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Evaluation of Steam Cleaning in AHU Coil Sanitization and Energy Conservation

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Abstract

Research on heating ventilation and air conditioning (HVAC) systems has indicated that microbial contamination is an immediate problem when it concerns the indoor environment and human health. A study has been performed to determine the effectiveness of steam cleaning latent clogged debris from on or within evaporator coils of an HVAC that is restricting air flow, as well as causing poor air quality. A dusty, rusty and clogged HVAC coil was treated with steam generated at 350ºC through a proprietary jet covering an area of 4'' X 1" vertically at a time. Environmental bulk samples for microbiological (bacteria/fungi) evaluation were collected before and after steam sanitization from the front central face (fin) area of the coil. Light perforation and air flow tests of the coil were undertaken before and after the treatment. The test results indicate that the steam cleaning is 99.99% effective in removing microbial contaminants and other surficial debris/lint. The light perforation, air flow, and static pressure tests reveal increased airflow and energy efficiency, leading significantly towards optimal coil performance.

1. Introduction

In recent years, buildings have been designed with the conservation and optimization of energy in mind. In most of these scenarios, the natural ventilation is replaced by the artificial management of air circulation with a minimum of fresh air intake. Often infiltration, moisture and temperature imbalance become a concern from a health and hygiene point of view in these buildings. Literature suggests that microbiological contaminants, such as bacteria and fungi, flourish within the structure (Schmidt et al 2012). This can accumulate over time on areas, such as counter tops, table tops, seating, etc., including deep inside the HVAC coil, as well as in the surrounding environment. These accumulated contaminants restrict the air flow pathway of the HVAC coil and cause excess energy consumption, while contaminants like bacteria and mold (fungi) adversely impact human health by causing allergies and other infections or diseases. A contaminated HVAC coil serves as a primary source of indoor air pollution as they provide the breeding ground for microbes and other contaminants. These biogenic and a-biogenic entities can cause serious hygiene problems besides adverse health affects. It has been often observed that these substances can cause unpleasant odors that impair the performance of occupants within the structures. It is easy to witness excess condensation around the fin and tubing area of an HVAC coil, especially when the air flow is restricted. Microbial growth thrives on this moisture and subsequently their inoculums are

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distributed throughout indoor environments. It has been observed that a temperature range of 25-30°C and over 70% relative humidity supports the microbial growth, especially in the case of bacteria and fungi. Jo and Lee (2008) reported that automobile and household air conditioning can discharge up to 2,500 colony forming units per meter cubed (CFU/m^3) of bacteria, as well as 1,000 CFU/m^3 of fungi at ambient levels during initial startup. Conspicuous growth (up to 10^6 CFU/cm^2) of bacteria is reported from air handling cooling coils. The colonization of microbes on the HVAC coil can also be influenced by the material used in the coil. Copper and aluminum is widely used for manufacturing the primary composition of AHU coils. The concentration of fungi and bacteria varies depending upon the material used for fabricating the coil. According to a report, copper is more resistive to microbes (fungi and bacteria) in comparison to the aluminum. It has been observed that the concentration of fungi on copper coils was 3,500 times less than that of the aluminum, whereas in the case of bacterial concentration, it was 500 times less on copper than that of aluminum; statistically, it does not correlate in the release of airborne microbes (Feigley et al 2012).

Demand has been growing for the proper remediation and sanitization of HVAC coils in an eco-friendly manner by utilizing green technology. Routine maintenance of an HVAC coil maximizes the energy efficiency and creates a healthy indoor environment. It is in this context that Pure Air Control Services, through Environmental Diagnostics Laboratory (EDLab), has undertaken an independent study to identify common mold and bacteria on the coil devoid of proper maintenance for the past several years. Steam treatment was implemented to assess its capability and efficiency in sanitizing a contaminated AHU coil, both by reducing or eliminating microbial contaminants, and enhancing the air flow within the coil. The steam used in the process is generated by heating water up to 350°C. The generated steam is jet blasted onto the dirty surface area on either side of the coil with deep penetration. A limited number of microbes can survive such an extreme condition. The water pressure generated during the process diminishes the deposited substances, removing the accumulated dust and debris. These actions together clean and sanitize the coil by removing microbial contaminants along with other noxious waste.

