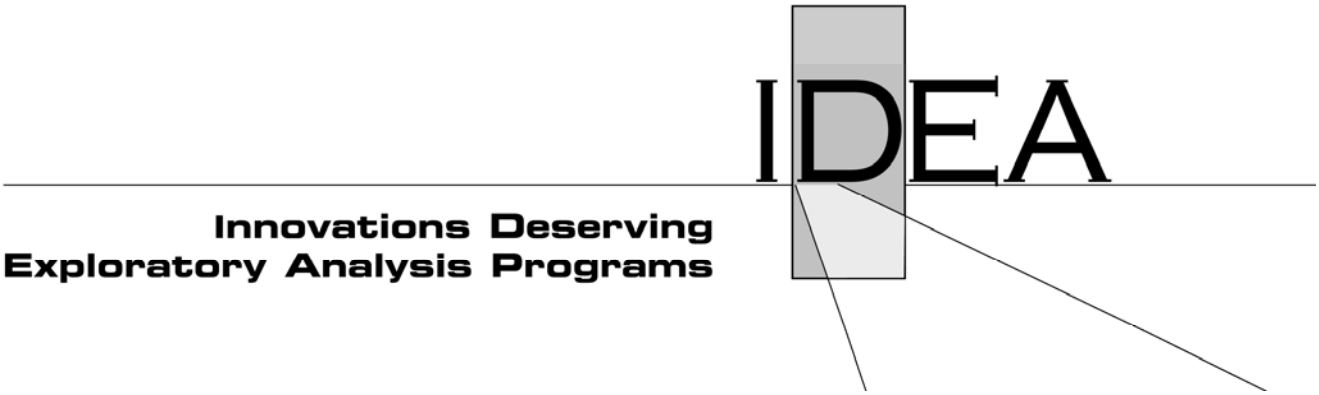

Transit IDEA Program

Ultraviolet Germicidal Irradiation for Transit Buses

Final Report for
Transit IDEA Project 53

Prepared by:
Lee Huston
JKA Company
Venice, Florida

July 2009

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

Innovations Deserving Exploratory Analysis (IDEA) Programs Managed by the Transportation Research Board

This Transit IDEA project was funded by the Transit IDEA Program, which fosters development and testing of innovative concepts and methods for advancing transit practice. The Transit IDEA Program is funded by the Federal Transit Administration (FTA) as part of the Transit Cooperative Research Program (TCRP), a cooperative effort of the FTA, the Transportation Research Board (TRB) and the Transit Development Corporation, a nonprofit educational and research organization of the American Public Transportation Association (APTA).

The Transit IDEA Program is one of four IDEA programs managed by TRB. The other IDEA programs are listed below.

- NCHRP Highway IDEA Program, which focuses on advances in the design, construction, safety, and maintenance of highway systems, is part of the National Cooperative Highway Research Program.
- High-Speed Rail IDEA Program, which focuses on innovative methods and technology in support of the Federal Railroad Administration's (FRA) next-generation high-speed rail technology development program.
- Safety IDEA Program, which focuses on innovative approaches for improving railroad safety and intercity bus and truck safety. The Safety IDEA program is funded by the Federal Motor Carrier Safety Administration and the FRA.

Management of the four IDEA programs is coordinated to promote the development and testing of innovative concepts, methods, and technologies.

For information on the IDEA programs, look on the Internet at www.trb.org/idea or contact the IDEA programs office by telephone at (202) 334-2441 or by fax at (202) 334-3471.

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(See Attachment #22: Air Flow Summary)
(See Attachment #23: Air Conditioning Intake Door)
(See Attachment #24: Temperature Data)

Acknowledgements

The participation in this Transit IDEA project and the guidance of the following professional staff of Houston Metropolitan Transit Authority Houston Metro and other transit agencies has been appreciated.

Transit Agencies:

- Houston Metropolitan Transit Authority, Andrew Skabowski, Senior Director Bus Maintenance
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- Houston Metropolitan Transit Authority, Donna La Force, Kashmir Superintendent Operations
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Others

- Dr. Robert Scherer, President, Steril Aire
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- Ron Anderson, Director Maintenance, Ft. Worth Transit
- Tom Jury, Director Maintenance, Tempe Transit
- Harvey Berlin, Senior Program Officer, Transit IDEA Program, Transportation Research Board

Expert Review Panel

This Transit IDEA project has been guided and reviewed by the expert review panel for this project. The purpose of this panel is to provide guidance to the Principal Investigator for the IDEA product development and transfer into practical applications. The panel members' comments and recommendations have been incorporated into the project reports and plans for implementing the results of the Transit IDEA project.

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Executive Summary

The purpose of this Transit IDEA project was to incorporate Ultraviolet Germicidal Irradiation (UVGI) into transit bus air conditioning systems, carry out tests and evaluate the results, with two objectives. First, to evaluate improvements of air quality and reduction of harmful pathogens within the bus, which effect passengers, drivers, and employees. Second, to identify and quantify maintenance costs saving associated with the air conditioning systems.

The project included testing and evaluation of UVGI Systems on fourteen (14) transit buses, in cooperation with the Houston Metropolitan Transit Authority (Houston Metro), who provided their buses for these tests. The selection of buses for testing included five (5) older buses that have had approximately 12 years service, four (4) midlife buses with approximately 8 years service, and five (5) new buses less than one year old. All UVGI System were installed without prior cleaning of the air conditioning system to test in a "worst case scenario".

Testing was done to evaluate reductions and exposure of passengers, drivers, and employees to harmful viruses, bacteria, mold, and fungi. Virus and bioterror organism surrogate testing was conducted by Biological Consulting of North Florida, Inc. in their laboratory using a simulated bus UVGI System. Other tests that evaluated odor elimination, coil cleaning effectiveness, airflow improvement, temperature improvements, fuel savings, and reduced maintenance costs were conducted on site at Houston Metro. Test period was for a six (6) month period, starting July 12, 2007, ending December 12, 2007. This time frame represents the hottest weather and the cooler operating conditions for Houston Metro's bus fleet.

