The Joy of Writing Control Sequences

Designers in best position to write sequences that integrate HVAC systems

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A well-thought-out, detailed operating sequence can make a building and its systems sing, while a bad one can turn even the highest-quality equipment into an inefficient, poorly performing mess and, occasionally, debris. However, there is more than pure technical expertise to what engineers do in this industry—there is art, craft, struggle, and passion. To improve things, engineers have to get in touch with that passion and embrace it.

Early in my career, I was trained that a brief narrative of an intended operating sequence is the foundation of design. In fact, I could not move a project into production until I had developed a brief narrative, system diagram, point list, and load estimate.

I soon discovered that although a brief narrative provides a good foundation, it is only a starting point, as narratives evolve with designs. Nuances and subtleties occur as systems and components interact with and respond to the processes and occupants served, other systems, and changes in the ambient environment.

'USELESS' DESIGN LOADS

In a discussion about loads, William J. Coad, PE, once told me, "Design loads are one of the most important, yet useless, pieces of information that we develop during our design process." Design loads are important because the capacities and configurations of systems and equipment are based on load assessments. However, they are useless in day-to-day operations because systems spend little time operating at design-load conditions.

For a 0.4 percent cooling design, outdoor conditions will exceed cooling design conditions only 0.4 percent (about 35 hr) of the year on average. The other 99.6 percent of the time, a system will be dealing with some other condition. Frequently, the "other condition" can be radically different from the design condition.

For example, consider an economizer process serving an air-handling system similar to the one in Figure 1 located in the environment in Figure 2. In the limit, HVAC processes and the loads they serve will be highly interactive with the local environment. However, there is more to consider than this interaction on a design day.

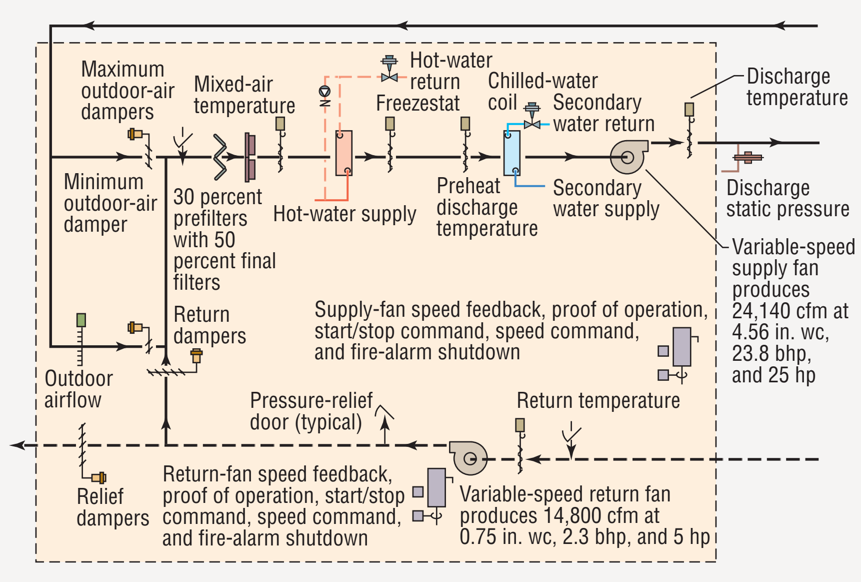

FIGURE 1. A typical variable-air-volume air-handling unit in a Midwest environment. This system is referenced in the "Integrated Operation and Control" section of the "Functional Testing Guide."

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In figures 1 and 2, the system is equipped with an economizer because it serves internal zones that require cooling year-round, including when the outdoor temperature is close to the desired discharge temperature and when it is significantly higher (95°F) or lower (2°F) than the required discharge condition. When considering these conditions in an economizer cycle serving a system similar to the one in this example, several questions arise as the design and control sequence evolve:

Will it get cold enough outside to cause the mixed-air temperature to be below freezing when the air-handling unit is running on minimum outdoor air? If it will, the heating coil needs to be selected, designed, installed, and controlled to handle subfreezing air without failing. In other words, you are dealing with a preheat application, rather than a warmup, heating, or reheat application. (A table that contrasts these various applications can be found in Chapter 5 of "Functional Testing Guide: Fundamentals to the Field," which is available as a free download at *www.peci.org/ftguide*.) This implies that certain physical installations, such as a pumped coil or a face-and-bypass-type arrangement, are needed.

