The Effects of Air Purification Technology on Environmental and Clinical Metrics in Two Healthcare Settings

Kathryn C. Worrilow, PhD
Associate Member

Stanislaw P. Stawicki, MD
Alicia R. Urrutia

Susan D. Schlener
Charles N. Kimble

ABSTRACT

Improvements in indoor air quality and overall occupant comfort and health can be achieved by reducing airborne sources of illness and infection. Many facility acquired infections (FAIs) originate from the air. Controlling these airborne pathogens is a priority for building's facilities teams across industries. An advanced air purification technology (AAPT) was designed to inactivate the DNA and RNA of all bacteria, fungi, and viruses, rendering them non-infectious. The technology also comprehensively remediates volatile organic compounds (VOCs). This study investigates the effect of AAPT on environmental and clinical metrics in two healthcare settings.

This study represents a post-hoc synthesis of two independent and institutional review board (IRB) approved projects where AAPT operated in an acute care hospital's medical surgical floor (ACH-MSF) and in a long-term care facility's (LTCF) memory support clinical unit. The AAPT was installed within each facility's heating, ventilation, and air conditioning (HVAC) ductwork. The AAPT unit in the ACH-MSF provided comprehensive remediation of all airborne pathogens and the AAPT unit in the LTCF remediated all airborne pathogens and VOCs. In the ACH-MSF, three zones were retrospectively studied on two floors: control floor with high efficiency particulate air (HEPA) filtration, mixed HEPA and AAPT remediation, and comprehensive AAPT remediation. In the LTCF, two zones were studied on two floors: control floor with HEPA filtration and comprehensive AAPT remediation. Statistical analyses were run on the hospital data to only include surgical patients (non-bariatric) admitted to any zone with a Case Mix Index (CMI) at discharge. CMI was used to adjust for the severity of illness. The LTCF data analyses included all residents in both zones. The control floor was used as the reference point for both installations.

In both facilities, the measured airborne and surface bacterial and airborne fungal levels, and VOC levels decreased as environmental purity increased. The ACH-MSF demonstrated a statistically significant decrease in patient length of stay (39.5%), improved discharge metrics and 23% cost savings. The FAI rate in the LTCF decreased by 39.6% pre- to post-installation. Additionally, clinical staff callouts decreased by 47% in the LTCF.

The AAPT significantly reduced levels of infectious airborne and surface pathogens and VOC levels in both healthcare facilities thereby removing two common vectors of illness. Both of the studied facilities experienced improved clinical and economic metrics, with similar size of the observed changes. The comprehensive removal of airborne pathogens in healthcare settings appears to have a direct positive impact on residents and patients, as wells as indirect positive impact on staff. The current findings, encompassing a post hoc analysis of a large combined sample, support the hypothesis that environmental factors impact wellness and can be applied to indoor environments across many industries.

Kathryn C. Worrilow is the founder and CEO of LifeAire Systems, LLC in Allentown, Pennsylvania, USA. **Stanislaw P. Stawicki** is a Professor of Surgery and the Chair of the Department of Research and Innovation at St. Luke's University Health Network in Bethlehem, Pennsylvania, USA. **Susan D. Schlener** is the Executive Director for Phoebe Ministries Allentown Campus in Allentown, Pennsylvania, USA. **Alicia R. Urrutia** is the Engineering Manager at LifeAire Systems, LLC in Allentown, Pennsylvania, USA. **Charles N. Kimble** is the Vice President of Market Development at LifeAire Systems, LLC in Allentown, Pennsylvania, USA.

INTRODUCTION

Healthcare facilities, including hospitals and LTCFs, are constantly working to remove pathogens responsible for FAIs. Successful infection control protocols and room sterilization methods have been implemented that have been proven to reduce FAI rates (Sharpe and Schmidt 2011). Although surface cleaning and infection control protocols have been the focus, literature indicates that many FAI causing pathogens originate from the air (Kowalski 2007).

