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Fan-Powered VAV Terminal Units

Application and Modeling Implications From Past and Current Research

BY GUS FARIS, LIFE MEMBER ASHRAE; DAN INT-HOUT, FELLOW/LIFE MEMBER ASHRAE; DENNIS O'NEAL, PH.D., FELLOW/LIFE MEMBER ASHRAE; PENG "SOLOMON" YIN, PH.D., ASSOCIATE MEMBER ASHRAE

A series of research projects measuring energy and performance for fan-powered VAV terminal units (FPTUs) were conducted at Texas A&M University, Texas A&M Qatar and Baylor University as part of a joint ASHRAE/AHRI and privately (manufacturer's) funded research. As a result of that research, more than two dozen technical papers have been presented at ASHRAE meetings over the past several years, with several winning "best paper" awards. This research was to provide information for comparison of series and parallel units as well as provide equations for modelers to use for proper evaluation of building performance with FPTUs.

This article is the first of a series of three that discuss the ground-breaking results of this research. We'll begin by providing background leading up to the studies. The second article will summarize the results in as non-technical a manner as is possible, and the third article will discuss issues with the current energy calculation software, which was the ultimate goal of the project.

Some of the research has been mentioned in earlier ASHRAE articles.¹⁻⁶ In addition, parallel research has been conducted on the state of today's lowered building loads on occupant comfort (ASHRAE RP-1515)⁷ and on the use of ADPI to allow designers to prove compliance to ASHRAE Standard 55 at the much lower loads and

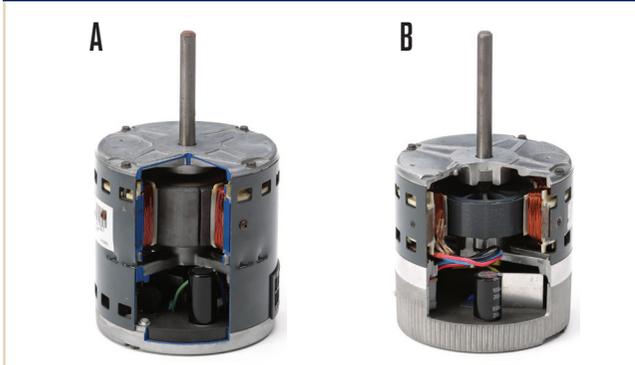
resulting lower air supply rates found in today's indoor environments (RP 1546).⁸ The new *Standard 55 User's Manual* references ADPI as a means of demonstrating compliance, and the RP-1515 data validated the Standard 55 statement that "there is no minimum air speed for comfort." Both play into the use of variable volume fan-powered terminal units, and the studies we will be describing here will show how significant energy savings can be documented as well.

History of Research and Why

The first fan-powered VAV terminal units were parallel style. They appeared in 1974, and were applied to

Gus Faris is vice president, engineering at Nailor Industries in Kingwood, Texas. He is a former chair of TC 5.3, Room Air Distribution. Dan Int-Hout is chief engineer at Krueger in Richardson, Texas. He is a former chair of SSPC 55 and a consultant to SSPC 62.1. Dennis O'Neal, Ph.D., is dean of the School of Engineering and Computer Science at Baylor University in Waco, Texas. He is a former chair of the Handbook committee. Peng "Solomon" Yin, Ph.D., is assistant professor, Department of Mechanical Engineering, at the University of Louisiana in Lafayette, La.

FIGURE 1A AND 1B ECM motors.



constant volume air handlers, as described in earlier Journal articles. Some mechanical devices for adjusting the supply air from the air handler existed at the time. They included barometric dump dampers in the equipment rooms or return plenums, adjustable sheaves, inlet guide vanes and adjustable pitch blades. While these devices were capable of reducing the supply fan volume, there were limitations to the turn down and for energy savings. However, even with the limitations and when paired with the FPTUs, they were successful at reducing energy consumption. Building energy comparisons in Houston showed savings of 20%.⁹

