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Part Three

Fan-Powered VAV Terminal Units

Issues With Fan-Powered Terminal Unit Modeling

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Fan-powered terminal units (FPTUs) have been widely used in commercial buildings since 1974. FPTUs can be either constant or variable airflow. Constant airflow FPTUs use either permanent split capacity (PSC) motors or electronically commutated motors (ECMs). Variable airflow FPTUs exclusively use ECMs. Compared with fans driven by PSC motors, ECMs facilitate the variable speed control in FPTUs and can be significantly more energy efficient at part-load conditions. Although the operation of FPTUs is well known to engineers, the performance of series and parallel FPTUs is still inadequately characterized by the existing models in whole building energy simulation programs, such as EnergyPlus.

This is the third article in a series summarizing the results and implications from a series of ASHRAE, AHRI and industry-funded research projects on FPTUs conducted over the past 14 years. The major findings from these research projects are published in several technical reports and more than 28 ASHRAE papers. This article focuses on issues with existing FPTU models in EnergyPlus and improvements that we recommend should be made to better characterize the annual energy performance of FPTUs in future software releases.

We identified three major issues with FPTU models in EnergyPlus that needed to be addressed to improve how EnergyPlus characterizes FPTUs. These include: 1)

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variable airflow FPTUs, 2) leakage from parallel FPTUs, and 3) specification of input parameters. Each is discussed below. The authors are aware that there are other building energy simulation software systems that may use some of the same modeling approaches used in EnergyPlus. Thus, while this discussion is specific to EnergyPlus, some of these same issues may apply to those simulation packages as well.

FIGURE 1 Simple diagram of a series fan powered terminal unit showing the locations of the three major components (heating coil, fan, and mixer) modeled in EnergyPlus.[5]

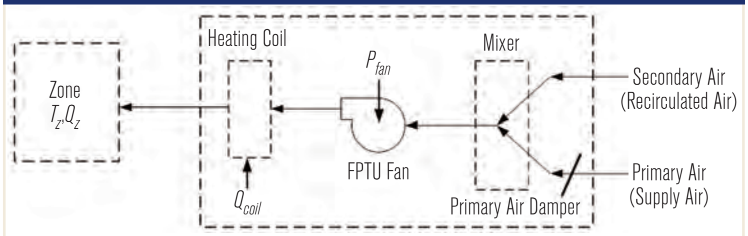
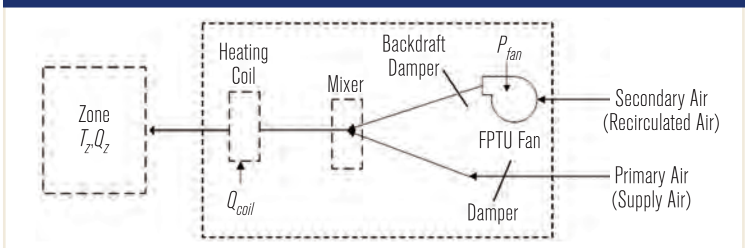


FIGURE 2 Diagram of a parallel fan powered terminal unit showing the locations of the three major components (heating coil, fan, and mixer) modeled in EnergyPlus.[6]



Modeling Variable Airflow FPTUs

As outlined in Section 15.1.6 of the EnergyPlus *Engineering Reference*,[1] the FPTU models treat the FPTU as a compound system, consisting of a heating coil, a fan and a mixer (see *Figures 1* and *2*). Each component has to be defined separately and referenced by the parent object to model the airflow and power of FPTUs. Variable airflow FPTUs with electronically commutated motors (ECMs) are increasingly being used because of their potential for reducing energy use and improving comfort control in buildings.

Engineers need to be able to capture variable airflow performance in building simulation programs to make better decisions on the type of equipment to use. This means that building simulation programs such as EnergyPlus need to capture the performance of variable airflow FPTUs. Complete modeling of ECM FPTUs includes both capturing the part-load performance of the ECMs as well as providing the user with the option to explore how sizing of the ECM FPTU affects annual energy performance.[2]

Currently, it only allows the modeling of constant airflow fans in FPTUs. This limitation in EnergyPlus prevents design engineers and building energy modelers from evaluating variable airflow FPTUs as an alternative design option.

The AHRI study conducted by O'Neal, et al.,[3] showed that the use of variable airflow series ECM FPTUs could lead to 6% to 10% total annual energy savings in the HVAC system compared with the use of conventional fixed airflow PSC FPTUs, and a 3% to 6% savings compared to fixed airflow ECM series FPTUs. The lack of effective modeling tools for variable speed FPTUs may limit the promotion of more energy-efficient designs.

Modeling Leakage From Parallel FPTUs

Both laboratory measurements and field surveys have confirmed the existence of air leakage from parallel FPTUs to the plenum space through the backdraft damper in the cooling mode. For example, the study conducted by O'Neal and Edmondson[4] reported that air leakage was found in all 12 tested units from three manufacturers, and the leakage ratio could be as high as 12% of the primary air. The leakage imposes two penalties on a parallel FPTU.

First, the leakage air lost to the plenum space never reaches the conditioned zone served by the FPTU. In this case, the central air handler must provide more primary air to the FPTU to satisfy the cooling load in that zone. The additional work by the central air handler will also generate more heat from the fan motor that must be offset with more cooling.

