Carrier Engineering Newsletter Volume 6, Issue 2

Evaluating Variable Air Volume (VAV) Packaged Rooftop Systems for Use in High Performance Environments

New codes and energy regulations have changed the standard for packaged rooftop unit construction. Packaged rooftop innovation over the last several years has made a huge impact on the overall efficiency of these systems and has introduced a shift in design for high-performance small commercial buildings. Owners and occupants of these buildings demand energy conservation and exceptional comfort conditions. High performance buildings that are smaller in size and/or consist of one level often sacrifice energy efficiency and comfort. One significant innovation is the use of Variable Air Volume (VAV) systems in smaller rooftop units to meet today's aggressive energy strategies and provide a high level of comfort.

This newsletter provides an in-depth look at five HVAC systems designed for high performance environments, followed by examples from a prototype office building configured to simulate conditions in four different climate zones.

Why are packaged rooftop units so popular?

A packaged rooftop unit (RTU) is one of the most important pieces of HVAC equipment for providing thermal comfort to an environment that is changing daily as well as yearly. In addition, the RTU must be applied across all climate zones and many different building types. The RTU provides what the International Energy Conservation Code (IECC) refers to as a "Simple HVAC System." The RTU system delivers heating, cooling, and required space ventilation to various zones from one single source.

Why VAV?

HVAC systems deliver thermal comfort to an environment as it changes daily as well as over the course of the year. If BTU efficiency is to be achieved through modulating the HVAC system,maintaining specified set points is not enough. Efficiency is also affected by control response and turndown efficiency.

Using a zone to link spaces with similar thermal requirements, then linking multiple zones to an HVAC system network, allows water or air delivery temperatures to be efficiently customized for each zone. The overall efficiency of the HVAC system can be further increased by turndown from full-load source capacity to lesser part-load amounts.Using these strategies with a VAV system helps to provide improved thermal environmental control per ASHRAE 55 and better energy strategies per IECC 2015.

Originally when RTUs were introduced to the industry, the packaged rooftop unit was provided with a single space thermostat for a single zone. The obvious drawback to this type of control system is that RTUs don't serve single zones, they typically serve multiple zones. On a single zone system, the only space that would receive comfort from the HVAC system was the one that contained the thermostat. Any additional zones served by the RTU didn't have their own space temperature sensor and their comfort was based on the conditions of an external space. In addition, the packaged rooftop unit often had minimal stages of cooling and heating capacity and operated at constant airflow. In this scenario, even the space that contained the thermostat experienced times where the conditions were uncomfortable as the equipment cycled on and off. Furthermore, the on and off cycling of the cooling system causes the humidity levels in the space to rise and fall, adding to the discomfort.

An upgrade to the single zone packaged rooftop unit was the implementation of a VAV system. Similar to a single zone system, a VAV RTU system has supply air distribution ductwork, and air distribution in the space. Instead of a motor starter, a variable speed drive has been added to the supply air fan. Instead of one space sensor there are multiple space temperature sensors serving multiple zones. For each zone there is an associated control damper (known as a VAV box). The zone damper, serving its individual spaces, modulates open or closed based on the input from the space temperature sensor. As the zone dampers open and close the static pressure in the supply ductwork changes. A static pressure sensor detects these changes and sends a signal to the VFD on the supply fan to change its speed/airflow higher or lower. The VAV system has an upgraded control system, but it would still be considered a simple HVAC system. The supply air from the rooftop unit is maintained at a constant temperature, in the approximate 55 to 60ºF range. If a space requires cooling it accepts this cool air. If a space requires less cooling, or heating, the first step is for the VAV box to reduce the airflow; if additional heating is required an auxiliary heating device is staged on. With VAV systems, each individual space almost never experiences situations where its space temperature can't be satisfied. In addition, a VAV system provides better thermal comfort than a single zone system because of the additional stages of airflow, heating and cooling.

With a VAV system, the RTU can maintain thermal comfort in multiple zones with diverse conditions while reducing energy consumption. Simultaneous heating and cooling is available. Varying the volume of airflow to a particular zone to maintain a changing thermal requirement allows for reduced fan energy at the source. In addition, turning down stages of heating and cooling capacity in the rooftop unit also reduces energy consumption and maintains thermal comfort across all of the zones in any condition.

In summary, VAV systems are an essential upgrade when implemented in high performance environments because of the additional thermal comfort they provide as well as additional energy savings. The comfort and energy saving benefits to upgrade from a single zone system to a VAV system traditionally outweigh the small additional first costs.