The following tasks were accomplished in this project.

Task 1: Selection of the fourteen buses for testing was made based on age and type of air conditioning system by Houston Metro. Series 3200 Buses represented the oldest buses, averaging approximately 12 years old, with Carrier Air Conditioning Systems. Series 4000 Buses were midlife buses, averaging approximately 8 years old, with Thermo King Air Conditioning Systems. Series 3500 Buses were the newest buses, less than 1 year old, also with Thermo King Air Conditioning Systems.

Task 2: Installation of the fourteen (14) UVGI Systems was completed and reviewed by Houston Metro staff on July 12, 2007.

Tasks 3: Installation Kits and Equipment for installation were supplied by JKA Company. Upon completion of each installation, baseline readings were recorded for each bus in the areas to be tested. Mold, bacteria, fungi, and air samples were sent to Biological Consulting Services of North Florida, Inc. for evaluation and analysis.

Task 4: Test Program:

1. Mold, Bacteria, Fungi By Biological Consulting
2. Virus and Bioterror Agent Testing By Biological Consulting
3. Visual Effectiveness Evaporator Cleaning
4. Cost Savings
5. Air Flow Tests
6. Temperature Tests
7. Odor Testing

Task 5: Maintenance Manual and Installation Instructions: The Maintenance Manual and Installation Instructions was completed and delivered to Houston Metro September 30, 2007.

Task 6: Installation Optimization: With the help of Houston Metro the best installation procedure was developed for each model of air conditioning system and included in the Maintenance Manual and Installation Instructions completed on September 30, 2007.

Task 7: Evaluation: The test data was evaluated for performance and cost effectiveness of UVGI Systems on transit buses.

Mold and fungi testing by Biological Consulting Services showed a 95% to 99% reduction with the UVGI System during the six-month test period. Testing showed a 99% reduction in common viruses. The Human Virus models MS-2 and PRD-1 showed a 99.9% reduction when passed over the UVGI System. Bioterror virus agents showed a 99% reduction. Testing of harmful bacteria on the bus showed a reduction of 99% when passed over the UVGI System. Harmful bacteria like Legionella Pneumophila and Pseudomonas Aeruginosea showed a 99.9% reduction when passed over the UVGI System. Visual Effectiveness Evaporator Cleaning was very evident in the testing. Use of the UVGI System and the newly designed Reusable Electrostatic Air Filter to improve particle size capture to 99% for 5 microns and larger, and 70% for .03 microns, without reducing the air flow to the evaporator, resulted in a major improvement to reduce evaporator cleaning time.

Airflows increased on the Series 3200 buses (averaging approximately 12 years old) by 31%, Series 4000 buses (averaging approximately 8 years old) by 24%, and Series 3500 buses (less than 1 year old) by 23% with the UVGI System. Increases in air flow contribute to better cooling and lower maintenance costs associated with the bus air conditioning system.

Temperature testing efficiency percentage on the Series 3200 buses improved by 19.2%, Series 4000 by 9.4% and Series 3500 buses by 19.4% with the UVGI System.

Odor testing done by Houston Metro personnel resulted in elimination of the odors in the bus equipped with the UVGI System.

The UVGI System in combination with the Reusable Electrostatic Air Filters allowed for a new labor saving method of cleaning evaporators without chemicals, merely by using a vacuum. Evaporator cleaning was reduced to 10 minutes labor time.

By using the UVGI System and Reusable Electrostatic Air Filters, maintenance cost savings identified are estimated to be approximately $129, 000 per year, per 100 buses. At an estimated cost of $2,100 per UVGI System, that would provide a return on investment in about 18 months.

The health-related benefits for bus passengers, drivers, and employees were very positive. There is also protection against many bioterror agents, as shown in testing conducted by Biological Consulting Services of North Florida, Inc. EPA and the Department of Homeland Security test results for hospitals and commercial buildings were consistent with test results by Biological Consulting Services.

The combination of air quality improvements in transit buses and health-related benefits, plus the cost savings, makes the UVGI System cost effective and beneficial to transit bus agencies and their riders. Based on the successful results of this Transit IDEA project, a number of transit agencies have subsequently purchased these systems and installed them in transit bus air conditioning systems.

IDEA Product

The concept was to develop a system utilizing Ultraviolet Germicidal Irradiation (UVGI) in a bus air conditioning system similar to those that are used in hospitals, schools and commercial buildings. In these applications two major benefits are achieved. First, is improved air quality in the bus by reducing harmful mold, bacteria, fungi, and viruses that affect our daily health. Second is to reduce the maintenance and operating costs associated with air conditioning systems.

Concept and Innovation

Several factors are different in bus air conditioning when compared to a stationary building application. Building air conditioning systems do not encounter the harsh transit environments, vibration, DC voltage applications, limited voltage, large voltage fluctuations, different DC voltages, and air filter requirements.

Development first started with the 24 Volt DC ballast (power supply), prior ballast were 110/220 Volt AC, which would not work in buses. After research and experimentation, ballast was finalized that incorporated all the features necessary for transit buses. 24 Volt DC operation, surge spike protection, voltage cut out for battery protection, end of lamp life circuits and other features to meet the requirements of transit bus. Next, UV Lamps were developed with special transit filaments for long life 24 Volt DC operations. End caps on the UV Lamps were redesigned to withstand the vibration of a transit bus. Special UV Lamp mounting brackets were developed incorporating vibration dampers for additional protection. After an additional two years of field-testing the electronic and mechanical apparatus was complete and satisfactory for a bus application.

Since this is a new technology for bus air conditioning mechanics, the investigators in this project went to great lengths to inform, explain and train mechanics on this technology. The product was very well received by the air conditioning mechanics. Working on bus air conditioning systems, mechanics endure many cuts and scrapes; with the UVGI System, chances of infections and health hazards for the mechanics are reduced.

