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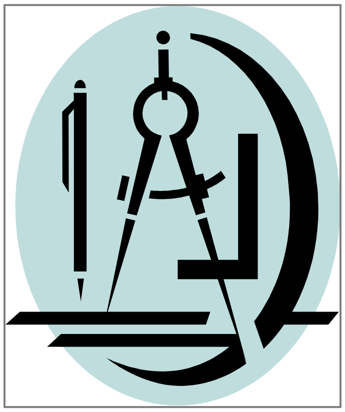
TARGETED MAINTENANCE FOR ENERGY SAVINGS

WHITE PAPER #3



Buildings have many maintenance activities – all are important to keep facilities running and looking good.

Some specific tasks produce savings to your business from avoided energy use. These are low-cost / no-cost measures. Explaining 'why' the activities create savings will help keep enthusiasm up for repetitive work, knowing company financial benefit is being created each time.

Focus items in this paper include heat exchangers, motorized valves and dampers, air economizers, VAV box response checks, space heaters, heat/cool overlap, boiler tune-ups, sensor calibration, control system settings and overrides. Some of these save energy directly; others are partners for operations and control tweaks to save even more. Optimized maintenance will act before performance is lost.

Table 1. Example Maintenance Activities with Energy Saving Benefit

Maintenance Measures with Energy Savings Benefit
Cleaning Heat Transfer Surfaces This applies to HVAC and refrigeration systems (air-cooled or water cooled), boilers, process heating, process cooling. When a heat exchanger surface is fouled, heat exchange rates are slowed. Eventually the fouling reduces performance and hot/cold complaints will result. But to a large extent the systems are self-compensating, and this is the source of silent energy waste. A boiler can achieve the same heat exchange rate through the fouled surface by running hotter or longer each cycle. Hotter flue gas means more heat out the roof. A chiller or DX unit can achieve the same heat exchange rate through the fouled surface by running colder or longer each cycle – colder refrigerant increases thermodynamic lift and energy use. A chilled water coil can achieve the same heat exchange rate through the fouled coil with increased flow and pumping cost. In some cases, like a cooling coil in an air handler, opening up and looking is a reasonable method to decide when it's time to clean. In many other cases, a measurement is needed if you really want to know. The preferred measurement to predict heat exchanger fouling is "approach". For a zero degree approach, hot water temperature leaving a boiler will equal flue gas temperature, but this is never the case – the closer the two *approach* each other the more complete the heat exchange was. The "approach" temperature gets wider with smaller heat exchangers and with fouling. The approach temperature gets smaller for higher efficiency heating and cooling equipment (better heat exchangers) and equipment in a new, clean state. The very best determination of when to clean a heat exchanger is based on what it was when it

Maintenance Measures with Energy Savings Benefit
was new or after being cleaned, so recording this baseline data is very beneficial. Where no data is available, there are typical approach values available to serve as rough guides (see Appendix). More can be found from manufacturer's data. Note: approach values are based on full load, so any system with variable flow or variable firing, etc. affects a measured value of approach. For example, a chiller may show a 2 degF approach at 30% load and seem fine when, at full load, the approach shows 5 degF and is fouled. Extrapolation of approach values is not recommended – unless baseline data is available for part load, the recommended way to do this diagnostic measurement is to temporarily operate the unit at full load. The task can be made predictive instead of reactive or on a fixed schedule with strategic measurements, provided it is known what "clean" behavior values are. For example, if the full fire stack temperature for a water heater is 190 degF when clean, an inexpensive stack thermometer or sensor can show when the stack temperature rises. Usually, a rise in stack temperature accompanies fouling of the heat exchanger, and so this can be a prompter for maintenance to return the heat exchanger performance to its clean state.
Annual Maintenance Check for Motorized Valves and Dampers Schedule a maintenance activity annually to locate and exercise every automatic control valve, to verify it responds to "open-close" commands and will close tightly.
Annual Maintenance Check for VAV Boxes Schedule a maintenance activity annually to locate and exercise every VAV box primary air damper to verify it responds to "open-close" commands.
Check Packaged Rooftop Unit Economizer Settings These settings tend to drift over time, and are easily checked: On a 50 degF day, temporarily turn down thermostats to create a call for cooling in the rooftop equipment and then walk around each of the DX units – if any 'hum' from a compressor is heard, the economizer controls are not working.
Reconcile Energy Management System Overrides An occasional override of automatic control may be necessary as a temporary measure until a repair is made. Multiple or long-term overrides are often a source of energy use increase. Examples are a schedule override that leaves something running all the time or lowering the supply temperature a chiller or air handler. The energy waste from something running all the time is obvious; a cooling override can make the cooling equipment less efficient, can over-cool a space, and can invoke the use of duct heaters or space heaters to compound the matter. Clearing overrides as soon as possible is good practice - anything needing an override longer than a week suggests a systemic issue such as an equipment repair or defective software. When the issue is a lack of understanding control software's purpose, training preferable to simply defeating it with an override.
Using the Energy Management System (EMS) to Verify Control System Response