Quantifying Energy Requirements

Constructing a zone's thermal comfort quantity

Start by looking at the three basic pillars—Ventilation, Building Envelope, and Internal Loads. These three pillars require thermal conditioning based upon the zone-required temperature set point, indoor air quantity, and occupant activities.

For example, consider an office building that has the following typical spaces:

EXTERIOR WALL OFFICES	ZONE-1
INTERNAL OFFICES	ZONE-2
CONFERENCE ROOM	ZONE-3
COPIER ROOM	ZONE-4
SERVER ROOM	ZONE-5
BATHROOM	ZONE-6

The first step is to evaluate the amount of cooling load required at peak design cooling conditions. With this information you can determine the maximum size of the HVAC equipment, and then if necessary downsize it by applying diversity factors. Look at the minimum design of thermal requirements as well as the transition between seasons, to see how the zone requirements associated to the thermal quantity modulate over dynamic ambient conditions. This will provide insight on what needs to be monitored by the modulation. It will also provide the minimum and maximum airflow that will be required to select a VAV box.

A VAV system is a powerful tool for balancing indoor air quality and energy reduction. It matches the reduction of cfm provided by a central supply, relating to reduced rpms that capture the power reduction from the fundamental Ideal Fan Law 3. Using the same duct static pressure sensor as a Variable Volume and Temperature (VVT) system, a VAV system modulates the variable frequency drive applied to the central supply fan(s).

Building on the foundation of the above objective by the evolution of the packaged rooftop unit and its rich rooted history in thermal quality and efficiency, we now look to the enacting of code requirements supporting progress. A deeper dive into efficiency code requirements will enhance rooftop unit system capability to deliver airflow at the most efficient thermal delta T and kwh/cfm.

Moving from ASHRAE 90.1 Standards to enacting those references to code is where the International Energy Efficiency Code (IEEC) becomes important. Most states use the IECC 2009 version or later as an Efficiency Code, beyond individual local developed codes, as well as ASHRAE 90.1

Standards. It is this common combined code that develops two pathways: equipment efficiency stated by ASHRAE 90.1, and an HVAC system approach to energy strategies.

IECC 2012 System Efficiency

In section C403.2.10.1 of IECC 2012, Variable Speed Drive requirements need to be implemented onto a supply fan for a simple or complex HVAC system when that fan is greater than 5 HP. The supply fan is not associated to an equipment type such as Air Handling Unit, Fan Coil Unit, or Packaged Rooftop Unit; instead the fan efficiency has been moved to its own referenced efficiency table C403.2.10.1(1). Furthermore, this applies to a signal zone[1] application, which enacts transition to the code efficiency implementation in IECC 2015 for multiple zones.

Another IECC 2012 system energy strategy was economizer requirements based on climate zone.[2] By defining the requirement around climate zones, the previously untapped ambient condition can be used to help condition the internal spaces. This also provides a platform for looking at VAV system discharge air temperatures to be changed from static design day conditions to dynamic interaction of BTU makeup.

IECC 2015 System Efficiency

IECC 2015 continued the progression of emphasizing energy reduction for HVAC systems with the VAV system based on an air system serving multiple zones, therefore directly affecting all HVAC systems based on multiple zones. Most mid-tier efficiency Packaged RTUs with a VVT system can meet the requirements with a two-speed variable speed drive.[3]

A further emphasis on saving energy from a BTU associated reduction of what modulates from worst case (static) to every day aspects (dynamic) is Demand Controlled Ventilation. Section C403.2.6.1 requires DCV for areas that service an area greater than 500 ft^2 or more than 25 people / 1,000 ft^2. This reinforces two things about ventilation: the high percentage of BTUs associated to quantity of the entire heating/cooling capacity, and how incremental reduction will reduce fan energy as much as thermal source.

Another important aspect of the IECC is Economizer Fault, Detection, Diagnostic protection, in section C403.2.4.7. This section emphasizes that even with the proper energy strategies for an HVAC system, particularly associated with a VAV system, proper maintenance is required to ensure the energy reduction through the life expectancy. It is critical to have proper sustainability like the mandated Economizer Fault and Diagnostic with a VAV System based on Proper Duty Cycle. Cooling and heating stages must be based on actual real-time MAT, without false loading or over-ventilating which could hamper IAQ based on relative humidity ranges.

Summary of Five HVAC Systems

These systems were selected for the evaluation because they were considered to be the most common choice for this type of small, single-story, high performance building. In addition, they offer similarities as well as major differences that should be carefully considered when choosing an appropriate HVAC system. There isn't one type of HVAC system that satisfies all requirements and scenarios; for this application other HVAC systems could be applied.