The technology employed in the AAPT was designed to comprehensively remediate harmful airborne pathogens in both outside and return air before it enters the protected space (LifeAire Systems 2021). This method of pathogen remediation is different from that of typically used HEPA filtration. HEPA filtration has a history of success within healthcare settings. One study found significantly reduced numbers of airborne Aspergillus organisms in HEPA filtered environments compared to other locations in the same hospital (Sherertz et al. 1987). Another published meta-analysis reported a lower rate of invasive fungal infections among patients in HEPA filtered environments (Eckmanns et al. 2006). HEPA filters function by capturing particulates of a particular size. These captured particulates, including bacteria, viruses, and mold/fungal spores remain in the filter and continue to proliferate. Captured pathogens can dislodge and reenter the airstream to be delivered into the space (Price et al. 2005). Unlike HEPA filtration, the AAPT inactivates harmful pathogens on a single pass, removing any opportunity for the pathogens infect occupants. The AAPT provides protection beyond that of HEPA filtration.

The purpose of the current project was to retrospectively explore the effect of the AAPT on environmental and clinical outcomes utilizing quantitative and qualitative data from two previous large sample studies involving a hospital and LTCF. The environmental and clinical hospital data was previously published (Stawicki et al. 2019 and Stawicki et al. 2020) and the LTCF experience was presented at a peer-reviewed international forum (Kelley et al. 2021).

MATERIALS AND METHODS

Advanced Air Purification Technology

The implementation process for the AAPT is characterized by a unique combination of flexibility and standardization. The AAPT is installed in the facility's HVAC duct work downstream of the AHU containing HEPA filtration. Similar systems were installed in both healthcare settings except the system installed in the LTCF included multiple stages of proprietary VOC remediation media along with pathogen remediation. The hospital installation contained only the pathogen remediation section. VOCs are organic compounds that are highly volatile due to their low vapor pressure at room temperature (Kamal et al. 2016). They are dangerous to individuals with compromised respiratory systems and known to have detrimental effects on pulmonary function, in particular, in elderly populations (Yoon et al. 2010). For this reason, it was critical that the LTCF environment include aggressive VOC remediation.

The pathogen remediation section employs the use of ultraviolet, germicidal irradiation technology. This technology is housed inside a reflective enclosure designed with adequate dwell time to remediate all pathogens in the air stream prior to entering the protected space. This section of the AAPT is genomically and mathematically modeled to provide a single pass kill of all infectious airborne pathogens. This is achieved by destroying the genetic material, DNA and RNA, of all pathogens entering the system, preventing them from infecting the occupants in the protected space. This modeling has been confirmed by testing at the National Homeland Security Research Center in which the AAPT was verified to kill the anthrax spore on a single pass. Based on the kill of the anthrax spore, the AAPT provides a 9-log reduction against all other harmful airborne pathogens (LifeAire Systems 2021).

Hospital Setting

The AAPT was retrofitted within the existing HVAC ductwork of an ACH-MSF and three air filtration zones were studied on two medical surgical floors. The data was collected from December 2017 to December 2018. The three air filtration zones contained the control floor (zone C) that only had AHU HEPA remediation, a section of an adjacent medical surgical floor that contained a mixture of AHU HEPA and AAPT remediated return air (zone B), and the rest of that medical surgical floor with comprehensive AAPT remediation (zone A), as shown in Figure 1.

The two ACH-MSF floors had the exact same physical layout and zone C, the control floor, was located directly beneath the floor containing zones A and B. The floor with zone C was constructed prior to the floor with zones A and B but similar construction practices and materials were employed on both floors. The clinical practices on each floor were similar as well, including staffing and standard operating procedures across the different study zones. Care was taken not to implement any new nursing or patient care initiatives during the study period.

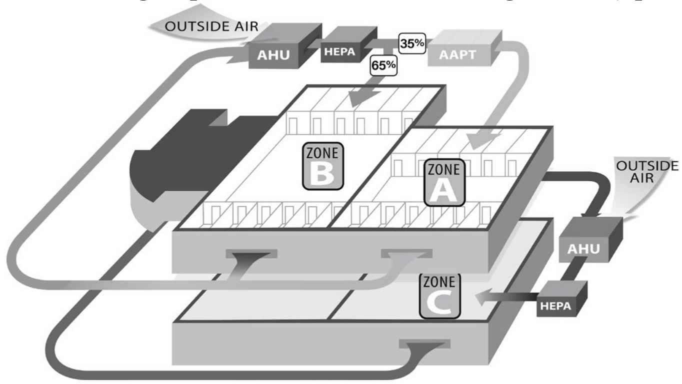

Figure 1. Schematic representing zones A, B, and C and the existing heating ventilation and air conditioning layout for all zones (Stawicki et al. 2020). Figures reproduced under the terms of byncnd4.0 international license.