2. Materials and Methods

An air-conditioning coil (22" x 20" x 8") with a total free face area of 2.40 sq. ft excluding was acquired for the study. The total free face area was divided into two identical areas of 8" x 20" yielding 1.11 sq. ft., excluding an area of 0.18 sq. ft. (1.3" x 20") for a band separating the two selected areas. This coil was installed during 1967 within a student housing building located at a Florida (USA) university campus. It was uninstalled and transported to the Pure Air Control Services experiment station on January 24, 2013. Visual inspection of the coil revealed that the coil was clogged with the deposition of dust and debris. Light and air flow testing confirmed the above finding.

Environmental samples and physical evaluation of the coil was made under the following steps:

(A) Pre-Sanitization Evaluation (PSE)
Physical evaluation was made on the coil at this stage and important anomalies were recorded. The Environmental swab samples were made by swabbing the surface (fin) area (**PLATE-I B**). The above mentioned samples were collected without treating the coil. The *PSE* samples were collected on January 24th, 2013 at 11:00 am.

(B) After Sanitization (ASE) Evaluation
The steam was generated with the use of a steam generator heating water up to 350°C. The steamed water was jet flowed with 350 PSI (pressure per square inch) over the coil surface area covering an average of 4" X 1" at a time for one minute until the entire target area of the coil was treated. This treatment was repeated three times. The coil was physically inspected at this stage ten minutes after treatment. Following the treatment, environmental swab surface samples were collected similarly to the *PSE* collection. The water coming out from the steamer was also collected as a control sample. *ASE* samples were collected on February 1st, 2013 at 11:45 am.

The collected samples were extracted in sterile, distilled water. The extracted specimens were plated on a microbiological media using a serial dilution technique (10, 100, and 1000). Tryptic Soy Agar (TSA) and Malt Extract Agar (MEA) microbiological media were used to isolate and culture bacteria and fungi, respectively. Inoculated plates were properly sealed with Parafilm tape and uniquely identified. The inoculated TSA plates were incubated for 24-48 hours at 30°C ± 2°C, whereas the inoculated MEA plates were incubated up to 120 hours at 25°C ± 2°C. Positive and negative samples were run along with the above specimens in order to insure the integrity of the experiment. Fungal identification was performed on the characteristics of isolated colony, color, size, and microscopic details of the isolated organisms. Wet mounts (Lacto-phenol cotton blue was used as a stain) were prepared in order to study the microscopic details. The characters of the isolated fungi were analyzed under 100X, 400X, and 1000X magnification by using bright field microscopy. The Biolog Microlog system ™ 5.2 GEN II FF was also used for verification and confirmation. Gram stain technique was used for the initial categorization/identification of isolated bacteria. However, biochemical reactions, Biolog Microlog system ™ 5.2 GEN III and Analytical Profile Index ™ were used for identifying the isolated bacteria. The qualitative results are expressed in terms of taxon (genus and speciation), whereas the quantitative results were enumerated in Colony Forming Units (CFU).

(C) Light Perforation Test
A Marley Engineered Product (A0300) was used for generating a light source. The intensity of the light at 18" away from the source was recorded as a control. Subsequently, this light source was placed at 18" away from the untreated, as well as the treated area. The source of light was placed at a height of 6", focusing centrally on the coil above the base. The intensity of the light is recorded at 18" on the other side (opposite to the light source) on a black screen.

(D) Air Flow Test
An air flow and velocity test was undertaken utilizing a VelociCalc® TSI on the untreated and the treated area of the coil. An Omni–Aire 600V Air Filtration System was used in order to provide constant air volume. The air flow and velocity was checked on a 1.11 sq.ft. coil surface area before and after steam cleaning the AHU coil.

(E) Static Pressure Test
A static pressure verification of the coil due to deposition of dust and debris build-up within the fin of the AHU coil was done with a VelociCalc® TSI before and after the treatment.

3. Observations

All the data generated during the experiment is recorded under the observation tables (*Table 1, 2, 3 and 4*). Photographs of some vital stages of the experiment are taken and presented in plates (*Figure 1, 2, 3, 4,* and *5*). At a glance view of the experimental findings are depicted in *Figure 1*.

