Exponent®

Tent Fresh-Air Ventilation System Report

W91CRB-07-D-0013

Tent Fresh-Air Ventilation System Report

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List of Acronyms

ACH	air changes per hour
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
CFM	cubic feet per minute
CO_2	carbon dioxide
FOB	Forward Operating Base
GP	general purpose
HEPA	high efficiency particulate air
HVAC	heating, ventilation, and air conditioning
IAQ	indoor air quality
PU	polyurethane
REF	Rapid Equipping Force

1 Summary

As part of the Rapid Equipping Force (REF) contract W91CRB-07-D-0013, Exponent was asked to investigate methods of improving indoor air quality (IAQ) in polyurethane (PU) foam-insulated General Purpose (GP) U.S. Army tents installed in Forward Operating Bases (FOBs). A previous report dated March 12, 2007, demonstrated that the rate of fresh air infiltration into the exemplar foam-insulated tent was inadequate to meet acceptable IAQ standards. Exponent was asked to develop a strategy to introduce a controlled volume of fresh air into the foam-insulated tent to maintain IAQ in accordance with industry-accepted practices.

Based upon the investigation, Exponent has the following findings:

- A ventilation system consisting of a passive fresh-air intake vent on the return side of the air-handling system and a supplemental mechanical exhaust fan mounted on the tent wall can be implemented using conventional tools and commercially available components.

- The installation of components was documented to assist in development of installation guidelines. A simplified installation checklist is presented in Appendix A.

- Air exchange rate measurements were performed with the improvements to determine the effect on fresh-air ventilation and to evaluate IAQ of the tent.

- The ventilation scheme consisting of fresh-air intake vent combined with a supplemental mechanical exhaust fan exceeded the minimum number of air changes required for acceptable IAQ standards with and without operation of the HVAC unit fan.

- Other arrangements and components were researched and presented as alternatives to enhance performance and energy efficiency in comparison to the prototype fresh-air ventilation system. The alternatives compromise on cost, simplicity, or performance, but may be more suitable depending on specific need. For implementation of alternates, IAQ should be evaluated prior to occupancy.

- A preventive maintenance schedule was provided to promote continued performance of the fresh-air ventilation system.

2 Scope of Work

As part of the Rapid Equipping Force (REF) contract W91CRB-07-D-0013, Exponent was asked to investigate methods of improving indoor air quality (IAQ) in polyurethane (PU)-foam insulated General Purpose (GP) U.S. Army tents installed in Forward Operating Bases (FOBs). A previous report dated March 12, 2007, showed that the rate of fresh air infiltration into the foam-insulated tent is insufficient to maintain acceptable indoor IAQ.

Exponent was requested to develop a strategy to introduce a controlled volume of fresh air into the foam-insulated tents to maintain IAQ in accordance with industry-accepted practices.

Exponent's tasks included:

- Conducting research on available systems and components to improve IAQ of a foam-insulated tent;
- Collaborating on design of a prototype fresh-air exchange system for installation on an exemplar foam-insulated tent;
- Documenting the installation of the prototype ventilation system on an exemplar tent at Fort Benning, Georgia;
- Performing fresh air exchange measurements on the foam-insulated tent to evaluate system effectiveness on IAQ.

3 Prototype Foam-Insulated Tent

Exponent Managing Engineer Neil Wu, P.E., traveled to Fort Benning, Georgia on May 3, 2007, to experiment and collect data on fresh-air exchange systems on an exemplar foam-insulated GP tent that is currently installed on site. Exponent's tasks for the Fort Benning inspection were to:

- Collaborate on development of a controlled fresh-air ventilation system that would allow introduction of outside air in a capacity needed to maintain indoor air quality;
- Document the installation of a prototype fresh-air ventilation system on the foam-insulated tent for development of installation guidelines;
- Perform air exchange rate measurements on the foam-insulated tent with the controlled ventilation system modifications.

The foam-insulated General Purpose (GP) – Large model U.S. Army tent measured approximately 55 feet long by 18 feet wide. The minimum ceiling height was approximately 74 inches (6 feet, 2 inches) along the exterior walls and the maximum ceiling height was approximately 123 inches (10 feet, 3 inches) at the interior posts.

