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A Control Study of Residential Central Air Duct Design Upon Static Pressure and Energy Consumption

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ABSTRACT

Space heating and cooling use represents about 40%-50% of total annual energy and is usually the highest end use in homes. Therefore, matters impacting space conditioning may have significant impact on home energy use. Correct refrigerant charge, preventative maintenance, and air distribution duct location, design, airtightness and insulation integrity can have significant impacts upon energy use. Inadequate duct design and installation can result in elevated total external static pressure, which can have significant impacts on performance. This research project was designed to investigate the cooling performance impacts of increased static pressure, which often results from poor design and installation practices. Two identical university lab homes sited next to each other were used with a metal duct system in one home and a flex duct system in the other. Each duct system had the same general layout within a vented attic. Space conditioning was provided by identical two-stage split-DX heat pumps having the same model numbers. The air handlers used electronically commutated motors that delivered design airflow across a wide range of static pressure. Energy use, temperatures and relative humidity and refrigerant line temperatures and pressure were monitored. An initial test 1 compared quality duct design, sizing, and installation meeting industry standards for each duct type. The metal duct system at 0.34 in WC (85 Pa) was used as a baseline of comparison to the flex duct at 0.44 in WC (110 Pa). Two additional tests were run with the flex system at higher static pressures. Test 2 operated the flex system at 1.00 in WC (249 Pa), which represented high compression and some poor radius turns. Test 3 operated the flex system at 0.82 in WC (204 Pa), which represented more typical installation practice. There were significant central fan energy impacts. Observed impacts of duct static pressure upon the ECM fan energy found flex duct energy increases of 33%, 148%, and 72% for tests 1, 2, and 3 respectively. This paper further discusses a comparison of the daily cooling energy impacts by condensing unit and air handler fan for typical summer days as well as an annual energy impact between the metal duct and 0.82 in WC (204 Pa) flex duct for three different locations in climate zone 1 and 2. Implications of over-compression of metal duct exterior FSK insulation wrap upon energy was also discussed.

INTRODUCTION

Poorly designed and installed duct systems may result in diminished energy efficiency, decreased comfort, and may even contribute to shorter equipment lifetime. Issues that contribute to higher external static duct pressure in systems using permanent split capacitor (PSC) or shaded pole motors result in airflow rates lower than design. Lower airflow rates diminish heating and cooling capacity and efficiency. In severe cases of restricted airflow during air conditioning, the evaporator coil will operate colder and frost may develop. This in turn will further restrict air and exponentially increase the frost and restriction, which can result in liquid refrigerant being pulled into the compressor. This problem is a known cause of premature compressor failure (Turpin 2005).

Higher static pressure also decreases heating and cooling energy efficiency of systems using electronically commutated motors (ECM). Manufacturers are now using ECM more to help meet more stringent residential central heating and cooling equipment efficiency requirements. ECM can operate at variable speeds and have very quiet startup. These motors are more efficient than PSC

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motors and they are better suited for delivering intended design airflow rates over a range of static pressure. However, overcoming increased static pressure comes at the expense of increased energy use for an ECM. High static pressure is common in central ducts. Even if design is planned properly, actual installation can be poor. Common flexible duct installation errors such as inadequate duct support, tight turns or kinks, undersized duct dimensions, and over-compression are some examples of problems that increase static pressure. The duct industry uses the term "compression" in different ways. In the case of flexible ducts, compression typically refers to how much extra un-necessary duct length is installed. Compression also refers to physical force acting upon a section of duct resulting in thinner insulation and possibly restricted airflow in severe cases. For clarity in this paper, compression referring to flex ducts will represent extra length, not physical constriction, since there was not constriction of flex ducts with exception of intentional sharp turns by design. Compression regarding metal duct insulation wrap will refer to constriction of the insulation only. The ACCA Manual D (ACCA 2016) "required standard of care for installing flexible wire helix duct" recommends a maximum of 4% compression along a straight line, no significant sag [2.5 inches (0.0635 m) sag per 5 feet (1.52 m) of span, or less] or snaking (several bends on the same duct). The radius of a bend should not be less than the diameter of the duct, and there should be no crimping or crushing at any point along a duct run.