Table 1. Pre- and post treatment evaluation of the AHU coil steam cleaning

Evaluation	Growth Media	Microorganism Identification	Concentration (CFU/ml)	Remarks
Pre-Treatment	TSA (Bacteria)	*Bacillus subtilis*	51000	100% Reduction in Bacterial Flora and 99.95% reduction in Fungal Flora
		Bacillus amyloliquefaciens	6000	
		Flavobacterium ferrugineum	48000	
		Variovorax paradoxus	39000	
		Brevibacterium casei	10000	
	MEA (Fungi)	*Penicillium canescens*	82000	
		Aspergillus versicolor	21000	
		Cladosporium cladosporioides	27000	
		Aureobasidium pullulans	2000	
Post Treatment	TSA (Bacteria)	*Bacillus subtilis*	BDL	
		Bacillus amyloliquefaciens	BDL	
		Flavobacterium ferrugineum	BDL	
		Variovorax paradoxus	BDL	
		Brevibacterium casei	BDL	
	MEA (Fungi)	*Penicillium canescens*	BDL	
		Aspergillus versicolor	BDL	
		Cladosporium cladosporioides	60	
		Aureobasidium pullulans	BDL	

Note: BDL = Below Detection Limit

Table 2. Air Flow, Light Perforation and Static Pressure Test

Parameter	Pre-Treatment	Post Treatment	% of Change	Remarks
Airflow (CFM)	250	340	36.00	Airflow increased by 36.00%
Air Velocity (FPM)	182	250	37.36	Air velocity better by 37.36%
Light Perforation (Lux)	1	17	1600.00	1600.00% increase in luminosity
Static Pressure (Pascal)	1	0.5	50.00	50.00% decrease in resistance to airflow

Note: CFM = Cubic Feet Per Minute; FPM = Feet Per Minute; Lux = SI unit of illuminance

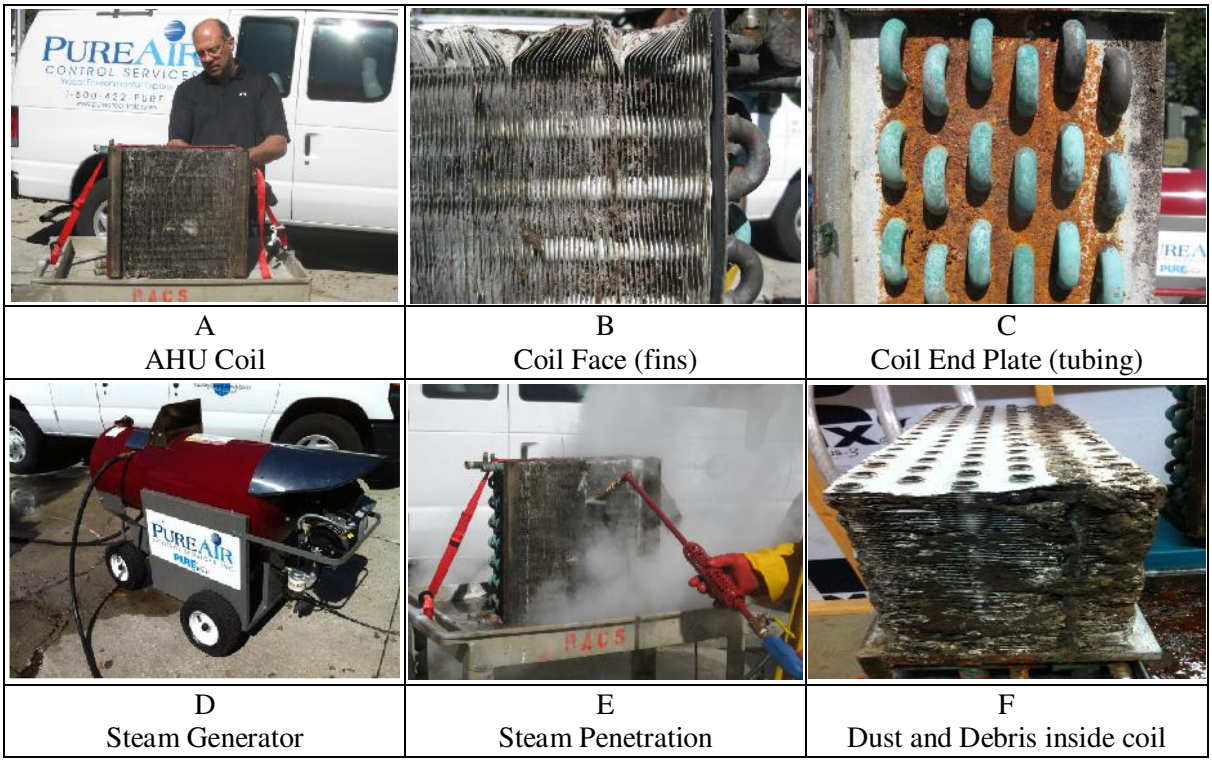
Table 3. Controls and Field Blanks

Parameter		Field Blank	Positive Control	Negative Control	Overall Performance
Microbiology	Bacteria	No growth	Growth observed	No growth	Passed Quality Control
	Fungi	No growth	Growth observed	No growth	

