ENVIRONMENTAL CONTROL UNITS SPECIFICALLY DESIGNED FOR USE IN NUCLEAR, BIOLOGICAL, AND CHEMICAL WARFARE ENVIRONMENT

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ABSTRACT

The design of an Environmental Control Unit (ECU) for a military application requires the engineer to evaluate multiple design solutions to insure the ECU meets the system requirements. When the additional requirement for operation in a Nuclear, Biological, and Chemical (NBC) warfare environment is imposed, the design task becomes even more difficult for the engineer. Issues that are not important for the non-NBC type ECU become extremely important. These issues include leakage, location of protected boundaries, overpressure requirements, fresh air supply, and the interface with NBC filtration equipment. Many of the NBC issues also influence the standard design considerations and directly affect size, weight, power, noise, and other features of the ECU. This paper examines the design tradeoffs and reports the performance of two different ECU's designed and manufactured by EEi specifically for use in the NBC warfare environment.

INTRODUCTION

The integration of an ECU into the protection scheme for the NBC shelter requires the ECU designer to incorporate not only the normal components and design features into the ECU but also components and design features that provide the protection for the occupants of the shelter. Through evaluation of the total system is necessary to make sure that the integration of the shelter and ECU addresses all the design features needed to prevent NBC agents from entering the protected space. Each system maybe different and must be evaluated.

DESIGN CONSIDERATIONS

The nuclear energy world has dealt with the problem of providing protection from radioactive particles and gases to the operators and maintenance personnel for nuclear reactors for many decades. During this time, the regulatory and advisory agencies and groups have developed a rigorous approach to designing and testing heating, ventilation, and air conditioning (HVAC) systems to ensure theses systems do not allow contamination of the "clean" spaces in a nuclear power plant. Two major standards used by engineers designing ventilating systems are <u>Nuclear Power Plant Air-Cleaning Units and Components</u>, (ASME N509) and <u>Code on Nuclear Air and Gas Treatment</u> (ASME AG-1) published by the American Society of Mechanical Engineers (ASME). These standards are written to address the design requirements for a filtration system for a nuclear power plant, but the engineering concepts presented can be used as guidance for the military NBC application. Included in the standard is a discussion of the leak rates allowed for ducts, fan housing, and dampers for different locations in the HVAC system.

The two major consideration in the design of a HVAC system that must provide protection to the operators or occupants inside the protected area are to reduce the leak rate to the smallest value possible and to provide a positive pressure differential between the protected space and the contaminated space.

The necessity to reduce the leak rate to the smallest value possible is readily apparent when the engineer determines the amount of filtered air required to produce a positive differential pressure inside the protected space. The greater the leak rate, the greater the amount of filter air that must be introduced into the protected space. To produce more filtered air either requires a larger filter unit (fan and filter) or, if the filter unit size is constant, reduced life for the filter element. Also, the more air introduced into the shelter, the greater the heating and cooling load for the ECU. Neither choice helps with the problems associated with a military application where weight, size, power, and operation time are all critical and can significantly affect the success of a program. Therefore, it is imperative for the engineer to spend a significant amount of time to insure that the space is sealed to minimize the leaks.

Once the space is sealed and the leaks minimized, then the engineer can develop a method to insure that there is always a positive pressure differential between the protected space and the contaminated space. For a military application, the protected space is typically a small shelter that is located in a contaminated battlefield environment. The engineer must determine the minimum positive differential pressure that must be maintained inside the shelter (the protected space) so that for any leak path, the flow is from inside the shelter to the external environment. He must consider the operational uses and what environmental conditions the system will encounter. This includes whether the shelter is operated only at a fixed site or if the shelter is mounted on a vehicle and must provide protection to the occupants when the vehicle is in motion (mobile). In either the fixed site or mobile application, the relative wind (either natural or induced by the motion of the vehicle) creates a pressure on the side of the shelter facing the wind that must be countered by the overpressure inside the shelter. This can increase the amount of overpressure required and the amount of filtered air that must be delivered to the shelter. The affects of wind on the fixed site shelter/ECU is an important concern, it is an even more critical concern for the shelter/ECU that must provide protection when the vehicle is moving.

