The ASHRAE HQ Building – Can the energy efficiency of the different mechanical systems really be compared?

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Can the energy efficiency of the different Mechanical systems really be compared?

Executive Summary

The renovated ASHRAE HQ building in Atlanta, GA, is a two story building that has two different types of mechanical systems installed:

> **First floor** - Multi-split, air-source, DX inverter-driven VRF (variable refrigerant flow) Heat Recovery units with indoor fan coil units.
>
> **Second floor** - 13 ducted two stage DX Heat Pump systems serviced by 12 geothermal ground-source bores, each 400 feet deep, and variable speed pumping system.

Several attempts to compare the systems energy efficiencies have been made public by some vendors. The "comparisons" have been expressed in used-energy per floor area, kWh/sq.ft, for the two solutions.

Previous comparisons have given No consideration to the different load characteristics (usage, solar load, ventilation, etc.) and therefore the published "efficiency numbers" have very little, if any, value.

By analyzing the building and the logged operating data for the building, this paper illustrates, and quantifies, some of the differences that must be considered when these types of comparisons are made.

In addition, the paper emphasizes that:

- Measuring only energy used is not a means of determining efficiency for a system.
- Mechanical systems efficiency should be tested in controlled environments.
- When comparing alternate solutions, all Life Cycle Costs should be considered.

The renovated ASHRAE HQ building – Office, Learning Center, Living Lab and Showcase

The renovation of the ASHRAE Headquarters building in Atlanta, GA was completed in 2008. It has been awarded a LEED Platinum Certification under the LEED New Construction 2.2 rating system design for the renovated building and also ENERGY STAR® from the U.S. Environmental Protection Agency. In addition to serving as an office building for ASHRAE staff, the building is designed to provide a learning center to advance education, create a living lab for access by members and to showcase alternate technologies. The building has extensive sensing and monitoring capabilities, mainly focusing on how the systems operate, energy usage, and the environment for the occupants in the building.

The main building mechanical systems are:

- Dedicated Outdoor Air Supply (DOAS) – Roof mounted air-to-air heat exchanger with dual-stage, air-to-air heat recovery desiccant heat wheels, variable speed outside air and exhaust air fans and DX cooling. It supplies outdoor air to the whole building based on the demand in the individual spaces.
- First floor primary mechanical system – Multi-split air-cooled inverter-driven VRF (variable refrigerant flow) Heat Recovery units with indoor fan coil units
- Second floor primary mechanical system – 13 ducted, two-stage DX Heat Pump systems serviced by 12 geothermal ground-source vertical bore holes, each 400 feet deep.

In addition to some office space, the 1st floor includes the ASHRAE Foundation Learning Center with one large room (200 person capacity) and 2 smaller rooms (75 person capacity). These rooms are used for training, committee meetings, conferences, workshops, member gatherings, etc. The first floor also consists of the shipping/receiving area, hoteling and the data center. The 1st floor has 20% larger floor area than the 2nd floor and it also has more window area.

The 2nd floor of the building serves as office space, a small library, and 2 conference rooms.

Building Analysis– Despite claims from some manufacturers, it is NOT an “Apples to Apples” comparison of mechanical systems

The sensing and monitoring of the HVAC systems in the building are comprehensive but mainly focus on the input power and operation of the systems, such as kW draw, temperatures, operating modes, etc. With the current setup, there is no ability to directly see how all the mechanical systems in the building perform regarding delivered capacity output.

True measurement of efficiency/performance is the ratio between output and input, therefore, it is not possible to complete a correct evaluation of the energy efficiency of the systems, much less to compare the systems. In spite of this, several attempts to compare the two main mechanical systems in the building regarding energy efficiency has been made public by a few vendors. These “comparisons” have been expressed in used energy per floor area, kWh/sq.ft, for each of the solutions. This is essentially the same as using the analogy as to which car is most fuel efficient only looking at the input (Gallons) instead of relating the input to the output (Miles per Gallon). Clearly, since the two floors in the building are very different regarding size, usage, occupancy, and layout, it is expected that the required capacity output and resulting energy usage would be different for the two mechanical systems.

