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Building Energy Management Systems (BEMS) control strategies for air conditioning efficiency

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Authors of this volume
Marco MASOERO (Politecnico di Torino, Italy)
Chiara SILVI (Politecnico di Torino, Italy)

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Building Energy Management Systems (BEMS) control strategies for air conditioning efficiency

This guide wants to illustrate in a more detailed way the many opportunities that BEMS offer in general to reduce the energy consumption and improve the operation of the air conditioning systems.

In order to optimise a system, it is important to understand basic BEMS capabilities. Features may vary widely from model to model, but some basic capabilities are almost universal. In this document the interest is focused upon energy management. The standard BEMS capabilities described hereunder are:

- Scheduling
- Set-points
- Alarms
- Safeties
- Basic Monitoring and Trending
- Energy and Demand Control
- Contract agreements

1. Scheduling

Energy management systems are sometimes referred to as “glorified time clocks” because many of their capabilities are frequently disabled or eliminated. In the past, these glorified time clocks have not even done a good job of scheduling. Today's systems, however, allow for greater flexibility in scheduling, defining not only ON/OFF times, but set-points as well. With multiple scheduling scenarios available in most BMS, even elementary time clock and scheduling features can offer significant savings. Clearly, the first step in smart scheduling is to shut down unnecessary equipment when it is not needed. Given the complexity of a building and the amount of equipment with potentially different schedules, this task requires some effort, but taking control of schedules may still be the quickest and simplest way to see an immediate reduction in energy bills. It is recommended that you check on schedules periodically to assess whether they still apply. Zone HVAC schedules have to be consistent with lighting and occupancy schedules. Lighting sweep schedules, which turn off lights at scheduled times, should be set so that they work for tenants and cleaning staff to minimize both lighting on-time and nuisance overrides. In addition, the following BMS capabilities should be investigated and used to reduce unnecessary equipment use.

*Daily Scheduling*. Many BMS software packages provide for up to 5 or 7 user-configurable start-and-stop schedules for each piece of machinery for each day of the week. Customize these schedules to fit your needs and reduce the time equipment is running unnecessarily.

*Calendar Scheduling*. In addition to typical holiday schedules, calendar scheduling allows for greater flexibility in BMS operation. Schedules can be programmed to service unusual events such as production schedules or seasonal changes in occupancy or occupancy hours. The BMS operator can enter schedules for any number of control points for any date during the year. Depending on the BMS software, calendar schedules may be erased once the dates have passed and schedules were successfully implemented. Alternatively, the scheduled dates may repeat in subsequent years (as is the case with holiday schedules). Calendar schedules allow the building manager to automatically provide space conditioning only when and where it is needed. Automatic conversion to and from daylight savings time is another convenient feature in many systems.
Exception Scheduling. If there is an exception to the regular schedule (e.g., a half day or longer hours than normal), this feature allows you to program the exception for that day only rather than changing the regular schedule. Once the exception period is passed, the program returns to the original schedule.

2. Set-points

Set-points range from those inside equipment logic, which are rarely changed, to space temperature set-points, which seem to need constant adjustment. Some set-points are defined by the operator and associated with a schedule; others may be adjusted by internal calculations of the program (e.g., reset temperatures or pressures).

Space Temperature Set-points. The building manager’s job, among other things, is to maintain occupant comfort while identifying ways to reduce energy consumption. Controlling the space temperature may be the single most time-consuming and problematic task a building operator deals with. Often, the possibilities for reducing energy use by altering space temperature set-points are not investigated for fear of adversely affecting comfort. This may be the case at times, but large multi-zone buildings with digital demand control DDC can present opportunities to move beyond a traditional building-wide Set-point. The following information should be reviewed when considering space temperature set-point changes:

- Time of day
- Number and fluctuation of occupants in zone
- Humidity conditions
- Size of zone
- Location of zone
- Zone exposure (perimeter or core, south or north, etc.)
- Impact on reheat or simultaneous heating and cooling
- Impact on pumping, fan, or plant efficiency
- Equipment in zone (e.g., computers or laboratory equipment).

Consideration of all these factors could lead, for example, to a well-justified decision to allow the afternoon summer temperature in a north-facing zone to drift up (e.g. by 2 degrees). Additionally, since comfort is a function not only of space temperature but also of radiant temperature (direct sunlight), airflow, and humidity, an entire floor of tenants with sedentary jobs could have a warmer set-point than a floor of more active workers. It is important to carefully analyze the net impact on adjusting space set-points. For example, increasing the zone set-point during the swing season to save cooling energy may result in increasing reheat energy in zones that require reheat.

Dual Set-point Control (Dead-band). The most common strategy for optimizing space temperature set-points is to have separate heating and cooling set-points or one set-point with a wide dead-band. This lowers the potential for simultaneous or overlapping heating and cooling, thereby reducing wasted energy and comfort complaints.

