Optimized Control Strategy for Building Operation Using Single Loop Operation

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Abstract
The paper considers alternative engineering approaches to energy efficient cooling and heating systems. Traditional HVAC design considers systems to be continuous flow with discrete independent control blocks for each of the numerous sub components. With the robust control technologies available, we may need to think batch flow concepts, with all subsystems dynamically optimized to meet required part load operation efficiency and ventilation requirements. The need for greater cooling capacity is a significant problem for all facilities.

Overview
The challenge for building owners with energy efficient component mechanical systems has evolved into how to properly care for the building occupants, ensuring proper ventilation to meet the statutory requirements. ASHRAE Standard 62-2010 generally requires 15-20 CFM per person depending on the facility type. Ventilation requirements may be higher yet if the actual mixing of out side air with facility return air is not uniform. Sophisticated air cleaning systems may be implemented to scrub undesirable constituents from the indoor environment, reducing the outside air requirement. The following plan details how to use technology to solve a problem with required airflow and energy efficiency imperatives. To begin, we must scope the problem.

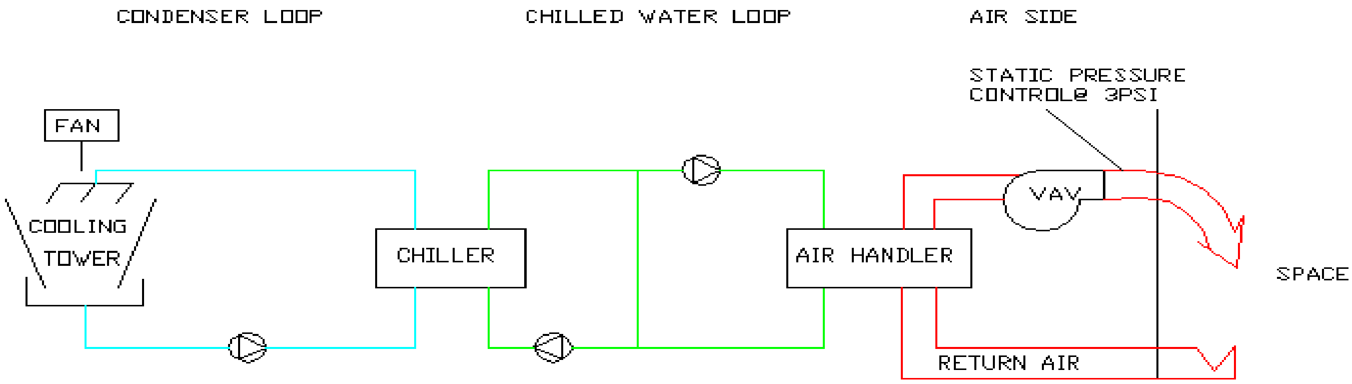
For simplicity of developing the techniques to be discussed here, we will discuss a simple HVAC system with VAV air supply. Typical VAV installations operate on the premise that the local thermostat will have available the necessary thermal solution for the space. The role of the thermostat is to regulate the amount (volume) of, typically, cooling for any given space. (There are many variants of VAV boxes, with fan powered heating units. These will not be the subject of this work, but are a logical extension of the thought process). Embedded in the available cooling is the proportion of ventilation air for the entire area served by the air handler. During the normal daily cycle, when occupants are present, lights are on and the heat load to be extracted drags along some ventilation air. At the end of the day the lights are turned off, and the space heat load may go to almost zero. Our early designs for VAV would let the VAV box shut off the flow of air to the space. Now we know that some limited airflow must continue into these spaces with no cooling load. The approach is to set the minimum flow for the VAV box to say 10-30 percent and provide reheat to prevent the space from over cooling. Given the typical pneumatic controls implementation for VAV, the reheat option solved the problem of overcooling. In the retrofit of existing buildings with VAV we are posed with a serious challenge.

Traditional VAV systems
Before we solve the need for reheat problem we must have some common definition for how the HVAC systems operate in the traditional manner. To do this, let us work back from the liberation of the heat by the cooling tower to the occupied space and define all of the control parameters from the cooling tower (or air cooled condenser) to the space. A diagram of the full sequence is shown below.

Working backward in the heat rejection process, from the tower to the space we have the following:

The cooling tower functions by passing water over the fill material, designed to create the greatest water and air contact, and into the tower basin. The tower fan will be operated to control water temperature in the basin to some desired level by forcing air to flow up through the tower. Even without the fan the hot water from the chiller will cause some level of convection airflow, due to the temperature differences. Not shown in the example drawing is the condenser water bypass valve that can divert water into the tower basin in cold weather and low load. Freeze protection is provided by tower basin heaters.

The condenser water pump operates the condenser water loop. The pump is selected to move the design quantity of water, gallon per minute, (GPM) through the condenser water barrel in the chiller. With safety factors the pump can be over sized.



