

**SETTLED DUST AND AIRBORNE PARTICULATE  
PILOT STUDY OF  
TRANE CLEAN EFFECTS™**

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Investigators from Environmental Health & Engineering, Inc. conducted a pilot investigation in which the potential associations between operation of Trane Residential System CleanEffects™ and settled dust accumulation as well as airborne particulate matter in occupied single-family homes was evaluated. The field study was conducted in five homes in Massachusetts over a four-month period in the winter of 2008.

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### **LIST OF ABBREVIATIONS AND ACRONYMS**

AHU	air handling unit
Air Cleaner	Trane CleanEffects™
cm <sup>2</sup>	centimeters squared
EH&E	Environmental Health & Engineering, Inc.
I/O	indoor concentrations to outdoor concentrations
lpm	liters per minute
PM	particulate matter
PM <sub>2.5</sub>	particulate matter that is 2.5 microns or smaller in size
RTI	Research Triangle Institute
Trane	Trane Residential Systems
µm	micrometer
XRF	X-Ray Fluorescence

## **1.0 EXECUTIVE SUMMARY**

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### **1.1 INTRODUCTION**

The Trane Residential Systems CleanEffects™ air cleaning systems (the Air Cleaner) reduces accumulation of dust on surfaces in homes according to anecdotal reports received by Trane from customers who have purchased the product. Environmental Health & Engineering, Inc. (EH&E) conducted a pilot investigation to evaluate the accuracy of these reports. Settled dust and airborne particulate matter (PM) levels were measured in five occupied homes during periods when the Air Cleaner was on and off. The pilot investigation was part of a larger field campaign that involved nine single-family homes in four states. Results of the larger campaign are presented in the EH&E report dated July 31, 2008.

### **1.2 MATERIALS AND METHODS**

Five single-family homes in the Boston area with the Air Cleaner were recruited to participate in the study over four winter and spring months. Settled dust samples were collected in three of the five homes. Two sets of samples were collected at each location, the first set were collected after the Air Cleaner operated for two weeks, and a second set were collected following two weeks when the Air Cleaner was not operated. Air samples for PM mass and elemental analysis was collected in three homes, one of which also was used for the settled dust investigation. Two sets of samples were collected from one indoor and one outdoor location, the first set of samples were collected while the Air Cleaner was operating and a second set were collected while the Air Cleaner was not operating.

### **1.3 RESULTS AND CONCLUSIONS**

Sampling was conducted between January and April, 2008, in homes in the Boston area. Settled house dust samples were collected from up to five locations in three homes. Indoor and outdoor PM samples that were analyzed for elemental composition were collected in three different homes.

The primary conclusions of the pilot investigation are that:

- Fifty percent less dust accumulated when the Air Cleaner was on than when it was off, on average.
- Airborne PM levels were lower indoors when the Air Cleaner was on compared to when it was off. Specifically:
  - The ratio of indoor PM to outdoor PM was lower when the Air Cleaner was on compared to when it was off in all three homes studied.
  - A marker of PM of ambient origin, sulfur, was lower when the Air Cleaner was on compared to when it was off, in two of the three homes.
  - Operation of the Air Cleaner resulted in lower indoor to outdoor ratios for components of dust, such as silica in all three homes, and elements generated indoors, such as copper, in two of the three homes studied.

The air handling units (AHU) and Air Cleaners in the five homes were set to run only when heating or cooling were called for by the thermostat. If the AHUs had been equipped with a variable speed fan capable of running at full speed during periods of heating and cooling demand and at half-speed during all other times, even greater reductions in settled dust and PM attributable to the operation of the Air Cleaner may have been observed.

These results are consistent with results obtained from previous EH&E investigations. For example, testing by EH&E in an unoccupied test home demonstrated that the Air Cleaner is highly effective at reducing indoor concentrations of PM generated indoors and reducing levels of PM that infiltrates into the home from outdoors. Similarly, indoor air quality modeling studies conducted by EH&E show that the Air Cleaner is effective at reducing levels of allergens in the home (Myatt et al., 2008). Considered together with the results of previous studies, the results confirm that the use of the Air Cleaner will substantially reduce accumulation of dust indoors and indoor levels of particulate air pollution. This study provides further evidence that the Air Cleaner lowers exposure to PM indoors, including bioaerosols. Further research is required to evaluate potential

health benefits that may accrue from the lower pollutant exposure afforded by the Air Cleaner.

