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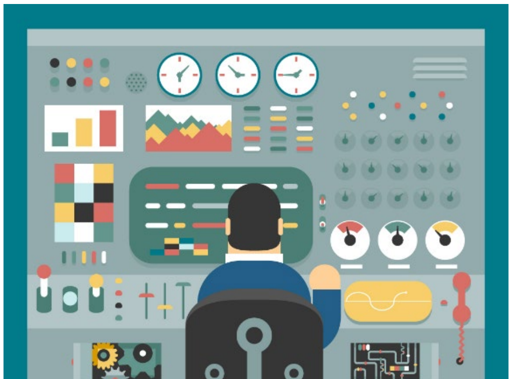
DIGITAL CONTROL SYSTEM ROUTINES

WHITE PAPER #31


techcrunch.com

Once installed, a Direct Digital Control (DDC) system is a very useful facility tool. Control system measure implementation is one of the most cost effective measures in most buildings.

In general, all control strategies should strive for the following:

- Decrease unnecessary equipment operation through scheduling and occupancy sensing.
- Schedule both on-off operation and time-of-day set point adjustments. Note that you can schedule ventilation rates to correspond with planned occupancy patterns.
- Schedule loads based on actual needs, rather than worst case
- Positive control of “dead band” spacing to prevent simultaneous heating and cooling.
- Match equipment operation to changing loads by sensing techniques and capacity-varying techniques.
- Vary fluid temperatures, pressures, supply air flows, water flows, outdoor air intake rates, based on demand and not worst case. The objective is always to *provide enough, but just enough*, of the item.
- For control actions designed to avoid on-peak times, allow a buffer of 30 minutes or so to be sure. Peak periods as of this writing are shown - note that the on/off peak times shift seasonally.

On-peak periods Oct. - March: 4 to 10 p.m. Monday through Friday
On-peak periods April - Sept.: 11 a.m. to 6 p.m. Monday through Friday
Off-peak periods: all other hours plus legally-observed holidays
csu.org

Other ways to leverage modern DDC controls include:

- Utility meter inputs allow measurement of results and real time feedback when testing a new optimization routine.
- Long term trends of heating/cooling/and major equipment loads provides true indication of load profiles and allows for right-sizing upon equipment replacement.

- Predictive maintenance for heat exchangers (fouling), filter changing (pressure drop), etc.
- Optimize primary equipment operation where different units have different efficiency characteristics.
- Optimize cooling towers from wet bulb or dew point measurements.
- Extend air-economizer settings based on outdoor dew point levels to keep cooling equipment off longer during mild and dry weather days.
- Extend chilled water reset settings based on outdoor dew point levels to monitor the need for dehumidification.
- Global point sharing that justifies higher quality instrumentation, such as outdoor air temperature, humidity, dew point, wet bulb, etc.
- Calibration of instruments so the software decisions are good ones. For sustained savings, all analog input and output sensors, transducers, and actuators of valves and dampers (travel and tight close-off) should be re-calibrated on a 2-year cycle, and control set points and occupancy schedules should be reviewed on a 2-year cycle as well.

Table: Common Control Strategies to Reduce Operating Cost

Notes:

'Basis of Savings' is shown as a good practice – identifying what is being leveraged for savings.

Buildings and processes are not all the same – these examples will show patterns that you can apply to your specific facility

Knowledge of impacted systems is needed for overall success including interactions and being sure the process is still being served. Comfort is a process.

Energy Management Control

Source: Commercial Energy Auditing Reference Handbook, 3e Doty,S., Fairmont Press.

Scheduled Start Stop

Basis of savings: Reduced run time

The most efficient setting for equipment is 'off'. The scheduling function can be leveraged to advantage by setting start and stop times according to user occupancy patterns, and by continually adjusting and fine tuning these schedules as those patterns change.

Optimal Start time programming can be used to turn on equipment prior to occupancy and have it reach temperature 'just in time.'

