CDC Workplace Safety and Health

NIOSH HEALTH HAZARD EVALUATION REPORT

HETA # 2003-0346-2969
Salvation Army Harbor Light Center
St. Louis, Missouri

May 2005

Stephen B. Martin, Jr.
Christopher C. Coffey, Ph.D.

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

NIOSH

PREFACE

The Respiratory Disease Hazard Evaluations and Technical Assistance Program (RDHETAP) of the National Institute for Occupational Safety and Health (NIOSH) conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) or the Occupational Safety and Health Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer and authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

The RDHETAP also provides, upon request, technical and consultative assistance to Federal, State, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease.

ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Stephen Martin and Christopher Coffey of the Laboratory Research Branch, Division of Respiratory Disease Studies (DRDS), NIOSH. Field assistance was provided by Catherine Calvert, Matthew Duling, Amber Harton, Judith Hudnall, Robert B. Lawrence, Robert Thewlis (Laboratory Research Branch, DRDS), Kenneth Mead, Duane Hammond (Engineering and Physical Hazards Branch, Division of Applied Research and Technology, NIOSH), Steven Fotta (Office of Administrative and Management Services, NIOSH), Paul Jensen (Division of TB Elimination [DTBE], National Center for HIV, STD, and TB Prevention [NCHSTP]), Ted Misselbeck (DTBE, NCHSTP Public Health Advisor assigned to the City of St. Louis Health Department), and Lynelle Phillips (DTBE, NCHSTP Public Health Advisor assigned to the Missouri Department of Health and Senior Services). Desktop publishing was performed by Terry Rooney (Field Studies Branch, DRDS). Review and preparation for printing was performed by Michelle Vingle (Field Studies Branch, DRDS).

Copies of this report have been sent to representatives of the Salvation Army Harbor Light Center, the State of Missouri Department of Health and Senior Services, the City of St. Louis Department of Health, the National Center for HIV, STD, and TB Prevention, and the OSHA Regional Office. This report is not copyrighted and may be freely reproduced. Single copies of this report will be available for a period of three years from the date of this report. To expedite your request, include a self-addressed mailing label along with your request to:

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Highlights of the NIOSH Health Hazard Evaluation at the Salvation Army Harbor Light Center

Engineering Interventions to Help Prevent Airborne Transmission of *Mycobacterium tuberculosis* at the Harbor Light Center

On August 20, 2003, National Institute for Occupational Safety and Health (NIOSH) received a request for technical assistance from the Division of Tuberculosis Elimination (DTBE), National Center for HIV, STD and TB Prevention (NCHSTP). The request concerned a tuberculosis (TB) outbreak at the Salvation Army Harbor Light Center in St. Louis, Missouri.

What NIOSH Did

- Met with representatives from the Salvation Army, City of St. Louis Department of Health, Missouri Department of Health and Senior Services (MO DHSS), Lenzy Hayes, Inc. (the facilities contractor for the Harbor Light Center), and DTBE/NCHSTP/CDC.
- Visited the shelter five times between September 2003 and October 2004.
- Conducted thorough inspections of all shelter air-handling units (AHUs).
- Monitored ventilation air flow rates during each visit.
- Provided recommendations to the shelter for the use of ultraviolet germicidal irradiation (UVGI) fixtures in conjunction with existing ventilation systems.
- Conducted tracer gas testing to better describe air exchange rates and air flow patterns in high-risk areas.
- Developed computational fluid dynamics (CFD) models as a qualitative tool to describe air flow patterns and monitor ventilation system improvements at the shelter.

What NIOSH Found

- Air-handling units were generally in poor repair and in need of cleaning and maintenance.
- Insufficient fresh, outside air was being supplied to many high-risk areas.
- Air flow patterns in some areas inappropriately flowed from the higher-risk areas to lower-risk areas.

What the Harbor Light Center Did

- Thoroughly cleaned all shelter air-handling units and made all necessary repairs.
- Instituted improved maintenance procedures for ventilation systems.
- Replaced existing MERV 7 filters with new MERV 11 filters for enhanced filtration efficiency.
- Installed in-duct and upper-air UVGI fixtures in the highest-risk areas.

What the Harbor Light Center Can Do

- Continue the improved routine maintenance of all air-handling units.
- Develop detailed written operations and maintenance (O&M) plans for the ventilation systems and UVGI fixtures at the shelter.
- Provide training to shelter staff and contractors introducing the new O&M plans.
- Thoroughly test, evaluate, and balance all ventilation systems, and properly adjust them to provide outside air in accordance with ASHRAE recommendations.

CDC Workplace Safety and Health

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NIOSH

Health Hazard Evaluation Report 2003-0346-2969
Salvation Army Harbor Light Center
May 2005

Stephen B. Martin, Jr.
Christopher C. Coffey, Ph.D.

SUMMARY

On August 20, 2003, the National Institute for Occupational Safety and Health (NIOSH) received a request for technical assistance concerning a tuberculosis (TB) outbreak at the Salvation Army Harbor Light Center in St. Louis, Missouri. The request was made by the Division of Tuberculosis Elimination (DTBE), National Center for HIV, STD and TB Prevention (NCHSTP), which was investigating the outbreak at the request of the Missouri Department of Health and Senior Services (MO DHSS). Between February 2001 and August 2003, MO DHSS had identified a total of 19 cases of active TB linked to the Harbor Light shelter.

NIOSH investigators made five visits to the Salvation Army Harbor Light Center between September 2003 and October 2004. Thorough inspections of the shelter air-handling units (AHUs) were conducted, and ventilation air flow rates were monitored. Tracer gas studies were conducted to calculate air exchange rates and describe air flow patterns. This work revealed that the majority of the AHUs at the shelter were in poor repair and in need of cleaning and maintenance.

Following our recommendations, the shelter improved the overall cleanliness of the AHUs and has instituted regular maintenance procedures. The filters in all AHUs were upgraded to MERV 11 filters from the original MERV 7 filters. Despite some AHU improvements in providing more outside air to the clients inside, some areas of the shelter are still not consistently capable of meeting the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) recommendations for outside air supply. Ultraviolet germicidal irradiation (UVGI) fixtures were installed in all of the highest-risk areas of the shelter to help kill or inactivate airborne *Mycobacterium tuberculosis*.

We continue to recommend that all areas of the shelter should be brought into compliance with applicable ASHRAE recommendations for outside air supply. Thorough testing and balancing of the AHUs, along with the proper establishment of setpoints for each AHU, should be completed and documented. Detailed operations and maintenance plans should also be developed to keep the ventilation systems and UVGI fixtures operating properly.

Preexisting conditions (prior to September 2003) relating primarily to inadequate fresh air supply and suboptimal filtration of air in the shelter's ventilation systems could have contributed to airborne *M. tuberculosis* transmission that resulted in the TB outbreak of 2001-2003.

Keywords: SIC 702 (Rooming and Boarding Houses); tuberculosis, TB, *Mycobacterium tuberculosis*, homeless shelter

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INTRODUCTION

On August 20, 2003, the National Institute for Occupational Safety and Health (NIOSH) received a request for technical assistance concerning a tuberculosis (TB) outbreak at the Salvation Army Harbor Light Center in St. Louis, Missouri. The request was made by Dr. Kenneth G. Castro, Director of the Division of Tuberculosis Elimination (DTBE), National Center for HIV, STD and TB Prevention (NCHSTP). DTBE was investigating the outbreak at the request of the Missouri Department of Health and Senior Services (MO DHSS). Between February 2001 and August 2003, MO DHSS had linked 19 active TB cases to the Harbor Light shelter. DTBE specifically requested help from NIOSH in assessing the shelter's heating, ventilation, and air-conditioning (HVAC) systems and improving environmental controls at the shelter.

BACKGROUND

TB and Homeless Populations

TB is a disease caused by *Mycobacterium tuberculosis (M. tuberculosis)* bacteria. When a person with active TB disease coughs or sneezes, tiny droplets containing *M. tuberculosis* may be expelled into the air. Many of these dry and remain suspended in the air for long periods as droplet nuclei. If another person inhales air that contains infectious droplet nuclei, transmission from one person to another may occur. Homeless people have been identified as a high-risk population for TB infection and disease since the early 1900s.[1] With the increase in homelessness in the United States since the 1980s, TB among homeless persons has become a subject of heightened interest and concern.[2-10]

Salvation Army Harbor Light Center

The Salvation Army Harbor Light Center in St. Louis, Missouri, provides services to any adult male without a place to sleep. Programs at the shelter include an emergency shelter (where homeless men directly off the street can receive food and shelter for a night), life-skills classes, addiction counseling, spiritual growth, job-search assistance, and a program for homeless U.S. military veterans. The shelter is comprised of two housing buildings connected by a common recreation/exercise building.

The annex is a two-story brick building constructed in 1987. It has two separate sleeping areas on the first floor (Figure 1). One side is furnished with 86 bunk beds where long-term respite clients (those too sick or injured to work) sleep. The other side is a large common area used for meetings during the day and for up to 50 transient, walk-in clients to sleep on mats during the night. The first floor also contains counseling offices, a laundry room, and a staffed monitor station to control access to the building. The second floor (Figure 2) also has two separate housing units for long-term clients, one for up to 31 Level 1 clients (those in the first phase of life rehabilitation programs) and one for up to 30 homeless U.S. military veterans (VA Area). These two housing areas are separated by a conference room and counseling offices. Both floors contain complete restroom and shower facilities. The annex has two rooftop AHUs, each providing ventilation to an entire floor of the building.

The main building, constructed in the 1930s, is a three-story brick construction. The first floor of the main building (Figure 3) houses the kitchen and cafeteria, medical offices and clinics. If more than 50 men register as transient clients for any given night, those additional transient clients sleep on mats in the nurse waiting area on the first floor of the main building. The second floor contains offices for shelter staff, the chapel, a conference room, and living space for long-term clients. The third floor is primarily long-term client living areas with a laundry room, meeting rooms, and lounges. Because of the age of the building, HVAC systems were not incorporated into the original construction. Eighteen (18) AHUs were later added to the main building to provide ventilation.

In late 2003, the Salvation Army contracted with Lenzy Hayes, Inc. (Bloomington, Indiana) facility management company to provide the shelter's facilities maintenance.

NIOSH Involvement

We visited the shelter five times from September 2003 through October 2004, summarized as follows:

1. During a visit on September 15-16, 2003, we met with representatives from the Salvation Army, Lenzy Hayes, Inc., City of St. Louis Department of Health (DOH), MO DHSS, and DTBE to discuss the shelter's HVAC systems in relation to the TB outbreak. The annex was judged the top priority because most of the TB cases in the outbreak were probably contracted there. Another high-risk area identified was the first floor of the main building, which houses the kitchen and cafeteria, medical offices and clinics, and associated waiting areas where many clients are closely congregated every day. After the meeting, we toured the shelter and visually inspected all AHUs. We later sent an interim report (Appendix A) detailing recommendations for cleaning and improving the ventilation systems.

2. During a visit on January 7-8, 2004, we met with representatives from the Salvation Army, Lenzy Hayes, Inc., City of St. Louis DOH, and DTBE to discuss ongoing facility improvements and the use of ultraviolet germicidal irradiation (UVGI) fixtures to reduce the spread of infectious airborne microorganisms. We also took air-flow measurements. After the meeting, we sent a second interim report (Appendix B) detailing recommendations for purchasing and installing UVGI fixtures

3. During a visit on April 12-14, 2004, we took physical measurements of the shelter and additional air-flow measurements. These measurements were needed to construct computational fluid dynamics (CFD) models which would be used to map air-flow patterns and locate areas of potentially stagnant air.

4. During the final two visits, on July 11-16, 2004 and October 12-22, 2004, we conducted tracer gas testing to quantify air exchange rates throughout the shelter and took additional physical and ventilation measurements (for use in CFD models). We also monitored indoor environmental quality parameters during the tracer gas tests conducted in October. In addition, we verified all duct connections in the annex, and did thorough visual inspections, with fan motor amperage measurements, of all AHUs.

METHODS AND RESULTS

AHU Inspections

Although it had been decided that we would primarily focus on the annex and first floor of the main building, a visual inspection was conducted of all 20 AHUs at the shelter. Visual inspections were conducted to determine the current state of the AHUs with regard to cleanliness, maintenance, and filtration efficiency.

The two rooftop units on the annex (Table 1; Figures 4 and 5) were generally clean and in good working order. However, the outside air dampers were screwed shut (Figure 6), allowing little or no fresh, outside air to the clients housed in the annex.

Table 2 provides the locations and general information on all 18 AHUs in the main building. Locations of the six AHUs serving the first floor of the main building are shown in Figure 3. These units were generally in need of cleaning, maintenance, and repair. They were typically installed inside small mechanical rooms that were also used for general storage (files, holiday decorations, extra ventilation filters, etc.). The outside surfaces of most AHUs in the main building were covered with dust and debris (Figure 7). Likewise, the inside surfaces were also covered with heavy layers of dirt and debris (Figure 8) and many had debris collected on the heating/cooling coils (Figure 9). Another common problem was stagnant, dirty water in clogged drain pans or drain pans having inoperable pumps (Figure 10). In some cases, it was evident that leaking or overflowing drain pans had caused floor damage (Figure 11). Other common problems included damaged pneumatic and/or electronic sensors and controllers, damaged outside air dampers, and loose fan belts.

Based on the visual inspection, we recommended a combination of improved maintenance, cleaning, and enhanced filtration as detailed in Interim Report I (Appendix A). Major recommendations included:

1. Improve the shelter's routine maintenance of AHUs, performing maintenance on a schedule consistent with the manufacturer's recommendations. The maintenance should include:
   a. Replacing filters (ensuring minimal filter bypass by inserting "blanks" where filters don't fill the filter bank completely);
   b. Cleaning fans, heating/cooling units (ensuring valves are operable and pipes have no leaks), and drain pans;
   c. Verifying AHU setpoints and operation of outside air dampers;
   d. Confirming the direction of fan rotation and revolutions per minute (rpm); and
   e. Replacing worn fan belts and greasing or replacing fan bearings, as needed.

2. Evaluate each AHU to determine the design specifications and actual performance specifications. Make necessary repairs to ensure proper operation.

3. Thoroughly test, evaluate, and balance the distribution systems for all 20 AHUs. Each year, evaluate air flow rates to determine if the AHUs need to be rebalanced.

4. Increase outside air intake to meet American Society for Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) recommendations.[11]

5. Replace current filters with new filters that have the highest possible efficiency while maintaining the designed flow rate through each AHU.

After the September 2003 visit, the Salvation Army and Lenzy Hayes, Inc. worked to implement our recommendations. The outside of each AHU was cleaned. Fan belts were replaced (if necessary), the pneumatic and/or electrical sensors and controllers were made operational, and the outside air dampers were repaired (unscrewed in the case of the annex rooftop units). With these improvements, each annex AHU can bring in up to 25% fresh, outside air (depending on outside temperature and individual AHU temperature set points) and each AHU in the main building can bring in up to 100% outside air. Increases in outside air supply should help prevent the transmission of *M. tuberculosis* by further diluting airborne contaminants, including infectious droplet nuclei.

The Salvation Army contracted Albert Arno, Inc. (St. Louis, Missouri) to thoroughly clean the heating/cooling coils of each AHU in the main building, a service that was completed in March 2004. (Coils in the annex AHUs did not require cleaning.)

Minimum Efficiency Reporting Value (MERV) 7 filters were replaced with new MERV 11 filters in all 20 AHUs. The MERV value relates to the minimum filtration efficiency of a given filter.[12] MERV 7 filters are around 25% efficient at filtering particles in the 1.0-3.0 micrometer (µm) size range, which includes droplet nuclei responsible for *M. tuberculosis* transmission. The new MERV 11 filters are around 70% efficient against 1.0-3.0 µm particles.[12]

In October 2004, we again thoroughly inspected the 18 AHUs in the main building. While the overall condition of the units was improved since our first inspection, there were still some issues that needed attention. The biggest concern was that the new MERV 11 filters had been installed backwards in nearly every AHU. Often, the wrong configuration (e.g., improper sizes) of filters was installed as well. During our reinspection, we removed all of the backward filters and reinstalled them properly. However, we did not replace incorrectly sized filters, as we did not have a supply of new filters. Other issues that still needed attention were loose fan belts, leaking water valves, and condensate pans that still contained stagnant, dirty water. We brought these issues to the attention of representatives of the facility management company and were assured the problems would be addressed. A summary of our findings during the visual reinspection in October 2004 is found in Table 3.

As part of the coil cleaning service provided by Albert Arno, Inc., amperage readings for each AHU fan motor were taken prior to cleaning, with the original used filters installed.[13] During our October 2004 reinspections and after the new MERV 11 filters had been installed, we took amperage readings of the fan motors with a UEi (Beaverton, Oregon) DL259 True RMS Clamp-On Multimeter. This multimeter is capable of reading AC amps in the range from 0-400 with a resolution of 0.1 amps.[14] Table 4 shows the amperage readings by Albert Arno, Inc. prior to coil cleaning compared to our readings. Every AHU showed an increase in fan motor amperage after coil cleaning with the new MERV 11 filters installed. These amperage increases ranged from 3.8 to 44.2 percent. After the coils were cleaned, and despite the increased resistance to flow of the new MERV 11 filters, there was a significant increase in fan motor amperage, consistent with an increase in overall air movement through the AHUs. This should make a noticeable difference in overall air distribution, temperature control, and client comfort in the main building.

Ventilation Measurements

We collected complete sets of ventilation measurements from the annex during all four visits in 2004. These air flow measurements were taken with a TSI (TSI Incorporated, St. Paul, Minnesota) Model 8373 ACCUBALANCE® Plus Air Capture Hood. The 8373 can measure flows between 30 and 2,000 cubic feet per minute (CFM) with an accuracy of ±5% reading and ±5 CFM.[15]

Each air handler on the roof of the annex provides ventilation to one entire floor. Metal main supply air ducts extend downward from each AHU through the center of the annex to the suspended ceiling plenum on one floor. Within each plenum, a metal central supply air duct extends north-to-south from the main supply to further distribute the conditioned air. All supply vents are connected with 10-inch diameter flexible ductwork that branches from this central duct. The area above the suspended ceiling also serves as the return air plenum for each floor. Air from the plenum is pulled into the metal return air main duct servicing each AHU. There are no ducted returns on either floor. The return air grilles mounted in the suspended ceiling allow room air to be pulled into the plenum for return to the AHU. Additional return air is pulled into the plenum through other locations in the non-airtight suspended ceiling. We took air flow measurements (Tables 5 and 6) from every supply vent and return grille (Figures 12 and 13) on both floors of the annex.

The data presented in Tables 5 and 6 show several oddities. There were supply vents serving as air returns (e.g., vents 10, 11, and 15 on the first floor in July), and returns that were supplying air (e.g., grilles D, E, F, and H on the first floor in April). There were also many zero readings. We had recommended testing and balancing (TAB) of the HVAC systems after our first visit in September 2003, but TAB was never completed during the time we conducted evaluations at the shelter. Thus, our readings in January, April, and July were taken with the building "as is." In October, we inspected all of the flex duct connections in the four main client areas in an attempt to explain the conditions mentioned above. In most cases, the flex duct was cracked or completely separated from the supply vent, causing supply air to leak directly into the return air plenum. In some cases, the end of the flex duct was several feet from the supply vent to which it should have been connected. Every supply vent was partially or totally disconnected in the respite area, and all but two were disconnected in the common area. The second floor Level 1 area and the VA area each had two disconnected supply vents. Prior to taking the October ventilation measurements, we reconnected the flex duct to all of the supply vents. Thus, the measurements taken in October are more realistic of actual ventilation system performance, and were the only set where all of the supplies functioned as supplies and all but one of the returns functioned as returns. No measurable flow was ever recorded at grille G on the second floor.

Individual supply values presented in Tables 5 and 6 can be summed to calculate total air flow (CFM) into various spaces in the shelter. Knowing the total air flow (CFM) into a given space, and the volume of that space, Equation 1 can be used to calculate the theoretical air changes per hour (ACH):

$$ACH = \frac{Q}{V} \times 60 \quad (1)$$

where Q is the volumetric flow rate into the space in CFM, and V is the volume in cubic feet (ft^3). Using values from October, Table 7 presents total air flows and estimated total CFM per person (CFM/person) based on typical occupancy rates, as well as air changes per hour for each area of the annex.