Investigation

Task 1: Fourteen buses were selected based on age and type of air conditioning system by Houston Metro. Series 3200 buses represented the oldest and had Carrier Air Conditioning Systems. These Carrier Air Conditioning Systems were approximately 12 years old. These units have much closer fin spacing on the evaporator coil and were very difficult to keep clean because of clogging of dirt and debris and one of the reasons for using in the testing. Series 4000 buses were the midlife buses with Thermo King Air Conditioning Systems. These Thermo King Air Conditioning Systems were approximately eight (8) years old. Thermo King Bus Air Conditioning Systems accounts for about 90% of the bus market. Their wide spread use in the transit industry was part of the decision to select these buses. Series 3500 buses were the newest buses less than one year old with Thermo King Air Conditioning Systems. The buses were selected to represent the latest model Thermo King Air Conditioning System so a comparison could be made of the UVGI Systems effects on older buses, midlife and the newest buses and air conditioning systems.

Task 2: Installation of the fourteen (14) UVGI Systems was completed and reviewed by Houston Metro Staff on July 12, 2007. The UVGI System was designed to be installed in the plenum chamber of the air conditioning system for optimal efficiency. Here in the plenum chamber germ-laden air is exposed to the maximum irradiation by the UV Lamps providing excellent destruction of the harmful pathogens. From a maintenance standpoint, placing the units in the plenum chamber provides maximum irradiation on the evaporator coil and drain pan to keeping it free from mold and fungi which reduce the efficiency of the air conditioning system and causes additional maintenance costs.

Series 3200 buses with the Carrier Air Conditioning System required a different UV Lamp Mounting Bracket because of the two-blower motors configuration in the plenum chamber of the evaporator. The Ballast Mounting Brackets were designed to fit either the Carrier or Thermo King Units, they are interchangeable. All other parts of the UVGI System are also interchangeable with Carrier and Thermo King Units.
(See Attachment #1: Installation Carrier UVGI System)

Series 4000 and Series 3500 Thermo King Air Conditioning System use the same UV Lamp mounting bracket on both. The Ballast Mounting Brackets fits both the older and newer models of the Thermo King Units. There were no problems involved in the installation of the fourteen (14) test units.
(See Attachment #2: Installation Thermo King UVGI System)

During the six (6) month test period there were no failures of any mounting brackets or hardware used in the installation. Two (2) UV Lamps were replaced during the six (6) month test program. One UV Lamp had a failure of a filament and the second had a broken wire that connected to the second filament. All UV Lamps come with a one-year warranty for manufacturing defects.

Upon completion of each installations baseline reading were recorded for each bus in the areas to be tested. Mold, bacteria, fungi, samples, and air samples were sent to Biological Consulting for evaluation and analysis.

Tasks 3: Installation Kits and Equipment for installation were supplied by JKA Company. Installation Kits consisted of complete bill of material list for each bus and components per the bill of material. The equipment needed for installation of the UVGI System is very simple, 3/8 drill motor, ¼ drill, ¾ drill, 2-7/16- box wrenches, 5/8-box wrench, utility knife, and screwdriver. An air conditioning mechanic can install the UVGI System in approximately 1½ hours.

Task 4: Mold, fungi, and bacteria tests were designed to show the effectiveness of the UVGI System to eliminate mold and fungi from the air conditioning systems evaporator. This is important because the evaporator is where the air-cooling process is accomplished. Two major things happen when there is mold, fungi, and bacteria on the evaporator coil. First, it causes many poor air quality and health problems for the passengers, drivers, and employees. Second the efficiency of the evaporator to cool the air is severely impacted causing additional maintenance, premature component failure.

Mold and Fungi Testing involved monthly testing of each bus. Mold and Fungi testing was done with a Petri Dish designed to show the type of mold or fungi and the colonies both surface and air. Petri Dish samples were taken at the evaporator in the plenum chamber of the air conditioning system on each bus every month. Air samples were taken inside eight of the buses. In a few cases buses were out of service for maintenance or repairs at those times tests could not be taken and were noted. Bacteria sample were taken every other month or three times during the six-month test period at the evaporator in the plenum chamber of the air conditioning system. Mold, fungi, and bacteria samples were taken on July 11, 2007 prior to the installation of the UVGI System and used as a baseline for the testing. Air samples were also taken on July 11, 2007 inside eight buses for a baseline.

Biological Consulting of North Florida was selected to evaluate the mold, fungi, and bacteria samples taken during the six-month test period. Biological Consulting also engaged Dr. James W. Kimbrough, Mycologist, Plant Pathology Department, and University of Florida for Fungal Population of Contact Plates and Air Samples. The baseline tests of the Petri Dishes by Dr. Kimbrough identified twenty-one (21) separate mold and fungi types found on the fourteen (14) test buses. The colonies (the amount of mold, fungi) ranged from one colony of Geotrichum Candidum on the newest Bus 3575 to fifty-two (52) colonies on Bus 4006 which is approximately 8 years old, consisting of five (5) colonies of Acremonium Charticola, forty-two (42) colonies of Cladosporium Cladosporoides and five (5) colonies of Sporotraichum Aureum.

None of the mold and fungi isolated in this project are individually primary human pathogens, but when several types are found they become a health hazard. Many of the mold and fungi that you find in the air can serve as **allergens** for people who must deal with allergies. Others can become **opportunistic pathogens** in people with a challenged immune system (AIDs patients, certain medications, etc) or if they experience persistent inflamed tissues on which spores may germinate and encroach. Testing showed a 95% to 99% reduction in mold and fungi. Any reduction in the **opportunistic pathogens** would be very beneficial to passengers, drivers, and employees. Bacteria testing showed a 99% reduction on the evaporator surface. Some of the major diseases caused by SPORE FORM and VEGETATIVE BACTERIA: Pseudomonas Aeruginosa, TB, Pneumonia, Legionella, Methicillin-Resistant Staphylocous, Vancomycin-Resistant Enterococcus, Typhoid Fever, Plague, Typhus Fever, Q Fever, Escherichia Coli, Cholera, Brucellosis, Meliodosis and Salmonella.