This obvious fact has also been pointed out by ASHRAE with a disclaimer on their website, see below, but the vendors that publish the “comparisons” have completely ignored ASHRAE’s disclaimer.

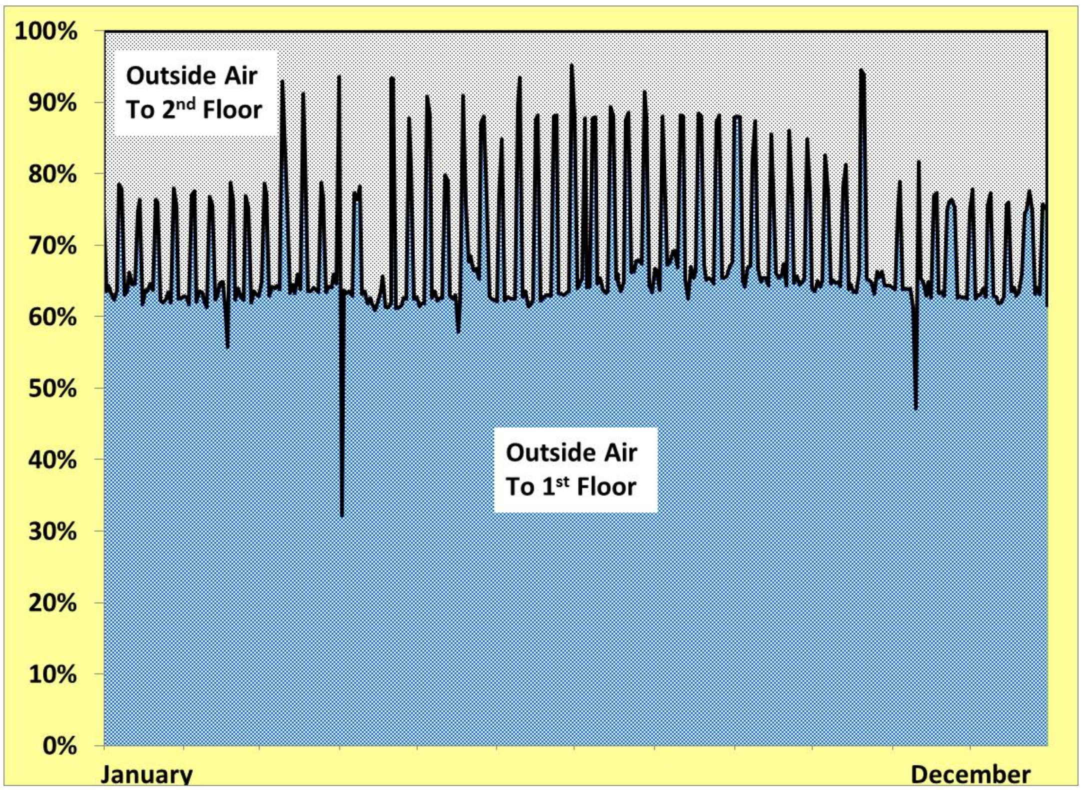
"The initial electrical end use data is being provided for members use in understanding the energy performance of the headquarters’ building. Data is provided on the three main mechanical systems including the Dedicated Outside Air Supply (DOAS) system serving the entire building, the Ground Source Heat Pump (GSHP) system serving the second floor and the Variable Refrigerant Flow (VRF) system serving the first floor. To fully evaluate the performance of these systems, additional data will be required to account for the difference in loads on the various systems. The areas served by each system as well as the envelope, occupant and ventilation loads differ. Additional data to support the characterization of these loads will be made available by ASHRAE in the near future."

Short of being able to measure the actual output from the systems, the two floors, and the mechanical systems serving them, could possibly be compared regarding efficiency if the test conditions were absolutely equal for the compared solutions. This would mean that they need to have the same sq.ft., solar load, people load, usage, ventilation, operating setup and ambient conditions. However, these conditions are almost impossible to create outside of a laboratory environment. Therefore, mechanical systems are performance tested in controlled environments. VRF systems energy efficiency is rated according to the ANSI/AHRI 1230 Standard which show values for specified Full Load and Part Loads conditions.