After the positive pressure differential is determined, then the design of the HVAC system must be evaluated. Any part of the HVAC system located in the contaminated space that provides a possible leak path into the shelter must have a positive pressure differential between the protected space and the contaminated space. As with the shelter, the relative wind effects must be evaluated. However, the effects of the operation of the equipment, for example the low pressure area created on the suction side of a fan, must be include in the analysis. The location where the filtered air is delivered to the shelter/ECU and the configuration of the HVAC system can increase the amount of overpressure required and the amount of filtered air that must be delivered to the shelter. The design of the ECU should minimize or eliminate any increase in overpressure required because of the ECU. Also the method of delivering the conditioned air (supply air) to the shelter and return air from the shelter affect the positive pressure differential required for protection.

Another design element that must be included in the analysis is the method of introducing fresh air (ventilation) into the shelter when the shelter is not in an NBC environment. The engineer must select and evaluate how the HVAC system will provide fresh air to the shelter. Typically, the design incorporates a damper that is open when there are no NBC contaminates but closes to isolate the contaminated environment from the clean environment. The fresh air damper/duct is designed to connect to the circulation fan intake plenum. A major concern with connecting the damper to the circulating fan intake plenum is that the intake plenum typically has the lowest pressure in the circulation air path and is likely to have a negative pressure differential (i.e., the pressure in the contaminated area is greater that the pressure in the fan plenum). This issue can be addressed in two ways. First, a "tight" sealing damper can be used to close the fresh air intake during NBC operation. The HVAC system can be designed so that the filter air is injected into the circulation fan plenum. The typical HVAC damper has a leak rate that is too high to prevent contamination of the protected space. "Bubble tight" dampers have been designed and manufactured for the nuclear power industry for many years, but these dampers are expensive and heavy. By combining a good "leak tight" custom damper design with the injection of the filter air into the circulating fan plenum, the engineer can produce a HVAC system design that will provide fresh air during non-NBC operation and provide the positive pressure differential required during NBC operation.

At EEi we have provided designs for three typical shelter/ECU configurations to satisfy the NBC requirements.

- The first configuration is a hard shell shelter and a split system ECU. This configuration is possibly the easiest from the design point of the ECU. In the split system, the condensing unit and the evaporator/circulating fan unit are two separate components with interconnecting refrigerant tubing and control wiring. This approach is can be used when the ECU is installed inside a "hard shell" shelter, which can support the weight of the evaporator section. There must be enough space inside the shelter for the installation of the evaporator/circulating fan unit. As long as the evaporator/circulating fan unit is completely inside the shelter with no common wall between the evaporator/circulating fan unit and the shelter, only the penetrations in the shelter wall for the refrigeration piping and the control wiring must be sealed. The shelter will typically require a fresh air intake and exhaust system to provide ventilation when the system is not in the NBC protection mode. This fresh air system must be closed during NBC protection mode. Standard "Mil Spec" fresh air systems are available with either pressure differential sensing and/or electrical interlocks. An example of this configuration is Standard Integrated Command Post (SICP) shelter and ECU.

- The second shelter/ECU configuration is the package unit where the supply and return air connect directly with the shelter and there are no ducts between the ECU and the shelter. This configuration is often seen installed on a hard shell shelter or trailer/van. With this ECU design, the sealing and positive pressurization of the evaporator/circulating fan section of must be incorporated into the ECU, and the design effort is more complex. An example of this configuration is the "Reconnaissance Vehicle Shelter and ECU".

- The final shelter/ECU configuration is a packaged unit that supplies conditioned air to a hard or soft shell shelter like a tent. The ECU is designed to sit on the ground near the tent and flexible supply and return ducts connect the ECU to the tent. As with the second configuration, the sealing and positive pressurization of the evaporator/circulating fan section must be incorporated into the ECU. Also, the sealing, protection, and positive pressurization of the flexible supply and return ducts between the tent and the ECU must be addressed. An example of this configuration is the "Lightweight Environmental Control Unit (LECU) combined with a CP EMEDS".