Environmental Data. The environmental data was studied prospectively and was previously published (Stawicki et al. 2019). In each of the three zones, two patient rooms were selected for testing. These rooms were active and occupied during the comprehensive air testing which included VOC testing and airborne and surface bacterial and fungal testing. Table 1 shows the various locations sampled and the samples taken in each location. All samples were evaluated by independent third-party laboratories. EMSL evaluated the fungal and bacterial testing and SGS Galson evaluated the VOC testing. Airborne bacterial and fungal air samples were taken by pulling 28 liters per minute of air for 5 minutes onto agar plates. The testing laboratory then grew the samples and identified the five most prominent species of bacteria and fungi present. Surface samples were collected by swabbing a 2-inch by 2-inch area for each sample. These swabs were evaluated by the testing laboratory and the 5 most prominent species of bacteria fungi were identified. VOC measurements were taken according to the EPA TO-15 method and samples were collected for 15 minutes. The laboratory identified all VOCs present in the sample using gas chromatography/mass spectrometry.

Table 1. ACH-MSF Environmental Sampling

Location	Surface Samples	Airborne Samples	VOC Testing
Zone A (2 patient rooms)	IV Control Faceplate, Pressure Cuff Bulb, Bedside Table, IV Support Pole, Patient Remote Control	Patient Room	Patient Room
Zone B (2 patient rooms)	IV Control Faceplate, Pressure Cuff Bulb, Bedside Table, IV Support Pole, Patient Remote Control	Patient Room	Patient Room
Zone C (2 patient rooms)	IV Control Faceplate, Pressure Cuff Bulb, Bedside Table, IV Support Pole, Patient Remote Control	Patient Room	Patient Room

Clinical Data. The clinical data was studied retrospectively and was previously published (Stawicki et al. 2020). The IRB of the hospital in which the study was conducted evaluated the study and considered it exempt. The total admissions to the three zones during the one-year study period included 8,255 patients. Patients were excluded if they did not have a CMI in their medical record when they were discharged or if they belonged to the unbalanced medicine or bariatric patient groups. CMI was assigned by the hospital and was used in the statistical analysis of the data to account for comorbidities, diagnoses, and underlying diseases. After these exclusions, the final number of patients studied was 1,002. The statistical analyses used included one-way analysis of variance, chi-squared testing, covariance, nonparametric tests, and logistic regression. Additional information on the statistical methods used can be found in the previously published manuscript (Stawicki et al. 2020). Significance was set at alpha <0.01 with a 99% confidence interval and the study was powered at 95%. All normalized data used zone C, the control floor, as the reference point and utilized a 95% confidence interval. All data, including hospital length of stay (LOS) and hospital charges, was provided by the hospital directly to an independent third-party epidemiologist.

Long Term Care Setting

The AAPT was retrofitted on the roof of a LTCF utilizing the existing HVAC layout. Two different air filtration zones were studied on portions of two different resident floors of the LTCF (Kelley et al. 2021). The floors had identical physical layouts, with the control floor directly below the study floor. The data was collected from October 2019 to January 2020. The two zones studied contained a control floor with HEPA filtration and a study floor with comprehensive AAPT remediation, including VOC remediation and HEPA filtration. The only difference between the floors was the presence of AAPT on the study floor. All packaged terminal air conditioners and unit ventilators remained operational during the study. Figure 2 shows the layout of the study floor and a summary of the quality of the air in each location of the floor. The study was performed in a typical LTCF HVAC layout. Due to the nature of the ductwork in the building and the individual temperature control required for resident rooms, it was impossible to supply comprehensively remediated AAPT air to all spaces in the floor. The system was designed to deliver comprehensive AAPT remediated air to as many spaces as possible (highlighted blue on the diagram) and to have locations that did not receive direct AAPT air (highlighted yellow on the diagram) negative and adjacent to spaces that did receive purified air so the air directly from the AAPT would be drawn into and mix with the air in these locations.