System 1	***Single Zone Gas RTU with Economizer***
System 2	***VAV, Gas Preheat RTU with Economizer; VAV Boxes with HW Reheat Coils, Condensing Boiler***
System 3	***VAV, Electric Preheat RTU Units with Economizer. VAV Boxes with Electric Reheat Coils***
System 4	***Air-Cooled, Heat Recovery, VRF Systems with Independent DOAS***
System 5	***Boiler/Tower WSHP System with Independent DOAS***

[1]Signal Zone is defined by an area experiencing the same building environment and usage/schedule.

[2]Climate Zone reference table is C403.3.1(1).

[3]A two-speed drive is synonymous with Stage Air Volume in coordination of staging on heating and cooling capacities.

Table 1 shows a comparison of the five systems that highlights some of the main concerns of owners, designers, occupants, installing contractors, and maintenance personnel. Each of the considerations was ranked on a scale of 1 to 5, with 5 being the highest and one being the lowest. There is a short explanation in the notes section to clarify certain rankings. Once again, there are many items to consider when evaluating different HVAC systems for different buildings and the results can be very different from the previous project.

Table 1: HVAC Systems Comparison Chart

CONSIDERATION	SYSTEM 1 – CV RTU	SYSTEMS 2 and 3 – VAV RTU	SYSTEM 4 – VRF + DOAS	SYSTEM 5 – WSHP + DOAS
I. OCCUPANT COMFORT				
TEMPERATURE COMFORT	★	★★★★	★★★★	★★★★
HUMIDITY COMFORT	★ (see note 9)	★★★★ (see note 9)	★★★★	★★★★
SIMULTANEOUS HEATING AND COOLING	★	★★★★	★★★★	★★★★
SPACE ZONING	★	★★★★	★★★★ (see note 4)	★★★★
INDOOR AIR QUALITY	★★★★	★★★★	★★★	★★★
REDUCTION IN OBJECTIONABLE NOISE	★★★	★★★	★★★★ (see note 8)	★★
II. COSTS				
INSTALLATION COSTS (FIRST COSTS)	$ (see note 4)	$$$	$$$$ (see note 5)	$$$$ (see note 6)
OPERATING COSTS	$$$	$$$$	$$$$	$$$$
SERVICE AND MAINTENANCE COSTS	$$	$$$	$$$$	$$$$
III. OTHER				
EASE OF START UP AND OPERATION	★★★★	★★★	★★	★★
EASE OF MAINTENANCE	★★★★	★★★	★★	★★
EASE OF FUTURE REPLACEMENT	★★★★	★★★	★★	★★★
FLEXIBILITY OF INSTALLATION	★★★	★★★	★★★★ (see note 7)	★★★

Notes and Observations:

1. Other HVAC systems that could be considered for this application: a) fewer, larger VAV rooftop units, b) fewer, larger commercial split systems with VAV control, or c) numerous, small residential split systems.
2. A DOAS system for System 4 or 5 can vary greatly in nature. Some options for its design could be: a) providing untreated outside air directly connected to the terminal equipment, or b) a simple energy recovery device with only fans, or c) a high end heating/cooling system tied into the VRF or WSHP system. There are also many intermediate offerings between these simple/inexpensive or complex/expensive systems.
3. Life cycle costs are an important factor but were not considered in this evaluation. In addition, such a detailed analysis is not normally performed on this type of small project with simple HVAC systems and with relatively short design and construction periods.
4. The most common system provided is single zone RTU.
5. Because of the higher first cost of VRF systems, often the number of fan coils and zones on a VRF system is reduced when compared to a VAV system.
6. For the application in this newsletter (approximately 80-120 tons) typically a WSHP system would have the highest first costs.
7. VRF systems have the greatest amount of flexibility due to the different types of FCUs available as well as the flexibility on selection a location for the condensing units.
8. Indoor sound quality is probably equal for Systems 1 through 4, but the VRF system has the quietest sound levels due to its condensing unit.
9. Packaged RTUs can add dehumidification control to their system for enhanced humidity control.