By using the logged data for the building, a few of the differences between the two floors have been analyzed and quantified as follows:

Ventilation

The demand driven Dedicated Outdoor Air Supply (DOAS) unit supplies air to both floors in the building. During 2012, the outside air supplied to the 1st floor was considerably higher than that to the 2nd floor as illustrated in the following graph. Typically, the air supply to the 1st floor was more than 60% of the total supply to the building. In some cases, it was more than 90% of the total supply.
Based on the logged values for the building, the calculated additional load on the 1st floor mechanical system due to the difference in air supply was 71,600 kBtu (21,000 kWh) for year 2012.



Lighting

The lighting in the building is occupancy sensor controlled. Logged values show that 1st floor used 30% more power than 2nd floor for lighting. The additional load on 1st floor during the cooling season 2012 was 16,000 kBtu (4,700 kWh).

Window transmission

As mentioned previously, the 1st floor is not only 20% larger than 2nd floor, it also has considerably more window area, especially on the front of the building as shown in the following photo. The calculated additional load on the mechanical system for the 1st floor due to extra windows is 16,200 kBtu (4,700 kWh) during 2012.

Usage

The building has demand modulation of makeup air by monitoring CO_2 in spaces with high variable occupancy. Since the total airflow to the 1st floor during 2012 was 87 % higher than the airflow to the 2nd floor, it indicates that the total usage of 1st floor was considerably higher. In fact, logged values show that certain days the makeup air supply to 1st floor was up to 20 times higher than the supply to 2nd floor.

When the training room(s) are utilized, the heat from the additional 200+ people increase the cooling load on the 1st floor with approximately 90,000 Btu/hr (26,000 W).

Summary of quantified additional load on 1st floor

Ventilation	71,600 kBtu	87% more air supplied to 1st floor
Lighting	16,000 kBtu	30% more on 1st floor
Window transmission	16,200 kBtu	
Total	**103,800 kBtu**	**Additional annual load on 1st floor**

Costs

When evaluating and comparing alternate mechanical solutions, energy usage is not the only factor that should be considered. All costs during the lifetime of the solution should be included in a comparison. For a mechanical system, the Life Cycle Cost includes Initial Cost (costs associated with engineering, purchasing, and installation of the system), Continuing Costs (energy and maintenance costs for operating the system during its lifetime), and Terminal Costs.

In spite of the functional differences between the systems in the ASHRAE building, both mechanical systems use DX units, piping, ducts, etc. However, the system on 2nd floor uses 13 central air-handling units occupying space inside the building, while the VRF system uses 3 units located outside the building.

In addition, the system on 2nd floor relies on 12 geothermal ground-source vertical bore holes (each 400 feet deep) outside the building. The cost for bores depends on many factors such as location, soil conditions, etc. For the ASHRAE building, the additional total cost for the vertical bores and the water circuit with piping, controls, and circulation pumps that are needed for the 2nd floor system is estimated to be more than $80,000.

In addition, this separate ground source water circulation system increases the total maintenance cost for the mechanical system on 2nd floor.

The VRF system in the ASHRAE building uses outside air for heat rejection/absorption. Although the first costs (equipment) might be higher than a WSHP system, the total installation cost (labor, materials, etc.) is typically very similar or lower than alternative systems, and the Geothermal loops are not needed. However, if a Geothermal approach is preferred, the VRF system also is available in a water cooled version, and thus the Geothermal loop technology could be used for the VRF system as well. This would obviously also increase the total cost for the VRF system but the Integrated Energy Efficiency Ratio (IEER, in cooling mode) and the Coefficient Of Performance (COP, in heating mode) according to ANSI/AHRI Standard 1230, would improve by 10% and 86%, respectively, compared to the air-cooled VRF system.