Table 4. Pool Data for Efficacy Test Results

Parameter		Pre-Treatment	Post Treatment	Remarks	Overall Performance
Microbes	Bacteria	154,000	BDL	100% kill for bacteria	99.98% effective against microbial contaminants
	Fungi	132,000	60	99.95% kill for fungi	

Figure 1. Coil steam cleaning (A-F)



A AHU Coil	B Coil Face (fins)	C Coil End Plate (tubing)
D Steam Generator	E Steam Penetration	F Dust and Debris inside coil

Figure 2. Effect of steam on microbial contaminants (A-F)

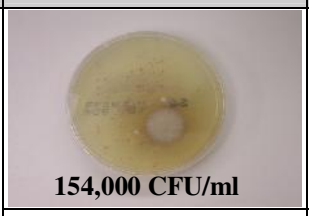
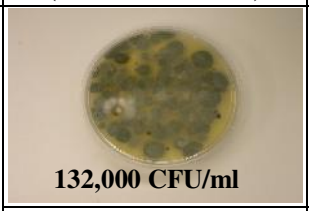
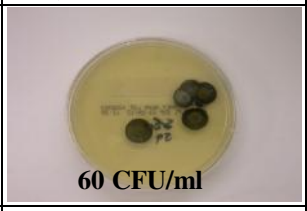
Microbes	Pre-Treatment	Post Treatment	Control	Remarks
Bacteria	 **154,000 CFU/ml**	 **BDL**	 **BDL**	100% Reduction
	A Isolated Bacteria Coil Face (Front View TSA)	B No Bacteria Isolated Coil Face (Front View TSA)	C No Bacteria Isolated Coil Face (Front View TSA)	
Fungi	 **132,000 CFU/ml**	 **60 CFU/ml**		99.95% Reduction
	D Isolated Fungi Coil Face (Front View MEA)	E Isolated Fungi Coil Face (Front View MEA)	F No Fungi Isolated Coil Face (Front View MEA)	

Figure 3. Microscopic view of bacteria isolated from the AHU coil (A-D)