The tent was previously covered with a 2-inch layer of polyurethane (PU) foam insulation, coated with acrylic. Prior to spraying the foam onto the exterior tent surface, two vestibules (approximately 4 feet long x 6 feet wide) had been built in front of the tent's two points of entry to further limit the exchange of air with the ambient when people enter or leave the tent.

The foam-insulated tent was supplied conditioned air by a 2-ton (24,000 BTU/hr) electric-powered Goodman heat pump, model PHK024-1B. The Goodman unit supplied the tent with approximately 900 cfm of air when operating. Supply air to the tent and return air back to the HVAC unit is accomplished through 16- to 18-inch diameter thermally insulated flexible duct. Supply air is distributed inside the tent by an 18-inch diameter fabric duct running along the centerline of the tent underneath the ceiling.

In the foam-insulated tent, the HVAC unit operates primarily as a closed loop. The return air from the tent passes through a 20-inch x 20-inch x 1-inch thick filter before being sent back to the outdoor HVAC unit. No makeup air is introduced into the foam-insulated tent other than by infiltration from the outside.

A more detailed description of the foam-insulated tent and HVAC system components is available in the Exponent report dated March 12, 2007.

4 Fresh-Air Ventilation System

Air exchange in buildings is critical to maintain the indoor air quality (IAQ) at acceptable levels and minimize the potential for adverse health effects to the occupants ("sick building syndrome"). Contamination of indoor spaces is caused by:

- Human occupation;
- Release of contaminants in the space from furnishing and accessories;
- Introduction of contaminants with the outdoor air.

Various methods are available to control the contaminant concentration within a conditioned space:

- Source elimination or modification;
- Dilution with outdoor air;
- Conditioned air cleaning (filtering).

Previous tests[1] conducted at Fort Benning, Georgia on January 25, 2007, showed that the air infiltration into the exemplar foam-insulated tent is insufficient to maintain acceptable indoor air quality.

4.1 Minimum Ventilation Requirements

Minimum ventilation rates (i.e. outdoor air flow introduced into a building) for acceptable air quality in buildings are specified in standards such as ASHRAE 62, *Ventilation for Acceptable Air Quality*. Minimum ventilation rates depend on various factors, including:

- The size of the conditioned space;
- The number of occupants and their activity in the conditioned space;
- The presence of other sources of chemical, physical or biological contaminants that affect air quality.

The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) has established ventilation standards to promote acceptable indoor air quality (IAQ). According to the data in ASHRAE 62, *Ventilation for Acceptable Air Quality*, 2004 Edition, the minimum outdoor air ventilation rate for "barracks sleeping areas" is 199.4 cfm (1.36 ACH) for the large model GP tent used for soldiers' sleeping quarters under the assumption of 28 occupants[1]. This

[1]Exponent report by Gavelli, F, and Wu, N., "Tent Foam Insulation Report: W9124Q-06-F-1204", March 12, 2007.

minimum value serves as a target for design and implementation of the prototype fresh-air ventilation system.

4.2 System Installation

Mr. Bryan Thompson, a mechanical contractor with the Shaw Group, was contracted to develop and install a prototype fresh-air ventilation system in the exemplar tent at Fort Benning, Georgia. Three variations of a controlled fresh-air ventilation system were explored during the May 3, 2007, site visit as follows:

1. A 5-inch diameter fresh-air intake vent installed on the return air side of the HVAC unit and 3-inch diameter passive exhaust vent installed on the tent wall most remote from return air grill.
2. A 5-inch diameter fresh-air intake vent installed on the return air side of the HVAC unit, a 10-inch diameter exhaust fan mounted on the tent wall, and the HVAC fan unit in the ON positions (cool mode).
3. A 5-inch diameter fresh-air intake vent installed on the return air side of the HVAC unit, a 10-inch diameter exhaust fan mounted on the tent wall, and the HVAC fan unit in the OFF position.

