Ventilation by induced draft
by Owen Arthur Kubal

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Mechanical Engineering
Montana State University

Abstract:
Occupants of family-type fallout shelters require' fresh ventilation air at the minimum survival rate of 3 cfm per person. Because cost limitations exclude the use of auxiliary power plants (diesel or-gasoline engines) to operate ventilating fans or blowers, an inexpensive, simple, and effective method of supplying fresh air to home shelters is needed.

It is demonstrated that minimum air rates can be obtained in home shelters by inducing a draft in the exhaust stack by means, of, a flame from a kerosene burner which can simultaneously provide illumination.

The ventilation test procedure included inducing air to flow through the shelter, determining the actual cubic feet per minute of air flowing, measuring air temperatures at inlet, room, and stack, measuring the pressure drop or restriction to air flow at the shelter inlet, and finding the effects of various stack sizes and configurations upon air flow-rates.

Although not originally intended to be a large part,of the research work, a considerable amount of time and money was spent in finding a sensitive and reliable means of measuring low velocity air flows. This work led to the conclusion (incidental as far as shelter ventilation is concerned) that bead-type thermistors are not reliable air measuring devices when used in a temperature-compensating Wheatstone-bridge circuit. See appendix.

Ventilation of family-type shelters by the induced draft method is effective and reliable if the following conditions are observed: 1. Wind velocities around the stack outlet are kept to a minimum or a good ventilator stack cap is used.

2. Filters are not used at the shelter inlet.

3. The intake area of shelter is much larger than the cross-sectional area of the stack.

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Abstract

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INTRODUCTION

As more and more countries attain nuclear capability, we, as a nation must accept the fact that the possibility of the use of nuclear weapons is increasing. Our ability to fight limited wars without having to resort to the use of nuclear weapons has also been increased. Isolation and protection from attack, once provided by oceans and huge land masses, is no longer naturally available to the population. Protection from "modern" attack must evolve from a cooperative, well-planned program. Military strength provides a high level of retaliatory capability, but civilian preparedness is one of the best means of providing defense and protection.

Over the past four or five years the civil defense program has been reoriented around fallout shelter protection. In a nuclear attack, fallout shelters offer the best single non-military defense measure for the protection of the greatest number of people.

Attacks on the United States with weapons totaling from 2,000 to 15,000 megatons would require shelter stays of from two days to two weeks, depending upon the attack pattern and location. A nationwide system of fallout shelters would save tens of millions of lives in any of these attacks. At the lower levels, 25 to 40 million people would be saved by fallout shelters alone. With heavier attacks the lifesaving potential of fallout shelters increases and the proportion of survivors who would be alive because they were sheltered increases even more sharply. If we have an adequate civilian preparedness program and a war does occur, we could conceivably save well over 100 million people by the use of shelters.

A fact proven physiologically is that the average healthy person can survive two weeks without food, clothing, berthing, light, and with only a minimum of potable water and sanitary facilities. All of these items constitute some of the desirable, though not necessarily mandatory, items for shelter habitability. It also is a physiologically proven fact that the average healthy person cannot survive for more than a few hours without fresh air. With perhaps the exception of adequate shielding, fresh air provided by some means of ventilation is the primary mandatory requirement for shelter survival.

Normal atmospheric air contains, by volume, 20.6 percent O_2 and 0.03 percent CO_2. Air becomes objectionable to people when it contains greater than 3 percent CO_2 and less than 18 percent O_2. Serious loss in vitality and ability will occur at CO_2 levels above 3 percent. Below 14 percent, lack of O_2 may cause sleepiness, headaches, inability to perform simple tasks, and eventual loss of consciousness. A ventilation rate of 3 cubic feet per minute (cfm) per person meets these requirements and will maintain the CO_2 level at about 0.6 percent and the O_2 level at about 19 percent.

The ventilation rate of 3 cfm of fresh air per person has been established as a minimum requirement by Civil Defense directors to be used in ventilation system design for shelters. It should be understood that in most shelters, this minimum will meet only brute survival conditions, not comfort conditions. A rate as high as 20 cfm per person may be required in some parts of the country for controlling the chemical content of the air plus providing means for heat, moisture, and odor removal which would approach comfort levels. Because our greatest concern during a nuclear attack would be survival and not comfort, the minimum rate of 3 cfm per person is the most significant figure concerning shelter ventilation.

Fallout shelters are of two major types; community and family. The community-type shelter is defined as one which provides shelter space for 50 or more people. Because it cannot be assumed that commercial power will be available during shelter occupancy, community shelters must contain some form of auxiliary power for operating ventilation systems. This might be a small diesel or gasoline engine or a mechanical-type manually-operated fan.

