4027

INDOOR AIR QUALITY—LESSONS FROM SUBMARINE ENVIRONMENTAL SYSTEMS

C.A. Edge, P.E.

ABSTRACT

U.S. Navy submarines have the capability to remain submerged for weeks at a time. A major contributor to this capability is the design of their environmental systems.
The issue of indoor air quality is recent to building environmental systems designers. However, submarine environmental system designers have dealt successfully with this issue for some time.
This paper shall present a description of Submarine Environmental Systems and features which relate to indoor air quality.

INTRODUCTION

With the development of the world's first nuclear submarine, the Nautilus, launched in 1954, the U.S. Navy had the first submarine capable of long-term continuous operation undersea. This achievement required in addition to a means of propulsion without oxygen consumption (nuclear power), a means of controlling and revitalizing the quality of its indoor air. Thus, the designers of the nuclear submarine had to solve the problem of indoor air quality at least thirty years ahead of those of us involved in buildings. A number of the lessons learned may be appropriate for consideration in buildings.

SUBMARINE ENVIRONMENTAL SYSTEMS

A submarine's environmental systems have the requirement to provide an acceptable air quality for the crew and to remove heat generated by machinery and electronic equipment. Crew members are allowed to smoke which generates a large CO and aerosol load. The main battery creates hydrogen when on charge. Cooking, fuel and lubricating oils, sewage waste handling facilities, and off-gasing of construction materials all add to the contaminant load of a submarine. These systems are:

--air-conditioning chilled water system
--ventilation system
--snorkel system
--main oxygen system
--CO_2 removal system
--CO-H_2 burners
--atmosphere analyzing system

Generally, chilled water is the medium for removing heat. The air-conditioning chilled water system consists of the chiller plant (typically a centrifugal chiller) and piping system to circulate the water to the cooling coils of the ventilation system.

The ventilation system filters, cools, and recirculates the air throughout the ship. In the engine room and machinery spaces the system is generally a local recirculation system,

C. Anthony Edge, P.E. is Manager, Building Projects and Civil Engineering, Northeast Utilities; formerly, Engineering Chief, Marine Engineering Department, Electric Boat Division of General Dynamics

i.e., fan-coil units with limited ducting. The control and living spaces are generally served by a central system from a main fan room with cooling coils and heaters in the supply ducting for each zone. A main supply duct originating in this fan room distributes air aft to the engine room and machinery spaces. Exhaust fans draw air from all the spaces for redistribution. The systems are generally high velocity. Vaneaxial fans are used because of their compact size and ability to develop static pressure. Louvered doors and bulkhead openings, in addition to forced supply and exhaust, permit concentrations of gases to dissipate throughout the ship's atmosphere. The reactor compartment is the exception, it is normally sealed off from the rest of the ship.

The snorkel system consists of air-intake ducting, main induction fans to draw outside air through the snorkel induction mast, and exhaust ducting to discharge exhaust from the low pressure blower (or diesel engine). This system can only be used at or near the surface and is infrequently used.

Air purification and revitalization in provided by the main oxygen system, CO_2 removal system, CO-H_2 burners, filters (high efficiency and activated-carbon) and electrostatic precipitators in the ventilation system. An atmosphere analyzing system provides the capability of monitoring atmospheric gases and contaminants in each compartment.

The main oxygen system generates, stores at high pressure, and distributes oxygen into the ship's air. Normal human consumption is about 2.2 pounds of oxygen each day per person. An oxygen generator produces the oxygen via electroysis of water. The oxygen produced is stored at high pressure in flasks located in the ballast tanks. The oxygen is discharged at one or two points into the ship's atmosphere through reducing valves. Chlorate candles which are burned in a special furnace provide a back up supply for an emergency.

The CO_2 removal system consists of "scrubbers" which run continuously to remove the carbon dioxide produced by the ship's crew. Normal human expiration of carbon dioxide is about 2.4 pounds each day per person. The "scrubbers" utilize a solution of MEA (monoethanalamine) and water. CO_2 is absorbed by the solution when cooled and is rejected when heated. The scrubbed carbon dioxide is discharged overboard. Granular lithium hydroxide (LIOH) is used as a backup means to remove CO_2. An absorbant (about 80% Ca $(OH)_2$) has also been used as a backup means of removing CO_2.

Recent submarine designs limit CO_2 concentrations to 1/2% (5000 ppm). Older submarine designs limited CO_2 concentrations to 1% (10,000 ppm). In actual operation, a level of about .7% is maintained on the older submarines. These limits are substantially greater than we should expect in buildings.

Disposal of light gases (i.e., CO, H_2, trace hydrocarbons) are burned off in a catalyst bed in the CO-H_2 burner. The light gases are turned into water vapor and carbon dioxide by this process. A CO level of less than 25 ppm is achieved.