Figure 2. Schematic representing the air purity in the various location of the study floor. Blue represents areas that were directly supplied by the AAPT (54.6%). Teal represents ventilation air that is AAPT protected air mixed with return air from the same space (8.9%). Yellow represents areas with no direct supply of AAPT air to the space and these spaces are negative to one of the "Blue" spaces which pull diluted AAPT protected air into the space (29.9%). Red represents no direct supply of AAPT air to the space and these spaces are negative to one of the "Yellow" spaces and pull even more diluted AAPT air into the space (2.4%). Green represents spaces that have no ventilation at all and have no AAPT protection (4.1%).

Environmental Data. The environmental data was studied prospectively following the same evaluation and sampling methods as the hospital setting described previously with the exception that the VOCs were collected for four hours instead of 15 minutes. Five different locations were selected on each of the floors for environmental sampling. Table 2 shows the various locations sampled and the samples taken in each location.

Table 2. LTCF Environmental Sampling

Location	Surface Samples	Airborne Samples	VOC Testing
Corridor (CORR)	Hallway Railing, Nurses Station	Corridor	Corridor
Resident Room Wing (RRW)	TV Remote, Bathroom Fixture, Bed Table	Room, Bathroom	Room
Resident Room Annex (RRA)	TV Remote, Bathroom Fixture, Bed Table	Room, Bathroom	Room
Community Area (CA)	Chair Handles/Table, TV Remote	Room	Room
Dining Area (DA)	Food Cart Handle, Chair Handles/Table	Room	Room

Clinical Data. The clinical data was studied prospectively between the control and study floors and retrospectively between pre- and post-installation. The study took place between October 2019 and January 2020. There were 14 staff and 38 residents per floor and none were excluded. All statistical analyses were performed using SPS 24.0 (IBM, ARMONK, NY), and the study was initially powered at 90%. Data were indexed using the control floor as the reference point. All data were provided by the LTCF provider and analyzed by an independent third-party epidemiologist. None of the data was normalized as the differences in demographics were not statistically significant.

RESULTS

Hospital Setting

The previously published environmental data, summarized in Table 3, shows that the airborne bacterial, fungal and VOC levels decreased from zone C to zone B to zone A (Stawicki et al. 2019). This decrease in the airborne contaminants between zones coincides with the increasing air purity between zones, with zone A having the purest air and zone C the least. Similarly, there was a decrease in measured pathogens present on common patient and clinical touch surfaces across the three study zones.

Table 3. ACH-MSF Key Environmental Metrics Associated with Environmental Purity

Previously published and reproduced with permission (Stawicki et al. 2019 and Stawicki et al. 2020).

Parameter	Zone A	Zone B	Zone C
Viable fungi by air (CFU/m^3)	0	7	144
Viable fungi by swab (CFU/in^2)	0	50	25
Viable bacteria by air (CFU/m^3)	0	35	141
Viable fungi by swab (CFU/in^2)	25	0	425
Volatile organic compounds (ppb)	1,300	2,350	3,100

The main study results for the ACH-MSF data are shown in Figure 3 (Stawicki et al. 2020). This graph overlays the environmental data from Table 2 with the clinical outcomes, which were normalized and compare the study zones (zone A and B) to the control floor (zone C). The clinical outcomes that were studied include hospital LOS and hospital charges. These two metrics were chosen because they are of great importance to hospital administrators who are always striving to minimize LOS and hospital charges while maintaining a high standard of care for their patients (Alexander et al. 2007). As seen in Figure 3, these two critical metrics decreased with increased environmental purity. There was a statistically significant decrease in LOS of 39.5% and the hospital realized cost savings of 23% over the course of the study in zone A compared to zone C.