The second penalty is more indirect. Cold air leaking into a common plenum reduces the temperature of the air in the plenum space. If some of the FPTUs are serving zones that are in heating mode, then the colder plenum air will be drawn into the secondary port of these FPTUs, which will require the FPTUs to use more energy than they would if there were no leakage of cold primary air into the plenum space. Considering the leakage air is conditioned by the central air-handling unit, the energy penalty due to air leakage from parallel FPTUs could become a predominant factor in the different energy use

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between series and parallel units and needs to be captured when modeling FPTUs.

If a parallel FPTU experiences 5% primary air leakage, then the performance of a variable airflow series FPTU will typically outperform the parallel unit. If a parallel FPTU experiences 10% primary air leakage, then the benefit of using an ECM parallel unit becomes marginal in some climates compared to a conventional PSC series unit.[3]

Version 8.7.0 of EnergyPlus cannot model the impact of air leakage on the energy consumption of parallel FPTUs. Although EnergyPlus provides a simple duct leakage model (SDLM) for modeling the air leakage from the supply ducts to the return plenum in a VAV system, the SDLM model is not available when the air terminal type is a fan-powered air terminal. Also, the SDLM calculates air leakage independent of the zone heating or cooling load, while the air leakage from parallel units primarily occurs in the cooling mode when terminal unit fans are not operating and the leakage is through the backdraft damper. Without considering the impact of air leakage from parallel FPTUs, design engineers and building energy modelers can easily overestimate the energy savings from parallel units.

Selection of Input Modeling Parameters

EnergyPlus models the terminal unit fan performance using the same approach used for large central blowers, requiring the input of fan total efficiency, total pressure rise across the fan, maximum flow rate and motor efficiency. The fans and motors in large central blowers are typically tested separately, so it makes sense that their efficiencies are specified separately. For fan-powered terminal units, the fans are often driven by fractional horsepower motors with the fan and motor being evaluated as a single unit. Even if the fan and motor were tested separately by the manufacturer, the positioning of the motor in the inlet of the fan and the tight confines of the cabinet provide a geometry far different for fans tested according to AMCA Standard 210-2016.[7] Thus, the approach used by the manufacturers is to provide

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airflow and power data with the fan/motor *in situ* to the FPTU cabinet.

Rather than using efficiency as the fan performance index, the W/ft^3 (or W/m^3) value is more commonly reported by manufacturers for the fans in FPTUs. Although some input parameters required by EnergyPlus can be calculated from airflow and power data over a range of static pressures provided by manufacturers, the inconsistency between the data provided by industry and the input required by the modeling community can cause confusion and difficulties in modeling terminal unit fan performance in EnergyPlus.

EnergyPlus also provides little guidance on the selection of input modeling parameters for FPTUs. For example, the EnergyPlus 8.7 template for fan-powered terminal units (also called powered induction units in EnergyPlus) found in the EnergyPlus *Input Output Reference*[8] describes all the inputs used to model a parallel or series FPTU. The defaults in the template include values of 70% for the terminal unit fan efficiency, 1,000 Pa (4 in. w.g.) for the fan pressure rise, 90% fan motor efficiency, and 50°C (122°F) heating supply air temperature. From analysis of FPTU fan/motor combinations provided by manufacturers in the AHRI 8012 project,[3] the overall combined fan/motor efficiencies were typically 35% or less at a maximum total pressure of 200 Pa (0.8 in. w.g.).

Many of the fans evaluated in the AHRI project could not operate at pressures above a maximum downstream static pressure of about 125 Pa (0.50 in. w.g.), and the rating point for FPTUs is at a downstream static pressure of 62.5 Pa (0.25 in. w.g.).[9] Based on guidance from the manufacturers involved in the AHRI project, the heating supply air temperature used in FPTUs should typically not exceed 8.3°C (15°F) above the zone setpoint to reduce temperature stratification in the zone. With a setpoint temperature of 23.9°C (75°F), the supply air temperature should only be 32.2°C (90°F) versus the default value in the template of 50°C (122°F). For a building energy modeler who is not familiar with field conditions of FPTUs, using the defaults for total pressure and fan/motor efficiencies in the template would provide values for the FPTU energy use that are far from realistic.

These examples were used to illustrate that a user must be very careful using the default values found in this portion of EnergyPlus. Proper modeling of FPTUs requires knowledge of expected ranges of temperatures, pressures and efficiencies for these systems in the field.

Conclusion

This is the last article in a three-part series summarizing the results and implications from a series of ASHRAE, AHRI, and industry-funded research projects on FPTUs conducted over the past 14 years. The first article covered the application and energy modeling implications from the inception of FPTUs to present day and previewed the next two articles. The second article went deeper into the research projects with thorough explanations of the energy impacts of casing leakage and ECMs. For more information on the issues presented in these articles, see the series of papers published by ASHRAE in a combined digital booklet titled, “Modeling and Energy Consumption with Parallel and Series VAV Terminal Units, 4th edition.” This is available in the ASHRAE Bookstore. Also see the new *ASHRAE Design Guide for Air Terminal Units*, which is expected to be published and available at the 2018 ASHRAE Winter Conference in Chicago.

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