The chart does not give weighting factors to every possible item because each HVAC system has unique strengths and weaknesses that can be matched to the individual requirements of the building construction, owner preferences, location, etc. Lowest first cost is often the most critical factor when selecting an HVAC system, but low first cost frequently results in insufficient occupancy comfort, higher energy costs, and higher maintenance costs. In this evaluation, System 2 and 3 (VAV RTU) and System 4 (VRF with DOAS) are slowly making inroads in the industry when compared to System 1 (CV RTU). Designers and owners are the driving factor for this increase in usage because they want to provide additional comfort to occupants. The ability to provide simultaneous heating and cooling to an entire building is an easy solution for minimizing occupant complaints. Furthermore, the ever-increasing code requirement for energy reduction along with increasing indoor air quality standards is straining the ability of the CV RTU to be a viable system in the future. Surveying the industry, it seems most designers and owners at this time are leaning towards providing System 4 (VRF with DOAS) as an upgrade to System 1 (CV RTU). It seems that System 2 and 3 (VAV RTU) is being overlooked as an upgrade for CV RTU systems. In a broad evaluation, when VAV RTU is compared to VRF with DOAS, VAV RTU is often lower in first cost, equal or better in energy usage, and easier to install and maintain. Other benefits of a VAV rooftop system for small, high performance buildings are described below.

Additional dehumidification control

A dehumidification control system is available as a factory-engineered and installed option on packaged rooftop units. In applications where buildings or zones are subject to higher than normal latent cooling load conditions, the addition of a dehumidification system could provide additional space comfort for the occupants. When the outside air or the zone contains higher than acceptable levels of moisture, a humidity sensor would trigger the operation of either:

- latent cooling operation or
- neutral air operation in the rooftop unit

This dehumidification system is an inexpensive option that doesn't require any special field modifications and has been available in constant volume units for years.

Improved indoor air quality

Packaged rooftop units have the ability to incorporate higher levels of filtration versus the tradition MERV 8 rating. In addition, IAQ would be improved during economizer operation because of the increased amounts of outside air brought into the building. Further improvements to IAQ could be realized with the implementation of a demand control ventilation (DCV) system with the use of CO_2 sensors. In addition, a DCV system would save additional energy by preventing over-ventilation of the spaces. The DOAS system for VRF and WSHP systems can have enhanced filtration, but the terminal equipment at the zone level for these two systems is limited in the amount of filtration that can be provided.

Simple, traditional HVAC system

The main equipment component of a VAV rooftop system is the packaged rooftop unit. This piece of equipment is a tried and true pillar of an HVAC system, one that has been around for many years and is familiar throughout the industry. The installation, operational, and maintenance requirements of the RTU have not changed much from its initial introduction many years ago. VAV boxes are simple to install and operate, and they require little maintenance. The use of a ductwork system and the overall control system are likewise similar and consistent in installation operation and maintenance requirements.

Commissioning

A VAV rooftop system doesn't require special training or extensive time to perform check/test/start-up as well as commissioning. Today's VAV control systems for the rooftop unit and VAV boxes are factory-installed and are typically plug and play with auto-discovery and pre-determined control algorithms.

Service, maintenance

With a VAV rooftop system, work (including filter replacements) takes place outside of the occupied area and does not disrupt the occupants. In addition, the system is simple enough that a larger base of available service technicians would be qualified to work on it. Because WSHPs are open to the atmosphere, these systems would have the highest maintenance costs.

Equipment life expectancy

The life expectancy of any HVAC system is highly dependent on the quantity and quality of service and maintenance. Ductwork systems traditionally have a longer life expectancy versus piping systems. Systems that operate their compressors in an on-off fashion typically have shorter life spans. Systems that operate their compressors in heating and cooling typically have shorter life spans versus cooling only systems.

Ease of future replacement

Replacing a rooftop unit requires integration with the existing support system as well as the control system. Replacing a component in a VRF system requires integration with the existing refrigerant piping system as well as the control system. Replacement of WSHPs is simple; they traditionally include isolation valves and hose kits on the piping connections.

Comfort

A VAV rooftop system can provide simultaneous heating and cooling operation similar to a VRF and WSHP system. Because it contains multiple space sensors, additional capacity stages, and VAV boxes, it provides better temperature and humidity control than a single zone system. Additional comfort can be provided by the simple addition of a dehumidification system. A supply air temperature and static pressure reset system would also enhance the building's comfort by providing more stable operating conditions.

First costs

System 1 (CV RTU) rates 5 stars since contractors and technicians are familiar with the system requirements, and the equipment cost of the rooftop equipment is lower when compared to the equipment in a VRF system and the DOAS unit. VAV rooftop units are traditionally very competitive with other HVAC systems across many different building types, applications, and locations when comparing first costs.

Sound

Because the compressors are located inside the building on WSHP systems, objectionable noise can sometimes be a problem. VAV rooftop units are traditionally quiet and are located away from the occupancy spaces.