ASHRAE has published recommended building ventilation design criteria and thermal comfort guidelines.[11,16-18] Although there are no specific guidelines for homeless shelters, 15 CFM of outside air per person is recommended for dormitory sleeping areas, assembly rooms, and conference rooms,[11,18] and 20 CFM of outside air per person is recommended in dining rooms and offices.[11] For restroom facilities, 50 CFM of outside air per toilet/urinal (including transfer air from adjacent locations) is recommended with direct exhaust to the outside.[11] The annex AHUs are each capable of bringing in a maximum of 25% outside air, so the maximum attainable outside air values from the ventilation systems are 25% of the total values shown in Table 7. These outside air supply and exchange rates for the annex are also presented in Table 7.

Assuming the maximum of 25% outside air, at the ventilation rates and typical occupancy levels presented in Table 7, the only areas that meet their respective ASHRAE recommendations were Office 1 and Offices 2 and 3 (Offices 2 and 3 are treated as one space here because the wall separating them does not extend to the ceiling) on the first floor, and Offices 1 and 3 on the second floor. It would require 92% outside air for all areas on the first floor to meet their respective ASHRAE recommendations, except for the women's restroom, which could never meet the 50 CFM per toilet recommendation since it only gets 35 CFM of total supply flow and has no exhaust fan or return air grille. The second floor would require 58% outside air intake for all areas to comply with ASHRAE recommendations.

We also collected ventilation measurements from the first floor of the main building during the July 2004 visit. Measurements were collected for each supply vent associated with AHUs 1, 2, and 5 (see Figure 3), which supply air to the main client locations on the first floor. The other AHUs supply air to the food storage areas, kitchen, and maintenance shop, which are generally unoccupied. AHU 1 provides ventilation to the chiropractic clinic, detoxification clinic, and the supporting offices and waiting rooms. AHU 2 supplies air to the medical offices, the nurse waiting/vending area, and the classroom. AHU 5 supplies air to the cafeteria only.

All three of these AHUs have exposed sheet metal supply ducts extending along the ceiling of the areas they serve. Supply vents were installed directly into the sides and bottom of this duct work. There are no ducted returns or return air ceiling plenums for the AHUs. The returns consist of large grilles installed through the walls of the mechanical rooms housing each AHU. This, in effect, results in the occupied space serving as the return air plenum. The supply vents and return grilles for AHU 5 are shown in Figures 14-16 to illustrate the supply/return configuration. Due to the small vent size, measurements were taken with a TSI Model 8324 VELOCICALC® Plus Rotating Vane Anemometer. This instrument is capable of measuring air velocities between 50 and 6,000 feet per minute (ft/min) at an accuracy of ± 1.0% of the reading or ± 3 ft/min, whichever is greater.[19] Several measurements were taken for each vent (in different locations at the vent) and averaged to obtain the air velocity. The total area of each vent was measured and used to convert the velocity measurement to a volumetric flow rate (CFM).

The calculated total CFM, CFM/person, and ACH values for the main building are shown in Table 8. Rough temperature mix measurements revealed that the average outside air setting of the main building AHUs was around 25 percent. So, the outside air exchange rates presented in Table 8 are calculated assuming 25% outside air intake. The actual amount of outside air brought in by each AHU will be higher or lower depending on its setpoints, and it will change as environmental conditions vary.

Assuming 25% outside air, all areas served by AHU 1 are in compliance with their respective ASHRAE recommendations, except for the chiropractic restroom. In fact, all areas, except the chiropractic restroom, would meet the ASHRAE recommendations with only 12% outside air. However, it would take 54% outside air for the chiropractic restroom to comply with the ASHRAE recommendation of 50 CFM per toilet/urinal. At 25% outside air, all the areas served by AHU 2 are in compliance, except the classroom. The classroom would meet the ASHRAE recommendation if only 26 people were inside. Otherwise, it would take 38% outside air to bring the class room into compliance with an occupancy of 40 people. At 25% outside air, AHU 5 does not supply the typical 80 clients in the cafeteria with the recommended 20 CFM/person. It would provide the recommended level of outside air if only 61 clients were allowed in at one time. Otherwise, it would require around 33% outside air to bring the cafeteria into compliance (occupancy of 80 clients).

In determining compliance with recommendations for outside air supply, AHSRAE allows for adjustments to outside air flow recommendations in areas with intermittent or variable occupancy.[11] Standard 62.2 states that "Where peak occupancies of less than three hours duration occur, the outdoor air flow rate may be determined on the basis of average occupancy for buildings for the duration of operation of the system, provided the average occupancy used is not less than one-half the maximum."[11] There are several areas of the shelter that could fall under this provision, such as the common area in the annex, and the cafeteria, classroom, and waiting areas on the first floor of the main building. This should be considered during future TAB of the air-handling systems and when establishing appropriate setpoints on each of the AHUs.

UVGI Interventions

Ultraviolet (UV) radiation is a form of electromagnetic radiation with wavelengths between 100 nanometers (nm) and 400 nm. The International Commission on Illumination has divided this wavelength range into three wavelength bands: UV-A (315–400 nm), UV-B (280–315 nm), and UV-C (100–280 nm).[20] Most commercially available UV lamps used for germicidal purposes are low-pressure mercury vapor lamps that emit radiant energy in the UV-C range, predominantly at a wavelength of 253.7 nm.[21]

Research has demonstrated that UVGI is effective in killing or inactivating *M. tuberculosis* under experimental conditions.[22-25] UVGI has also proven effective in reducing the transmission of other infectious agents in hospitals, military housing units, and class rooms.[26-28] Due to the results of controlled studies and the experiences of clinicians and engineers, UVGI has been recommended as a supplement to other TB infection-control and ventilation measures to kill or inactivate *M. tuberculosis*.[29-31] In-duct UVGI fixtures provide high-intensity UV-C radiation to irradiate the supply air flowing from AHUs. These fixtures are completely enclosed inside the AHUs, so there is no danger of exposing building occupants to UV radiation. Upper-air UVGI fixtures are mounted inside rooms, either on a wall or suspended from the ceiling. These fixtures are placed 7 feet above the floor and are designed to provide a beam of UV radiation in the upper room (toward the ceiling) while shielding occupants in the lower part of the room.[32]

With assistance from Mr. Ted Misselbeck of the St. Louis DOH, the Salvation Army and Lenzy Hayes, Inc. contacted Mr. Charles Dunn, Sr., Chairman of Lumalier (Memphis, Tennessee), a leading manufacturer of ultraviolet germicidal air disinfection fixtures. Mr. Dunn subsequently visited the shelter and provided options for using

UVGI in conjunction with the existing AHUs to reduce the risk of further airborne disease transmission. In January 2004, we conferred with Mr. Dunn and Dr. Paul A. Jensen, a UVGI expert with DTBE, to develop recommendations to upgrade existing environmental controls to include the enhanced protection offered by UVGI technology.

Our final recommendations for a combination of in-duct and upper-air UVGI fixtures were separated into two installation phases, based on the availability of funding, as detailed in Interim Report II (Appendix B). The recommendations were presented in a priority order intended to provide the most protection against airborne *M. tuberculosis* transmission in the highest-risk areas of the shelter. Major Phase 1 recommendations included:

1. Install in-duct UVGI fixture inside the two annex AHUs.

2. Install upper-air UVGI fixtures in the following areas:
   a. common area (annex);
   b. respite area (annex)
   c. glass-enclosed monitor station (annex);
   d. gym/indoor recreation facility;
   e. second-floor conference area, including the counseling areas, offices, and the storage room (annex);
   f. nurse and doctor offices (main building) (Also, air returns from examination rooms should be hard-ducted back to AHU 2 to make it easier to keep the examination rooms under negative pressure relative to the surrounding areas.);
   g. detoxification clinic, detoxification office, and chiropractic clinic waiting areas (main building);
   h. cafeteria/dining area and adjacent corridor (main building);
   i. classroom (main building);
   j. nurse waiting/vending area (main building).

Major Phase 2 recommendations, intended to provide additional UVGI protection within the main building of the shelter and to supplement the protection offered by the Phase 1 recommendations, included:

1. Install upper-air UVGI fixtures in the following areas:
   a. Level 1 and VA areas (annex);
   b. chapel and chapel foyer (main building);
   c. various "community" rooms (e.g., television rooms, study rooms, and classrooms) and high-risk client sleeping areas on the second and third floors (main building);

2. Install an in-duct UVGI fixture in each AHU system (main building).

After receiving our recommendations, the Salvation Army contracted with Lumalier to begin supplying and installing the UVGI fixtures. All installations associated with the Phase 1 recommendations (and Phase 2 recommendation #1a) were completed by our visit in October 2004. In all, five types of fixtures (Table 9) were installed in various locations on the first and second floor of the annex and the first floor of the main building (Figures 17-19). Figures 20-22 show photographs of some of the UVGI fixtures installed. In addition to the UVGI fixtures shown in Figures 17-22, one Silent Air Mover (SAM) unit was installed in the chapel foyer on the second floor of the main building. Also, two high-intensity wall-mount units (17 UV-C watts each) were installed in the common recreation/exercise building.

Our upper-air UVGI recommendations were intended to achieve 0.03 UV watts/ft^2 (assuming no mechanical air mixing)[33,34] or 0.02 UV W/ft^2 where mechanical air mixing is provided with the SAM units. In areas requiring more than one UVGI fixture, the placement of fixtures was arranged to provide overlapping irradiation zones in the upper-air. Table 10 shows the amount of irradiation per square foot for each area of the shelter having upper-air UVGI fixtures installed. These values are calculated using UV-C wattage specifications over the lifetime of the lamps, provided by the lamp manufacturer. The NIOSH Recommended Exposure Limit (REL) for ultraviolet irradiation (254 nm) is 6.0 millijoules per square centimeter (mJ/cm^2) for an 8-hour exposure time.[35,36] All UVGI fixtures used at the shelter meet this criterion and were thoroughly tested by Lumalier after installation.

With the installation of new MERV 11 filters and in-duct UVGI fixtures in the annex AHUs, an overall "effective" filtration efficiency can be calculated. The effective filtration efficiency takes into account the ability of the AHU to filter *M. tuberculosis* from the air stream and the ability of the in-duct UV irradiation to kill or inactivate any *M. tuberculosis* bacteria getting through the filter. This effective filtration efficiency is calculated as:

$$E_{eff} = 1-[(1-E_F)\times(1-E_{UV})] \qquad (2)$$

where E_{eff} is the effective filtration efficiency, E_F is the filter efficiency, and E_{UV} is the efficiency with which the in-duct UV irradiation kills or inactivates *M. tuberculosis*.

The MERV 11 filters are approximately 70% efficient at capturing *M. tuberculosis* in the form of infectious droplet nuclei. The in-duct UVGI fixtures are better than 85% efficient at killing or inactivating *M. tuberculosis*.[37] This gives an overall effective filtration rate of around 95% per pass through the ventilation systems. The presence of upper-air UVGI fixtures in addition to the in-duct UVGI accounted for in our preceding calculations will provide protection above and beyond this 95% effective filtration.

Tracer Gas Testing

Tracer gas testing has been used in many applications, including medical diagnostics and treatments, critical leak detection, atmospheric tracing, and ventilation studies.[38-42] We used the tracer gas decay technique to measure localized air changes per hour (ACH_L) in the annex. This technique is the easiest and most widely used tracer gas technique for measuring air flow in a building.[43] To conduct these tests, a small amount of tracer gas is injected into the building and given time to mix. Then samples of the air inside the building are collected and analyzed to monitor the dilution of tracer gas over time.

Three different tracers were used simultaneously during the studies. They were sulfur hexafluoride (SF_6) and two perfluorocarbon tracers (PFTs) [perfluorodimethylcyclobutane (PDCB) and perfluoromethylcyclohexane (PMCH)]. SF_6 is maintained in the gaseous state and was released using a gas-tight syringe. The PFT tracers are stored as liquids and were volatilized to constitute the release. The initial target concentration for each tracer was 30-50 parts per billion (ppb). This was around 5 orders of magnitude lower than the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) for SF_6 of 1000 parts per million (ppm) as an 8-hour time-weighted average (TWA).[44] The NIOSH REL and the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV) are also 1000 ppm.[36] The PFTs do not have established exposure limits. All three tracers are non-toxic, colorless, odorless, tasteless, non-reactive, non-flammable, and environmentally safe. They posed no risk to shelter clients or staff at the concentrations used.

For testing in the annex, one tracer was used to dose the entire first floor through the main supply duct of annex AHU 1. A second tracer was used to dose the entire second floor through the main supply duct of annex AHU 2. The third tracer was released from inside the respite area. This "burst" release gave us two tracers inside the respite area from which to monitor the decay rate. It could also be used to monitor air moving from the respite area to other locations (cross-talk). A total of five tracer gas tests were conducted in the annex on five different days (Table 11).

To begin the tests, the three tracers were released simultaneously and then allowed 30 minutes to mix in the building. Every 10 minutes for one hour and then every 20 minutes for two additional samples, we took samples at various locations on the first and second floors of the annex (Figures 23 and 24, respectively). All samples were collected 3 feet off the ground into 60 mL disposable syringes. An air-tight cap was placed on the syringe to preserve the sample for analysis. We analyzed all samples on two separate Lagus (Lagus Applied Technologies, Inc., Escondido, California) AUTOTRAC® Automatic Tracer Gas Monitors. The AUTOTRAC® uses electron capture gas chromatography to monitor tracer concentrations in the linear range of 0.5 to 50 parts per billion (ppb) with a precision of ±3% of the reading.[45] One monitor was optimized to measure the concentration of SF_6, while the other was optimized to measure the concentrations of the PDCB and PMCH. Both Lagus monitors were calibrated onsite with standards we prepared.

The localized air changes per hour (ACH_L) for each sampling location were calculated from the following equation:

$$ACH_L = \frac{1}{t} \ln\left(\frac{C_i}{C_f}\right) \quad (3)$$

where t is the elapsed time (hours) between the first and last samples, C_i is the initial tracer concentration, and C_f is the final tracer concentration. ACH_L is different than the ACH based on ventilation measurements (see above). ACH is the theoretical number of air changes per hour provided by the ventilation system and is calculated solely as a function of room volume and air flow rate. ACH_L is the number of air changes per hour provided by all sources of ventilation not containing the tracer being monitored. That is, air moving from one floor to the other would be included in the ACH_L measurement, but not in ACH. Similarly, any air coming through open doors and windows or any leakage through the building envelope would be included in ACH_L, but not in ACH. This is important since all tracer gas testing was done with the building "as is," with clients and staff entering and exiting the building, and moving around inside the building during each tracer gas test.

We calculated ACH_L values for each sampling location and each test in the respite area and common area of the first floor (Tables 12 and 13) and for the Level 1 area and the VA area on the second floor (Tables 14 and 15). The tables also include the average ACH_L value for each area for each test. From this average, Equation 1 can be modified and rearranged to calculate Q_L, the total volumetric air flow entering the space in CFM:

$$Q_L = \left(\frac{ACH_L \times V}{60}\right) \quad (4)$$

From the value of Q_L, the CFM/person can be calculated based on a given occupancy rate. Tables 12-15 present CFM/person results based on the same occupancy levels used in Table 7. When comparing the CFM/person values from the tracer gas tests (Tables 12-15) to those from the ventilation measurements (Table 7), it is important to remember that client activity was not controlled. From the tracer results, there was negligible cross-talk from the first floor to the second floor, and from the second floor to the first floor, so air movement between floors was not a major factor in the measured tracer gas decay rates. However, the main door into the annex is opened and closed several times each minute during the day and there are two other outside doors that are occasionally opened. Exterior door opening introduces significant outside air into the annex by a means other than through the AHUs. This outside air affects the tracer gas results and potentially explains the variability in the CFM/person results from one test to the next (Tables 12-15), as well as the observation that, in all four client areas, the outside air CFM/person measured during the tracer gas tests were higher than those calculated from the ventilation measurements.

Additionally, we collected samples from the main supply duct and the return plenum on each floor during each tracer gas test. Samples were also collected from outside the building to check for background levels of the tracers being monitored. From these samples, the percentage of outside air (from the ventilation systems and open doors/windows) can be calculated using:

$$xC_{out} + (1-x)C_r = C_s \quad (5)$$

where x is the fraction of outside air, C_{out} is the concentration of tracer in the air outside the building, C_r is the tracer concentration in the return plenum, and C_s is the tracer concentration in the supply duct. Since the outside concentration was always zero, the first term in Equation 5 drops out. Rearranging the remaining terms, gives:

$$x = \frac{C_r - C_s}{C_r} \quad (6)$$

This calculation showed that the first floor of the annex had 45% outside air during Test 4 and

41% outside air during Test 5. The second floor had 23% outside air for both Test 4 and Test 5. (Problems with the samples collected during Tests 1-3 in July rendered them useless for this calculation.) Since annex AHU 1 is only capable of bringing in a maximum of 25% outside air, these results indicate that opening of external doors does provide added outside air intake on the first floor.

Unfortunately, accounting for the infiltrating outside air is insufficient to result in additional areas of the annex meeting ASHRAE recommendations (beyond those areas already estimated to meet ASHRAE recommendations based on ventilation measurements). Even considering infiltrating outside air, Office 1 and Offices 2 and 3 on the first floor, and Offices 1 and 3 on the second floor were still the only areas that met their respective ASHRAE recommendations.

The tracer gas studies we conducted on the first floor of the main building were done for qualitative analysis rather than quantitative results. Here, we used tracers to "trace" airflow patterns within the first floor and the mixing of air from one space to another. In theory, if the tracer gas were a client-generated, infectious aerosol, the aerosol would migrate through the areas in a pattern similar to that described by the gas. This contrasts with our use of tracer gas testing in the annex building to quantify tracer decay rates. Our approach involved releasing three different tracers, one in each of three different areas (detoxification clinic, chiropractic clinic, and Nurse Office 1) and sampling at various locations throughout the first floor (and stairwells to the upper floors). The three tracers were released simultaneously and then allowed 30 minutes to mix in the building. Every 10 minutes for one hour and then every 20 minutes for an additional 2 samples, we collected samples in disposable 60 mL syringes 3 feet off the ground at various locations on the first floor (Figure 25). The actual dosing regimens for Tests 6 and 7 are shown in Table 11.

Release of PDCB from Nurse Office 1 resulted in high concentrations of PDCB in the nurse waiting area and the classroom. This was not surprising since Nurse Office 1 was expected to be under positive pressure in relation to these two areas due to the arrangement of the air supplies and returns, and the areas are all served by the same AHU (AHU 2). Moderate concentrations of PDCB were measured in the main corridor, and in both stairwells on the second and third floors. Insignificant concentrations of PDCB were measured in the cafeteria (AHU 5) and the chiropractic waiting area (AHU 1).

Release of SF_6 from the detoxification clinic resulted in the highest concentrations measured in the chiropractic waiting area and the chiropractic clinic. (Samples were not collected from inside the detoxification clinic itself at the request of shelter staff). Again, due to the arrangement of air supplies and returns, this was expected since the detoxification clinic was under positive pressure compared to the chiropractic waiting area, and the AHU servicing that entire area (AHU 1) is located there. Insignificant concentrations of SF_6 were measured in the nurse waiting area, class room, and the main corridor.

Release of PMCH in the chiropractic clinic resulted in the highest concentrations being measured in the chiropractic clinic itself and the chiropractic waiting area. Here, the chiropractic clinic is expected to be under positive pressure compared to the chiropractic waiting area, and AHU 1 is located adjacent to the chiropractic waiting area. Insignificant concentrations of PMCH were measured in the nurse waiting area, class room, and the main corridor.

From these tracer tests in the main building, we concluded that AHU 1, AHU 2, and AHU 5 are fairly independent of one another. However, within the area served by each AHU, there is a significant negative pressure pull toward the AHU because of the open returns. While this is not an issue in the cafeteria, because AHU 5 is totally contained inside that area, it is a major concern with AHU 1 and AHU 2, where air flows from areas of higher risk to areas of lower risk. For instance, air from the nurse offices (higher-risk) was noted to flow through the nurse waiting area and the classroom (lower risk) on returning to AHU 2. To reduce the possibility of airborne disease transmission, air should flow from lower risk to higher risk areas.