Other Set-points. The building operator should be familiar with a number of other basic set-points. It is critical to have an understanding of the purpose behind each set-point and the impact on energy and other systems when the set-points are altered. An up-to-date consolidated list of all primary set-points as part of the system documentation is very useful.
3. **Alarms**

Registering and recording alarms is a critical part of any BMS. In addition to basic alarm functionality, a BMS provides options in specifying how alarms are monitored, reported, routed, and ultimately dealt with. For any monitored or controlled point, most systems’ basic alarm functions can be set up to register and display the following:

- Equipment failures
- Sensor failures
- High parameter value (temperature, pressure, etc.)
- Low parameter value (temperature, pressure, etc.)
- Invalid temperatures (sensor is being tampered with)
- Manual override of machinery at remote locations
- Communications problems

**Alarm Features.** Alarms are fundamental and critically important, so most systems will need little or no extra configuration to provide basic alarm functionality. However, building managers benefit from alarm-handling features that assist in formulating a quick and accurate response. Alarm messaging provides extra information on the source of the alarm, such as the state of the equipment when the alarm was generated. Additional messages can sometimes be attached to alarms as well. Alarm routing is a feature that gives flexibility in delivering messages to a prescribed series of outputs (e.g. computer screens, printers, or remote monitoring sites via modem). In addition, some systems have a paging feature that works with alphanumeric pagers where the actual alarm text with current point value is displayed on the pager. Responses for some non-critical alarms can be dealt with via automatically pre-programmed alarm handling routines. Often there is a distinction between an “alarm” and a “warning.” A point may generate a warning if it is slightly out of range but an alarm if it is significantly out of range. Once the operator understands the alarm programming of the BMS, there is often latitude to use some creativity in defining points and alarms. For example, the difference between a temperature and its set-point may be a more relevant point to alarm than the temperature itself. Alarms are a potentially powerful tool to be used in managing a building, but if not well defined they can become an annoyance or even worse.

**Nuisance Alarms.** If alarms are poorly defined and too easily set off, the operator may acknowledge alarms without review just to get rid of them. This could cause real problems if a significant alarm comes in. A log should be created of all alarms to be reviewed periodically to improve the alarm rules and limits. For those facility managers who have little time to do anything but respond to alarm after alarm, this approach is worthwhile. Furthermore, if enhanced alarm handling features are available but underused, it may be that full utilization will result in faster problem-solving response time and better documentation for future reference.

4. **Safeties**

Safeties are sequences programmed into a BMS that are automatically initiated to protect equipment, property, or life. The condition that initiates the safety sequence may also generate an alarm (e.g. high duct static fan shut down, freeze condition fan shut down, etc.). Using safeties can protect equipment and the building itself from damage and may also reduce or
eliminate the need for alarm reporting to remote sites to engage an after hours emergency service call. For example, a high-water condition in the cooling tower may indicate a clogged intake screen or faulty make-up valve. This condition is serious enough to require immediate attention for a tower without a separate float control. After hours, an alarm would be required to sound offsite for immediate service. A safety sequence would simply close the make-up water valve and/or shut down the chillers until the normal facility operators could deal with the issue the following morning. Safeties that protect life and equipment (freeze-stats, high pressure limits, and smoke detectors) should not rely on software and programming functions to work—they should be hardwired.

5. Basic Monitoring and Trending

In addition to controlling equipment, BMS has the basic capability to monitor or record various parameters of equipment operation. In BMS terminology, monitoring is referred to as trending. Trending can be executed on most points that control equipment, for other monitored-only points that may have been installed, and for some software or virtual points (calculated values such as resets). Monitoring and trending through BMS offer significant advantages over other data measurement methods. With the sensors already in place to monitor equipment, the cost of monitoring through BMS is often less than that of purchasing or renting other devices or taking spot measurements with handheld instruments. The communications structure of BMS facilitates monitoring many data points simultaneously. Since trend data are an actual record of performance, BMS trends are often used to verify equipment operation, energy conservation project results, and energy savings performance contracts.

**Trending Points.** Ideally, the BMS should be capable of providing the following types of information:

- Temperature
- Pressure
- Damper and valve position commands, including variable frequency drive control signals
- Virtual points (internal calculations such as enthalpy or changing set-points and targets)
- (ON/OFF) status or stage
- Flow rate (water or air)
- Alarm state
- Current
- Power demand (kW)
- Energy consumption (kWh)
- Revolutions per minute (RPM)

Some types of data points are not commonly used because of the cost of their sensors or transducers. These include air and water flow rates, power demand and energy consumption. If a necessary point is not available, it is usually a simple matter to add it, especially when there are open input channels in the panel.

