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Reflections on ARI/ASHRAE Research Project RP-1292, Comparison of the Total Energy Consumption of Series versus Parallel Fan Powered VAV Terminal Units

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This paper is based on findings resulting from ASHRAE Research Project RP-1292.

IMPORTANT POINTS FROM THE EXECUTIVE SUMMARY

The first phase of the project generated voluminous data that were used to develop mathematical models of each of the units being tested and modeled. There were 12 units total – two series and two parallel from each of three manufacturers. One series and one parallel from each manufacturer were sized for a small zone, and one other series and one other parallel from each manufacturer were sized for a large zone. Consequently, each manufacturer supplied equipment for both parallel and series to study both a representative small and large zone. The zone sizes were picked by the Project Monitoring Subcommittee (PMS). The three manufacturers were chosen to represent the largest possible cross section of equipment available in the market today.

Each unit was placed on a test stand and operated at different inlet and outlet static pressures as well as at different airflows. Every component was mathematically modeled and equations were written to describe the operation over the entire operating range of the unit. Once the models were developed, a test stand was built to accommodate 3 boxes at one time. The units were mounted to this test stand in groups and the models that had been developed were tested under field simulated applications that would resemble real field operations. The purpose of this test was to verify that the mathematical models generated earlier would prove to be accurate under real world conditions when the units were grouped like they would be with a duct system. Rather than making manual adjustments and charting data through the operating ranges of the equipment, these tests were conducted under various settings for upstream static pressure, downstream static pressure, airflow, damper positions and SCR settings for the motors. Then the damper positions, pressure drops, fan settings and electrical data were checked to determine if the predicted results from the earlier models were confirmed. There were few differences, but where differences did occur, the models were updated.

The second phase of the project took the mathematical models that had been verified and inserted that operating data into workbooks that represent the performance of a system with 5 zones that have been equipped with series or parallel units. Each workbook consists of several spreadsheets. Each spreadsheet describes one of the models that were developed. The spreadsheets, all working together within a workbook, simulate the operation of a building. The zones for this building are interior, north, east, south and west. At that point, the workbooks were expanded to simulate building performance using only the fan powered VAV terminal unit selection as a variant during different times of the year and in different locations. The purpose being to simulate operating costs for each type of unit so that a comparison could be made. DOE 2 data and performance were used as input data for the simulations.

The spreadsheets were designed so that certain sections could be turned on or off. This allows the user to not only simulate a building performance, but also to evaluate the effect on total energy consumption caused by any individual component. The return air heat gain can be turned off or set to any percentage thus simulating interior floors and top floors or single story buildings. The air handler fan energy can be turned off making the air movement through the ducts magical, or the terminal unit fans can be turned off making the air movement

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through the terminal units magical. These are useful as evaluation tools to allow examination of the effects caused by individual components within the system. These magical options were not part of the original research plan, but as the PMS began to realize that preconceived notions about the operational characteristics of the equipment were going to contradict conventional expectations, they needed additional evaluation tools to better understand the results.

The intent was to make models that were averages of all three different units by each of the three manufacturers. This proved to be problematic in that the units were distinctly different in some ways. Representative models were arrived at that are believed to be representative of the market place, but it was not a straightforward deduction.

Finally, the program for the comparison work was written and conclusions began filtering out. There were some issues that were viewed as inconsistent by either the PMS or the researchers. Each time this occurred, more study was needed and another meeting was called. Inlet static pressure on the parallel units was an issue, but not as large as was anticipated by the PMS. The leakage on the parallel units was a larger issue than anticipated by the PMS. Set points on the SCR motor speed controllers had to be evaluated. There were others, but these are the largest.