## 2.0 INTRODUCTION

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Household dust has been shown to be a major source of exposure to allergens such as fungi, dust mites, cat, dog, cockroaches, and rodents (Vojta et al., 2002). Additionally, a variety of chemical contaminants including lead, polychlorinated biphenyls, polycyclic aromatic hydrocarbons, flame retardants, plasticizers (phthalates, phenols), have been identified in household settled dust (Roberts et al., 1995; Butte et al., 2002; Vojta et al., 2002; Bornehag et al., 2004; Maertens et al., 2004; Bornehag et al., 2005; Allen et al., 2008; Stapleton et al., 2008).

Due to the constituents of settled household dust, exposure to dust is of concern. Exposure to household dust occurs primarily by inhalation of airborne dust or the accidental ingestion of dust that has adhered to food or skin. Inhalation rates of dust for children range between 0.15 milligrams (mg) and 0.34 mg of dust per day while adults inhale approximately 0.81 mg per day. Ingestion rates are higher for children, ranging from 50 to 100 mg of dust per day, while adults are estimated to ingest 0.56 mg of dust per day (Hawley, 1985).

PM exposure indoors represents a large fraction of total exposure because Americans spend approximately 69% of their time indoors at home (Echols et al., 1999; Klepeis et al., 2001). Indoor PM is comprised of PM generated outdoors that penetrates into the home and PM generated from activities that take place indoors. Major sources of PM generated indoors that are responsible for the large personal exposures include cooking, smoking and activities that resuspend settled household dust, such as dusting, cleaning, and simply walking around (Ferro et al., 2004b; Ferro et al., 2004a). Particles that are re-suspended from these activities have been shown to be between 0.7 and 10 micrometers ( $\mu\text{m}$ ) (Abt et al., 2000).

An intervention that can reduce indoor levels of settled dust PM should be able to reduce personal exposures to the contaminant constituents of these materials. While laboratory experiments and tests conducted in an unoccupied test home have demonstrated that the Trane Residential System (Trane) Air Cleaner is very efficient at removing airborne PM, less is known about the ability of the Air Cleaner to reduce PM in occupied settings. Therefore, in order to investigate the capability of the Air Cleaner in reducing settled dust

and indoor PM levels in occupied homes, EH&E conducted a pilot investigation in which settled dust and PM were measured in five occupied single-family homes.

## **3.0 MATERIALS AND METHODS**

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### **3.1 OVERVIEW**

Five single-family homes with the Air Cleaner were recruited to participate in the study. Field testing occurred over four months during the winter and spring when air exchange rates are likely to be low (i.e., windows will be closed for the majority of the time) and therefore any outdoor air impact on either settled dust accumulation or indoor air elemental concentrations would be minimized. Four or five sample locations were identified in each of the three homes participating in the settled dust evaluation. Two sets of samples were collected at each location, the first set was collected after the Air Cleaner operated for two weeks, and a second set was collected following two weeks when the Air Cleaner was not operating. Indoor and outdoor measurements of airborne PM were collected in three of the homes. Similar to the settled dust samples, PM measurements were collected during a period when the Air Cleaner was operating and a second period when the Air Cleaner was not operating. The PM samples were pre- and post-weighed to determine PM mass concentration and analyzed for their elemental composition.

### **3.2 TEST HOMES**

EH&E worked with Trane and its representatives to recruit five Boston-area homes into the study. Homes were required to be single family and non-smoking, with a whole-house forced air heating and/or cooling system. To the extent possible, homes were selected to represent a variety of the Air Cleaner installation and residential conditions. The AHU was set to operate when cooling or heating was triggered by the thermostat and the variable fan speed mode was disabled, so that information could be collected when the Air Cleaner was operating. Sampling was also conducted during periods when the Air Cleaner was not operating. During these periods, the only filtration in the AHU was the standard media pre-filter, which was expected to have minimal removal efficiency for particles less than 10  $\mu\text{m}$ .

The location and basic information of each field test home is presented in Table 3.1. Dust sampling was carried out in homes 1, 2 and 5, while PM mass and elemental

composition sampling was carried out at homes 3 through 5. The five homes evaluated here, were also part of the field study described in the EH&E report dated July 31, 2008.

Home	Location	Approx. Year Built	Square Footage	Number of Air Handling Units	Percent of Time Air Cleaner Operating	Number of Residents		
						Adult	Children	Pets
1	Stow, MA	1979	2820	1	73%	2		
2	Southborough, MA	2004	2150	1	26%	2		1
3	Natick, MA	1990s	1500	1	42%	2		1
4	Acton, MA	1979	2480	1	100%	3	2	2**
5	Weston, MA	1992	6060	3*	57%	2		

\* Indicates only one air handling unit is connected to the air cleaner  
 \*\* Indicates that two cats lived in home prior to sampling period

### 3.3 SCHEDULE

Table 3.2 presents the sampling periods for settled dust and airborne PM for each test home. Settled dust samples were collected in homes 1, 2 and 5 and airborne PM samples were collected in homes 3, 4, and 5.