**Basic Trending.** There are two basic trend types—a data stream and a change of value (COV). In a data stream, the BMS at each time interval gathers the current value of a data point and stores it with the exact time the parameter was polled. A COV trend records the time and parameter value only when the parameter changes by a preset amount. Instructions can be
given to the BMS to track more than one data point at the same time. The data is stored in the control field cabinets or the central computer. When the cabinet memory is full, it may download the trend data to the central computer’s hard drive or begin erasing the oldest data. It is important to understand how to set up this memory and data management in your system. The data can be retrieved and viewed in a tabulated numerical form on the computer screen or on a hard-copy printout or, preferably, by a graph of the data. Many energy management systems have features that allow trend data to be viewed graphically. Some even provide a real-time view of the graph as events are actually happening, although these tools are typically inflexible. For more rigorous graphical analysis, the data may be exported to a commercial spreadsheet program. BMS software will typically have some default trend plots (sometimes called history logs) already set up in the system. Other custom trends can be set up and initiated at will.

6. Energy and Demand Control

Many of the strategies for saving energy or improving building control require only set-point changes to current programming, others may require some control programming. Each strategy consists of set-points, parameters and sequences that will ultimately determine how successful the strategy is for saving energy or improving building control. Often, energy saving strategies are nominally incorporated, but because of faulty sequence logic or ineffective parameters, the strategy does not meet its potential. For example, resetting the entering condenser water temperature set-point from the cooling tower to be equal to the outside air dry bulb temperature is not nearly as effective as setting it equal to the outdoor wet bulb plus five degrees. Question your design engineer, energy consultant, or reference materials about the most effective settings for each strategy used.

Scheduling

Holiday Scheduling. BMS software will typically provide for holiday schedules. These schedules could be as simple as a full-day shutdown at setback levels (such as a typical weekend day) or could be a partial shutdown of the facility for various hours of the day. Holiday schedules can be programmed a year or more in advance, often for 26 or more special holiday schedules. Each holiday can be designated as a single date or a range of dates for extended shutdowns. This feature reduces unnecessary energy use on unoccupied dates.

Zonal Scheduling. Zonal scheduling refers to controlling HVAC system at the zone level with schedules, so that unoccupied areas can be shut down. Ideally, this means that when a space is unoccupied, the dampers of the terminal units go past minimum to shut. The zone terminals do not open (except to maintain a low or high limit) until the zone is occupied (controlled by occupancy sensors or tied to light switches, etc.). This saves energy during generally occupied periods and greatly saves during afterhours overrides.

Override Control and Tenant Billing. When tenants need to work in the building outside of normal schedules, manual override is often used to obtain heating, ventilating, or air-conditioning. This feature allows the operator to take control of any piece of equipment as needed. Override of automatic control may also be needed at times of testing, equipment malfunction, or as part of a problem-solving effort.

An increasingly popular override feature enables the occupant to dial into the system and request heating, cooling, lighting, or other equipment operation. Override could be accomplished for the whole building (gross override) or for part of the building (zone- or blocklevel override). This feature is desirable when occupant use is widely variable and difficult to program as a schedule into the BMS; furthermore, the property managers can, for an agreed-upon cost per
square foot, bill tenants for the off-schedule operational hours they request. The override request can be telephoned in, executed and timed automatically by the BMS, which also computes billing information.

Night Setup/Setback. Most energy management systems have setback and setup capabilities included and programmed as standard features. This commonly used strategy changes set-points during unoccupied hours. The space temperature set-points are reduced in the winter and increased in the summer, reducing energy use. This strategy may save more energy than turning systems completely off during unoccupied periods, if morning warm-up or cool-down use inefficient energy sources (e.g., resistance heat). However, except in extreme climates, most setup/setback routines are used more as a safety. In these cases, the energy savings strategy is to turn the equipment off all night, except in the most extreme weather, when the setup/setback will be initiated. For HVAC systems that use heat pumps, this strategy should be used with caution, especially in winter—the cost of the make-up electric resistance heat often outweighs the energy savings from the setback. Auxiliary electric resistance heat should be locked out during the warm-up cycle, regardless of system type.

Optimum Start. BMS can provide customized routines for starting up the building in the morning. Starting the equipment only as early as required to bring the building to set-point at the occupied time yields energy savings. These routines take into account outside temperature and inside space temperatures when initiating the morning warm-up or cool-down cycles. This strategy is most appropriate for facilities that have unoccupied periods when the zones are allowed to go beyond normal temperature comfort limits. The goal for an optimum start procedure in heating mode is to provide as much heating as possible to warm up the building for the least amount of energy possible, while avoiding demand spikes and set-point overshoot. Normal equipment heating operation, when used in building start-up, will frequently produce longer lead-time and wasted energy. Some best practices can be incorporated by using your BMS:

- Close outside air dampers. Also, turn off exhaust or relief fans.
- Open return air dampers. This will facilitate rapid warm-up.
- Open terminal dampers 100% and drive full heat from the central boiler or heating plant to air handlers.
- For electrically heated buildings, keep careful tabs on electric energy use and demand.
- Watch for excessive cooling directly after warm-up sequences.
- Carefully evaluate shutting down or having large setbacks or setups with heat pump systems.

