off the AC, which could result in complaints from occupants not sensing the air flow, a bias could be added to the set point to save energy. The thermal mass of the building ensures that the space temperature always remains within the comfort zone.

Equipment Interlocks

Coordinating the operating functions of different equipment through interlocking helps to reduce energy consumption. A few application examples are (a) parking lot ventilation fan control based on CO sensor, and (b) kitchen ventilation fan control with actual kitchen activity (else it always keeps running).

Duty Cycling

In the HVAC system, chiller, fan, pump, etc. are all designed for peak load conditions, which exist only for a few hours in an entire year. The equipment operate at part load for the rest of the year. Duty cycling looks at the possibility of turning off the equipment for a short interval to meet energy saving targets, without compromising comfort and IAQ. The equipment turning off and on happens at a fixed interval in a cyclic manner, as shown in *Figure 6*.

Duty cycling has an associated 'comfort override' point. But

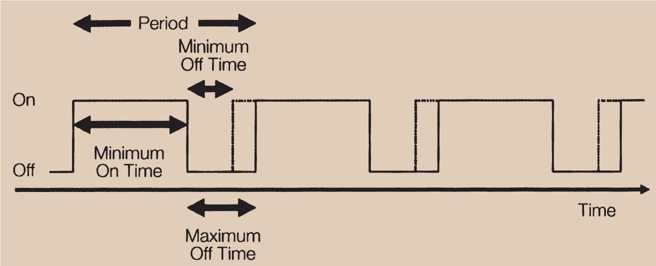

Figure 6: Duty cycling parameters

when comfort overrides in the alarm state, the equipment is no longer turned off.

Demand Limiting

In this strategy the BMS monitors power consumption over a sliding 15-minute interval and then compares the projected demand with the user-defined target for maximum demand. Based on the outcome, the BMS automatically sheds load (auto turn-off) or increases set points to ensure that the demand stays below the target.

The control requests for demand limiting are integrated with control requests for duty cycling, as they share a common 'load table' (*Figure 7*). This calculation can result in low, normal or aggressive shedding. Refer *Figure 8*. On specific evaluation of cooling capacity requirement and load limiting, the BMS could also advise the operator when to start the generator, so that future peaks are avoided and the cost is justifiable.

The key to applying Demand Limiting strategy is to use the

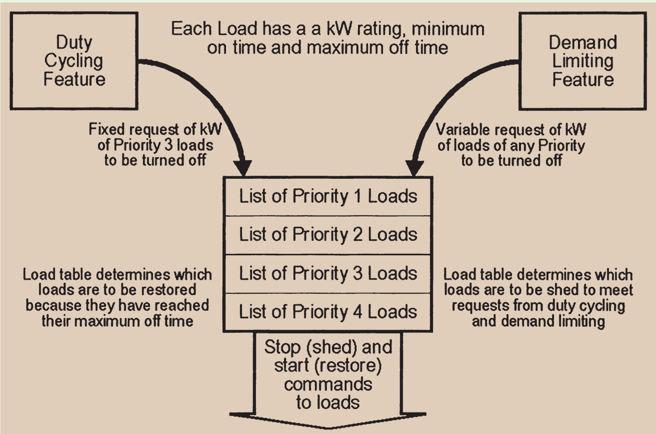

Figure 7: Load table for demand limiting and duty cycling

trend feature of BMS to create a load profile showing how the demand is varying throughout a typical day. Refer *Figure 9*. A

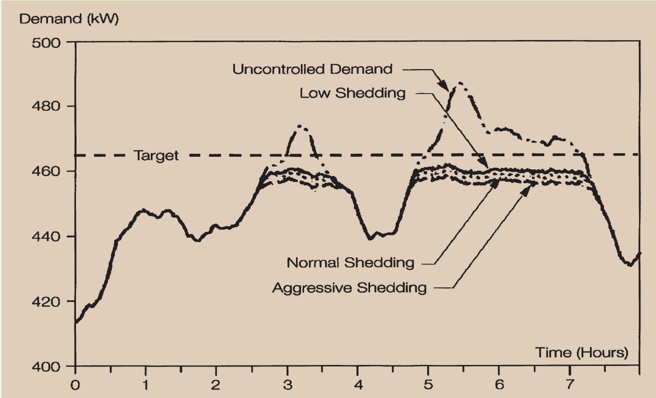

Figure 8: Demand limiting impact on power consumption

visual analysis of this load profile points out the time of day when maximum demand occurs and a reasonable maximum demand target to pursue. The demand limiting feature in BMS also warns the operator when the demand target will be exceeded, so that manual efforts can be made.

