Independent Lab Comparison of Whole-Home Electronic Air Cleaners

A Technical White Paper

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1.0 Introduction

1.1 The increased need for better indoor air quality. An estimated 50 million Americans (one in five) suffer from asthma and allergies[1]. Poor indoor air quality can contribute to this epidemic. According to the U.S. Environmental Protection Agency, indoor air pollution is one of the top five environmental risks to public health, and indoor air can be up to 100 times more polluted than the air outside. One solution that can be used to improve the quality of the indoor air is to filter particulates from the air that is circulated through the heating and cooling system. Many products exist to perform this task, and one that has long been considered the most efficient product for removing the contaminants that contribute to poor indoor air quality is the whole-home electronic air cleaner.

1.2 What is a whole-home electronic air cleaner? Whole-home air cleaners attach to the forced-air heating and cooling equipment and filter the air that gets distributed throughout the home by the air ducts. Throughout this document the term "air cleaner" refers to a filtering component that is contained by a manufactured housing and has seals and doors to control the air that enters and exits. Whole-home air cleaners can be either mechanical or electronic. Mechanical air cleaners generally use a pleated, extended media as the filtering component. Electronic air cleaners (EAC's) use a power supply to generate an electric field which actively charges the particles in the air that passes through and require an external power source. The charged particle is then captured in the collection mechanism of the air cleaner.

1.3 Why choose an electronic air cleaner? Particles that remain suspended in the air throughout the home duct system vary in size. For various reasons, existing industry-recognized air cleaner test standards quantify the efficiency with which air cleaners remove particles in the size range between 0.30 microns and 10 microns[2], and as such particles in this size range are the focus of this work. The removal efficiency of common whole-home air cleaners on particles within this range is lowest on small particles and highest on large particles. Electronic air cleaners are generally considered to be the best-performing whole-home air cleaner, with respect to particle removal efficiencies, particularly on the smaller particles within this range. The electrostatic attraction between particle and collector is the main reason that electronic air cleaners remove smaller particles more efficiently than mechanical air cleaners. Some mechanical air cleaners use a media made from fibers that are electrostatically charged during their manufacture which can increase their small particle efficiency.

1.4 There currently is no industry-accepted test method for EACs. The industry-accepted method for testing the particle removal efficiency of air cleaners cannot be used on electronic air cleaners. One of the elements of the test involves loading the filter with a dust that contains a conductive component; this prevents consistent operation of an EAC. Due to the lack of a standard, the reporting of performance information can vary from one manufacturer to another. The purpose of this project was to perform tests based on industry-accepted standards by an independent testing facility to generate data that could be used to quantify the performance of EACs in a way that is most beneficial to the consumer.

2.0 Independent Laboratory Testing

A test protocol was developed that was based as closely as possible on existing industry-accepted test standards. Changes to the standard were made only where strict adherence would result in an EAC not functioning properly, which is contradictory to the purpose of this work. Samples that were selected are four of the leading electronic air cleaners available in the residential HVAC market.

2.1 LMS Technologies, Inc. of Bloomington, MN is an independent laboratory and global leader of particulate contamination testing. LMS performs particulate air filtration testing in accordance with national and international test standards. LMS also performs contamination testing for the food, drug, and semiconductor industries.

2.2 Test Samples. LMS independently acquired one sample of leading EACs to ensure a random selection. All manufacturers selected make various size air cleaners, so the particular sizes (model numbers) selected were done so that the face area of each was as close as possible to being the same. The EACs tested by LMS include:

- **Trane CleanEffects TFD175ALFR000A**
- **Aprilaire Model 5000**
- **Honeywell F300E 16X25**
- **Carrier Infinity GAPAXCC1625**

2.3 Tests and Test Standards. Tests were conducted following ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) test standards[2], which are the industry-accepted methods for testing. All results shown represent one test. Listed in the following table are the specific tests and test standards.