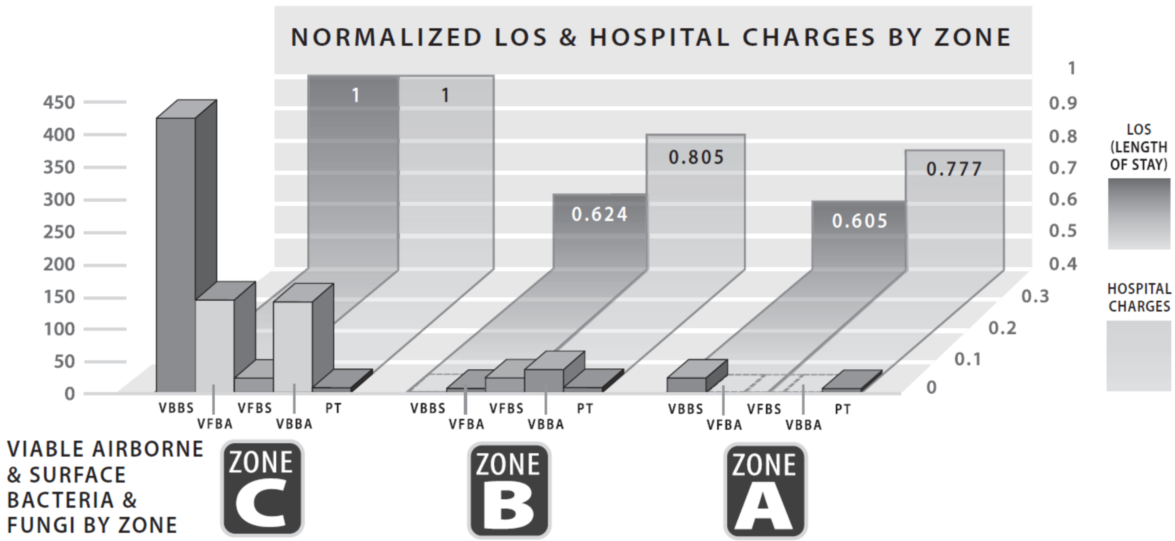

Figure 3 The clinical and economic outcomes mirrored the level of environmental purity from zone C to zone B to zone A. PT, particulates; VBBA, viable bacteria by air; VBBS, viable bacteria by swab; VFBA, viable fungi by air; VFBS, viable fungi by swab (Stawicki et al. 2020). Figures reproduced under the terms of byncnd4.0 international license.

Long Term Care Setting

The environmental data comparing the study floor pre and post AAPT installation is presented in Figure 4. This data clearly shows that there was a significant reduction in airborne pathogens and VOC levels that coincided with the installation of the AAPT across all sample locations. An 88.43% reduction in airborne biological and fungal pathogens and an 89.88% reduction in VOCs was realized by the LTCF.

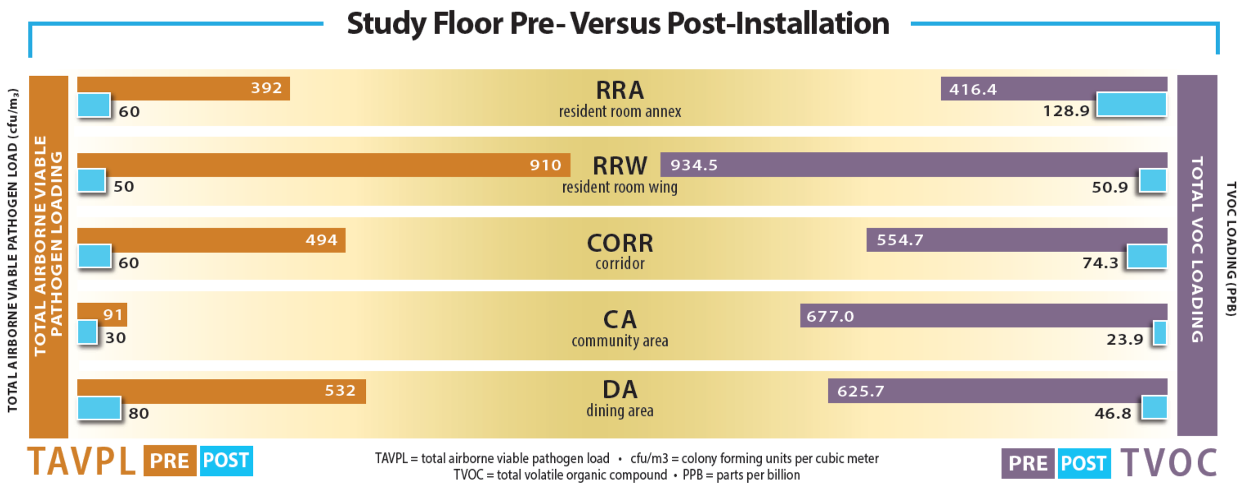

Figure 4. LTCF airborne environmental metrics associated with environmental purity.