In turn, these installations require specific control-sequence structures. For example, a pumped coil would require points and software to control the pump, including starting and stopping the pump and monitoring its status. A face-and-bypass arrangement would require provisions for modulating the face and bypass dampers while keeping the heating elements fully active when the outdoor temperature is below freezing. The sequence also would need to be able to shut down the heating elements when they no longer are required to eliminate the associated parasitic energy burden.

How will I decide when to terminate the economizer process? The answer to this question will vary with the sophistication of the control system, the geographical location of the air-handling system, and the requirements of the load served.

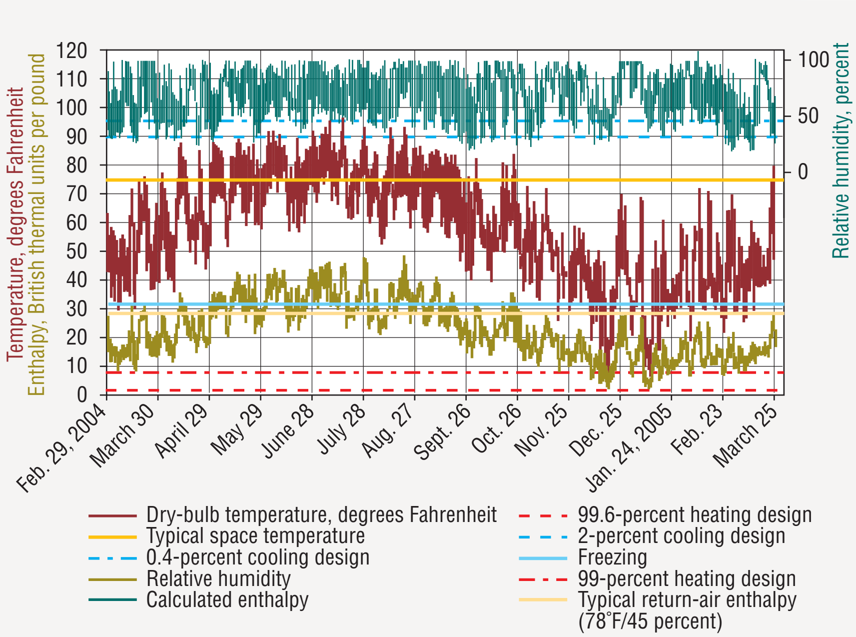

FIGURE 2. St. Louis weather data and critical HVAC design parameters.

A simple strategy is to base the decision on outdoor temperature. For a non-integrated economizer process, a changeover is triggered any time the outdoor temperature is above the desired leaving-air temperature. Such an approach is simple and easy to assess and implement, but sacrifices some of the possible savings. By selecting the changeover temperature in light of the mean coincident wet-bulb temperature typically associated with that outdoor temperature, the operation of the economizer can be integrated with the operation of the mechanical cooling system to provide additional savings. For example, in the Midwest, the outdoor-air-based changeover set point for an integrated economizer serving an office building typically is in the 68-to-72°F range. In Oregon, the optimal settings are closer to 72 to 76°F because it is not as hot and humid during summer. (Chapter 3 of the "Functional Testing Guide" contains more information on economizers and changeover settings.)

If the system in question serves a surgery suite, the changeover set points would tend to drop in both locations because the return air coming from the surgery suite typically would be cooler and dryer than the return air coming from an office-type load. The total energy content of the return air from the surgery suite would be lower, and the outdoor conditions favorable for economizer operation would be limited to cooler (and, by implication, dryer) outdoor temperatures.