Indoor Environmental Quality (IEQ) Parameters

Measuring ventilation and comfort indicators such as temperature, relative humidity (RH), and carbon dioxide (CO_2) concentrations can help provide information relative to the proper functioning and control of HVAC systems. The perception of comfort is related to one's metabolic heat production, the transfer of heat to the surrounding environment, physiological adjustments, and body temperature. Heat transfer from a person's body to the environment is influenced by temperature, RH, air movement, personal activities, and clothing. ASHRAE specifies conditions in which 80% or more occupants in a given space would be expected to find the environment thermally comfortable.[16] The recommended range for temperature is 68°F to 76°F in the winter and 74°F to 80°F in the summer. As winter temperatures increase beyond 76°F, air quality is perceived as degrading, regardless of the actual quality. The recommended range for RH is 30 to 60 percent. RH below 30% may produce discomfort from dryness. At the same time, RH should be at the lowest possible level within the prescribed range to inhibit microbiological growth on walls, floors, furnishings, and other environmental surfaces.

CO_2 is a normal constituent of exhaled breath and measuring its concentration indoors can be useful as a screening technique to evaluate whether adequate amounts of fresh air are being brought into an occupied space. Indoor CO_2 concentrations are normally higher than the generally constant outdoor concentration (approximately 350 ppm).[11] When indoor CO_2 concentrations exceed 700 ppm over the outdoor concentration (approximately 1050 ppm total) in areas where the only known CO_2 source is exhaled breath, inadequate ventilation is suspected.[11] Elevated CO_2 concentrations can also suggest that concentrations of potentially hazardous indoor contaminants may also be increased.[46]

IEQ parameters (temperature, RH, and CO_2) were measured during the last visit to the shelter in October. These measurements were taken with three TSI (TSI Inc., St. Paul, MN) Model 8551 Q-Trak IAQ Monitors. The Q-Trak is capable of providing direct readings for dry-bulb temperature using a thermistor and RH using a thin-film capacitive sensor, ranging from 32°F to 122°F (±0.6°F) and 5% to 95% (±3%), respectively. The model 8551 measures CO_2 with a non-dispersive infrared sensor in the range of 0 to 5,000 ppm (±3% of reading). The instruments were calibrated for temperature and RH by the manufacturer in accordance with their standards and recommendations.[47] Just prior to use, the instruments were calibrated for CO_2 with certified gas standards provided by the manufacturer. Each selected area was monitored continuously for the IEQ parameters during the tracer gas tests.

In the annex, IEQ data were recorded in the respite area, Level 1 area, and VA area on October 15, 2004 (during tracer Tests 4 and 5). The results from Test 4 (Figure 26) show that the temperature in the Level 1 and VA areas was below the ASHRAE recommendations. The temperature in the respite area met the recommendations. The RH was between 30% and 60% in all three areas. CO_2 concentrations were below 1050 ppm in the respite area and VA area throughout the test. Two short duration peaks that exceeded the 1050 ppm level were seen in the Level 1 area.

Figure 27 shows the IEQ results from the annex during tracer Test 5. All three parameters were within the recommended ranges in all three areas, except for the temperature in the VA area, which started out slightly below the 68°F minimum for winter months.

During tracer Tests 6 and 7 (conducted on October 19 and 20, respectively) on the first floor of the main building, IEQ parameters were monitored in the cafeteria, the nurse waiting area, and the chiropractic clinic. On October 19 (Figure 28), the temperature in the cafeteria and nurse waiting area was within the recommended ranges. The chiropractic clinic was a couple of degrees lower than the 68°F minimum for winter months, although it was unoccupied at the time and may have been warmer if people were in the area. All three areas met the RH criteria. Similarly, all three areas showed CO_2 levels below 1050 ppm, except for the cafeteria once it opened for lunch service. The doors were opened for lunch at around 11:30 am when the CO_2 level was around 650 ppm. By noon, the CO_2 concentration had exceeded 1050 ppm. Because the Q-Trak was turned off shortly after noon, we do not know how high the CO_2 concentration eventually climbed.

Figure 29 shows the IEQ results for October 20. Again, the unoccupied chiropractic clinic was below the 68°F minimum for winter months. Also, during lunch, the temperature in the cafeteria exceeded the 76°F maximum temperature recommendation. All three areas met the RH criteria and all three areas showed CO_2 levels below 1050 ppm, though CO_2 levels in the cafeteria were rapidly increasing after the doors were opened for lunch at around 11:30 am. Again, because the Q-Trak was turned off at about noon, the eventual maximum CO_2 concentration remains unknown.

Computational Fluid Dynamics (CFD) Modeling

To help describe the movement of air through the shelter annex, we used CFD modeling. CFD is the mathematical (computational) study of the dynamics of fluid flow. In this case, the fluid of interest is air. Airpak® (Fluent, Inc., Lebanon, New Hampshire), a CFD software package designed specifically for ventilation modeling,[48] was used to develop a three-dimensional model of the annex and to input the ventilation measurements (supply and return) taken during our visits. The software then applied well-described physics to simulate fluid (air) flow in the space. In this case, the software output is air flow patterns inside the shelter annex, allowed us to visualize and enhance our understanding of air movement and predict how changes in the HVAC systems will affect the air flow patterns in the annex.

Separate models were created for the first and second floor of the annex using ventilation measurements from the January and October 2004 visits. The model output is the "mean age of air" within the space (in minutes), defined by Airpak® as "the average lifetime of air at a particular location in the room relative to the time when it first entered the room."[48] Caution should be taken when interpreting the mean age of air values from the CFD models, because the modeling results are solely based on the information put into the model, and certain factors that may affect the results (e.g., the effects of solar loads on the building, the effects of high temperatures associated with lighting fixtures, appliances, etc.) were not considered in the models.

Figure 30 shows the CFD modeling results for the annex first floor based on ventilation measurements from January. Darker shading represents lower mean age of air values, and therefore more ventilation air flow and more outside air. The respite area had a mean age of air of at least 30 minutes. The common area had a mean age of air around 10 minutes. Office 1, Offices 2 and 3, the storage area, and the monitor station all had mean age of air values of around 20 minutes. The mean age of air in the women's restroom and the laundry room was around 30 minutes. Since no sampling was ever conducted in the annex stairwells, the model was not solved for these areas and they appear bright white. However, the model was solved in the entryway, where the main door is opened and closed frequently. There, the model appears dark black, as the mean age of air was only one or two minutes.

The same model was solved using ventilation measurements from October (Figure 31). All of the flexible duct connections had been repaired and all of the UVGI fixtures were installed in October, and the ventilation associated with these improvements are included in the model. Compared with Figure 30, Figure 31 shows a dramatic improvement in the mean age of air for the respite area dropping from around 30 minutes in January to about 10 minutes in October. The model also shows that the air mixing in the respite area is fairly uniform with the SAM units operational. The mean age of air in the common area stayed about the same, at around 10 minutes. However, there were improvements in all other areas of the first floor, with the exception of the monitor station. Here, the mean age of air rose from around 20 minutes in January to closer to 30 minutes, corresponding to a measured reduction in air flow through the single vent in the monitor station from 90 CFM in January to 70 CFM in October (see Table 5).

Two similar CFD models were developed and solved for the second floor of the annex. Figure 32 shows the results using the January measurements. The mean age of air for the Level 1 and VA areas was around 20 to 25 minutes. The conference room and Office 4 both had a mean age of air around 20 minutes. Office 1 had a mean age of air of 10 minutes because of the high air flow from the supply vent located there. Offices 2 and 3 show up bright white because there was no air flow (flow rates of zero recorded) from the supply vents in those spaces in January. The restroom on the second floor had mean age of air of 25 minutes and greater, depending on the location. Again, solutions for the stairwells were not solved in the model, so they show up bright white.

Compared with the January results, CFD model results using the October measurements (Figure 33) shows that the mean age of air was generally reduced nearly everywhere on the annex second floor, meaning there was more air flow and increased outdoor air supply. The lone exception is Office 1, where the mean age of air increased to around 15 minutes because the air flow value measured in October was less than that in January (see Table 6). The Level 1 and VA areas have mean age of air values generally less than 15 minutes. The conference room and Offices 2, 3, and 4 all had a mean age of air around 15 minutes. The restroom on the second floor had mean age of air of 15 to 20 minutes.

CONCLUSIONS

Preexisting conditions (prior to September 2003) with the shelter's ventilation systems could have contributed to airborne *M. tuberculosis* transmission that resulted in the TB outbreak of 2001-2003. These conditions, relating primarily to inadequate fresh air supply and suboptimal filtration of air within the shelter, are summarized in the following paragraphs.

The ventilation systems in both buildings needed complete testing and balancing to assure optimal distribution of air within the shelter. The annex AHUs, while generally in good working order, had the outside air dampers screwed shut, severely limiting fresh air supply to that part of the shelter. The units in the main building clearly needed maintenance and repair and were extremely dirty, limiting airflows in the main building. Also, the MERV 7 filters that had been used in the AHUs are only about 25% efficient at filtering 1.0-3.0 µm particles, and would therefore allow most of the infectious droplet nuclei associated with *M. tuberculosis* transmission to pass through the filters, even under the best circumstances.

The overall condition of the AHUs was improved by cleaning, repairing, and replacing parts to improve outside air supply and airflows through the systems, as well as by upgrading the filters. The MERV 11 filters are about 70% efficient at filtering particles in the 1.0-3.0 µm size range, and should therefore capture most of the infectious droplet nuclei in the air that passes through them.

Unfortunately, even after cleaning and repairing the ventilation systems, many areas of the shelter still do not meet ASHRAE recommendations for outside air delivery to occupied areas. In fact, many of these areas probably can not meet the ASHRAE recommendations with the existing ventilation systems. For instance, our ventilation measurements in the annex showed that it would require 92% outside air intake for all areas on the first floor to meet ASHRAE recommendations (except for the women's restroom) and 58% outside air intake for all areas on the second floor to comply with ASHRAE recommendations. But, according to manufacturer specifications on the annex AHUs, they are only capable of bringing in a maximum of 25% outside air. Tracer gas tests showed that opening the main door (and other doors) into the annex does introduce additional outside air into the building by a means other than through the

AHUs. Unfortunately, this additional outside air is insufficient to result in additional areas of the annex meeting ASHRAE recommendations.

As with the annex, our measurements indicated that many areas of the first floor of the main building has do not meet the ASHRAE recommendations for outside air (i.e., the chiropractic restroom, classroom, and cafeteria). However, the AHUs in the main building can be set to bring in additional outside air, so they may be capable of supplying adequate outside air in some areas. This can be determined when the recommended testing and balancing of these AHUs is eventually done. From tracer tests in the main building, AHU 1, AHU 2, and AHU 5 are fairly independent of one another. This limits cross-flow of air between the areas served by these AHUs, which can help limit airborne transmission of infectious diseases from an infected individual to a susceptible person located in separate areas. However, within the area served by each of these AHUs, there is a substantial negative-pressure pull toward the AHU through the occupied space because of the open returns. While this is not an issue in the cafeteria, it is a major concern with AHU 1 and AHU 2, where air tends to flow from higher-risk areas to areas of less risk. To help prevent airborne transmission of disease, air should flow from lower-risk areas to higher-risk areas. It was also determined that the detoxification restroom was inappropriately under positive pressure in relation to the adjacent corridor. Restrooms should always be under negative pressure relative to the adjacent areas, if only to contain odors.

In addition to AHU improvements, UVGI fixtures have been installed in the highest-risk locations of the shelter. The annex has complete UVGI coverage with in-duct fixtures in both AHUs and upper-air fixtures in all areas, except the restrooms. Considering the combination of the MERV 11 filters and the in-duct UVGI fixtures, each AHU is capable of providing an "effective" filtration/inactivation efficiency of around 95% per pass for *M. tuberculosis* droplet nuclei. The presence of upper-air UVGI fixtures in the occupied space will further enhance this protection from infectious aerosols. The main building has appropriate upper-air UVGI fixtures installed in all high-risk areas of the first floor, providing an inactivation/kill rate for *M. tuberculosis* droplet nuclei of about 85% in those areas. Dilution ventilation from the fresh outside air supplied by the AHUs in the main building should enhance this protection, so attention to improving fresh air supply to meet ASHRAE recommendations is important.

In addition, we also noted that essentially all areas of the shelter in which we assessed temperature and relative humidity complied with the relevant ASHRAE recommendations intended for occupant comfort. The chiropractic clinic was slightly cooler than recommended, but temperature measurements were made when this room was unoccupied, and it might be warmer and in compliance with the ASHRAE recommendations when occupied. Temperature and relative humidity conditions in the shelter might be very different in the summer, but we did not assess them during summer conditions.

Since August 2003, there have no new cases of active tuberculosis at the shelter. While this may not be a direct result of the ventilation system improvements and UVGI installations, these environmental controls should help reduce the risk of transmission of *M. tuberculosis* at the shelter.

RECOMMENDATIONS

While AHU improvements and the installation of UVGI fixtures were important steps to reduce the likelihood of airborne disease transmission at the shelter, additional work is recommended. Based on our findings described in this report, the following recommendations are intended to further improve the ventilation systems at the shelter and reduce or prevent future outbreaks of TB or other airborne diseases:

- The facility management contractor should monitor all AHU maintenance work to ensure that each system is maintained properly. The routine maintenance of AHUs should be performed on a schedule consistent with the manufacturer's recommendations. The maintenance should include:
    - Proper filter installation and replacement (MERV 11 filters);

- Cleaning fans, heating/cooling units (ensuring valves are operable and pipes have no leaks), and drain pans;
- Verifying AHU setpoints and operation of outside air dampers;
- Confirming the direction of fan rotation and fan speed in revolutions per minute (rpm); and
- Replacing worn fan belts and greasing or replacing fan bearings, as needed.

- The facility management contractor should develop a written operations and maintenance (O&M) plan for the shelter AHUs. This plan should include appropriate preventive maintenance and filter replacement schedules, proper maintenance and filter replacement procedures, and a log for documenting maintenance and filter replacement events.

- The facility management contractor should develop a written O&M plan for the UVGI fixtures at the shelter. This plan should include appropriate preventive maintenance schedules, including lamp cleaning and replacement. It should also include the proper procedures and safety precautions to follow while working on the UVGI fixtures, and a log for recording maintenance and lamp replacement events.

- Provide training to shelter staff and contractors introducing the new written O&M plans. This training should cover proper maintenance procedures and associated safety precautions.

- Upgrade all ventilation systems to provide fresh, outdoor air sufficient to meet all applicable ASHRAE recommendations in all occupied spaces of the shelter. Incoming outside air will need to be adequately heated and cooled to maintain temperature control during winter and summer seasons. This will undoubtedly require additional boiler and chiller capacity, and potentially new coils and/or air preheaters. In some areas of the shelter, appropriate levels of outside air and temperature control are achievable with existing equipment. In other areas, upgrades to existing units or new units may be required.

- Have the HVAC systems throughout the entire shelter thoroughly tested, evaluated, and balanced by a licensed professional HVAC engineer, and have these results documented in writing. Every year, evaluate air flow rates through each area and each AHU to determine if systems need to be rebalanced.

- Install hard-ducted air returns from both nurse offices and the doctor's office to AHU 2 in the main building. Similarly, install hard-ducted returns from the chiropractic clinic and the detoxification clinic back to AHU 1. This will help keep these higher risk areas under negative pressure to the surrounding areas, limiting air flow from these areas to other adjacent areas. If negative pressure is not achieved by hard-ducting the returns, fans should be used in the return ducts to develop the necessary pressure difference.

- Finish installing UVGI fixtures throughout the remainder of the main building as funding becomes available. The fixtures should be installed in the priority order established in Interim Report II (Appendix B), summarized here:
  - Install upper-air UVGI fixtures inside the chapel.
  - Install upper-air UVGI fixtures in various "community" rooms (e.g., television rooms, study rooms, and classrooms) and any high-risk client sleeping areas. The fixture density should be based on manufacturer's recommendations.
  - Install in-duct UVGI fixtures in each of the 18 HVAC systems. These fixtures will provide a general level of ultraviolet irradiation to every area of the main building, and will result in an "effective" filtration of 95% per pass for each unit, as was achieved in the annex.
  - Install upper-air UVGI fixtures in any remaining dormitory areas.

Along with the general recommendations presented above, the following are some specific recommendations for small improvements that should ideally be implemented as soon as possible:

- Fix the leaks in the AHU pneumatics system in the main building. These leaks could affect the accuracy of pneumatic setpoints, and are causing the compressor (adjacent to AHU 6) to run constantly, instead of cycling on and off as it should. Fixing this problem should result in better AHU control and savings on electricity.

- Ensure that all restrooms are under negative pressure to the adjacent areas. During our visits, the detoxification restroom was under positive pressure compared to the adjacent corridor. Additional exhaust fans directly to the outside may be required.

- Replace all flexible ducts in the annex. The flexible duct material currently installed is very brittle and cracked, causing leaks of supply air directly into the return air plenum.

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TABLES AND FIGURES

Table 1. General AHU Information – Annex

Air Handling Unit (AHU) Number	Location	Carrier[A] Model	Unit Size[B]	Proper Filter Configuration in Unit[B,C]	Nominal Filter Face Area (ft^2)[B,D]	Nominal Capacity (CFM)[B,D]	Motor Power Rating (hp)[D]	Motor Amperage Rating (amps)[D]
1	Annex Roof - supplies first floor	48DR	014	2-16×20×2 4-16×25×2	15.6	5000	2	7.4
2	Annex Roof - supplies second floor	48DR	014	2-16×20×2 4-16×25×2	15.6	5000	2	7.4

[A]Carrier Corporation, Syracuse, New York 13221.
[B]Taken from Carrier Product Data for 48DP, DR Combination Heating/Cooling Units, Form 48DP-2P, 1994.
[C]Filter dimensions are in inches.
[D]ft^2 = square feet, fpm = feet per minute, CFM = cubic feet per minute, hp = horsepower, amps = amperes.

Table 2. General AHU Information – Main Building									
Air Handling Unit (AHU) Number	Floor	Location	Carrier[A] Model	Unit Size[B]	Proper Filter Configuration in Unit[B,C]	Nominal Filter Face Area (ft^2)[B,D]	Nominal Capacity at 550 fpm (CFM)[B,D]	Motor Power Rating (hp)[D]	Motor Amperage Rating (amps)[D]
1	1st	Chiropractic Clinic Waiting	39LF	12	3-20×25×2	10.4	5126	5	16
2	1st	Class Room	39LF	12	3-20×25×2	10.4	5126	5	16
3	1st	USDA Food Storage	39LE	08	2-20×25×2	6.9	3619	3	10
4	1st	Pantry	39LF	06	2-20×20×2	5.6	2596	2	6.3
5	1st	Cafeteria	39LF	15	6-16×20×2	13.3	6666	5	16
6	1st	Maintenance Area	39LE	06	2-20×20×2	5.6	2596	2	6.3
7	2nd	East Across from Main Stairwell (Room #19)	39LF	08	2-20×25×2	6.9	3619	5	16
8	2nd	West Across from Main Stairwell (Room #20)	39LF	10	2-16×25×2 1-20×25×2	9.0	4372	5	16
9	2nd	West of Main Stairwell	39LF	06	2-20×20×2	5.6	2596	2	6.3
10	2nd	Capt. Best’s Office	39LF	08	2-20×25×2	6.9	3619	3	10
11	2nd	Outside Chapel Entrance	39LD	03	2-16×16×2	4.4	1996	1	3.2
12	2nd	Office Behind Copy Room	39LF	06	2-20×20×2	5.6	2596	2	6.3
13	2nd	Back of Chapel	39LD	03	2-16×16×2	4.4	1996	1	3.2
14	3rd	East Across from Main Stairwell	39LF	10	2-16×25×2 1-20×25×2	9.0	4372	5	16
15	3rd	West Across from Main Stairwell	39LF	15	6-16×20×2	13.3	6666	5	16
16	3rd	East End of Main Corridor	39LF	08	2-20×25×2	6.9	3619	3	10
17	3rd	Bathroom	39LF	10	2-16×25×2 1-20×25×2	9.0	4372	5	16
18	3rd	Beside Spiritual Growth TV Lounge	39LF	10	2-16×25×2 1-20×25×2	9.0	4372	5	16

[A]Carrier Corporation, Syracuse, New York 13221.
[B]Taken from Carrier Product Data for 39L Central Station Air Handlers Sizes 03-25, Form 39L-4PD, 1998.
[C]Filter dimensions are in inches.
[D]ft^2 = square feet, fpm = feet per minute, CFM = cubic feet per minute, hp = horsepower, amps = amperes.