Figure 5 summarizes surface pathogen data collected on commonly touched surfaces swabbed in each location comparing the study and control floors. There was a significant reduction in surface bacteria in all locations except for the resident room annex. The bacteria identified in was staphylococcus epidermidis, which is commonly found on skin and was likely transferred to the surface directly from a resident or staff member, rather than from the air.

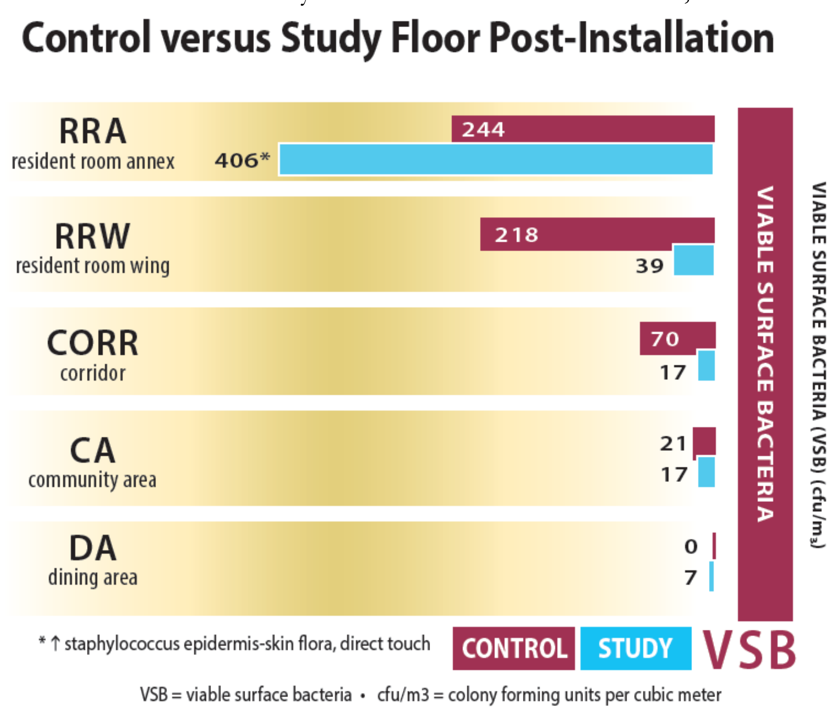

Figure 5. LTCF surface environmental metrics associated with environmental purity.

The clinical outcomes are summarized in Table 4. The overall FAI rates for the LTCF were 17.3% and are defined as the total number of infections divided by the total number of patient days. The FAI rates were analyzed in two different ways. First, prospectively comparing the study floor to the control floor during the study period which resulted in a 39.6% reduction in FAIs. The FAI rates were also analyzed retrospectively by comparing the rates on the study floor pre- and post- installation which resulted in a 54.5% reduction on the study floor. The difference in FAI rates pre-and post- installation for the control floor were not statistically significant, which confirms that there were no outside factors influencing the FAI rate during the study. Staff callouts were also analyzed and there was a 47% reduction in call outs post installation as compared to pre installation.

Table 4. LTCF Clinical Outcomes: Number of FAIs

	Control Floor	Study Floor
Study Period	53	32
Pre-Installation	41	44
Post-Installation	43	20

DISCUSSION

The hospital and LTCF settings described in this study were operating in accordance with industry standards of air filtration and room sterilization practices prior to the installation of the AAPT. Both facilities continued these practices throughout the study in both the control and AAPT areas. This included HEPA filtration and routine cleaning. It was critical that all aspects of the facility's operation remain the same with no new initiatives implemented during the study period other than the installation of the AAPT. Care was also taken to keep the study confidential from healthcare workers, cleaning staff, patients and residents to prevent any subconscious changes in their behavior that may skew the study. In doing this, the results of the study can be applied to understand the impact of the AAPT compared to how these building types were functioning pre-retrofit. The control floor data along with the pre- and post- data provide insight into the typical operation of these facilities.

The results show the presence of both airborne and surface pathogens in the samples taken from the control floors of both healthcare facilities and in the pre-installation testing in the LTCF. These pathogens are a potential source of illness and infection for the occupants and indicate an opportunity for improvements. One area that had comparatively low airborne and surface pathogen levels on the control floor and pre-installation testing was the Community Area in the LTCF. The authors hypothesize that the lower levels of pathogens in this area compared to the others tested, particularly the resident rooms, was because this space was larger and less densely occupied.