The chiller compressor is sized to transfer the heat from the evaporator to the condenser. This compressor operational working range is usually defined over a narrow set of operating curves, specifying entering water and leaving water temperatures. Very cold condenser water generally limited to 10 degrees F above chilled water (verify requirements from the chiller manufacturer) can cause internal refrigerant flow problems for the compressor.

The evaporator water pump or pumps are designed to get the chilled water to the air handler. There are many possible configurations for the chilled water design. (See the chilled water design example.)

The air handler is designed to convey the airside heat to the chilled water, and to supply the cooled air to the space. There are many design variations here also. In this example we consider variable air volume (VAV) as the airside control. The air handler may use a variable frequency drive, inlet air dampers or outlet air dampers to vary the airflow. Typically the air handler controlled to provide a fixed pressure output to the ductwork. The operating pressure was established in the design analysis.

The airflow is conveyed to the VAV box, which based on the local sensor will cool as necessary to meet the temperature set point.

Each of the above system components function as an autonomous elements, controlled by individual set points. Let's go back through my simple example and determine how many control loops exist:

Cooling tower-

- Divert water through the tower or to the basin (1)
- Operate the fan speed (1)
- Operate the basin heaters, if freezing weather (1)

Condenser water

- Pump with pressure verification generally on/off (1)

Chiller

- Condenser water flow, for chiller shut down
- Compressor inlet vane control to maintain chilled water temperature (1)
- Chilled water flow, for chiller shut down

Chilled water pump(s)

- Pump with pressure verification, generally on/off (1)

Air handler

- Chilled water flow through the cooling coil (1)
- Fan start/stop (1)
- Fan pressure control set point (1)
- Minimum outside air for ventilation (1)

VAV box

- Flow control based on space set point (1)
- May have minimum flow set point with reheat (1)
- Space humidity (1)

Recognizing this to be a simple system we have about 15 control loops total. For those of pure heart we will only consider the loops marked with a (1) as controlling energy. Even in this simple example we have 13 loops that all have an impact on the energy consumption for the entire system. Further I submit that if the information available to the 13 individual control loops were available to all 13-control loops the decision-making would further reduce facility energy consumption.

Opportunity for Single-Loop Software Solutions to HVAC Systems

Let's evaluate the opportunity for energy reduction in each of the control loops discussed above. For simplicity the energy consumed for each HVAC element will be considered on a per unit basis as a percent of the chiller power (horse power). And the opportunity for energy reduction will be estimated per element.

1. The cooling tower fan airflow is designed to extract the thermal load from the condenser water. Typical design yields 250 CFM per ton of airflow with specific approach temperature of the condenser water to the actual wet bulb. The cooling tower fan energy as a percent of the chiller energy will normally be 5-8 percent. Typical control strategies operate the condenser fan to provide 85degree F. return water. Using the vendor provided data for tower performance as the control for actual leaving condenser water temperature will optimize the fan energy and reduce chiller energy consumption. (Note: Older chillers often required the entering condenser water to be 85 degrees F. to prevent compressor surge at off peak conditions. Current chiller design with micro-processor control can operate with colder condenser water, and lower resulting energy consumption.) The take away here is that the cooling tower fan at high speed will have a fixed approach temperature compared to wet-bulb and dry-bulb conditions. Operating the fan at high speed is wasting energy when the weather conditions are not favorable. The fan speed determination will be an integrated solution based on marginal chiller energy consumption. Stated differently, the tower fan will be operated to yield the lowest real time energy consumption from the system. Opportunity on the annual cycle for energy reduction of 1-2 percent.
2. The condenser water pumps are sized to provide a nominal 3 GPM per ton of chiller capacity. Typical pump energy consumption will be 5-7 percent of the chiller. The system opportunity here is to understand that at part load performance the condenser water flow can be reduced consistent with the chiller vendor performance tables. Second, the condenser pump is selected with safety factor for dirty pump screens (filters). And third pumps are selected up to the next frame size for the application. The net result is an annual opportunity with Variable Frequency Drives (VFD) to reduce energy 1-2 percent
3. The chiller is the largest single consumer of energy in the HVAC system. Optimized with the lowest condenser water temperature and the highest chilled water temperature will produce savings of approximately 2 percent per degree of reduced lift. (Where the lift is defined as the temperature differential from the condenser water leaving temperature and the chilled water leaving temperature. Normal design is 50 degree F. lift from 45 degree F. chilled water to 95 degree F. condenser water. Hence the 2 percent reduction per degree F at 1/50.) (Control strategies for chilled water reset discussed below). Opportunity for savings for the annual cycle at 8-10 percent. Additional savings are available with replacement of the chiller with equipment selected to better meet the annual cycle loads. Savings with new chiller equipment can range 15-50 percent
4. (Note The operation of the chiller in Single-Loop can resolve hardware problems in the design of HVAC equipment. Consider the undersized air handler that has 300-500 hours per year where temperature is not met in the space. The chiller can be commanded to produce lower chilled water temperature increasing the capacity of under capacity equipment. And secondly, One-Loop can document the cost of operation for the problem area for driving a cost based solution.)
5. Chilled water systems design get complex and Variable primary Flow is the subject of another paper. For this work a simple chilled water system will have pumping energy of 5-7 percent of the chiller system. By allowing Single-Loop to control evaporator flow based on the chiller vendor data for the chiller barrel design, and allowing one chilled water valve to be 95 percent open will yield the lowest pumping energy. Typical savings with VFD will be 1-2 percent.
6. The airside distribution is typically the second largest consumer of HVAC energy. The fan energy can range from 25-75 percent of the chiller energy. The opportunity here is to reduce the artificial head from the airflow by allowing on VAV to be 95 percent open. (In some systems I allow the worst-case zone to operate a 1 degree F. above set point of the zone controller. The one-degree provides stable operation of the zone controllers and