The second and third options were selected based on performance, which will be discussed in Section 5. Table 1 summarizes the components, quantities, and cost per unit for installation of the prototype fresh-air ventilation system in the foam-insulated GP-Large tent.

Table 1 Summary of fresh-air ventilation system components.

Component	**Quantity**	**Cost**
5-inch Diameter Flat Gasket Take-off Vent with Damper (Johnstone Product #ATD-5)	1	$4.95
5-inch Diameter Double-Wall Vent Cap (Johnstone Product #5MC)	1	$8.32
Smilie Custom Filter, 20-inch x 30-inch x 1-inch	1	$4.88[2]
Crown Bolt #6, ½-inch, Sheet Metal Screw, Hex Head, Self Drilling, Zinc Plated, Box of 200	1	$7.26[2]
Virginia Foam Insulation Tape, Model KMP K-501, 10-yard length	1	$10.83[2]
Broan 10-inch Diameter Utility Fan, Model 504-C (Stock #X89-325)	1	$85.73
White-Rodgers Digital Non-programmable Thermostat, Model 1F78-144	1	$34.85
Accord Return Filter Grille, 20-inch x 20-inch, Model #ABRFWH2020	1	$33.57
Glass Air Filter, 20-inch x 20-inch x 1-inch	1	$0.97
Sheet Metal Return Air Box, 20-inch x 20-inch x 8-inch, shop fabricated (estimated)	1	$20.00
Sheet Metal Weather Hood and Protective Wire Guard for Exhaust Fan (estimated)	1	$20.00

Criteria for selection of the components are function, cost, and commercial availability. Alternates and optional equipment are discussed in Section 4.4. The estimated cost of materials for the fresh-air ventilation system is approximately $225 for installation in the exemplar foam-insulated tent, excluding labor. As with installation of most conventional HVAC systems, these components will require some mechanical system expertise for fabrication, assembly, and installation.

[2] Unit cost for material utilized for installation is a fraction of the bulk purchase price.

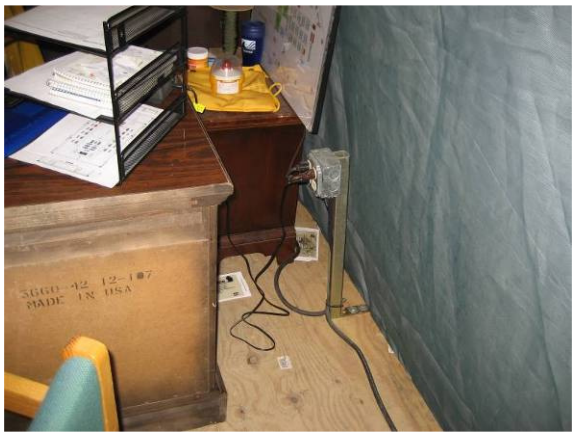
4.3 Installation Procedure

During the site inspection on May 3, 2007, Exponent witnessed the installation of the prototype fresh-air ventilation system on the foam-insulated exemplar tent at Fort Benning, Georgia. Particular components such as the digital thermostat control unit, return air box and filter grille, were installed prior to the site visit, therefore, details on their installation were unavailable. The product manufacturer's instructions and specifications can be referenced for additional installation information.

The following illustrative steps are based upon this author's experience at a typical FOB and the assumption that each tent will be provided with a similar electrical service, HVAC system, and general tent configuration. A simplified checklist of installation steps is included as Appendix A.

4.3.1 Prior to Spray-Foam Application

Step 1. Disconnect power to the tent, including the HVAC unit, and relocate all electrical boxes to prevent contact of receptacle box or conductors with tent surfaces.



Step 2. Remove all electrical appliances from contact with tent material and provide proper clearance for any heat-generating appliance.

Step 3. Protect all light fixtures against accidental contact with tent material by installing cages or guards. (Optional compact fluorescent light bulbs are recommended for energy conservation and fire safety purposes.)

Step 4. Install the 10-inch diameter exhaust fan (Broan Model 504-C, Stock # X89-325). Position the exhaust fan housing in the unused tent ventilation opening in the wall most remote from return air box. Install a single pole - single throw electrical switch for the exhaust fan control. Label the control switch “EXHAUST FAN”.