The installation of the AAPT in both ACH-MSF and LTCF significantly reduced the levels of airborne pathogens. The removal of these harmful pathogens from the air also resulted in significant reductions in surface pathogens as airborne pathogens can be deposited on surfaces and ultimately infect individuals who touch these surfaces (Beggs 2003). The reduction in these two common vectors of illness is critical in creating a safe environment for all individuals present in these spaces including but not limited to patients, senior residents, staff and visitors.

Along with the environmental benefits realized by the AAPT, clinical and economic metrics were also improved (Kelley et al. 2021 and Stawicki et al. 2020). The significant reduction in LOS and hospital costs experienced by the ACH-MSF provides a compelling argument for the installation of the AAPT beyond the environmental benefits. Hospitals are constantly striving to reduce costs while maintaining the highest standard of care available (Alexander et al. 2007). In this study, 87.8% of patients in zone A were discharged to home compared to 63.7% in the control zone (zone C). The improved discharge metrics and reduced LOS indicate that there was no lapse in standard of care provided in the zones that experienced cost savings (Stawicki et al. 2020). In fact, the patients in these zones experienced better outcomes than those in the control zone. Similarly, residents on the study floor in the LTCF experienced statistically significant reductions in FAIs. The reduction in FAIs is particularly important in LTCF because the ageing population in these facilities are particularly susceptible to infections and illness because of underlying conditions, compromised immune systems and frailty (Stuart, Lim, and Kong 2014). Reducing FAIs has a direct and positive impact on resident wellness and quality of life, preferred provider ratings, increased referrals, citation reductions and reduced admissions of residents to hospitals for FAIs.

CONCLUSION

Indoor air quality is known to be of great importance to providing safe and healthy environments across all facilities, but in particular, in healthcare and senior living environments (Lindvall, Maroni and Seifert 1995). Others have previously shown that there is a link between ventilation and airflow within buildings and the spread of harmful pathogens and diseases (Li et al. 2007). Air quality management systems are needed, especially in healthcare facilities, to protect patients, residents, staff, and visitors (Leung and Chan 2006). The AAPT offers an effective solution to significantly reduce the presence of harmful airborne pathogens, with an associated improvement in clinical outcomes at both types of healthcare settings examined in the current study.

The findings of the current study support the hypothesis that environmental factors impact wellness and can be applied to indoor environments across many industries. Healthcare facilities are not alone in requiring high levels of indoor air quality for their occupants. The implementation of the AAPT could extend observed environmental health benefits to individuals and settings across other industries. Consequently, further research is warranted in this important and largely unexplored area.

REFERENCES

Alexander, Jeffrey A., Larry R. Hearld, H. Joanna Jiang, and Irene Fraser. "Increasing the Relevance of Research to Health Care Managers: Hospital CEO Imperatives for Improving Quality and Lowering Costs." Health Care Management Review 32, no. 2 (2007): 150–59. https://doi.org/10.1097/01.hmr.0000267792.09686.e3.

Beggs, C. B. "The Airborne Transmission of Infection in Hospital Buildings: Fact or Fiction?" Indoor and Built Environment 12, no. 1-2 (November 4, 2003): 9–18. https://doi.org/10.1177/1420326x03012001002.

Eckmanns, Tim, Henning Ruden, and Petra Gastmier. "The Influence of High-Efficiency Particulate Air Filtration on Mortality and Fungal Infection among Highly Immunosuppressed Patients: A systematic Review." The Journal of Infectious Diseases 193 (April 2006): 1408-18.

Kamal, Muhammad Shahzad, Shaikh A. Razzak, and Mohammad M. Hossain. "Catalytic Oxidation of Volatile Organic Compounds (Vocs) – A Review." Atmospheric Environment 140 (May 18, 2016): 117–34. https://doi.org/10.1016/j.atmosenv.2016.05.031.

Kelley, K. C., S. D. Schlener, L. Levicoff, and S. P. Stawicki. Economic Effects of Air Purification Technology on Healthcare-Acquired Infection Costs: A Study of Simulated Implementation across Low-and-Middle-Income Regions of the Globe. International Journal of Academic Medicine 2021;7:285-286.