Table 1 – Specific Tests and Standards

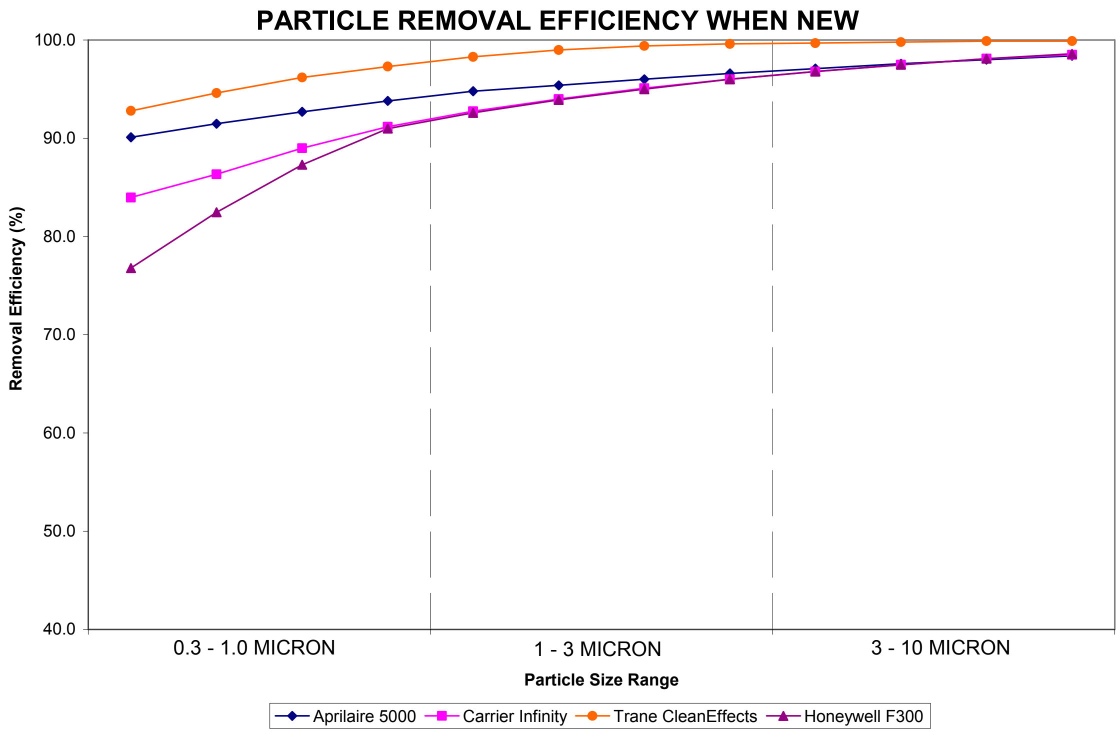
Performance Characteristic	Definition of Performance Characteristic	Reference Test Standard
Initial (as new) Efficiency	This test measures the efficiency with which particles are removed by the air cleaner "right out of the box".	ASHRAE Standard 52.2-2007
20 gram Efficiency	This test measures the particle removal efficiency after loading 20 grams of a synthetic laboratory dust at the filter.	ASHRAE Standard 52.2-2007
60 gram Efficiency	This test measures the particle removal efficiency after loading 60 grams of a synthetic laboratory dust at the filter.	ASHRAE Standard 52.2-2007
Dust Holding Capacity	This test quantifies the amount of loading dust required to increase the airflow resistance of an air cleaner to a specified final point.	ASHRAE Standard 52.1-1992
Airflow Resistance	This test measures the amount of air flow resistance caused by the air cleaner at various air velocities.	ASHRAE Standard 52.2-2007

3.0 Independent Lab Test Results – Particle Removal Efficiency

3.1 Initial (as new) Efficiency.

3.1.1 Test Method: Challenge particles are generated and introduced into a test duct upstream of the air cleaner to be tested. The challenge particles vary in size between 0.3 and 10 microns (μm). A particle counter is used to count the number of particles upstream and then downstream of the filter. These counts are used to calculate the efficiency with which the air cleaner removes the particles. The particle counting equipment is capable of distinguishing particles in 12 distinct size ranges, and so efficiencies are calculated for each range. Test samples were prepared and operated in accordance with the manufacturer literature that accompanied the unit. This particular test was performed in accordance with ASHRAE Standard 52.2-2007 and represents the efficiency of the air cleaner when the unit is new. According to the standard, efficiency results are reported not for each of the 12 size ranges, but as the average of the first (E1), second (E2) and third groups of four (E3); these are referred to as Particle Size Designators. All efficiency results shown in this document will be reduced to these values. For example, the first four particle size ranges are 0.3-0.4 micron, 0.4-0.55 micron, 0.55-0.7 micron and 0.7-1.0 micron; the reported value (E1) for this set is the average of the efficiencies in these four size ranges. All tests were run with the airflow in the test duct set at 1,200 cfm (cubic feet per minute).

3.1.2 Test Results[3]:



- ✓ All air cleaners tested removed over 95% of 3-10 micron particles when the air cleaner is new.
- ✓ Aprilaire and Trane air cleaners remove over 90% of 0.3-1.0 micron particles when the air cleaners are new.