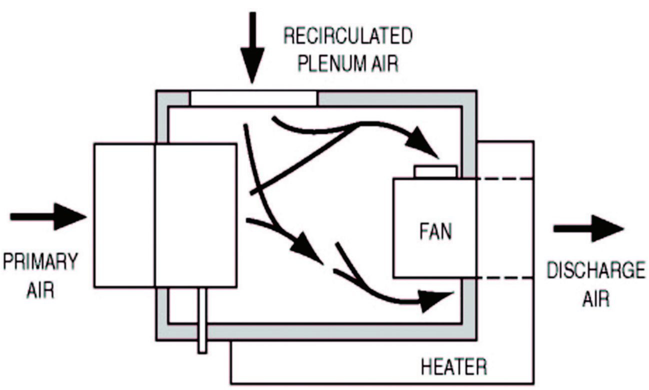


Figure 1 *Series flow terminal configuration.*

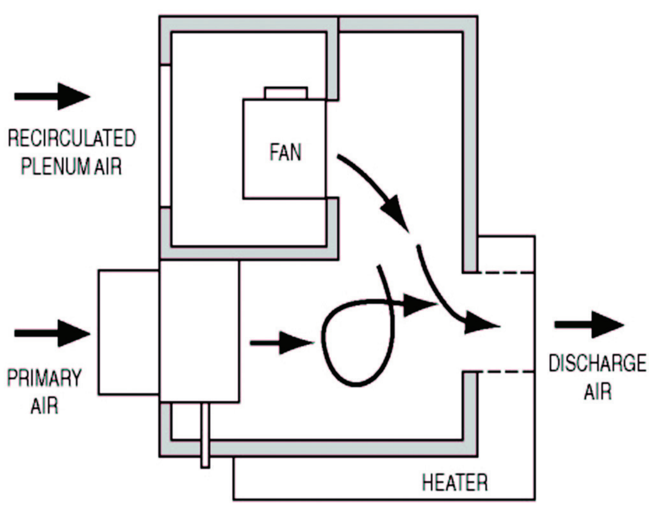


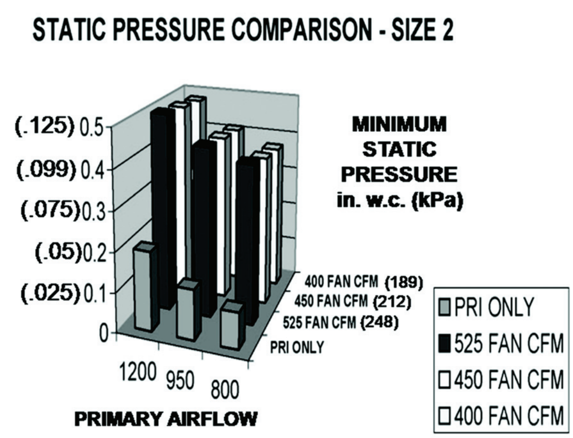
Figure 2 *Parallel flow terminal configuration.*

THE TEST STAND

If additional research is done, it would be nice to do it on a much grander scale. An entire building or at least multiple floors within a building might cause additional issues to reveal themselves that are hidden from our view due to averaging within the system. The cost for instrumentation alone would be problematic, but maybe something could be worked out.

FINDINGS

When embarking on a research project, the first requirement is to clear your mind of preconceived notions and prepare to evaluate the results based on the experiments. That does not mean to throw out your past experience. That is a valuable asset as you plan and go through your research. Researchers are researchers. The PMS was entirely made up of people familiar with applied units and job site experience. There were areas of expertise that did not overlap, and they led to some really fun discussions. These issues surfaced mostly at the final stages of the project. See Figures 1 through 3.



CFM (l/s)

	1200 (566)	950 (448)	800 (378)
PRI ONLY	0.2 (.05)	0.125 (.03)	0.09 (.02)
525 FAN CFM	0.5 (.12)	0.43 (.11)	0.4 (.10)
450 FAN CFM	0.49 (.12)	0.42 (.10)	0.38 (.09)
400 FAN CFM	0.48 (.12)	0.41 (.10)	0.37 (.09)

in. w.c. (kPa)

Figure 3 *Static pressure comparisons at different primary airflows and fan settings for a parallel fan powered terminal unit.*

INLET STATIC PRESSURE

Inlet Static pressure requirements was one of the issues that seemed to be a sticking factor. The PMS members' experience was that the parallel units needed quite a bit more than the series units. The researchers had their mathematical model, and the verification tests seemed to vindicate them rather than the PMS.

The PMS members were all in the industry before electronic controls were used. We are all familiar with the practice of defining critical paths and setting static pressure based on a sensor somewhere along that particular duct run. That process causes the entire duct system to be operated at a static pressure that services one duct run during all conditions affecting the building. Today, ASHRAE 90.1 recognizes that the critical path is not static, but rather it is dynamic and varies depending on the conditions both inside and outside of the building. Recognizing this, ASHRAE Standard 90.1, paragraph 6.3.3.2.3 requires that the duct static pressure on systems with direct digital control of individual zone boxes reporting to the central control panel be reset to cause at least one VAV damper to operate at a nearly completely open position under all operating conditions. This can be a huge energy savings practice in the building. But important to 1292-RP is that the real difference between the parallel and series units was used in the comparison, not differences that are imposed because of controls limitations in measuring static in the duct system. It was not as large as has been used in practice, and that provided a great deal of discussion as we worked our way through the findings. With pneumatic controls or systems that are not capable of dynamic reset, the practice has been to identify a critical zone and set the static in that duct run to be maintained at either 0.75 in. wg for series units or 1.5 in. wg for parallel units. The real difference found during the research was less.

MOTOR HEAT

The heat generated by the motors on both series and parallel units will raise the ambient air temperature by 1 to 3^{o} F (.56 to 1.7^{o} C). This was a much larger issue on the series units than the PMS members had anticipated. As the units are turned down from the full cooling mode, this heat is still being put into the airstream. Since we are not at full cooing and consequently not taxing the chiller or chilled water system, we tend to ignore this in real life applications. This is wrong, because the motor heat load is fairly constant. As the zone load decreases, the motor load, being constant, becomes a larger percentage of the instantaneous zone load and consequently becomes a larger percentage of energy use for the zone. Table 1 shows how each unit is affected by the motor heat.