Step 5. Cover the exterior supply and return air flex duct with sheathing material to protect against overspray of foam insulation. (Spray foam may physically and/or chemically alter the flex duct performance.)

Step 6. Fabricate a return air box that can support a 20-inch x 20-inch x 1-inch return air filter grille. (Optional depth of can be chosen to accommodate HEPA filter.)

Step 7. Fabricate a metal exhaust fan outlet protective hood with metal grille to prevent entry of water or accidental contact with the exhaust fan blades.

4.3.2 After Spray-Foam Application

Step 1. Install the fresh-air intake vent with damper. Remove the top panel off the outdoor HVAC unit. Locate the condenser coil and potential inlet opening in panel.

a. Mark a 5-inch diameter opening on the top panel of the HVAC unit. (The fresh-air intake location should allow fresh air to pass through the condenser coil prior to entering the HVAC blower fan.)

b. Cut a 5-inch diameter hole in panel using metal snips or a pneumatic knock-out set.

c. Cut and remove the insulation beneath the hole. Tape the edge of the remaining insulation to prevent drop down.

d. Peel the adhesive strip from the 5-inch diameter flat gasket fresh-air intake vent with damper (Johnstone Product Number ATD-5). Place the 5-inch diameter fresh-air intake vent on top of the hole.

e. Secure the fresh-air intake vent by installing four (4) self-tapping sheet metal screws through the flange.

Step 2. Install the fresh-air intake vent filter. Cut a 6-inch square piece of custom filter media (hog hair, polyester, or fiber glass).

a. Place filter media square inside 5-inch diameter double-wall vent cap (Johnstone Product Number 5MC).

b. Close the intake vent damper and place one 8-inch length strip of foam insulation tape on the vent body to create a seal against the damper plate. While keeping the damper closed, apply another 8-inch strip of foam insulation tape to the vent body on the opposite side of the damper plate most remote to the first strip of tape. The tape seals should still allow the damper to open.

c. Apply a layer of foam insulation tape to the intake vent body and place the vent cap on top of the intake vent. Fasten the vent cap by installing two (2) self-tapping sheet metal screws through the vent cap body.

d. Place the stocking on top of the double-wall vent cap. (Optional as a second filter media.) Determine the position of the damper and mark OPEN and CLOSED positions on the fresh-air intake vent body. Leave the damper in the full OPEN position.

Step 3. Install the return air system inside the tent. Place the fabricated return air box at the opening closest to the HVAC unit return duct, which should be the most remote wall from the supplemental exhaust fan. Fasten the return air flex duct from the return air box to the HVAC unit. Install a 20-inch x 20-inch return air filter grille with a 20-inch x 20-inch x 1-inch glass filter in the return air box.

Step 4. Install the digital thermostat on an appropriate surface of the tent support frame. (White-Rodgers, Series 70, single-stage heating/cooling non-programmable Model # IF78H-144, or other compatible thermostat).

Step 5. Restore power to the HVAC unit and turn the supplemental exhaust fan ON.

Step 6. Adjust the supply plenum openings to optimize circulation throughout the tent.

4.4 Alternate Ventilation Systems

Prior to conducting the site inspection and experiments at Fort Benning, Georgia, Exponent was asked to research and assist in developing multiple strategies for ventilating the foam-insulated tent. To accomplish this, Exponent collaborated with Mr. Brian Thompson of the Shaw Group and Mr. James Poland of GACO Western. Table 2 presents the alternative systems including component information and pros and cons.

Table 2 Summary of alternate ventilation systems.

System Description	Pros	Cons
Energy and Heat Recovery Ventilators (Honeywell Model No. ER200B2006, HR200B1005,)[3] (Aprilaire Model No. 8100)[4]	• Turn-key solution to air exchanges; • Conserves up to 85% of energy versus conventional ventilators which lose 100% of heating or cooling energy; • Simplicity in installation requires minimal skilled labor; • Allows for advanced filtration of fresh air; • Adjustable speed control with capacity need for GP large tent.	• Cost is $2000/unit; • Additional power consumption for operation; • May require purchase of an energy recovery unit for warm climates and a heat recovery unit for cold climates; • May require additional maintenance.