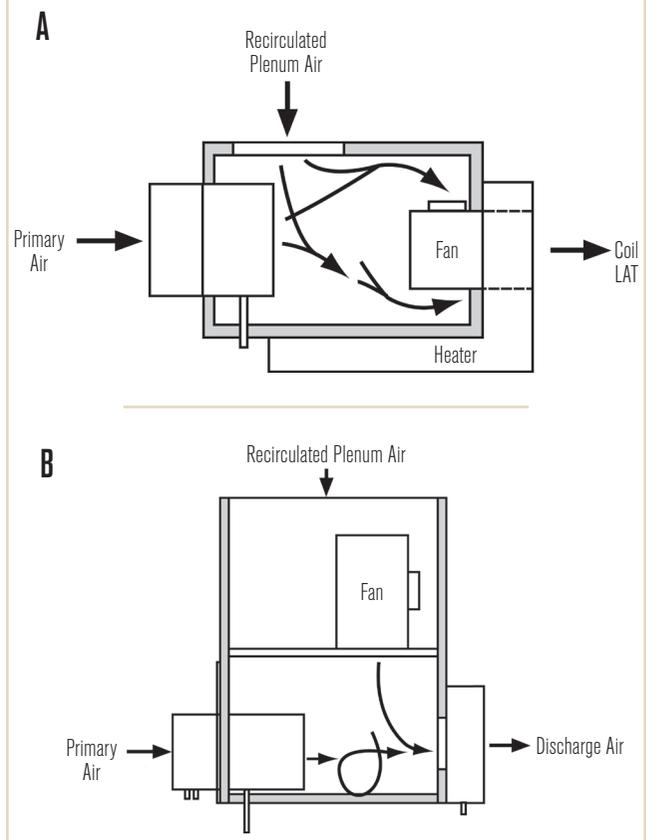
In the late 1970s, the components in the parallel unit were reorganized with the fan and VAV air valve in series. FPTU fans were constant volume, but the primary air moving through the VAV air valve was modulated. The airflow in the parallel fans was set at the heating airflow rate unlike the series FPTU fan, which was set at the cooling airflow rate, generally higher than the heating rate. There were other differences, too. The inlet static pressure required for the parallel FPTU was higher. The series FPTU fan ran during all occupied times whereas the parallel FPTU fan ran only during heating, deadband and the low end of the cooling modes. Later, when digital controls became popular and outdoor air requirements were increased, the parallel unit fan sequences were reduced to run in heating and deadband modes only.⁵

Two schools of thought on energy consumption developed. One believed that parallel FPTUs used less energy because the terminal unit fans ran intermittently. The other believed that the series FPTUs used less energy because the inlet pressure requirement was considerably lower. In 1996, electronically commutated motors

TABLE 1 Comparison of parallel and series terminal units.

ISSUE	PARALLEL	SERIES
Low Temperature Air	Poor Control	Available Option
Dedicated Outdoor Air Supply	Poor Control	Available Option
First Cost	Increased	Unchanged
Operating Costs	Increased	Unchanged
90.1 Requirement to Count Motor Horsepower	No	Yes
Increased Air Handler Horsepower	Yes	No
Noise Levels	Variable	Constant
Comfort Levels	Variable	Constant
62.1 Allows Credit for Recirculated Air Reducing Outdoor Air Requirements	No	Yes
Potential Savings with ECM Motors	No	Yes

FIGURE 2A Parallel unit. FIGURE 2B Series unit.



were introduced in the terminal unit products (Figures 1a and 1b). This exacerbated the energy question. In 2003, the Air Control and Distribution Devices section of ARI decided to initiate a research project to measure and compare the total energy use of both series and parallel FPTUs. The research project was proposed by ASHRAE Technical Committee 5.3, Room Air Distribution, with

ARI cosponsoring the project. This project was ultimately approved as ASHRAE RP-1292 and awarded to Texas A&M University.

The project focused on the fixed airflow terminal units with permanent split capacitor (PSC) motors whose airflow could be set with silicon-controlled rectifiers. Laboratory measurements were made on parallel and series units that had two different-sized primary inlet diameters. Three manufacturers provided FPTUs for the project. Building simulations were developed from the laboratory measurements. One important finding from this study was the measurement of significant leakage from some of the parallel units. The final results were issued in June 2007.¹⁰ A tabulation of the general findings is found in Reference 11.

The terms in *Table 1* (Page 19) are based on whether the research suggested changes from typical industry concepts. For instance, the casing leakage in the parallel units would require that more primary air would be needed to offset the casing losses to the plenum. Air

bypassing the zone being controlled has to be replaced. Another example would be “Poor Control” when dumping two pressure independent airstreams into a common positively pressurized plenum. This causes the two regulating devices to fight against one another, which causes very irregular airflows from each device as they fight over control of the common plenum (*Table 1* and *Figures 2a* and *2b*, Page 19).

Commercial buildings do not typically operate at their designed loads. Equipment is typically designed to handle heating and cooling needs on design days at maximum capacity calculated for each zone. However, the operating loads are far below those levels. Typically, zone loads during cooling modes are below 50% of the design load about 85% of the time. Zone loads in heating modes are below 35% of the heating design about 95% of the time. While designing equipment for the maximum loads is important, it is just as important to look at efficiencies of the equipment and the building when all the components of the HVAC system are active and the building is in part-load conditions. This is where the building lives as it responds to climate and interior loads, and where the energy and noise levels should be evaluated.