EEi EXAMPLES/OVERVIEWS

The hard shell shelter/split system configuration does not present the design challenges from the NBC aspect that the second and third configurations do. Therefore, examples of the design of ECU's for the second and third configurations are discussed. One recent system was designed and manufactured for an NBC reconnaissance vehicle (HUMMV with a hard shelter) and a second one was designed and manufactured use with a NBC soft shelter. These two applications will be used to demonstrate two different design approaches for ECU's that provided heating, cooling, and ventilation while providing a positive pressure differential during NBC operation.

Reconnaissance Vehicle Cab and Shelter ECU

The customer for the NBC reconnaissance vehicle had established a positive pressure differential of requirement of 1.5” to 3.0” water column (W.C.) for the shelter. Additional constraints on the design were the obvious ones for a mobile military design, weight, size, and power. EEi worked closely with the customer to select a design approach that would meet the NBC requirement and reduce the weight, size, and power. Since the system had to operate while the vehicle was moving, there was an auxiliary power unit (APU), consisting of a generator set and power conversion module, that provides prime power when shore power was not available. The ECU design incorporated the radiator for the APU into the ECU cabinet. This approach saved weight and power and reduced the size of the APU. The radiator for the APU was added downstream of the condenser coil and used the airflow provide by the condenser fan. Since the temperature of the air leaving the condenser was less than 150°F at the high ambient temperature and the APU water temperature is limited to 185°F, there is sufficient temperature differential to select a radiator coil to provide the required performance. The additional power to over come the increased static of the APU radiator coil was minimum. Further, the hot water from the APU was used to provide heat during operation of the APU again reducing the amount of power the APU had to provide to the ECU.

To insure a positive differential pressure, the Gas Particulate Filter Units (GPFU) were integrated into the ECU design (See Figure 1). The fresh air intake duct was used as the duct for the filter air. A tightly sealing damper, designed by EEi, was installed between the GPFU’s and the fresh air intake. The damper was controlled by the GPFU controller that opened the damper when the GPFU’s were not operating and closed the damper when the GPFU’s were operating. The damper actuator was selected to be fail safe, that is the damper closed anytime power was removed from the actuator. This insured that the damper was closed in the event the APU did not provide power to the ECU, increasing the protection for the occupants. The fresh air/filtered air duct was connected to the circulating fan intake plenum.

