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Centralized vs Decentralized HVAC System Cost & Efficiency in Schools

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This article examines the efficiency of a centralized HVAC system vs a decentralized system in the following areas:

- Air Quality
- Energy Consumption
- Thermal Comfort
- Sound
- Maintenance
- Building Ceiling Plenum Height

For this discussion, we're going to compare a centralized VAV system to a unit ventilator for our decentralized system. Both systems will use chilled water and hot water for cooling and heating and both will incorporate an enthalpy energy recovery wheel and 100% economizer. Chilled water will be supplied by a high efficiency magnetic bearing chiller and heating water by a high efficiency condensing boiler in both cases. Flow control will be 2-way modulating valves on both the heating and cooling systems.

Fig. 1 24,000 CFM VAV Air Handling Unit with 48"H x 60"W main supply duct. Unit is 20'L x 8'W x 7'H

Fig. 2 Temspec 1000CFM ducted supply energy recovery unit ventilator 44"W x 30"D x 93"H.

1.0 Air Quality

We can break this down into two categories; air cleanliness – filtration, and air quality- CO_2 and VOC's.

1.1 Air filtration - both systems will use a 2" pre-filter and MERV 13 final filter.

1.2 Air Quality – Centralized – maintaining air quality in a central system can be challenging if you are monitoring the CO_2 and VOC levels only in a common return. Obviously with this system, there is no way of guarantying either of these counts in any given classroom so some areas could be over-ventilated, which wastes energy while others may be under ventilated. In my experience, most facilities are over-ventilated with this control strategy. In a case study conducted by McMaster University in Hamilton ON, six facilities tested had an average CO_2 count of 480PPM which is just over the outdoor count of 402PPM when the target PPM was 900. This over ventilation represented thousands of dollars per week in fan and thermal energy losses.

The table below shows the ventilation requirements for different space types.

TYPE	cfm/per person	cfm/ft²
Classroom (ages 5-8)	10	0.12
Classroom (age 9 plus)	10	0.12
Lecture Classroom	7.5	0.06
Lecture Hall (Fixed Seats)	7.5	0.06
Art Classroom	10	0.18
Science Laboratories	10	0.18
University/College Labs	10	0.18
Computer Lab	10	0.12
Restaurant /Dining room	7.5	0.18
Hotel Bedroom	5	0.06
Office Breakroom	5	0.12
Office Main Entry	5	0.06
Office space	5	0.06
Office Reception Area	5	0.06

Table 1: ASHRAE Standard 62.1 Ventilation Standards

The formula for calculating the ventilation rate is as follows:

$V_{bz} = R_p \times P_z + R_a \times A_z$

Where:

V_{bz} = outdoor airflow rate in zone (cfm)

R_p = outdoor air rate per person (cfm/person)

P_z = number of people in zone

R_a = area (cfm/ft^2)

A_z = zone area

Example: 1000 sq. ft. classroom with 30 students.

=10 x 30 + 1000 x .12
= 420CFM

1.3 Air Quality – Decentralized – monitoring occupancy, CO_2/VOC in a single zone is straight forward and ensures the lowest energy cost and highest air quality. Research shows the average classroom is utilized 35% of the typical 8 hour school day and of that 35%, the occupancy level is not at capacity. We strongly recommend Demand Control Ventilation, DCV, where occupancy levels vary. DCV can save 60 to 80% combined thermal and fan energy in a typical classroom with no compromise to air quality. Over ventilating a space uses more energy, reduces equipment life and increases equipment maintenance. A unit ventilator can be programmed to provide the minimum fresh air volume during the day when the classroom is un-occupied, and match the ventilation air flow to maintain the desired CO_2 level as the occupancy changes. (typically 900PPM)

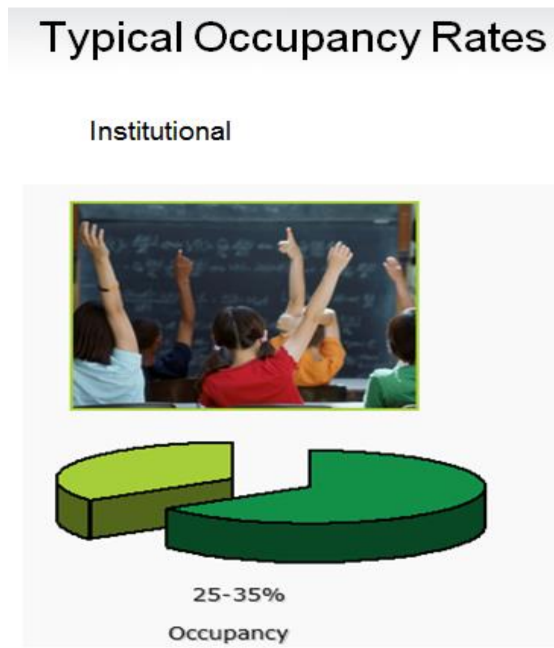

Fig. 3 Studies have shown that classrooms are occupied 25 - 35% of the 8 hour school day