EH&E field technicians conducted three site visits per home, each approximately two weeks apart. During the first visit, the settled dust sampling locations were identified and cleaned and/or the airborne PM sampling equipment was installed. The PM sampling equipment was set to shut off automatically after seven days of sampling. EH&E field technicians ensured that the Air Cleaner was operating and asked the residents to keep it powered on during the duration of the sampling period. The second visit included the collection of the first set of settled dust and/or PM samples, followed by cleaning and resetting of the sampling locations for the second set of settled dust samples and preparations to collect the second set of PM samples. Also, the Air Cleaner was turned off with the residents' permission and the understanding that it would remain off until the final visit. During the final visit, the second set of dust samples and/or PM filters were collected and the Air Cleaner was turned back on.

<b>Table 3.2</b> Sampling Periods of when Settled Dust and PM Mass Sampling Occurred in Each Test Home			
<b>Home</b>	<b>Air Cleaner Status</b>	<b>Dust Sampling Period</b>	<b>PM Sampling Period</b>
<b>1</b>	<b>On</b>	1/17 – 1/31	—
	<b>Off</b>	1/31 – 2/14	—
<b>2</b>	<b>On</b>	1/25 – 2/8	—
	<b>Off</b>	2/8 – 2/22	—
<b>3</b>	<b>On</b>	—	2/27 – 3/4
	<b>Off</b>	—	3/4 – 3/11
<b>4</b>	<b>On</b>	—	2/27 – 3/4
	<b>Off</b>	—	3/4 – 3/11
<b>5</b>	<b>On</b>	3/10 – 3/27	3/19 – 3/26
	<b>Off</b>	3/27 – 4/9	3/27 – 4/3

### 3.4 SETTLED DUST

#### 3.4.1 Settled Dust Measurement

Settled dust accumulation was measured in four to five sampling locations in each home. During the initial visit, sampling locations of approximately 500 centimeters squared (cm<sup>2</sup>) were identified and marked off with painter’s tape. The homeowner was asked not to disturb the sites, and to keep a log of any possible dust-generating activities carried out in the home (e.g., wood fires or vacuuming carpets).

The dust accumulation sampling procedure was based on the North American Duct Cleaning Association Verification of heating, ventilating and air-conditioning System Cleanliness Method (NADCR, 2006). A Dawson 1300 Air Sampling Pump operated at 15 liters per minute (lpm) was used to draw air through a 37 millimeter (mm) pre-weighed five µm PVC filter (SKC, Eighty Four, PA) contained in a three-piece plastic open faced cassette. The filter cassette was drawn slowly across a template with a 2 cm x 25 cm opening. This process was repeated five times within the sampling location until at least 500 cm<sup>2</sup> had been sampled. This process was repeated with a new filter at each of the sampling locations. After sampling was complete, the sampling locations were thoroughly cleaned with pre-cleaned wipes and deionized water. Liberty Mutual Industrial Hygiene Laboratory (Hopkinton, MA) conducted gravimetric analysis on the filters.

### **3.4.2 Measurement Locations**

Four or five settled measurement locations were selected at each participating home. The criteria for choosing locations were the size of the location and areas that would be generally free of disturbances from the occupants and pets. The most common measurement locations were window sills, bookshelf tops, and shelves.

## **3.5 PARTICULATE MATTER**

### **3.5.1 Particulate Matter Mass and Elemental Composition Analysis**

Airborne PM samples were collected using sampling equipment consisting of a Gilian Gilair 5 air pump running at 2 lpm and 37 mm Teflo membrane filters (Pall Gelman, Ann Arbor, MI) with a 2 µm pore size. The filters were pre-weighed by Research Triangle Institute (RTI) International (Research Triangle Park, NC). The pumps were set to run for 7 days. After sampling, the filters were returned to RTI for gravimetric and X-Ray Fluorescence (XRF) analysis for 42 elements. XRF is used for analysis of bulk samples and provides a rapid, non-destructive method for determining the elemental composition of a sample. Indoor and outdoor PM samples were collected over two seven day sampling periods. The first set of samples were collected when the Air Cleaner was operating and the second set of samples were collected when the Air Cleaner was disabled.

### **3.5.2 Monitoring Locations**

One indoor and one outdoor airborne PM sampling location was selected at each home. The indoor sampling location was the living room or other frequently occupied room. The outdoor location was an outdoor location where the sampling equipment could be protected from heavy precipitation.