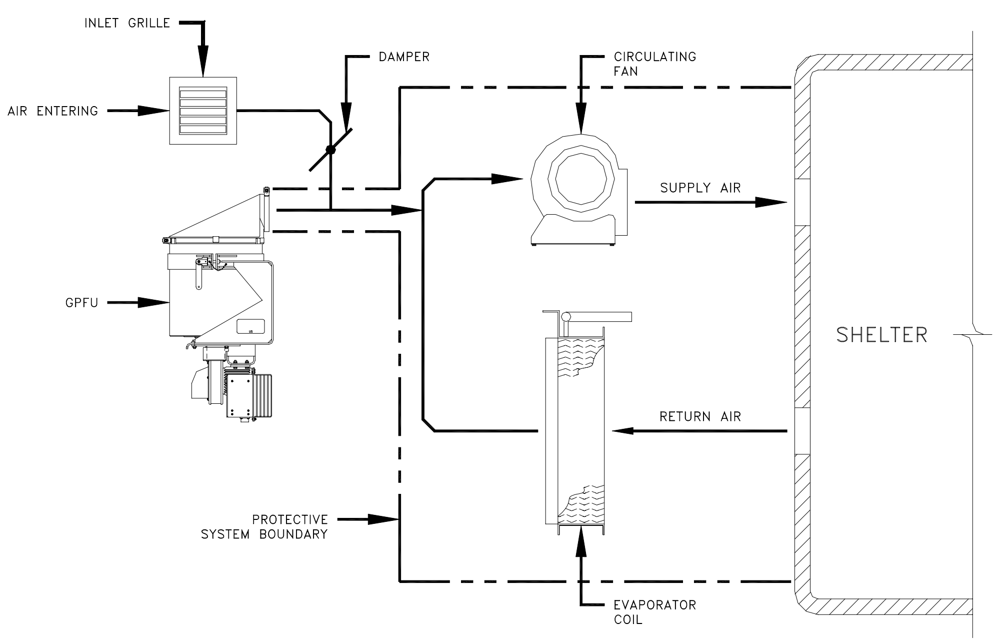

Figure 1. Reconnaissance vehicle airflow schematic.

Thus, when the GPFU’s were not running and fresh air ventilation was required, the damper was open and the circulating fan drew fresh air into the shelter. In the NBC mode, the GPFU’s were turned on, the damper was closed, and the circulating fan intake plenum had a positive differential pressure generated by the GPFU's

The ECU was mounted over the cab of the vehicle (See Figure 2), and there are two GPFU's installed on the front of the ECU. The condenser section consists of two sets of coils located with one set located on the curbside of the ECU and one set located on the roadside. The road side set of coils has a refrigerant condenser coil and an APU radiator while the curb side set of coils has a power conversion module radiator, a refrigerant coil, and an APU radiator. The evaporator section (See Figure 3) has the circulating fan, the duct for fresh/filtered air, and the evaporator coil.

Figure 2. EEi Model ECU 34534 installed on reconnaissance vehicle.

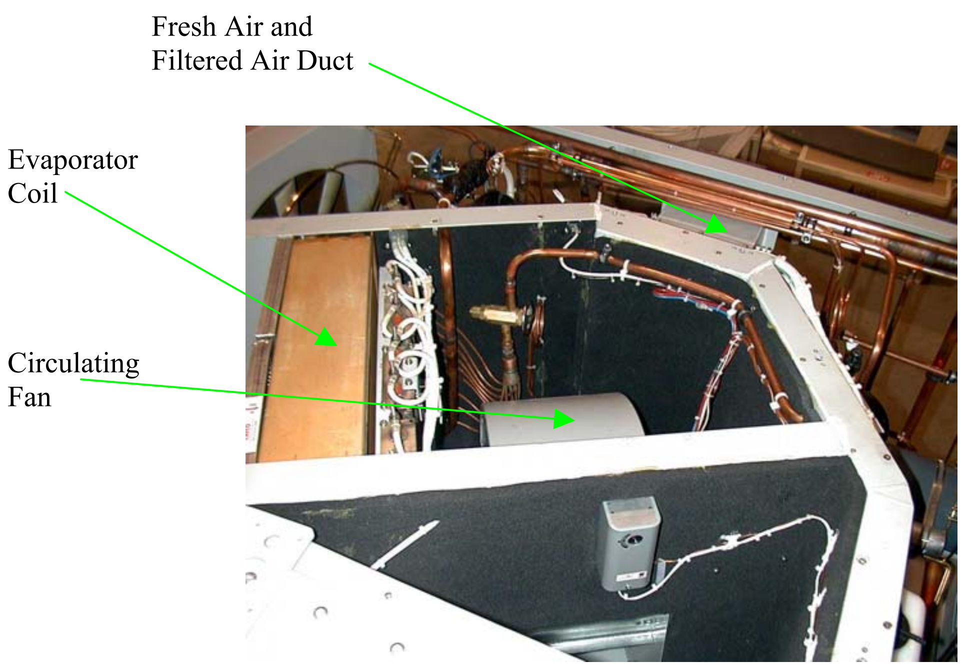

Figure 2. Evaporator section of EEi Model ECU 34534.