LEAKAGE

Leakage became another issue that in the past has been mostly ignored, but is, in reality, a much larger issue than we anticipated. In fact, it is the largest single issue next to the operating schedule. Neither series nor parallel units have sealed panels and the parallel unit has a back draft damper designed to stop leakage of cold air to the plenum when the fan is not running. Leakage occurs all the time in both models. However, in the parallel unit, the casing is pressurized from the primary inlet to the back draft damper compared to the return air plenum; in the series unit, the casing is nearly neutral at all operating conditions compared to the return air plenum. There are other differences. The parallel unit is positive compared to the return air plenum, so leakage is cold primary air moving outward on the parallel unit, and it is always a bad thing. Leakage on the series unit, even though the difference is very small, is negative, and it is plenum air moving inward on the series unit. Since the series unit is always inducing some air, except at full cooling when there is no leakage and since the leakage is the same air being induced through the induction port, the leakage is not an issue. The parallel unit experiences the lowest internal pressure at near minimum primary damper position when the fan is off. It experiences the highest internal pressure when the fan is running or when in full cooling mode depending on the fan airflow setpoint. Conversely, the series unit experiences the most neutral pressure when the primary airflow is at maximum and the highest when the unit is in deadband or heating mode. As stated above, leakage at deadband is of no consequence because it is simply part of the induced air. Consequently leakage on the series unit is inconsequential, whereas leakage in the parallel unit is a huge issue as cooling air is recirculated back to the air handler bypassing the occupied space. Overall cooling air must be increased to get the space needs to the room while the leaked air short circuits back to the air handler. Table 2 shows how leakage affects both units.

Table 1. Comparison of Motor Heat Issues

Parallel Unit	Series Unit
• Motor heat only present when motor is running	• Motor heat present all the time
• Motor runs during deadband mode	• Motor heat adds to heat load at part load conditions
• Motor runs during heating mode	• Motor heat add is constant and bigger part of total load at part load conditions

ENERGY USE

Of particular interest in this body of research is that, as forceful and dramatic as the arguments over energy use for these two unit types were, they proved to be about equal, albeit for very different reasons. The series unit motor heat was more than expected, and the central fan energy savings were less. The parallel unit leakage was more than expected, and the central fan energy was higher, but less than expected. Table 3 shows how energy use is affected by both units.

CONCLUSIONS

The plan was to help decide how to

- build better buildings,

- create better environments, and
- capitalize on new and existing technologies,

focusing on how best to apply new technologies. These new technologies include:

- dedicated outdoor air systems
- lower coil and discharge air temperatures
- ECM motors

The ECM motors were a later addition to the research program. Since they were not included in the original project, a second research program was planned to investigate the motor options. It is pretty straight forward to expect energy savings in excess of 50% on series units operating at typical conditions and employing the ECM motors; however, nobody knows what the results will be with parallel units until the research is done.

SO WHICH ONE DO WE USE?

Every job needs to be evaluated based on local issues and occupant needs. Some local codes such as the ability to go to full shut-off of the primary damper may allow benefits for the parallel unit, but even in this case, the leakage needs to be accounted for. If the area has very short heating seasons as well, maybe a single duct reheat unit is the best choice rather than a parallel unit. Even though outside the scope of this research, the issue of fan cycling and associated noise has to be considered as well. This can be a huge noise issue. So in general, the issues listed in Table 4 dictate the selection.

REFERENCE

ASHRAE. ARI/ASHRAE Research Project 1292 Comparison of the Total Energy Consumption of Series vs. Parallel Fan Powered VAV Terminal Units. Final Report, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA (www.ashrae.org/research) and Air-Conditioning and Refrigeration Institute, Arlington, VA (www.arti-research.org/21cr_completed.php).

Table 2. Comparison of Leakage Issues

Parallel Unit	Series Unit
• Positive internal casing pressure	• Neutral internal casing pressure
• Primary air leaks outward bypassing the zone	• Plenum air leaks inward replacing plenum air pulled into the induction port
• Highest leakage at full cooling	• Lowest leakage at full cooling
• Typical leakage is between 5 and 20%	• Typical leakage not measured
• All bypassed primary air must be replaced by additional primary air to satisfy the zone requirements	• No effect to energy
• At full load, the unit may be undersized	• No effect

Table 3. Comparison of Energy Use

Parallel Unit	Series Unit
• Uses 17% less energy than series unit with o% leakage	• Uses 5.5% less energy than parallel unit with 20% leakage
• Uses 3-4% less energy than series unit with 10% leakage	
• Maximum leakage can be in excess of 30%	
• Typical leakage is between 5 and 20%	• Units are equal in energy use for all practical purposes

Table 4. Issues to Evaluate when Selecting a Terminal Unit Type

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 hp	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