Table 2 – Particle Removal Efficiency for New EACs

Air Cleaner	**Initial Particle Removal Efficiency at Various Particle Size Ranges**		
	E1 (0.3-1.0 µm)	E2 (1.0-3.0 µm)	E3 (3.0-10.0 µm)
Aprilaire 5000	92.0%	95.7%	97.8%
Carrier Infinity GAPAAXCC1625	87.6%	94.5%	97.7%
Trane CleanEffects TFD175ALFR	95.2%	99.1%	99.8%
Honeywell F300E 16X25	84.4%	94.4%	97.8%

3.1.3 Conclusion: On particles larger than 3 microns there was little difference between air cleaners; the lowest efficiency was 97.7% while the highest was 99.8%. Particles from one micron and larger are most responsible for fouling the evaporative coil on heating and cooling system, which can lead to loss in the efficiency of the heating/cooling system. Again, there was little difference between electronic air cleaners as all tested had an average efficiency greater than 95% with the lowest performing unit at 96.1% and the highest at 99.5%. The air cleaners show larger differences in the size range of 0.3-1.0 microns. In the smallest particle sub-range (0.3-0.4 microns), the lowest performing unit had an efficiency of 76.8% while the highest performing unit had an efficiency of 92.8%.

3.1.4 Relevance and Recommendation(s): Existing test standards are sufficient to quantify the performance of electronic air cleaners when new. This performance is often what is reported when manufacturers of electronic air cleaners publish efficiency numbers. However, the "as new" efficiency does not necessarily represent the particle removal efficiency that can be expected during use for some types of electronic air cleaners.

3.2 Efficiency after 20 gram Dust Load.

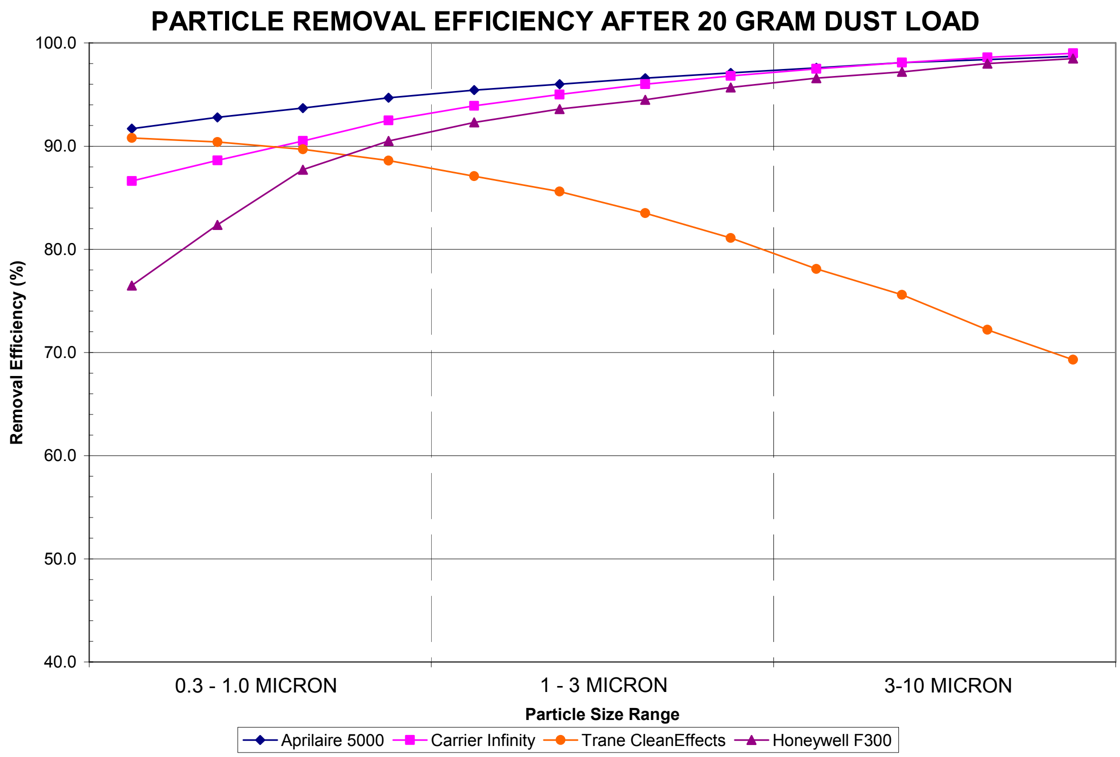
3.2.1 Test Method: A synthetic loading dust is used as part of ASHRAE Standard 52.2-2007 to simulate the effect of time in the field. The performance of an air cleaner may worsen over time and the purpose of this dust is to simulate the effect to reveal the true minimum efficiency of the air cleaner. Multiple efficiency tests are performed as part of the standard; one when new (clean) and several more after incremental dust loads. From this series of tests, the lowest efficiencies recorded in each size range, as designated by the Particle Size Designator (i.e. E1, E2 and E3), are used to categorize the performance of the tested device using a Minimum Efficiency Reporting Value (MERV) in accordance with Table 3.