Note: *The demand limiting feature of BMS is highly beneficial in*

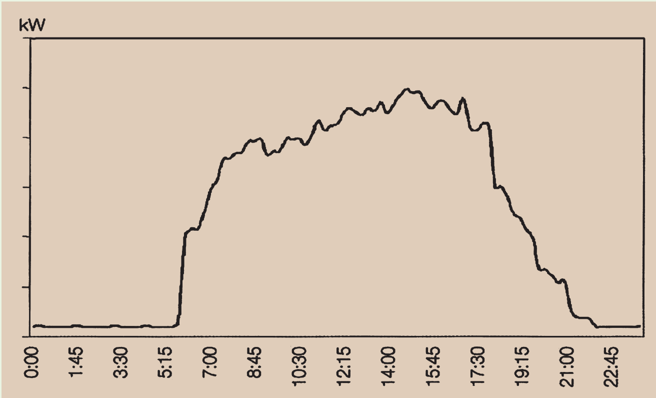

Figure 9: Typical load profile of an office building

developed countries like the USA, where the electricity utility industry is de-regulated and service providers offer attractive hourly tariffs. In India, a few states do offer different tariff during daytime and night-time, where this BMS feature will be highly useful.

Intelligent Chiller Control Strategies

One of the ideal strategies for a chiller is 'plant optimization', as the chiller accounts for the highest energy consumption within a modern commercial building. Given below are some of the strategies that are adopted to derive energy saving benefits.

Plant Start/Stop Time Reset

This method delays the starting of the plant in the morning and advances the stop time in the evening. Refer *Figure 10*. The BMS incorporates an adaptive calculation based on the difference between the outdoor ambient and space set point temperature. 'Few minutes early' stop of the plant does not affect the thermal comfort of people, as the significant thermal mass of the building keeps the occupied space cool.

Resetting Leaving Chilled Water Set Point with Constant

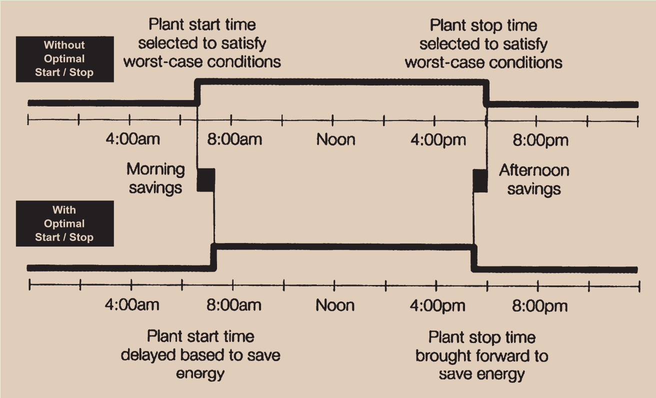

Figure 10: Optimal start/stop strategy

Primary Flow

A primary-only constant speed pump chiller schematic is shown in *Figure 11*. Increasing the leaving chilled water set point by 1°C reduces chiller energy consumption by 1 to 1.5%. In this control strategy the chilled water valve actuator position of different AHUs, as monitored by the BMS, is analyzed and a decision is taken to slightly increase or decrease the chilled water set point. Refer *Figure 12* for the decision making process followed.