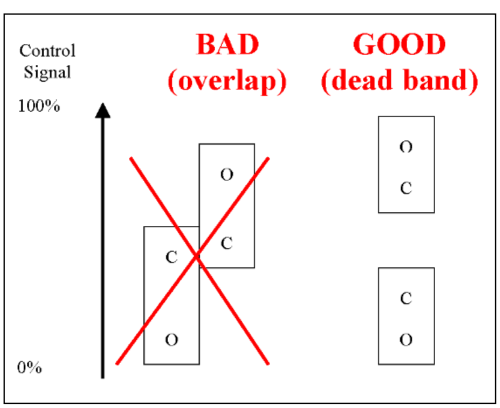
Dead Band Controls

Basis of savings: Avoided control overlap, control fighting, and simultaneous heating/cooling

Control settings shall prevent preheat coil action when air economizer is operational, requiring a 5 degF dead band between mixing dampers returning to minimum position and preheat. For example, when any form of cooling is active (chilled water, DX, or Economizer) the preheat coil control would be held closed in a "one or the other but not both" control. This limits the use of a standard "proportional control" sequencing scheme where a single proportional controller output is shared by several devices for ease of sequencing. Rather, a control loop with a heating set point and a control loop with a cooling set point, with dead band spacing between the two.

It is recommended to separate space heating and cooling functions by at least 4 degF to prevent heating and cooling to occur simultaneously.

Some DDC systems have a pre-defined watch dog algorithm available that will further prevent simultaneous heating and cooling. When heating is called for it automatically overrides any other control action and forces the cooling output to zero.



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Source: Commercial Energy Auditing Reference Handbook, 3e Doty,S., Fairmont Press.

Stop Ventilation in Unoccupied Periods

Basis of savings: Reduced ventilation load

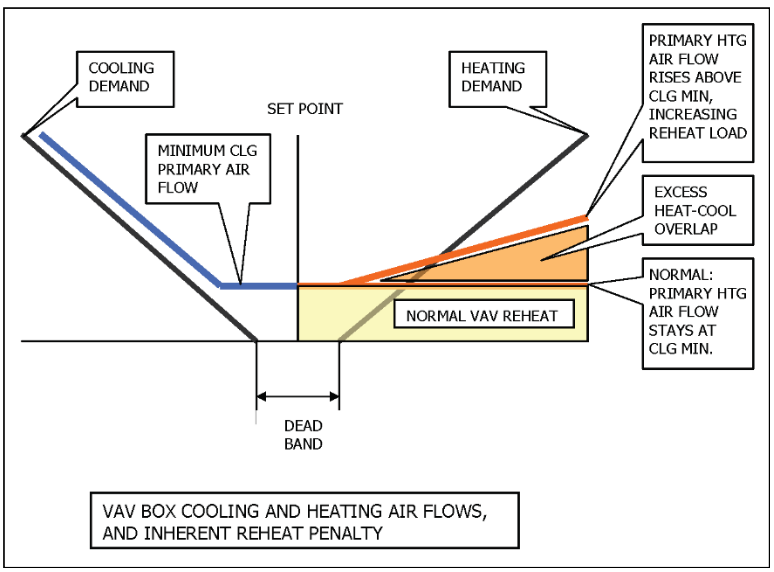
If air handler system is operated in unoccupied or morning warm up mode, control outside air damper and associated exhaust fans off (interlock). Simply turning off air handlers and ventilation while leaving exhaust fans running defers the ventilation load until morning start-up and can also create a freezing condition near building cracks that can burst pipes.

VAV Box Settings

Basis of savings: Reduced reheat penalty (simultaneous heating and cooling)

Review all VAV box settings for minimum air flow and 'heating air flow' settings.

Excess minimum air flows increase heating burden in winter. If VAV boxes are allowed to open back up again in heating, it increases air flow across the heaters and increases winter heating costs proportionally. All VAV systems have some reheat penalty, but it is minimized when controlled properly. This measure is to be sure the "heating maximum" control setting to equal the "cooling minimum" air flow setting for all VAV boxes.



Energy Management Control

Source: Commercial Energy Auditing Reference Handbook, 3e Doty,S., Fairmont Press.

Supply Air Reset for Single Zone Constant Air Flow

Basis of savings: Reduced refrigeration load, provided the supply air temperature increase is felt at the refrigeration equipment

Unless in a very dry climate or monitored by a supervisory process (OA or RA dew point) this measure can create elevated humidity inside the building by reducing dehumidification work at the cooling coils.

Return Air Temp	Supply Air Temp
77F	55F
65F	67F

Basic reset schedule achieves good savings. Resetting from most-open-valve control achieves additional savings.

Supply Air Reset for Variable Air Flow (VAV)

Basis of savings: Reduced reheat penalty in heating mode

While in cooling mode, no reset of supply air is suggested, as all refrigeration savings will be lost to fan energy increase. Basis of savings is avoiding false-loading of heating coils in heating mode.