Before the ECU was installed in the Reconnaissance Vehicle, EEi has the opportunity to test the ECU and APU combination at our facility in Cincinnati, OH. The customer wanted to demonstrate the ability of the integrated system to provide the required cooling capacity (ECU) at the high ambient temperature (120°F) and the return air conditions (85°F and 50% relative humidity). Also, the customer wanted to examine the effect of the system equipment load on the performance of the APU and PCM, so EEi developed a simulator for this load. EEi installed the ECU in our climate-controlled chamber and instrumented the ECU and APU to provide the data necessary to evaluate the performance of each of the components (See Figures 3 and 4). Initial testing of the ECU and APU allowed EEi and the customer to resolve some minor issues with the integration of these components. Then additional tests were conducted on the equipment to demonstrate the validity of the solutions, with the most severe test being a 24 hour continuous run with the ambient temperature at 120°F. During this test, the cooling load on the ECU simulated the cooling load expected in the vehicle during a mission and the system equipment simulator approximated system equipment load expected during a mission. After the testing was completed, the data were analyzed to evaluate the performance of the ECU. The ECU demonstrated its ability to provide the required environmental conditions for the interior of the shelter.

Figure 3. EEi ECU 34534 installed in environmental chamber for integration testing.

Figure 4. Generator used for integration testing.

After completion of the integration tests at EEi, the ECU was shipped to the customer who installed the ECU on the Reconnaissance Vehicle. The customer performed initial tests of the integrated system, including a test of the ability of the ECU and GPFU's to provide at least 1.5" W.C. overpressure inside the shelter. Then the completed vehicle underwent testing by the military. One of the significant tests (from an NBC perspective) was the testing performed at Dugway Proving Grounds using simulated chemical agents. The results to date indicate that the system supplies the over pressure inside the protected space to provide a safe environment for the crew of the Reconnaissance Vehicle.

NBC Soft Shelter ECU

In early 2001, the United States Air Force (USAF) issued a request to industry to develop a new LECU. The LECU would be evaluated for a possible replacement for the Field Deployable ECU (FDECU) used with the CP EMEDS. The FDECU weighs approximately 700 pounds (current variant) and provided the five-ton capacity at 115°F. The USAF was looking for a five-ton ECU that was significantly lighter, smaller, and had a higher static fan capability on the circulating fan than the existing five-ton ECU. New LECU was to meet the following goals and provide the following improvements over the existing ECU's:

- Have a five-ton capacity at 125°F and 90°F return air temperature.
- Operate off 208-volt, 50/60 Hz, 3-phase, 4-pole, 5 wire, 60 amp, wye-connected power.
- Utilize the standard government NBC Hardening Kit for NBC mode operation.
- Operate at up to 3 inches w.c. of static pressure.
- Improved design/quantity for palletized air transport.
- Reduce the complexity of maintenance.

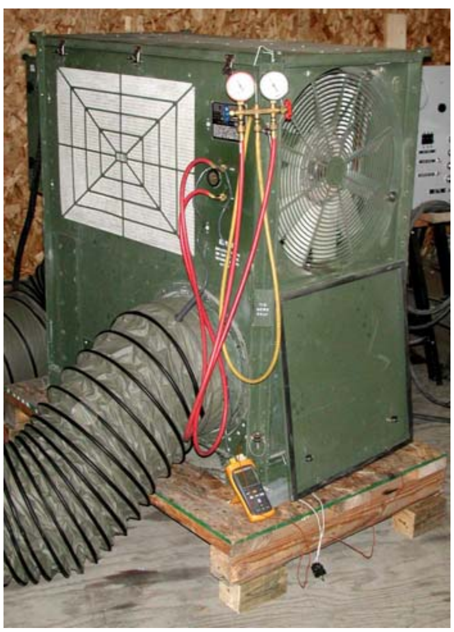

Figure 5. LECU with standard flexible ducts.