Maintenance Measures with Energy Savings Benefit

Valves or dampers that stick or stop in a last commanded state can, in some cases, go undetected. Often this occurs when there is sufficient heat/cool overlap that the resulting loss of comfort is minimal. A convenient way to verify this is through the energy management system. By issuing a large change of state command (more open or more closed), the downstream temperature sensor will predictably sense the change; if it does not, then the controller or actuator may be defective.

This method is very effective at verifying status of VAV box controllers and is a time saver compared to personally visiting each one to visually verify blinking lights and motion. The same concept can be applied to air handler control valves, mixing dampers, etc. The computer control system can be programmed to run this diagnostic on-line commissioning routine as often as desired – say every six months, and list non-responsive items.

Heat / Cool Overlap

Another silent energy consumer, this condition occurs in a variety of places. It can sometimes be detected with an EMS screen but is best rooted out in the field. Maintenance checks can identify these and lead to corrective measures…and energy savings.

- When an air handler is cooling, either with the air economizer, water economizer, or mechanical cooling, the heating valve should not be operational.
- When a downstream terminal unit is heating, either a duct heating coil, or a perimeter fin tube heater, the upstream cooling should be off or reset as high as it can go.
- When a VAV box heat coil is active, the box should be at minimum position.

Boiler Tune Up

In addition to the annual state inspection, a 'tune up' is a good idea for reliable operation and energy savings.

Energy benefits from boiler tune up:

- Combustion efficiency improvements from reduced excess air (air/fuel adjustments)
- Thermal efficiency improvements from improved heat exchange rates (monitor approach temperature and clean tube surfaces)
- Monitor operation for staging, short cycling, and other standby losses. (adjust controls)

Keeping records of basic parameters, along with a good-condition baseline allows predictive maintenance.

This sample table represents minimum data to collect and track for boiler efficiency testing.

Boiler B3	Low Fire	High Fire
Stack Temp degF	242	355
Excess Air %	70	29
O2 %	2.6	5.4
Combustion Efficiency %	81.6	82.4
Leaving Temp degF	175	175
Approach degF	67	180
Normal Approach degF		150

Maintenance Measures with Energy Savings Benefit
Tracking Locations of Hot / Cold Calls and Space Heaters Patterns of complaints and heavy usage of space heaters in certain areas sometimes point to larger, systemic issues. Space heaters especially can cover an underlying problem and are a source of heat/cool overlap in many cases. By charting where these occur it can become visually apparent that "something else" is going on and prompt an investigation. The underlying cause can be anything from a defective actuator to a valve left in the off position to an errant control setting.
Periodic Review of Control Screens The EMS graphic screens are more than bells and whistles. They are a useful tool in spotting anomalies, which then become targeted maintenance. Examples of how this system can work for you: • A supply air set point is 55 degrees, but the sensor shows 98 degrees and the heating valve shows it is commanded closed. *Something is wrong.* • A heating set point is 75 degrees, but the sensor reads 125 degrees and the valve shows it is commanded closed. *Something is wrong.* • A package unit supply air temperature cycles between room temperature and 50 degrees, which means the compressor is starting and stopping, but its 40 degrees outside which probably means *the economizer isn't working.* • A heat pump shows 130 degree water leaving a water-cooled condenser. *Something is wrong.* • A schedule shows an air handler running at 10:00 pm, while the building closed at 3:30pm. *Something is wrong.* Of course, sitting in front of a screen to watch this stuff all day long is not realistic. Unless there is some sort of 'sanity check' software to run and issue exception reports, the recommendation is to review the EMS screens once or twice annually to catch issues.

Maintenance that is targeting efficiency will act before performance is lost

Of course, there is a balance and cleaning a heat exchanger every five minutes is not practical. Maintenance for energy savings is a strategy that identifies the range of 'good' condition vs. 'performance loss' condition and intervenes at some mid-range point. A common example is a heat exchanger: when it is 'clean' the heat exchange rate is as good as it gets for that machine, and the performance indicators can be recorded so it is clear what 'clean' looks like. For this example, as the indicators of fouling move away from 'clean', a point is reached where a maintenance event is triggered.