Outside Air Temp	Supply Air Temp
70F	55F
40F or the point where most VAV boxes are at minimum	62F or as allowed by areas that may need some cooling in cold weather

Basic reset schedule achieves good savings. Resetting from most-open-valve control achieves additional savings.

While in cooling mode, no reset of supply air is suggested, as all refrigeration savings will be lost to fan energy increase.

Reset schedules based on outside air may require one or two seasons to find ideal settings

Energy Management Control

Source: Commercial Energy Auditing Reference Handbook, 3e Doty,S., Fairmont Press.

Hot Water Reset

Basis of savings: Lowering hot water temperature in mild weather reduces thermal heat loss from the insulated piping system. This is an advantage of hot water heating over steam heating.

Coordinating this reset schedule with chilled water reset schedules limits the times when both run. Some overlap is unavoidable in most buildings, but to the extent the overlap can be minimized it will inherently limit heating and cooling activities at the same time. I.e. if the boiler is off in summer it doesn't matter if the control valve opens.

Hot Water Reset Schedule – Suggested Starting Spot

Outside Air	Leaving HW temp
Above 65F	Boiler Off
65F	120F (or minimum temperature)
10F	180F (or maximum temperature)

Reset schedules based on outside air may require one or two seasons to find ideal settings

Chilled Water Reset for Constant Flow Chilled Water

Basis of savings: Raising chilled water temperature in mild weather reduces refrigeration power (kW/ton).

Unless in a very dry climate or monitored by a supervisory process (OA or RA dew point) this measure can create elevated humidity inside the building by reducing dehumidification work at the cooling coils.

Chilled Water Reset Schedule – Suggested Starting Spot

Outside Air	Leaving HW temp
Below 50F	Chiller Off
50F	50F
70F	45F(or design temperature)

For variable flow chilled water systems, much of the savings from refrigeration efficiency are lost to increased water flow. There is a small net gain.

Reset schedules based on outside air may require one or two seasons to find ideal settings

Cooling Tower Condenser Water Reset

Basis of Savings: Reduced refrigeration lift

This uses outdoor air wet bulb temperature, which can be measured directly, but is usually calculated from temperature and humidity. The evaporative process can get close to, but never reach or exceed, the wet bulb temperature. By knowing the wet bulb temperature, the control system will know its boundaries and won't try to achieve something it cannot.

For water-cooled refrigeration equipment, the low limit for the reset is normally around 55 or 60 degrees F and the chiller mfg needs to be consulted to confirm. Resetting the cooling water temperature down in this way, in lieu of a constant temperature setting, will reduce kW/ton energy use and demand.

Energy Management Control Source: Commercial Energy Auditing Reference Handbook, 3e Doty,S., Fairmont Press.
Reset VAV fan static pressure set points in mild and cold weather. Basis of savings: Reduced fan energy Fan Static Pressure Reset Schedule – Suggested Starting Spot OA / SP in. w.c. 70F / 1.0 or 1.2 / Max value is design condition for summer weather 40F / 0.6 / Or half of design value Basic reset schedule achieves good savings. Resetting from most-open-valve control achieves additional savings. Reset schedules based on outside air may require one or two seasons to find ideal settings
Standardized Temperatures with 2F Local Adjustment Basis of savings: Reduced control overlap 74 cooling and 70 heating are reasonable temperatures for most facilities that involve people comfort. Significant is the differential or “dead band” between the two. By maintaining 4 degF between heat/cool settings the opportunity for unintended heat/cool overlap is reduced. Personal preferences do vary between people. When local set point adjustment is included with the temperature sensor, limiting the local adjustment to +/- 2F satisfies many people and also will prevent overlap.
Set Back Temperatures Basis of savings: Reduced envelope loss Savings from this measure are from reduced envelope losses – reducing envelope temperature difference reduces thermal transmission directly. Envelope savings are typically 1 percent (heating or cooling) per degree set back/set up provided the set back/set up period is at least 8 hours. Where indoor temperatures are moved up/down permanently savings are approximately 2 percent per degree F.

Fan Static Pressure Reset Schedule table:

OA	SP in. w.c.	
70F	1.0 or 1.2	Max value is design condition for summer weather
40F	0.6	Or half of design value

Energy Management Control Source: Commercial Energy Auditing Reference Handbook, 3e Doty,S., Fairmont Press.