## **3.6 DATA CAPTURE AND ANALYSIS**

### **3.6.1 Settled Dust**

The total weight of settled dust collected onto each filter was reported by the laboratory.

The reported mass was divided by the corresponding sampling area to calculate dust accumulation in micrograms per square centimeter ( $\mu\text{g}/\text{cm}^2$ ). The detection limit for the dust samples was  $0.06 \mu\text{g}/\text{cm}^2$ . Two of the four sampling locations in Home 5 were discarded due to damage during shipping or issues with the sample collection.

The mean value of settled dust accumulation for each home was calculated by dividing the sum of the individual sample values by the number of samples. Percent decrease in settled dust levels were calculated for each home. We estimated the overall Air Cleaner impact in two ways. We conducted a Pairwise T test between dust samples collected when the Air Cleaner was operating and not operating and used them to determine the statistical significance between the samples. We also estimated the impact of the Air Cleaner on the log transformed settled dust levels using a generalized linear model (PROC GLM, SAS Institute, Cary, North Carolina) that included a dichotomous variable for operation of the Air Cleaner (On/Off), a categorical variable for the type of sampling location, and a categorical variable for home.

$$\text{Natural Log(Settled Dust Concentration)} = \beta_0 + \beta_1 * \text{Operational Status of Air Cleaner} + \beta_2 * \text{Location} + \beta_3 * \text{Home} + \varepsilon$$

The location and home variables were included in the model to control for systematic differences in potential impacts of the Air Cleaner (i.e. sampling locations that were low to the ground and potentially impacted by resuspension of large particles), air exchange rate, the frequency of dust creating activities in the home, or other factors among homes that could influence settled dust levels.

### **3.6.2 Airborne Particulate Matter and Elemental Composition**

Filters were weighed and analyzed for 42 elements. PM mass and elemental concentrations were calculated using the volume of air collected. Two of the outdoor samples that were collected were less than  $1 \mu\text{g}/\text{m}^3$  and considered unreliable. Therefore, these samples were replaced with the best available data. For the Home 3 outdoor sample collected between March 4, 2008, and March 11, 2008, the sample was replaced with the outdoor concentrations collected during the same period from home 4 located approximately 19 kilometers away. For the Home 5 outdoor sample

collected between March 19, 2008, and March 26, 2008, the sample value was replaced with the nearest  $PM_{2.5}$  concentration for that week reported by the Massachusetts Department of Environmental Protection. The element concentrations for this sample were adjusted by multiplying the average element fraction of all the reliable outdoor samples by the regional  $PM_{2.5}$  concentration.

I/O of PM mass and elements were calculated by dividing the indoor concentration by the corresponding outdoor concentration. For the elements with concentration below the detection limit (<DL), half of the instrumental detection limit was used to calculate the I/O ratio.

## 4.0 RESULTS

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### 4.1 SETTLED DUST

Descriptive statistics by sampling location for each of the three homes are presented in Table 4.1. Settled dust accumulation ranged from less than the limit of detection to  $2.0 \mu\text{g}/\text{cm}^2$  when the Air Cleaner was operating and less than the limit of detection to  $3.8 \mu\text{g}/\text{cm}^2$  when the Air Cleaner was not operating. The highest accumulation level occurred in House 1 on the top of a bookshelf near the front door of the home. Of the 12 sampling locations, nine locations had lower settled dust accumulation during the period when the Air Cleaner was operating. For these 9 locations, dust accumulation levels were reduced by 14% to 97% when the Air Cleaner was operating compared to when it was not.

The average settled dust accumulation for each home was lower when the Air Cleaner was operating. Average settled dust accumulations decreased by 58%, 58% and 54% for home 1, 2 and 5, respectively. The settled dust accumulation in Home 5 was substantially less compared to Homes 1 and 2, which may be due to inactivity in the home or changes in the sampling methods, where a different sampling template was used in Home 5. The Pairwise T test and the multivariate statistical model demonstrated that the operation of the Air Cleaner was associated with a statistically significant reduction in settled dust levels (Pairwise T Test:  $p=0.01$ , multivariate model:  $p=0.02$ ).