Conclusion

The two main mechanical systems in the ASHRAE HQ building in Atlanta, GA, operate under very different conditions. The attempts to compare the two systems energy efficiency based on used kWh per sq.ft. have very little, if any, value.
The VRF system on the 1st floor manage additional load compared to the 2nd floor due to:

- 20% larger floor area than 2nd floor
- Demand driven DOAS that supply considerably more air to the 1st floor (87% more than 2nd floor).
- Additional window area on 1st floor.
- 1st floor use more electric power for the occupancy sensor controlled lighting (30% more than 2nd floor).
- Training rooms usage (200+ people)

True efficiency/performance is the ratio between output and input. Therefore, Variable Refrigerant Flow systems are tested and rated under controlled conditions according to ANSI/AHRI 1230 Standard which show efficiency levels for specified Full Load and Part Loads conditions.
To perform a meaningful comparison of two alternative solutions, all Life Cycle Costs should be considered, not only the energy usage.
Differences, and similarities, for the two systems are shown and briefly discussed in the following Feature/Benefit Matrix:

Feature / Benefit Matrix
for Ground Source Heat Pump (GSHP) and Variable Refrigerant Flow (VRF) systems

Feature	Benefit	Ground Source Heat Pump, GSHP	Air Cooled Variable Refrigerant Flow, VRF
Space Efficient	Enables Space in the building to be used for the main business	★★ Central Air Handlers, mechanical room and air distribution ducts to each room occupies space in the building.	★★★ Condensing Unit located outside the building. Refrigerant piping used for distribution to zones/rooms. Optional small ducts for local zoning.
Zoned Comfort	Optimum comfort for people in each individual zone (part of room, room, or several rooms)	★★ One central Air Handler (in either cooling or heating mode) per zone required. Ducts used for air distribution.	★★★ Up to 62 zones, with individual temperatures, operation modes and control (cooling or heating) on one piping network. Ducted or ductless options.
Proven Technology	Reliable function	★★★ Heat Pump Technology used many years	★★★ VRF heat pump technology used globally more than 30 years
Energy Efficient	Lower Continuing (operating) Costs	★★ Central Air Handler fans for air distribution, and pumps for water circulation, uses energy. 2 stage compressor.	★★★ Inverter driven, variable speed, compressor. Efficient, zoned fan coils. IEER value (according to ANSI/AHRI Standard 1230) is up to 25.8.
Complete System From One Manufacturer	Minimizes costly coordination issues and delays. Unified user documentation, training, service and parts	★ Several vendors needed to create a complete system.	★★★ A complete system from one vendor.
★ = Fair ★★ = Good ★★★ = Excellent			

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Feature / Benefit Matrix (cont'd)

Feature	Benefit	Ground Source Heat Pump, GSHP	Air Cooled Variable Refrigerant Flow, VRF
Low System Cost	Optimum use of capital	★★ Requires geothermal ground-source bores with separate water circulation circuits for heat rejection / absorption	★★★ Uses outside air for heat rejection / absorption
Adaptability	Can be used in existing buildings	★★ Space requiring Air Handlers, air ducts (and outside geothermal field) can inhibit installation of the system in existing buildings.	★★★ Only refrigerant piping, optional ducts, and space efficient fan coils (available in many different sizes and styles) inside the building.
Quiet Operation	Comfort for people	★ Compressors and air distribution fans inside the building.	★★★ Quiet condensing unit with compressor outside the building. Whisper quiet indoor fan coil units.
Simultaneous Cooling and Heating function	Lower continuing (energy) costs	★★ Requires several systems. One system can specifically only cool or only heat at the same time	★★★ One system can cool and heat many zones simultaneously
Low Maintenance	Lower continuing (operating) costs	★★ Water circuits, refrigerant circuits and air distribution, with associated components and controls require maintenance.	★★★ Refrigerant circuits and fan coils, with associated components and controls, require maintenance. No water circuits to maintain.
★ = Fair	★★ = Good	★★★= Excellent	

ASHRAE Citations
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