Table 2. Example Optimized Maintenance Events

System	Common Maintenance Practice	Optimal Maintenance Practice
Heat exchanger, boiler, chiller, air/water coil	Periodic or when complaints occur from performance loss	Approach temperature (difference between key fluid temperatures in a heat exchange process) compared to 'clean' unit performance.
Filters for air/water	Periodic	Pressure drop compared to 'new filter'. Sometimes this will be less often than time-based service interval
Compressed air leaks	Periodic or when gross leaks are audible	Compressed air flow meter reading with compressor on and end uses off establishes 'tight' system; Periodic re-check will prompt maintenance when leaks have crept up again.
Steam traps	Periodic or when steam equipment performance is degrading	Leak testing methods show when a steam trap is functioning normal, where normal = letting condensate pass with minimal steam.
Hydronic sealed system hot water or chilled water leaks	None. Automatic fill replenishes	Make up water flow exceeds limit. Meter required.
Air economizer	Only if it generates a complaint	Annual check to run the economizer through its paces.
V-belt adjustment	Belts jumping or belts broken	Temperature rise on the drive and driven pulleys to indicate slippage.
Automatic control start/stop schedule settings, overrides	None	Annual review of schedule settings vs. actual requirements, monthly clearing of overrides or repair what is necessitating overrides, interval data identifies usage in closed periods.
Excess 'ghost loads' from occupant equipment being left on	None	Annual check using interval data from utility customer portal to see usage levels when the building is closed. Keep records or snap shots, to compare to prior years. Do not necessarily turn things off for the occupants, but the monitoring can prompt a helpful discussion.

Maintenance or repair items that are disablers for energy savings

Maintenance and operations are connected. The greatest contribution between the two is maintenance. Operations may call for something to open or close, or a temperature to be reset – if the equipment does not respond, operating costs go up. Examples to get you thinking along these lines are shown.

Table 3. Example Maintenance Choices that can Make or Break Savings

Maintenance Disabler Scenario	Easy Response	Optimal Response
A heating water system uses grooved pipe fittings and has leaks from the seasonal reset of hot water temperature (contraction, expansion).	Override the reset schedule to a constant high value and leave it there all season or all year, since the leaks stop when that is done.	Repair leaks and keep the reset schedule doing what it was designed to do
Air-cooled equipment location is causing it to run 'hot' and head pressure will be high, although there are no complaints. Location problem sources may include debris from shrubbery or mowing the grass, too close to each other, enclosed to hide from view, etc.	That's just the way it was installed.	Create a wide and bare perimeter around any air-cooled equipment so it can breathe and does not draw in debris. This would include landscape adjustment, sprinkler settings, etc. Look at the height of the air intake and create a debris-free zone two or three times that amount all around it. If grass is near the unit, adjust tact while mowing to 'aim' the clippings away. If enclosed, look for ways to get fresh air to the intakes, by removing portions of the 'wall' If physically installed too close, moving is ideal but may be costly, so this one needs discussion and may actually have to wait, depending on what is involved. There is value in raising the issue in any event because it will come up as an owner requirement for future work.
A duct coil was installed without cleaning access doors or a filter. Service access provision was missed.	That's just the way it was installed.	Add access doors as a minimum, for cleaning. Ideally, a filter would also be added to extend cleaning intervals.
The building air and water systems were just balanced and running sweet. It was not cheap. Experience shows the balance will begin to degrade over time from people messing with the settings.	Such is life	Can of spray paint or a scratch awl to mark the settings, so they can be put back. Keep a copy of the TAB report, preferably electronic, so it can be consulted over the years and not lost.

Recognition and Management Support

Sometimes the wrong people are tossed under the bus when energy waste from poor maintenance is identified. For success, the maintenance staff need to be enabled and empowered.

- Enough people.
- Properly trained.
- Reasonable O/M budget as a tool, without having to beg.
- Encouraged and acknowledged; even connecting effective maintenance to performance review.
- Acknowledged for good work. Show some interest, walk around with them, notice things that are organized and cleaned, instill pride and appreciation to keep up momentum…and the savings.