<b>Table 4.1</b> Settled Dust Accumulation Levels ( $\mu\text{g}/\text{cm}^2$ ) When the Air Cleaner was Operational and Non-Operational				
House	Air Cleaner		Percent Decrease in Dust Accumulation when the Air Cleaner Operating	Sampling Location
	ON	OFF		
<b>1</b>	1.2	1.4	14%	Top of bookshelf A
	0.8	3.8	79%	Top of bookshelf B
	0.6	2.2	73%	Top of shelf A
	1.2	1.4	14%	Window sills
	0.1	0.5	80%	Top of shelf B
<b>Mean (stdev)</b>	0.78 (0.46)	1.86 (1.24)	58%	
<b>2</b>	2.0	1.7	-18%	Door sill
	0.6	1.6	63%	Top of shelf A
	1.0	3.5	71%	Top of shelf B
	0.2	3.8	95%	Window sills
	1.0	0.7	-43%	Top of shelf C
<b>Mean (stdev)</b>	0.96 (0.67)	2.26 (1.33)	58%	
<b>5</b>	0.06	0.2	97%	Window sills A
	<0.06	<0.06	0%	Window sills B
<b>Mean (stdev)</b>	0.06 (0.00)	0.13 (0.10)	54%	
stdev    standard deviation				

## 4.2 AIRBORNE PARTICULATE

Table 4.2 presents the PM mass concentrations along with the I/O ratios. The indoor PM concentrations ranged from 1.6 to 8.2  $\mu\text{g}/\text{m}^3$  when the Air Cleaner was operating and 2.9 to 12.5  $\mu\text{g}/\text{m}^3$  when the Air Cleaner was not operating. The outdoor PM concentrations ranged from 5.1 to 7.6  $\mu\text{g}/\text{m}^3$ . The PM I/O ratios were lower in each of the three homes when the Air Cleaner was operating compared to when it was not operating, indicating that the Air Cleaner was reducing indoor PM levels.

<b>Table 4.2</b> Concentrations and Indoor to Outdoor ratios of PM Mass measured over 5 sampling days when the Air Cleaner was operating and not operating				
Home	Air Cleaner Status	Location	Particulate Matter	
			$\mu\text{g}/\text{m}^3$	I/O Ratio
3	ON	Indoor	4.5	0.62
		Outdoor	7.3	
	OFF	Indoor	12.5	2.3
		Outdoor	5.5	
4	ON	Indoor	8.2	1.1
		Outdoor	7.6	
	OFF	Indoor	6.9	1.3
		Outdoor	5.5	
5	ON	Indoor	1.6	0.32
		Outdoor	5.1	
	OFF	Indoor	2.9	0.41
		Outdoor	7.2	

$\mu\text{g}/\text{m}^3$  micrograms per cubic meter  
I/O Indoor to outdoor concentrations

Table 4.3 presents the I/O ratios of selected elements for homes 3, 4, and 5. Of the 42 elements analyzed, 22 elements were detected in more than 40% of the samples. Their concentrations are reported in Appendix B for each of the three homes.

<b>Table 4.3</b> Indoor-Outdoor Ratios of Elemental Concentrations Measured Over 5 Sampling Days When the Air Cleaner was Operating and Not Operating					
Home	Air Cleaner Status	I/O Ratio			
		Cu	Pb	S	Si
3	ON	0.06	0.07	0.28	0.44
	OFF	3.26	2.80	0.52	3.65
4	ON	0.40	1.09	0.79	0.53
	OFF	1.13	NA	0.71	0.60
5	ON	1.04	NA	0.28	0.08
	OFF	0.79	2.20	0.43	0.11

I/O Indoor to outdoor concentrations  
NA Indoor concentrations were below detection limit and therefore I/O Ratio was not calculated

Sulfur, has no known indoor sources, and is therefore used as a marker of outdoor air that has penetrated indoors. The sulfur I/O ratio was lower when the Air Cleaner was operating in two of the three homes. Assuming the air exchange rates were similar between periods in which the Air Cleaner was operating or not, a lower I/O ratio when

the Air Cleaner is operating indicates that the Air Cleaner is reducing the levels of PM that have penetrated into the home from outdoor sources.

The lead levels in the three homes were very low, which is consistent with homes that do not contain lead paint. For homes without lead paint, the primary source of airborne lead indoors is from outdoor sources, such as contaminated soil. In home 3, the lead I/O ratio was substantially lower when the Air Cleaner was operating compared to when the Air Cleaner was disabled. Indoor samples with concentrations below the detection limit preclude a comparison of I/O ratios by Air Cleaner operational status, however, results from Home 3 and Home 5 (where lead was not detected indoors when the Air Cleaner was operating), indicate that the Air Cleaner is potentially impacting indoor lead levels.

Similar to lead, silica and other crustal elements such as calcium, potassium, and iron, can be transported via air into the home or tracked in by occupants and resuspended. The I/O ratios for these four crustal elements were lower in all three homes when the Air Cleaner was operating, indicating that the Air Cleaner is reducing airborne levels of contaminants that are most likely resuspended from surfaces in the homes.

