TYPICAL ENERGY SAVINGS USING NAILOR'S ECM MOTOR OPTION IN VARIABLE AIR VOLUME FAN-POWERED TERMINAL UNITS

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BACKGROUND

MOTORS and AIRFLOW CONTROL

Tapped, multiple-speed induction motors and induction motors controlled by SCR's, commonly referred to as "wave-choppers," are the most common technologies currently used to provide adjustable airflow in terminal units. Both have serious disadvantages in controlling airflow and comfort. SCRs are relatively simple electronic devices that switch (i.e., duty-cycle) a silicon controlled rectifier to adjust, or chop, the effective voltage to an induction motor. As the voltage to the motor is lowered, the rotor slips to the lower speeds needed to produce less than the terminal unit's maximum or rated airflow. There are major problems with this technology and the disadvantages of wave-choppers are widely known:

1. They generate electronic noise and line voltage notching that contribute to a building's poor power quality.
2. They cause the motor to operate at very low efficiency.
3. They have no direct motor torque control, which makes airflow adjustment against varying static pressure impossible.
4. They can create or aggravate acoustic noise, at very low fan speed.

The tapped, or multi-speed induction motor is usually used with an SCR and has all of the problems described above; however, if it is used without an SCR, it usually avoids the electronic noise, line notching and interference problems of the SCR-controlled motor. Nevertheless, tapped induction motors have all the other disadvantages listed above, plus they cannot be tapped to provide the wide speed range needed in terminal units. A tapped motor without an SCR needs to have an additional control device, a balancing damper, added; and the balancing damper lowers efficiency even further.

By far, the main drawback of attempting to control fan airflow either with tapped induction motors or with SCR controllers is the inefficient process by which they change the speed of the blower. Induction motors in blowers are designed to deliver maximum efficiency at a single voltage, load and speed, typically at their rated load and speed. Moving the motor's operation off of that point dramatically reduces the motor's efficiency from a peak, typically 55-65%, to as low as 12% to 18%. The further away the motor operates from its design point, the greater are its losses and the hotter it gets. It is common for an induction motor operating on its low speed taps or under wave-chopped conditions to consume as much power at "off-load and speed" operating points as it does at rated load and speed, thus completely offsetting the energy reduction inherent with reducing airflow. This degrading efficiency has a compounding effect on electrical energy use throughout the system – very low airflow per input watt at each terminal unit, plus additional power must be applied in the plant chiller to remove the extra heat load caused by the inefficiency of the motor in every unit. The GE ECM™ motor avoids all of the disadvantages of both multi-speed motors and SCR-controlled motors while providing additional advantages.

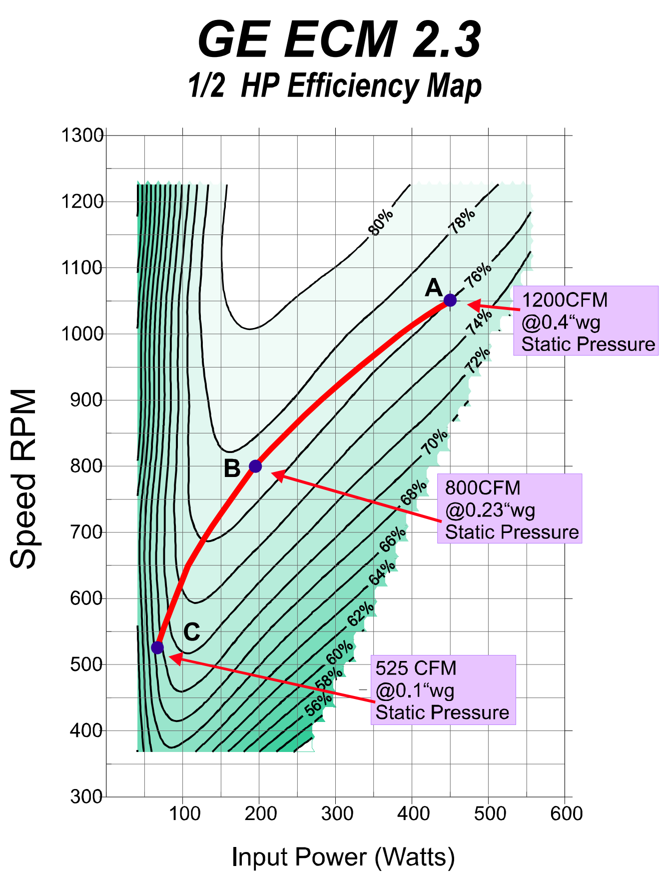
The ECM has been applied in residential heating, ventilation and air conditioning (HVAC) systems since 1985. The HVAC OEM's quickly recognized their advantages:

1. Very high efficiency at all loads and speeds, with power unloading very close to the centrifugal fan power and speed cubic relationship, thus dramatically lowering operating cost;
2. Set-up versatility, permitting simpler and broader airflow setting and control;
3. Better functional performance, creating additional energy savings and product value by allowing the BMS to control the terminal unit fans directly..

Today, they are in use by all major HVAC manufacturers in gas and electric furnaces, air handlers and condenser fans. The installed base will exceed one million units worldwide in 1998. Penetration into the residential system market is increasing at approximately 12% per year, while total volume is increasing at a higher rate now that the ECM has been successfully implemented into commercial HVAC systems. We predict that by 2002, no project involving fan powered VAV terminal units will be designed without ECM technology. The ECM's energy efficiency, cost, effectiveness and performance advantages are adding product value in the US and in Europe, particularly in commercial HVAC.

ELECTRONICALLY COMMUTATED MOTORS

Rotor slip is a requisite element of ac induction motor operation. The rotor must rotate at a speed below the synchronous speed determined by the number of poles and the frequency of the ac line current. The speed difference, the slip, is what induces the currents in the rotor necessary to produce torque. Unfortunately, the torque generating rotor current and the fields it produces cause high energy losses in the rotor which increase dramatically if the slip is more than a few percent. The ECM is a brushless dc motor.



Since dc motors are synchronous machines, the ECM rotor does not slip to change the speed of the rotor. The efficiency of dc motors and the ECM is higher than induction motor efficiency because there are no losses in the rotor – speed and torque can be easily changed in a dc motor by adjusting the voltage and current delivered to the motor, maintaining maximum efficiency over a wide operating range.

The efficiency of the ECM is 75% to as high as 80% at its full rated output. At lower loads and speeds – for example, at 10% load and near 500 RPM – its efficiency remains above 68%. **Figure 1** is the efficiency map of a ½ horsepower ECM motor in a Nailor fan powered VAV terminal unit over the speed/input power range. Notice the ECM is more than 60% efficient all the way down to the lowest airflow. Contrast the typical ECM performance curve, to an induction motor curve, and the induction motor, if it could run as slow, would be only 18% efficient, or less. It is not even possible to superimpose the performance of an SCR-driven induction motor on the chart, above, because its efficiency at any operating condition is too low to appear on the map. The inefficiency of the induction motor at off-loads almost completely offsets the cube-law unloading of a centrifugal blower and consumes nearly as much power at low speed as at full speed and load.

TEMPERATURE RISE

It is common with well designed buildings to add 5% or more to the sensible load for motor and fan heat added to the system. Because the air handler fan is operated by a frequency drive and because of it's motor design, it is much more efficient than the terminal unit fans. About 1/4 of this 5% is usually associated with the air handlers, and the other 3/4 with the terminal units. So a minimum of 3.75% of the total sensible load in a well designed building using well designed fan powered terminal units is consumed by the motors in the terminal units.

The ECM motor has no perceptible temperature rise across the motor. The higher efficiencies and lower waste heat generation keep the outer casing at ambient temperature while the unit is running. This saves the heat gain discussed above in the total sensible cooling load on the building.

OPERATING RANGES

In addition to the efficiency disadvantages, a unit with an SCR-driven motor cannot match the speed and airflow range of a unit equipped with the ECM motor. A 1/2hp ECM in a size 3 Nailor terminal unit can vary airflow from 1100 CFM to as low as 200 CFM over an RPM range of 1300 RPM down to 200 RPM. An SCR-driven 6-pole induction motor has serious torque production problems below 500 RPM. This effect can be seen in **figure** 2 which shows a single 1/2hp ECM-driven fan powered terminal unit that can deliver 200 to 1000 CFM, more range and more maximum airflow than can be supplied through the ranges of two (size 2 and size 3) conventional units utilizing induction motors. This standardization opportunity has additional and significant economic advantages for the engineer, the contractor and the building owner. There are fewer sizes to choose from when selecting equipment for a project, which means more common sized equipment on the job. And because of the wider operating ranges, adjustments rather than replacements can be made when tenants move and interiors have to be changed.