Filters play a vital role in maintaining air quality aboard a submarine. High-efficiency filters are used in both the supply and exhaust ducting to remove particulate and aerosol contaminants. Activated carbon filters are used extensively to absorb many gaseous contaminants from such sources as the galley and water closets. A lithium carbonate filter in the exhaust duct from the CO-H_2 burner removes harmful byproducts produced by combustion of hydrocarbons. Contaminants in the form of aerosols or particulates are also removed by electrostatic precipitators.

Concentrations of vital and harmful gases in the ship's atmosphere are monitored by the ship's atmosphere analyzing system. This system consists of sampling piping that can draw samples from all of the ship's spaces; an atmosphere analyzer for measuring concentrations of oxygen, carbon dioxide, carbon monoxide, refrigerants, and hydrogen; and a total hydrocarbon analyzer which detects excessive levels of hydrocarbon contaminants (e.g., methane, benzene). Backup monitoring is performed with portable gas detectors (glass sampling tubes with hand pumps).

LESSONS

Obviously, economical buildings cannot be designed and built as if they were to be sealed up for weeks without any outdoor air similar to a submarine. However, the design, construction, and operating experience can be useful for buildings. Pertinent lessons from submarine environmental systems are discussed in the following paragraphs.

DESIGN

1. A healthy indoor air environment can be achieved by stressing control of the contaminants at the source, and removal of contaminants. Sufficient outdoor air to revitalize the buildings' air (reduce CO_2 levels and restore O_2 consumed) only may be necessary.

2. Use of high-efficiency filters, electrostatic precipitators, activated charcoal and activated alumina can very effectively reduce atmospheric contaminants.

3. Careful attention should be paid to ventilation effectiveness to ensure that conditioned air is distributed well. As an example, on a submarine the crew members berth (i.e., bed) is a shelf area with a mattress. To ensure adequate ventilation each berth receives 15 cfm of conditioned air by design.

4. Access plates are used extensively to ensure that the duct system and its components are fully accessible for inspection and cleaning.

5. Close attention is paid to ensure cooling coils drain properly, a length of clear plastic tubing is used in the drain line of each coil to provide a visible means of inspection. Coil velocities are carefully limited to prevent moisture blow-off.

6. A layer of thin plastic sheet (1 or 2 mils) is used to cover the fiberglass lining of ducting to prevent moisture absorption and the resultant breeding grounds for fungus and bacteria. Tests were conducted to check the impact of this practice on sound absorption. The results indicated a minimum impact.

CONSTRUCTION

1. Careful attention during the construction process is required to ensure that the systems are built as designed. Submarine designers frequently review their systems during construction.

2. Prior to any testing or operation the systems are cleaned and flushed carefully to remove any construction debris.

3. The air and water systems are carefully balanced to ensure that the design flow rates are achieved. Exhaust as well as supply air systems are balanced. After balancing the systems are operationally tested. A detailed test procedure, prepared by the designers, defines the required operational checks to ensure that the system functions as designed. Operational data is taken during these tests (i.e., temperatures, flow rates, pressures, voltage, amps, etc.) This data is reviewed for adequacy by the designers and retained by the ship as a reference for future operational checks.

OPERATION

1. Operators are well trained to ensure that they have a full understanding of these systems. Training classes are conducted for the operators during the construction process, often by the systems' designer. Plans, operation and maintenance manuals are reviewed in detail by the operators.

2. During operation, the ships' atmosphere is frequently monitored for levels of gaseous contaminants by the atmosphere analyzing system to ensure that the systems are functioning.

3. As a routine, extensive maintenance is performed on these systems. This includes cleaning, replacing and/or recharging filters, cleaning cooling coils and their drain pans, precipitators and ducting. This is done as part of the ship's planned preventative maintenance process.

CONCLUSION

A quality indoor environment is achieved aboard submarines without any outside air using available technology. The principle lesson for building designers is that a quality environment can be achieved using a minimum of outside air (to replenish O_2 and purge CO_2) filtration of recirculated air, and attention to detail in design, construction and operation

In 1915, Steinmetz predicted "When electricity is developed we shall have apparatus that will destroy the bad air and bring fresh air into the home. We shall constantly have good fresh pure air indoors." At the present time we have yet to achieve this, but with efforts as represented at this conference we shall make it happen.