Virus and Bioterror Agent Testing were conducted by Biological Consulting Services of North Florida in their laboratory at Gainesville, Florida. The tests were designed to show the effects of the UVGI System on Viruses and Potential Bioterror Agents. A UVGI System for transit buses was provided to Biological Consulting Services for the testing. The unit was tested for efficiency against two surrogates that represent many harmful human viruses. Human Virus models used were MS-2 and PRD-1; these surrogates have been used extensively in the literature and in industrial applications as models that represent harmful human viruses for testing. Some of the major diseases caused by viruses: Smallpox, Ebola Virus, Marburg Virus, Pneumonia, Bird Flu, General Influenza, Common Cold, SARS, Asian Flu and Hong Kong Flu. The Human Virus models MS-2 and PRD-1 showed a 99% reduction when passed over the UVGI System.
(See Attachment #3: Biological Consulting Evaluation of UVGI System installed on Houston Metro Buses for Coil Surface Microbial Contamination and Air Quality)
(See Attachment #4: Fungal Population of Contact Plates and Air Samples by, Dr James W. Kimbrough, Mycologist, and Plant Pathology Department, University of Florida)
(See Attachment #5: Biological Consulting Testing UVGI System for Viruses & Bacteria)

EPA Office of Research and Development, National Homeland Security Research Center conducted similar testing on Biological Inactivation Efficiency by HVAC In-Duct Ultraviolet Light Systems June 2006. The following is the Executive Summary from that report. The U.S. Environmental Protection Agency's (EPA's) National Homeland Security Research Center (NHSRC) Technology Testing and Evaluation Program (TTEP) is helping to protect human health and the environment from adverse impacts resulting from acts of terror by carrying out performance tests on homeland security technologies. Under TTEP, RTI recently evaluated the performance of the Steril-Aire Model SE 1 VO. The objective of testing the device was to evaluate its bioaerosol inactivation efficiency as a heating, ventilation, and air-conditioning (HVAC) in-duct ultraviolet light system. The product was tested using a test plan approved by EPA, *Test/QA Plan for Biological Inactivation Efficiency by HVAC In-Duct Ultraviolet Light Air Cleaners*. (1) The tests were conducted using three organisms, two bacteria (*Bacillus atrophaeus* and *Serratia marcescens)* and one bacterial virus (MS2). These organisms were selected because their sizes, shapes, and susceptibility to UV inactivation make them reasonable surrogates for biological warfare agents (BWAs). Generally, vegetative bacteria are readily killed and bacterial spores are more difficult. To model use in an HVAC system, RTI used a test duct designed for testing filtration and inactivation efficiencies of aerosol, bioaerosol, and chemical challenges.

The bioaerosol inactivation efficiencies calculated for the three organisms were 96% for *B. atrophaeus*, 99.96% for *S. marcescens,* and 99% for MS2. The irradiance was measured as 6800 W/cm2 at 161 cm (63.4 in.) upstream from the closest plane of lamps with airflow of 0.93 m/sec (1970 cfm). The system had six lamps that were burned in prior to measurements.
(See Attachment #6: Biological Inactivation Efficiency by HVAC In-Dust Ultraviolet Light System)

Visual Effectiveness of Evaporator Cleaning by the UVGI System: The Visual Effectiveness of Evaporator Cleaning was documented with pictures. Lee Huston of JKA Company and Ben Behimehr of Houston Metro inspected each bus monthly according to the procedure. The visual inspection was conducted on both the "Exhaust Side of Evaporator" (Side inside Plenum Chamber the Bus) and the "Intake Side of Evaporator" (Side inside the Bus with air filter) and documented each month in pictures.

NOTE 1: None of the bus evaporators were cleaned prior to installation of the UVGI System in order to demonstrate the cleaning effectiveness in a **worst-case** scenario.

NOTE 2: The air filters currently used on the Series 3200, 4000, 3500 Buses were the most economical filters available and do not provide for the best filtration for this application. Economical air filters are not constructed for the heavy airborne dirt and debris seen on transit vehicles. The air filters were changed on a regular basis PM schedule but were one of the major causes of dirt and debris on the evaporator. A newly designed **Reusable Electrostatic Air Filter** designed for transit buses was installed in conjunction with the UVGI System. The filter is reusable, cleaned by washing with high-pressure water, 5 year prorated warranty. It is designed to increase the capture of dirt and debris to an efficiency of 99% to 5 microns and arrestance to .3 microns at 70%, without reducing the airflow to the evaporator for transit buses. The economical air filters now being used by most transit properties are purchased because of cost and not efficiency, yet use of cheap filters causes more costs than saved. The Reusable Electrostatic Air Filter cost of $89.50 each and represent a yearly cost of $17.50, current air filters used are approximately $105.00 yearly. The use of the new filter kept the intake side of the evaporator clean and free from dirt and debris. The filter also kept dirt and debris from flowing into the plenum chamber, keeping it cleaner. The UVGI System and the new air filter changes the way of cleaning bus evaporator by eliminating any need for washing with chemicals or water. Merely vacuum the intake side of the evaporator. The UVGI System and Reusable Electrostatic Air Filter reduced the evaporator cleaning time from 45 to 60 minutes to ten (10) minutes. Five (5) minutes to clean air filter and five (5) minutes to vacuum the intake side of the evaporator.
(See Attachment #7: Reusable Electrostatic Air Filter)
(See Attachment #8: Vacuum Cleaning)

NOTE 3: The Series 3200 buses are equipped with Carrier Air Conditioning. This series of buses had the original evaporator intake doors modified to reduce noise. It should also be noted that the Carrier A/C evaporator cooling fins had a much closer spacing than the Thermo King A/C. The closer evaporator fin spacing provides more cooling surface, but can also clog easier and harder to keep clean.

