The Future of HVAC

Part 1: A Revolution in HVAC Design

Donald R. Wulfinghoff, P.E.

Contemporary practice in heating, ventilation, and air conditioning ("HVAC") is inadequate to fulfill the stringent demands of the 21st century. It is deficient in comfort, ventilation, indoor air quality, fire safety, energy efficiency, and resistance to terrorism.

For several decades now, HVAC designers have known that they must make their systems more energy efficient, but combining efficiency with high standards of comfort and health has proven to be an elusive goal. It may seem that performance compromises are inescapable, but that is not true. Present problems stem from continuing along an evolutionary design path that took a wrong turn in the past.

In this series of two articles, we will recognize flawed premises in present HVAC practice, make a major change in HVAC design, and eliminate the defects of HVAC equipment. We will find that it is possible to satisfy all the requirements that HVAC must meet during this century.

HOW HVAC REACHED ITS PRESENT STATE

The evolution of HVAC has not been a steady march toward systems that are ideal for today's conditions. On the contrary, as in biological organisms, HVAC systems evolved in response to conditions that existed at various times in the past. As a result, HVAC has accumulated historical baggage that makes it poorly adapted to present conditions.

Contemporary HVAC began its evolution about 120 years ago, when centrifugal fans were introduced in the first large steel frame buildings to circulate outside air for the purposes of cooling, odor removal, and prevention of infectious diseases. In quick succession, these ventilation systems acquired additional functions and requirements. With each new requirement, variations of existing methods were attempted, and new problems usually accompanied them.

Steam heating coils were added, creating central forced-air heating. These introduced the problem of temperature control for individual spaces, which was met with manual dampers. Soon, prior expertise in mechanical cooling for meat preservation, ice making, and beer brewing led to the addition of cooling coils in central systems. This increased the problem of space temperature control further, as cooling became associated with uncomfortable "dumping" and stratification chilled air.

Early in the 20th century, dehumidification was introduced by circulating space air through piles of salt desiccant. This proved to be unacceptably expensive, bulky, and labor intensive. It was soon replaced by dehumidification with refrigeration, which introduced the problem of balancing cooling and humidity control.

By the 1960's, the comfort problems appeared to be solved. Constant-volume reheat systems become the epitome of high quality conditioning. These systems came very close to being an all-purpose design that could do everything well. But, they had an Achilles heel – a voracious appetite for energy.

This lurking flaw abruptly emerged as the dominant issue of HVAC design in the aftermath of the worldwide oil shock of 1973. Disruptions and rising energy costs made energy efficiency a public concern for the first time in history, forcing engineers to abandon constant-volume reheat systems. From habit, engineers tended to seek alternatives that could fit into the same space plan as the earlier systems, so they stayed in the realm of centralized multiple-zone air handling systems.

Within this self-imposed constraint, VAV became the default option. It brought several new problems, and engineers have struggled to make it both energy efficient and as comfortable as the earlier constant-volume reheat systems. However, no such system was ever devised. The evolutionary path of multiple-zone systems finally reached the point that attempting to solve one problem always aggravated others, or created entirely new problems. For example, we see this in the current proposals for low-temperature air distribution.

Meanwhile, other functions – filtration, in-space air circulation, smoke suppression, space pressure control, heat recovery, and energy storage – were incorporated into the schema of centralized system designs, adding further complications and compromises.

From their inception, central systems also created problems in building design unrelated to their conditioning functions. Early on, it was recognized that they provide paths for the spread of fire throughout the building. Much later, it was recognized that the HVAC system itself can cause a variety of health problems, collectively labeled "sick building syndrome."

At the beginning of this century, the emergence of chemical and biological terrorism led thoughtful engineers to recognize that contemporary HVAC design is a boon for terrorists. And, no effective solutions are in sight within the schema of centralized systems.

THE LOGIC OF THE HVAC REVOLUTION

The accumulation of unsolved problems in contemporary HVAC requires us to stop and take a fresh look. While we exploit the lessons of past experience, we will abandon assumptions that are no longer relevant and change practices that fail to achieve optimum performance.

HVAC today uses two broad approaches. For compartmentalized buildings, the dominant design approach is using centralized air handling systems that serve multiple zones. For smaller buildings, and for individual spaces whose conditioning requirements do not match the rest of the building, the dominant approach is using single-zone systems.

The first step toward optimum HVAC is recognizing that multiple-zone air handling systems inherently cannot optimize all HVAC functions, nor can they operate with a high level of energy efficiency unless they seriously degrade the comfort and health functions of the systems. This is a theoretical limitation, not just a practical one. Therefore, multiple-zone HVAC systems must be abandoned.

The need to abandon multiple-zone systems forces HVAC to rely on single-zone systems. However, contemporary single-zone systems have serious shortcomings, to the point that they are widely viewed as inferior alternatives to centralized systems. Fortunately, the deficiencies of single-zone systems are curable. They result from lack of care in design and from inadequate evolution of the equipment.

In the first of these two articles, we improve HVAC design generally by reintroducing a focus on the functions that we want each system to perform. In the second article, we will correct the specific deficiencies of contemporary HVAC equipment, with particular emphasis on eliminating the notorious deficiencies of single-zone equipment in humidity control and ventilation. Further, we will develop HVAC improvements that lie outside the equipment boxes.

Table 1 lists the specific improvements that will be covered. At the conclusion, we will have HVAC that is almost fully optimized for the conditions of this century, with only some deficiencies in ventilation remaining.