Table 3. Filter Configurations and General Notes from NIOSH AHU Inspections – Main Building, October 2004

Air Handling Unit (AHU) Number	Proper Filter Configuration[A]	Actual Filter Configuration	Filter Configuration Correct?	Additional Notes
1	3-20×25×2	3-20×25×2	Yes	Filters were installed backwards, corrected by NIOSH Untreated, stagnant water in condensate pan
2	3-20×25×2	3-20×25×2	Yes	Loose fan belt Untreated, stagnant water in condensate pan
3	2-20×25×2	3-16×25×2	NO	Untreated, stagnant water in condensate pan
4	2-20×20×2	1-20×20×2 1-20×25×2	NO	Filters were installed backwards, corrected by NIOSH but configuration still incorrect Untreated, stagnant water in condensate pan
5	6-16×20×2	6-16×20×2	Yes	Filters were installed backwards, corrected by NIOSH Untreated, stagnant water in condensate pan
6	2-20×20×2	2-20×20×2	Yes	Fan motor needs maintenance
7	2-20×25×2	3-20×25×2	NO	Filters were installed backwards, corrected by NIOSH and 2 of 3 filters reinstalled (correct)
8	2-16×25×2 1-20×25×2	3-20×25×2	NO	Filters were installed backwards, corrected by NIOSH but configuration still incorrect
9	2-20×20×2	1-20×20×2 1-20×25×2	NO	Filters were installed backwards, corrected by NIOSH but configuration still incorrect
10	2-20×25×2	2-20×25×2	Yes	Filters were installed backwards, corrected by NIOSH
11	2-16×16×2	2-16×20×2	NO	Filters were installed backwards, corrected by NIOSH but configuration still incorrect
12	2-20×20×2	1-20×20×2 1-20×25×2	NO	Loose fan belt
13	2-16×16×2	2-16×20×2	NO	AHU locked out – never used – could not be started
14	2-16×25×2 1-20×25×2	3-16×25×2	NO	Filters were installed backwards, corrected by NIOSH but configuration still incorrect Hot water coils very dirty Air leaking from electric-pneumatic switch on control panel
15	6-16×20×2	6-16×25×2	NO	Filters were installed backwards, corrected by NIOSH but configuration still incorrect Loose fan belt Hot water valve leaking on floor
16	2-20×25×2	2-20×25×2	Yes	Unit was clean
17	2-16×25×2 1-20×25×2	1-16×25×2 2-20×25×2	NO	Filters were installed backwards, corrected by NIOSH but configuration still incorrect Loose fan belt
18	2-16×25×2 1-20×25×2	3-20×25×2	NO	Filters were installed backwards, corrected by NIOSH but configuration still incorrect

[A]Taken from Carrier Product Data for 39L Central Station Air Handlers Sizes 03-25, Form 39L-4P, 1989. Filter dimensions are in inches.

Table 4. Amperage Draws on AHU Fan Motors – Main Building				
Air Handling Unit (AHU) Number	Before Cleaning Coils with MERV[A] 7 Filters Installed (Dirty)[B]	After Cleaning Coils with New MERV[A] 11 Filters Installed		
	Amperage Reading (amps)	Amperage Reading (amps)	Difference Dirty w/ MERV 7 vs. Clean w/ MERV 11	
			Amperage (amps)	Percent (%)
1	8.2	10.0	+1.8	+22.0
2	8.4	10.2	+1.8	+21.4
3	6.8	7.6	+0.8	+11.8
4	4.1	5.4	+1.3	+31.7
5	8.7	9.5	+0.8	+9.2
6	3.4	3.9	+0.5	+14.7
7	NR[C]	10.1	N/A[D]	N/A[D]
8	10.5	10.9	+0.4	+3.8
9	3.6	5.2	+1.6	+44.4
10	6.6	7.9	+1.3	+19.7
11	2.2	2.6	+0.4	+18.2
12	3.4	3.8	+0.4	+11.8
13	NR[C]	N/A[D,E]	N/A[D,E]	N/A[D,E]
14	8.7	10.8	+2.1	+24.1
15	9.8	10.8	+1.0	+10.2
16	6.1	7.7	+1.6	+26.2
17	8.8	10.0	+1.2	+13.6
18	8.0	9.5	+1.5	+18.8

[A]MERV = Mechanical Efficiency Reporting Value.
[B]These readings collected by representatives from Albert Arno, Inc., under contract to Lenzy Hayes, Inc. All other readings collected by NIOSH.
[C]NR = not reported. These values were not included in the report from Albert Arno, Inc. to Lenzy Hayes, Inc. (faxed April 12, 2004).
[D]N/A = not applicable.
[E]AHU was locked out and could not be started.

Table 5. Ventilation Measurements (CFM) – Annex First Floor				
SUPPLIES				
Vent #	January 2004	April 2004	July 2004	October 2004
1	105	125	120	90
2	165	170	160	215
3	155	165	160	150
4	170	180	170	180
5	150	150	160	185
6	105	130	140	150
7	155	130	150	240
8	120	125	125	195
9	90	40	105	70
10	not measured	0	-150	35
11	not measured	0	-40	55
12	150	170	170	150
13	40	160	150	145
14	150	170	185	155
15	180	190	-40	280
16	270	280	225	320
17	190	215	200	230
18	215	240	225	260
19	220	240	250	220
20	135	160	150	160
21	220	260	240	225
22	140	150	150	135
23	110	130	120	110
RETURNS[A]				
Grille ID	January 2004	April 2004	July 2004	October 2004
A	-170	-200	-190	-230
B	-175	-240	-240	-285
C	-155	-200	-210	-200
D	-155	160	-140	-250
E	-45	175	-150	-135
F	0	50	0	-35
G	0	-40	-70	-90
H	0	30	-55	-60

[A]Negative values reflect proper operation of returns (i.e., air is leaving the space).

Table 6. Ventilation Measurements (CFM) – Annex Second Floor				
SUPPLIES				
Vent #	January 2004	April 2004	July 2004	October 2004
1	175	180	185	180
2	180	190	200	190
3	250	230	240	210
4	180	210	170	115
5	220	225	240	220
6	190	180	180	175
7	not measured	220	210	200
8	210	215	210	185
9	120	125	125	105
10	0	0	0	60
11	0	0	0	85
12	170	170	160	155
13	105	110	85	235
14	75	85	80	87
15	300	300	270	280
16	245	260	245	230
17	150	150	155	130
18	200	205	190	195
19	215	230	200	190
20	185	190	185	180
21	260	270	275	240
RETURNS[A]				
Grille ID	January 2004	April 2004	July 2004	October 2004
A	-220	-100	-120	-120
B	-210	-100	-105	-160
C	-190	-90	-70	-115
D	-185	-80	-240	-210
E	-200	-120	-165	-190
F	-190	-90	-260	-240
G	0	0	0	0
H	0	0	-155	-330
I	0	0	-35	-20

[A]Negative values reflect proper operation of returns (i.e., air is leaving the space).

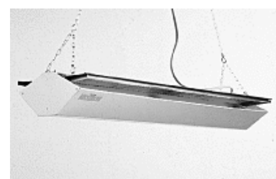
Table 7. Total and Outside Air CFM/person and ACH Delivered by Ventilation System – Annex								
FIRST FLOOR								
Space	Vents Included in Calculation	Total Flow into Space (CFM)	Approximate Volume of Space (ft^3)	Typical Occupants in Space[A]	Theoretical TOTAL CFM/person	Theoretical OUTSIDE AIR CFM/person[B,C]	TOTAL Air Changes per Hour (ACH)	OUTSIDE AIR Air Changes per Hour (ACH)[B]
Respite Area	1-8	1405	21,210	86	16.3	**4.1**	4.0	1.0
Monitor Station	9	70	720	2	35.0	**8.8**	5.8	1.5
Restroom/Laundry	N/A[D]	725[D]	4455	N/A[E]	120.8[E]	**30.2**[E]	9.8	2.4
Ladies Room	10	35	360	N/A[E]	35.0[E]	**8.8**[E]	5.8	1.5
Common Area[F]	16-21	1415	16,720	50	28.3	**7.1**	5.1	1.3
Office 1	15	280	1440	1	280.0	70.0	11.7	2.9
Offices 2 and 3[G]	22-23	245	3120	2	122.5	30.6	4.7	1.2
Entire 1st Floor[H]	1-23	3955	48,025	141	28.0	**7.0**	4.9	1.2
SECOND FLOOR								
Space	Vents Included in Calculation	Total Flow into Space (CFM)	Approximate Volume of Space (ft^3)	Typical Occupants in Space[A]	Theoretical TOTAL CFM/person	Theoretical OUTSIDE AIR CFM/person[B,C]	TOTAL Air Changes per Hour (ACH)	OUTSIDE AIR Air Changes per Hour (ACH)[B]
Level 1 Area[I]	1-8	1475	24,420	31	47.6	**11.9**	3.6	0.9
Office 1	9	105	575	1	105.0	26.3	11.0	2.7
Office 2	10	60	470	1	60.0	**15.0**	7.7	1.9
Office 3	11	85	540	1	85.0	21.3	9.4	2.4
Restroom	N/A[D]	520[D]	4345	N/A[E]	86.7[E]	**21.7**[E]	7.2	1.8
VA Area	15-21	1445	22,320	30	48.2	**12.0**	3.9	1.0
Entire 2nd Floor[H]	1-21	3645	52,670	64	57.0	**14.2**	4.2	1.0

[A]Based on maximum number of beds available or observations while at the shelter. May or may not be typical of most days.
[B]Assuming 25% outside air intake, which is the maximum for the annex AHUs.
[C]Numbers in **bold** show those areas that **do not** meet their respective ASHRAE recommendations.
[D]N/A = not applicable. Since both restrooms are correctly under negative pressure, calculations are done using return and exhaust air, not supply values.
[E]N/A = not applicable. Restroom values are in CFM per toilet/urinal.
[F]For this calculation, the Common Area includes the Storage Area (beside Office 1) because the walls do not extend to the ceiling.
[G]For this calculation, Office 2 and Office 3 are combined because the wall separating them does not extend to the ceiling.
[H]Does not include stairwells and/or unventilated closets/storage space where doors are constantly closed.
[I]For this calculation, the Level 1 Area includes the Conference Room and Office 4 because the walls in these areas do not extend to the ceiling.

Table 8. Total and Outside Air CFM/person and ACH Delivered by Ventilation System – Main Building

Space	Supply Vents in Space	Total Flow into Space (CFM)	Approximate Volume of Space (ft^3)	Typical Occupants in Space[A]	Theoretical TOTAL CFM/person	Theoretical OUTSIDE AIR CFM/person[B,C]	TOTAL Air Changes per Hour (ACH)	OUTSIDE AIR Air Changes per Hour (ACH)[B]
AHU 1								
Chiropractic Clinic	3	1675	12,015	6	279.2	69.8	8.4	2.1
Chiropractic Restroom	N/A[D]	275[D]	1955	N/A[E]	91.7[E]	**22.9**[E]	8.4	2.1
Chiropractic Waiting Area	1	660	8290	3	220.0	55.0	4.8	1.2
Detoxification Clinic	2	1310	6160	8	163.8	40.9	12.8	3.2
Detoxification Office	2	355	1335	2	177.5	44.4	16.0	4.0
Detoxification Corridor	1	435	1740	0	N/A	N/A	N/A	N/A
Detoxification Restroom	2[F]	1010	2930	N/A[E]	505.0[E]	126.3[E]	20.7	5.2
Entire AHU 1	12	5645	34425	19	297.1	**74.3**	9.8	2.5
AHU 2								
Space	Supply Vents in Space	Total Flow into Space (CFM)	Approximate Volume of Space (ft^3)	Typical Occupants in Space[A]	Theoretical TOTAL CFM/person	Theortical OUTSIDE AIR CFM/person[B,C]	TOTAL Air Changes per Hour (ACH)	OUTSIDE AIR Air Changes per Hour (ACH)[B]
Nurse Office 1	1	295	1890	1	295.0	73.8	9.4	2.3
Nurse Office 2	1	265	1575	3	88.3	22.1	10.1	2.5
Doctor Office	1	200	1575	2	100.0	25.0	7.6	1.9
Nurse Waiting Area	3	1965	12,505	25	78.6	19.7	9.4	2.4
Classroom	2	1585	7055	40	39.6	**9.9**	13.5	3.4
Electrical/Phone Closet	1	120	135	0	N/A[D]	N/A[D]	N/A[D]	N/A[D]
Entire AHU 2	9	4430	24,735	71	62.4	**15.6**	10.7	2.7
AHU 5								
Space	Supply Vents in Space	Total Flow into Space (CFM)	Approximate Volume of Space (ft^3)	Typical Occupants in Space[A]	Theoretical TOTAL CFM/person	Theoretical OUTSIDE AIR CFM/person[B,C]	TOTAL Air Changes per Hour (ACH)	OUTSIDE AIR Air Changes per Hour (ACH)[B]
Cafeteria/Entire AHU 5	9	4910	21,925	80	61.4	**15.3**	13.4	3.4

[A]Based on maximum number of beds available or observations while at the shelter. May or may not be typical of most days.
[B]Assuming 25% outside air intake. This value could increase or decrease depending on actual system setpoints.
[C]Numbers in **bold** show those areas that **do not** meet their respective ASHRAE recommendations.
[D]N/A = not applicable. Since restroom is correctly under negative pressure, calculations are done using return air, not supply values.
[E]N/A = not applicable. Restroom values are in CFM per toilet/urinal.
[F]Detoxification Restroom was under positive pressure (i.e., supply exceeded return), so calculations were done using supply values.

Table 9. UVGI Fixtures Used at Harbor Light Shelter			
Type of Fixture	Nominal Watts	UV-C Watts[A]	Picture of Fixture
In-Duct Fixture[B]	60	17	
Upper-Air – Wall Mount Fixture[C]	36	9.4	
Upper-Air – Pendant Fixture	36	9.4	
Upper-Air – Corner Mount Fixture	36	9.4	
Upper-Air – Silent Air Mover (SAM)[D]	36	9.4	

[A]UV-C watts over the lifetime of the lamp (9000 hours for in-duct lamps, 8000 hours for upper-air lamps) provided by the manufacturer.
[B] Four of the in duct fixtures were placed in each AHU on the Annex for a total of 240 nominal watts (68 UV-C watts) in each.
[C]The two wall mount fixtures installed in the conference room on the second floor of the annex were lower intensity units. Each provided 18 nominal watts and 5.5 UV-C watts.
[D]SAMs are the only UVGI fixtures that move air themselves. These units pull in room air from the bottom and exhaust irradiated air from the top, parallel to the ceiling. The flow rate is approximately 500 cubic feet per minute (CFM).

Table 10. UV Irradiance (W/ft^2) in Areas with Upper-Air UVGI Fixtures			
Annex – First Floor			
Location	UV-C Watts[A] (W)	Approximate Area of Space (ft^2)	Irradiance (W/ft^2)
Respite Area	47	2360	0.02
Common Area[B]	75	1675	0.04
Monitor Station	9.4	90	0.10
Office 1	9.4	145	0.06
Offices 2 and 3[C]	19	315	0.06
Annex – Second Floor			
Location	UV-C Watts[A] (W)	Approximate Area of Space (ft^2)	Irradiance (W/ft^2)
Level 1 Area[D]	47	2700	0.02
VA Area	38	2230	0.02
Office 1	9.4	75	0.13
Office 2	9.4	60	0.16
Office 3	9.4	70	0.13
Main Building – First Floor			
Location	UV-C Watts[A] (W)	Approximate Area of Space (ft^2)	Irradiance (W/ft^2)
Main Corridor	47	865	0.05
Cafeteria	75	1825	0.04
Nurse Waiting Area	38	1185	0.03
Class Room	38	670	0.06
Chiropractic Waiting Area	19	790	0.02
Detoxification Clinic	19	585	0.03
Detoxification Office	9.4	125	0.08
Nurse Office 1	9.4	170	0.06
Nurse Office 2	9.4	145	0.06
Doctor Office	9.4	145	0.06

[A]UV-C watts over the lifetime of the lamp (8000 hours) provided by the manufacturer.
[B]For this calculation, the Common Area includes the Storage Area (beside Office 1) because the walls do not extend to the ceiling.
[C]For this calculation, Office 2 and Office 3 are combined because the wall separating them does not extend to the ceiling.
[D]For this calculation, the Level 1 Area includes the Conference Room and Office 4 because the walls in these areas do not extend to the ceiling.

Table 11. General Tracer Gas Test Information with Dosing Regimen			
Test ID	Building	Date	Dosing Regimen
Test 1	Annex	July 13, 2004	50 mL SF_6 gas released in Annex AHU 1 supply 0.14 mL PMCH volatilized inside Respite Area 0.37 mL PDCB volatilized in Annex AHU 2 supply
Test 2	Annex	July 14, 2004	150 mL SF_6 gas released in Annex AHU 1 supply 0.42 mL PMCH volatilized inside Respite Area 1.11 mL PDCB volatilized in Annex AHU 2 supply
Test 3	Annex	July 15, 2004	150 mL SF_6 gas released in Annex AHU 2 supply 0.42 mL PMCH volatilized inside Respite Area 1.11 mL PDCB volatilized in Annex AHU 1 supply
Test 4	Annex	October 15, 2004	150 mL SF_6 gas released in Annex AHU 1 supply 0.42 mL PMCH volatilized inside Respite Area 1.11 mL PDCB volatilized in Annex AHU 2 supply
Test 5	Annex	October 15, 2004	150 mL SF_6 gas released in Annex AHU 1 supply 0.42 mL PMCH volatilized inside Respite Area 1.11 mL PDCB volatilized in Annex AHU 2 supply
Test 6	Main	October 19, 2004	30 mL SF_6 gas released inside Detoxification Clinic 0.2 mL PMCH volatilized inside Chiropractic Clinic 0.5 mL PDCB volatilized inside Nurse Office 1
Test 7	Main	October 20, 2004	30 mL SF_6 gas released inside Detoxification Clinic 0.2 mL PMCH volatilized inside Chiropractic Clinic 0.5 mL PDCB volatilized inside Nurse Office 1

Table 12. Tracer Gas Results – Annex First Floor Respite Area										
Location	Test 1		Test 2		Test 3		Test 4		Test 5	
	SF_6[A] Results (ACH_L)	PMCH[A] Results (ACH_L)	SF_6[A] Results (ACH_L)	PMCH[A] Results (ACH_L)	PDCB[A] Results (ACH_L)	PMCH[A] Results (ACH_L)	SF_6[A] Results (ACH_L)	PMCH[A] Results (ACH_L)	SF_6[A] Results (ACH_L)	PMCH[A] Results (ACH_L)
1	1.95	1.63	2.40	2.28	2.93	2.02	1.87	1.83	1.97	1.82
2	Error[B]	Error[B]	2.31	2.38	2.90	1.97	NS[C]	NS[C]	NS[C]	NS[C]
3	1.74	1.72	2.38	2.45	2.94	1.92	1.86	1.87	1.93	2.13
4	2.01	1.72	2.41	2.43	2.90	1.89	NS[C]	NS[C]	NS[C]	NS[C]
5	1.99	1.74	2.38	2.39	2.89	1.93	1.76	1.84	1.90	1.82
6	1.82	1.55	2.46	2.44	2.93	1.95	NS[C]	NS[C]	NS[C]	NS[C]
7	1.92	1.69	2.46	2.34	2.92	1.93	NS[C]	NS[C]	NS[C]	NS[C]
8	1.99	1.68	2.40	2.30	2.89	1.93	1.90	1.82	1.89	1.85
AVERAGE	1.92	1.68	2.40	2.38	2.91	1.94	1.85	1.84	1.92	1.91
CFM/person[D]	7.9	6.9	9.9	9.8	12.0	8.0	7.6	7.6	7.9	7.9

[A]SF_6 = sulfur hexafluoride, PMCH = perfluoromethylcyclohexane, PDCB = perfluorodimethylcyclobutane.
[B]Caps used to seal the syringes fell off the first three samples prior to analysis.
[C]NS = No sample taken.
[D]CFM/person based on outside air delivered by ventilation system and outside air entering the building through open doors and leaks in the building envelope (e.g., around windows). May also include air from second floor migrating to the first floor. Based on the average for all sampling locations. Assumes an occupancy of 86 people, based on the available number of beds

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Table 13. Tracer Gas Results – Annex First Floor Common Area

Location	Test 1	Test 2	Test 3	Test 4	Test 5
	SF_6[A] Results (ACH_L)	SF_6[A] Results (ACH_L)	PDCB[A] Results (ACH_L)	SF_6[A] Results (ACH_L)	SF_6[A] Results (ACH_L)
9	2.03	2.69	2.91	Error[B]	2.20
10	2.02	2.91	2.94	Error[B]	2.19
11	1.96	2.53	2.90	Error[B]	2.23
12	1.96	2.95	2.88	Error[B]	2.22
AVERAGE	1.99	2.77	2.91	N/A[C]	2.21
CFM/person[D]	11.1	15.4	16.2	N/A[C]	12.3

[A]SF_6 = sulfur hexafluoride, PDCB = perfluorodimethylcyclobutane.
[B]Due to a computer problem, analytical results were lost.
[C]N/A = not applicable.
[D]CFM/person based on outside air delivered by ventilation system and outside air entering the building through open doors and leaks in the building envelope (e.g., around windows). May also include air from second floor migrating to the first floor. Based on the average for all sampling locations. Assumes an occupancy of 50 people, based on NIOSH experience at the shelter.