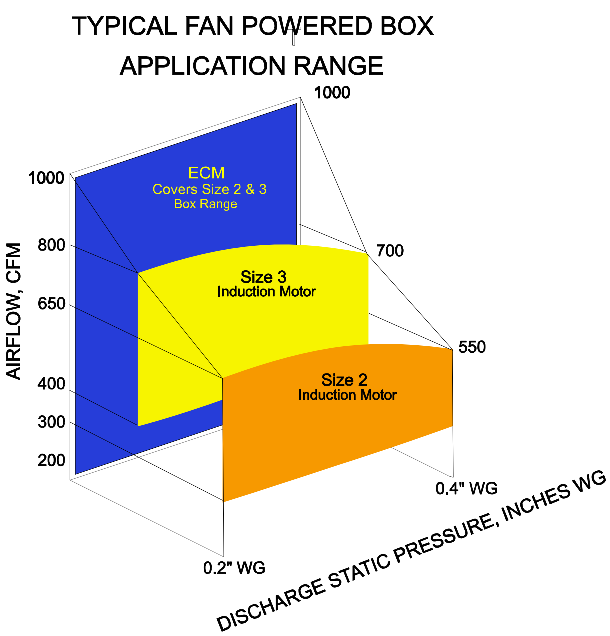


Figure2

In April 1997, Nailor Industries introduced the first ECM-powered fan-powered terminal units. During development tests, Nailor verified the efficiency advantages and quickly recognized the ECM's tremendous operating cost advantages in the mostly unloaded operating conditions of terminal units. They also understood that precise airflow control could be programmed into the ECM to lower set-up cost for the contractor and building owner.

THE VARIABLE-SPEED MOTOR AND ELECTRICAL ENERGY

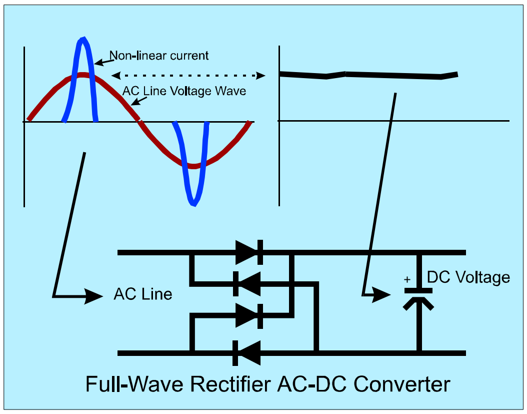


Figure 3

The ECM motor's electronics serves two major purposes. First, it switches, or commutates, the dc magnetic fields that make the motor operate – in other words, it acts as the commutator and brushes necessary in other types of dc motors. Second, it controls torque and speed so that the proper airflow is maintained regardless of the pressure on the inlet and outlet of the fan. These tasks are handled by the microcomputer in the motor that has been programmed by Nailor to match torque and speed to the blower's output characteristics.