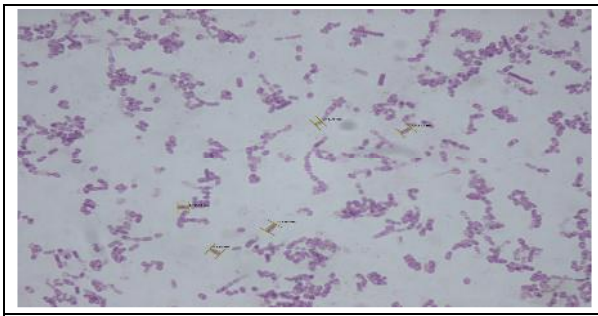
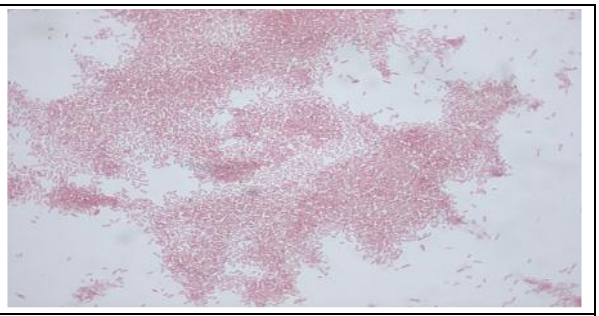
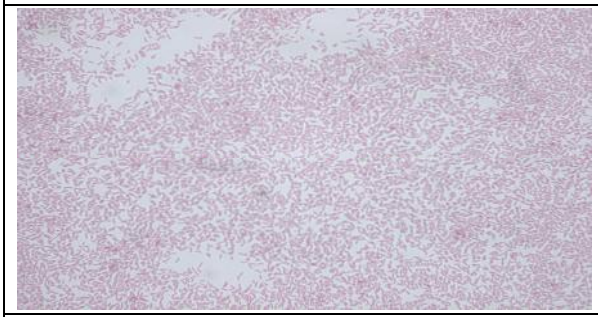
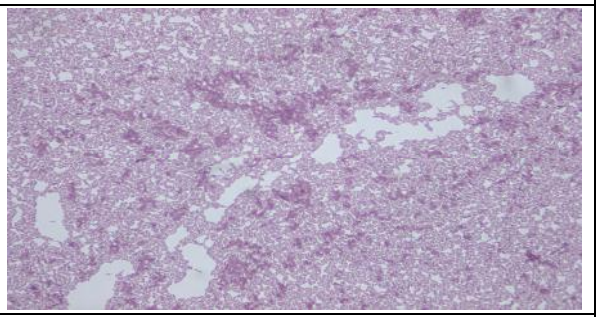
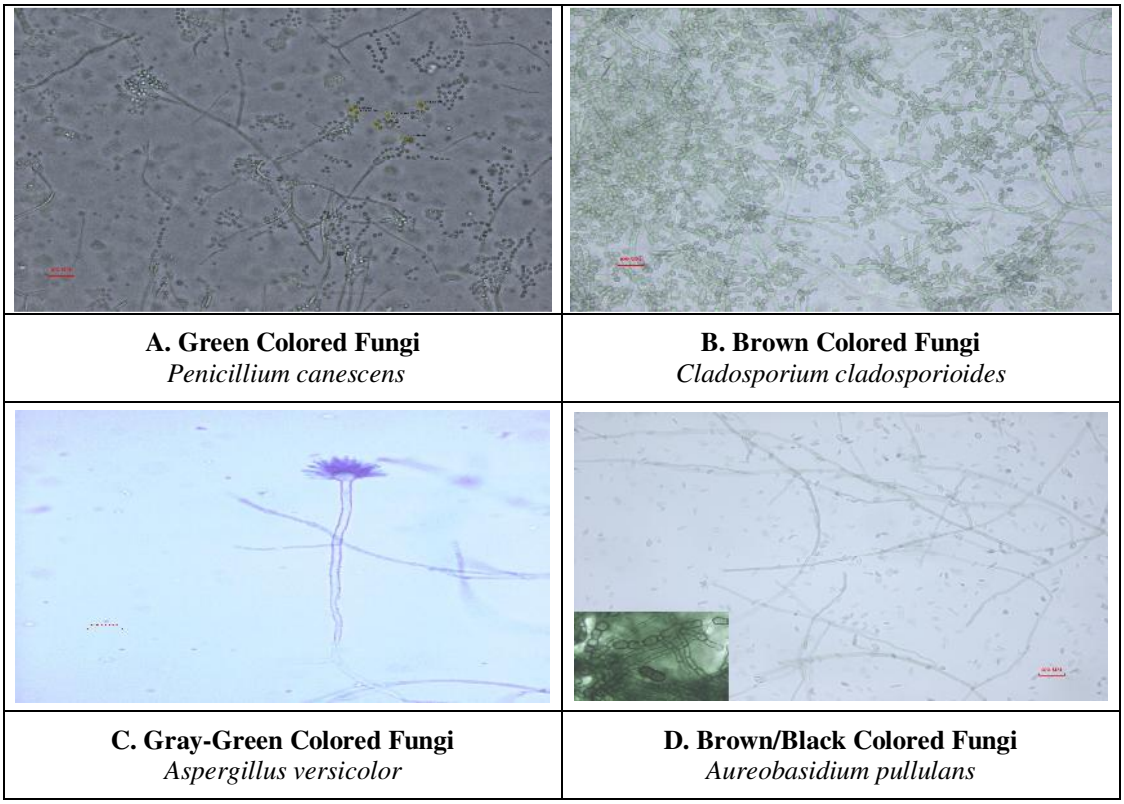
	
A. Spore Forming White Color Bacteria *Bacillus subtilis*	**B. Gram Negative Yellow Rods Bacteria** *Variovorax paradoxus*
	
C. Gram Positive Red Color Bacteria *Flavobacterium ferrugineum*	**D. Gram Positive White Color Bacteria** *Brevibacterium casei*

Figure 4. Fungi isolated from coil (A-D)