Table 1. Implementation of Optimized-Function HVAC

HVAC FUNCTION	EQUIPMENT IMPROVEMENTS	DESIGN IMPROVEMENTS
FUNCTIONS THAT DO NOT INVOLVE OUTSIDE AIR VENTILATION:		
Heating the Occupant Environment	• **None needed. The heating function is performed well by a variety of zone heating equipment.**	• **Nothing novel.**
Sensible Cooling of the Occupant Environment	• **Refine cooling coils and accessories to eliminate moisture retention.** • **Develop and incorporate features that inhibit the growth of microorganisms on wetted surfaces.**	• **Include a drying cycle to minimize biological fouling.**
Lowering Humidity Originating Within the Space	• **Commercialize DX units having integral reheat from heat of compression.** • **Commercialize hydronic cooling units having integral reheat from chiller heat of compression.** • **Improve the efficiency of in-space dehumidifiers, and offer models more suitable for commercial environments.** • **Develop more efficient alternatives to dehumidification by refrigeration.**	• **Implement efficient reheat in single-zone cooling equipment, both DX and hydronic.** • **Dehumidify at the point of greatest moisture concentration.** • **Broaden application of in-space dehumidifiers, and coordinate their operation with sensible cooling.**
Increasing Humidity of the Occupant Environment	• **Offer work station humidifiers appropriate for commercial environments.**	• **Increase application of work station humidifiers.**
Air Distribution to Convey Conditioning	• **Optimize supply air velocities in relation to conditioning load.**	• **Increase attention to avoiding drafts, dumping, and trapping of supply air against exterior surfaces.**

Intra-Space Air Circulation for Cooling	• **Offer in-space circulation fans for a greater variety of environments.**	• **Increase application of in-space circulation fans in commercial environments.** • **Coordinate circulation cooling with mechanical cooling.**
Removal of Space Air Contaminants	• **Develop reliable sensors for control of ventilation in response to internally generated pollutants.** • **For specialized applications, continue development of filtration and biocides to minimize cost, size, and air flow resistance.**	• **Continue research about the nature of internally generated air contaminants.** • **For specialized applications, apply contamination removal equipment as it becomes practical.**
Control of Inter-Space Pressures	• **None needed.**	• **Adapt pressure control doctrine to optimized single-zone systems.**
FUNCTIONS THAT INVOLVE OUTSIDE AIR VENTILATION:		
Select the Cleanest Outside Air Source	• **None needed.**	• **Improve locations of air intake and relief apertures for cleanest air.** • **Coordinate with architectural design to provide chases connecting intake and exhaust points to single-zone systems throughout the building.**
Optimize Energy Efficiency of Outside Air Ventilation	• **Improve single-zone equipment to optimize ventilation.** • **Offer prefabricated intake and exhaust fixtures that neutralize wind pressure.** • **Develop air distribution fixtures and systems for efficient distribution of ventilation air to work stations.**	• **Control air intake by dynamic control of fans based on flow measurement.** • **Use occupancy sensors to shut off ventilation when spaces are vacated.** • **Design intake and relief apertures to avoid wind pressure.** • **Install hermetic dampers at air intake and exhaust points.** • **Distribute ventilation air to work stations efficiently.**
Outside Air Ventilation for Cooling (“Economizer Cycle”)	• **Improve single-zone systems to optimize economizer cycle operation.**	• **Design system controls and hardware to accommodate all economizer modes efficiently and to separate them from non-economizer ventilation.** • **Select outside air intake location to exploit ambient air with lowest enthalpy.**
Recovery of Heating and Cooling from Exhaust Air	• **Incorporate heat recovery into smaller single-zone equipment.**	• **Optimize zoning of heat recovery.** • **Optimize the combination of sensible and latent heat recovery.**

Dehumidification of Ventilation Air	**In addition to in-space dehumidification improvements listed above:** • **Improve efficiency of latent heat exchangers.**	**In addition to in-space dehumidification improvements listed above:** • **Apply latent heat recovery optimally.** • **Apply ventilation air pre-conditioning equipment appropriately.**
Humidification of Ventilation Air	• **None needed.**	• **Nothing novel.**
Control of Zone Pressure Relative to Outside	• **None needed.**	• **Nothing novel.**
Removal of Ventilation Air Contaminants	• **For applications where cleaning of outside air is desirable, continue development of filtration and biocides to minimize cost, size, and air flow resistance.**	• **Select air cleaning equipment for outside air that has the best combination of effectiveness, reliability, and economy.**
Protection of the Ventilation System from Attack	• **None needed.**	• **Make the entire outside air intake path inaccessible to mischief.**
Fire Protection	• **Integral controls to stop systems in response to smoke or high temperature.**	• **Adapt fire protection doctrine to optimized single-zone systems.**
FAN ENERGY EFFICIENCY, GENERALLY:		
	• **Use variable-speed fans to modulate air flow in response to load and to exploit coil bypassing.** • **Eliminate control dampers.** • **Bypass idle coils using 2-position dampers.**	• **Abolish control dampers and substitute dynamic fan control.**

THE INHERENT FLAWS OF MULTIPLE-ZONE AIR HANDLING SYSTEMS

The most fundamental and startling shift in our HVAC revolution is abandoning multiple-zone conditioning systems. This change is needed because multiple-zone systems have deficiencies that are both serious and incurable.

Reheat vs. Energy Efficiency vs. Comfort

When constant-volume reheat systems crashed after the 1973 oil shock, a scramble ensued to devise systems that were efficient as well as comfortable. Engineers soon flocked to the variable-air-volume (VAV) concept, which throttles air flow to control temperature. The promise of reduced fan energy consumption was an attractive bonus. But, in the decades that followed, VAV never achieved its apparent promise. Providing heating as well as cooling was awkward. The earlier problem of "dumping" of concentrated cold air into the space reappeared. Also, VAV introduced new problems of space air stagnation at low conditioning loads, flow noise in the terminal units, and loss of outside air ventilation.

The main response to these comfort problems was to maintain minimum zone air flow rates. In turn, this required re-introducing a substantial amount of reheat. Supply air temperature reset was added to reduce the reheat, but reset is limited by the load diversity of multiple zones. And that's where VAV stands today, vacillating between energy waste on one hand, and discomfort and health problems on the other hand.