Optimum Stop. The optimum stop strategy determines the earliest possible time to turn off equipment before unoccupied periods and still maintain occupant comfort. This is known as “coasting.” Some equipment may be turned off in the afternoon while the building is still occupied. However, it is important to carefully evaluate shutting down equipment (fans, etc.) that provides ventilation for occupants.

Morning Warm-Up/Cool-Down. On days of extreme temperature, the greatest daily demand for heating or cooling may occur in the morning as the building is prepared for occupancy. Night-time conditions due to equipment scheduling and setbacks for unoccupied hours will necessitate a significant and rapid change in temperature. Usually, these cycles are basic time-clock functions with some interlocks. The optimization of the warm-up sequence is covered in the “Optimum Start” topic above.

Ventilation Control
Non-residential buildings require a minimum amount of outside air for ventilation. Depending on the function of the building, this requirement is approximately 7 to 19 dm³ per second per occupant. In some buildings, such as hospitals and laboratories, there is a need for 100% outside air supply. Earlier methods, which set the outside air dampers' minimum position as a fixed value, will not maintain a constant supply of fresh air in VAV systems, as the terminal units turn down during heating or periods of low cooling load. Consequently, strategies that allow variable control of minimum outside air damper position are used. A few of the available strategies are provided below, as well as information on controlling exhaust fans.

**Carbon Dioxide Monitoring.** In this strategy, the CO₂ level is generally used as an indicator of the number of occupants, as CO₂ is not itself a dangerous contaminant. Calculations are used to relate the CO₂ level to the fresh outside air, in m³ per person, being provided to the space. CO₂ monitors are typically placed in the return air stream. When the CO₂ level rises to a predetermined threshold, outside air dampers open further to increase the outside air volume.

**Supply Air Volume/Outside Air Damper Compensation Routines.** According to a schedule set up by the air balancer, this strategy increases the outside air damper minimum setting as the supply fan flow decreases (via inlet vanes or variable speed drive) in order to keep the minimum outside air volume constant.

**Flow Sensing Methods.** There are a number of outside air flow sensing methods that can dynamically measure and regulate the minimum outside air flow using the BMS. One method is to use a Pitot tube flow station, if adequate lengths of straight duct and outdoor air velocity is provided. Another method is to maintain a minimum pressure differential across a flow plate in the outside air intake.

**Occupancy Sensors.** This strategy detects occupants in a space. When the space is unoccupied, the lights are turned off and the VAV box minimum airflow is set to zero. This is especially effective in intermittently occupied spaces such as conference rooms, cafeterias, break rooms, etc. Savings come from cooling, heating and ventilation reduction. Ideally, the strategy should be disabled during periods of outside air economizing.

**Injection Fans.** A BMS can provide control of a dedicated outside air fan that delivers a constant volume of outside air into the mixed air stream.

**Exhaust Fans.** Dedicated system exhausts (rest room, mechanical room, garages, meeting rooms, etc.) can be programmed to start and stop as required. In parking garages, carbon monoxide sensors can be used to cycle exhaust fans when the levels approach predetermined limits.

**Air-Side Economizing**

Economizing, in this context, means the use of cooler outside air to cool a building.

**Typical Air-Side.** Air-side economizing, also known as free cooling, is the practice of bringing outside air directly into the building to augment or supplant mechanical cooling. In this strategy, the BMS compares the outside air conditions with either the inside conditions or a preset condition or set-point.

When outside air will benefit cooling, the outside air dampers open to maximum or to meet a mixed or supply air temperature minimum set-point. The simplest method is dry-bulb economizing and examines dry-bulb temperatures only. In concept, a more efficient method is to compare enthalpy (total heat content of the air, including moisture). However, the enthalpy sensors may require more maintenance and calibration.
Night Ventilation Purge. For climates with a large night-time temperature drops (dry climates), purging or flushing the building with cool outside air in the early morning hours, with supply fans in economizer mode, can reduce the cooling load in the building later in the morning and save energy. Implementing this strategy will be profitable if the cooling energy savings outweigh the increased fan energy and fan heat penalty (for dry climates this usually means not purging until the outside air temperature is at least 3.5°C below inside air).

Resets

Reset routines are among the most common and most effective energy-saving practices for BMS. The logic and calculation power of DDC allows for more than just the simple proportional reset strategies of the past to be incorporated. Polling numerous point values and using them to make calculations for optimised reset routines can easily be accomplished with DDC. The intent of a reset strategy is to identify changes in demand (cooling, heating, pressure, flow rate) and reset delivery of air or water to meet that demand. This is accomplished by monitoring the control point in question (e.g., discharge air temperature) and several other parameters that impact that point (e.g., return air temperature, outside air temperature). When these parameters indicate that load is decreasing or increasing, the control point can be reset to better fit the current demand.