Visual Inspection of the Series 3200 Exhaust (Plenum Chamber) side showed a very similar pattern on all buses prior to installation of the UVGI System, July 10-12, 2007.

a. Visual mold or fungi on evaporators exhaust side.
b. Visual mold or fungi on drain pan.
c. Major dirt accumulation on evaporators exhausts side.
d. Major dirt accumulation drains pans.
e. General condition of plenum was not clean.

(See Attachment #9: Exhaust Side of Evaporator before UVGI Installation)

Visual Inspection of the Series 3200 "Intake Side of Evaporator A/C" showed the same pattern on all buses prior to installation of the UVGI System, July 10-12, 2007.

a. Visual mold on evaporator intake side.
b. Visual dirt and debris on evaporator intake side.
c. General Conditions dirty.

(See Attachment #10: Intake Side of Evaporator Before UVGI Installation)

The Series 3200 buses during the six-month test program showed excellent improvement in the visual effectiveness of coil cleaning with the UVGI System and electrostatic air filter. The cleaning was very evident and could be clearly seen within 60 days and only increased with time. At the end of the six-month test program the exhaust side of the evaporator looked like new. There was no visual mold, fungi on the evaporator or in the drain pan. The dirt accumulation on the evaporator was eliminated. The drain pan dirt was reduced by over 90%. General condition was one that was clean.

(See Attachment #11: Intake Side of Evaporator Six Months After Installation 12.13.07)
(See Attachment #12: Exhaust Side of Evaporator Six Months After Installation 12.13.07)

The Series 4000 buses are equipped with Thermo King Air Conditioning.

Visual Inspection of the 4000 Series exhaust side (Plenum Chambers) showed a similar pattern on all buses prior to installation of the UVGI System, July 10-12, 2007.

a. Visual mold or fungi on evaporators exhaust side.
b. Visual mold or fungi on drain pan.
c. Major dirt accumulation on evaporators exhaust side.
d. Major dirt accumulation drains pans.
e. General condition of plenum was not clean.

(See Attachment #13: Exhaust Side of Evaporator Before UVGI Installation)

Visual Inspection of the 4000 Series "Intake Side of Evaporator A/C" showed the same pattern on all buses prior to installation of the UVGI System, July 10-12, 2007.

a. Visual mold on evaporator intake side.
b. Visual dirt and debris on evaporator intake side.
c. General Conditions, dirty.

(See Attachment #14: Intake Side of Evaporator Before UVGI Installation)

The Series 4000 buses during the six-month test program showed an excellent improvement in the visual effectiveness of coil cleaning on both exhaust side and intake sides of the evaporators. The cleaning was very evident and could be clearly seen within 30 days and only increased with time. At the end of the six-month test program there was a major improvement of the exhaust side of the evaporator. There was no visual mold, fungi on the evaporator or in the drain pan. The dirt accumulation on the evaporator was eliminated. The drain pan dirt was reduced by over 90%. General condition was one that was much cleaner.
(See Attachment #15: Intake Side of Evaporator Six Months After Installation 12.13.07)
(See Attachment #16: Exhaust Side of Evaporator Six Months After Installation 12.13.07)

The Series 3500 buses are equipped with Thermo King Air Conditioning.

Visual Inspection of the 3500 Series Plenum Chambers

a. No visual mold or fungi on evaporators exhaust side.
b. No visual mold or fungi on drain pan.
c. No Major dirt accumulation on evaporators exhaust side.
d. No major dirt accumulation in drains pans.
d. General condition of plenum was clean.
(See Attachment #17: Exhaust Side of Evaporator Before UVGI Installation)

Visual Inspection of the 3500 Series "Intake Side of Evaporator A/C" showed a clean pattern on all buses prior to installation of the UVGI System, July 10-12, 2007.

a. No visual mold on evaporator intake side.
b. No visual dirt and debris on evaporator intake side.
c. Intake area was clean.
(See Attachment #18: Exhaust Side of Evaporator Before UVGI Installation)

The 3500 Series buses during the six-month test program showed some improvement in the visual effectiveness of coil cleaning with the UVGI System electrostatic air filter. Visually the evaporators appeared clean and looked new at the time of installation. There were no visible signs of mold or fungi on the evaporators and none in the drain pan. The Petri Dish testing showed a totally different situation. There were large amounts of mold on the evaporators and drain pans of various kinds that were not visible to the human eye. For mold or fungi to be seen by the human eye there will be 30-40 million mold particles per square inch. The best way to check for mold, bacteria, and fungi is by use of a Petri Dish designed for this application. Petri Dish testing was conducted and is addressed in Tests 1 and 2 of the Series 3500 buses. At the end of the six-month test program there was no mold or fungi on the exhaust side of the evaporator. There was no dirt, mold or bacteria accumulation on the exhaust side of the evaporator or plenum chamber. There was no dirt in the drain pan. General condition of the plenum chamber was clean.
(See Attachment #19: Intake Side of Evaporator Six Months After Installation 12.13.07)
(See Attachment #20: Exhaust Side of Evaporator Six Months After Installation 12.13.07)

The cost savings portion of the test program contains six (6) areas that can be quantified. The cost figures used here were provided by Houston Metro. Each area is addressed separately and present in "100 Bus Context". This was done so other transit properties may compare costs by their fleet size.