Unfortunately, many flexible duct systems are designed following recommended guidance, yet installed outside of these tolerances by a wide margin. In review of 7 field tests that included a total of 245 homes, researchers found most residential duct systems are being undersized using arbitrary inputs for duct selection without regard for available static pressure, actual duct length, or fittings (Proctor 2000). While some work has been conducted to measure static pressure drop in flexible duct systems with varying amounts of compression (Abushakara 2002, Weaver 2006) no experimental work has been done to evaluate the space conditioning energy impact and to factor in energy costs into lifecycle costing.

TEST METHOD

The primary purpose of this research project was to investigate the space conditioning impacts of varying amounts of total external static pressure (TESP). External static pressure was continually measured and recorded by a data acquisition system. Experimental testing used two different duct systems installed in two different identical lab houses. A metal duct system served as the experimental control that maintained the same relatively low TESP throughout testing. A flexible duct system was used to evaluate seasonal impacts at three different TESP.

Test Buildings

Experimental work was conducted in two 1,536-ft^2 single-story residential research facilities. Each test house was geometrically identical and located at the same site side-by-side shown in Figure 1. Testing occurred in east central Florida. The exterior walls were concrete masonry block with single-pane windows set in metal frame. Each house had the exact same wall and window dimensions and orientation. Ceiling insulation was R19 batt. Building airtightness was tested using a blower door and measured a normalized air leakage rate of 2.7 air changes per hour at 0.20 in WC (50 Pa) or less. Both houses had continuous supply mechanical ventilation of 65 cubic feet per minute (cfm) (1.84 m^3/min) in accordance with ASHRAE Standard 62.2-2019. The mechanical ventilation systems operated independently from the central ducted systems and had no influence on the central duct pressure. Tests were also run for periods without mechanical ventilation to provide conditions that helped widen variable sensible and latent cooling loads.

Figure 1. Tests were conducted in identical side by side research houses.

Each central duct system was installed new at the start of the project and had the same grille locations, heat pump models, and house designs. Both duct systems were tested and verified to be reasonably airtight. The air distribution systems had tested air leakage to outside of less than 38 cfm at 0.100 in WC (1.08 m^3/min at 25 Pa) test pressure. The test leakage is more commonly represented by mixed units such as 38 cfm at 25 Pa. The leakage normalized by conditioned floor area was less than 2.9 cfm at 25 Pa (CFM25)/100 ft^2 floor area in each lab home. Based upon ANSI/RESNET/ACCA Standard 310-2020, the tested duct tightness in both labs easily qualifies for the top Grade I duct tightness. Flexible ducts addressed in this project were manufactured with an inner plastic (polyethylene) membrane spiral wound and reinforced by wire fastened with an adhesive on overlapping membrane seams. The inner liner was covered by R6 fiberglass insulation with a class 1 moisture retarder on the outside circumference. The metal duct system was externally wrapped with Foil Reinforced Kraft (FRK) fiberglass insulation rated at R6 when installed at 1.625 in thick.

The test houses were cooled by two-stage split-DX electric heat pumps. The air handlers contained the evaporator coil and blower fan, and were vertically mounted with a return plenum below and supply plenum above. Both heat pumps had a rated cooling efficiency of 16 SEER and heating efficiency of 9.0 HSPF. The first stage cooling was designed to provide 74% of full capacity (26.0 MBtuh) under rated test conditions and second stage provided 100% of rated capacity (35.0 MBtuh). First stage air flow provided 820 cfm (23.2 m^3/min) air flow and second stage provided 1200 cfm (34.0 m^3/min).

Test Descriptions

Temperature and relative humidity were monitored in conditioned spaces, garage, attic, outdoors and entering and leaving evaporator coil. Electronic micro manometers were used to measure TESP. The TESP was measured identically for the metal and flexible duct systems with the return side static pressure measured at the inlet of air handler and the supply side static measured in the supply plenum several inches after the blower fan. The air filter was located at the return grille instead of at air handler inlet. Clean air filters were maintained during testing. The temperature and pressure of the vapor and liquid refrigerant lines were also measured. Energy use of air handlers, condensers, and internal sensible loads were sub-metered with energy meters.