Supply Air/Discharge Air Temperature. For fan systems that use terminal reheat, resetting the supply air temperature set-point up as the cooling load decreases reduces required reheat. Higher discharge air temperatures can also increase efficiency of direct expansion compressors. Supply or discharge air can be reset based on indirect load indicators, such as outside air, but the preferred method is to base reset on direct indicators of load, such as return air/supply air temperature difference or cooling coil valve position. There are many ways to set up the routine. One method is to raise the discharge temperature set-point incrementally until one zone is 1°C above its dead-band. Note the interaction issues in the Reset Interactions section below.

Hot Supply and Cold Supply Temperature. Many HVAC systems utilize a dual duct or multi-zone arrangement with parallel hot and cold decks. These systems meet cooling loads by providing simultaneous heating and cooling. Warm air from the hot and cool air from the cold supply must be mixed to deliver the proper temperature of mixed air. Without reset or optimization, these systems are very inefficient, particularly when the temperatures are fixed. To minimize energy waste, reset the temperatures, decreasing the differential between the supplies. With this strategy, the EMS selects the zones with the greatest demand for heating and cooling. The supply temperatures are then set to provide the warmest cold supply and coolest hot supply possible while still satisfying the extreme zones.

Mixed Air Temperature. Systems with a mixed air temperature set-point can control the set-point with a DDC system. By raising the mixed air temperature when cooling loads in the building are low, the periods of free cooling (economizing) are maximized.

Heating Water Temperature. For hot water heating systems, the hot water supply temperature can be reduced as the heating requirements for the building are reduced. The most common form of hot water reset is to recalculate the hot water supply temperature set-point as a function of outside air, an

Indirect load indicator. A preferable method is to reset the hot water using the supply and return water temperature difference (ΔT) to determine the actual building load. This is accomplished most effectively with 3-way valves. As the ΔT drops, the hot water supply temperature is reduced until the ΔT increases to a predetermined differential, or until a minimum hot water supply temperature (based on outside air temperature) is reached. Another load-based method is to
reset the heating water temperature set-point down incrementally until one heating valve is 100% open. Note the interaction issues in the Reset Interactions section below.

**VAV Fan Duct Pressure and Flow.** Resetting VAV airflow or static pressure down during periods of low cooling load reduces unnecessary fan energy. Traditional VAV fan control strategies use a fixed duct static pressure set-point control that is independent of actual airflow requirements at the terminal units. With DDC data coming back from the terminal units in the form of damper position or airflow, the supply fan can be incrementally slowed down using a variable speed drive (or closed inlet vanes) to maintain one terminal box at 100% of design flow. This makes the fan run as slowly as possible while still keeping all boxes satisfied. Implementation methods vary: some reset the duct static pressure set-point downward to meet the criteria; others bypass this intermediate calculation and go directly to the fan speed or inlet vane controller and simply reduce flow, without any duct static pressure set-point. In addition to load-related reset, other opportunities are available when addressing outside air requirements. In most VAV systems, each VAV box is assigned a minimum airflow set-point, designed to ensure adequate outside airflow for maintenance of indoor air quality and usually kept constant over time. However, the box may deliver excess fresh air at the minimum airflow set-point, depending on the outside air fraction in the supply air. Energy saving optimization would recalculate the box minimum airflow set-point periodically throughout operation. This reset strategy and the calculation of percent outside air may involve direct measurement of outside airflow. Note the interaction issues in the Reset Interactions section below.

**Entering Condenser Water Temperature.** Resetting the chiller entering condenser water to a lower value will save energy by increasing chiller efficiency. When outside air wet bulb temperatures are high enough that lower condenser water temperatures cannot be achieved, increasing cooling tower fan stages would be of no benefit. Therefore, make the attainable condenser water temperature the set-point for controlling fans.

**Chilled Water Supply Temperature.** For chilled water systems, the chilled water loop temperature can be raised as the cooling requirements for the building are reduced, increasing chiller efficiency. As with hot water reset, the typical variable for reset calculation is outside air. However, direct load-related parameters, such as supply and return water temperature difference or chilled water valve position, are preferable. A typical method of load reset is to raise the chilled water temperature set-point until one chilled water valve is 100% open, subject to any special space humidity requirements that would require the chilled water temperature to remain at its minimum. Chilled water reset is most effective when the chiller horsepower is more than three or four times the horsepower of the chilled water pumps. Under these conditions, the decrease in power drawn by the chiller will more than compensate for any additional chilled water pumping requirements due to higher chilled water temperatures.

**Chilled Water Secondary Loop Pressure.** Instead of controlling the secondary chilled water loop to a fixed differential pressure set-point under all conditions, this strategy resets the pressure down as the load decreases (the chilled water valves close) to always have one cooling coil valve 100% open. This keeps the pumps operating at the very lowest pressure and speed possible.

**Heating Water Secondary Loop Pressure.** This strategy is the analogous to the one for chilled water systems.

**Reset Interactions.** There can be significant interactions among some of the reset strategies that can easily be programmed using DDC.