Global Warming

The EUI (energy use intensity) for the entire building is shown on Figure 2 bar charts in the energy analysis section of this newsletter. The cities chosen were Houston, Los Angeles, Philadelphia, and Chicago. The EUI value is represented in kbtu/sq ft per year of total building energy consumption; it also includes lights and plug load energy consumption. As you will see, VAV rooftop system have competitive EUI values when compared to other high performance systems. Please note that electricity can be generated at the site or the source (power plant). Source EUI accounts for the inefficiency of generating and transmitting electricity. Source EUI is more meaningful to someone concerned about global warming since it is a true measure of environmental impact. Source EUI increases the EUI for electricity by a factor of about 3 since average electricity generation and transmission efficiency is about 28%.

Low energy costs

VAV rooftop units are traditionally competitive with other HVAC systems across many different building types, building applications, and locations when comparing energy costs. Operating costs for rooftop units are traditionally lowest when an airside economizer can be effectively utilized. In addition, operating costs of a rooftop unit are greatly enhanced when there is a larger percentage of heating hours and gas is the preferred utility (instead of electric heating). Furthermore for VAV rooftop systems, during operation at part load conditions a supply air temperature reset and static pressure reset system must be provided to satisfy energy codes. Although these two additional energy saving measures traditionally are overlooked, they are easy to implement; the control devices are already included in the base system and the programming logic is already included in the controller. These two control sequences save additional fan energy as well as cooling/heating energy. VRF and WSHPs also have low operating costs based on their ability to transfer energy between zones, but not having an economizer system is a disadvantage.

Energy Simulation

An energy simulation was performed for the five different HVAC systems across four different climate zones. Below is a brief description of the general features for all models as well as additional details of each of the five systems.

HVAC Systems:

General Features of All System Models:

- 75°F/70°F occupied thermostat setpoints
- 80°F/65°F unoccupied cycle setpoints
- ASHRAE 90.1 office operating schedule
- Ventilation ASHRAE 62.1-2013 ventilation rate procedure (effectiveness, people diversity, critical space included)
- Utility Rates State average prices compiled by US Energy Information Admin (EIA)

System 1 Single Zone Gas RTU Units

- Houston, Los Angeles and Chicago comply with IECC-15. Philadelphia complies with IECC-09.
- 10 units one per thermal block
- Stage air volume operation: 2 speed cooling, 1 speed heating
- Outside air: Integrated enthalpy economizer
- Gas heat
- RTU compressor and outdoor fan from product selections
- 57°F design supply air temp to building

System 2 VAV RTU Units Gas Preheat-HW Reheat Coils, Condensing Boiler

- Houston, Los Angeles, and Chicago comply with IECC-15. Philadelphia complies with IECC-09.
- 2 units each serving 2 perimeter thermal blocks
- 2 units each serving 3 interior thermal blocks
- Outside air: Integrated enthalpy economizer
- Gas heat in rooftop unit
- RTU compressor and outdoor fan from product selections
- 55°F discharge air temp
- Variable air volume operation: Forward curved fan with VFD
- 30% min VAV box position
- 95% efficiency natural gas HW condensing boiler for reheat coils

System 3 VAV RTU Units ELEC Preheat and Box ELEC Reheat Coils

- Same as System 2 but electric resistance heat throughout

System 4 Air-Cooled, Heat Recovery, VRF Systems with Independent DOAS

- Houston, Los Angeles, and Chicago comply with IECC-15. Philadelphia complies with IECC-09.
- 2 separate air-cooled heat recovery VRF systems 5 thermal blocks each
- Each VRF fan coils served by DOAS
- Outside air: DOAS, 60% ERV, gas heat, electric cooling
- Electric supplemental heat if required
- VRF ODU variable speed rotary compression
- ODU and outdoor fan kW from product selections
- 57°F design supply air temp indoor terminal units
- VRF fan coil: Low static 0.3 in. TSP cassette type non-ducted
- VRF system has 140 feet indoor/outdoor separation, 15 feet vertical