2.0 Energy Consumption

Energy is the single largest cost in a schools HVAC post construction budget so purchasing the highest efficiency equipment will obviously provide the lowest life cycle cost (LCC). The next step is to optimize the control strategy to further reduce the operating cost regardless of the system choice. In any system, we have thermal energy to produce the heating and chilled water, pumping energy to pump the chilled or heating water to the AHU or terminal unit, and fan energy to deliver the conditioned air to the space. We'll compare these three energy consumers in each system. In both cases, we have energy recovery which in itself, offers significant energy savings and allows you to reduce the cooling equipment capacity by the amount of energy recovered. (we recommend sizing the heating coil for design conditions without taking credit for energy recovery) Table 2 illustrates the energy savings with and without energy recovery with varying occupancies. 'A" is the thermal energy percentage and 'B' is the fan energy expressed as a percentage.

S-Factor (Occupancy)	Without energy recovery $A=0.55E_0$ $B=0.45E_0$	With energy recovery $A=0.33E_0$ $B=0.45E_0$
1.0	0%	22%
0.9	18%	37%
0.8	33%	51%
0.7	46%	61%
0.6	57%	70%
0.5	67%	78%

Table 2 Energy savings based on occupancy (S-Factor) with and without energy recovery

2.1 Centralized System

The challenges with this are the ceiling plenum space required for the duct work and the amount of energy to move the air over long distances. Moving energy around a building with air takes up an enormous amount of space and is expensive due to the low energy content of air compared to water or refrigerant. A typical classroom requires about 1000CFM to achieve a thermal balance so if we have 24 classrooms, our central station AHU would be designed to deliver 24000CFM. Assuming the classrooms are 30ft x 30ft and the AHU is located in the center of the building, the AHU must produce enough static to supply 1000CFM over a minimum distance of 240ft. The water pumping energy in centralized system on the other hand is quite low due to the proximity of the pumps, chiller and AHU giving it an advantage.

For example:

2.1.1 Fan Energy

BHP = CFM x TSP"wc/u x 6356

Where:
BHP = brake horse power
CFM = air flow
TSP = total static pressure ("wc)
u = fan efficiency

BHP = 1000 x 2.5/.65 x 6356
BHP = .605 or **.45kW**

2.1.2 Pump Energy

BHP = Flow (GPM) x Head (ft)/3960 x Pump Eff
=5 x 40/3960 x .6
= .084 HP or **.062kW**

2.1.3 Ventilation Energy

The second challenge with a central system is maintaining air quality in all zones. To achieve this, the minimum fresh air damper position is typically set to meet the ASHRAE Standard 62.1 which is this case is 420CFM. (10 x 30 + .12 x 1000)
Q_{total} = 4.5 x CFM x delta h - $Q_{recovered}$
= 4.5 x 420 x 6.1 x .3

On a design cooling day, this load is 3,456 BTU or **1.01kW**

2.1.4 Centralized Summary

Since the time of day rate is highest between 11am and 4pm, the blended electrical rate is $0.185/kWh The combined fan, pump and ventilation energy for this classroom for an 8 hour design day is Fan Energy + Pump Energy + Ventilation Energy or (.45kW + .062kW + 1.01kW) x 8 hours x $0.185 = **$2.25**

2.2 Decentralized System

Our decentralized air distribution system requires very little ceiling plenum space and little energy to move air over the short distance. As well, the supply air fan uses an EC motor which has an inherent 10% efficiency advantage over the induction motor used on the central station AHU.

Following the centralized example,

2.2.1 Fan Energy

BHP = Q x TSP "wc/u x 6356

BHP = 1000 x .75 /.71 x 6356

= .16 or **.12 kW**

2.2.2 Pump Energy

The pumping energy will be greater with a decentralized system due to the higher head pressure required to meet the required flowrate at the furthest unit from the pump.