Family-type shelters are those that provide shelter space for less than 50 people--usually between 5 and 15 persons. Auxiliary power in the form of a diesel engine for a shelter of this type would provide adequate ventilation, but it is impractical from the cost viewpoint. The average family cannot assume the cost of a standby powerplant of this nature. A manually-operated ventilator is also impractical because of the limited number of people available to operate it.

The solution to the problem of family shelter ventilation must be a means of supplying fresh air effectively yet inexpensively. It is proposed in this thesis that adequate ventilation air can be supplied to small shelters without the use of either electrical or mechanical power. The proposed method of ventilation requires inducing a draft by means of a flame in a chimney. The technique is simple, relatively inexpensive, safe, and easy to use.

CHAPTER I

DESCRIPTION OF SHELTER

The shelter used for conducting ventilation tests is located on the Montana State College campus in Bozeman, Montana. The shelter was adapted from an underground tunnel located beneath the floor of the Mechanical Engineering Department's power laboratory. The original tunnel structure was rectangular in shape with internal dimensions of 37 ft by 6 ft. The ceiling is flat and approximately 6 ft high. Adjacent to the east end of the room is a 6 by 7 ft open entryway. Modifications were made to the original tunnel to the extent of adding a partition and door at a distance of 7 ft from the east end. This leaves the space used as a test shelter with 30 ft by 6 ft dimensions. The walls, floor, and ceiling of the shelter are all 8 in. thick concrete.

The partition, with 2 x 4 framing, consists of 6 mil polyethylene sheet fastened to the frame with duct tape. Caulking compound and duct tape were used to close all cracks between the partition framing and concrete. A 2-1/2 ft by 6 ft particle-board door was installed in the center of the partition and sealed with weather stripping.

An 8 in. diameter 3.8 ft long sheet metal duct was installed in the polyethylene partition about 2 ft from the floor and sealed with tape. This duct was used as the air intake to the shelter. To assure streamline flow in the intake, 1 in. dia. aluminum foil tubes, 12 in. long, were nested in the upstream end of the 8 in. duct.

At the west end of the shelter a 1 ft 9 in. square section of concrete was removed from the ceiling through which the outlet stacks were installed. Figure 1 on page 3 is a line sketch of the shelter test facility showing intake duct and stack locations.

Minimums established by the Civil Defense other than the 3 cfm ventilation rate include 60 to 65 cu ft of space per person and 10 sq ft of floor space per person. The test shelter, with a floor area of 180 sq ft and a 6 ft ceiling, provides 60 cu ft of space for each of 18 people. Based on the minimum air rate, at least 54 cfm of outside air is required.

With a rated capacity of 18 people, the test shelter is in the category of family-type shelters. It also represents an ideal family basement shelter in other ways. The stack is completely contained within the power laboratory which has a ceiling approximately 30 ft high. Intake air is drawn at the floor level of and exhausted near the ceiling of the laboratory. Skylight windows in the laboratory ceiling may be opened to permit the hot stack gases to escape into the atmosphere.

Homes with basement shelters can utilize this same principle. The stack can be partially enclosed in stud spaces or run upward through a hallway and can exhaust directly to the atmosphere or to a ventilated attic. If the stack exhausts directly to the atmosphere, a ventilator stack cap should be used, not only to utilize the "suction" forces of prevailing winds to aid ventilation, but also to keep fallout radiation particles and other debris from entering the shelter. If the stack exhausts to an attic containing louvers or other vent openings, a ventilator cap is not needed at the stack outlet because the roof will keep out fallout particles, rain, etc., and will limit wind effects. Intake air can be drawn from the main part of the house. Outside air will enter the house in the normal infiltration method. B. H. Jennings in <u>Heating and Air Conditioning</u>