Additional Maintenance Tips for Energy Efficiency

- Use good quality filters. 30 percent pleated (MERV-8) should be a minimum. Avoid the flat filters - their efficiency is very low.
- The dirt that gets past the filters accumulates on the coils and in the ductwork. Dirty ducts have higher friction than clean ducts. Dirt covering heat exchange coils slows heat transfer making the heat/cool equipment run longer.
- Clean air handler coils annually – to keep heat exchange rates high.
- Clean air-cooled condenser fins annually. This applies to A/C outdoor condensers, kitchen cooler condensers, ice machine condensers, vending machine condensers, etc.
- Defrost reach in freezers often.
- Check and verify that control valves FULLY close when told to, annually. Internal leak by is hard to detect without visual inspection and can creep up energy costs if neglected.
- Cycle all valves annually (so they really work when you need them!).
- Calibrate electronic control sensors each 5 years.
- Test VAV box actuators (electric) annually. These have a short life – usually 5-7 years - and will fail in last-commanded state, and it is sometimes hard to tell they have failed by comfort complaints alone.
- Clean chiller condenser tubes annually – to keep primary cooling efficiency high. Determine the "new clean machine" full load approach temperatures and use these as a gage of when more frequent cleaning may be warranted. Tube cleaning is suggested whenever the approach temperature is more than 25 percent higher than clean state values.
- Clean boiler tubes annually – to keep primary heating efficiency high. Boiler tube cleaning is usually indicated whenever the flue gas temperature is more than 25 percent higher than clean state values.
- Replace insulation removed during repairs.
- Add insulation to bare hot piping.

Some Energy Savings from Good Operations and Maintenance Practices

→Values are not exact, and list is not complete. Point is that energy savings (dollar savings) are not trivial and targeted maintenance is valuable.

- Dirty outdoor coils can increase energy use up to 20 percent.
- Dirty indoor evaporator coils can increase energy use by 15-20 percent.
- A 1/16th inch layer of soot on a fired heat exchanger can increase energy use 4-5 percent.
- A 1/16th inch layer of mineral deposit on the water side of a fired heat exchanger can increase energy use 12 percent.
- Simultaneous heating and cooling from leaking terminal reheat valves or overlapping controls can increase summer cooling loads by 20 percent.
- Automatic control sensors that are out of calibration or adjusted incorrectly can increase energy use by 10 percent or more.
- HVAC equipment left on continuously instead of turned off each night can increase energy use by 15 percent.
- Boilers left on during summer can increase gas use by 30 percent.
- It is common for savings measures based on automatic controls to lose 20-30% of the initial savings within three years.
- In plants where steam traps are not serviced, it is common to find 40% of them with dysfunction (blowing by), with no symptom of performance loss in the equipment using the steam.
- Compressed air leaks are a large source of energy waste. 30-40% leakage rates are common, where 10-20% is achievable.

Additional Resources

Energy Systems Maintenance, Energy Management Handbook 8e, Berngard, G., Fairmont Press

Simultaneous Heating and Cooling—The HVAC Blight , Doty,S, Energy Engineering, Volume 106, Number 2 / February - March 2009

Appendix (following pages)

Heat exchanger approach values
(Typical clean values)

Refrigeration cycle diagram to visualize power reduction from lower approach
(From cleaning heat exchangers and other influences such as high efficiency equipment and control resets)

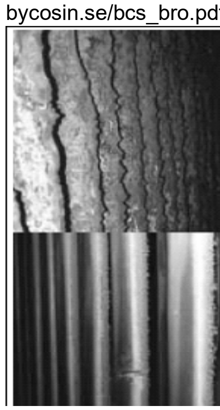
Heat Exchange Arrangement	Approach Temperature Between Where and Where	Approach degF (typ.)
Water-Cooled Condenser (shell and tube)	Saturated condensing temp minus leaving condenser water temp. This can be approximated by the liquid temperature	0.5-5
Water-Chiller Evaporator (shell and tube)	Leaving chilled water temp minus saturated evaporator (suction) temp	0.5-5
Air-Cooled Condenser	Saturated condensing temp minus entering ambient air temp. This can be approximated by the liquid temperature	25-40
DX Cooling Coil	Leaving air temp minus saturated evaporator (suction) temp	15-30
Dry Cooler	Fluid out temp minus entering air temp (ambient)	30
Hot Water Boiler	Flue gas out temp minus leaving hot water temp	75-150
Fired Water Heater	Flue gas out temp minus leaving hot water temp	20-100
Fired Steam Boiler	Flue gas out temp minus saturated steam outlet temp	75-150
Fired Air Heating Furnace	Flue gas out temp minus leaving air temp	20-100
Steam Heater	Saturated steam temp minus leaving hot water temp	10-30
Cooling Tower	Leaving (sump) water temp minus ambient wet bulb temp	7-15
Fluid Cooler (coil pack)	Leaving process fluid temp minus sump water temp sprayed onto the coil pack	10-20
Chilled Water Coil – Air Cooling (counter flow multi-row coil, coldest air in contact with coldest water)	Leaving air temp. minus chilled water inlet temp	7-10
Hot Water Coil – Air Heating (counter flow multi-row coil, hottest air in contact with hottest water. 50 degF approach is for single row coils)	Hot water supply inlet temp minus leaving air temp	10-50
Shell and Tube – Heating, Water-to-Water, Hottest Water in the Shell	Shell water outlet temp minus tube water outlet temp	10-20
Shell and Tube – Heating, Water-to-Water, Hottest Water in the Tubes	Tube water outlet temp minus shell water outlet temp	10-20