Of course, outdoor dry-bulb temperature can only be a statistically based proxy for outdoor wet-bulb temperature and related moisture content. True optimization would require the control system to measure both parameters. Enthalpy sensors provide a means of accomplishing this, but at an added level of cost and complexity, especially if the enthalpy of both air streams is measured.

INTEGRATING A SYSTEM

For a system similar to the one in Figure 1 to work in harmony with the environment and loads it serves, the following questions need to be answered:

How will the system's operation be affected by the daily temperature and load profiles the system encounters? An important design goal for any control system is to maintain stability while responding to the load swings associated with daily and seasonal variations in temperature and other parameters. Systems serving loads with extreme variations in daily or seasonal requirements will demand more attention to the details of the control-sequence design and the selection and sizing of the related hardware when contrasted with systems that need to deal only with modest load swings.

Will temperature and load profiles vary with the seasons, as well as the occupancy of the building? Achieving successful performance from a system is much easier located in a relatively benign environment, such as San Diego, than it would be in an environment in which there are large variations between seasons. Similarly, a system that must operate successfully whether at full occupancy or 5 percent of full occupancy would require that more attention be paid to the control sequence and related hardware than a system that experiences the same occupancy level and pattern every day.

How will the operation of the economizer be integrated with other processes that occur in the system it serves? Integration of economizer operation with the mechanical-cooling process is only one of the interactions that might occur in a typical system. Other common economizer interactions include those with a minimum-outdoor-airflow control system or an engineered smoke-evacuation cycle.

Generally, the higher the number of interactions that must occur, the greater the amount of attention that needs to be paid to control-sequence development. Each interaction should be considered, with knowledge of the possibilities associated with the other interactions.

This is not a linear relationship. Doubling the number of processes can quadruple the number of issues that need to be addressed. Each independent process is like a different section of an orchestra. To create a symphony, a composer must consider the characteristics of each section of the orchestra and develop each score to complement and blend with the other sections' scores. Similarly, when a control sequence is developed, the characteristics of each HVAC process and what is required for success in each process must be considered, as well as how each process will interact with the other processes under all of the operating conditions that can occur.

How will the operation of the economizer and the system it serves impact the operation of other systems in the building? The issues that relate to this question are similar to those discussed for the preceding question, but on a broader scale. For instance, integrating the economizer with the mechanical-cooling process will impact the mechanical-cooling system. Instability in the economizer could trigger instability at the central chilled-water plant or vise versa in a worst-case scenario. Similarly, because the economizer introduces extra outdoor air into the building, it will impact building pressure relationships between the interior and exterior of the building and between the zones served by the system and those served by other systems.

How will the operating team interact with the set points and tuning parameters associated with the economizer? Every building will require commissioning to fine-tune the set points and control processes for its real-time evolving needs. Generally, providing operators access to set points and tuning parameters via the keyboard through adjustable parameters is more desirable than modifying program code. However, limiting such access to operators with an appropriate level of training and understanding is equally desirable. Identifying adjustable parameters and the access level required to perform those adjustments is an important topic to include in any control sequence. Using this topic for a discussion about a control sequence also can provide an opportunity to document the initial settings that a designer anticipates will serve as a starting point as the building is commissioned or a recovery point if the tuned settings are lost.

How will I balance the flexibility associated with software-based control solutions with the need to protect equipment and occupants from critical conditions? It frequently is tempting to take advantage of the flexibility afforded by software-based solutions to allow one sensor to perform multiple functions. However, in some instances, this can be a recipe for disaster. For example, in climates in which ambient temperatures drop below freezing, a freezestat is a desirable or essential safety device. Typically, freezestats are arranged to shut down the fan system, close the outdoor-air dampers, and modulate the heating source or operate the return fan to keep the mixed-air plenum from freezing. When I first started to use direct digital control (DDC), I was tempted to use simply the mixed-air sensor and software to perform all of these functions. However, as I deliberated on how a system could operate or fail, I thought of several problems that made me change my mind:

- One of the things that can lead to a freezestat trip is the failure of the control that is supposed to prevent the trip in the first place. The mixed-air sensor I planned to use to trigger my freezestat sequence could be the root source of the failure I was trying to detect and, thus, ineffective.
- Software functions typically are relegated to the "black box"/direct-digital controller and are wired into the control system on the "auto" side of the starter's hand-off-auto selector switch. As a result, safeties programmed into the software will be eliminated from the system, if it is placed in "hand."