Kowalski, Wladyslaw J. "Hospital-Acquired Infections." HPAC Engineering, January 2007. https://www.researchgate.net/profile/Wladyslaw-Kowalski/publication/284450012_Air-Treatment_Systems_for_Controlling_Hospital-Acquired_Infections/links/5653701f08aefe619b194c0e/Air-Treatment-Systems-for-Controlling-Hospital-Acquired-Infections.pdf.

Leung, Michael, and Alan H.S. Chan. "Control and Management of Hospital Indoor Air Quality." Med Sci Monit 12, no. 3 (March 1, 2006): SR17–23.

Li, Y., G. M. Leung, J. W. Tang, X. Yang, C. Y. Chao, J. Z. Lin, J. W. Lu, et al. "Role of Ventilation in Airborne Transmission of Infectious Agents in the Built Environment? A Multidisciplinary Systematic Review." Indoor Air 17, no. 1 (2007): 2–18. https://doi.org/10.1111/j.1600-0668.2006.00445.x.

LifeAire Systems, September 21, 2021. https://lifeaire.com/.

Lindvall, Thomas, Marco Maroni, and Bernd Seifert. Indoor Air Quality: A Comprehensive Reference Book. 3. Vol. 3. Amsterdam: Elsevier, 1995.

Price, Daniel L., Robert B. Simmons, Sidney A. Jr, and Donald G. Ahearn. "Mold Colonization during Use of Preservative-Treated and Untreated Air Filters, Including HEPA Filters from Hospitals and Commercial Locations over an 8-Year Period (1996–2003)." Journal of Industrial Microbiology & Biotechnology 32, no. 7 (July 1, 2005): 319–21. https://doi.org/10.1007/s10295-005-0226-1.

Sharpe, Peter A., and Michael G. Schmidt. "Control and Mitigation of Healthcare-Acquired Infections: Designing Clinical Trials to Evaluate New Materials and Technologies." HERD: Health Environments Research & Design Journal 5, no. 1 (2011): 94–115. https://doi.org/10.1177/193758671100500109.

Sherertz, Robert J., Anusha Belani, Barnett S. Kramer, Gerald J. Elfenbein, Roy S. Sullivan, Ronald G. Thomas, and Gergory P. Samsa. "Impact of Air Filtration on Nosocomial Aspergillus Infections: Unique Risk of Bone Marrow Transplant Recipients." The American Journal of Meidicine 83 (October 1987): 709-718.

Stawicki, Stanislaw P., Chad Brisendine, Lee Levicoff, Frank Ford, Beverly Snyder, Sherrine Eid, and Kathryn C. Worrilow. "Comprehensive and Live Air Purification as a Key Environmental, Clinical, and Patient Safety Factor: A Prospective Evaluation." Vignettes in Patient Safety 4 (2019). https://doi.org/10.5772/intechopen.84530.

Stawicki, Stanislaw P., Samantha Wolfe, Chad Brisendine, Sherrine Eid, Matthew Zangari, Frank Ford, Beverly Snyder, William Moyer, Lee Levicoff, and William R. Burfeind. "The Impact of Comprehensive Air Purification on Patient Duration of Stay, Discharge Outcomes, and Health Care Economics: A Retrospective Cohort Study." Surgery 168, no. 5 (November 2020): 968–74. https://doi.org/10.1016/j.surg.2020.07.021.

Stuart, Rhonda, Ching Jou Lim, and David Kong. "Reducing Inappropriate Antibiotic Prescribing in the Residential Care Setting: Current Perspectives." Clinical Interventions in Aging, 2014, 165. https://doi.org/10.2147/cia.s46058.

Yoon, Ho-Il, Yun-Chul Hong, Soo-Hun Cho, Ho Kim, Yoon Hee Kim, Jong Ryeul Sohn, Mikyung Kwon, Seok-Hwan Park, Myoung-Hee Cho, and Hae-Kwan Cheong. "Exposure to Volatile Organic Compounds and Loss of Pulmonary Function in the Elderly." European Respiratory Journal 36, no. 6 (March 29, 2010): 1270–76. https://doi.org/10.1183/09031936.00153509.