Inadequate Ventilation

Centralized air handling systems inherently cannot ventilate efficiently. Outside air enters the system at a single point. As a result, the fraction of outside air in the supply air stream is the same everywhere, whereas the ventilation requirements of spaces may vary widely.

VAV made this problem radically worse. The delivery of air to an individual zone is determined by the thermal conditioning load of the zone, not by its ventilation requirement. If a zone has little need for heating or cooling, it will receive little ventilation air.

Transport Losses

Centralized air handling systems expend large amounts of fan energy to overcome the resistance of convoluted ducts, balancing dampers, throttling VAV terminals, and diffusers. The conflict between duct size and rentable space pushes design toward ducts that are too small. Duct routing difficulties and fabrication constraints for duct fittings cause high flow resistance.

Air Leakage and Infiltration Into Idle Space

Centralized systems have vast expanses of ducts with significant leakage, which waste conditioning energy and some fan energy. Leaky terminal devices waste energy by conditioning idle space. Leakage through large outside air dampers wastes energy throughout the building when the systems are turned off.

Health Hazards

Any ducted HVAC system exposes all the occupants served by the system to any harmful airborne agents – diseases carried in aerosols, cigarette smoke, leakage from chemical containers, etc. – that originate within any part of the zone that is served by the system.

The emergence of "sick building syndrome" led to the realization that the HVAC system itself acts as a breeding and concentration site for pathogens and allergens. The greatest danger is the wet environment created by cooling coil condensate, but it is not the only danger. Investigators discovered the concentrations of filth inside ducts, a problem that is virtually impossible to prevent. Insulation installed inside ducts to attenuate noise traps and concentrates dirt. Insulation fibers themselves are now recognized as a health hazard. Insulation on the outsides of cold ducts becomes infested with mold and mildew, the result of unavoidable condensation.

Fire Hazard

The ducts and plenums of central air handling systems are fatally convenient paths for fire, smoke, and explosive gases. Defenses are unreliable. Smoke dampers are leaky and subject to jamming. "Active" smoke control schemes that require reliable operation of fans and dampers in the midst of a roaring fire are considered by many engineers to be a deadly folly.

And Now, Terrorism …

A pattern of terrorist attacks starting in the 1990's marked large buildings as prime targets of terrorists. Centralized air handling systems radically increase vulnerability to terror agents, just as they do for other airborne health hazards and for fire. A chemical or biological agent released anywhere inside a building will spread quickly and widely through a centralized HVAC system.

Effective defense for central systems does not appear feasible. No type of filtration can protect against all agents, and filtration requires a high level of maintenance. Using sensors to shut down air systems is unpromising for the same reasons, as well as for other reasons.

Multiple-Zone Air Handling Cannot be Fixed

Now, we are ready to answer the crucial question: are the deficiencies of multiple-zone systems inherent or can they be solved with sufficient ingenuity? As we review their deficiencies, we see that they have these causes:

- the use of a common air stream to condition zones with different conditioning requirements
- the need for ducts and their accessories for air distribution
- coverage of large areas by a single system
- ineffective exclusion of conditioning and ventilation from unoccupied zones.

The first three of these problems are inherent to multiple-zone air handling systems. Therefore, it is impossible for any multiple-zone design to provide good energy efficiency and simultaneously avoid comfort and health problems. We conclude that multiple-zone centralized air handling systems are a dead end in HVAC design.

A Clue from the Failure of VAV

Attempts to salvage VAV systems are hopeless in themselves, but some of these attempts comprise evolutionary steps in the direction of single-zone systems. In the 1980's, fan-powered VAV terminal units were introduced to avoid dumping and to maintain high space air flow without reheating the supply air from the central system. Two types were developed, called "series" and "parallel." Each type retains serious shortcomings. What makes them interesting is that they begin to limit the role of the central system, using it more as a pre-conditioning unit and a source of ventilation air. They show that current conditions are pushing HVAC toward single-zone systems as the ultimate destination.

MAKING THE TRANSITION TO SINGLE-ZONE HVAC

Single-zone systems can be highly energy-efficient. Transport losses are small. Temperature control requires neither reheat nor throttling of supply air. Conditioning inherently is isolated to the desired area. Single-zone systems cover smaller areas, limiting the spread of fire and noxious agents. And, they eliminate or radically reduce the costs and problems of ducts.

Engineers recognize these advantages. Then, why have single-zone systems not displaced multiple-zone systems? One reason is a misconception that single-zone systems are more expensive on a large scale and that they would occupy more space than multiple-zone systems in buildings with many zones. As we will see, all these perceptions are false.

Another reason is the undeniably poor quality of much single-zone equipment. Primitive controls, noisy fans, inaccessible filters, coils that don't drain, dampers that don't block infiltration, sharp edges on sheetmetal, difficult electrical connections – all seem to impugn the concept of single-zone systems. However, these failings are not inherent to single-zone systems. Single-zone equipment is shoddy because designers are willing to inflict shoddiness on their clients. When designers write specifications for high quality, that is what manufacturers will provide.

The most damaging misconception is that single-zone systems cannot satisfy all desired HVAC functions, or cannot satisfy them well. This misconception arises because contemporary single-zone systems do exhibit notorious deficiencies, especially in humidity control and in regulation of outside air ventilation.

Again, these deficiencies are not inherent, but are the result of old design habits inherited from the era of constant-volume reheat systems. Those systems satisfied the main comfort-related functions – heating, cooling, ventilation, humidity control, space air distribution, and pressure control – without any special effort or even awareness by the designer. An unfortunate result of this easy design was that engineers became heedless of the underlying functions of the system.