Both houses had duct board returns located within an air handler support platform located in attached garage space. Supply ducts were located within a vented attic. An ACCA Manual J and Manual D calculation were performed prior to installation of new supply ducts in each house. The supply duct sizes are shown in Table 1. Several flexible duct sections had a larger diameter to account for the added frictional loss of the flexible duct compared to the metal duct. Both systems had identical duct board return plenums. The flexible duct system had a duct board supply plenum and the metal duct system had a sheet metal supply plenum.

Table 1. Supply Duct Sizes for the Metal and Flexible Duct Systems

Duct System	Supply Plenum (in) (m)	Trunk 1 ∅ (in) (m)	Trunk 2 ∅ (in) (m)	Trunk 3 ∅ (in) (m)	Branch 1 ∅ (in) (m)	Branch 2 ∅ (in) (m)	Branch 3 ∅ (in) (m)	Branch 4 ∅ (in) (m)	Branch 5 ∅ (in) (m)	Branch 6 ∅ (in) (m)	Branch 7 ∅ (in) (m)	Branch 8 ∅ (in) (m)
Metal	18 x 17 0.46 x 0.43	16 0.41	14 0.36	12 0.30	7 0.18	9 0.23	6 0.15	7 0.18	9 0.23	6 0.15	4 0.10	7 0.18
Flexible	18 x 18 0.46 x 0.46	18 0.46	16 0.41	14 0.36	8 0.20	9 0.23	6 0.15	8 0.20	10 0.25	6 0.15	4 0.10	8 0.20

Brief descriptions of the three tests follow:

- Test 1 was established to compare a flexible duct system to a metal duct system when both are designed and installed in accordance with good industry practice. The flex duct system TESP was 29% higher than the metal duct system with 0.344 in WC (86Pa). Older past published research studies indicated average TESP in the range of 0.41 in WC (102 Pa) to 0.55 in WC (137 Pa) (Blasnik et al. 1995, Proctor et al. 1995, Blasnik et al. 1996, Proctor et al. 1996, Parker et al. 1997).
- Test 2 compared the temporarily modified flex duct system with TESP of 1.000 in WC (249 Pa) to the unmodified metal duct control TESP at 0.344 in WC (86 Pa). Pressure this high is higher than averages measured in past studies, but it is still at a level known to occur at times. This exploratory test over four weeks was completed to observe high TESP impacts on cooling energy use. The higher static pressure was temporarily created by adjusting each supply

register opening to be mostly blocked and by installing a more restrictive MERV 8 air filter at the return.

- Test 3 evaluated a flex duct system with a more typical TESP likely to occur in a common installation. A TESP of 0.82 in WC (204 Pa) was targeted based upon (Falke 2016, 2019). While this TESP is greater than the averages indicated in studies over 25 years ago, the ducts of the older studies were much more likely to be leakier than newer residential construction today due to utility duct-tightness programs and more stringent building codes. Leakier ducts, air handlers, and furnaces would result in lower static pressure. The type of air filter is not known in most past studies, but it is known that the use of higher efficiency air filters was much less prevalent in the past. Higher MERV filtration more likely today would cause additional TESP. The flex duct was modified by increasing compression by adding about 30% more duct length to main trunk and about 50% more to branch ducts. Some flex turns were also made sharper than industry standard. These modifications and some final small adjustments to supply register grilles resulted in meeting the Test 3 target TESP. The flex duct diameters were not modified.

RESULTS

Performance was evaluated based upon energy use, refrigerant temperatures and pressure, and ability to maintain indoor air set points. There was no significant difference measured in the refrigerant or indoor air conditions among the three different tests. Significant energy differences were measured.