BHP = Flow (GPM) x Head (ft)/3960 x Pump Eff

=5 x 60/3960 x .6

= .13 HP or **.094kW**

2.2.3 Ventilation Energy

On a design cooling day, this ventilation load is 3,456 BTU or **1.01kW**

Q_{total} = 4.5 x CFM x delta h - $Q_{recovered}$

A DCV control strategy saves energy. From Table 3, the maximum ventilation air is typically 80% of the design and the average is 60%. DCV should be considered in applications where there are varying or unpredictable loads. If we use a conservative occupancy rate of 50%, our ventilation load becomes:

$V_{bz} = R_p \times P_z + R_a \times A_z$

=10 x 0 + 1000 x .12

= 120CFM

(Q_{total} = 4.5 x CFM x delta h x (Q_{total} – $Q_{recovered}$)

=4.5 x 120 x 2.4

= 1296 BTU or **.38kW**

2.2.4 Decentralized Summary

The combined fan, pump and ventilation energy for this classroom for an 8 hour design day is Fan Energy + Pump Energy + Ventilation Energy or (.12kW + .094kW x 8hrs) + (1.01kWx 4 hrs) + (.38kW x 4 hrs) x $0.185 = **$1.35**

2.3 Energy Savings Summary

The centralized system carries a classroom operating cost of $2.25 on a design day Vs the decentralized operating cost of $1.34 for a **40% savings.**

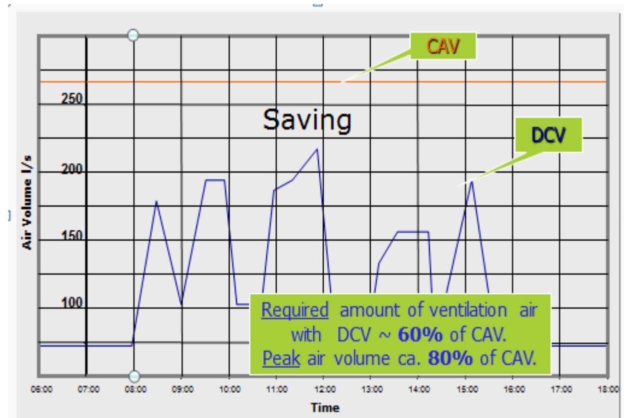

Table 3 Ventilation requirements over typical 8 hour period.

3.0 Thermal Comfort

Both systems offer very good comfort. Having said that, if the minimum position on the VAV box is set to provide .42CFM/Sq.ft. to meet the minimum ventilation load, there is a chance of over cooling the space under low load conditions and upsetting the rooms' thermal balance, especially if the VAV box has been over-sized. Alternatively, reheat can be used which obviously adds to the first, and operating system cost. In a unit ventilator system, the ventilation and air flow rates are always matched to the load minimizing energy consumption regardless of the classroom load.

4.0 Sound

We all know that keeping sound sources far away from the occupied space means lower NC level in the space. A healthy classroom NC target is 35-40 which is completely achievable with both systems. The VAV system will have noise attenuators to achieve NC35 in the classrooms closest to the AHU while the unit ventilators produce the same noise regardless of their location. As part of Temspecs' design support service, we'll conduct a sound analysis and design in the attenuation needed to achieve your specific sound target. This gives peace of mind that your classroom will always provide a comfortable learning environment. All we need is the duct layout, floor and ceiling materials, room dimensions and your target NC,RC or dBA level and we'll do the rest.

5.0 Maintenance

From a time stand point, there is no doubt that a central system has maintenance advantages with the equipment located in close proximity. On the down side, maintenance has to be carefully scheduled to avoid comfort disruptions and the chiller or boiler system typically needs to be shut down to perform routine maintenance tasks like filter changes.

The unit ventilator maintenance can be performed during regular schools hours when the class room is unoccupied and the source heating and cooling systems can remain operational. In many cases, the school janitorial staff can be trained to change the filters which is the main maintenance requirement on a unit ventilator where a licensed HVAC technician is usually required to service a large AHU due to the system shut down requirement.

6.0 Building Ceiling Plenum Height

For our example of a 24,000 CFM central air handling unit, the plenum height required to house the 48"H x 60"W duct is 54". When the duct is split to run two directions, the plenum height is still 36" where ceiling plenum for the unit ventilator air distribution is 18". This 18" difference adds considerable cost to the structural steel, exterior cladding and partition wall cost to the project. In a real life example in Toronto, reducing the building height by 26" on a 32,000 sq. ft. building represented a $160,000 in structural and exterior building cladding cost savings.

In summary, more and more, building owners are looking at life cycle cost as a key point in their HVAC system considerations. A decentralized unit ventilator system offers one of the lowest first installed cost, operating and maintenance cost and offers exceptional thermal and acoustic comfort, and unsurpassed air quality.

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