	Labor Hrs Per Vehicle	Labor Cost/Hr	Vehicle Quantity	Estimated Cost Saving Per Year
1. Evaporator Maintenance: Typical labor to clean and maintain evaporator.	8	$50.00	100	**$40,000**
2. Cleaning Chemical & Disposal	Cost Per Vehicle	Labor Cost/Hr	Vehicle Quantity	
Gallons of Cleaner Disposal Cost	$40		100	**$4,000**
3. Air Filter Replacement:	Labor Hrs Per Vehicle	Labor Cost/Hr	Vehicle Quantity	
(Reusable filter $17.50 year.) Disposal air filter cost 8 times year @ $13.00 each	$105		100	**$10,500**
Labor	8	$50	100	**$40,000**
4. Component Replacement & Excess Wear:	Cost Per Vehicle		Vehicle Quantity	
Ref: Evap Motor, Compressor, Condenser Motors, Alternator, Engine, parts, & labor	$50		100	**$5,000**
5. Out of Service Cost:	Days Per Year In Operation	Passengers Per Hour	Vehicle Quantity	
Avg. Fare $1.25 1 Bus X 8 hrs @ 30 Passengers/Bus	300	30	100	**$30,000**

TOTAL YEARLY ESTIMATED SAVINGS PER 100 BUSES $129,400

Cost Savings identified are estimated to be approximately $129,400 per year, per 100 buses. At a cost of $2,100 per UVGI System, that would provide a return on investment in about 18 months.

The additional cost savings for health-related benefits of the UVGI System to drivers, employees, and passengers are difficult to quantify in dollars. Health-related benefits are seen as the "reduction" of harmful pathogens, mold, fungi, bacteria, and viruses found on the transit buses. It would be a reasonable assumption if we eliminated harmful pathogens and improved the air quality that there would be a beneficial effect for drivers, employees, and passengers. These could result in less absenteeism of bus drivers, lower insurance cost, improved productivity, less overtime for transit employees, fewer passenger complaints, and other indoor air quality related items.

Fuel Expenditure: Houston Metro elected to run their bus air conditioning systems in what is called "Reheat Mode"; this means the compressor is locked-up or continually running while the bus is running to provide both cooling and heat. The other operating mode is "Non Reheat Mode"; in this mode the compressor cycles "ON" and "OFF" according to the air conditioning load.

The UVGI System fuel saving is only derived in the "Non Reheat Mode" where the compressor cycles "ON" and "OFF". The calculated savings would be approximately .4 gallons per day, based on 10 hours of bus operating time per day. This was calculated on the following: 280 hp engine, 4 miles per gallon, a/c compressor engine load 28 horsepower, or 10%. The UVGI System will reduce the compressor operation by approximately one (1) hour per day by keeping the system in like-new conditions. Forty (40) gallons of diesel fuel per day at a 10% saving is .4 gallon per day savings, per 100 buses; this would be 40 gallons per day. 40 gallons of fuel at a cost of $2.75 per gallon would result in an estimated savings of $110 per day per 100 buses. Yearly savings based on 300 operating days per year for 100 buses would be an estimated savings of $33,000 per year in fuel costs.

(See Attachment #21: Miles Per Gallon and Total Six Months Miles)

Air Flow Testing: The airflow tests were conducted on five Series 3200 buses, four Series 4000 buses, and five Series 3500 buses. None of the evaporators were cleaned prior to installation in order to have a ***worst-case*** scenario to determine the effectiveness of the UVGI System. Airflow readings were taken at nine locations on the intake side of the evaporators, and then averaged for a monthly reading. Locations: Left side top, Left side middle, Left side bottom, Center top, Center middle, Center bottom, Right side top, Right side middle, Right side bottom. These nine readings were then averaged to provide one monthly airflow reading.

Airflow and evaporator heat exchange rates are a critical part of any vehicle air conditioning system. When airflow and evaporator heat exchange rates are reduced the vehicle will not cool as effectively as when the airflow is at designed air speed and evaporator fins are clean. The test of UVGI System in conjunction with the electrostatic air filter showed that the use of these two new technologies maintains proper airflow; cleans evaporator fins and prevents clogging. The major cause of reduced airflow and low heat exchange rates in transit vehicles are large amounts of biofilm, dirt, and debris from both interior and exterior sources accumulating on the evaporator fins. Second, major clogging of the evaporator is due to the use of cheap air filters that allow very large particles of dirt and debris through the filter and get trapped in the evaporator coils. Once the biofilm, dirt, and debris become entrapped in the evaporator it is extremely difficult to get out thereby reducing airflow and heat exchange.

Normal evaporator maintenance is to flush out the evaporator with chemicals or high-pressure water; in many cases this only makes the problem worse for several reasons. The evaporator is usually always cleaned from the intake side applying water from the intake side only compacts the dirt and debris more deeply in the evaporator clogging it and rarely clean all the way through. When only water is used there is no removal or elimination of mold, fungi, viruses or bacteria, this procedure only promotes more growth on the evaporator fins and reduces the heat transfer needed to cool the bus. The labor time when using water or chemicals increases from approximately 45 minutes to 60 minutes to clean one evaporator. Use of cheap air filters will result in more labor to maintain the a/c system.

The use of the UVGI System eliminated most of these problems. It eliminated the mold, fungi and bacteria that adhered to the evaporator cooling fins reducing heat exchange; this also increases the air-flow through the evaporator for better cooling. By eliminating the use of water they are now able to vacuum the intake side of the evaporator reducing labor time up to 50 minutes per cleaning. Cleaning time with the UVGI System and the Reusable Electrostatic Air Filter installed is approximately five (5) minutes to clean the air filter and five (5) minutes to vacuum the intake side of the evaporator.

The Series 3200 buses with a Carrier Air Conditioning system showed a combined 31% improvement in airflow during the test period June 2007 to December 2007. The Series 3200 was the oldest bus in the test program.

The Series 4000 buses with a Thermo King Air Conditioning system showed a combined 24% improvement in airflow during the test period June 2007 to December 2007. The Series 4000 was the midlife bus in the test program.