As opposed to other contaminants, elements such as copper have well defined indoor sources, such as devices with electric motors (e.g., electric fans and vacuum cleaners) and materials such as houseplant fertilizers and cosmetics. The I/O ratios above one during the periods when the Air Cleaner was not operating indicate the presence of indoor sources of copper. In two of the three homes, the copper I/O ratio was reduced, from above one to below one, indicating that the Air Cleaner was removing PM generating indoors.

## 5.0 DISCUSSION

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This pilot study was designed to evaluate the ability of the Air Cleaner to reduce settled dust and airborne PM levels in occupied homes. The operation of the Air Cleaner reduced the dust accumulation levels by more than 50% in all three homes and reduced the airborne PM levels in two of the three homes. These results indicate that the use of the Air Cleaner may be an effective way to reduce settled dust loading and airborne PM levels in the home.

The amount of dust that accumulates in a residence varies across homes and among locations within a home as a result of occupant and home-specific factors. These factors include the activity level of the occupants and building characteristics that influence airflow. Occupant activities such as dry dusting and walking or playing on carpet cause large particles on the floor to be suspended into the air. These large particles fall out of the air quickly in comparison to airflow through the home and therefore are not likely to be removed by an Air Cleaner. Consequently, these activities are likely to produce relatively high accumulation of dust near to the activity. Because of situations like this, we do not expect the reduction of dust accumulation that results from use of the Air Cleaner to be equal in all homes or even in all locations within a home.

The composition of the settled house dust was not analyzed in this pilot study; however, materials associated with a variety of health effects are commonly detected in settled dust collected in homes (Adgate et al., 1995; Roberts et al., 1995; Butte et al., 2002; Vojta et al., 2002; Bornehag et al., 2004; Maertens et al., 2004; Bornehag et al., 2005; Allen et al., 2008; Stapleton et al., 2008). Direct comparisons of the mass of settled dust is difficult due to differences in sampling methodologies. For example, samples collected from window sills in 216 homes in New Jersey had a mean settled dust level of 100  $\mu\text{g}/\text{cm}^2$  (Adgate et al., 1995), which is over two orders of magnitude greater than the levels we observed in the study homes. There are two major differences between the Adgate study and our measurements. First, and most importantly, the Adgate study measured dust from pre-existing conditions, which could have been collecting over a number of weeks, while we were measuring dust accumulation over a two-week period. Secondly, the Adgate study collected dust using a wipe method, while we used a vacuum pump method. Regardless of the study differences, numerous studies have

demonstrated that settled dust is an important reservoir of lead and other contaminants in the home, which can result in elevated exposures, especially in children.

Similar to the analysis of settled dust, the composition of PM collected from indoor and outdoor air can be used to investigate the sources of the PM. For example, sulfur is typically used to estimate the fraction of indoor PM that originates outdoors, as there are no indoor sources of sulfur (Suh et al., 1992; Sarnat et al., 2002; Wallace et al., 2005; Sarnat et al., 2006). Sulfur I/O ratios are lowest when air exchange rates are lowest, such as during the winter months or during summer months when air conditioning is used. For example, homes located in Pennsylvania with air conditioning had an average sulfur I/O ratio of 0.69, while homes without air conditioning had a ratio of 0.86 (Suh et al., 1992). By comparison, the sulfur I/O ratio in one of our study homes with the Air Cleaner had a ratio of 0.28, compared to a ratio of 0.52 when the Air Cleaner was not operating. These results indicate that our study homes have relatively little air exchange rate with the outdoors and that the Air Cleaner is playing an important role in removing PM infiltrating from outdoors.

Locations with high degrees of activity, such as classrooms, have I/O ratios above one for elements that are resuspended from settled dust such as silica and lead (Janssen et al., 1999). In one of the study homes (Home 3), the I/O ratios for silica and lead were both above one when the Air Cleaner was not operating and substantially below one when the Air Cleaner was operating. If the level of activity in the home was similar in both sampling periods, these results indicate that the Air Cleaner was very effective at removing particles that are typically resuspended from settled dust.

Several studies have shown that copper as a metal typically generated from indoor sources such as electric fans, vacuum cleaners, houseplant fertilizers, and cosmetics (Brunekreef et al., 2005; Lanki et al., 2007; Yli-Tuomi et al., 2008). Our results, where copper levels are lower in two of the three homes with the Air Cleaner operating, indicate that the Air Cleaner is reducing indoor levels of PM that was likely to be generated indoors.

## 6.0 CONCLUSIONS

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EH&E conducted a pilot study in which settled dust and airborne PM levels were measured when the Air Cleaner was operating and periods when the Air Cleaner was not operating to determine the impact of the Air Cleaner on reducing the levels of these materials in occupied homes.