In contrast, single-zone systems satisfy only those functions that they are explicitly designed to satisfy. Problems occur in single-zone systems when designers fail to explicitly include each function that is needed in each zone. Before we can make the transition to HVAC that is ideal for the conditions of this century, the individual HVAC functions must be addressed systematically. To do this, we will introduce an updated design doctrine for HVAC.

FIXING HVAC DESIGN: INTRODUCING OPTIMIZED-FUNCTION HVAC DESIGN

HVAC for this century must become fully optimized. Each comfort, health, and safety function required for each zone in the facility must be executed perfectly, and no energy waste is permitted. This criterion is entirely achievable by a disciplined design process that focuses on the system functions.

We will introduce the term "optimized-function HVAC" for this design approach. This name signifies a break with the past, in which the designer would begin (and often end) the HVAC design on the basis of sub-optimal considerations, such as preferences for certain types of systems, or equipment budgets, or space constraints imposed by architects, or other considerations that are less important than providing the best HVAC.

This is the design sequence for optimized-function HVAC:

1. Define all the conditioning functions that are needed for each application in the facility.

This involves studying the application and using a checklist to make sure that all the relevant functions are being considered for each zone. The first column of Table 1 can serve as the checklist for most applications. All these functions are familiar to HVAC engineers. What may surprise the engineer is the number of functions that each system is expected to perform.

2. Define the spatial zones that correspond to each function.

The definition of a "zone" remains unchanged. It is a region in which conditioning requirements are always the same throughout. A zone may be as small as a single desk. Or, it may cover thousands of square meters, such as the merchandising area of a large store.

Zones may comprise different areas for different functions. For example, a group of laboratories may comprise a single zone for pressure control, while individual laboratories are separate zones for temperature control.

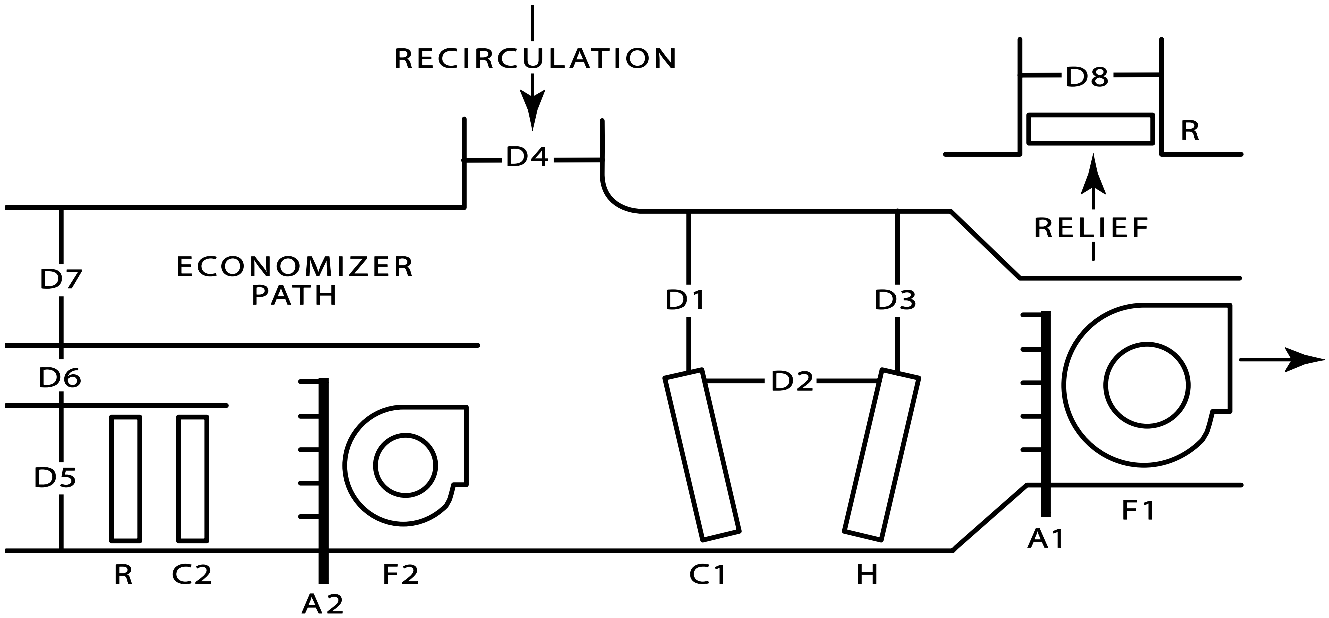
3. For each zone, identify the kinds of equipment that can fulfill each function optimally.

Breaking down the design into individual functions makes it easy to identify the most appropriate kinds of equipment. The designer identifies the kinds of heating equipment that can best serve the heating function, the kinds of cooling equipment that can best serve the cooling function, the best kinds of equipment for outside air ventilation, and so forth. At this stage, the designer is selecting the equipment for each zone on a "cost is no object" basis.

4. Consolidate the equipment for each zone without compromising optimum performance.

The previous step leaves the designer with a potpourri of choices. Because each function is optimized individually, the overall system may have many possible configurations. So, the next step for the engineer is to find a suite of equipment that satisfies all the HVAC functions optimally while satisfying other considerations as well. Usually, these other considerations will be compactness and cost. Sometimes, the application will emphasize other characteristics, such as minimizing noise.

For example, Figure 1 shows an optimized system for a typical zone. It performs all the common HVAC functions. (Filtration, humidification, and pressure control are omitted for clarity.) This particular example uses fans and coils for heating, cooling, and dehumidification. This choice allows all the equipment to be concentrated in a single box, plus a separate air relief.



(Filtration, humidification, and pressure control are omitted for clarity.)