Coordinating Upstream/Downstream Set Points (a.k.a. 'Most Open Valve' Control)

Basis of savings: Reduced control fighting, false loading, simultaneous heating/cooling

This concept applies to any system that includes a main "upstream" air handler with associated "downstream" terminal units with heating capability. The concept is simple enough but will require some programming. The objective is to provide enough, but just enough, cooling and heating from the upstream device and to avoid heating and cooling fighting between upstream and downstream components. Typical control system design does not include interaction between air handler and terminal unit, and each behaves as if the other does not exist. Because of this, heat/cool overlap can easily occur and not be detected. The same concept applies to fan or pump pressure when variable speed fan/pump control is used to maintain a downstream pressure.

Examples:

1. Resetting AHU supply temperature upwards until at least one terminal unit heating coil is at least 95% closed.
2. Resetting AHU fan static pressure downwards until at least one VAV box damper is at least 95% open.
3. Resetting boiler hot water supply temperature downward until at least one heating control valve is 95% open.
4. Resetting chilled water supply temperature upward until at least one chilled water control valve is 95% open.
5. Resetting pump static pressure downwards until at least one terminal coil control valve is at least 95% open.

The benefit of this measure can sometimes be observed with two DDC screens open: one for the main air handler and another for a terminal unit (if several are in heating mode). If the terminal unit is operating in heating mode and the supply air is relatively low (less than 60 degF), slowly raise the supply air temperature, 2 degF at a time, and wait several minutes – you may see the reheat coil stop heating, which demonstrates that they were 'bucking' each other, silently consuming energy. The control strategies described above police this automatically.

Energy Management Control Source: Commercial Energy Auditing Reference Handbook, 3e Doty,S., Fairmont Press.

Load-Limiting for Step Changes in Load

Basis of Savings: Avoided demand charges from large, short term demand

Notes:

- This is not about 'inrush current' for motor starting; it is about *curbing large machines or heaters that see a step change to go to full capacity for a short time* (15 minutes, hour, etc.) to pull-down / pick-up the process to the set point. (like coming out of unoccupied period, or as a lag unit starts in sequence) Where the process can tolerate a delay, or when the step change is can be pre-empted by starting early, *savings occur when spreading out the work over a longer time.*

- Load limiting method described can create a delay 'catching' the load change, meaning the set point is lost for a period of time. For heating/cooling at beginning of shift or beginning of occupancy period, simply starting early solves this with no process impact at the onset of occupied period. For processes that cannot tolerate a delay from a load change, this approach may not be feasible at all and the demand charges may be a cost of business. Process must come first.

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This measure requires the controlled equipment to have a load-limit input that will respond to the controller output of maximum load. These are the reins.

For a single machine about to see the step change, start it unloaded using the load limit control feature of the machine: Note the average current load of the machine before the step change; select a mid-range value of load limit that will allow a capacity increase of the machine but not allow it to follow its natural response for full load operation. For example, if at 25% just before the event, try 60% as a load limit value. The process WILL pick-up / pull-down, it will just take a little longer. Where the event is occupancy based, comfort can be improved by starting earlier. Where the event cannot be predicted and pre-empted, the process pick-up / pull-down will be delayed because it takes longer to catch up to the load.

Ancillary control for a lead/lag arrangement about to see the step change: reduce the load on the lead machine (presumably at full load and not keeping up) to 50% and then start the lag machine with load limit to the same value; this will result in two machines at the same capacity acting as one; this just keeps the lag machine from trying to operate at an awkward low value like 10% load. Now operating two machines as one, proceed with the load limit as described for a single machine, spreading out the load over time, to avoid the high demand during hard pull-up / pull-down.

Watch dog:
Load limiting effectively makes the machine smaller. The intent is for it to do the job, but over a longer period of time (like a couple hours vs. 15 minutes), since that saves money. If the machines are excessively load limited, it is possible that they are now 'too small' to do the job. A watchdog control should be put in place to see that the process IS being pulled-up / pulled-down, just slower. If load limit value is too restrictive and the process is running away, the nominal load limit value can be relaxed in increments, such as an additional 10% capacity each ten minutes until the load is no longer running away.