[3] RE Michel Catalog, Honeywell Perfect Window System.
[4] RE Michel Catalog, Aprilaire 8100 Series Energy Recovery Ventilator.

Fresh Air Ventilation Systems (Honeywell Model No. Y8150A1009)[5] (Aprilaire Model No. 8126)[6]	• Uses existing HVAC system return to draw fresh air; • Contains user-adjustable motorized damper to control amount of fresh air; • Can be integrated with HVAC run time to minimize energy loss; • Can be integrated to control indoor moisture levels.	• Modest cost at less than $300/unit; • Requires skilled labor for installation; • Requires additional modifications for FOB application (weather guard and filters); • May require use of supplemental exhaust fan on tent to create desired air changes • Additional power supply and energy consumption needed for operation; • May require additional maintenance.
CO_2 Monitor with Alarm[7] and Manual Activation of Exhaust Fan	• Conserves energy by using real-time monitoring of IAQ to trigger localized alarm to signal occupant activation of supplemental exhaust fan.	• Cost for CO_2 monitoring equipment ranges[8] from $400 to $2500/unit; • Requires manual occupant response to alarm and activation of exhaust fan; • Perpetual calibration costs for CO_2 monitoring device.

[5] RE Michel Catalog, Honeywell Fresh Air Ventilation System.
[6] RE Michel Catalog, Aprilaire Ventilation Control System.
[7] Bacharach Model 2800 CO_2 monitor is battery operated, has a threshold alarm, but does not allow operation during charging process.
[8] Email dated May 1, 2007, from James Poland of GACO Western.

Integrated CO_2 Monitor Interfaced with Exhaust Fan for Automatic Operation	• High-energy efficiency solution allows for automatic fresh-air exchanges only when needed by using real-time monitoring of IAQ to activate supplemental exhaust fan.	• Cost for CO_2 monitoring equipment ranges[8] from $400 to $2500/unit; • Sophisticated system of multiple independent devices leads to complexity of installation; • Continued maintenance costs on equipment; • May require programmable logic controller to synchronize events; • Perpetual calibration costs for CO_2 monitoring device.

Based on product literature, the alternate methods are intended to introduce a controlled volume of fresh air to improve IAQ. In summary, the trade-offs for the alternate systems are generally cost, performance, and/or complexity of installation. Depending on specific need, such as a mandate for absolute energy conservation or prevention of all outdoor airborne contaminants inside the foam-insulated tent, implementation of an alternate system may be more suitable to the application. It is noted that these alternate systems are untested with respect to actual air exchange capacities, and ventilation rates should be tested in accordance with IAQ standards prior to occupancy when implementing these systems.

As an alternate to the Broan Model 504-C 10-inch diameter utility fan, which was the only model available at the time of the site inspection, a Broan Model 508 10-inch diameter utility wall ventilation fan is a better choice for the application due to the horizontal mounting orientation. Similar to the Model 504-C, the Model 508[9] also has a current draw of 1.7-amps at 120-volts and a slightly lower maximum exhaust capacity of 270 cfm. As with the other alternates, IAQ should be evaluated when using this product as component of the foamed-tent fresh-air ventilation system.

[9] Broan Model 508 product specification sheet.

4.5 Maintenance Schedule

Table 3 contains recommended preventive maintenance actions and schedule for the fresh-air ventilation system on the foam-insulated tent. These actions and intervals are based upon experience with similar systems in a conventional household. In general, the product manufacturer's literature should be referenced for maintenance intervals.

Table 3 Fresh-air ventilation system recommended preventive maintenance schedule.