Watts per CFM

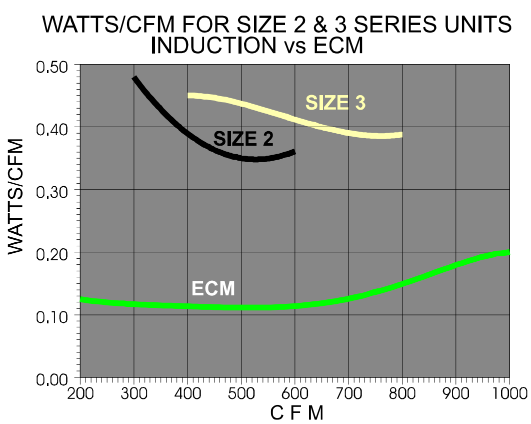


Figure 4

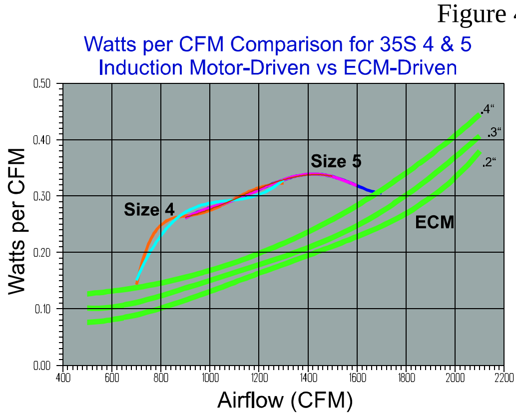


Figure 5

Figure 4 shows the power consumption of size 2 and 3 fan-powered terminal units while **figure 5** shows the same for size 5 fan-powered terminal units. Both show airflow delivered into a typical external static pressure range of 0.2" to 0.4" W.G. The first striking fact about both charts is that the ECM-powered units are capable of delivering significantly more airflow into the restrictions plotted. The size 5 ECM unit, for example, can deliver from 500 CFM up to 2,000 CFM, while its induction motor-driven counterpart can deliver only up to 1,700 CFM. On the low end, the induction motor cannot operate with stability below 700 CFM. One size 5 ECM-driven unit extends the entire airflow range of the two (size 4 and size 5) induction motor units. The same effect can be seen in **figure 4** for the size 2 and 3 units. One size 3 ECM box delivers airflow into 0.4"W.G. from 200 CFM to 1,000 CFM.

The figures also highlight the tremendous power consumption advantage the ECM has over its induction motor-driven counterpart. At 700 CFM into 0.4"W.G. static pressure, for example, a size 3 ECM-equipped unit consumes 160 watts less than its induction motor counterpart – a 2.5:1 power advantage. At a typical 1400 CFM and 0.3" W.G., the size 5 ECM-equipped box consumes only 294 watts compared to 462 watts for the equivalently sized induction motor-driven unit – a better than 1.5:1 advantage. These advantages convert directly to the seasonal operating cost savings that will be described in the attachments to this paper.

CONCLUSION

There are several features of the ECM motor that make it advantageous for use in fan-powered terminal units. They include:

Soft start and stop,
Slewed speed ramps,
Programmability,
Low operating temperatures
Long life expectancy
Ball bearings
Wide CFM ranges
Low energy consumption
Constant airflow regardless of filter loading.

Soft starts and slewed speed ramps eliminate most of the starting torque applied to the motor mounting brackets. This eliminates stress on those brackets and minimizes field service. The motor operates over 100° F. cooler than an induction motor. This low heat generation adds to the longer life expectancies (90,000 hours of operation) for ECM motors. Ball bearings rather than sleeve bearings in the motor provide much lower rotational speed capability and permanent lubrication under all operating conditions. Wider operating ranges allow each model to replace 2 models using induction motors. This provides several benefits, a simpler product line to choose from, little or no equipment changes necessary when tenants change or move, more similar sized units on a job, decreased spare parts inventory and increased contractor flexibility. The constant airflow delivery, regardless of filter loading, allows use with HEPA filters or other high efficiency type filters. This allows units equipped with ECM motors to be used as pressurization units for critically sensitive areas such as hospitals and clean rooms. Units equipped with induction motors would not be acceptable in these applications because of their large airflow shifts associated with the static pressure changes that would be experienced under these conditions. While all of these features are nice, the pay back they provide is difficult to calculate. However, the last and most important 3 advantages, low waste heat generation, programmability and low energy consumption, directly contribute to measurable pay back.

Measurable payback periods are calculated as shown on the attachment to this paper. They cover the 3 advantages listed above. There is always a 1 to 2° F. temperature rise through a series box due to motor heat with induction motors. There is no perceptible temperature rise through a series box that uses an ECM motor saving 3.7% or more of the sensible building load. Low energy consumption has been discussed at length. Charts and hard data are available for specific applications, but general applications are shown on the attachment. Factory setting of the fan cfm can eliminate that job for the balancing contractor. He should never be required to enter the ceiling for the purpose of balancing the fans in the fan powered VAV terminal units. As you will see, pay back periods are relatively short, typically less than 24 months at the long end, and as little as 6 months at the short end. Equipping fan-powered terminal units with ECM motors is a guaranteed return on investment for the building owner. It is anticipated therefore that ECM type motor technology will supplant the current induction motor designs in the next few years, thus contributing significantly to improved environmental energy consumption and improved indoor air quality.