Measured Space Conditioning Energy Impact

The total space conditioning energy use impacts of the three different test configurations was evaluated under normal operation that included equipment cycling. The daily total central cooling energy use was plotted against the daily average temperature difference (dT) between outdoors and indoors to complete a least-squares, best-fit regression analysis. Tests 1 and 2 were more exploratory tests only conducted during typical summer weather conditions whereas Test 3 was conducted over much more variable weather. Since the first two tests were only conducted over typical Florida summer conditions a linear fit was used to compare the daily energy use at a typical summer day with dT=5°F (Δ2.8°C), which would be representative of daily average outdoor temperature of 80°F (26.7°C) when indoor temperature average is 75°F (23.9°C). Figure 2 shows measured data and best-fit lines for Tests 1 and 2.

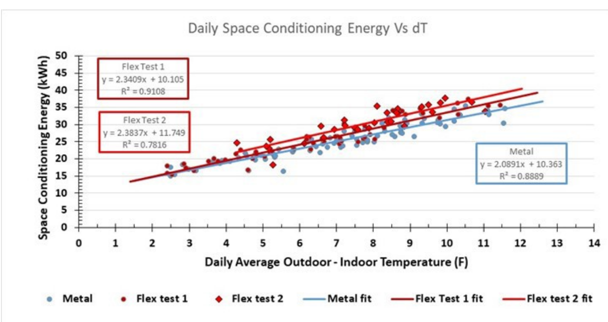

Figure 2. Daily cooling energy use of Tests 1 and 2.

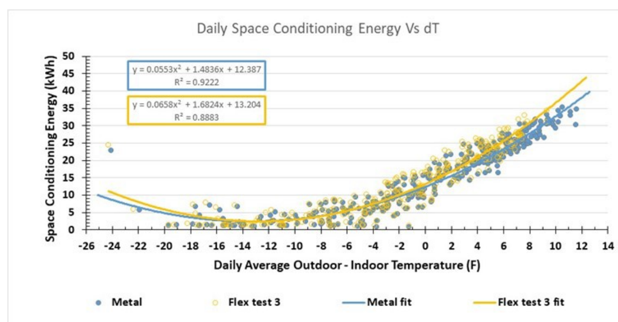

Figure 3. Daily energy shown for Metal and Flex Test 3.

Figure 3 shows a second-order polynomial regression fit for Test 3. This test was conducted over 51 weeks resulting in a much wider range in cooling and some minor occasional heating loads. This longer period of testing is more appropriate for predicting annual energy use than the shorter test period of several weeks for Tests 1 and 2. As seen in Figure 3, there were very few days with heating energy use. Heating occurred at dT < -14°F (Δ-7.8°C). Due to inadequate heating data, only cooling energy use was evaluated. Test 1 and Test 2 were not conducted long enough to produce a reliable prediction for a whole year. However, a comparison can be made during warm weather conditions. The results are shown in Table 2. The TESP is shown two ways since two-stage systems were used and allowed to cycle naturally. First, the measured daily average runtime TESP at first stage capacity is shown in Table 2. This is much lower than when the system operated at the second stage and is more representative of normal use. The systems operated at first stage at least 90% of an average summer day. The variability in energy use and static pressure throughout the day is also illustrated in Figure 4. The measured TESP is also shown at full capacity. This is the capacity at which manufacturers state the static pressure limit. The manufacturer stated limit for these systems was 0.500 in WC (125 Pa). Table 3 shows daily energy increase of the flex Test 3 compared to the metal duct test. This test was shown in a separate table since Test 3 period occurred over about eleven months instead of one month like Tests 1 and 2. The larger data set and greater variability in weather in Test 3 resulted in a predicted daily energy of the metal system a little lower than is predicted during the Test 1 and 2 period. Each comparison within tables is appropriate since both systems were tested simultaneously under the same environmental conditions.