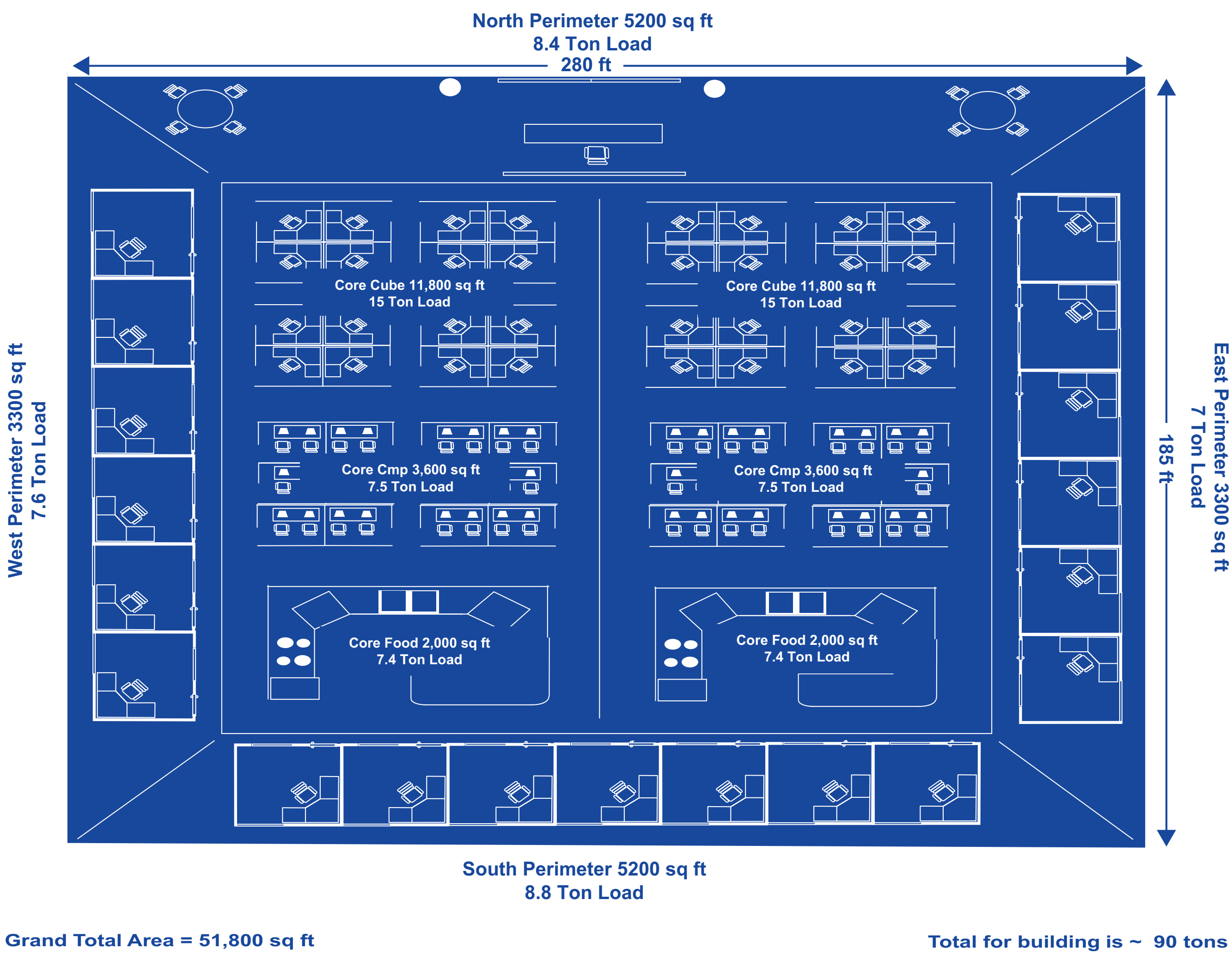
System 5 WSHP System with Independent DOAS

- Closed loop, reverse return piping system, water source heat pump system
- Outside air: DOAS, 60% ERV, gas heat, electric cooling
- Heat adder, gas boiler, 95% efficiency
- Heat rejector, cooling tower, 0.05 kw/ton VFD fan
- Loop range 68°F to 86°F high, pump 30 ft wg, 3 gpm/ton
- WSHP energy efficiency = ASHRAE 90.1-2013 compliant
- 57°F design supply air temp indoor terminal units
- Water source heat pumps: Medium static 0.6 in. TSP, horizontal type, ducted

Building Type

The building used for the simulation was patterned after a Prototype Pacific Northwest National Laboratory (PNNL) office building. See Figure 1.