**Lockouts**
Lockouts are used to ensure that equipment does not come on at a point when it is rarely, if ever, needed. This protects against nuances in the control system programming that may cause the equipment to turn on unnecessarily. When locking out a major piece of equipment, remember to also lock out any other associated equipment that doesn’t need to be on.

**Boiler System.** The boiler and associated pumps can be locked out above a set outside air temperature, by calendar date, or when building heating requirements are below a minimum (see Heating Water Temperature above).

**Chiller System.** The chiller and associated pumps can be locked out below a set outside air temperature, by calendar date, or when building cooling requirements are below a minimum.

**DX Compressor Cooling.** Lock out direct expansion (DX) cooling when outside air conditions will allow economizer operation to meet the cooling loads. This should be subject to any relative humidity control that may require dehumidification with the DX even during economy cycles.

**Resistance Heat.** Resistance heating is a major source of energy waste in systems. Lock out all resistance heating above a set outside air temperature and in any warm-up modes, regardless of temperature, when possible. If locking out reheat above a set temperature causes overcooling of a space, consider raising the supply air temperature, reducing airflow, or rearranging diffusers.

**Miscellaneous Strategies**

**Simultaneous Heating/Cooling Control.** An EMS can be used to control and minimize simultaneous heating and cooling for a number of equipment types, including dual duct mixing, VAV boxes, and terminal reheat systems (as discussed in the Resistance Heat section above). This is accomplished by maintaining wide space temperature dead-bands between heating and cooling, raising cold supply set-points and lowering hot deck set-points, and locking out heating and cooling when appropriate.

**Chiller Staging.** Most optimization strategies for central cooling plant equipment have two elements: staging equipment for maximum efficiency, and resetting output parameters for maximum energy savings. For facilities that use multiple chillers, the ideal strategy will determine the total cooling load on the chiller system, compare the part load efficiencies and capacities of all available chillers, and determine the most efficient mix of chillers to have online. This strategy is complicated by the need to keep run-times over the year close to equal and the danger of cycling the chillers so much that efficiency and equipment life are compromised. Some EMS have standard chiller optimization programs that require minimal programming.

**Boiler Control.** For facilities that use multiple boilers, some logic must be applied to determine sequencing. If the boilers are small, of roughly equal size and efficiency, and have little energy overhead associated with starting and stopping operation, the logic is simple: Add and subtract boilers as necessary to meet the load. To maximize efficiency in more complex plants, schedule the boilers to give preference to the most efficient boiler and minimize partial loading. In addition, it is sometimes desirable to control the boiler firing mode to increase efficiency.

**Building Space Pressure.** For VAV air handlers, it is advantageous to monitor and control space pressure. Lab environments often use this sequence to control flow of contaminants, fumes, or lab air. The space pressurization level is maintained by monitoring the pressure and adjusting supply and return flows (via dampers, inlet vanes or variable speed drives) in order to achieve the desired pressure. Space pressurization can have effects on both energy use and indoor air quality (IAQ). Unless you have special requirements, the recommendation is to maintain a slightly positive pressure inside the building relative to the outside. This ensures that no
unfiltered or untreated air infiltrates the building and that exterior doors are not hard to open due to a negative pressure. This is especially critical for moisture control in humid climates.

**Air-Side Heat Recovery.** For systems with a large fraction of outside air or systems with large auxiliary exhaust fans, heat can be extracted from the exhaust air stream via a coil heat exchanger and a water or glycol loop and transferred to the incoming cold outside air via heating coils. Heat wheel heat exchangers in the exhaust air stream are also used.

**Lighting**

As the market for lighting products has moved toward energy-efficiency, more and more building owners are implementing lighting retrofits and upgrades, often using BMS controls.

**Lighting Sweep.** The main energy saving strategy with lighting ON/OFF control is the same as that for other equipment: provide lighting only when and where it is needed. The simplest way to ensure that lights are turned off at night and remain off is to have the EMS periodically “sweep” them off. For example, the BMS could be programmed to turn off all lights on various floors every hour on the hour from 9 pm to 5 am. Ideally, the switches that allow lights to be turned back on should only control small zones.

**Occupancy Sensors.** For advanced control, lighting systems are tied to occupancy sensors and to the BMS to provide information on occupancy status. Both lighting and HVAC are set back or turned off when the space is unoccupied.

**Daylight Dimming.** In perimeter zones of the building with sufficient windows, the lighting can be dimmed to maintain a minimum light level in the space. This is best accomplished through continuously dimmable electronic ballasts (rather than lowering light output in discreet steps).

**Zonal Lighting Control.** Reducing the size of lighting zones can save energy by allowing only the occupied zones to be lit, rather than an entire floor. Savings can be significant in cases where there are smaller groups of tenants who start or end work at different times or frequently come in after normal occupied hours.