Table 2. Daily Cooling Energy Comparison Tests 1 & 2 During Warm Summer Weather

Test Condition	TESP Daily Avg. (in WC) (Pa)	TESP at full capacity* (in WC) (Pa)	Cooling Energy (kWh) (Btu)	Flex Duct Increase from Metal (kWh) (Btu)	Flex Duct % Increase from Metal (%)
Metal Duct	0.194 48	0.344 86	20.805 70,990	---	---
Flex Test 1	0.207 52	0.436 109	21.810 74,419	1.005 3,429	4.8
Flex Test 2	0.595 148	1.000 249	23.668 80,759	2.863 9,769	13.8

*TESP when cooling at full capacity 2nd stage

Table 3. Daily Cooling Energy Comparison Test 3 During Warm Summer Weather

Test Condition	TESP Daily Avg. (in WC) (Pa)	TESP at full capacity* (in WC) (Pa)	Cooling Energy (kWh) (Btu)	Flex Duct Increase from Metal (kWh) (Btu)	Flex Duct % Increase from Metal (%)
Metal Duct	0.194 48	0.344 86	20.084 68,529	---	---
Flex Test 3	0.374 93	0.820 204	21.945 74,879	1.862 6,353	9.3

*TESP when cooling at full-stage capacity 2nd stage

The cooling peak power impact was evaluated for Test 3. The cooling power use profile over a 24 hour period is shown in Figure 4. This data was measured at 15 minute intervals and summarized for each hour of a specific representative hot summer day to compare both systems. The July day shown in Figure 4 had a high temperature of 90°F (32°C). Here it can be seen that the higher static flex duct uses more power than the metal lower static pressure system. This is most pronounced in the later afternoon between 4-6 pm when the cooling load is greatest and the systems move from first stage to second stage operation. Power use during the 4-6 pm period is compared in Table 4. This shows that the largest absolute and percentage energy impact is from the AHU. The higher static system resulted in 130 W (444 Btu/h) (51%) more peak AHU power use than the metal system. The condenser of the higher static flex system used 103 W (351 Btu/h) more power than the lower static metal system, but due to the much higher energy use of condenser systems, it only represented 4.5% more than the metal condenser system. It appeared that the higher condenser use was, in part, due to the added cooling load of added fan heat to the space from working harder to overcome additional static pressure. This resulted in a little longer cooling runtime. The Flex Test 3 system had a total cooling peak power increase of 233 W (796 Btu/h), which was 9% more than the metal system.

The AHU ECM power response to increased TESP was investigated using an electric power analyzer. Figure 5 shows the ECM power versus the TESP for first stage and also second stage. The lowest TESP is representative of good design and installation practice. Tests were performed up to about 1 in WC (249 Pa) in second stage. This motor performance data shows the potential for very significant increases in power consumption as TESP increases. For example, consider if first stage operated under the manufacturer upper limit of 0.5 in WC (125 Pa) instead of at 0.2 in WC (50 Pa), ECM power would increase 78%.

Annual cooling was predicted for Test 3. The least-squares best-fit regression analysis shown in Figure 3 was used to characterize the cooling energy consumption over a full year for the metal and the Flex Test 3 systems. The daily cooling energy was calculated for the outdoor temperature minus the indoor temperature for each day of the year. The daily average outdoor temperature was based upon Typical Meteorological Year TMY3 data. The daily average indoor temperature was set at 75°F

(23.9°C). Heating energy was not included due to inadequate heating weather during testing.

TMY3 data from Miami, Orlando, and Houston, were used to predict annual cooling energy for these three cities located within climate zones 1A & 2A. An assumed indoor temperature of 75°F (23.9°C) was subtracted from the TMY3 outdoor temperature to calculate a daily temperature difference for each day of the year. Only days with temperature differences equal to or greater than -15°F (Δ-8.3°C) were used to predict cooling energy. The dT of -15°F (Δ-8.3°C) with indoor at 75°F (23.9°C) would mean the outdoor daily average temperature would be 60°F (15.6°C). While the balance point between heating and cooling is typically around 64°F (17.8°C), some cooling did occur on very sunny 60°F (15.6°C) days. This limit was also used because there is still standby power used when unit does not cycle on. Heating would be expected at dT less than -15°F (Δ-8.3°C). The annual results for Tests 1-3 are shown in Table 5.