Item	Action	Interval
Appliances and Heaters	Inspect for proper clearance from tent wall and ceilings	Daily
Exhaust Fan	Inspect for proper operation	Daily
Fresh-air Intake Vent Damper	Inspect for damper position	Weekly
Return Air Filter	Replace	Monthly
Fresh-air Intake Vent Filter	Inspect for obstructions Replace	Weekly Monthly

5 Air Exchange Measurements

Implementation of the prototype fresh-air ventilation system on the foam-insulated tent requires an evaluation of indoor air quality (IAQ) prior to occupancy. Measurements of air exchange rates for a building provide direct quantification of the infiltration of outdoor air into a conditioned space (in this case, a tent). Different methods are available to perform air exchange measurements. The most common approach is to introduce a tracer gas in the conditioned space and to measure its dilution over time, from which the rate of air exchange can be calculated. This approach is standardized in ASTM E741, *Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution*.

5.1 Concentration Decay Test

Exponent followed the Concentration Decay Test Method from ASTM E741, *Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution*, to perform the air exchange measurements at Fort Benning, Georgia on May 3, 2007. The test protocol included the following general steps:

- Preparing the zone by setting the forced ventilation system to the desired value (e.g., ON or OFF), recording initial conditions and ensuring the air is well mixed;
- Injecting the tracer gas into the zone until the desired concentration is achieved;
- Ensuring that the tracer gas concentration is uniform within the zone;
- Sampling the gas concentration at regular intervals (1 minute) for a period of time sufficient to dilute the original concentration by at least 25%.

Three (3) CO_2 concentration decay tests were performed (numbered in order of execution) as improvements were implemented to the foam-insulated tent during the Fort Benning, Georgia site visit. Each test is described as follows:

1. Air exchange measurements on the foam-insulated tent with a 5-inch diameter fresh-air intake vent installed on the return air side of the HVAC and 3-inch diameter passive exhaust vent on the tent wall.
2. Air exchange measurements on the foam-insulated tent with a 5-inch diameter fresh-air intake vent, a 10-inch diameter supplemental exhaust fan mounted on the tent wall, and the HVAC fan unit in the ON position (cool mode).
3. Air exchange measurements on the foam-insulated tent with a 5-inch diameter fresh-air intake vent, a 10-inch diameter supplemental exhaust fan mounted on the tent wall, and the HVAC fan unit in the OFF position.

During testing all doors and windows remain sealed on the foam-insulated tent from time the CO_2 gas was injected to the completion of the test. Wind was reported steady at 4 mph, and outdoor temperature was 87°F. The concentration decay test results are summarized in Table 4.

Based on the previous study[10], the target ventilation rate is 1.36 ACH for the exemplar GP-Large foam-insulated tent anticipating an occupant load of 28 persons.

Table 4 Results from Fort Benning air exchange measurements.

Test	Air Changes per Hour (ACH)
No. 1 (passive fresh-air intake vent, passive exhaust vent)	0.732
No. 2 (passive fresh-air intake vent, mechanical exhaust fan, HVAC fan ON)	2.886
No. 3 (passive fresh-air intake vent, mechanical exhaust fan, HVAC fan OFF)	2.706

5.2 Findings

The following comments can be made from a review of the air exchange test results:

- The passive intake vent on the HVAC fan return side combined with a passive exhaust vent from the foam-insulated tent (Test No. 1) provided twice the volume of fresh air compared to the closed loop system[11], but was inadequate to satisfy fresh-air exchanges necessary for acceptable IAQ.
- The passive intake vent on the HVAC fan return side combined with a supplemental mechanical exhaust fan on the tent wall and constant operation of the HVAC fan (Test No. 2) more than doubled the minimum requirements for acceptable IAQ.
- The passive intake vent on the HVAC fan return side combined with a supplemental mechanical exhaust fan on the tent wall without HVAC fan operation (Test No. 3) exceeded the minimum requirements for acceptable IAQ.
- A supplemental mechanical exhaust fan in combination with a fresh-air intake vent allowed filtering of particulate matter and regulated the amount of outside air introduced into foamed-insulated tent.
- Use of the supplemental mechanical exhaust fan with a fresh-air intake vent satisfied the minimum acceptable air changes (1.36 ACH) with and without operation of the HVAC unit blower.
- The fresh-air intake vent damper was manually adjustable, but was operated in the full OPEN position for all tests.

[10] Exponent report by Gavelli, F, and Wu, N., "Tent Foam Insulation Report: W9124Q-06-F-1204", March 12, 2007.