Conditioning Mode	F1	F2	C1	C2	H	D1	D2	D3	D4	D5	D6	D7	D8
Heating: all conditions	O	O	X	X	O	O	O	X	O	X	O	X	O
Mechanical cooling: no dehumidification needed	O	O	O	X	X	X	O	O	O	X	O	X	O
Mechanical cooling: low outside humidity, inside moisture requires dehumidification	O	O	O	X	O	X	X	X	O	X	O	X	O
Mechanical cooling: outside humidity requires dehumidification	O	O	O	O	O	X	X	X	O	O	X	X	O
Economizer cooling: mechanical cooling not needed	O	X	X	X	X	O	X	O	X	X	X	O	O
Economizer cooling: supplemental mechanical cooling required, but not dehumidification	O	X	O	X	X	X	O	O	X	X	X	O	O
Economizer cooling: supplemental mechanical cooling and dehumidification	O	X	O	X	O	X	X	X	X	X	X	O	O
Purge Cycle (for cooling or air cleaning)	O	X	X	X	X	O	X	O	X	X	X	O	O
Zone Shutdown	X	X	X	X	X	X	X	X	X	X	X	X	X

Legend:
- F – Fan. All fans are variable-speed.
- C – Cooling coil
- H – Heating coil
- D – Damper. All dampers are 2-position (open/closed) and hermetic.
- R – Heat recovery (coil or heat exchanger)
- A – Air flow sensor
- O – “on” (for fans and coils) or “open” (for dampers)
- X – “off” (for fans and coils) or “closed” (for dampers)

Figure 1. An optimized-function HVAC system for a typical application. Note the high degree of equipment consolidation. Other optimized configurations are possible for the same application.

Other configurations could serve the same zone equally well. For example, the heating function could be performed by baseboard convectors, providing total quiet during the heating season.

5. Provide optimum control for all operating conditions.

Optimized HVAC perfectly tailors the operation of the equipment to the requirements of the zone at every instant in time. Therefore, many operating modes may be needed. For example, the model system in Figure 1, which is designed for an ordinary application, has nine operating modes, involving the control of 13 components.

Microprocessor controls are ideal for this high level of control detail, especially in packaged single-zone systems. The challenge to designers is to make the effort to identify all the operating modes for each zone, to provide the appropriate controls, and to program them meticulously.

The HVAC engineer should coordinate with the other building designers here. For example, occupancy sensors can be used to turn the zone system on and off, or to turn outside air ventilation on and off. The engineer should coordinate with the architect to select the best location for the sensors to determine occupancy. Similarly, the same sensors may control the lighting in the space, which requires coordination with the lighting designer.

CENTRAL PLANT EQUIPMENT IN OPTIMIZED SYSTEMS

Single-zone systems may generate heat and cooling individually, or they may receive heating and cooling energy from a central plant through water loops. In the strictest sense, centralized plants – especially cooling plants – cannot optimize energy efficiency. A chiller must make water cold enough to serve the zone that needs the coldest water. This reduces the COP of the chiller in serving other zones. Also, central plants require pump energy.

This theoretical disadvantage may be offset by the higher efficiency of larger central equipment and by the ability of central equipment to use fuels that cannot be delivered to individual zones. Hydronic systems provide advantages such as compact equipment and quiet operation. If central energy plants are used, the capable engineer will seek to minimize the tendency of individual zone requirements to degrade the efficiency of the central plant.

THE ECONOMICS OF OPTIMIZED-FUNCTION HVAC

The idealized performance of optimized-function HVAC extends to its economics. Human productivity is the highest cost associated with HVAC. By definition, optimized-function HVAC provides the best comfort and health, so it offers the greatest productivity.

The second-highest cost of HVAC is energy. Life-cycle cost is greatly reduced because optimized systems operate with the least possible energy.

Optimized HVAC reduces the cost of equipment space and increases rentable space. Air handling rooms are eliminated. Duct space is minimized or eliminated.

Equipment cost for optimized systems probably will be about the same as for centralized systems. All the major components of an optimized-function system have counterparts in a centralized system. For example, the fan-coil units in a typical optimized-function system have counterparts in the terminal units and perimeter heating units of a typical centralized system.

The higher cost of the zone system components is offset by the absence of central air handling units and ducts.

Only maintenance cost is likely to be higher. Each zone system will require routine maintenance, such as filter replacement. There will be more parts to wear out, such as fan motors. However, components will be small, highly standardized, and easy to reach. In any event, maintenance is a very small cost, for example, much lower than the cost of typical janitorial service.

The Future of HVAC

Part 2: Optimizing HVAC Equipment

Donald R. Wulfinghoff, P.E.

The previous article began with the observation that contemporary HVAC has lagged seriously in providing the level of performance that is needed in this century. To correct its deficiencies, we introduced a radical change in design procedure. In this second article, we will continue to optimize HVAC by eliminating prevailing deficiencies in design and equipment. Table 1 (in the first part of this article) summarized the improvements that we seek. The second column of Table 1 listed desired improvements in equipment, while the third column listed desired improvements in design.

We showed why the optimized HVAC for this century must rely entirely on single-zone systems. To make this acceptable, this article will eliminate the weaknesses of contemporary single-zone systems, especially their lack of rational humidity control and their poor control of ventilation.

Beyond that, we will correct all remaining energy waste, comfort problems, and health problems in HVAC systems. At the end, we will have achieved fully optimized HVAC, with the exception of one remaining area of development.

OPTIMIZING DEHUMIDIFICATION

Typical single-zone cooling units have earned a notorious reputation for creating “cold and damp” conditions, resulting in discomfort, moisture damage, and health hazards. We can fix this problem completely without much change to existing equipment.

For brevity, we assume that dehumidification by refrigeration will continue to be the most economical method for most applications. Problems arise with this method because the cooling coil inherently performs two entirely different functions – cooling and dehumidification. The shotgun wedding of these two functions is the cause of poor dehumidification in contemporary single-zone systems.

If we operate cooling equipment to dehumidify air, we also cool the air – whether we want cooling or not. The solution is to add reheat to single-zone systems.