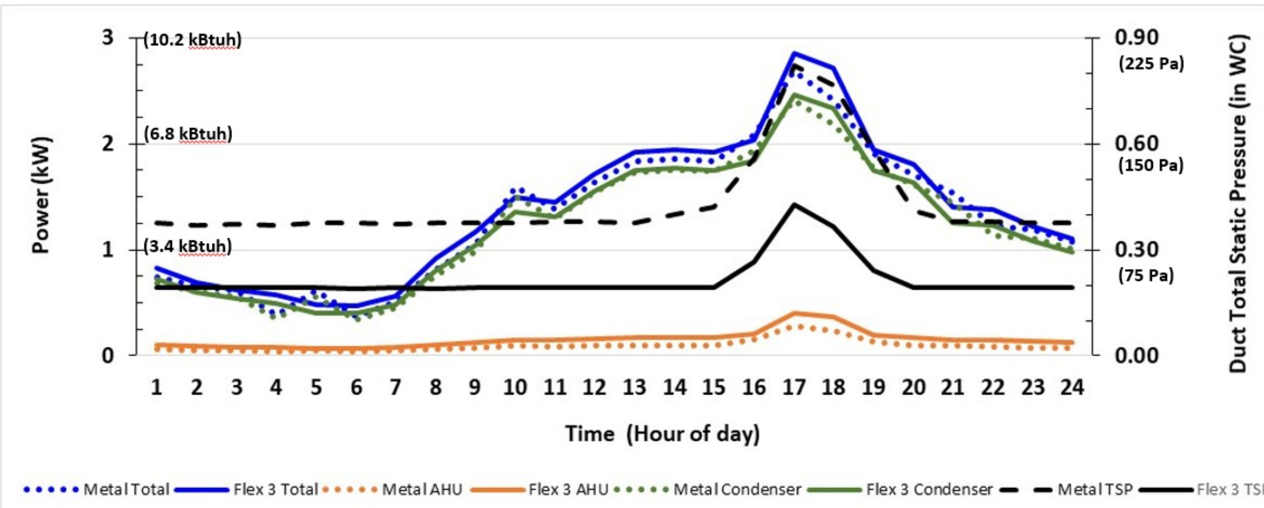

Figure 4. Cooling power use and fan TESP measured in two systems simultaneously during a typical summer day.

Table 4. Average Cooling Peak Power Use from 4-6 PM During Summer Weather

Test Condition	Cooling Energy (kW) (Btu/h)	Flex Duct Increase from Metal (kW) (Btu/h)	Flex Duct % Increase from Metal (%)
Metal AHU	0.257 878	---	---
Flex Test 3 AHU	0.386 1,318	0.130 444	50.5
Metal Condenser	2.295 7,838	---	---
Flex Test 3 Condenser	2.398 8,190	0.103 352	4.5
Metal Total	2.552 8716	---	---
Flex Test 3 Total	2.784 9,508	0.233 796	9.1
Daily Average Temperatures: Outdoor 84.0°F (28.9°C) , Metal indoor 74.2°F (23.4°C), Flex Test 3 indoor 74.3°F (23.5°C)			