Table 3 – Minimum Efficiency Reporting Values (MERV)

MERV	Particle Removal Efficiency (%)			Notes
	E1 (0.3-1.0 microns)	E2 (1.0-3.0 microns)	E3 (3.0-10.0 microns)	
1	n/a	n/a	0-19	Requires an ASHRAE 52.1 test to report efficiency
2	n/a	n/a	0-19	
3	n/a	n/a	0-19	
4	n/a	n/a	0-19	
5	n/a	n/a	20-34	Most typical residential mechanical air cleaners fall in this range
6	n/a	n/a	35-49	
7	n/a	n/a	50-69	
8	n/a	n/a	70-100	
9	n/a	0-49	85-100	
10	n/a	50-64	85-100	
11	n/a	65-79	85-100	
12	n/a	80-100	90-100	
13	0-74	90-100	90-100	Initial (as new) efficiency of tested electronic air cleaners falls in this range
14	75-84	90-100	90-100	
15	85-95	90-100	90-100	
16	95-100	95-100	95-100	

One of the components of the standard synthetic dust is carbon, which is extremely conductive. Electronic air cleaners have built-in safety features wherein an electrical short that causes a sudden or excessive increase in current draw will shut down the air cleaner. Therefore, an alternate dust, that does not include carbon, was used to load the air cleaners in this project. Alternate dust was used to reveal any performance loss and to avoid the possibility of the unit shutting down due to the test. The dust prescribed in the standard is (by weight) 72% SAE (Society of Automotive Engineers) Standard J726 test dust (fine), 23% carbon and 5% milled cotton linters; the dust used in this project was 97% SAE fine and 3% cotton linters. For each filter tested, 20 grams of this alternate dust was loaded at the filter, and then a particle size efficiency test as defined in section 3.1.1 was performed. All testing was done with airflow rate held constant at 1,200 CFM.

3.2.2 Test Results[3]



✓ After 20 grams of dust loading, the performance of the Trane CleanEffects dropped by 20% on particles from 1 to 10 microns.

Table 4 – Particle Removal Efficiency after 20-gram Dust Load

Air Cleaner	Initial Particle Removal Efficiency at Various Particle Size Ranges		
	E1 (0.3-1.0 µm)	E2 (1.0-3.0 µm)	E3 (3.0-10.0 µm)
Aprilaire 5000	93.2%	96.3%	98.2%
Carrier Infinity GAPAAXCC1625	89.6%	95.4%	98.3%
Trane CleanEffects TFD175ALFR	89.9%	84.3%	73.8%
Honeywell F300E 16X25	84.3%	94.0%	97.6%

3.2.3 Conclusion: The graph above illustrates the impact on performance as the air cleaner loads with dust. Two air cleaners, the Aprilaire 5000 and the Carrier Infinity showed a slight performance increase. Two air cleaners, the Trane CleanEffects and Honeywell F300E show a performance loss; the particle removal efficiency of the Trane unit dropped by 20% on particles one micron and larger as compared to the as new performance. This graph demonstrates that the performance of particular types of air cleaners when they are new does not represent their minimum efficiency.

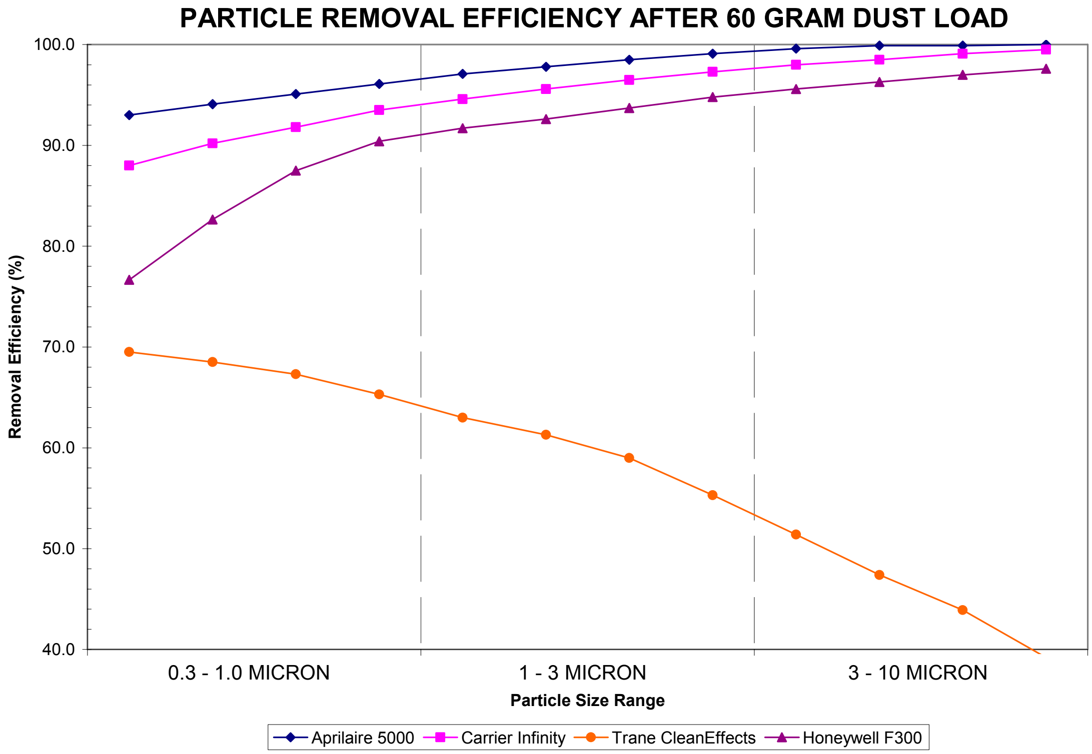
The two models that showed performance loss, Trane CleanEffects and Honeywell F300E, rely solely on electrostatic attraction between the particle and the collector section for collecting particles. Aprilare 5000 and Carrier Infinity use a media collector so the performance of these units relies on mechanical particle collection mechanisms in addition to electrostatic attraction. The performance drop of the Honeywell unit was significantly less than that of the Trane unit while both use the same particle collection mechanism. One possible explanation is the amount of dust that the Honeywell unit actually collected. Twenty grams of dust were loaded at each of the units in accordance with the loading procedure defined in ASHRAE Standard 52.2-2007, however, not all of the air cleaners collected the same amount of dust. Both the Aprilaire 5000 and the Carrier Infinity collected over 99.8% of dust fed. The Trane CleanEffects collects around 80% of the dust fed[5] during a 20 gram dust load and the Honeywell F300E collects around 70% of the dust fed[6].