Heat exchanger approach values
(Typical clean values)

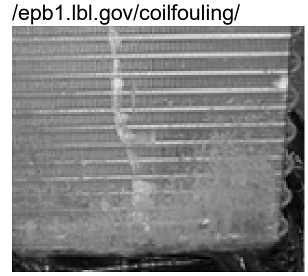
Source: Commercial Energy Auditing Reference Handbook, Fairmont Press

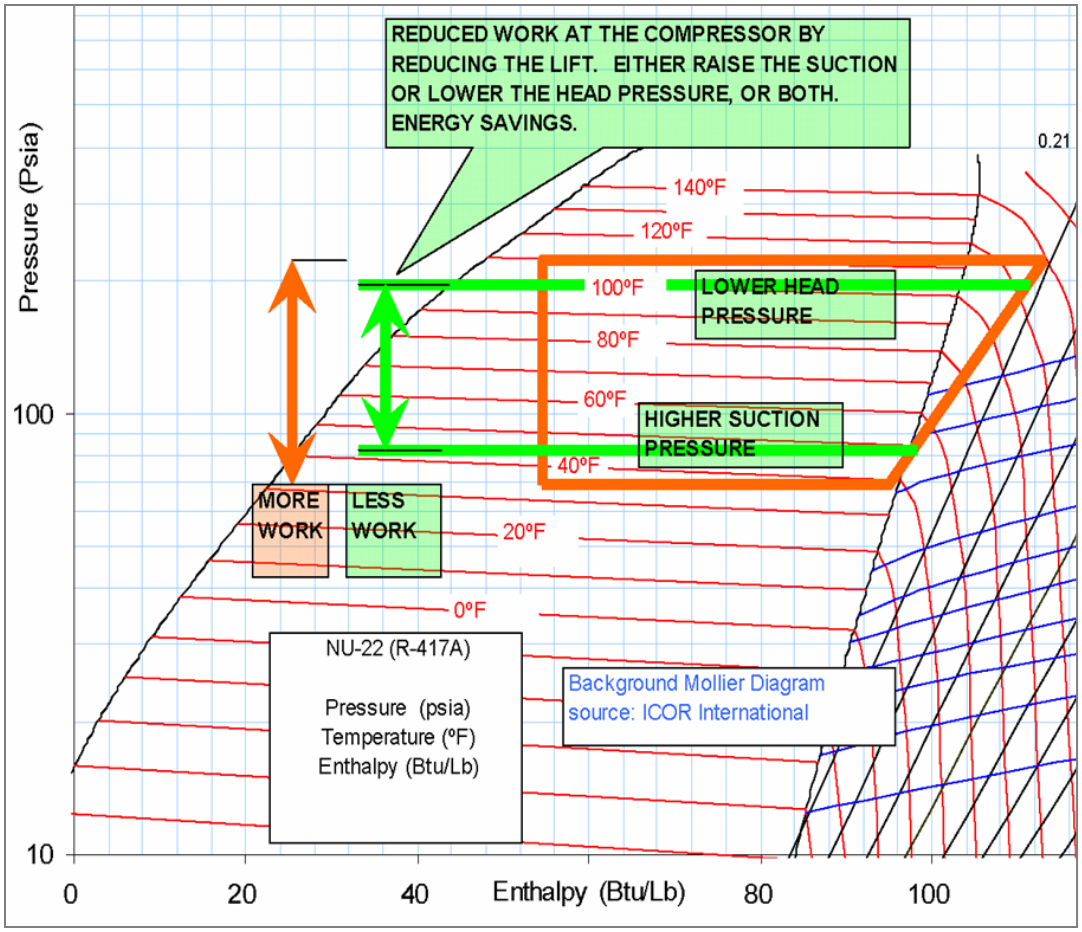
Clean heat exchanger =lower approach =higher efficiency

Boiler Tubes
Source: bycosin.se/bcs_bro.pdf



HVAC Coils
Source: /epb1.lbl.gov/coilfouling/





Refrigeration cycle diagram to visualize power reduction from lower approach

From cleaning heat exchangers and other influences such as high efficiency equipment and control resets

Clean heat exchangers reduce the approach and narrows the gap between the high and low pressure sides of the refrigeration cycle – the compressor sees less 'lift' and does less work.