Table 14. Tracer Gas Results – Annex Second Floor Level 1 Area					
Location	Test 1	Test 2	Test 3	Test 4	Test 5
	PDCB[A] Results (ACH_L)	PDCB[A] Results (ACH_L)	SF_6[A] Results (ACH_L)	PDCB[A] Results (ACH_L)	PDCB[A] Results (ACH_L)
1	1.60	2.33	1.12	1.10	1.16
2	1.60	2.36	0.95	1.12	1.08
3	1.58	2.42	1.07	1.11	1.30
4	1.52	2.39	1.09	1.13	1.01
5	1.53	2.35	1.15	NS[B]	NS[B]
AVERAGE	1.58	2.37	1.08	1.12	1.14
CFM/person[C]	20.7	31.1	14.2	14.7	15.0

[A]PDCB = perfluorodimethylcyclobutane, SF_6 = sulfur hexafluoride.
[B]NS = No sample taken.
[C]CFM/person based on outside air delivered by ventilation system and outside air entering the building through open doors and leaks in the building envelope (e.g., around windows). May also include air from first floor migrating to the second floor. Based on the average for all sampling locations. Assumes an occupancy of 31 people, based on the available number of beds.

Table 15. Tracer Gas Results – Annex Second Floor VA Area					
Location	Test 1	Test 2	Test 3	Test 4	Test 5
	PDCB[A] Results (ACH_L)	PDCB[A] Results (ACH_L)	SF_6[A] Results (ACH_L)	PDCB[A] Results (ACH_L)	PDCB[A] Results (ACH_L)
6	1.29	2.35	1.22	1.10	1.26
7	1.56	2.38	1.24	1.13	1.14
8	1.41	2.36	1.35	1.10	0.99
9	1.52	2.40	1.28	1.06	1.13
10	1.60	2.40	1.09	NS[B]	NS[B]
11	1.62	2.40	1.23	NS[B]	NS[B]
AVERAGE	1.50	2.38	1.24	1.10	1.13
CFM/person[C]	18.6	29.5	15.4	13.6	14.0

[A]PDCB = perfluorodimethylcyclobutane, SF_6 = sulfur hexafluoride.
[B]NS = No sample taken.
[C]CFM/person based on outside air delivered by ventilation system and outside air entering the building through open doors and leaks in the building envelope (e.g., around windows). May also include air from first floor migrating to the second floor. Based on the average for all sampling locations. Assumes an occupancy of 30 people, based on the available number of beds.

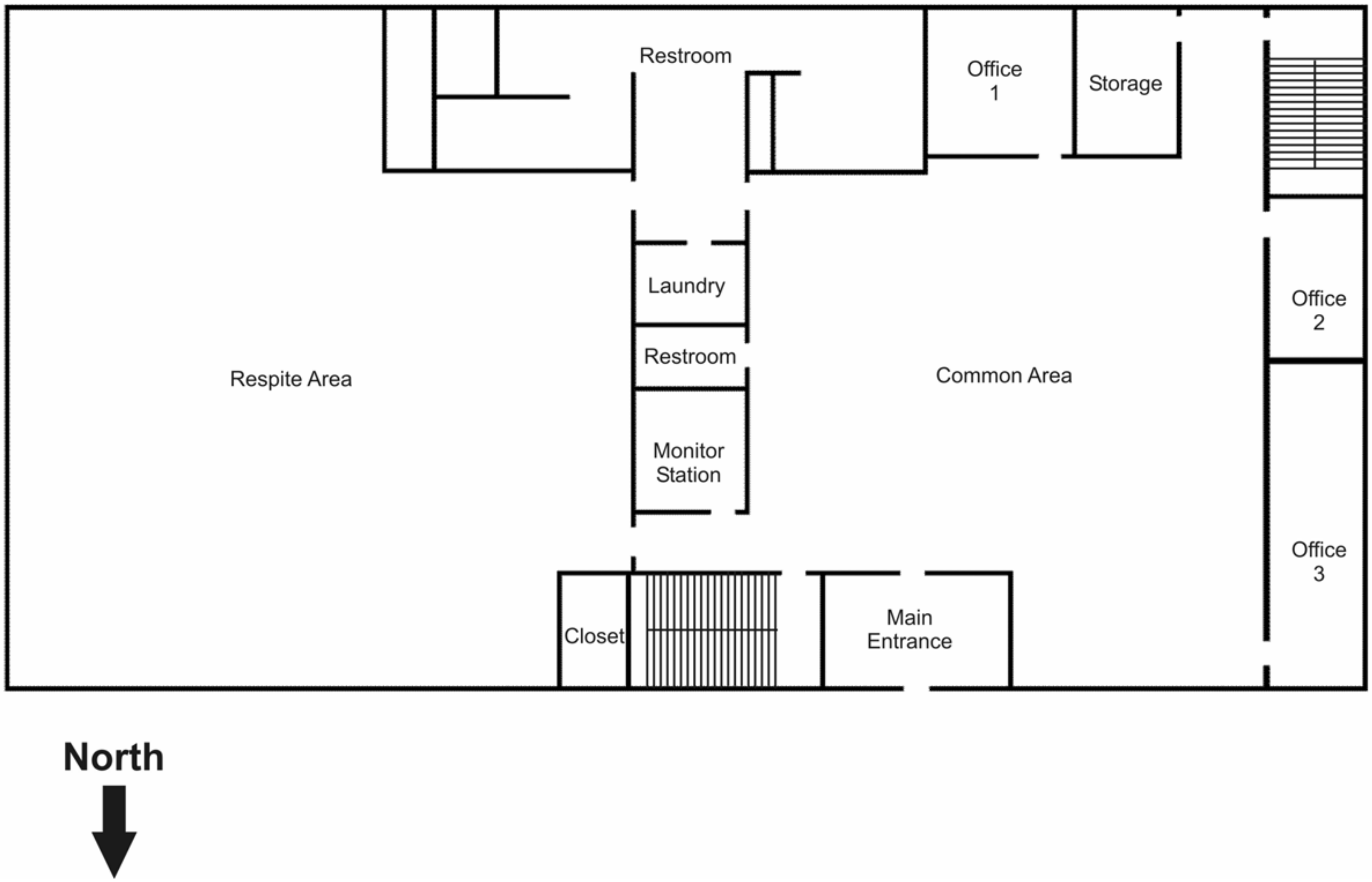


Figure 1. Basic floor plan of the annex first floor.

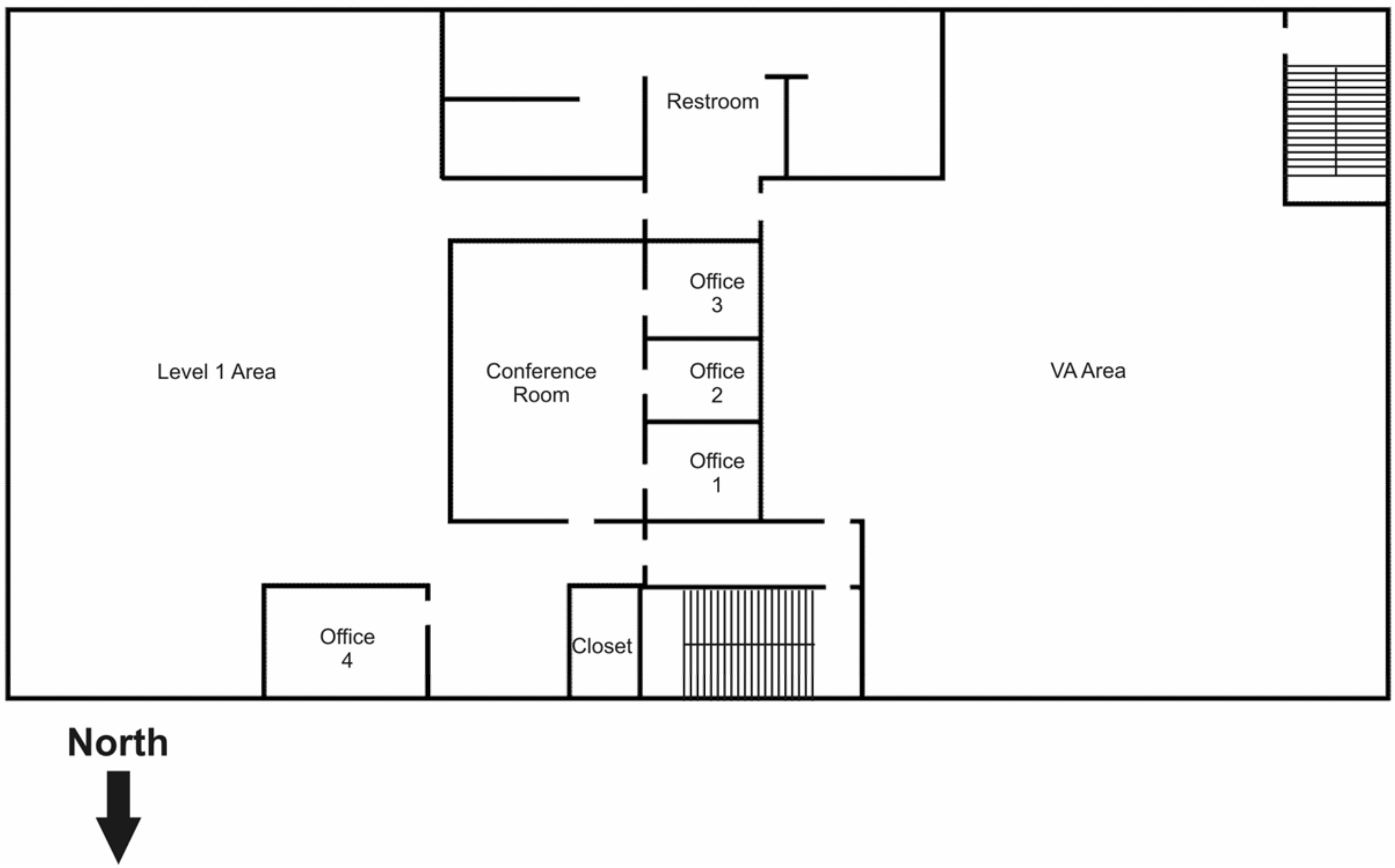


Figure 2. Basic floor plan of the annex second floor.

Figure 3. Basic floor plan of the main building first floor, including the locations of AHUs.

Figure 4. Rooftop AHUs on the annex. Picture shows outside air intakes.

Figure 5. Back side of annex rooftop AHUs.

Figure 6. Outside air damper of annex AHU. Arrow is pointing to screws holding damper closed.

Figure 7. AHU in main building covered with dust and debris.

Figure 8. AHU in main building showing thick layer of dust and debris inside.

Figure 9. AHU in main building showing dust and debris built up on heating/cooling coils.

Figure 10. Condensate pan for AHU in main building having inoperable pump. The pan is full of stagnant, dirty water.

Figure 11. Damage to tile floor where a condensate pan leaked or overflowed.

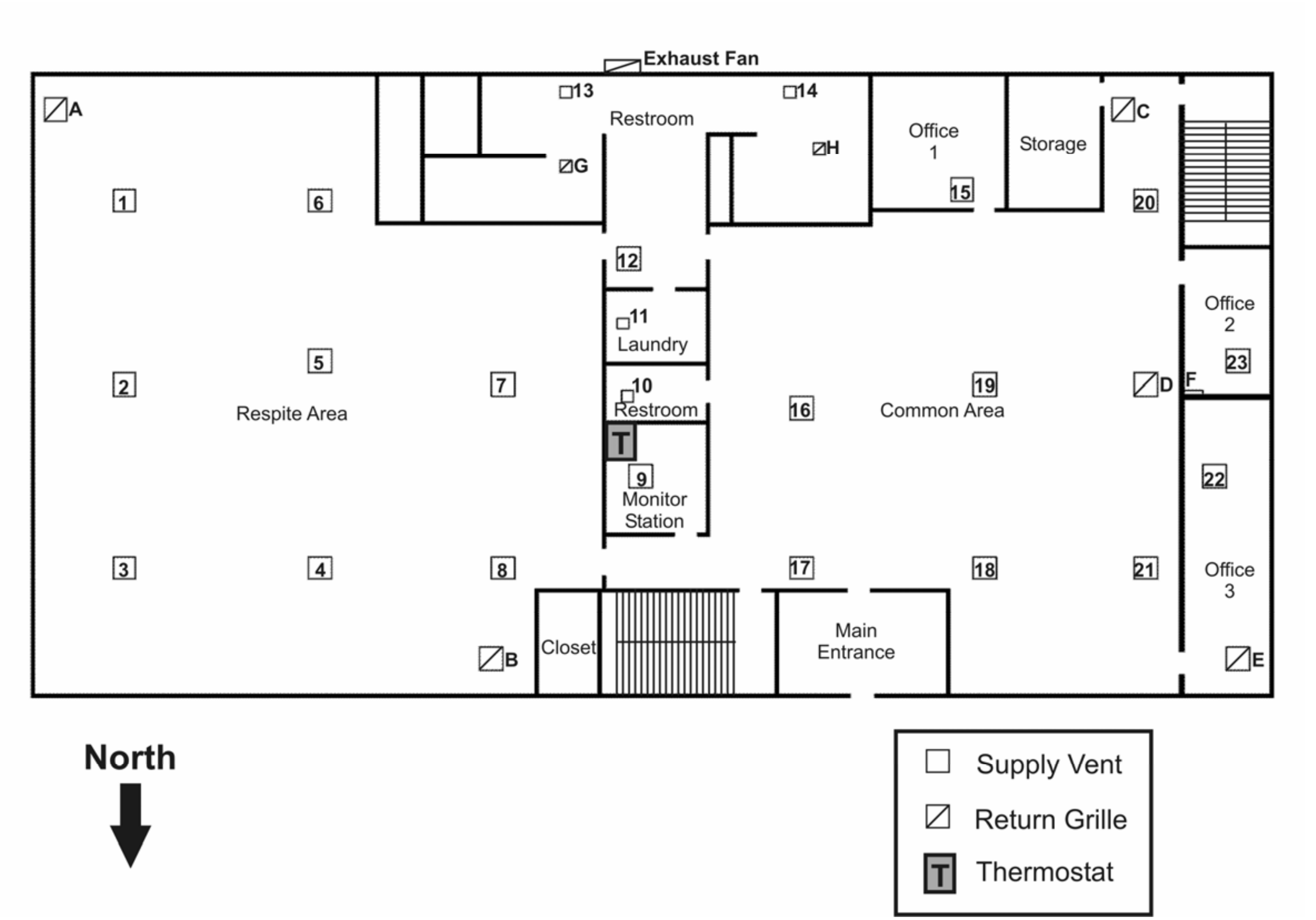


Figure 12. Supply vent and return grille locations on the annex first floor.

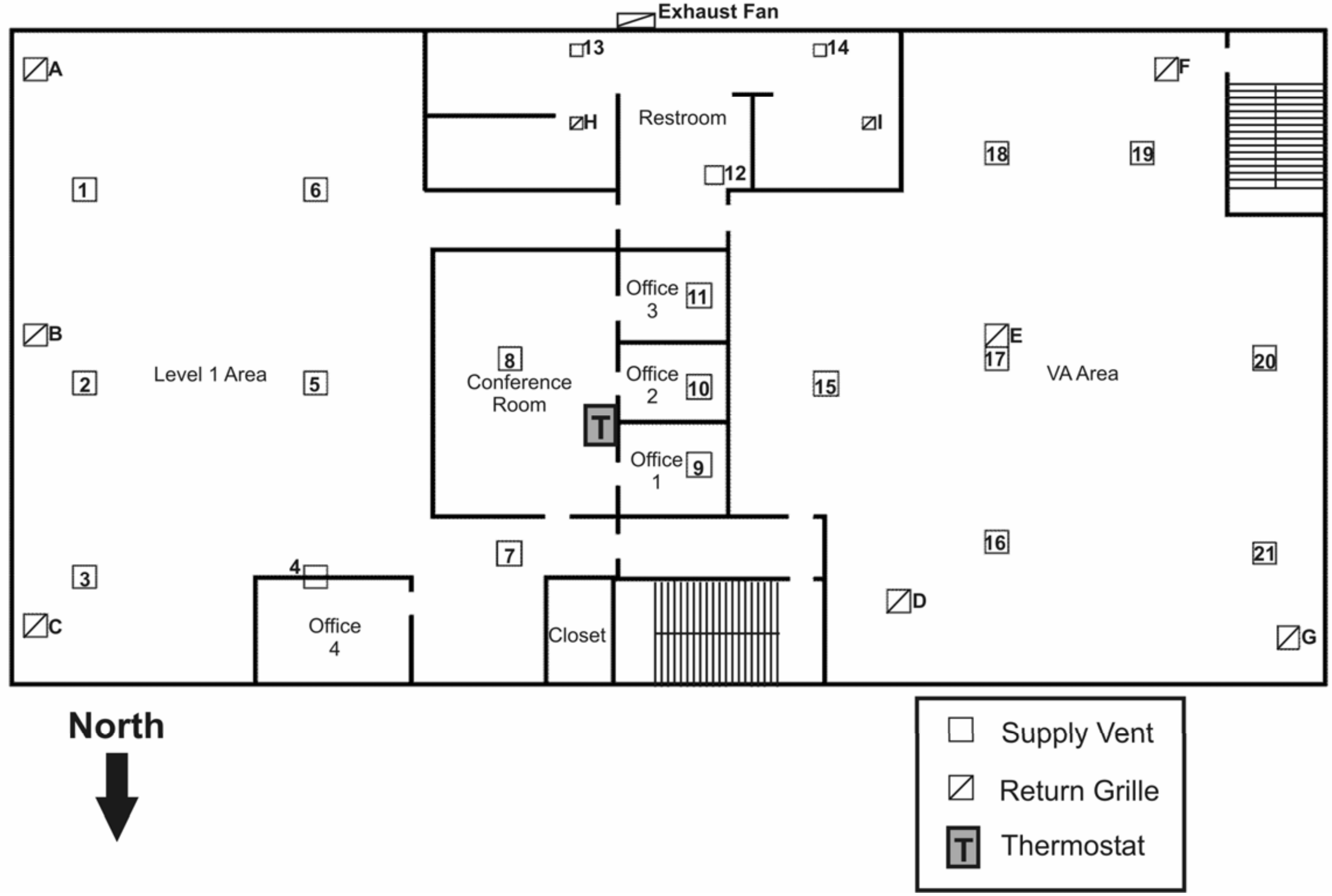


Figure 13. Supply vent and return grille locations on the annex second floor.