Reheat is the source of good humidity control in multiple-zone systems. But, isn’t reheat terribly expensive? It is expensive only in multiple-zone air handling systems, which waste huge amounts of reheat energy for zone temperature control. In contrast, single-zone systems do not use reheat for temperature control.

Furthermore, reheat for dehumidification is always free. This is true because (1) any cooling process rejects more heat than it removes, and (2) reheat is needed only to cancel a portion of the sensible cooling process, the part that makes the space temperature lower than we want it to be.

Adding Reheat to Self-Contained (DX) Single-Zone Systems

To apply reheat in a packaged direct-expansion cooling unit, let's start with an ordinary packaged air conditioner. We add a reheat coil downstream of the cooling coil, as in Figure 2. A diverter valve routes a portion of the condenser discharge gas into the reheat coil, which behaves like a second condenser.

The diverter valve is controlled by a space humidistat. The compressor output is controlled by the space thermostat and the humidistat. We can build such a machine with ordinary components. Only the controls and the packaging are unusual.

A bonus is that using recovered condenser heat for reheat is more efficient than using external sources of free energy. The discharge from the cooling coil reduces the backpressure in the reheat coil, which in turn reduces the backpressure on the outside condenser, maximizing the system COP.

In fact, the configuration shown in Figure 2 is the most efficient method of combining cooling and dehumidification that is theoretically possible. It eliminates all cost of reheat, and it minimizes compressor work.

Combining Dehumidifiers with Air Conditioners

If the machine in Figure 2 sends all of the compressor discharge gas to the exterior condenser, it becomes an ordinary air conditioner. At the other extreme, if all the discharge gas goes to the reheat coil, the machine becomes an ordinary room dehumidifier. This suggests that we could achieve equivalent performance by using a common air conditioner in coordination with a common dehumidifier. Control of such a combination is elementary. The air conditioner is controlled by its thermostat, and the dehumidifier is controlled by its humidistat.

In fact, such a combination is theoretically equivalent to our combination unit. The differences are practical. Using separate equipment is more expensive, takes more space, makes more noise, and requires two condensate drains.

Adding Reheat to Hydronic Single-Zone Systems

To apply reheat in single-zone hydronic systems, visualize an ordinary 4-pipe fan-coil unit, with a cooling coil located ahead of a heating coil. For humidity control, the heating coil is controlled by a space humidistat. For temperature control, the cooling and heating coils are controlled in sequence by the space thermostat. The reheat energy is recovered from the chiller condenser.

Maximizing the energy efficiency of hydronic single-zone systems faces two challenges. Condenser water temperature must be minimized to maximize chiller COP. This requires radical redesign of the reheat coil to use tepid water for reheat. Also, tepid water has low energy content, which increases the amount of pump energy needed to deliver the reheat.

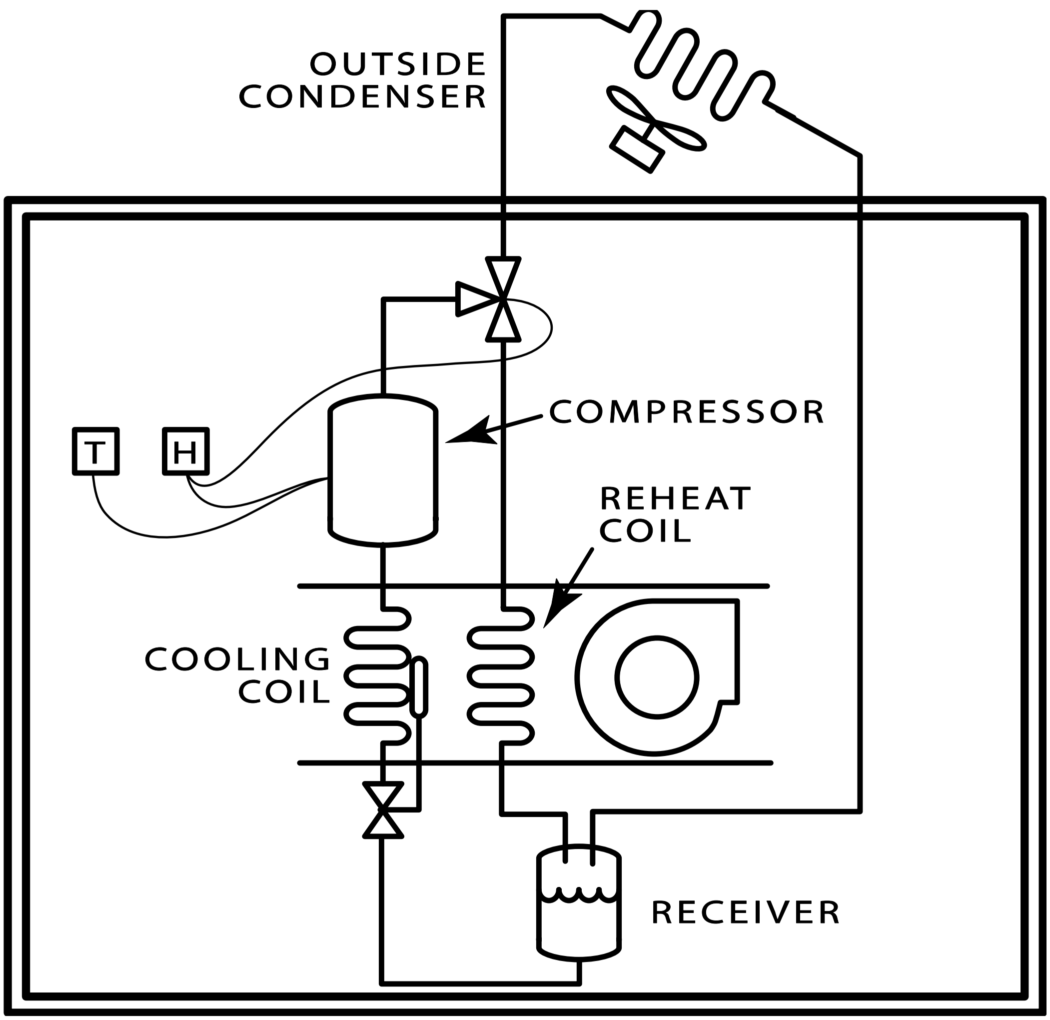


Figure 2. A single-zone cooling unit with optimized dehumidification. This is the most efficient combination of cooling and dehumidification by refrigeration that is theoretically possible.