The Series 3500 buses with a Thermo King Air Conditioning system showed a combined 23% improvement in airflow during the test period June 2007 to December 2007. The Series 3500 were the newest buses in the Houston Metro fleet and had been in service for a few months.
(See Attachment #22: Air Flow Data)

Learning curve comments on bus airflow:

1. The UVGI system will improve airflow.
2. Bus evaporators should be cleaned thoroughly before installing the UVGI System.
3. New buses like the Series 3500 benefit, even though evaporators look clean biofilm like mold and bacteria do build up even when not visible to the human eye.
4. The Series 3500 buses have an evaporator door design that when closed reduced the airflow 50%-60%; air intake door design should be considered.
   (See Attachment #23: Air Conditioning Intake Door)
5. Biofilms that reduce airflow are easily detected by Petri Dish sampling.
6. UVGI System prevented fungi growth, which is what stops up the drain pans and causes the bus to be taken out of service.
7. Air Filters are a critical part of the a/c system.
8. Cleaning evaporator with water only promotes faster growth of biofilm agents.

Temperature Tests were another measurement that could provide a comparison for buses with the UVGI System the data was used in the following format. The six-month temperatures were averaged, and then the temperature difference between July and December calculated, the temperature difference between July and December was divided by the six month average to show a percentage rating increase or decrease. Temperature reading was taken monthly: Position 1, Drivers side, six feet from rear bus wall at a/c outlet. Position 2, Curb side, six feet from rear wall at air conditioning outlet. The a/c system was turned to lowest reading and bus run 20 minutes each time before taking reading. This allowed the buses to have a common test format. The ambient temperature outside ranged from 104º to 70º during the testing program.

Series 3200 buses are the oldest; they had an overall increase in temperature percentage rating of 19.2% for the six-month test period. These were the Carrier Air Conditioning System with the close fin spacing on the evaporators that were difficult to keep clean. The air conditioning systems showed a major temperature benefit from the installation of the UVGI System and Reusable Electrostatic Air Filter. The evaporator fin cleaning and increased airflow improved the cooling temperature of the Carrier air conditioning system as shown through the percentage rating. The temperature achieved on the interior of the bus is directly related to the conditions of the evaporator cooling fins and air-flow. From the maintenance standpoint the more efficient the air conditioning system operates the less maintenance is required saving money.

Series 4000 buses are the middle life buses, had an overall increase in percentage rating of 9.4% for the six-month test period. Buses 4003 and 4008 showed the lowest percentage benefit, but both buses had excellent temperature readings considering the ambient air temperature July and August was over 100 degrees. One possibility was that the air conditioning system expansion valve might have had a different setting allowing for lower temperatures. There was no definitive reason identified for buses 4003 and 4008. Buses 4005 and 4006 showed a larger increase in cooling temperature. The Thermo King Air Conditioning System equipped with the UVGI System and electrostatic air filter did show improved temperature reading.

Series 3500 Series, the new buses had an increase in percentage rating of 19.4% during the test period. Bus 3571 on the passenger side did have a lower rating; this was attributed to the squirrel cage fan on the curbside of the bus. The other buses showed a very similar improved performance. Series 3500 test data showed the UVGI installation on newer buses can be a major factor on the temperature output of the air conditioning system. Here we found even though the mold, fungi, and bacteria were not visible to the human eye on the evaporators it was there and had an impact on the temperature output. The UVGI System restored the evaporators to a like-new condition even though the buses were only one year old.
(See Attachment #24: Temperature Data)

Odor testing was conducted by Donna LaForce, Superintendent Kashmere Garage, May 3, 2007. Odor agents used were deer estrogen and catfish bait because of the high degree of smell. Bus 4105 equipped with the UVGI System and Bus 4017 without. Trays were filled with half of each odor agent and placed in the buses. Three Houston Metro personnel entered each bus on 10-minute intervals. At 10 minutes, the UVGI System bus was beginning to loose the smell. Bus 4017, the non-UVGI bus, still had the original strong odor. At 20 minutes, the 4105 UVGI System bus had virtually no odor expect for stand directly over the tray. Bus 4017 still had the odor when you stepped on the bus however it was not as strong. At 30 minutes, the UVGI bus 4105 was odor free; bus 4017 still had odor at the front door area. The conclusion is that the UVGI System had removed this biological odor from the bus.

Side Note: When the trays were removed, the catfish bait proved roach bait. On bus 4017 the non-UVGI bus, 50 or more roaches were found crawling in the tray after the food. Bus 4105 was roach free.
(See Attachment #25: Houston Metro Odor Test)

Task 5: A Maintenance and Installation Manual was developed and produced for the UVGI System for both the Thermo King and Carrier Air Conditioning Systems. The manual included complete bill of material with picture associated parts, part numbers, installation, wiring diagram, maintenance procedures and trouble shooting guide. Houston Metro was provided copies.

Task 6: Installation Optimization during the installation process there were several changes made to the UVGI System were made. These changes resulted in less labor time, easier installation, and easier electrical connections and reduced maintenance. The following are the major ten items in the optimization.

1. Assembling the UVGI System into a "KIT FORM." We found it was an easier installation if all the component parts were seen as one kit.
2. A picture of a complete kit with components numbered and identified by part number provided a better understanding of the system during installation.
3. A picture process of installation was provided; this was very helpful in the understanding of the system.
4. Mount hole positions changes were made to the ballast bracket for easier installation.
5. UV Lamp holder brackets were preassembled for easier installation.
6. Sight glass installation and reflective foil installation procedures were modified for less installation time.
7. Installation hardware was changed to have more commonality of parts.
8. Predetermining wire lengths and adding electrical connection prior to installation saved labor time and made electrical connections easier.
9. Power connection location to bus was simplified.
10. Problem Solving Guide developed.

The installation on a Carrier A/C requires different UV lamp holders, due to the configuration of the plenum chamber. All other parts including the ballast bracket were designed to be interchangeable for either Carrier or Thermo King A/C Systems.