**Demand Control**

The goal of demand strategies is to reduce whole-building demand (the parameter upon which demand charge is based), not to reduce individual equipment demand. For example, it is acceptable for one piece of equipment to peak heavily in the middle of the night when other equipment is off and whole-building demand is low. Similarly, at times of peak demand, reducing any demand will contribute to lower demand charges. It is wise to review the operation of the BMS demand limiter, especially as building loads and operations change. Also, review conditions when demand limiting is invoked. If it is during building start-up, an improved start-up sequence may be a better option. Exercise caution when implementing demand strategies. Most of the time, the reason the electric demand is high is that maximum cooling is needed; it may be that you cannot reduce demand without sacrificing comfort.

**Demand Limiting or Load Shedding.** This strategy can be based on a single electric meter, multiple meters, or on equipment current (e.g., chiller). Implementation of demand limiting or shedding varies. Typical methods are:

When the demand (based on kW or current amps) on a building meter or piece of equipment approaches a predetermined set-point (which may be different for each month), the system will not allow the piece of equipment to load up any further (e.g., chiller), or it may globally increase the space temperature set-point, or some other set-point, to stop the increase in equipment
loading and thus the demand. Some methods increase the space temperature set-point in one or more zones and if that is not sufficient, add other zones.

Another method is to select equipment to shut off, rather than just limit its loading. Parameters to be set for load shedding control points include: rated kW, minimum shed time, maximum shed time, minimum time between shed, shed type, and shed priority. There are sophisticated BMS controllers that automatically integrate a demand-limiting and load-shedding strategy with utility real-time pricing rate structures. The control parameter, rather than the static kW demand limit, is the optimization of the real-time energy cost based on the hourly energy price.

**Sequential Start-up of Equipment.** To eliminate demand spikes, program time delays between start-up of major electrical load-generating equipment so that the start-up peak loads stay below the peak demand later in the day.

**Energy Monitoring**

Energy consumption is an important parameter to track. It is the bottom line for most control strategies and has ramifications to maintenance needs as well. Whole-building annual kWh per square metre is a useful metric for comparison with other similar buildings. However, energy consumption is rarely monitored by BMS, other than possibly chiller kW, or total building or system kW for buildings with significant demand limiting. For monitored systems, the following may be tracked:

- kWh consumption and demand
- Time the peak occurred
- Selected demand limit
- Natural gas consumption
- Steam consumption and flow
- Time that any load was shed

For energy performance projects, kWh may be monitored for other equipment as well, including minimum, maximum, and average outside air temperatures (OSAT) and outside environmental information. In addition, it is useful to plot energy consumption versus different driving factors, such as OSAT, occupancy, or production. Direct monitoring of energy consumption is difficult because of the initial setup required; the use of proxies may be more feasible and answer the same energy use questions. For example, monitor run-time for pumps rather than energy consumption, or variable frequency drive control signal rather than energy consumption. Energy monitoring even a few major end-uses can greatly improve traditional monthly energy accounting. The uncertainty involved in using energy accounting software packages will be reduced if additional end-use data are available. The BMS can add critical information on major end-uses to the picture and allow for usable and reliable energy accounting recommendations.

**Performance Contracts.** BMS energy and performance monitoring capabilities can be utilized in energy performance contracts. The BMS can determine and document baseline conditions (hours of operation and occupancy, equipment efficiencies, etc.) and verify post-installation performance by aiding in commissioning and operations tracking. The BMS can also be instrumented to calculate and track weather conditions (degree days, etc.) and correlate that with whole building or end-use (equipment) energy consumption tracked in the BMS.
7. Contract agreements

Often service contract options are the last thing considered when purchasing an BMS, yet without proper maintenance and operation, these expensive and sophisticated systems frequently end up underused, overridden, and blamed for any number of O&M problems.

In the BMS industry, there is no standard or set of definitions for the various kinds of service contracts or agreements. Each manufacturer or distributor puts together a unique package of service offerings. The package often consists of three or four types of contracts at different levels of comprehensiveness and with different features. Below, we briefly discuss five traditional types of contracts:

- Full-maintenance agreements
- Software monitoring agreements
- Full-service agreements (combination of the above two)
- Preventive maintenance agreements
- Open or flexible agreements

Within these five types, there can be many variations, depending on an owner’s needs and the contractor’s willingness to modify or customize service agreements. Many BMS vendors also provide service contracts that not only include the BMS but also all other building equipment and systems. For the purpose of this document we will only discuss service contracts for BMS.