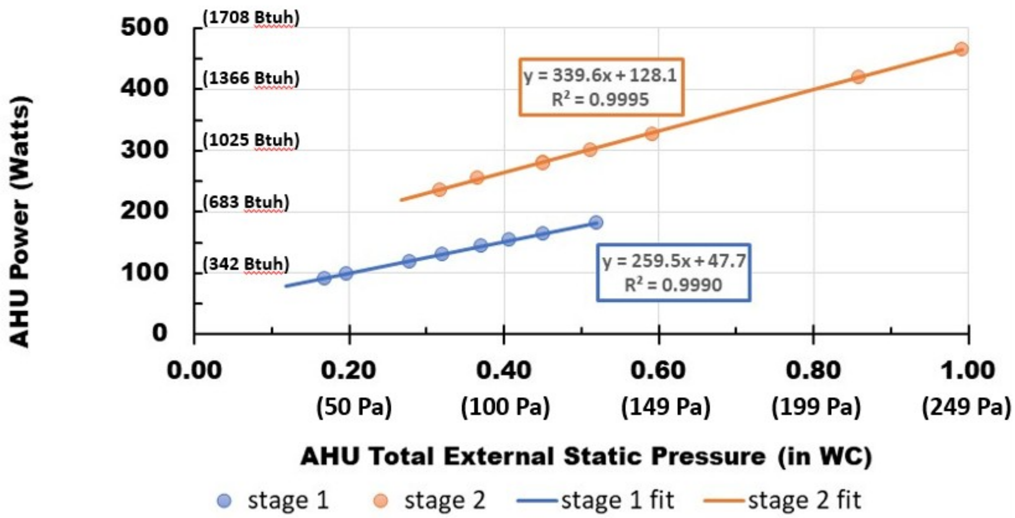

Figure 5. AHU ECM measured power versus TESP shown at first and second stages of cooling operation.

Table 5. Predicted Annual Central Cooling Energy of a Metal Duct System and Three Flex Duct Configurations for Three Cities Within Climate Zones 1A and 2A

	Metal Test 1 &2	Flex Test 1	Flex Test 2	Metal Test 3	Flex Test 3
			Miami, FL (1A)		
Annual kWh	4540	4793	5165	6061	6618
Annual MBtu	15.5	16.4	17.6	20.7	22.6
Delta kWh from Test 1	0	253	625	0	557
Delta % from Test 1	0	5.6%	13.8%	0	9.2%
			Orlando, FL (2A)		
Annual kWh	2812	2942	3198	4139	4467
Annual MBtu	9.6	10.0	10.9	14.1	15.2
Delta kWh from Test 1	0	129	386	0	328
Delta % from Test 1	0	4.6%	13.7%	0	7.9%
			Houston, TX (2A)		
Annual kWh	3146	3331	3580	4191	4573
Annual MBtu	10.7	11.4	12.2	14.3	15.6
Delta kWh from Test 1	0	185	434	0	382
Delta % from Test 1	0	5.9%	13.8%	0	9.1%
			Three City Average		
Annual kWh	3499	3689	3981	4797	5219
Annual MBtu	11.9	12.6	13.6	16.4	17.8
Delta kWh from Test 1	0	189	482	0	422
Delta % from Test 1	0	5.4%	13.8%	0	8.8%

Energy Use Adjustments Made for Metal Duct Insulation Wrap Over-Compression

Condensation was noticed on the exterior FRK insulation wrap of the metal ducts late into the second summer of testing. It was not evident during inspections the first summer. This prompted a detailed inspection of the entire system by research staff, insulation, and sealant manufacturers. At the end of the project samples of insulation wrap were sent to the manufacturer's lab for analysis. A sealant manufacturer representative inspected the ducts on site and concluded with research staff that the condensation was not due to poorly sealed seams, which would allow moist air to come into direct contact with the cold metal. There were no defects indicated in the insulation material. Based upon on-site inspections, duct surface temperature and RH monitoring, and lab-analyzed insulation samples, the insulation manufacturer and research staff concluded that the insulation wrap was compressed to an effective R-value of R2.5 or less, instead of R6. While there was some compression at duct supports, over 90% of the compression was due to over-stretching the insulation jacket around ducts. The lower R-value resulted in colder exterior insulation surfaces that reached the ambient dew point resulting in external surface condensation. This combined with long cooling runtimes of the two-stage cooling system and attic air dew points well over 70°F (21.1°C) resulted in prolonged periods of cold ducts that reduced the drying potential between cooling cycles.

The lower R-value of the metal duct system imposed more heat gain than would occur on the R6 flex duct system. An annual energy simulation was performed to determine the potential impact of diminished R-value of supply ducts in a vented attic located in central Florida. The simulation results indicated the metal duct system would have used about 8% less annual cooling energy if it had an effective R6 insulation instead of an effective R2.5 insulation installation. Had the metal insulation performed at R6, the authors believe that the three city average metal duct energy shown in Table 4 would have been 4,413 kWh (15,057 kBtu) instead of 4,797 kWh (16,367 kBtu) (8% less). Therefore, the annual cooling increase of the higher static pressure flex system was more likely to have been 806 kWh/yr. (2,750 kBtu) (17% instead of 9% greater) compared to an effective R6 metal system.