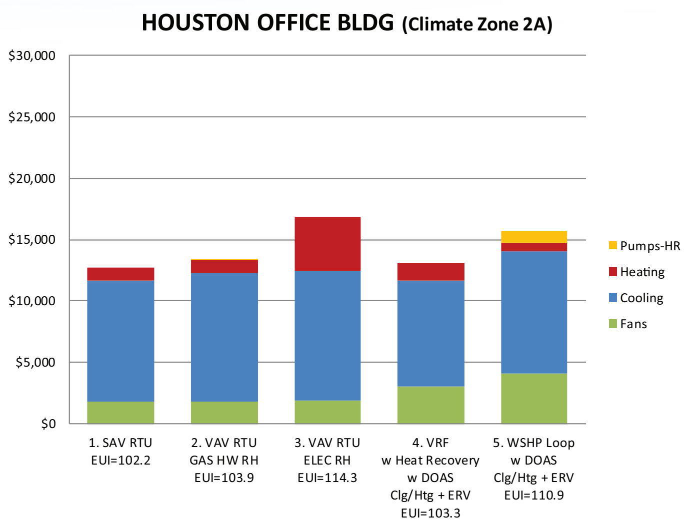
Figure 1: Modified DOE Benchmark Building – Medium Office V3

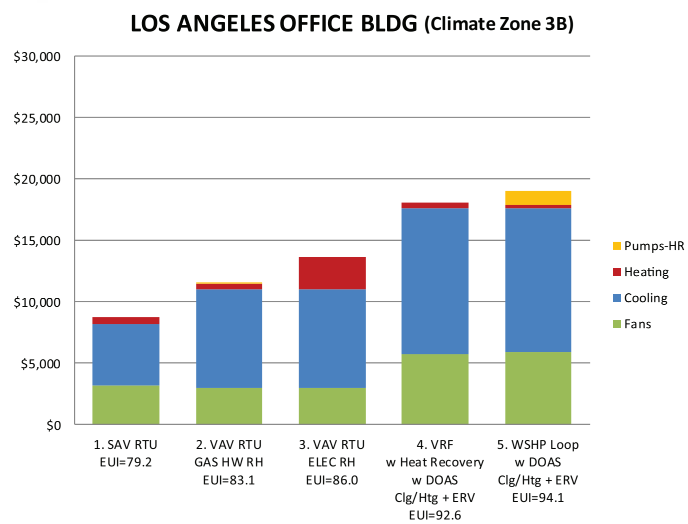


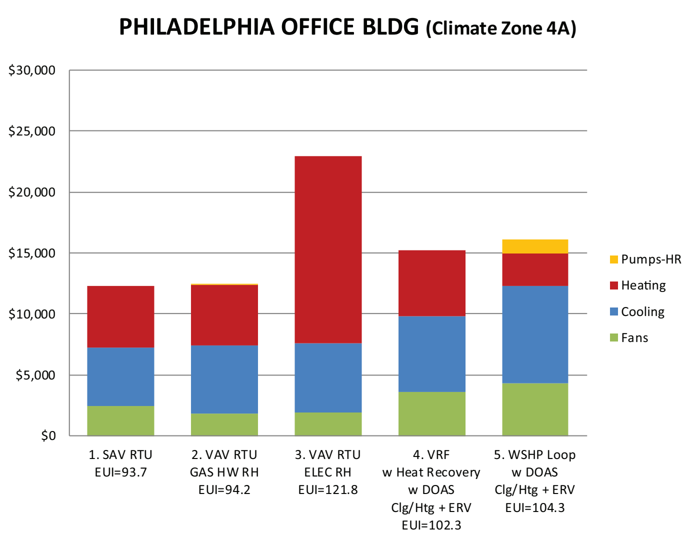
Building Features:

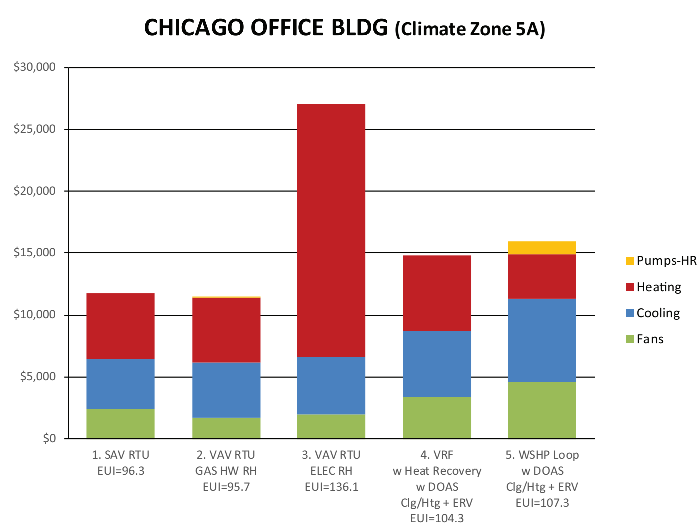
- Rectangular shape; 1.5 aspect ratio; overall dimensions 280 X 185; single story (PNNL was 3 story)
- 33% window to wall ratio all 4 sides; window depth 4.29 ft
- 10 thermal block zones: 4 perimeter, 6 interior (this modification was made to accommodate more zones)
- Perimeter zone depth 20 ft
- Ventilation per ASHRAE 62.1-2013 of 5 cfm/pp, 0.06 cfm/sq ft
- Occupancy 200 sq ft /person office work using an office occupancy schedule (normal office hours)
- Overhead lighting 1.1 W/sq ft; Office lights/electric schedule and 0.98 W/sq ft for open office area
- Electrical equipment 0.75 W/sq ft; Office lights/electric schedule
- Building envelope walls/roof/window assembly ASHRAE 90.1-2013 compliant based on climate zone
- All HVAC systems ceiling supply ceiling return