Full-Maintenance Agreement

The full-maintenance agreement may be thought of as an extended warranty. This type of contract is generally purchased following the installation of a new system. For a set annual fee, the contract covers all labour and materials for BMS hardware failures and generally includes an emergency response arrangement. Both the duration of the agreement and the emergency response feature are usually negotiable. Typically, these contracts are purchased to cover a one- to five-year period. One of the main advantages of this type of contract is ease of budgeting. The owner knows exactly what maintenance will cost no matter how sparse or extensive the repairs are for the contract period. However, this type of contract is usually expensive because of the risk to the provider. Contracts are often more expensive for older systems because they are more likely to fail. The contract price should be closely scrutinized. The cost should reflect the age and condition of the system. The owner should compare the total cost of the service contract to the cost of a new system. Over the contract period, the cost of the contract may be close to or the same as the cost for a new system. When evaluating a contract of this type, consider the fact that the newer distributed (DDC) systems are much less prone to failures than the older mainframe type systems. Failures of any size in a distributed system typically do not become catastrophic as long as the system is well grounded and surge-protected. In addition, if there is well-trained onsite staff to do most of the repairs for the system, this type of contract may be inappropriate.

Software (Remote) Monitoring Agreement

The software-monitoring type of contract may be purchased anytime during the life of the system. With this type of contract, the service provider remotely monitors the BMS for problems. When a problem occurs, the decision on how to remedy it depends on the contract arrangements. The contractor may have the authority to make certain limited decisions about
how to solve particular problems. For example, the contractor may have the authority to raise or lower set-points within a certain range to alleviate comfort problems. However, some owners may require contractor notification whenever any problem arises. Usually, major or permanent changes to the system regarding scheduling, set-points, or programming are done at the request of the owner. Emergency response arrangements vary according to the level of involvement of the service provider in actually repairing the system. The software monitoring contract is most appropriate for facilities where knowledgeable staff is not always available and/or where the need for consistent and reliable operation is critical.

Full-Service Agreement
The full-service agreement combines the two contracts discussed above and addresses both hardware and software issues. The full-service agreement is often purchased by owners who have complex multiple facilities and prefers to outsource most work that is not a core business component. This is the most expensive service contract. An emergency response arrangement is typically part of the agreement.

Preventive Maintenance (PM) Agreement
The PM agreement is generally purchased for a fixed fee and includes a preset number of scheduled visits each year. The purpose of this type of contract is to periodically inspect the system for problems and perform the agreed-upon PM activities that keep the system in good working order and the programming current for the season. The contract may or may not include any arrangements regarding emergency calls. The main advantage of this type of contract is that it is generally less expensive than either the full-service or full-maintenance contracts. It also provides a focus on high-quality preventive maintenance. However, budgeting and cost control for emergencies, repairs, and replacements are more difficult, because these activities are generally done on a time-and-materials basis. The owner carries most of the risk.

Open or Flexible Agreement
Another option is the purchase of a block or pool of hours for labour at a set annual fee. Under this arrangement, the owner may use these hours for a range of needs from programming to installing hardware or upgrades. If, at the end of the year, the hours are not exhausted, some service providers allow the owner to roll them over to the next year. This type of arrangement may be purchased alone or in combination with several of the other agreements discussed above.

Mix, Match, and More.
The following discussion highlights some cost-effective ways of obtaining appropriate, high-quality service agreements. Owners with well-trained and available onsite staff should consider purchasing any combination of the following service arrangements:

• Flexible agreement
• Preventive maintenance agreement
• Long-term purchasing agreement
The long-term purchasing agreement allows the owner to keep an inventory of BMS parts onsite for an agreed-upon time, usually three to five years. The amount of inventory is based on the likelihood of BMS failures and the urgency of the possible repair. Parts that seldom fail or are not critical to the owner or tenant’s business are generally left out of the inventory. For example, the failure of a control panel board for a packaged rooftop unit serving a major tenant would be considered urgent; the failure of a space temperature sensor for an infrequently used conference room would not. Although an owner may keep an inventory of parts worth several thousands of euros, under this agreement a part is not paid for until it is used. The failed part is removed and sent back to the manufacturer. The agreement is usually negotiated so that the owner pays published list price for the parts less a certain percent (20% to 60%). At the end of the agreement period, the contract may be renewed or the unused inventory may be returned to the supplier at no further charge. The fees paid to the supplier for this type of agreement are minimal and are generally related to the interest rates and property taxes on the inventory. The long-term purchasing agreement may be effectively coupled with a preventive maintenance (PM) agreement from the same supplier that offers annual software, firmware, and hardware upgrades plus any agreed upon PM activities and emergency response arrangements. Another cost-effective arrangement is the purchase of a pool of labour hours from the vendor based on an assessment of programming needs for the year. This arrangement works well for owners of somewhat smaller buildings that have building operators with expertise in BMS operation. Combining this with a PM contract that includes system upgrades often provides the owner with the most quality at the least cost.

Some BMS suppliers offer a technical support agreement. With this option the owner can purchase a range of technical support activities from one day of hands-on training for their building operators to a weekly onsite visit by a technician (coach). When the agreement requires a technical coach for the building operators, the duration of the arrangement may last anywhere from a few weeks to years. This agreement can also be coupled with several of the other types of contracts, depending on the owner’s needs.