3.2.4 Relevance and Recommendation(s): Efficiency after dust loading represents the performance of an air cleaner that can be expected over time. This test demonstrates that publishing the performance only when new, does not give a consumer enough information to adequately compare the performance of different air cleaner models. A new standard or revisions to existing standards need to be made to ensure that the performance of electronic air cleaners can be properly quantified. If loading with an alternate dust is the answer, then the procedure must account for dust collected and not dust loaded. While the results of this project clearly demonstrate the trend with which performance changes, absolute performance values need to be determined after the air cleaner has **collected** the desired amount of dust.

3.3 Efficiency after 60-gram Dust Load.

3.3.1 Test Method: Sixty grams of dust, as described in section 3.2.1, were loaded at the filters, after which a particle size efficiency test was performed as described in section 3.1.1. All testing was performed at an airflow rate held constant at 1,200 CFM.

3.3.2 Test Results[3]



- ✓ Aprilaire 5000 had the highest removal efficiency in every particle size range.
- ✓ Aprilaire 5000 was better than the other brands of electronic air cleaners at removing particles in the 0.3-1.0 micron size range by as much as 27% (percentage points).
- ✓ Aprilaire 5000 was better than the other brands of electronic air cleaners at removing particles in the 3.0-10.0 micron size range by as much as 54% (percentage points).

Table 5 – Particle Removal Efficiency after 60-gram Dust Load

Air Cleaner	**Initial Particle Removal Efficiency at Various Particle Size Ranges**		
	E1 (0.3-1.0 µm)	E2 (1.0-3.0 µm)	E3 (3.0-10.0 µm)
Aprilaire 5000	94.6%	98.1%	99.9%
Carrier Infinity GAPAAXCC1625	90.9%	96.0%	98.8%
Trane CleanEffects TFD175ALFR	67.7%	59.7%	45.5%
Honeywell F300E 16X25	84.3%	93.2%	96.6%

3.3.3 **Conclusion:** As was shown with the 20-gram dust load, the efficiency of two of the air cleaners increased as the amount of dust loaded at the filter increased. Both the Aprilaire 5000 and the Carrier Infinity showed marginal efficiency improvements (2%-3%) in all particle size ranges. The Honeywell F300E efficiency reduced slightly while the Trane CleanEffects reduced by as much as 54% in the 3.0-10 micron size range.

The two air cleaners that showed an efficiency reduction both depend solely upon electrostatic attraction for particle collection. Larger particles used for efficiency measurements are heavier than smaller particles. One possible reason for the efficiency drop for the Trane unit is that the momentum of the particle, particularly the larger particles, was too great for the weakened electrostatic forces to attract the particles to the collector.

4.0 Independent Lab Test Results – Airflow Resistance

4.1 Test Method: Initial resistance is the resistance of the air cleaner to airflow when the unit is new. Testing was performed in accordance with ASHRAE 52.2. Resistance measurements were made at 25%, 50%, 75%, 100% and 125% of the rated airflow, which for this project was 1200 cfm.

