DESIGN STRATEGIES FOR EFFICIENT HVAC SYSTEMS

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The integration of high performance HVAC design strategies can do as much to make systems energy-efficient as specifying high energy efficiency ratings.

Learning Objectives:

- Understand HVAC design strategies to reduce reheat.
- Grasp the advantages of using dedicated outside-air systems.
- Learn how heat recovery can reduce HVAC loads and energy.

Ventilation

HVAC equipment exists to fulfill two goals: ventilation and comfort conditioning. To accomplish those two goals, a certain amount of energy has to be expended, but the goal of an efficient HVAC system is to minimize the energy input to do it. Ventilation in hot, humid, and cold climates is one of the largest loads on HVAC systems.

ASHRAE 62.1: Ventilation for Acceptable Indoor Air Quality sets the minimum amount of ventilation required for each space in a commercial building. Centralized HVAC systems have to condition more ventilation air to meet the minimum ventilation requirements for the individual spaces on the system due to differing requirements. This ends up with some spaces being overventilated and critical zones underventilated to meet the standard's requirements for a multizone, mixed-air system expending more energy than necessary.

Dedicated outdoor-air systems (DOAS) are HVAC systems specifically designed for conditioning outdoor air. Using a DOAS often results in lower total installed cooling and heating capacity because only the required amount of outside air (OA) for each zone is conditioned and delivered directly. In humid climates, mixed airstreams often have to be cooled lower than necessary for the sensible loads to reduce the humidity.

Using a DOAS to decouple the ventilation load from the comfort cooling system allows only the OA to be subcooled, rather than the entire supply airstream. It also expands the number of hours a supply-air temperature reset can be employed on the comfort conditioning system. Dual-path air handling units (AHUs) use these features of a DOAS by having separate cooling coils for the OA and return air (RA), but they are still subject to the increased OA of a multizone, mixed-air system.

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ASHRAE 62.1-2016 includes ways to reduce the minimum required ventilation through dynamic ventilation reset and air cleaning in conjunction with the Indoor Air Quality Procedure (IAQP). Section 6.2.7 of ASHRAE 62.1-2016 allows the ventilation-zone airflow (Voz) and/or the outdoor-intake airflow (Vot) to be reset as operating conditions change. The design Vot is calculated for the worst-case scenario. The building is fully occupied and all terminal units are at minimum heating airflow.

Figure 1

701 Brickell in Miami has been twice certified under LEED EB: O&M Gold in 2013. TLC Engineering for Architecture performed multiple energy audits and modeling to provide the owner with recommendations to meet their certification goals. Courtesy: TLC Enginnering for Architecture.

This is a very unlikely scenario. Dynamic ventilation reset is often employed by having the building automation system (BAS) recalculate the required outdoor air based on the current conditions. Variable air volume boxes all have flow measurement that feeds back to the BAS and zones with carbon dioxide sensors to give the BAS a measure of occupancy. This can be used to determine the required Vot based on the current conditions.

It's a simple control scheme that many BAS have the ability to do if they have the right input data. Dynamic ventilation reset can save lots of energy by optimizing the required ventilation at all times.

IAQP is an alternative ventilation design calculation detailed in Section 6.3 of ASHRAE 62.1-2016. It's a performance-based procedure that uses mass-balance equations to calculate the required OA rate for each zone based on contaminants of concern. Because it's a performance-based calculation, the engineer can account for the effects of air-cleaning devices.

When using the IAQP with certain air-cleaning technologies, it is possible to design a system with less required OA and maintain equivalent or higher indoor air quality than with the ventilation-rate procedure alone. Reduced outdoor air also allows for a reduction in peak heating and cooling equipment capacities and overall energy consumption. The cost reduction in installed equipment capacity can be used to offset the cost of an air-cleaning device.

Figure 2

The Global UCF Building houses students enrolled in the University of Central Florida's Global International Studies Program. The HVAC system uses desiccant wheels in the air handling units to provide dehumidified primary air to active chilled beams for space conditioning. Courtesy: TLC Enginnering for Architecture.

Zone control

Heating is the single largest energy end use in buildings. In Facilities with high minimum ventilation rates and/or code-required minimum air-change rates most of the heating energy is reheat. Reheat refers to heating done after cooling the supply air to avoid overcooling a space. Proper zone control can nearly eliminate reheat.

The classic example of reheat is in hospitals. ASHRAE Standard 170-2017: Ventilation of Health Care Facilities specifies the minimum OA changes and total air changes per hour (ACH) for the various space types in health care facilities. For instance, critical and intensive care patient rooms require six total ACH and two outdoor ACH. The six total air changes require the design airflow for the room to be greater than the cooling load to maintain the room setpoint, so if a centralized AHU serves the space, the cool, dehumidified air will need to be reheated at the room to not overcool it. Thus, any space with a required supply airflow greater than the load will need reheat.

Reheat can be combatted by changing to a zone-based heating and cooling system. Zone-based heating and cooling systems, such as water-source heat pumps, active chilled beams, passive chilled beams, variable refrigerant flow (VRF) systems, and fan coil units, allow the central unit to supply the minimum ventilation air to the zone while the zone unit turns on and off to maintain the setpoint for comfort.

The ability to control how much heating and cooling is being done at the zone level nearly eliminates reheat and reduces cooling energy. In labs with high sensible loads, active chilled beams provide the space cooling and heating at the zone while a DOAS provides the minimum OA changes. This way, all the required air isn't supplied at 55°F and reheated, and the zone heating and cooling unit can modulate the heating and cooling as needed to meet the load. A zone-based system arrangement is essentially giving greater zone control to only use heating or cooling based on the needs of that zone. Centralized systems have to supply air to meet the needs of the worst-case zone.