Additional research was initialized by the Variable Air Volume Research Consortium and conducted at Texas A&M University. The Consortium included terminal unit and electric motor manufacturers. The final report was issued in May 2011 and provided to ASHRAE.¹² As with ASHRAE RP-1292, laboratory measurements were first made on both parallel and series FPTUs with two different sized primary inlet diameters from three manufacturers. In this case, all of the FPTUs had electronically commutated motors (ECMs). As with the ASHRAE RP-1292 project, significant leakage was found in some of the parallel terminal units. The laboratory results were used to develop simulations that could be used to compare the performance of both parallel and series FPTUs employing either ECM or PSC motors. The results showed large energy savings if the ECM in the series unit was properly programmed.

A third research project, AHRI 8012, was started in 2015 to rewrite all of the equations from the existing research in mass and energy balances so that it could be easily incorporated into modeling programs. The idea pushed by the AHRI Systems Steering Committee was to get equipment manufacturers to develop operating

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maps for their equipment instead of the single point rating system currently in use. This would allow energy programs to be developed, which would overlay these equipment maps to configure energy predictions for a commercial building under all the different load conditions during the year. Effectively, this would allow energy engineers to evaluate energy use, taking into account how the different components affect one another within the system.

EnergyPlus was selected as the modeling software for our use because it is the basic engine for most of the others. However, several problems with EnergyPlus were identified when this project was undertaken. For example, EnergyPlus was limited to the modeling of a fixed airflow fan/motor in the fan-powered terminal unit and did not allow modulating the terminal unit fan to meet varying zone loads.

EnergyPlus also required separate inputs of fan efficiency and fan motor efficiency, but most manufacturers document the fan/motor performance as a whole, and do not provide these data separately. The lack of guidance on the input parameter selection led to unrealistically high pressure rise across the FPTU fan. In addition, EnergyPlus does not allow the explicit modeling of air leakage from parallel FPTUs that was found in the previous laboratory measurements.

Given the above limitations, a series of equations following the mass and energy balances were implemented in a general equation-solving program to simulate and compare the performance of fixed and variable airflow FPTUs with PSC and ECMs. EnergyPlus, version 8.7, was recently released and it now states that it allows the user to simulate modulation of the terminal unit fan airflow through a part-load fan curve or a performance table. The user is still required to enter total pressure across the fan and fan/motor efficiency for design conditions. While leakage is not explicitly included in specifying a parallel unit, it is possible to simulate leakage in the ducts upstream and downstream of the FPTU with the difference being a leakage attributable to the parallel unit.

“Developing Fan Powered Terminal Unit Performance Data and Models Compatible with EnergyPlus”¹³ was issued in September 2016. Further verification of ECM savings was indicated in the analysis. Additional results can be found in a series of papers published by ASHRAE in a combined digital booklet.¹⁴

While all this research was being done, codes were developed by different groups that attempted to specify system selections that did not follow the research findings. ASHRAE/IES Standard 90.1, Appendix G uses the parallel FPTU as the basis of design for buildings using FPTUs. This seems to indicate that a building with parallel units would use less energy than one with series units. That is not always the case according to the research. Unfortunately, the amount of casing leakage in the parallel units was not well understood at that time this decision was made, but it still exists in Standard 90.1, Appendix G some eight years later.

Standard 90.1-2013 now requires all fractional horsepower motors from 1/6 to 1 hp to be ECM. This would seem to fix the issue as long as the design engineer specifies fan air volumes in the series units to track the load in the served zone. However, some local codes such as in the City of Houston still permit parallel units to be installed with PSC motors. Alternatively, the City of Seattle has required series units equipped with ECMs for several years.

The *ASHRAE Design Guide for Air Terminal Units* will be published by January 2018. Some basic energy modeling has been done to evaluate the building energy use with the latest information from the earlier research. One software company has an energy modeling program that uses all the equations developed through the different research projects. It will clearly show large savings for series over parallel FPTU with the proper fan air modulation.

Reviewing many successful applications of series FPTUs over the last several years has shown that modulating the fans in the series units has other benefits besides just the energy. Noise is reduced significantly in the occupied space. Perceived reductions can be as large as 10 NC. Drafts are reduced or eliminated. Occupants seem to report better comfort in the space. The data from ASHRAE RP-1515 showed very high occupant satisfaction at airflows down to 0.25 cfm/ft² (1.27 L/s-m²), at or near minimum ventilation rates in many codes.

Once an energy simulation program has been released that can show the real benefits of a “load following” ECM fan-motor combination, engineers can then design systems taking advantage of actual measured energy savings available with this technology.

This article recaps the history of FPTUs and introduces the readers to product improvements over time

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as controls and associated mechanical equipment have improved. Keeping up with the new capabilities as they occur is difficult for designers. This first article highlights these newer options by covering 14 years of research evaluating building energy use and how to use that information for building energy simulations. The next article will more specifically cover the research and what we learned in each phase.

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