Task 7: Evaluation: The test data was evaluated for performance and cost effectiveness of UVGI Systems on transit buses.

Mold and fungi testing by Biological Consulting Services showed a 95% to 99% reduction with the UVGI System during the six-month test period. Testing showed a 99% reduction in common viruses. The Human Virus models MS-2 and PRD-1 showed a 99.9% reduction when passed over the UVGI System. Bioterror virus agents showed a 99% reduction. Testing of harmful bacteria on the bus showed a reduction of 99% when passed over the UVGI System. Harmful bacteria like Legionella Pneumophila and Pseudomonas Aeruginosea showed a 99.9% reduction when passed over the UVGI System. Visual Effectiveness Evaporator Cleaning was very evident in the testing. Use of the UVGI System and the newly designed Reusable Electrostatic Air Filter to improve particle size capture to 99% for 5 microns and larger, and 70% for .03 microns, without reducing the air flow to the evaporator, resulted in a major improvement to reduce evaporator cleaning time.

Airflows increased on the Series 3200 buses (averaging approximately 12 years old) by 31%, Series 4000 buses (averaging approximately 8 years old) by 24%, and Series 3500 buses (less than 1 year old) by 23% with the UVGI System. Increases in air flow contribute to better cooling and lower maintenance costs associated with the bus air conditioning system.

Temperature testing efficiency percentage on the Series 3200 buses improved by 19.2%, Series 4000 by 9.4% and Series 3500 buses by 19.4% with the UVGI System.

Odor testing done by Houston Metro personnel resulted in elimination of the odors in the bus equipped with the UVGI System.

The UVGI System in combination with the Reusable Electrostatic Air Filters allowed for a new labor saving method of cleaning evaporators without chemicals, merely by using a vacuum. Evaporator cleaning was reduced to 10 minutes labor time.

By using the UVGI System and Reusable Electrostatic Air Filters, maintenance cost savings identified are estimated to be approximately $129, 000 per year, per 100 buses. At an estimated cost of $2,100 per UVGI System, that would provide a return on investment in about 18 months.

The health-related benefits for bus passengers, drivers, and employees were very positive. There is also protection against many bioterror agents, as shown in testing conducted by Biological Consulting Services of North Florida, Inc. EPA and the Department of Homeland Security test results for hospitals and commercial buildings were consistent with test results by Biological Consulting Services.

The combination of air quality improvements in transit buses and health-related benefits, plus the cost savings, makes the UVGI System cost effective and beneficial to transit bus agencies and their riders.

Plans for Implementation

JKA Company will disseminate the results of the UVGI System testing that was done at Houston Metropolitan Transit Authority. Dissemination will include presentations at professional meetings, trade shows, and conferences by the Principal Investigator. The test data shows the system is very effective in its design to improve air quality in transit buses and health of passengers, drivers, and employees. The maintenance data shows the UVGI System can reduce maintenance costs associated with the air conditioning system.

Houston Metropolitan Transit Authority is leaders in establishing the air conditioning requirements for transit buses. Their test procedure very early on was known as the “Houston Pull-Down Test for Air Conditioning.” The testing done in this Transit IDEA project and with the participation of Houston Metropolitan Transit Authority provides other transit properties confidence that the UVGI System is viable. Based on the successful results of this project, a number of transit agencies have subsequently purchased these systems and installed them in transit bus air conditioning systems.

Conclusions

The testing of the UVGI System had two objectives. First, to test the effectiveness of the UVGI System to improve the air quality in transit buses by reducing harmful pathogens, mold, fungi, bacteria and, viruses within the bus for passengers, drivers and employees. Second, to identify and quantify maintenance cost savings associated with bus air conditioning systems with the UVGI System.

The tests conducted by Biological Consulting Services of North Florida, Inc. and Dr. James W. Kimbrough, Mycologist, University of Florida, showed an effective reduction of 95% to 99% on mold, fungi, and bacteria on the buses tested. Testing showed a 99% reduction in common viruses. The use of UVGI Systems designed for transit buses was effective and produced positives results. These test results were very similar to other test results found in hospitals, schools, commercial buildings, food processing plants, and other stationary applications of UVGI Systems. EPA Office of Research and Development, National Homeland Security Research Center testing for hospitals and commercial buildings titled "Biological Inactivation Efficiency by HVAC In-Duct Ultraviolet Light Systems", June 2006, is consistent with testing results at Houston Metro for transit buses.

The additional cost savings for health-related benefits of the UVGI System to bus drivers, employees, and passengers are difficult to quantify in dollars. Health-related benefits are seen as the "reduction" of harmful pathogens, mold, fungi, bacteria, and viruses found on the transit buses. If we reduced harmful pathogens and improved the air quality on buses, there would be a beneficial effect for drivers, employees, and passengers. Such reductions could result in less absenteeism of bus drivers, improved productivity, less overtime for transit employees, fewer passenger complaints, and other indoor air quality related benefits.

One of the objectives was to identify and quantify the maintenance cost savings associated with bus air conditioning systems. The UVGI System does provide substantial maintenance cost savings, enough to provide a return on investment in about 18 months. Those savings were identified in evaporator maintenance, cleaning chemicals and disposal, air filter replacement, component replacement cost, and out of service costs. Using Houston Metropolitan Transit Authority costs, those savings per 100 buses per year are estimated at approximately $129,000.

For transit systems that utilize bus air conditioning in a "Non-Reheat Mode", there is also a fuel savings. Based upon 100 buses, 300 days operation and diesel fuel at $2.75 per gallon, the total estimated yearly saving would be $33,000 or $330 per year per bus.

The combination of air quality improvements in transit buses and health-related benefits, plus the cost savings, makes the UVGI System cost effective and beneficial to transit bus agencies and their riders. Based on the successful results of this Transit IDEA project, a number of transit agencies have subsequently purchased these systems and installed them in transit bus air conditioning systems.

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