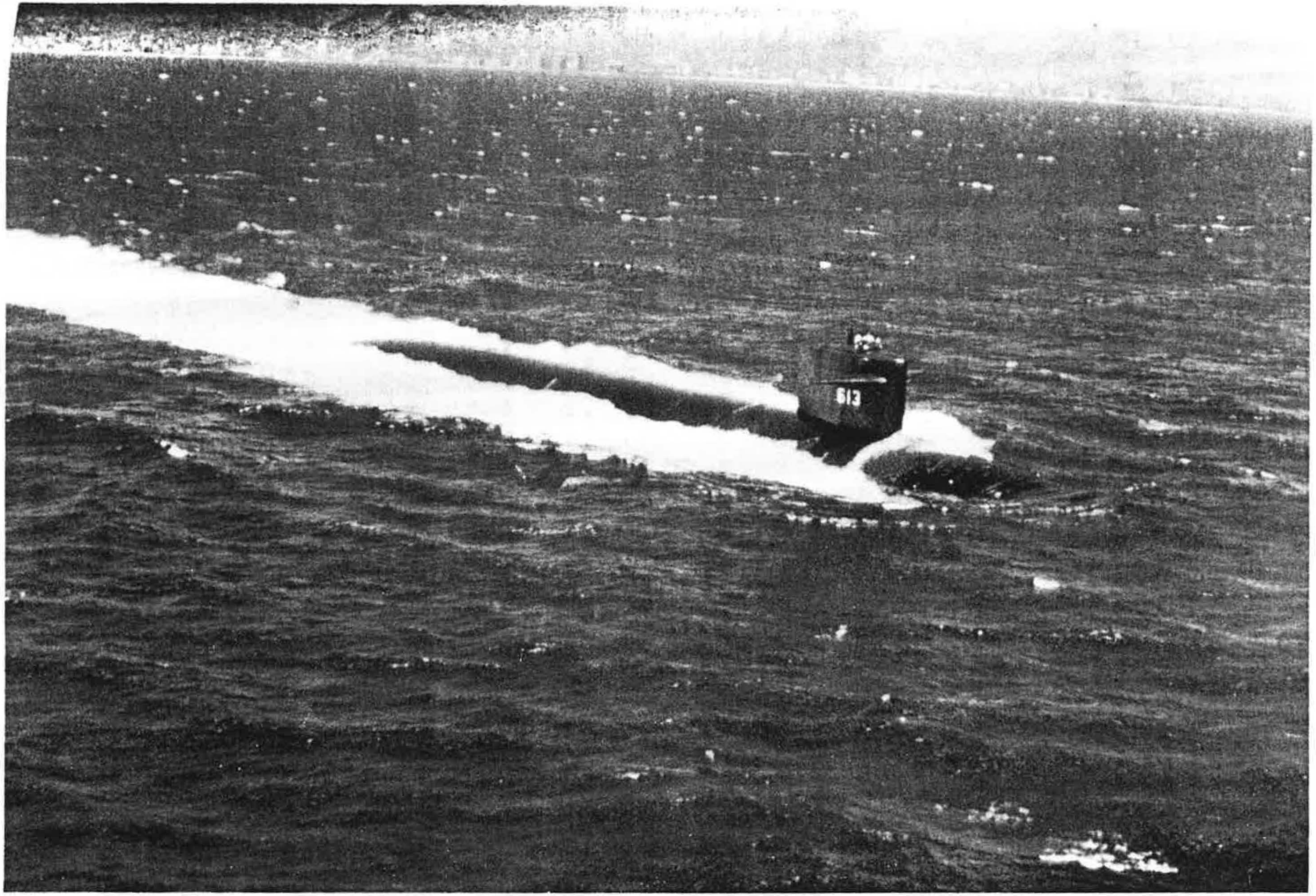

Figure 1. A typical submarine

Discussion

H. LEVIN, University of California, Berkeley: What is the actual or assumed period of efficacy of the activated carbon filters?

EDGE: Submarines have no better means of determining when a charcoal filter has served its useful life, than simply when the odors return. I do not know the frequency of recharging these filters.

LEVIN: Describe the recharging process and system for charcoal including storage and disposal of contaminants.

EDGE: The recharging is simply a replacement process, and the spent charcoal is then discarded.

K. TRAMPASCH, Center for Residential Health, Wayland, MA: In the residential environment, healthful indoor air to a large degree depends on personal habits of the occupants. Is there a training program for ways to promote indoor air quality? Were consumer products analyzed for their effects on indoor air quality? Is there a data base that resulted from these concerns to promote a healthful indoor air quality?

EDGE: There was no formal training program when I left the business other than what would be covered in training lectures on the environmental systems. A limited amount of products were banned from use on submarines. I am not aware of a data base covering consumer products specifically.

C. LAWSON, Carl N. Lawson and Associates, New Port Richey, FL: In submarines, what was the life expectancy of high efficiency filters, and are they that efficient?

EDGE: The high efficiency filters often lost 2 months or more because they are used with less efficient pre-filters. The high efficiency filters are about 95% efficient.

J. REPACE, US EPA, Washington, DC: How much of the data base on a submarine is accessible? It would be particularly useful to get information on outgassing of paints, etc.

EDGE: Much is classified and inaccessible. However, a significant amount is not classified. I suggest you contact your congressman, who should help facilitate a good response.