Heat recovery

Every cooling process creates some amount of rejected heat. There are several ways to capture that wasted heat and use it to reduce the heating energy in buildings. The most common means of heat recovery is by air-, water-, and refrigerant-based systems.

Air heat-recovery systems are most often employed to preheat and/or precool ventilation air to reduce the system load. Simply put, air-based heat-recovery systems use the exhaust/relief building air to temper the OA before it is heated or cooled by putting the two airstreams through a heat exchanger. Some heat-recovery ventilators, often referred to as energy-recovery ventilators, have wheels that spin between two airstreams to transfer heat. Others have cross-flow static cores or coils connected by a pumping loop to ensure airstream separation.

Water-cooled chillers usually employ cooling towers for rejecting their heat. Many water-cooled chillers can be equipped with a heat-recovery module to divert some or all of the waste heat for preheating domestic hot water or the heating hot-water loop. There also are dedicated heat-recovery chillers (HRC) specifically designed to produce hot water from the condenser for heating and cold water from the evaporator for cooling. It's important to make sure the Coefficient of performance (COP) doesn't drop enough to negate the savings because the compressor lift is so high. HRC are best used when they are sized for the base load, so it can be used at full load 24/7. The building just has to have enough coincident heating and cooling load to fully use it. This is common in buildings with a high reheat load.

Direct-expansion (DX) systems with hot-gas reheat and VRF or variable refrigerant volume (VRV) systems employ refrigerant-based heat recovery. Hot-gas reheat is a common type of heat recovery often employed in a DOAS. The hot gas from the outlet of the DX cooling coil bypasses the condenser and is used as free reheat to both decrease the relative humidity of the supply air and reduce the possibility of overcooling when in dehumidification mode.

Figure 3

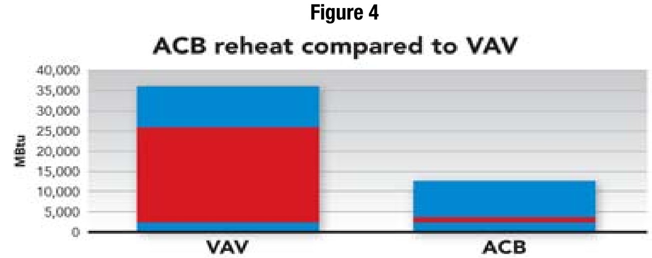
Air-based energy recovery uses a heat exchanger between the supply (OA, outside air) and exhaust/relief airstreams (EA, exhaust air) to provide precooling and/or preheating. This reduces the peak coil loads and annual energy consumption. Courtesy: TLC Engineering for Architecture.

Hot-gas reheat is an efficient strategy anytime dehumidification is dominant or a neutral to warm supply air temperature is desired, such as in natatoriums where there is a constant dehumidification load and the space setpoint is around 80°F. Specialized pool-dehumidification units also can use the recovered heat for pool heating.

VRF systems come in two types: heat recovery and heat pump. Only heat-recovery VRF systems allow for simultaneous heating and cooling on the same refrigerant network. The simultaneous heating and cooling feature is possible by using recovered heat based on the predominant mode of operation (heating or cooling).

For instance, if the majority of the VRF indoor units (IUs) are in cooling mode, then the condensing unit will be in cooling mode, but the hot gas leaving the IUs in cooling mode can be routed to any IU calling for heat. The non-predominant condition is being served with free heating or cooling, and it lowers the amount of heat the outdoor unit needs to reject, which reduces the condensing unit fan energy required.

Figure 4



Zone-based active chilled-beam (ACB) systems provide more control to satisfy the zone loads. By allowing for heating and cooling control at the zone, they nearly eliminate the need for reheat. Courtesy: TLC Engineering for Architecture.

Operations and maintenance

Over time, buildings in operation drift out of specification. Sensors get out of calibration. Maintenance people adjust settings to deal with complaints. Because of this, a great way to make an HVAC system energy-efficient is to ensure it is operating effectively. This entails making sure it is operating as designed and maintaining it during operation. Retro-commissioning, monitoring-based commissioning, and unoccupied controls are all ways to make sure the systems are operating as efficiently as possible.

Retro-commissioning often begins with an energy audit to look for problems in the building operation. Then recommendations are made to get the building operating correctly again. One of the most effective strategies is rebalancing the system airflows. Retro-commissioning is so effective it often has an immediate payback on investment.

Rather than just having someone retro-commission a building every few years to keep it operating correctly, monitoring-based commissioning can be used to continuously monitor how the building is operating. This allows the owner to fix issues as they arise rather than waiting until it gets bad enough to notice on a larger level or during an energy audit.

The most efficient piece of equipment is one that is turned off. More sophisticated building control systems allow for greater control of shutting off equipment when spaces are not in use. Most buildings already employ unoccupied temperature setbacks and shut off the ventilation at night. Some owners are taking it one step farther by shutting off ventilation to unoccupied spaces even during the day, and the energy code has started to incorporate these measures as well.

ASHRAE 90.1-2016: Energy Standard for Buildings Except Low-Rise Residential Buildings, Section 6.4.3.3.5, calls for guest rooms to have the ability to automatically raise/lower the setpoints and shut off the ventilation and exhaust within 30 minutes of an occupant leaving. This is a great example of turning off a system when it's not needed, and it saves lots of energy.

HVAC systems will operate more efficiently when strategies are in place to reduce loads, reduce reheat, recover waste heat, and operate more effectively. The most efficient HVAC systems use all those attributes.

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