CONCLUSION

This experimental study was conducted in two brief phases and one longer phase to evaluate cooling performance based upon different types of central system duct design. This research project was designed to investigate the space conditioning impacts of a low static pressure metal duct system and higher static pressure flexible duct systems, with each system having the same general layout, heat pump, and house design. The research sought to determine if higher static pressure duct systems used more energy and if they showed evidence of indications for diminished equipment life relative to a lower static duct system. The lower static pressure metal duct system did not have any modifications made to it throughout testing and served as the control baseline, whereas the flex duct did have modifications intended to represent different levels of static pressure likely to occur in residential systems. The metal duct system was maintained as the lower static control case instead of the flex duct system since it demonstrated the lowest static pressure compared to the best-practice design and installed flex duct system. Although the metal duct system was maintained as the lower static pressure system, it should not be inferred that metal duct systems will always have the lowest TESP. A poorly designed and installed metal duct system can also have higher TESP and result in higher energy use than a lower TESP system.

The flex duct system, best-case installation, was tested first simultaneously with the best-case installation of a metal duct system (Test 1). The best-case flex duct system of Test 1 had a TESP 0.09 in WC (22 Pa) (26%) greater than the best-case metal duct system when running at full cooling capacity. This modest increase in TESP resulted in about 5% more cooling energy than the metal duct control case. A second brief exploratory test was made using the flex duct system with the total external static pressure temporarily manipulated to 1 in WC (249 Pa) by partially closing supply registers and using a higher static MERV 8 filter instead of a lower static, lower MERV fiberglass spun filter at the return (Test 2). This resulted in the high static system using 14% more energy. The final test evaluated what was to represent an average flex duct system having TESP of 0.82 in WC (204 Pa) (Test 3). The testing clearly demonstrated the trend for higher static pressure to cause increased space conditioning energy use with systems that had ECM fan motors. The long-term testing of Test 3 found that the predicted annual cooling energy of the flex duct was about 422 kWh (1,440 kBtu) (9%) more than the metal duct. Peak power increased by 0.233 kW (795 Btu) (9%) in the Test 3 flex duct. Measurements of the refrigerant line pressure and temperature did not indicate any detrimental impacts upon the condensing unit. This study did not measure any substantive results on degradation of the blower motor when operating under static pressure higher than manufacturer specifications, however the higher energy use would indicate the motor temperature would be higher and perhaps some long-term operation may shorten the life.

Unintended over-compression of the metal duct insulation jacket significantly lowered the R-value and resulted in colder exterior insulation surfaces that approached the ambient dew point resulting in condensation. It also increased the cooling load in the house with the metal duct system, which resulted in higher cooling energy use than the intended R6 insulation level. The lower R-value of the metal duct system imposed more heat gain than what occurred on the R6 flex duct system. Further analysis indicated the higher static flex duct system of Test 3 should have used about 806 kWh (2,750 kBtu) more annual cooling energy (17%) than the lower static metal duct system with an effective R6 insulation. Therefore, the actual measured energy increases of higher static systems presented earlier in this paper are less than what would have occurred with effective R6 metal duct insulation.

The study results support the need for verification of industry-based good installation practice. Duct design should be planned and installed carefully to minimize static pressure impacts upon the space heating and cooling performance. The installed fit and finish of the insulation wrap looked very well upon completion, however insulation jacket compression is not something that can be easily measured or determined visually. The unintended duct condensation issue that occurred, highlights the importance of training and the need for installers to make insulation blanket compression assessment measurements during installation. The potentially significant energy increase due to excessive TESP observed in this research clearly reinforces the need for proper training and verification of correctly sized and installed duct systems.

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With the unexpected late development of condensation on the metal duct system, there was a need to determine the cause. We are especially grateful for input and assistance from several individuals among the air distribution industry. For insulation wrap evaluation by Owens Corning: David Burd, Victor Salvador, Agustin Hernandez, and Kathryn Smith. For site inspection of the taped and sealed insulation wrap: Gary Prine with Reeves Sales & Marketing and Tim Eorgan at Hardcast.

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