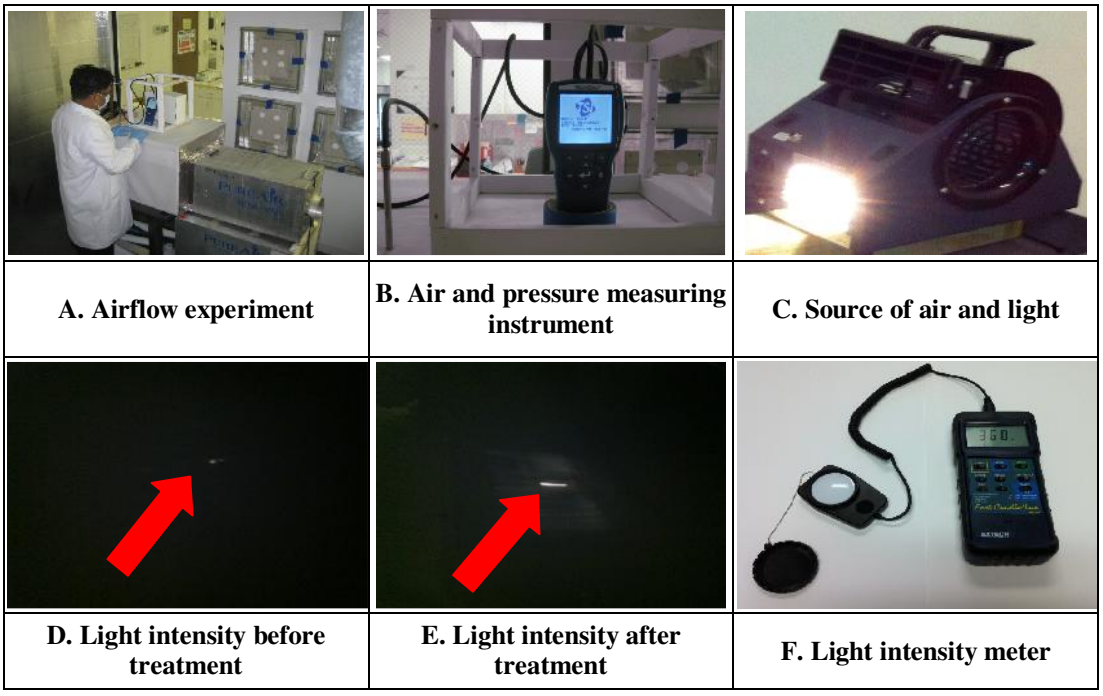
A. Green Colored Fungi
Penicillium canescens

B. Brown Colored Fungi
Cladosporium cladosporioides

C. Gray-Green Colored Fungi
Aspergillus versicolor

D. Brown/Black Colored Fungi
Aureobasidium pullulans

Figure 5. Air velocity, light intensity and pressure test (A-F)



A. Airflow experiment

B. Air and pressure measuring instrument

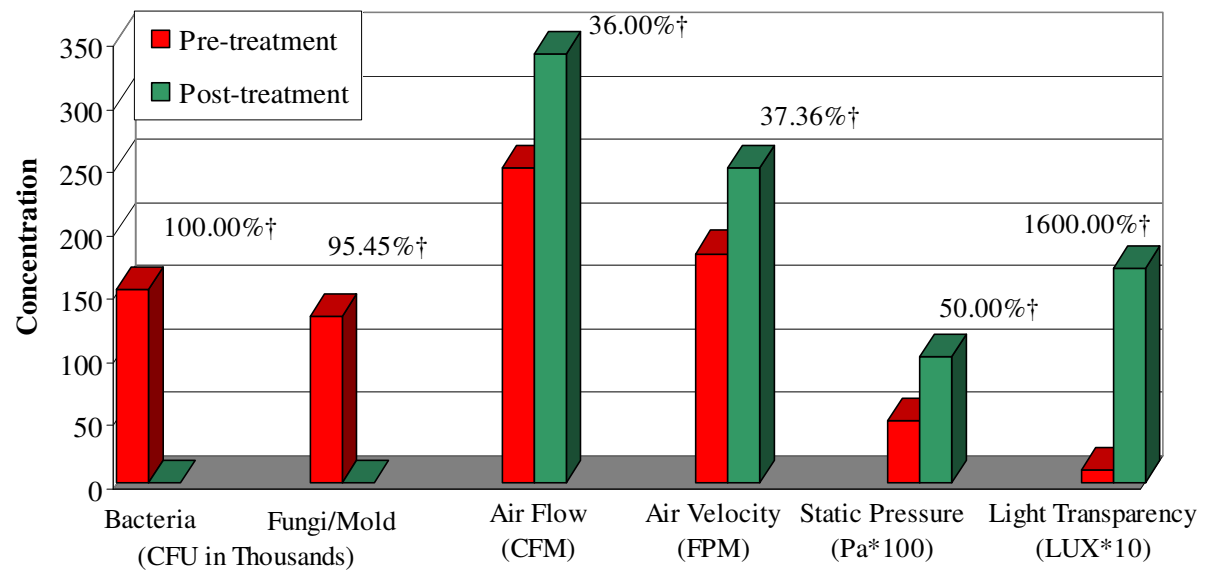
C. Source of air and light

D. Light intensity before treatment

E. Light intensity after treatment

F. Light intensity meter

Figure 6. Steam Treatment Results



Note: CFU = Colony Forming Units; CFM = Cubic Feet per Minute; FPM = Foot per Minute; Pa = Pascal; Lux = Luminous Flux per Unit Area