In response to the request from the USAF, EEi designed the LECU (Patent Pending) (See Figure 5) to meet or exceeded these goals. The LECU was developed at EEi's expense without government or customer money. The initial concept for employment of the LECU was with a NBC shelter with the LECU's supply and return connected to the shelter with flexible duct. In order to insure that the flexible return air duct provided adequate protection from NBC agents, EEi used a coaxial type duct and NBC Hardening Ring (See Figure 6) similar to the concept used by the FDECU. The actual design differed from the FDECU with the changes

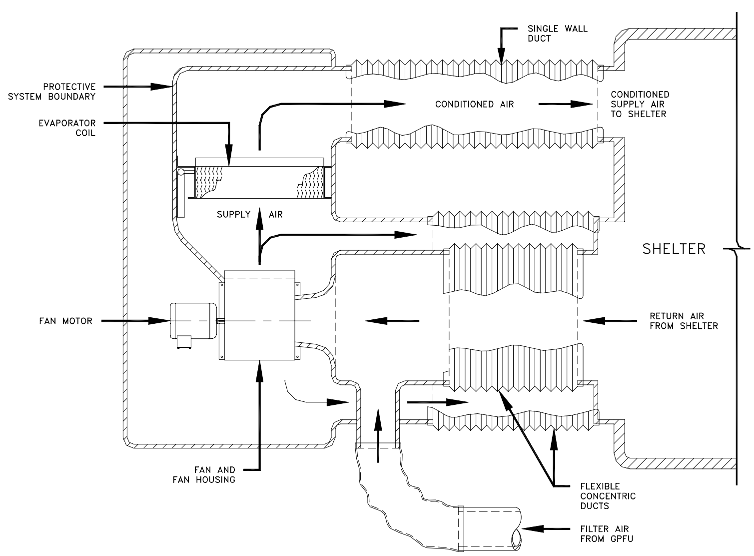

Figure 6. Airflow schematic for LECU with NBC hardening.

made to reduce weight and increase the resistance to NBC infiltration. In the design, the higher-pressure air from the discharge side of the circulating fan is used to pressurize the space between the two walls of the duct to prevent the inner wall from being exposed to the NBC agent. Also, the use of a coaxial duct provides protection from damage to the duct. In an NBC environment, the LECU is employed with a standard military GPFU that provides 400 cfm of filtered air at the NBC Hardening Ring to pressurize the ECU and the NBC shelter. The fresh air intake was designed so that in the NBC mode, the intake is within the high-pressure area to prevent infiltration of contaminated air.

EEi delivered the LECU to the USAF in January 2002 for evaluation and testing. The tests included:

- Vapor/Particulate Challenge Testing.
- Performance Testing at extreme temperature conditions.
- Logistics Testing.
- Power Factor Testing.
- Noise Testing.
- Shock and Vibration Testing.
- Corrosion Resistance Testing.
- Power Consumption Testing.

Based on the evaluation conducted by the USAF, the LECU "is considered an excellent ECU that outperforms the FDECU in nearly every evaluation factor." Further, the LECU has "proved itself to be a capable direct replacement for the FDECU" and "with minor corrections, it is recommended that the LECU be the 5-ton capacity unit of choice to meet the Joint Service CP needs…."[1] The LECU currently in production by EEi meets or exceeds these goals, and EEi is making additional improvements and refinements.

EEi is currently producing the LECU in several variants and is developing a family of ECU's based on the design of the 5-ton version to provide capacity between 3-tons and 6-tons in the same cabinet size.

CONCLUSION

An ECU that will be used in a NBC environment requires the integration of competing requirements into a design that will meet the needs of the end user. The design must address the normal requirements every ECU must meet capacity, power, weight, and size. In addition, the design must consider the protection of the operator and provide the ability to eliminate infiltration of NBC agents into the protected space. The two different ECU's discussed above, show that there are different ways to approach the design. The approach must be tailored to the application and the other requirements established by the customer. EEi has demonstrated our ability to take a particular application and develop an ECU design that meets the customer's requirements and needs for the NBC environment.

ACKNOWLEDGEMENT

I want to thank Joe Lane of EEi for the artwork he produced for this paper.

REFERENCE

[1] Lightweight Environmental Control Unit Test Report, 26 April 2002, TEAS, Reference Number 400456.