Energy Management Control Source: Commercial Energy Auditing Reference Handbook, 3e Doty,S., Fairmont Press.
Demand-Reduction (DR or Price Signal Following) Basis of Savings: Avoided demand charges from high price periods The 'trigger' for the DR response may be receipt of a utility signal or a hardware / software 'button' that is used manually. Automatic response is suggested for the most consistent results. When the DR response is called, automatically invoke the chosen measures. Each will be temporary to flatten a demand peak. Some will create higher loads before/after the DR period, such as pre-cool before and catch-up after. A second layer of load limiting to prevent 'snap back' high demands may also be needed. Depending upon the facility, these can include: Turn off non-essential loads Reduce light levels Pre-cooling, pre-heating, pre-ventilating a space or process to help 'ride through' the event. These actions would precede the actual event. Bump up or down a setting (such as cooling temperature) that will unload machines naturally Issue load-limiting control (such as 'fan speed cannot exceed 75% or chiller load cannot exceed 50%). Temporarily reduce ventilation where occupancy allows it. Display and record the demand reduction if the control system includes electricity kW as an input
VAV Box Occupancy Sensor Control Basis of Savings: Increased unoccupied time, reduced over-cooling, reduced ventilation load When unoccupied to where the lights are turned off (can share the same sensor via a relay), the temperature control setting assumes unoccupied status (or some mid-range value), and minimum air flow is set to zero.
Terminal Unit Occupancy Control (Fan Coil, Unit Ventilator) Basis of Savings: Increased unoccupied time, reduced ventilation load When unoccupied to where the lights are turned off (can share the same sensor via a relay), the temperature control setting assumes unoccupied status (or some mid-range value).
Occupancy Sensors for HVAC in Variable Occupancy Rooms Basis of savings: Reduce ventilation load, reduced over-cooling. In conjunction with the DDC controls and HVAC systems, provide ceiling-mounted occupancy sensors in classrooms, meeting rooms, auditoriums, etc. When unoccupied, in addition to turning lights off: VAV systems: o Reset minimum setting to 0% of occupied air flow. o In vacant areas, temporarily adjust VAV box minimums to zero to correspond to no occupancy. Record design values for VAV minimums so the design intent can be restored once the area is occupied. Constant volume systems (single zone HVAC, unit ventilators): o close ventilation dampers

Energy Management Control

Source: Commercial Energy Auditing Reference Handbook, 3e Doty,S., Fairmont Press.

After-Hours Override

Basis of savings: Reduced run time from compressed schedules.

Temperature sensors equipped with override buttons allow occupants to get 2 hours of cooling or heating during a regularly unoccupied period. At the same time, this provision allows schedules to be compressed to ~ 1 hour after normal building closure time.

VAV Electric Heat Lockout in Unoccupied Time (Systems with gas preheat and VAV boxes with electric heat coils)

Basis of Savings: Fuel switching / less expensive fuel in unoccupied set back periods

This is for systems that have fuel-fired 'warm-up' equipment and VAV boxes with electric resistance heating coils. By default, any heating that occurs in unoccupied time is with electric heat. This measure changes system type to one without any electric heat available, thus providing any needed heating from the fuel fired equipment as with a warm-up cycle, except only warming up to the unoccupied setting.

VAV Morning Warm-Up (Systems with gas preheat and VAV boxes with electric heat coils)

Basis of Savings: Reduced demand charges upon initial warm up

After extended 'off' periods, such as night set back, normal automatic control response will be to start 'morning warm-up' to pull the building up to occupied temperature. When this happens quickly, air temperature leads building mass temperature and when control is 'handed off' to the electric heaters, many/all of them must run concurrently until the building mass finally achieves temperature. By 'over-heating' the building a couple of degrees, this can be eliminated.

EMS Override Report

Basis of savings: Reduced control system performance backslide

With a large energy management system and a variety of system users, it is inevitable that settings will be changed. This usually takes the form of an override. The issue is when the override or changed setting is forgotten and left. An easily configurable feature of most EMS systems is to report overridden system values or outputs. Reviewing the list each week will help eliminate long-standing forgotten overrides and whatever environmental or energy impacts they have.

Some control systems have the option for a "timed override" which will reset itself automatically in a chosen number of hours.

Demand Limiting Control

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Additional control strategies exist for complex systems. Call or write us to discuss:

- Optimal start
- Daylight harvesting
- Sequencing multiple boilers/chillers
- Multi-zone /dual duct reset of hot and cold deck
- Dual duct terminal units
- District heating and cooling
- Demand controlled ventilation
- Water-loop heat pump loop temperature control
- Water-side economizer control

Credits:

Information for this paper was drawn from *Commercial Energy Auditing Reference Handbook*, 3e Doty,S., Fairmont Press.