• Software-based solutions can become complex and place a lot of hardware and control programming between the triggering sensor and the output that implements the required function. Therefore, a significant number of points at which a failure could occur are placed into the logic chain, along with the potential for inadvertent modification via the keyboard. In contrast, a freezestat wired into the common leg of a starter circuit is a relatively simple time-proven mechanical device operating on a fairly simple physical principle. Because it is hard-wired, it is more likely to persist once it has been installed and verified as being correct.

How will I balance the potential to improve performance and the flexibility of software-based control solutions with the realties of a budget? This question often is addressed best with a life-cycle, rather than a first-cost, perspective. Returning to the economizer example, one output could be used to control the minimum-outdoor-air, maximum-outdoor-air, return-air, and relief-air dampers and save the cost of three outputs. However, this also gives up some flexibility and performance options that are at the heart of why a DDC system is purchased. Providing independent outputs for each actuator allows the system to adapt as the needs of the air-handling unit and the building it serves change over time.

Independent control of the minimum-outdoor-air damper enhances the ability to provide good indoor environmental quality and optimizes energy consumption, when contrasted with a minimum position signal sent to a damper assembly that also provides maximum outdoor air.

Independent relief-damper control allows the modulation of relief dampers based on building pressure, rather than a temperature-control function, further optimizing comfort and efficiency when contrasted with modulation based on the same signal as that of outdoor-air and return-air dampers.

Independent outputs for each damper function allow the fine-tuning of spans and response characteristics as the building is commissioned, operated, and modified. This can be much more difficult to do when a single output serves multiple actuators.

Balancing these issues is the need to design to a budget and match the system to the operating capabilities of the staff charged with maintaining it. If budgets are tight, the maintenance is performed out of house, the environment is mild, and the system is a small constant-volume, economizer-equipped system that will spend most of its operating hours bringing in significantly more than the minimum outdoor-air

requirement, then a decision to use one output for all of the dampers and the chilled-water valve, as well as a simple discharge-temperature-based control sequence, will help the project come in on budget while delivering the intended functionality in a manner that is more readily understood and maintained.

How will I balance the creative doors opened by software-based control solutions with the realties of the real-world operating environment? Many creative DDC options have an associated price tag in terms of development, installation, and operating costs and the ability to persist. Efficiency and performance enhancements will deliver intended results only if certain criteria are met, including:

- The underlying principles are sound and conveyed correctly to the field.
- The enhancements are affordable, including the costs for robust, dependable, reliable, accurate, and repeatable components.
- The team charged with installing and operating the enhancements has documentation.
- The staff charged with operating the enhancements is trained.
- The enhancements undergo ongoing repair and maintenance as required, ensuring persistence. (Training and realistic maintenance budgets are keys to success in this area.)

If the project budget or maintenance capabilities do not match the sequence requirements, the sequence probably will fail in the long run. As a result, everyone involved would be better served with a simpler approach.

CONCLUSION

You may think you do not have the time or knowledge to fulfill all of these criteria. However, HVAC systems designers are the only people in a position to develop the details of the control sequence that will orchestrate them.

A significant portion of the pleasure I get from my occupation comes from the joy of the creation, whether writing an article, teaching a class, or developing a system diagram, test strategy, or control sequence. Some of my biggest challenges and creative opportunities have come from control sequences I developed. Although the effort can be significant, so can the rewards. A well-written sequence paves the way for smooth installation and reliable, robust operation. Spend some time developing the details of your control sequence, thinking through the nuances and details that make each system a little different from the one before it. A well-orchestrated HVAC system can be a thing of joy and a creation of which to be proud.