If POSMAX (Position Maximum of the valve actuator) is less than 70%, we could increase the chilled water set point by 0.2°C, which will result in all valves opening slightly more to continue to satisfy the cooling load. For every adjustment of the set point, we need to wait for approximately 20 minutes for the system to stabilize and a new POSMAX to be established, before going through the cycle again to make the next reset.

BMS helps in this strategy with a 'valve report', a simple database application with a point history file. The valve report analyses the historical position of all valves in the system and prepares a report, to help in the above reset strategy.

Cooling Tower Water Temperature Reset

Reducing cooling tower outlet water temperature by 1°C could save about 3% energy in centrifugal chillers. The cooling tower outlet water can be controlled to remain as close to possible to the 'ambient wet bulb temperature + cooling tower approach'

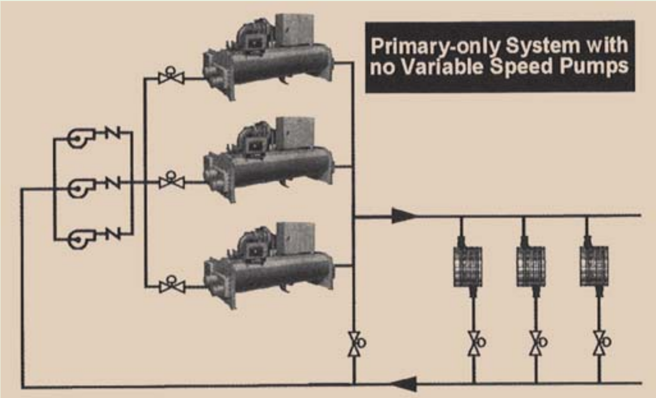

Figure 11: Primary-only chiller system

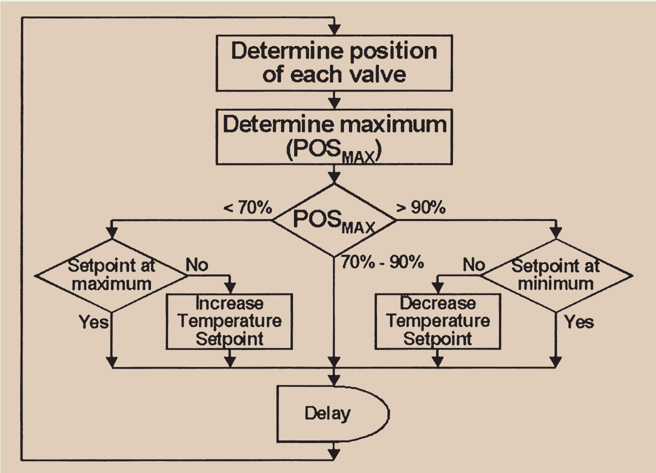

Figure 12: POSMAX and chilled water reset process

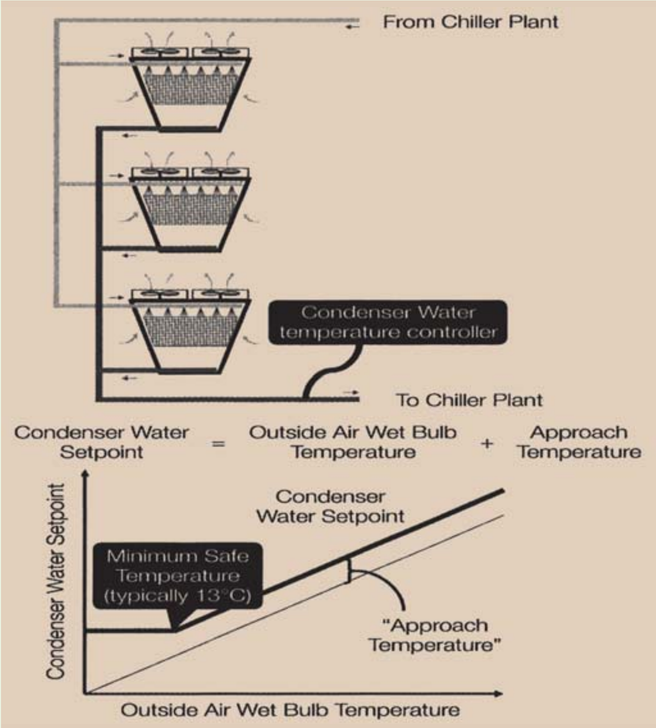

Figure 13: Cooling tower outlet water temperature reset

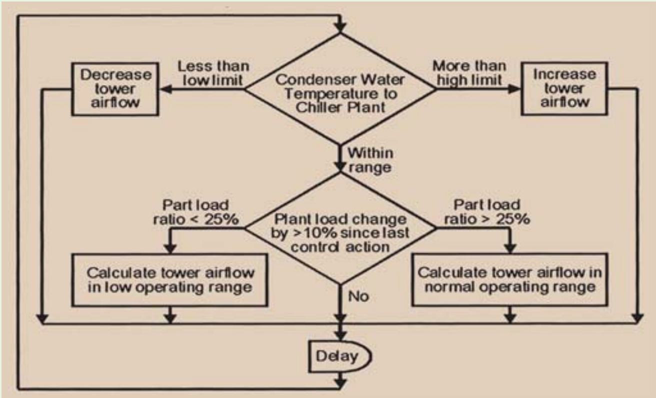

Figure 14: Cooling tower outlet water temperature 'near optimal' strategy

level. Refer *Figure 13*. Cooling tower fans are usually fitted with VSD in this method. This control strategy is shown in *Figure 14*.

Chiller Optimization Using Variable Speed Drives (VSD)