† Performance change due to steam cleaning is reflected in terms of percentage in the above *Figure 6.*

4. Results and Discussion

A thick deposition of dust and debris was observed on either side of the fin (*Figure 1* B). It has been observed that rusting on the endplates along with blue-green and/or black deposition is prevalent on the copper tubing of end plates (*Figure 1* C). An air circulation comparison from the before and after treatment of the AHU coil was 250 CFM and 340 CFM, respectively. The air velocity test showed 182 FPM through the untreated coil, while the value increased to 250 FPM after the treatment (*Figure 5* A). Light perforation test reveals a very low intensity of light (1 Lux) coming across the untreated side of the coil (*Figure 5* D). Under similar conditions, the intensity of light was observed to be much brighter (17 Lux) passing through the treated coil (*Figure 5* F). The static pressure measurement divulges a decrease from 1.0 Pa to 0.5 Pa when a comparison was made using the same surface area (1.11 sq. ft.) of the coil before and after treatment, respectively (*Table 2*). After the steam treatment, the airflow across the coil increased by 36.00% in comparison to the untreated coil (*Table 2* and *Figure 6*). Air velocity was also improved by 37.36% due to the treatment. The result of the light perforation test demonstrated an increase of 1600% when a comparison is made between the treated coil with respect to the original condition of the coil (*Table 2* and *Figure 6*). Static pressure test ascertained a 50.00% decrease in resistance to airflow which translates into energy savings (*Table 2* and *Figure 6*).

The anti-microbial capability of steam cleaning has been determined by collecting pre- and post treatment samples. A total concentration of bacteria was reduced from 144,000 CFU/ml to BDL that exhibits a 100% (*Table 4; Figure 2* A and B; *Figure 6*) efficacy of this process. Likewise, the effectiveness on fungi has also been

observed. The concentration of fungi went down from 132,000 CFU/ml to 60 CFU/ml, which is a reduction of 99.95% (*Table 4; Figure 2* D and E; Figure *6*). By using serial dilution technique, the bacteria and fungi were isolated on TSA and MEA, respectively, by using standard microbiological culture method. The isolated bacteria were *Bacillus subtilis, B. amyloliquefaciens, Brevibacterium casei, Flavobacterium ferrugineum and Variovorax paradoxus* having concentrations of 51000 CFU/ml, 6000 CFU/ml, 10000 CFU/ml, 48000 CFU/ml and 39000 CFU/ml, respectively, before the treatment (*Table 1*). After the treatment, each of the bacterial organisms was BDL. *Penicillium canescens*, *Cladosporium cladosporioides, Aspergillus versicolor* and *Aureobasidium pullulans* were isolated from the coil and their corresponding concentrations were 82000 CFU/ml, 27000 CFU/ml, 21000 CFU/ml and 2000 CFU/ml before the treatment. After the treatment, only *C. cladosporioides* was reported growing with a concentration of 60 CFU/ml. Positive and negative control samples were collected and analyzed to validate the microbiological findings. *Staphylococcus aureus* and *Rhizopus stolonifer* were used as positive controls for bacteria and fungi, in that order. These samples showed good growth when incubated along with other samples under similar conditions. The water used as the steam was treated as a negative control and no growth was observed upon culture. Field blanks were also collected by not opening the microbiological culture plates (MEA and TSA) during the experiment. These samples had no growth when incubated under similar conditions.

In recent years, indoor environment/air quality has become an issue from a health and hygiene point of view, especially in energy efficient buildings. For optimization of building performance, the ventilation of such buildings depends on HVAC systems most of the time. The coil of the air handler unit is an integral part of an HVAC system. It handles both cooling and heating cycles depending upon the environmental needs and runs the HVAC system efficiently. The area surrounding an HVAC system is typically supposed to be clean without having any nuisance dust. Many times with breaches of building filtration systems, as well as other unchecked access points, dust and debris become exerted inside the building. Inherited particles remain suspended in the ambient indoor environment or settle down on surfaces within the structure depending upon their buoyancy. Once these constituents enter inside an HVAC system, basic requirements are provided for microbial amplification as the system may be rich in moisture and other organics due to deferred or neglected maintenance. With a lack of maintenance over time, growth of microorganisms (bacteria and fungi/mold) becomes imminent due to aforesaid facts. Bacteria, fungi, and actinomyces are reported as primary microbial colonizers (Flannigan and Miller 2001) as they easily adapt in these conditions. Mites, insects, and other plant and animal born materials are reported as secondary invaders. The potential distribution of coil born microbes and other contaminants in indoor environments should be dealt with a high priority. These a-biogenic or biogenic particulates are linked to building health and hygiene (Park et al. 2006; Ross et al. 2000; Sahay et al. 2008; Smedje et al. 1997; Xin Li et al. 2011). Few references are available on the microbiological makeup and concentration of bacteria and fungi which reside on the coil. Fungi such as *Acremonium*, *Aureobasidium*, *Phoma*, *Sporobolomyces, Rhodotorula, Cladosporium, Penicillium, Aspergillus*, yeast, etc. are common in