the fan VFD. Annual savings of 10-30 percent are achievable.

7. (Note The airside ductwork can be operated in a batch process where cooling is delivered for a portion of each hour, and ventilation delivered during other time periods based on the needs of the spaces, and eliminate reheat.)
8. The worst-case zone for temperature, humidity, and ventilation (CO2) (may be different zones for each) will determine how the air handler is operated, leaving dew point, supply air temperature, and ventilation mix. The humidity will drive the chiller leaving water temperature. Annual savings of 5-10 percent.
9. Actual performance can be measured and compared to manufacturer specification for chillers, pumps, air handlers, cooling towers and other components. For example, if some of the cooling tower nozzles were fouled the performance degradation would show up over time, as the tower would not continue to meet part load performance. Using the method of today, the tower will degrade until even running the fans on high will not meet condenser water set point.
10. One project I worked had significant production swings in the electrical demand. By allowing the thermal mass of the chilled water system to absorb short periods, 5–15 minutes, of reduced chiller demand, we were able to reduce facility site demand by over 100 KW per month, a saving of over $15K per year. This was accomplished by reducing chiller load during peak periods of demand. And recovering the cooling thermal mass during the reduced production demand. This cycle operated several times during a day in the hot weather without comfort interruption. Key here was available cooling capacity beyond breakpoint such that the chilled water system could recover quickly.
11. Return airflows may be monitored for carbon dioxide. Given reasonable testing and familiarity with these devices over ventilation may be reduced, or as part of a fault tolerance solution available cooling can be better utilized when equipment failures prevent all the required cooling from operating. The key here is the knowledge of actual operating parameters allows informed decision-making.
12. CO2 banking may be considered. The premise is that the facility has a large volume of air space. An early morning flush for say 1 hour will improve indoor conditions at the lowest cost time for energy. Now the CO2 content of the facility may be operated in a CO2 demand function (where the upper limit of CO2 is modulated with ventilation) or used as an electrical demand control (large facilities have natural ripple in the electrical demand, by trimming a few percent, the demand profile can be flattened. (A project completed many years ago invoked an inquiry from the local electric utility when they realized there were long periods of the day where the building demand was flat. Saving demand charge)
13. A Dedicated Outside Air System (DOAS) may be required in the humid climates to provide night and weekend facility pressurization of conditioned air without the need for reheat. (Reheat energy obtained from the rejected cooling condenser energy.

Two inter-related principles have been discussed above. The existing approach of multiple, single loop control subsystems, where the loops are not working together has tremendous energy savings opportunity.
Aggregate savings from the Single-loop can range from 15-40 percent of the chiller energy. Typical numbers are 15-20 percent. Secondly, shortcomings in the existing subsystems may be overcome by operating the system as a single loop reset with data from each subsystem. In practice other sub-systems can cover some or all, of the shortfall from parts of the larger system

Summary

The discussion above opens a new opportunity to reduce energy consumption. When we decouple the ductwork from continuous temperature flow and begin to think in terms of the High Occupancy Vehicle (HOV) lanes on the highways. Now we can use the ductwork by time phasing the temperature and quality of the air and routing that air to the area with special needs.

About the Author

Alan is owner and Principal Engineer for Stewart Engineering Services. His prior work includes 14-year veteran of Honeywell Inc., where he developed a wide variety of facility and process solutions for fortune 100 companies. He is a Honeywell President's Club member and recipient of the Johnson and Johnson Quality award. He served twenty-one years in the U.S. Air Force in a variety of engineering and technical roles; both in flight simulation systems and facility operation and design. Alan has published several technical articles. He is active in AEE, ASHRAE and NSPE. Alan is a licensed engineer in four states. His bachelor of electrical engineering degree is from Rutgers University and his graduate studies in mechanical engineering were through the Air Force Institute of Technology.