Sampling was conducted over four months in the winter and spring in homes in the Boston area. Settled house dust samples were collected from up to five locations in three homes. Indoor and outdoor PM samples that were analyzed for elemental composition were collected in three different homes.

The primary conclusions of the pilot investigation are that:

- Fifty percent less dust accumulated when the Air Cleaner was on than when it was off, on average.
- Airborne PM levels were lower indoors when the Air Cleaner was on compared to when it was off. Specifically:
  - The ratio of indoor PM to outdoor PM was lower when the Air Cleaner was on compared to when it was off in all three homes studied.
  - A marker of PM of ambient origin, sulfur, was lower when the Air Cleaner was on compared to when it was off, in two of the three homes.
  - Operation of the Air Cleaner resulted in lower indoor to outdoor ratios for components of dust, such as silica in all three homes, and elements generated indoors, such as copper, in two of the three homes studied.

The AHU and Air Cleaners in the five homes were set to run only when heating or cooling were called for by the thermostat. If the AHUs had been equipped with a variable speed fan capable of running at full speed during periods of heating and cooling demand

and at half-speed during all other times, even greater reductions in settled dust and PM attributable to the operation of the Air Cleaner may have been observed.

These results are consistent with results obtained from previous EH&E investigations. For example, testing by EH&E in an unoccupied test home demonstrated that the Air Cleaner is highly effective at reducing indoor concentrations of PM generated indoors and reducing levels of PM that infiltrates into the home from outdoors. Similarly, indoor air quality modeling studies conducted by EH&E show that the Air Cleaner is effective at reducing levels of allergens in the home (Myatt et al., 2008). Considered together with the results of previous studies, the results confirm that the use of the Air Cleaner will substantially reduce accumulation of dust indoors and indoor levels of particulate air pollution. This study provides further evidence that the Air Cleaner lowers exposure to PM indoors, including bioaerosols. Further research is required to evaluate potential health benefits that may accrue from the lower pollutant exposure afforded by the Air Cleaner.

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**APPENDIX A  
LIMITATIONS**

## LIMITATIONS

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1. Environmental Health & Engineering, Inc.'s (EH&E) indoor air assessment described in the attached report number 15477, *Settled Dust and Airborne Particulate, Pilot Study of, Trane Cleaneffects<sup>TM</sup>* (hereafter "the Report"), was performed in accordance with generally accepted practices employed by other consultants undertaking similar studies at the same time and in the same geographical area; and EH&E observed that degree of care and skill generally exercised by such other consultants under similar circumstances and conditions. The observations described in the Report were made under the conditions stated therein. The conclusions presented in the Report were based solely upon the services described therein, and not on scientific tasks or procedures beyond the scope of described services.
2. Observations were made of the site as indicated within the Report. Where access to portions of the site was unavailable or limited, EH&E renders no opinion as to the presence of chemical residues, or to the presence of indirect evidence relating to chemical residues in that portion of the site.
3. The observations and recommendations contained in the Report are based on limited environmental sampling and visual observation, and were arrived at in accordance with generally-accepted standards of industrial hygiene practice. The sampling and observations conducted at the site were limited in scope and, therefore, cannot be considered representative of areas not sampled or observed.
4. When an outside laboratory conducted sample analyses, EH&E relied upon the data provided and did not conduct an independent evaluation of the reliability of these data.
5. The purpose of the Report was to assess the characteristics of the subject site as stated within the Report. No specific attempt was made to verify compliance by any party with all federal, state, or local laws and regulations.