HVAC systems (Yang 1999). Among bacteria that may colonize in HVAC equipment are *Acinetobacter*, *Arthrobacter*, *Bacillus*, *Blastobacter*, *Cedecea*, *Corynebacterium*, *Flavobacterium*, *Pseudomonas* and *Staphylococcus* (Hugenholz and Fuerst 1992). Our findings reveal *Bacillus* dominated over *Flavobacterium* and *Acidovorax* among bacterial flora. The fungal flora is dominated by *Penicillium canescens* over *Cladosporium cladosporioides*, *Aspergillus versicolor*, and *Aureobasidium pullulans*. These organisms are reported by others as mentioned above. Since there is no established type of bacteria or fungi that colonize air conditioning coils, their isolation and identification greatly depends upon the nature of microbiological media used for isolation and cultivation. Others have also had similar observations (M.G. Schmidt 2012). Besides, the bacterial and fungal flora within the air conditioning coil greatly depends on the maintenance, moisture content, organic dust and debris, geographical location, and other environmental factors (Mike White et al. 2012). Although no environmental and clinical correlation has been established with a set pattern, as the immunity of an individual greatly varies, so do the environmental factors. Commonly, it has been observed that HVAC systems are likely to serve as a primary source of inoculum that is responsible for spreading, as well as colonizing, contaminants throughout the facilities in a typical building hygiene evaluation. The vulnerability of an HVAC coil is potent in cases where unfiltered air circulates. The unfiltered air brings copious amounts of dust and debris which contains both biogenic and a-biogenic entities capable of forming biofilms in and around coils.

During the present evaluation, we noticed a thick layer of dust and debris between the fins (*Figure 1* F). This deposition may have constricted or completely clogged the circulating space between the fins. This act severely affected the efficacy of the air handler coil and cost much more energy to operate the system. We measured the static pressure of an 1.11 sq. ft. area on the AHU coil being 1.0 Pascal without treatment and after cleaning, the pressure dropped down to 0.5 Pascal. It is our observation that it wastes approximately 50.00% more static pressure to produce the same amount of CFM before the treatment was performed; this could be due to a variation in the air flow. High static pressure requires more energy to move the air through coil. Therefore, it is concluded that the coil cleaning process significantly improvers the air flow with less energy consumption. Also, energy savings may be realized from the increased heat transfer from the air to the coil, resulting in more BTU delivered to the space. Other studies also verify coil cleaning saves energy (Ross D. Montgomery and Robert Baker 2006). Good maintenance and operating practices of an HVAC system, including coil cleaning, can significantly improve energy efficiency and IAQ in a building up to 10-15% (Ross D. Montgomery and Robert Baker 2006). The PURE-Steam cleaning process, certified green by the Green Clean Institute, has the capacity to attain greater than 15% energy savings without using harsh chemicals.

It has been also reported that complaints on poor indoor air quality reduced, subsided, or disappeared after bio-contaminant removal from AHU coil/HVAC (Yang 1999). We have noticed that the steam is effective against both bacteria and fungi. This may be significant in reducing indoor air quality complaints, specifically those which arise due to microbial contaminants, such as

bacteria and fungi. It may also help in managing health related issues caused due to these microorganisms in indoor environments.

5. Conclusion

Based on the understandings of AHU coil efficiency and operation, the results (*Table 2*) show that after performing a steam treatment, the AHU coil can operate at a more efficient state and at a lower energy consumption level. From a health and hygiene perspective, cleaning with steam versus tempered water can drastically lower airborne contaminants, such as bacteria and fungi, in order to preserve the health of individuals in the environment where the AHU coil is operating. A more detailed and comprehensive study on the microbiological contaminants in and around AHU coils is recommended for a better understanding of hygiene conditions within the building. The research suggests that steam cleaning will improve the energy efficiency in addition to improving overall indoor environmental quality. Typical steam coil cleaning can provide a return on investment of less than one year.

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