Figure 2: System Comparison by Zone









Analysis

Houston, Climate Zone #2 — Heavy cooling climate with some heating

- Cooling costs reduced slightly (5%) by economizer
- Heating costs minimal
- Reasonable utility costs: electric—8.5 cents/kwh; gas rate—$6.95/MCF

Observations: During long cooling season, System 1-3 (rooftops) benefit from airside economizer and VFD equipped supply fans (SAV = 1, VAV = 2 and 3). System 3 is the same as System 2 except electric reheat coils result in higher costs than a gas boiler. System 4 (VRF) benefits from the VFD (inverter) equipped compression but the fans on the DOAS and VRF fan coils are detriments. In addition, efficiency of System #4 is penalized by not having an economizer. System 5 (WSHP + DOAS) is penalized by constant speed compressors and constant volume fans. In addition, there is no economizer on WSHP. The loop pump energy is small portion but the pumps operate whenever cooling or heating is required.

Los Angeles, Climate Zone #3 — Temperate climate suited for economizer

- Cooling costs reduced over 30%
- Heating costs minimal
- High electric rate—15.73 cents/kwh; gas rate—$8.04/MCF

Observations: RTU Systems 1-3 minimize electric usage (cooling with economizer and VFD on fans). Not enough heating required for RTU System 3 electric reheat makes it uncompetitive. High electric rates impact VRF and WSHP systems (they are being penalized because they don't have economizer, and when they don't have VFDs).

Philadelphia, Climate Zone #4 — Northern cooling and heating climate

- Cooling costs minimized by economizer
- Using electricity for heating (versus gas) results in much higher operating costs
- Reasonable utility costs: electric—9.6 cents/kwh; gas—$9.32/MCF

Observations: RTU Systems 1-2 minimize cooling (economizer), and heating (gas) costs. Electric reheat of System 3 is uncompetitive due to large number of heating hours. VRF and WSHP very competitive due to heat recovery and reverse cycle heat pump feature and reasonable utility costs.

Chicago, Climate Zone #5 — Northern cooling and heating climate

- Cooling costs minimized by economizer
- Heating costs benefit from low natural gas rate
- Electric rate—9 cents/kwh; gas rate—$7.29/MCF

Observations: Chicago has similar results to Philadelphia. Since the gas rate is even lower, the RTU Systems 1-2 are lowest operating cost.

Energy Analysis Overall Summary

For this sample office building, HVAC systems that incorporate natural gas for heating, integrated airside economizer for cooling, and VFDs to minimize fan energy during part load operation deliver attractive operating costs consistently across all four climate zone locations.

For this application, the energy usage of 2 speed and variable speed fans was comparable. However, these type of fan systems save energy when compared to constant speed fan systems.

Systems that utilize electric resistance heat can also be an attractive alternative in locations where minimal heating is required. This is especially true even if electric rates are high such as in California. In colder climates, gas heat is more commonly used; the additional energy costs associated with the use of electric heat would probably not justify its lower first cost.

Systems that utilize refrigerant or water loop heat recovery and reverse cycle inverter heat pump technology (VRF) are attractive alternatives but not necessarily in all four climate zone locations. The use of a DOAS and ERV to minimize the ventilation load further increases the efficiency and helps offset the lack of an airside economizer.

CONCLUSION

For HVAC systems in high performance buildings, small VAV rooftop units provide an attractive solution. Owners of high performance buildings demand top of the line HVAC systems that provide individual occupant comfort at low operating costs. Small VAV rooftop systems traditionally offer competitive or lower first costs when compared to other high tier HVAC systems. These systems also satisfy owners requirements for ease of operation, commissioning and ongoing maintenance. As demonstrated in this newsletter, small, gas heat, VAV rooftop units can provide slightly lower energy costs while still satisfying the requirement for simultaneous heating and cooling.