**APPENDIX B**  
**PM MEASUREMENT RESULTS**

PM Measurement Results														
Home	Air Cleaner Status	Location	$\mu\text{g}/\text{m}^3$	Element Concentrations ( $\text{ng}/\text{m}^3$ )										
			PM	Al	Br	Ca	Cl	Co	Cr	Cu	Fe	K	Mg	Mn
3	ON	Indoor	4.5E+00	1.2E+01	7.0E-02	5.0E+00	3.2E+01	2.2E-02	3.8E-02	1.8E-02	4.4E+00	9.9E+00	<DL	<DL
		Outdoor	7.3E+00	1.9E+01	2.3E-01	2.1E+01	1.8E+02	<DL	5.7E-02	2.9E-01	3.2E+01	1.4E+01	3.2E+00	5.1E-01
	OFF	Indoor	1.3E+01	4.8E+01	2.2E-01	1.7E+01	5.8E+01	3.7E-02	5.9E-02	4.4E-01	1.3E+01	3.7E+01	<DL	1.6E-01
		Outdoor	5.5E+00	5.8E+00	2.1E-01	9.5E+00	7.6E+00	5.9E-02	9.3E-03	1.3E-01	9.9E+00	8.0E+00	1.5E+00	1.8E-01
4	ON	Indoor	8.2E+00	2.4E+00	2.9E-01	8.4E+00	2.1E+01	<DL	<DL	6.9E-02	4.7E+00	1.4E+01	8.8E-01	2.5E-02
		Outdoor	7.6E+00	5.6E+00	6.0E-01	1.5E+01	3.1E+01	5.2E-02	2.2E-02	1.7E-01	8.9E+00	9.9E+00	4.2E+00	6.5E-02
	OFF	Indoor	6.9E+00	2.6E+00	1.3E-01	9.6E+00	1.8E+01	5.3E-02	<DL	1.5E-01	5.5E+00	1.3E+01	4.9E-01	5.3E-02
		Outdoor	5.5E+00	5.8E+00	2.1E-01	9.5E+00	7.6E+00	5.9E-02	9.3E-03	1.3E-01	9.9E+00	8.0E+00	1.5E+00	1.8E-01
5	ON	Indoor	1.6E+00	<DL	8.1E-02	3.3E+00	3.5E+00	5.4E-03	<DL	1.6E-01	1.1E+00	1.5E+00	<DL	<DL
		Outdoor	5.1E+00	7.9E+00	2.8E-01	1.1E+01	4.7E+01	4.8E-02	2.4E-02	1.5E-01	1.3E+01	8.1E+00	2.7E+00	2.2E-01
	OFF	Indoor	2.9E+00	<DL	2.0E-01	2.9E+00	8.7E+00	4.3E-02	<DL	1.9E-01	1.7E+00	3.5E+00	6.1E-01	5.8E-03
		Outdoor	7.2E+00	1.2E+01	5.0E-01	1.7E+01	4.8E+01	7.6E-02	4.6E-02	2.4E-01	1.8E+01	1.2E+01	6.0E+00	4.1E-01

PM Measurement Results (continued)														
Home	Air Cleaner Status	Location	Element Concentrations ( $\text{ng}/\text{m}^3$ )											
			Na	Ni	P	Pb	S	Si	Sr	Ti	V	Zn	Zr	
3	ON	Indoor	1.6E+01	<DL	<DL	1.9E-02	1.6E+01	2.9E+01	<DL	3.5E-01	<DL	5.4E-01	1.3E+00	
		Outdoor	7.6E+01	<DL	5.5E-01	2.5E-01	5.6E+01	6.6E+01	1.7E-01	2.2E+00	3.1E-02	1.2E+00	1.5E-01	
	OFF	Indoor	2.0E+01	4.7E-02	1.4E+00	2.2E-01	3.3E+01	9.1E+01	7.4E-02	3.2E+00	<DL	1.4E+00	6.0E+00	
		Outdoor	1.6E+01	4.7E-02	2.3E-01	7.7E-02	6.3E+01	2.5E+01	5.1E-03	7.7E-01	<DL	9.3E-01	1.2E-01	
4	ON	Indoor	1.5E+01	1.7E-02	5.1E-01	1.3E-01	7.5E+01	2.7E+01	7.9E-02	3.9E-01	3.0E-02	9.4E-01	<DL	
		Outdoor	4.1E+01	4.9E-02	2.2E-01	1.2E-01	9.4E+01	5.2E+01	3.0E-01	4.8E-01	<DL	1.0E+00	<DL	
	OFF	Indoor	9.5E+00	1.3E-02	1.6E-01	<DL	4.5E+01	1.5E+01	1.7E-01	8.4E-01	1.0E-02	8.5E-01	6.0E-01	
		Outdoor	1.6E+01	4.7E-02	2.3E-01	7.7E-02	6.3E+01	2.5E+01	5.1E-03	7.7E-01	<DL	9.3E-01	1.2E-01	
5	ON	Indoor	2.5E+00	<DL	<DL	<DL	1.5E+01	2.8E+00	<DL	<DL	<DL	2.9E-01	<DL	
		Outdoor	3.3E+01	4.7E-02	2.8E-01	9.2E-02	5.5E+01	3.4E+01	9.9E-02	8.2E-01	<DL	7.7E-01	<DL	
	OFF	Indoor	9.0E+00	<DL	<DL	1.4E-01	3.5E+01	4.8E+00	<DL	<DL	<DL	5.6E-01	<DL	
		Outdoor	4.8E+01	9.1E-02	5.4E-01	6.3E-02	8.1E+01	4.4E+01	1.0E-01	9.9E-01	<DL	9.7E-01	<DL	