Figure 14. Supply duct work with vents extending from room housing AHU 5 in the main building. A return grille cut into the wall can also be seen on the left.

Figure 15. Supply duct work with vents extending along the ceiling of the cafeteria in the main building.

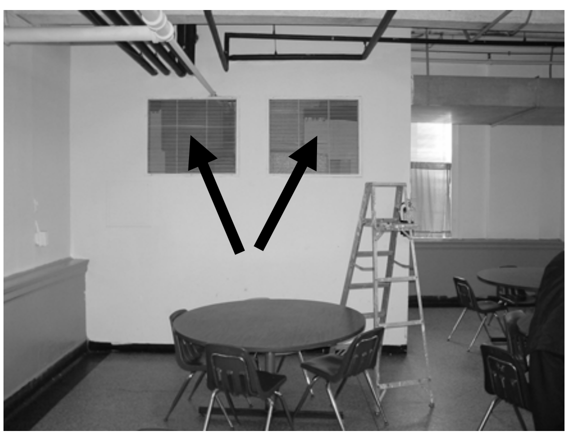


Figure 16. Return grilles through wall into the room housing AHU 5 from inside the cafeteria.

Figure 17. Placement of UVGI fixtures on the first floor of the annex.

Figure 18. Placement of UVGI fixtures on the second floor of the annex.

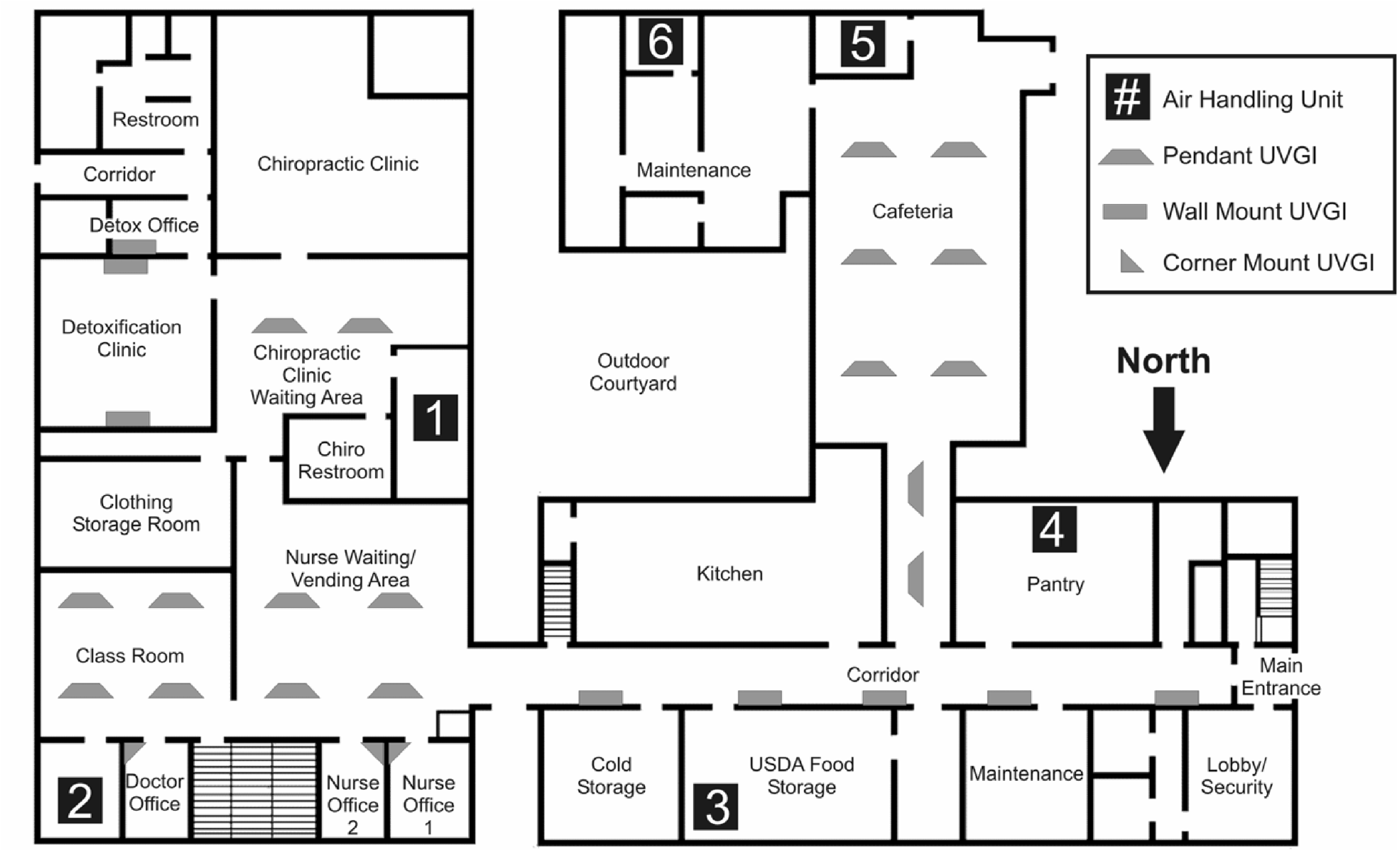


Figure 19. Placement of UVGI fixtures on the first floor of the main building.

Figure 20. Silent air mover (SAM) UVGI fixtures installed in the annex respite area.

Figure 21. Pendant UVGI fixtures installed in the main building cafeteria.

Figure 22. Corner-mount UVGI fixture installed in Nurse Office 1 in the main building.

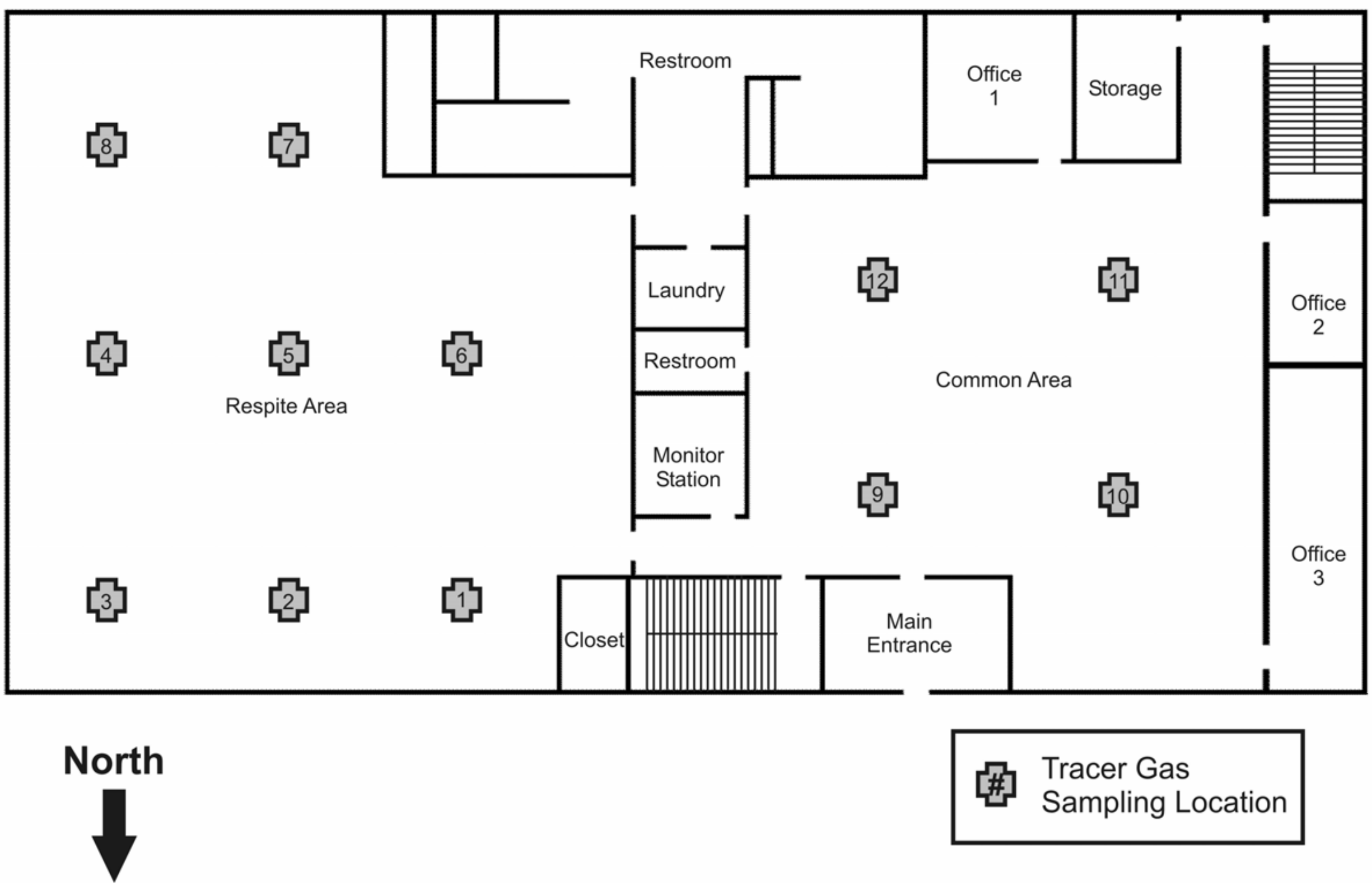


Figure 23. Tracer gas sampling locations on the first floor of the annex.

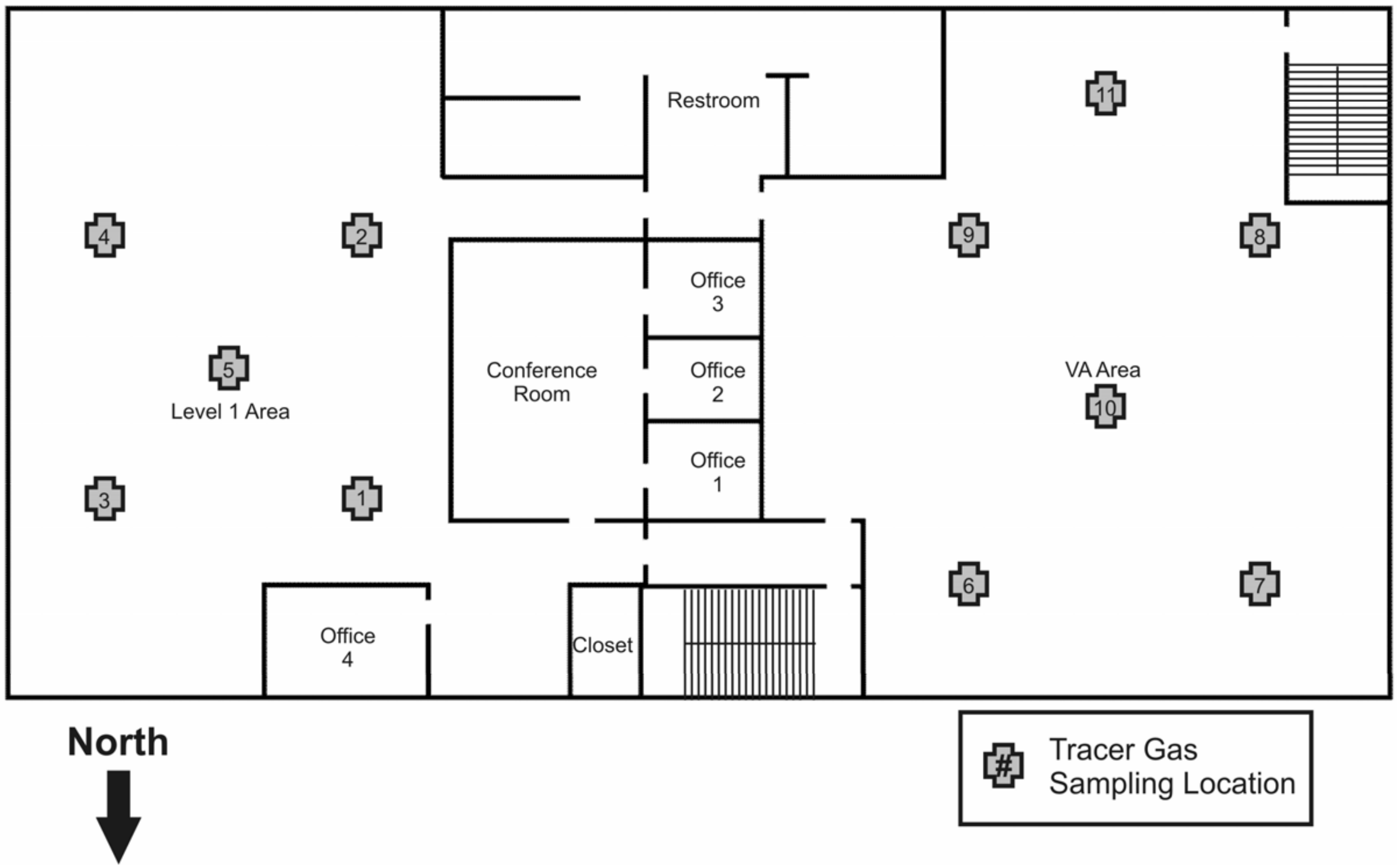


Figure 24. Tracer gas sampling locations on the second floor of the annex.

Figure 25. Tracer gas sampling locations on the first floor of the main building. Samples 17 and 19 were collected on the second floor and third floor landings of the east stairwell, respectively. Samples 18 and 20 were taken on the second floor and third floor landings of the west stairwell, respectively.

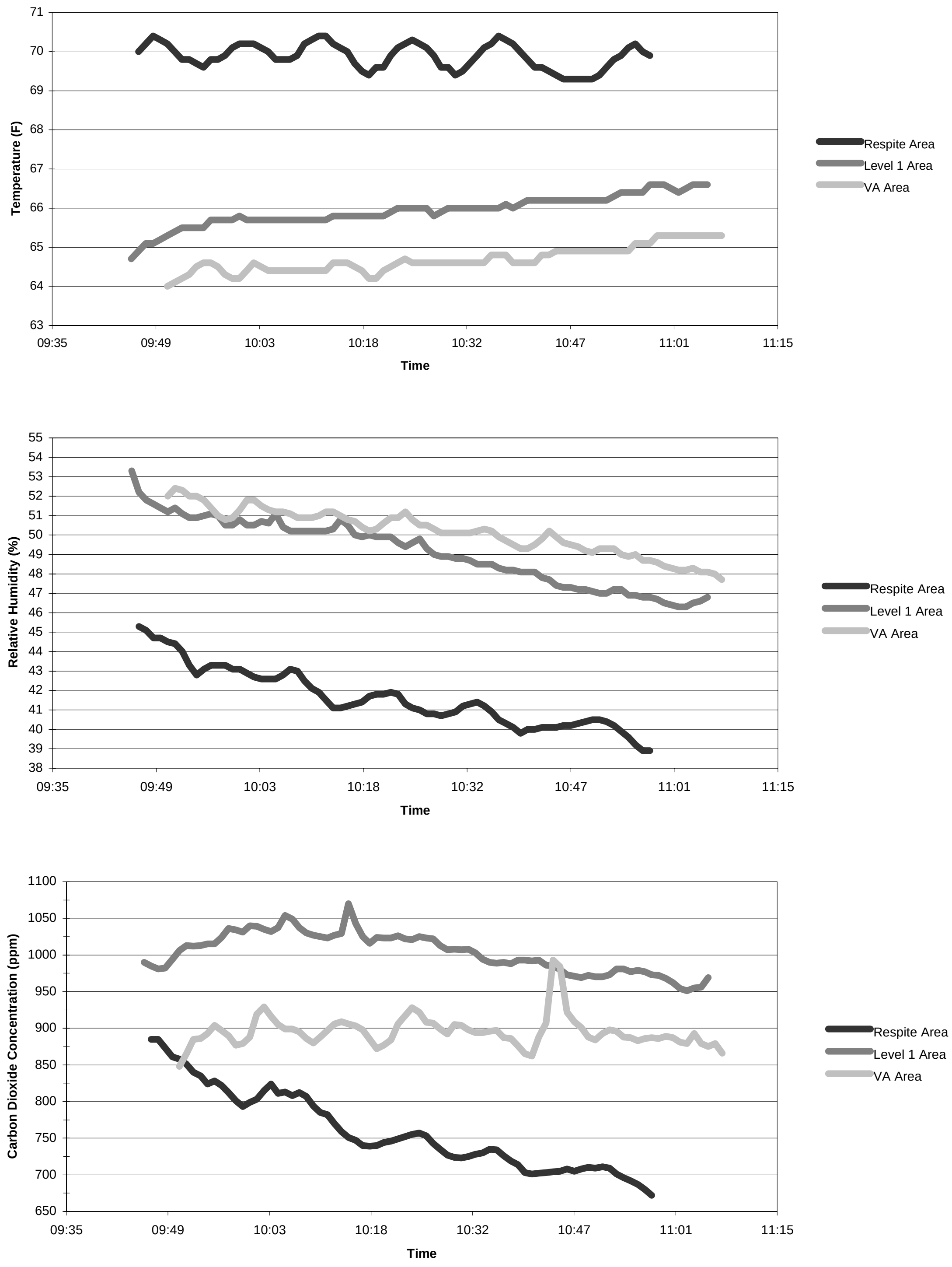


Figure 26. IEQ parameters in the annex on October 15, 2004 (tracer gas Test 4). ASHRAE recommends winter temperatures between 68°F and 76°F and relative humidity between 30% and 60%. Carbon dioxide concentrations should be below 700 ppm above the ambient concentration (approximately 1050 ppm total).

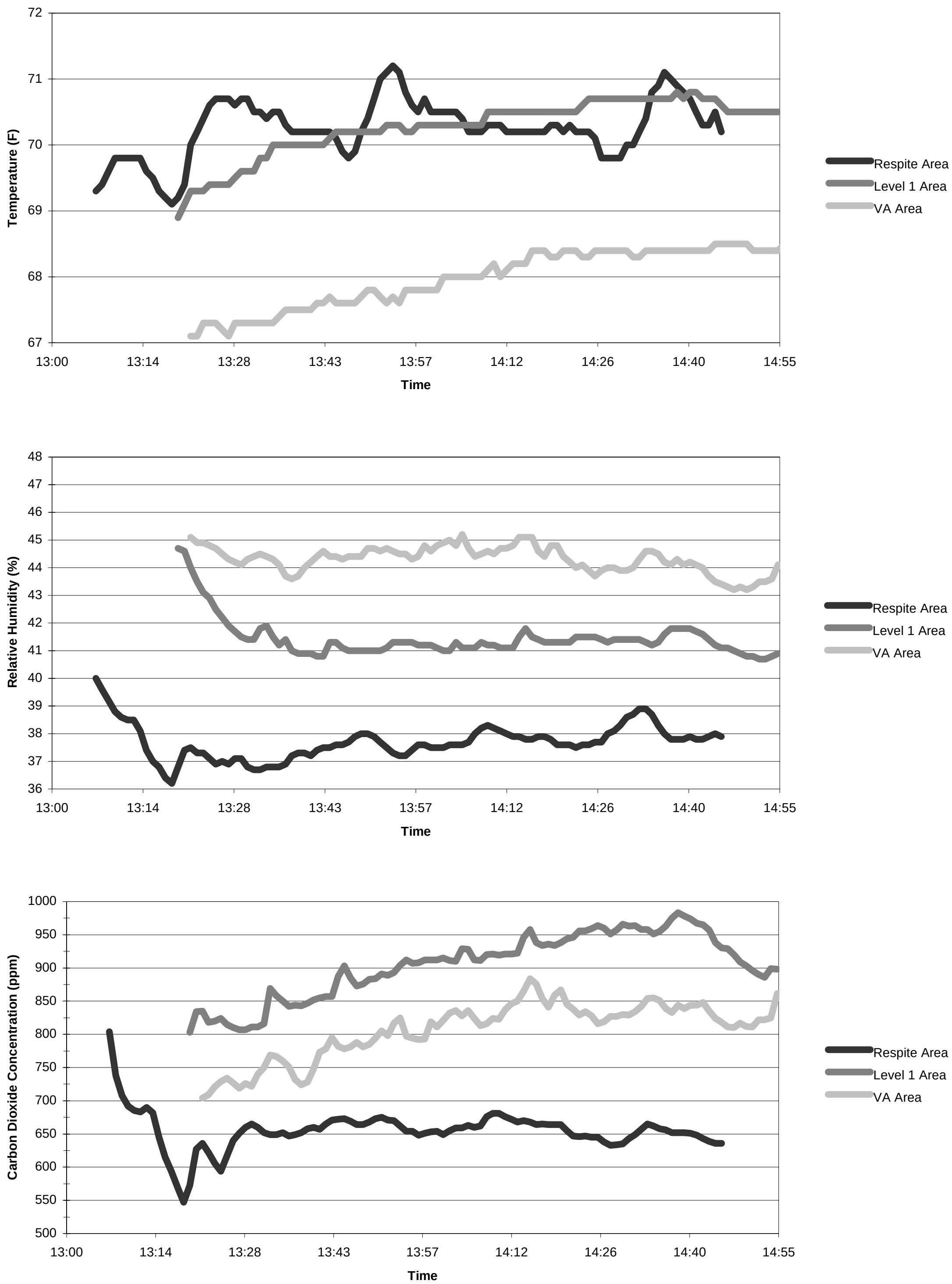


Figure 27. IEQ parameters in the annex on October 15, 2004 (tracer gas Test 5). ASHRAE recommends winter temperatures between 68°F and 76°F and relative humidity between 30% and 60%. Carbon dioxide concentrations should be below 700 ppm above the ambient concentration (approximately 1050 ppm total).