4.2 Test Result[3]

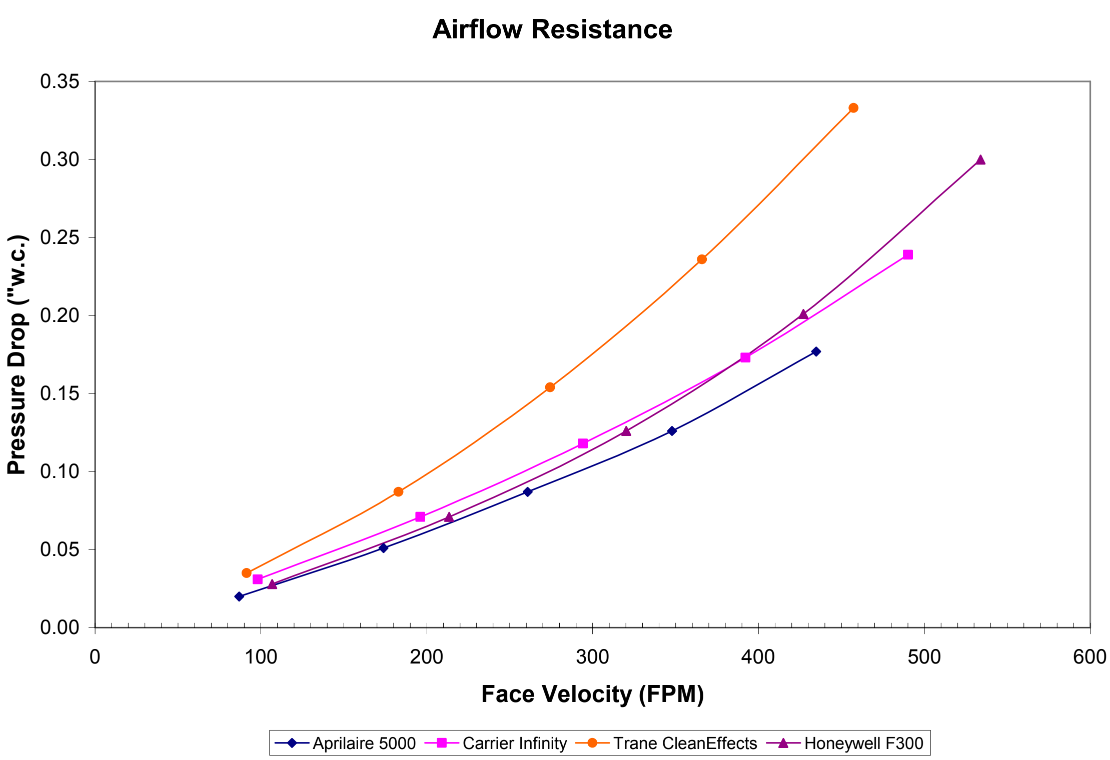


Table 6 – Airflow Resistance of Electronic Air Cleaners

Manufacturer/Model	Airflow (CFM)	Face Velocity (FPM)	Resistance ("w.c.)
Aprilaire 5000	300	87	0.020
	600	174	0.051
	900	261	0.087
	1200	348	0.126
	1500	435	0.177
Carrier GAPAAXCC1625	300	98	0.031
	600	196	0.071
	900	294	0.118
	1200	392	0.173
	1500	490	0.239
Trane TFD175ALFR000A	300	91	0.035
	600	183	0.087
	900	274	0.154
	1200	366	0.236
	1500	457	0.333
Honeywell F300E 16x25	300	107	0.028
	600	214	0.071
	900	320	0.126
	1200	427	0.201
	1500	534	0.300

4.3 Conclusion: The table above shows the resistance of the air cleaner at various airflow rates and their corresponding face velocity. Air cleaner resistance, whether the air cleaner is mechanical or electronic, is a function of the face velocity of the air entering the air cleaner. Face velocity is a useful quantity when comparing one air cleaner to another, but is not useful to either the HVAC technician or the consumer; of greater value is the air cleaner resistance at various air flow rates. The Aprilaire 5000 had the lowest resistance at all airflow rates tested, and as shown in the graph, at all face velocities between 110 fpm (feet per minute) and 440 fpm.

All components of the HVAC system, from the supply registers to the evaporative coil, contribute to the overall system resistance against which the blower must work to deliver air to the rooms of the house. High resistance results in increased energy use and/or a reduction in airflow through the HVAC system. Airflow reduction can cause the cooling equipment to run less efficiently, and if left unchecked could cause insufficient heat transfer and subsequent failure of components.

The resistance of some air cleaners, unlike other components of the system, will increase over time. Mechanical air cleaners or hybrid air cleaners like the Aprilaire 5000 and Carrier Infinity will increase in resistance as dust loads onto the filter media.

4.4 Relevance and Recommendations: Airflow resistance of an air cleaner in application is a function of face velocity. The velocity of the air entering the air cleaners tested as part of this project was held uniform for the purposes of comparison; however, in application, the velocity is unlikely to be held constant. Refer to manufacturer-published information for airflow resistance values.