This strategy uses VSD for pumps, fans and chillers. A VSD centrifugal chiller could save 30% energy compared to a constant speed centrifugal chiller. The challenges in optimizing the control strategy for VSD pumps are similar to those for AHUs connected to VAV boxes. The VSD pump optimization algorithm resets the differential water pressure set point to optimize energy saving, which is based on the valve positions in AHUs. The valve report generated by the BMS is useful in optimizing the pump set point.

When a plant has multiple chillers, a chiller sequencing strategy is deployed for energy saving and comfort. For this, the capacity demand and flow demand are monitored and analyzed to suitably choose and run the required combination of chillers. Refer *Figure 15*. The relationship between capacity and flow for a building load is non-linear. Once a chiller sequencing program is designed, it must be fine-tuned. Chiller fine-tuning is a slow and iterative process. The BMS helps to fine-tune the parameters of chiller sequencing program.

Conclusion

From the above discussion, it becomes evident that BMS is a crucial and integral element of building design to deliver thermal comfort to occupants, ensure IAQ and optimize the energy performance of the HVAC system through various strategies. BMS makes available a lot of data, trending, building load profile, valve report and other relevant information, which facilitates appropriate decision-making in deploying the strategies.

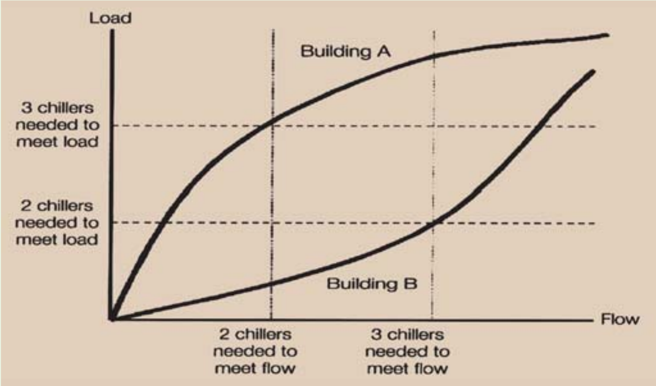

Figure 15: Chiller sequencing matched to building requirement

References

1. *www.epa.gov*
2. ASHRAE Fundamentals Handbook 2013
3. Albert Ting-pat So and Wai Lok Chan, *Intelligent Building Systems,* published by Johnson Controls
4. Different articles and presentations on BMS by Johnson Controls

In the concluding Part 7 of this Classroom series, in the September-October 2016 issue of the Journal, we shall discuss the latest trends and the next level of BMS control techniques.