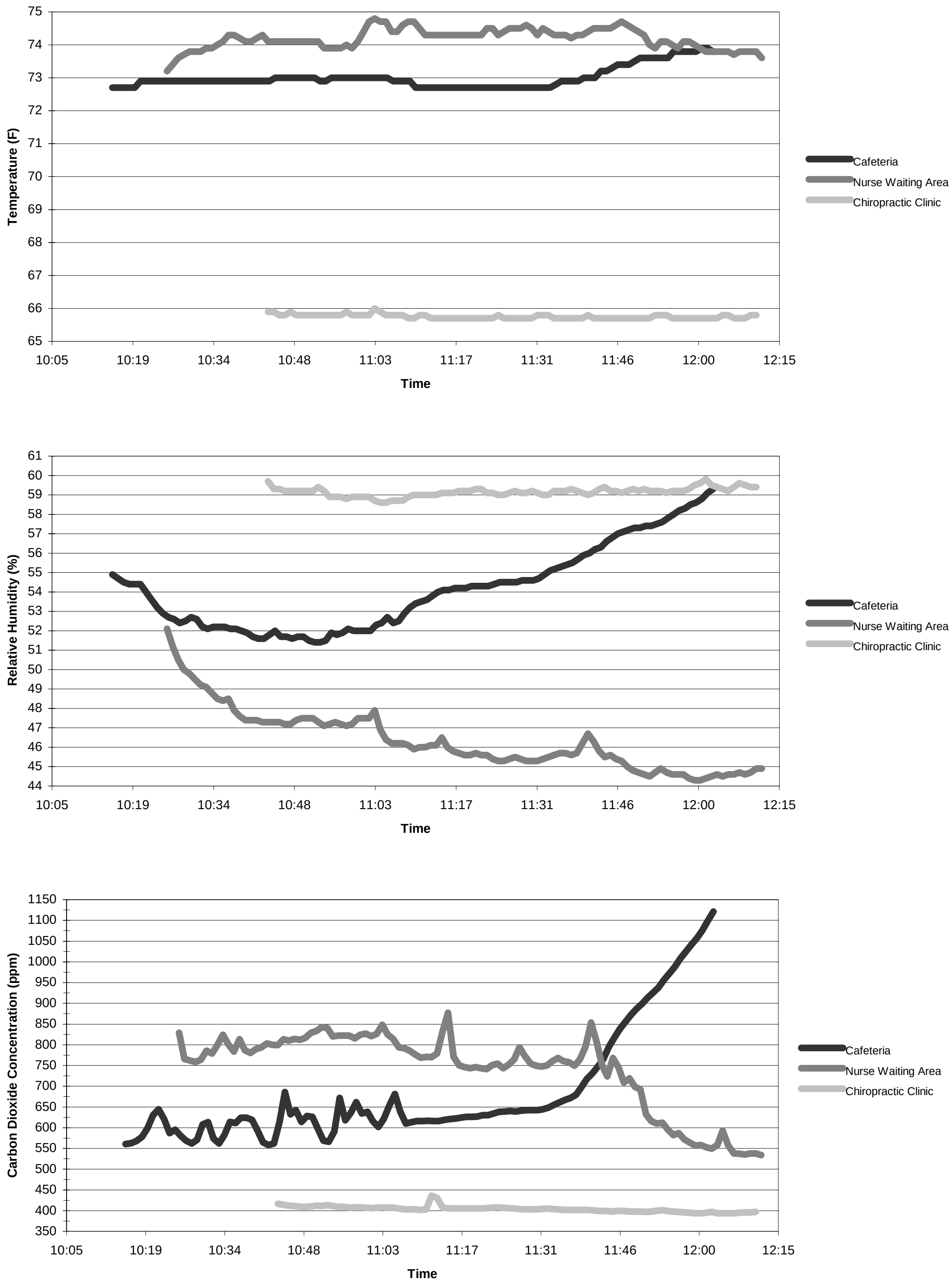
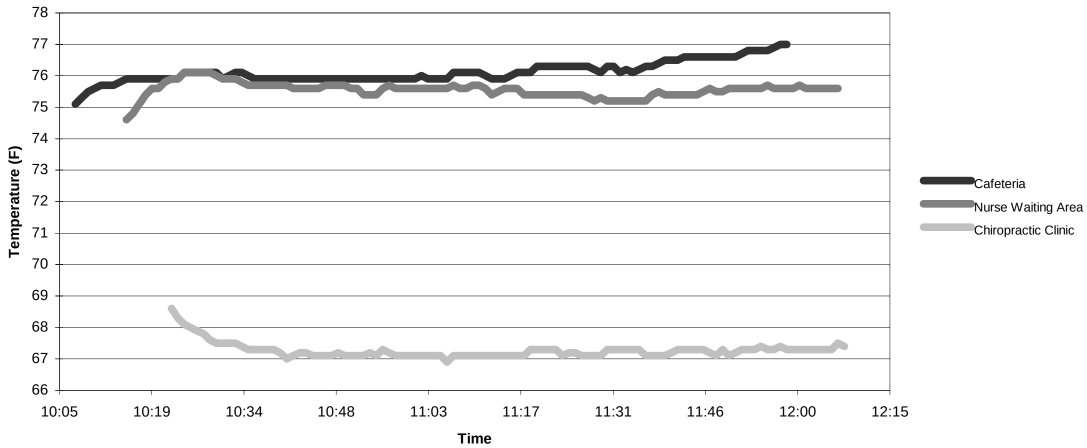
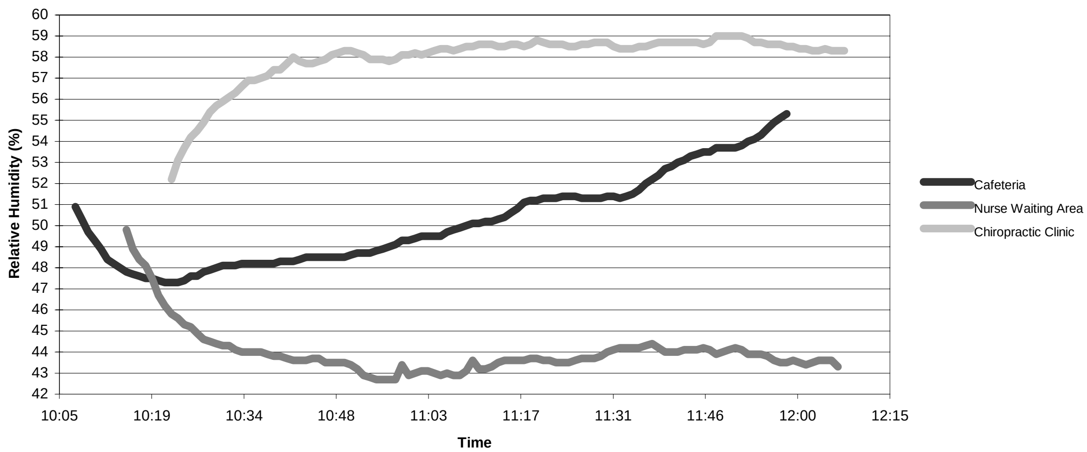


Figure 28. IEQ parameters in the main building on October 19, 2004 (tracer gas Test 6). ASHRAE recommends winter temperatures between 68°F and 76°F and relative humidity between 30% and 60%. Carbon dioxide concentrations should be below 700 ppm above the ambient concentration (approximately 1050 ppm total).





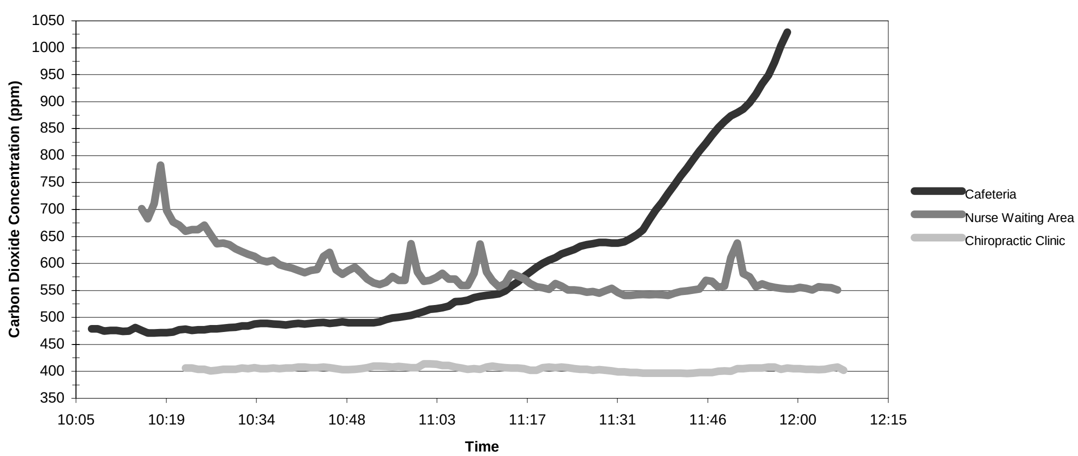


Figure 29. IEQ parameters in the main building on October 20, 2004 (tracer gas Test 7). ASHRAE recommends winter temperatures between 68°F and 76°F and relative humidity between 30% and 60%. Carbon dioxide concentrations should be below 700 ppm above the ambient concentration (approximately 1050 ppm total).

Figure 30. CFD modeling results showing mean age of air (in minutes) at three feet off the floor for the annex first floor in January 2004.

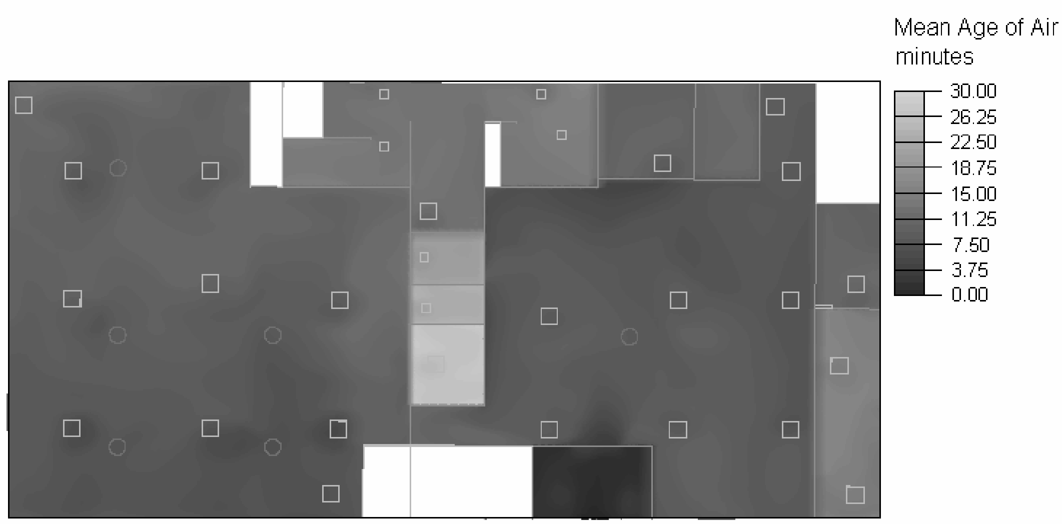


Figure 31. CFD modeling results showing mean age of air (in minutes) at three feet off the floor for the annex first floor in October 2004.

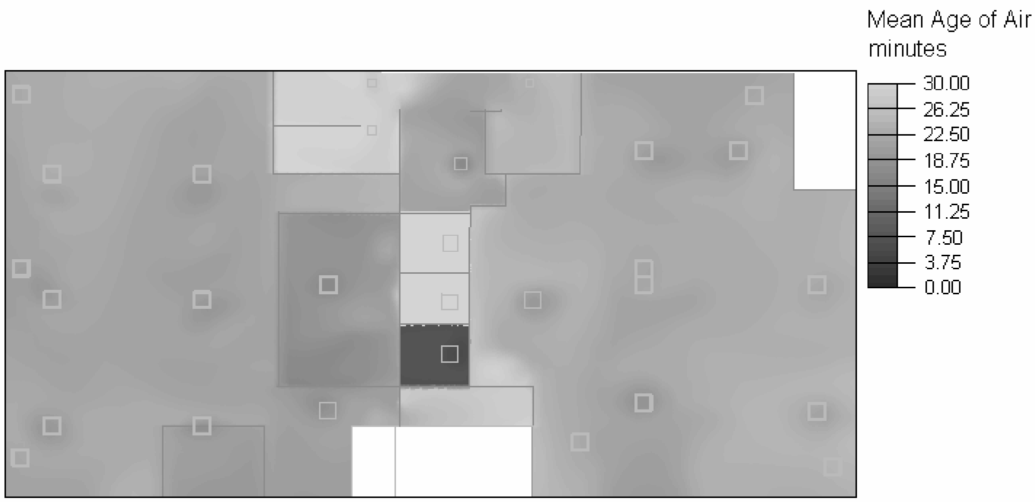


Figure 32. CFD modeling results showing mean age of air (in minutes) at three feet off the floor for the annex second floor in January 2004.

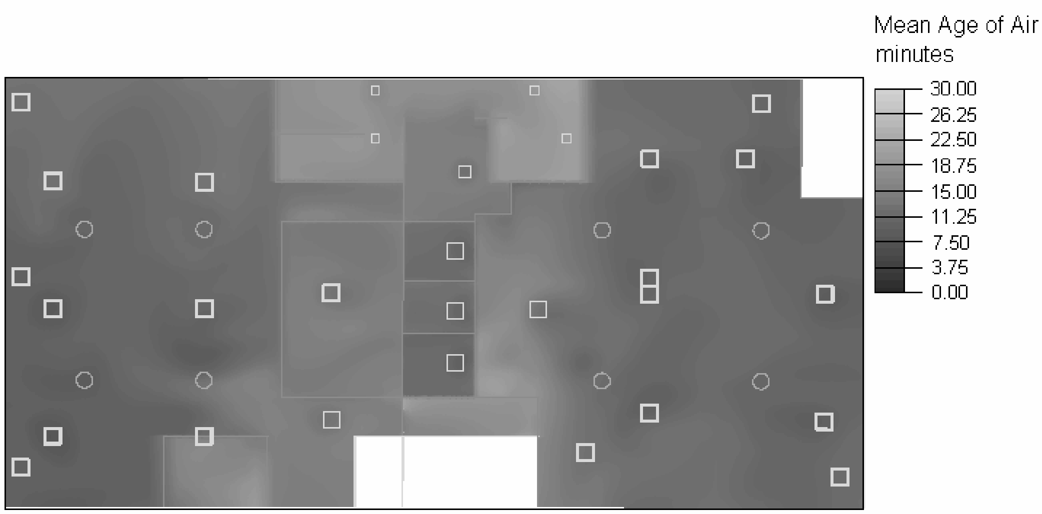


Figure 33. CFD modeling results showing mean age of air (in minutes) at three feet off the floor for the annex second floor in October 2004.

APPENDIX A

Interim Report I

DEPARTMENT OF HEALTH & HUMAN SERVICES Public Health Service

Phone: (304) 285-5790
Fax: (304) 285-6321

Centers for Disease Control
and Prevention (CDC)
National Institute for Occupational
Safety and Health (NIOSH)
1095 Willowdale Road
Morgantown, WV 26505-2888

October 2, 2003
HETA 2003-0346
Interim Report I

Captain Timothy Best
Captain Beverly Best
Salvation Army
Harbor Light Center
3010 Washington Avenue
St. Louis, MO 63108

Dear Captains Best and Best:

On August 20, 2003, the National Institute for Occupational Safety and Health (NIOSH) received a request for technical assistance concerning a TB outbreak at the Salvation Army Harbor Light Center in St. Louis, Missouri. The request for technical assistance was made by Dr. Kenneth G. Castro, Director of the Division of Tuberculosis Elimination (DTBE) of the Centers for Disease Control and Prevention (CDC). DTBE is investigating this TB outbreak at the request of Dr. Bao-Ping Zhu from the Missouri Department of Health and Senior Services (DHSS). This interim report is written in response to our initial visit to the Harbor Light Center.

The St. Louis Harbor Light Center provides shelter to any adult male without a place to sleep. The shelter has three major components: 1) the drug treatment (detoxification) area located in the main building, 2) the respite program located in the Annex, and 3) the transient, open-to-the-public program located in the Annex (overflow to the main building when necessary). Since 2000, fourteen (14) cases of TB have been epidemiologically linked to Harbor Light Center, and in particular the Annex. The Annex has two sleeping areas on the main floor. One side is furnished with bunk beds (86 total beds) where respite and employed clients sleep. The other side of the Annex is a large, open room where transient, walk-in clients are issued mats and sleep on the floor. This area may hold 40-60 clients on a given evening, but this number is very dependent on weather conditions.

During our visit on September 15 and 16, 2003, we toured the facility and met with representatives from the Salvation Army, City of St. Louis Department of Health (DOH), MO DHSS, Lenzy Hayes, Inc. and DTBE. We discussed the extent that existing shelter ventilation systems have contributed to and will continue to perpetuate the TB outbreak at Harbor Light and the feasibility of a combination of filtration and ultraviolet light interventions to reduce TB transmission.

As you are aware, any tuberculosis infection control program includes three key components: administrative controls, engineering controls, and a respiratory protection program. Ideally, engineering controls and respiratory protection should supplement an administrative control program. In high-risk environments, or in the case of failure of administrative controls, engineering controls and/or respiratory protection are the secondary level of control.

During our visit to Harbor Light Center, we were very pleased with the many administrative controls you have in place to minimize the risk of tuberculosis transmission. Aside from your thorough client case management system, these include your efforts in providing weekly PPD TB skin tests, training shelter staff to read PPD test results and recognize signs and symptoms of TB, and providing incentives to increase client participation in the TB program. You and your staff should be commended on your administrative controls, particularly given the fact you deal with such a transient and seasonal clientele. It is this ever-changing population that would make an effective respiratory protection program extremely difficult to implement as a secondary measure to control the spread of disease. This leaves engineering controls as our primary focus for better controlling the spread of tuberculosis and improving the overall air quality of the facility.

Based on our initial walk-through evaluation of Harbor Light, we developed several recommendations for maintaining the existing ventilation systems, controlling the spread of infectious diseases, and improving overall air quality in the facility. Our initial recommendations are:

6. Routine maintenance of air handling units (AHUs) should be performed on a schedule consistent with the manufacturer's recommendations. The maintenance should include:
    a. Filter replacement (ensuring there is minimal filter bypass with "blanks")
    b. Cleaning heating/cooling units (ensuring valves are open and pipes have no leaks)
    c. Cleaning fans and coils
    d. Verification of the AHU setpoints and operation of outside air dampers
    e. Verification of the direction of fan rotation and revolutions per minute (rpm)
    f. Fan belt replacement when required
    g. Maintaining the fan bearings (grease and/or replace as needed)

7. A physical evaluation of each AHU in the facility should be performed to determine the design specifications (including fan power curves) and actual performance specifications (e.g., measured air flow rates, operation of dampers, including offsets [i.e., minimum and maximum outside air flow rates] for outside air, identification of filters, qualitative evaluation of filter leakage, qualitative drawings of duct work, etc.). Necessary repairs should be made to ensure proper operation of the air handling systems. In conducting these evaluations, the highest priority should be the Annex due to the large number of transient and/or unprocessed clients. The Annex evaluation should be followed by other high-risk areas (i.e., the first-floor hallway, dining facility, nurse waiting room, classroom, and detoxification area).