5.0 Independent Lab Test Results - Dust Holding Capacity

5.1 Test Method: Dust-holding capacity tests were performed in accordance with ASHRAE Standard 52.1-1992 and were performed only on the Aprilaire 5000 and Carrier Infinity. Collector cell type air cleaners, like the Trane and Honeywell units, will reduce in efficiency as dust is loaded, therefore, a comparable end point cannot be achieved. This test involves loading the air cleaner with a synthetic dust until the final pressure drop across the loaded air cleaner reaches a predefined limit. The amount of dust collected by the air cleaner is measured and reported as the dust-holding capacity of the device. The efficiency with which the air cleaner captures the loaded dust is also measured and is reported as an arrestance value. Both the Aprilaire unit and the Carrier unit had arrestance values in excess of 99.8%[4], so virtually all of the dust that was fed was captured by the air cleaner. The dust used for this test is the standard loading dust which includes carbon (refer to section 3.1.1). For this particular test use of dust with carbon is applicable as the intent of this test is not to quantify the efficiency of the unit, but only to quantify the amount of dust it can hold, so the testing was performed with the power off.

5.2 Test Result[4]

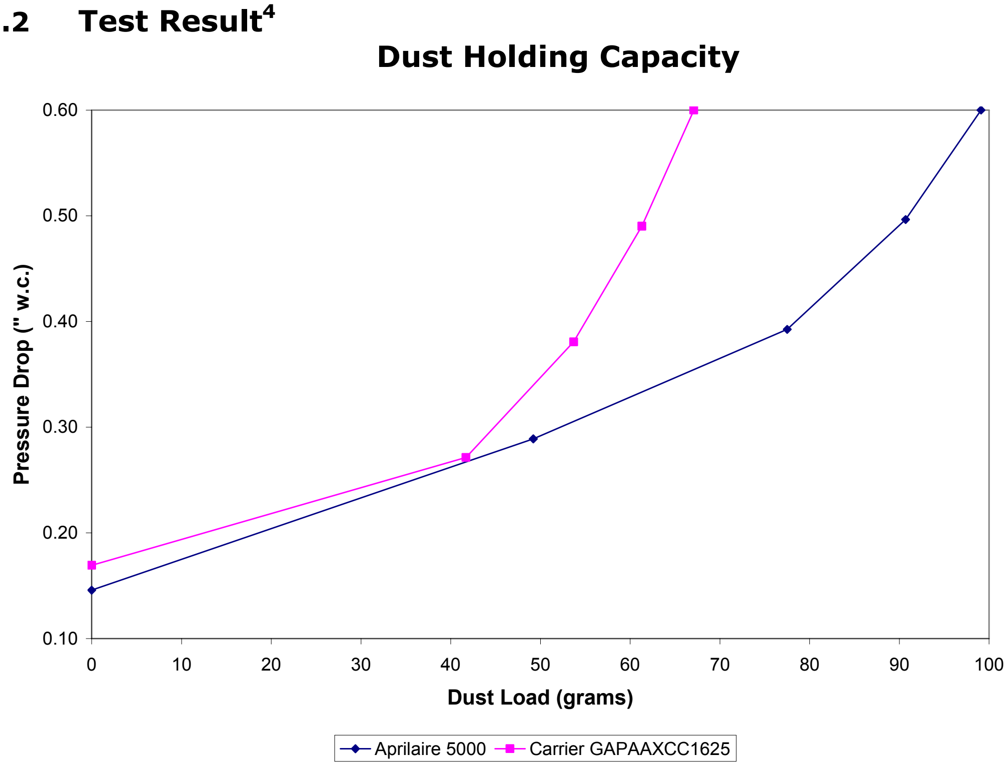


Table 7 – Dust Holding Capacity

Resistance of Air Cleaner* (" w.c.)	Dust Required to Reach Resistance (grams)	
	Aprilaire 5000	Carrier GAPAAXCC1625
0.16	0	0
0.28	49	42
0.39	78	54
0.50	91	61
0.60	99	67

*Average resistance

5.3 Conclusion: Up to a final pressure of 0.3″ w.c., the Carrier Infinity held 85% as much dust as the Aprilaire 5000. Due to the construction of the media the Carrier unit increased sharply in resistance as more dust was added. At a final pressure drop of 0.4″ w.c. (and at 0.5″ w.c. and 0.6″ w.c.), the amount of dust that the Carrier unit was able to hold was 68% that of the Aprilaire 5000.

5.4 Relevance and Recommendation(s): For mechanical air cleaners, dust-holding capacity can be used to compare service interval between air cleaners; this also applies to hybrid electronic air cleaners like the Aprilaire 5000 and Carrier Infinity. The service interval of these types of air cleaners is dependent on what is acceptable as a final pressure drop for the air cleaner. However, there are a number of variables that prevent the correlation between synthetic dust-holding capacity and absolute life in terms of time. The environment surrounding the home, the number of people and pets, the activities of the occupants and the amount of time the heating and cooling system fan operate all contribute to the actual amount of particulate that an air cleaner will see and subsequently the amount of time that it will take to reach a predetermined final pressure drop.