Eliminate Moisture Retention on Coils

The second major cause of "cold and damp" conditions is moisture retention on cooling coils, which makes them act like sponges. The problem is largely independent of the cooling load. It can create high humidity even when the ambient temperature is high and the ambient humidity is relatively low. Once a coil becomes soaked, it turns from a dehumidifier into a humidifier as soon as the compressor or chilled water valve is turned off.

Narrow fin spacing is the prime culprit, the result of trying to increase heat transfer without raising coil cost. Present solutions are widening the fin spacing and limiting coil height. Future improvements will exploit aerodynamics to dry coils better. Perhaps, permanent surfactants may be applied to coils to enhance drainage.

Dehumidify at the Point of Greatest Moisture Concentration

In humid climates, most latent load enters with the ventilation air. In such cases, it is most efficient to dehumidify the incoming air at the intake. Doing this can cut dehumidification energy by as much as half.

The principle is to wring the water molecules out of the air before they are diluted by recirculation. It is easy to exploit this principle in single-zone systems. For example, the model optimized system in Figure 1 (in the first part of this article) has a separate cooling coil (C2) at the air intake for this purpose.

Optimize Recovery of Latent Heat

Optimized design treats dehumidification as a two-step process, in which mechanical dehumidification is only the second step. The first step is to exploit as much "free" dehumidification as possible by using the exhaust air to absorb moisture from incoming ventilation air. This is done with latent air-to-air heat recovery equipment. Single-zone systems with integral heat recovery already comprise a niche market. The model optimized system in Figure 1 illustrates it.

OPTIMIZING VENTILATION

Ventilation is the HVAC function that is currently the furthest from the ideal of optimized-function design. We can completely eliminate all ventilation deficiencies that are related to the HVAC equipment itself. Other ventilation deficiencies, unrelated to the HVAC equipment, await further development.

Control Air Intake Accurately

In the past, good control of ventilation air intake required an array of three dampers – intake, relief, and recirculation. However, control dampers inherently waste fan energy because they operate by creating resistance to air flow.

Optimized HVAC systems make control dampers obsolete. Air flow is controlled entirely by fan modulation that is based on air flow measurement. The development of efficient small variable-speed motors now makes it economical to exploit variable-flow fans even in smaller single-zone systems. To illustrate, the optimized system in Figure 1 has no control dampers. It includes air flow measurement instruments (A1 and A2) for each variable-speed fan.

Such control sophistication can be added easily, and it is necessary. Accurate control of ventilation requires dynamic control. Only a small pressure difference is needed to bring air from the outside into the building, and another small pressure difference to exhaust air from the building to the outside. These small pressure differences cannot be statically isolated from the much larger pressures needed to force air through coils and filters, and from large wind pressures on the exterior of the building. These larger pressures change continuously, requiring rapid response by the fans to control ventilation accurately.

Control Space Pressure Accurately

The obsolete triple array of control dampers in multiple-zone systems could not differentiate the pressures in the individual spaces served by the system. Single-zone systems inherently provide the potential for accurate control of space pressure, depending on the fan configuration that is selected. An intake fan creates positive space pressure. An exhaust fan creates negative pressure. A combination of three fans can regulate pressure at any desired value with respect to adjacent spaces or the outside.

Dynamic control is needed to regulate space pressure, as for control of ventilation. This is achieved by integrating pressure differential sensors into the fan controls.

Optimize Economizers in Single-Zone Systems

Single-zone systems of any size can be designed to use economizer cycles to full effect. Air-side economizers need outside air intake and relief openings that are large enough to pass the maximum flow rate of the conditioning system without substantial pressure drop. Such big openings need hermetic dampers to prevent infiltration when the economizer is not operating.

For example, the model system in Figure 1 uses parallel intake channels, one of which (through damper D7) is dedicated to economizer operation. During economizer operation, fan F2 and its flow measuring device A2 are not used. They are isolated by dampers D5 and D6.

Air-side economizers entangle two different HVAC functions, ventilation and cooling. Usually, this is not a problem. The economizer cycle simply increases the ventilation rate above the minimum required. If the outside air is dirty, water-side economizers can be adapted easily to single-zone units.

Eliminate Air Leakage

Infiltration through idle HVAC systems is a general problem. It is especially conspicuous in single-zone systems because the outside air intake is close to the conditioned space and to coils that can freeze.

The collective flaw is relying on control dampers to provide isolation from the outside. Control dampers are not used in optimized HVAC. For isolation, we use hermetic dampers at outside air inlets and exhaust air outlets. Effective, economical hermetic dampers are currently available.

To illustrate, in the model system of Figure 1, the intake dampers (D5, D6, and D7) and the relief damper (D8) are hermetic. They are either fully open or fully closed.

Optimize Ventilation Heat Recovery in Single-Zone Systems

Exhaust air heat recovery is physically awkward because of the need to bring the intake and exhaust air streams together for heat exchange. To minimize space, equipment cost, and installation labor, single-zone HVAC units should be offered with integral heat recovery exchangers. It should be easy to install the box and to attach one or two ducts.

Hydronic runaround loops can also be used, but they have minimal ability to recover latent heat, and they waste pump energy if they are not designed carefully.

Select the Best Source of Outside Air

More attention should be paid to the location and configuration of the outside air intakes. This factor has major effects on system performance that are not adequately appreciated. Fortunately, no new methods are required.