[11] Previous testing on January 25, 2007, resulted in 0.35 ACH without the fresh-air intake or tent exhaust opening.

- The energy needed to operate the supplemental exhaust fan[12] and energy loss from exhausting conditioned air from inside the tent is expected to reduce energy efficiency and increase the heating/cooling load on the HVAC system.

5.3 Recommendations

The following recommendations are based upon installation of the fresh-air ventilation system in the exemplar foam-insulated tent and may be followed in order to improve the indoor air quality inside the tent. These recommendations are intentionally general in nature so that they may be applied to tents of different make and size. However, the effectiveness of the following recommendations should be verified on a case-by-case basis, by performing specific calculations or exemplar testing, prior to their implementation on tents.

- The 10-inch diameter, 350-cfm capacity exhaust fan in the tent wall coupled with a 5-inch diameter fresh-air intake vent produced approximately double the required air changes needed to maintain acceptable IAQ. Further analysis should be performed on the exhaust fan capacity to promote a reduction of the heating/cooling load on the HVAC unit.
- The fresh-air intake vent damper position can be adjusted to throttle the amount of fresh air introduced. Additional analysis is recommended to determine a more energy efficient damper position that reduces the amount of excessive outdoor air through the system.
- Carbon dioxide (CO_2) is a product of human respiration and a heavier gas than air. The mechanical exhaust fan should be mounted near the ground level on the tent wall most remote from the return air vent. An integrated means to automatically operate the exhaust fan at all times the tent is occupied is recommended to prevent stratification during occupancy and to improve IAQ, while preventing unnecessary energy losses from the exhaust fan.
- Where skilled personnel are unavailable for installation of the fresh-air exchange system, absolute thermal efficiency is needed, or airborne contaminant prevention is imperative, implementation of an alternative heat and energy recovery ventilation appliance is recommended.
- Previous results showed that the heating and cooling load for a foam-insulated GP-Large tent with 28 occupants was approximately 4 tons. A survey of existing equipment capacities is recommended prior to implementation of the spray foam and fresh-air exchange systems in FOBs.
- Where airborne particulate matter is unacceptable, a High Efficiency Particulate Air (HEPA) filter should also be installed in the return duct to remove dust, pollen, mold, bacteria and any airborne particles from the conditioned space.
- A protective metal exhaust fan hood with wire guard should be provided on the exhaust fan outlet side to protect against water intrusion through the fan opening and/or

[12] Broan Model 504 product specifications indicate a 1.7-amp current draw at 120-volts.

accidental contact with the fan from the outside. The fan protective hood should be labeled with an appropriate warning label.

- Penetrations through the tent wall for electrical conduit or ventilation equipment should be in place prior to spray-foam application to facilitate airtight seals around openings.
- Flexible supply and return air ducts outside the tent may be chemically or physically altered during the spray-foam application as noted during the inspection. The ducts should be covered with a sheathing material to protect against overspray.

6 Conclusions

As part of the Rapid Equipping Force (REF) contract W91CRB-07-D-0013, Exponent was asked to investigate methods of improving indoor air quality (IAQ) in polyurethane (PU) foam-insulated General Purpose (GP) U.S. Army tents installed in Forward Operating Bases (FOBs). A previous report dated March 12, 2007, demonstrated that the rate of fresh air infiltration into the exemplar foam-insulated tent was inadequate to meet acceptable IAQ standards. Exponent was asked to develop a strategy to introduce a controlled volume of fresh air into the foam-insulated tent to maintain IAQ in accordance with industry-accepted practices.

Based upon the investigation, Exponent has the following findings:

- A ventilation system consisting of a passive fresh-air intake vent on the return side of the air-handling system and a supplemental mechanical exhaust fan mounted on the tent wall can be implemented using conventional tools and commercially available components.

- The installation of components was documented to assist in development of installation guidelines. A simplified installation checklist is presented in Appendix A.

- Air exchange rate measurements were performed with the improvements to determine the effect on fresh-air ventilation and to evaluate IAQ of the tent.