Because of the variables involved in determining the absolute service interval in terms of time, manufacturers of residential air cleaners will publish a service interval (or recommended filter replacement schedule), generally based on the amount of filtering media in the air cleaner. Air cleaners with more filter media will publish service intervals up to one year (such as the Aprilaire 5000) and those with less filtering media (such as flat panel furnace filters) will suggest a service interval of one month. Using the dust-holding capacity values from this project as a relative measure, the service interval of the Carrier unit would be 85% (10 months) of the service interval for the Model 5000 if the desired final pressure drop for the filter is 0.3″ w.c. or lower. If the desired final pressure drop is 0.4″ w.c. or higher, the service life of the Carrier unit would be 68% that of the Aprilaire 5000 or 8 months.

6.0 Summary

6.1 Particle Removal Efficiency: The current industry-accepted test standard, ASHRAE Standard 52.2-2007, prevents the same testing to be performed on electronic air cleaners as is done on mechanical air cleaners. Conductive dust used to reveal the minimum efficiency of a mechanical air cleaner causes the electronic air cleaner to shut down and does not give a true representation of its particle removal capabilities. Thus, publishing a MERV in the strict accordance with the standard is not possible. Alternate dust must be used to demonstrate any loss in efficiency that might occur; one such dust used by LMS Technologies Inc., contains 97% SAE fine and 3% cotton linters. Using this dust, testing can be performed to be able to compare the performance of electronic air cleaners.

When new, all tested electronic air cleaners performed well with all units achieving particle removal efficiencies over 90% on particles one micron and larger. The difference in particle removal efficiency between air cleaners was largest in the smallest particle size range.

Particle removal efficiency after the air cleaner has loaded with dust represents what can be expected over time. Due to the many variables involved, it is not possible to give an exact correlation between the amount of dust loaded and service life for all applications. After loading the air cleaners with dust, two of the tested units showed an increase in efficiency in all particle size ranges while two showed a loss in efficiency. The two that increased use media as the particle collection mechanism, and the two that decreased use collector cells. Efficiency loss as large as 26% in the 3-10 micron particle size range occurred on one of the units with as little as 20 grams of dust loaded at the air cleaner. After 60 grams of loaded dust, the efficiency of the same unit dropped by 54%.

The method used to load the dust at the air cleaner for future work will need to be reconsidered. While an equal amount of dust was loaded at all air cleaners tested, only the two electronic air cleaners that used media as the collection device were able to hold virtually all (99.8%) of the dust loaded. Both collector cell type units that showed efficiency loss were able to collect only a fraction of the dust loaded; one collected only 80% while the other collected 70%.

6.2 Airflow Resistance: Air cleaners contribute a portion of the overall system resistance against which the heating and cooling system blower must work to move air through the ducts in the home. Increased airflow resistance can result in a loss in efficiency for the heating and cooling system or can result in an increase in the amount of energy the blower requires to move the air. For the purpose of comparing one air cleaner to another, the best value to use is the resistance of the device at a particular face velocity. Of the units tested, the resistance at 400 fpm ranged from a low of 0.16” w.c. to a high of 0.27” w.c.

Unlike other components that contribute resistance to the blower, an air cleaner’s resistance will increase over time as it loads with dust. The increase will continue until either the unit is cleaned or the collection media is replaced. Failure to clean a collector cell type electronic air cleaner will result in less of an airflow resistance increase than a media collector type air cleaner, but will also result in a loss in particle removal efficiency as was shown during this project. Failure to replace the media in a media collection type electronic air cleaner will result in continually increasing efficiency but will also show more of an increase in airflow resistance.

6.3 Dust Holding Capacity: This variable applies only to media collector type air cleaners. Collector cell type air cleaners will reduce in efficiency as dust is loaded, therefore, a comparable end point cannot be achieved. The appropriate end point to use when comparing the dust-holding capacity of a media collector type air cleaner is final pressure. Construction of the media used in this type of air cleaner can significantly affect the amount of dust it can hold. One of the air cleaners tested during this project was able to hold only 80% of the amount of dust required to reach the same final pressure of 0.3" w.c. At final pressures above 0.3" w.c., the same air cleaner was able to hold only 68% of the amount the other was able to hold even though each air cleaner had the same amount of media.

7.0 References

1. "CDC Fast Facts A-Z," Vital Health Statistics, 2003
2. ASHRAE Standard 52.2-2007
3. LMS Technologies Inc.; test report numbers 1368, 1372, 1373, 1374; June 2007
4. LMS Technologies Inc.; Dust Loading test; test numbers T060707A, T061107A
5. LMS Technologies Inc.; Dust Loading test; test numbers T061906A
6. Research Products Corp.; test number 2007026