Ventilation air should be drawn from the cleanest location available. Intakes should be shielded from wind pressure. Intakes and ducting must be inaccessible to terrorists. If cooling is a major load, intakes should be located to draw from the coolest accessible body of clean air. Generally, these considerations point to the roof as the best location for outside air intake. The engineer should advise the architect where to include chases to distribute the air. Chases should be well insulated and tightly sealed, as they are part of the external surface of the building.

Match Ventilation Rate to Need

Everyone now recognizes the value of controlling ventilation rates based on the nature and concentration of pollutants that originate inside the space. Reliable sensors that respond to those pollutants are still evolving. Further research is needed about the types of internally generated pollutants and the degree of risk they pose.

It is less well recognized that systems should protect against pollutants that enter from outside the building. The old assumption that outside air is cleaner than inside air is obsolete. On the contrary, it may be necessary to limit outside air intake. In such cases, ventilation will increasingly rely on cleaning recirculated air.

OPTIMIZING AIR MOVEMENT WITHIN THE SPACE

Optimize Ventilation Air Distribution to Occupants

Ideally, ventilation air should remain uncontaminated as it travels through the space until it is respired once, and only once, by a single occupant. Contemporary ventilation practice doesn't approach anywhere near this ideal. The main reason is lack of targeted air distribution. ASHRAE Standard 62 currently requires HVAC system to expend 7 to 30 times more energy for ventilation than would be required if ventilation air were delivered with perfect efficiency.

This area invites bold innovation. For example, individual desks might have ventilation outlets, along with task lighting and other environmental functions.

Avoid Drafts, Dumping, and Heat Trapping

The most immediate comfort problem with all kinds of HVAC systems is the distribution of air within the space. For example, during hot weather, restaurant patrons are often forced to seek tables that are not in the path of frigid air from a diffuser.

It pays to recall (if you are old enough) that constant-volume reheat systems provided excellent comfort because they provided a luxuriant volume of air at a velocity high enough for good distribution without using noisy diffusers. The high flow rates allowed heating and cooling to be provided with only a small differential between the space temperature and the supply air temperature.

No energy efficient system can quite match this level of comfort, especially when there is a large cooling load. Still, single-zone systems provide the opportunity to avoid specific problems of drafts and dumping by selecting air velocities, diffuser types, and diffuser layouts carefully. To save energy, the equipment can be designed to modulate the air flow proportional to the temperature differential.

When heating or cooling with perimeter equipment, it is important to avoid trapping the supply air against exterior walls by draperies and other window treatments. A few simple tricks can avoid this problem, but they require coordination with the interior decorator.

Coordinate Circulation Cooling with Mechanical Cooling

A major opportunity for improving efficiency and cooling comfort simultaneously is to combine refrigeration cooling with the ancient method of circulating air to cool occupants by evaporation of moisture from the skin. Engineers tend to overlook this beneficial combination, even though the two methods are compatible under all cooling conditions. Effective use of circulation fans allows the space temperature to be raised by a significant amount and it eliminates the concentrated drafts that are so commonly annoying with refrigeration cooling.

The two cooling methods require different equipment. Mechanical cooling generally distributes air at velocities that are much too high for comfortable contact with people. Traditional ceiling paddle fans are just fine for skin contact, and models are now available with very large diameters. As with all HVAC systems, they have specialized requirements that must be observed, such as avoiding light fixtures and small skylights above the blades.

MINIMIZE AIR MOVEMENT ENERGY

Single-zone systems inherently require less air movement energy than multiple-zone systems because they move air over short distances, they minimize duct resistance, and they do not need restrictive terminal fittings. We have further reduced air movement energy by using variable-speed fans to generate precisely the pressure needed at each moment of operation. And, we have eliminated the resistance of control dampers.

The final refinement is eliminating the energy wasted by dragging air through idle coils. It is common to place cooling and heating coils in series, sequencing them as needed. The resistance of the idle coils can be eliminated by installing 2-position (open or shut) dampers to bypass idle coils. In Figure 1, this function is performed by the trio of dampers D1, D2, and D3, and by the pair of dampers D5 and D6.

ELIMINATE ALL HEALTH HAZARDS

Engineers must no longer permit HVAC systems to be a cause of health problems or to be an accomplice in spreading them. Single-zone systems make a major stride by eliminating or minimizing the use of ducts.

The remaining focus of concern is the wet cooling coil environment. Equipment should be designed so that coils, coil headers, supports, baffles, and drain pans avoid trapping condensate and provide a steeply downhill path at every point. A daily drying cycle, which turns off the cooling coil and circulates air through the equipment to dry it out, should be part of the controls wherever the application allows it..

All surfaces exposed to air flow should be kept sterile. Ultraviolet biocidal lamps appear to be effective, especially for sterilizing the wet areas of cooling units. Catalytic coatings that destroy microorganisms and biological residues on contact may become practical in the future.

Beyond that, air handling equipment should remove dangerous agents from the interior environment by appropriate filtering. The cost of all these measures is minimal in relation to the benefit of finally providing the healthy environment that our profession has long promised.

ONWARD TO THE FUTURE!

Important changes in engineering often occur as seismic shifts, in which current practices are abruptly abandoned and nascent approaches quickly rise to dominance. Such upsets occur after years of increasing tension, when important realities grow too strong to ignore. We are now at such a point in the design of HVAC systems. A revolution in HVAC is needed to make buildings survivable in a century of very high energy costs and terrorist threats.

The coming jolt in HVAC design is analogous to the extinction of the dinosaurs, which grew too large and unadaptable and were replaced by small, versatile mammals. Similarly, multiple-zone air handling will be replaced by a versatile new design concept that we have called "optimized-function HVAC."

The change begins now. Design your HVAC systems for this century, not the last one.