8. All AHUs throughout the facility should be thoroughly tested, evaluated, and balanced. Each year, evaluate air flow rates through each area and air handling system to determine if systems need to be rebalanced. This testing and evaluation should be prioritized in the same way as described in Recommendation #2.

9. The outside air intake into the facility should be increased to meet American Society for Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE) recommendations. Although

there are no specific guidelines for homeless shelters, a minimum of two (2) outside air changes per hour are recommended for other establishments, including health-care facilities. Increasing the outside air will likely result in better, more constant temperature control throughout the facility and help prevent the transmission of disease. Before increasing the amount of outside air, the operating capacity of the boiler and chiller currently installed at the facility should be determined. Any changes made to the operation of the air handling units, where more outside (fresh) air is brought into the facility, may require additional boiler capacity in the winter months and additional chiller capacity in the summer months. Before any changes are made, the projected increases/decreases in operating costs associated with the additional heating/cooling loads should be calculated. The priorities for increasing outside air intake are the same as in Recommendation #2 above.

10. Upper-room Ultraviolet Germicidal Irradiation (UVGI) should be considered in the activity area of the Annex (i.e., basketball court, pool table, weights). In addition to installing the UVGI fixtures, installation of ceiling fans (or some other means of moving room air) to facilitate proper mixing for the effective inactivation of biological agents, such as tuberculosis, would also be required. Additionally, upper-room UVGI may be feasible in the open area of the Annex first floor (where clients sleep on floor mats); however, it does not seem feasible in other areas of the Annex because of nine-foot ceiling heights and the height of the upper bunk beds.

11. The filters in the air handling units should have the highest possible efficiency (i.e., Mechanical Efficiency Reporting Value [MERV] rating) while still maintaining the designed flow rate through each system. This improved filtration efficiency can be augmented with UVGI fixtures installed inside existing duct work to achieve more effective removal and/or inactivation of infectious agents, such as *Mycobacterium tuberculosis*.

12. Locations where it may be appropriate to install hard-ducted air returns in high-risk areas throughout the facility should be determined. Hard-ducted air returns from high-risk areas will keep the return air from mixing with return air from surrounding areas in the existing plenum until just before the air is irradiated and/or filtered. In some cases, certain high-risk areas may need to be isolated completely by hard-ducting the returns to the AHU and ensuring that the AHU only provides air to and receives air from the room(s) of interest. (See Recommendation #2).

13. The capacity of the existing electrical system should be determined, especially in the Annex. Installing UVGI fixtures or increasing the load on the AHU fans anywhere in the facility will require an increase in electrical power. During our visit, we discussed the reported power supply shortage in the Annex. It should be determined what options exist to increase the available capacity of the existing electrical systems. If modifications and/or improvements are needed, these should be made prior to or concurrent with the implementation of any engineering controls. Priority should be the same as described in Recommendation #2.

14. Based on the on-site evaluation of the Fuller UVGI units, the residence time of a particle in the UVGI unit is less than 0.1 seconds. The flow rate of 700 CFM through the Fuller unit tested during our visit is too high to provide the residence time required to inactivate the majority of *Mycobacterium tuberculosis*. Methods to modify the units to increase the exposure time and reduce the air flow rate should be investigated. One easy, cost-effective method for reducing air

flow may be the installation of a rheostat to alter the voltage to the fan so that each Fuller unit is set to a flow rate of approximately 250 cubic feet per minute (CFM). This will give a residence time inside the units of around 0.1-0.2 seconds to provide an adequate inactivation of infectious agents per pass. Upon making modifications to these UVGI units, consider placement in high-risk areas such as nurse offices, counseling rooms, case management offices, intake areas, hallway to dining room, and other small areas.

To further assist Harbor Light Center with controlling the spread of infectious diseases, NIOSH would like to propose that we conduct the following work:

1. Computational Fluid Dynamics (CFD) modeling of the air flow distribution in the Annex, based on the performance of the air handling units and layout of the floor space. This will require us to take physical measurements of the air flow through each supply and return vent. The computer modeling will allow us to analyze air flow patterns within the Annex and identify areas with poor air exchange. We will then be able to make virtual modifications to the Annex ventilation system and determine the effects of these changes prior to implementation. In the model, we will be able to move supply and exhaust locations within each room, make changes to the supply and exhaust grilles, and modify air flow rates. This will allow us to optimize the air flow throughout the Annex and recommend any changes that should be made to increase protection of the shelter staff and clients. Analyzing any modifications to the Annex in a virtual world will help ensure the success of any suggested improvements and keep the associated renovation costs at a minimum. If necessary, additional areas within the main building will be modeled on the computer as well.

2. Conduct detailed tracer gas studies of the Harbor Light facility. This involves the controlled release of sulfur hexafluoride (SF_6), a colorless, odorless, biologically inert, non-toxic and non-combustible gas, from various locations throughout the facility. The concentration of SF_6 at various locations can then be monitored with portable detectors. These studies will allow us to measure the actual ventilation effectiveness of a given area, not simply the air supplied by or exhausted to the air handling units. This analysis will include air transfer between the area of interest and other adjacent areas, as well as overall building leakage to/from the outside. Conducting a second tracer gas study in a slightly different way will allow us to measure fresh air supply to the area of interest by monitoring the decay of SF_6 concentration over time. The results from these studies, while useful on their own, can then be used in conjunction with the CFD modeling results to provide the best, most cost-effective recommendations for modifications to the existing ventilation systems.

3. Conduct additional work on the Fuller UVGI units once they have been installed in small areas throughout the facility. Also, determine the best configuration for installing upper-room UVGI units in the activity area of the Annex and in-duct UVGI systems in other areas at Harbor Light Center. We will develop tables and/or graphs of air flow rates through each recommended system vs. the expected tuberculosis bacteria inactivation efficiency. Once we establish recommendations for UVGI systems at Harbor Light, calculations can be made to determine installation and annual operating costs, and necessary power requirements. During our discussion, you mentioned the possibility of purchasing/building a new Harbor Light shelter. It is important to remember that any UVGI systems purchased and installed at the existing Harbor Light facility could easily be moved and installed in the new shelter.

While we can immediately begin working on Item #3 above, we will not be able to start work on Item #1 and Item #2 until the ventilation systems (at least those in the Annex) are evaluated and any necessary repairs made, as per Recommendations #1-4, and #6 above.

This interim report provides numerous recommendations and a suggested approach for the next steps in this evaluation. We will follow-up this letter with continued contact with all interested parties to discuss the progress being made in implementing the suggestions and recommendations. Once your work on the ventilation systems in the Annex is completed, we can discuss convenient dates for performing the tracer gas studies and taking the necessary measurements for the CFD modeling.

We look forward to working further with you and all interested parties to better control the spread of tuberculosis and other infectious diseases. In the process we feel there will be a noticeable improvement in the overall air quality and comfort levels at Harbor Light Center. If you have any questions or need additional information, please contact me at SMartin1@cdc.gov or (304) 285-6367.

Sincerely,

Stephen B. Martin, Jr.
Engineer, Laboratory Research Branch
Division of Respiratory Disease Studies

cc: Dr. Paul A. Jensen, CDC/NCHSTP/DTBE
Dr. Kenneth G. Castro, CDC/NCHSTP/DTBE
Dr. Christopher C. Coffey, CDC/NIOSH/DRDS
Ted Misselbeck, City of St. Louis DOH
Dr. Bao-Ping Zhu, MO DHSS
Lynelle Phillips, MO DHSS
Fred StJohn, Lenzy Hayes, Inc.
Rick Hartle, HETAB
OSHA Region 7

APPENDIX B

Interim Report II

DEPARTMENT OF HEALTH & HUMAN SERVICES Public Health Service

Phone: (304) 285-5790
Fax: (304) 285-6321

Centers for Disease Control
and Prevention (CDC)
National Institute for Occupational
Safety and Health (NIOSH)
1095 Willowdale Road
Morgantown, WV 26505-2888

January 16, 2004
HETA 2003-0346
Interim Report II

Captain Timothy Best
Captain Beverly Best
Salvation Army
Harbor Light Center
3010 Washington Avenue
St. Louis, MO 63108

Dear Captains Best and Best:

On August 20, 2003, the National Institute for Occupational Safety and Health (NIOSH) received a request for technical assistance concerning a TB outbreak at the Salvation Army Harbor Light Center in St. Louis, Missouri. The request for technical assistance was made by Dr. Kenneth G. Castro, Director of the Division of Tuberculosis Elimination (DTBE) of the Centers for Disease Control and Prevention (CDC). NIOSH and DTBE staff visited the Harbor Light Center on September 15 and 16, 2003. An interim report dated October 2, 2003 detailed numerous recommendations for improving the existing shelter ventilation systems and the feasibility of a combination of filtration and ultraviolet light interventions to reduce TB transmission.

NIOSH and DTBE staff again visited Harbor Light on January 7 and 8, 2004 to discuss ongoing facility improvements, take some background air flow measurements, and discuss future work at the facility. We were particularly interested in finalizing our recommendations for the use of ultraviolet germicidal irradiation (UVGI) throughout the facility to reduce the spread of TB and other airborne diseases. This second interim report is written to detail the NIOSH/CDC recommendations regarding the purchase and installation of ultraviolet germicidal irradiation (UVGI) fixtures at Harbor Light.

Since our initial visit on September 15 and 16, 2003, there have been ongoing improvements to the Harbor Light Center made by your facilities contractor, Lenzy Hayes, Inc. All of the air-handling units have been adjusted to maximize outside (fresh) air being brought into the facility. This has resulted in more uniform temperature control throughout the Annex where the majority of the shelter clients reside. While actual measurements have not yet been made, this should improve the overall air quality within the shelter since little or no outside air was being supplied previously. Also, a new filter supplier was identified to provide higher efficiency filters at a reasonable price. Thus, mechanical efficiency rating value (MERV) 11 filters have been or are planned to be installed in all of the air-handling units in the main building at Harbor Light. The Annex will have MERV 14 filters installed in the air-handling units on the roof. This improvement in filter efficiency will have a positive effect on overall air quality and dust levels. Further, used in conjunction with the NIOSH/CDC UVGI recommendations contained in this report, these new filters will help reduce the possibility of TB disease transmission at the facility.

In conferring with Dr. Paul Jensen from DTBE and UVGI fixture manufacturers, we offer you the following recommendations for upgrading the existing heating, ventilation and air-conditioning (HVAC) systems at Harbor Light to include the enhanced protection offered by UVGI technology. Our recommendations are broken down into two categories, namely short-term and long-term, and they appear in a prioritized order. We have also included approximate costs associated with each recommendation.

SHORT-TERM RECOMMENDATIONS

The following short-term recommendations should be implemented as soon as possible. These recommendation are made to provide the most protection against TB disease transmission in the highest-risk areas of the shelter.

3. If this has not already been done, evaluate the recently discovered electrical system in the Annex to ensure the system can handle the additional power requirements of the UVGI fixtures recommended for the Annex in this letter. (**COST:** Lenzy Hayes, Inc. could conduct this evaluation at little or no cost)

4. Upgrade all filters in the two Annex air-handling units to MERV 14 filters (if this work has not already been completed). Fred StJohn with Lenzy Hayes, Inc. has discovered a new, local supplier of MERV 14 filters for use at the Harbor Light shelter. The cost of each filter will be roughly $5.00, depending on the size. (**COST:** $60.00)

5. Install in-duct UVGI fixtures inside the two Annex HVAC systems. These fixtures will provide an initial level of 140 UV-C watts of ultraviolet irradiation to the air being supplied to the Annex from the air-handling units. (**COST:** $1,300.00 + installation)

6. Install new upper-air UVGI fixtures in the lobby/transient area of the Annex. These fixtures will provide an added level of ultraviolet irradiation in this area to supplement the in-duct systems. A total of 110 UV-C watts of ultraviolet irradiation is required for an area of this size. This area is of particularly high risk since it is the sleeping area for transient clients and can be crowded during months of inclement weather. (**COST:** $3,500.00 + installation)

7. Install enclosed UVGI silent air movers in the first-floor respite area of the Annex. This unit will provide additional UVGI protection (66 UV-C watts) in this area because of the higher-risk of disease transmission in this space. The unit will also serve to improve the circulation of air within the space and remove the perceived pockets of stale air that exist in this space. (**COST:** $9,000.00 + installation)

8. Install one upper-air UVGI fixture inside the glass-enclosed respite reception area inside the Annex lobby. This unit should provide 11 UV-C watts of irradiation and will provide enhanced protection to Harbor Light staff working in the Annex facility in close proximity to the respite care dormitory. (**COST:** $500.00 + installation)

9. Install two upper-air UVGI fixtures in the gym/indoor recreation facility to provide 35 UV-C watts of ultraviolet irradiation. These units should be installed on top of the existing heaters inside the gym. The heaters are both mounted above eye level for clients playing ping pong on the balcony. The heaters are suspended on four rods from the ceiling. These rods will offer some protection to the UVGI fixtures from flying basketballs, soccer balls, etc. If more protection for the lamps is required, cages could be mounted around the fixtures during installation. (**COST:** $900.00 + installation)

10. Install upper-air UVGI fixtures in the second-floor conference area (including the counseling areas, offices, and the storage room) in the Annex. These areas require a total of 44 UV-C watts of ultraviolet irradiation. These fixtures will provide additional protection to the shelter staff working in these areas, as well as clients meeting within these rooms. (**COST:** $2,100.00 + installation)

11. Install upper-air UVGI fixtures in each of the three lower-level nurse examination rooms of the main building. These small rooms are of high-risk due to the number of clients they serve and the nature of the services provided. Eleven (11) UV-C watts of ultraviolet irradiation should be provided in each examination room. Some thought should also be given to the possibility of hard-ducting the air return from these nurse examination rooms. Hard-ducting these air returns will make it easier to keep the examination rooms under negative pressure to the surrounding areas, and it would reduce the risk of disease transmission since it would eliminate air from inside these examination rooms from being returned through the common ceiling plenum. (**COST:** $1,400.00 + installation [not including hard-ducted air returns])

12. Install upper-air UVGI fixtures in the lower-level detoxification area, the detoxification registration room, and the chiropractic and dental clinic waiting areas of the main building. Like the nurse examination rooms, these areas are of high-risk due to the number of clients served and the nature of the services provided. The detoxification area should have fixtures installed to provide 22 UV-C watts of ultraviolet irradiation, while the registration room should receive 11 UV-C watts of irradiation. The waiting areas for the chiropractic and dental clinics require a total of 22 UV-C watts of irradiation. (**COST:** $1,800.00 + installation)

13. Inside the main building, have upper-air UVGI fixtures installed inside the cafeteria/dining area and down the main hallway where clients line up awaiting food service. Clients spend significant time in these locations in close proximity to many other clients and staff. The cafeteria/dining area should have 88 UV-C watts of ultraviolet irradiation, while the hallway outside the dining area should have fixtures installed that provide a total of 55 UV-C watts of irradiation (**COST:** $4,500.00 + installation)

14. Install upper-air UVGI fixtures in the lower-level classroom of the main building. The size of this room requires 44 UV-C watts of ultraviolet irradiation. (**COST:** $1,400.00 + installation)

15. In the main building, install upper-air UVGI fixtures in the transient area outside the nurse examination rooms. This area contains the snack vending machines and serves as the waiting area for the various clinics, examination rooms, and classrooms. This area also serves as the overflow sleeping area when the number of walk-in clients exceeds the sleeping capacity of the Annex. The size of this room would require 44 UV-C watts of ultraviolet irradiation. (**COST:** $1,400.00 + installation)

LONG-TERM RECOMMENDATIONS

The following long-term recommendations are for consideration after the successful implementation of the short-term recommendations above, and as the necessary funding becomes available. These recommendations are made to provide additional UVGI protection within the main building of the shelter and to supplement the protection recommended above. The implementation of these long-term recommendations will ensure that all areas of the Harbor Light Center are adequately protected against possible TB disease transmission.

3. Install a UVGI silent air mover in each of the dormitory areas on the second floor of the Annex. These units will further supplement the in-duct irradiation systems and will remove any pockets of poor air circulation within each of the dormitory areas. (**COST:** $12,000.00 + installation)

4. Install upper-air UVGI fixtures inside the chapel and the chapel foyer on the second floor of the main building. During our visit to Harbor Light in September 2003, we discovered that there is no existing mechanical ventilation in these areas, aside from wall-mounted heaters with fans that simply recycle air from inside the chapel. (**COST:** $1,500.00 + installation)

5. In the main building, install upper-air UVGI fixtures in various "community" rooms (e.g., television rooms, study rooms, and classrooms) and high-risk client sleeping areas. (**COST:** $5,800.00 + installation)

6. Upgrade all filters in the 17 main building air-handling units to MERV 11 filters (if this work has not already been completed). In addition to the added protection from disease transmission, these improved filters will have a positive impact on overall air quality and dust levels in the main building. (**COST:** $350.00)

7. Install in-duct UVGI fixtures in each of the 17 HVAC systems in the main building. These fixtures will provide a general level of ultraviolet irradiation to every area of the main building served by one of these 17 HVAC systems. (**COST:** $10,600.00 + installation)

8. Install upper-air UVGI fixtures to the remaining dormitory areas of the main building not covered by Long-Term Recommendation #4 above. (**COST:** $6,700.00 + installation)

The 13 short-term recommendations can all be implemented at a total cost of approximately $26,000-$28,000 plus installation costs. Putting these recommendations in place will decrease the risk of further TB outbreaks occurring at Harbor Light, as the highest-risk areas will have a combination of increased fresh air supply, enhanced air filtration, and some level of ultraviolet germicidal irradiation. The long-term recommendations will cost a total of approximately $37,000 plus installation to implement fully. However, the long-term recommendations can be implemented in steps as the necessary funding becomes available and do not necessarily need to be implemented in the order of priority given here. Another important point to remember, since there is the possibility of constructing a new Harbor Light facility in the near future, is that all of the UVGI fixtures recommended here and installed at the current shelter can easily be moved to a new building. Thus, all new fixtures will not be required if a new shelter is built.

During our meetings in September 2003 and January 2004, we discussed various options for funding this work with you, Ted Misselbeck from the City of St. Louis Department of Health, Lynelle Phillips from the Missouri Department of Health and Senior Services, and representatives from Lenzy Hayes, Inc. I am certain that some funds are available from these sources to begin work implementing the short-term recommendations. However, no funding for the purchase or installation of these UVGI fixtures is available from NIOSH or DTBE.

This interim report provides numerous recommendations for the incorporation of UVGI into the TB prevention plan at Harbor Light. We will continue our contact with all interested parties to discuss the progress being made in implementing the recommendations. After some of the initial installation of the UVGI fixtures, Lenzy Hayes, Inc. will have a contractor test and balance all of the HVAC systems in the main building and Annex of the shelter. Once the testing and balancing work is completed, we can discuss convenient dates for performing the tracer gas studies and taking the necessary measurements for the computational fluid dynamics (CFD) modeling that we have discussed previously.

We look forward to working further with you and all interested parties to better control the spread of tuberculosis and other infectious diseases. In the process we feel there will be a noticeable improvement in the overall air quality and comfort levels at Harbor Light Center. If you have any questions or need additional information, please contact me at SMartin1@cdc.gov or (304) 285-6367.

Sincerely,

Stephen B. Martin, Jr.
Engineer, Laboratory Research Branch
Division of Respiratory Disease Studies

cc: Dr. Paul A. Jensen, CDC/NCHSTP/DTBE
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OSHA Region 7

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health
4676 Columbia Parkway
Cincinnati, OH 45226-1998

National Institute for Occupational Safety and Health

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