- The ventilation scheme consisting of fresh-air intake vent combined with a supplemental mechanical exhaust fan exceeded the minimum number of air changes required for acceptable IAQ standards with and without operation of the HVAC unit fan.

- Other arrangements and components were researched and presented as alternatives to enhance performance and energy efficiency in comparison to the prototype fresh-air ventilation system. The alternatives compromise on cost, simplicity, or performance, but may be more suitable depending on specific need. For implementation of alternates, IAQ should be evaluated prior to occupancy.

- A preventive maintenance schedule was provided to promote continued performance of the fresh-air ventilation system.

Appendix A

Fresh-Air Ventilation System Installation Checklist

Prior to Spray-Foam Application:

- ❑ Disconnect power to the tent, including HVAC unit and relocate all electrical boxes to prevent contact of receptacle box or conductors with tent surfaces.
- ❑ Remove all electrical appliances from contact with tent material and provide proper clearance for any heat-generating appliance.
- ❑ Protect all light fixtures against accidental contact with tent material by installing cages or guards. (Optional compact fluorescent light bulbs are recommended for energy conservation and fire safety purposes.)
- ❑ Install a 10-inch diameter exhaust fan (Broan Model 504-C, Stock # X89-325). Position the exhaust fan housing in one of the unused tent ventilation opening in the wall most remote from return air box. Install a single pole - single throw electrical switch for the exhaust fan control. Label the control switch "EXHAUST FAN".
- ❑ Cover the exterior supply and return air flex duct with sheathing material to protect against overspray of foam insulation. (Spray foam may physically and/or chemically alter the flex duct performance.)
- ❑ Fabricate a return air box that can support a 20-inch x 20-inch x 1-inch return air filter grille. (Optional depth of can be chosen to accommodate HEPA filter.)
- ❑ Fabricate a metal exhaust fan outlet protective hood with metal grille to prevent entry of water or accidental contact with the exhaust fan blades.

After Spray-Foam Application:

- ❑ Install the 5-inch diameter fresh-air intake vent with damper. Remove the top panel of the outdoor HVAC unit. Locate the condenser coil and potential inlet openings in the panel and mark a 5-inch diameter hole on the panel. (The fresh-air intake vent location should allow fresh air to pass through the condenser coil prior to entering the HVAC blower fan.)
- ❑ Cut a 5-inch diameter hole in the metal panel and secure the HVAC unit insulation with tape.
- ❑ Place the intake vent over the opening and secure the intake vent by installing four (4) self-tapping sheet metal screws through the flange into the HVAC metal panel.
- ❑ Close the intake vent damper and place one 8-inch length strip of foam insulation tape on the vent body to create a seal against the damper plate. While keeping the damper closed, apply another 8-inch strip of foam insulation tape to the vent body on the opposite side of the damper plate most remote to the first strip of tape. The tape seals should still allow the damper to open.

- Install the fresh-air intake filter. Cut a 6-inch square piece of custom filter media (hog hair, polyester, or fiber glass) and place the filter inside the 5-inch diameter double-wall vent cap.
- Place a strip of foam insulation tape on the top edge of the intake vent body. Slide the vent cap on top of the 5-inch diameter intake vent. Secure the vent cap by installing two (2) self-tapping sheet metal screws through the vent cap body. Place the stocking on top of the double-wall vent cap. (Optional as a second filter media.)
- Determine the position of the damper and mark OPEN and CLOSED positions on the intake vent body. Leave the damper in the full OPEN position.
- Install the return air system inside the tent. Place the return air box at the opening closest to the HVAC unit return duct which should be the most remote wall from the supplemental exhaust fan. Fasten the return air flex duct from return air box to HVAC unit.
- Install a 20-inch x 20-inch return air filter grille with a 20-inch x 20-inch x 1-inch glass filter in the return air box.
- Install a digital thermostat (White-Rodgers, Series 70, single-stage heating/cooling non-programmable Model # IF78H, or other compatible thermostat).
- Restore power to the HVAC unit.
- Turn the supplemental exhaust fan ON while the tent is occupied.
- Adjust the supply plenum openings to optimize circulation throughout the tent.