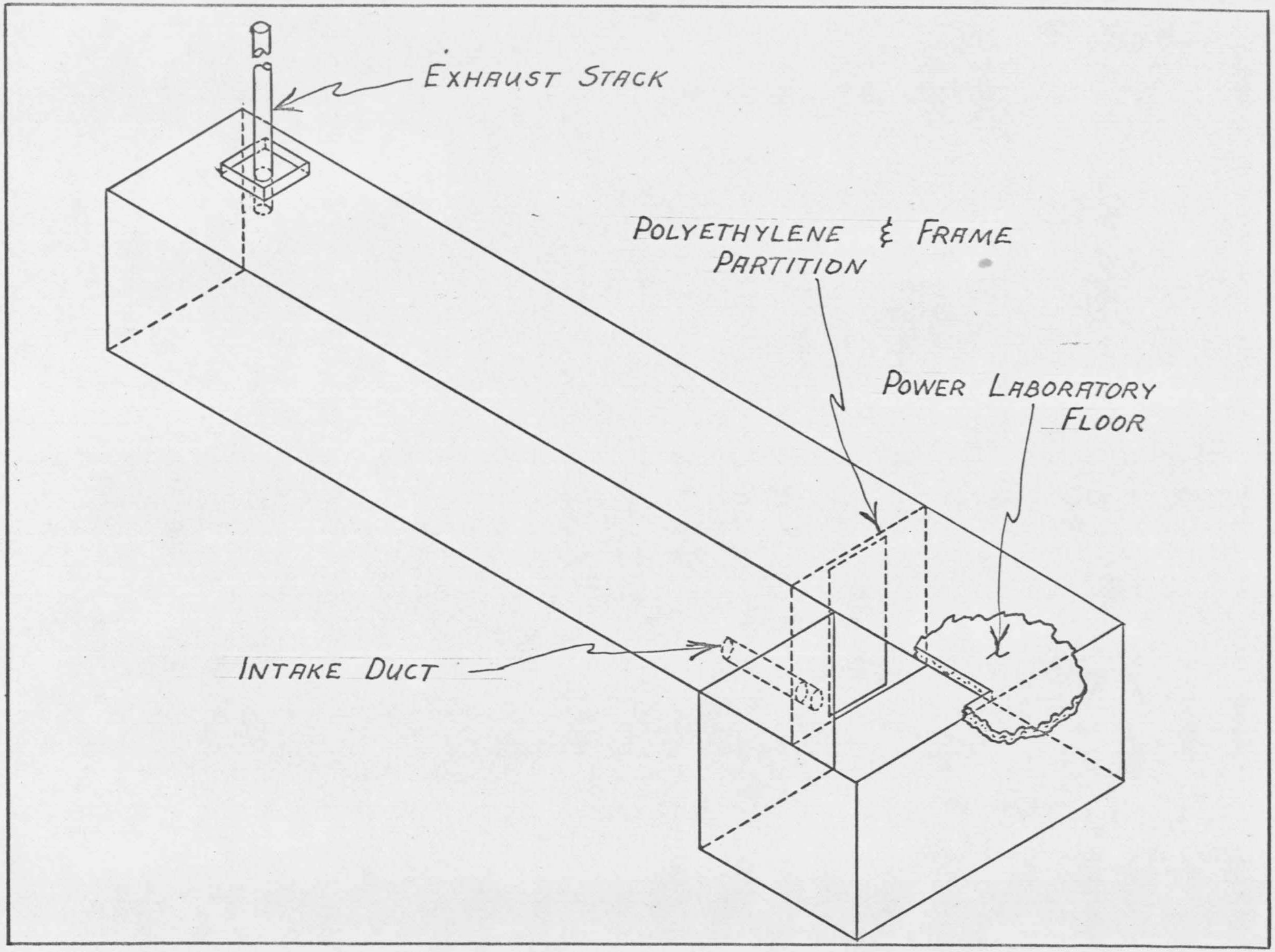

FIGURE 1. FALLOUT SHELTER TEST FACILITY

indicates that for the average residence the probable air change rate is about 1-1/2 air changes per hour by natural infiltration. If the average residence is considered to have a floor area of 1200 sq ft and an 8 ft high ceiling (9600 cu ft of space), this means that normal air infiltration is about 240 cfm. This is more than enough intake air for most basement shelters. Used as the intake air "plenum", the house itself would act as the principal filter for keeping fallout particles from entering the shelter intake. Little additional filtering, if any, would be needed at the intake. Thus a minimum restriction to air flow at the shelter inlet may be obtained.

To obtain the required 54 cfm of ventilation air through the test shelter, a safe, inexpensive, and easily operated combustion unit is needed to generate heat in the stack bottom. Liquefied petroleum gases such as propane and butane were excluded because of their high specific gravities. Being heavier than air, these fuels would collect in the shelter if leaks developed and would be inherently dangerous from an explosion standpoint. They also present a problem of storage because pressurized containers must be used. Again, this would be dangerous if punctures or leaks developed.

Natural gas would be an ideal fuel to use in the shelter, but it, like electricity, cannot be assumed to be available through normal commercial channels during shelter occupancy.

Gasoline would be unsafe in a shelter situation because of its high volatility and flammability. It would require special and perhaps expensive combustion equipment. When held in storage over relatively long periods of time, gasoline sometimes has a tendency to form gums. Their presence in the fuel could lead to combustion equipment plugging.

At a first consideration it appears that coal, being inexpensive and relatively easy to burn, would be a good fuel. However, coal presents problems from the standpoint of storage space and ash removal. Coal burning devices would be complicated and require more draft than those for oil or gas because of the resistance of the fuel bed. For these reasons coal was deemed undesirable as a test fuel.

It was decided that kerosene (No. 1 diesel oil) would best serve the purpose. This fuel burns with a relatively clean flame, burners need not be complex or expensive, and storage in cans or other ordinary containers is relatively safe. It is also suitable as an illuminant when burned in a wick lamp or wick-type burner.

CHAPTER 2

AIR FLOW MEASURING EQUIPMENT - ANEMOMETRY

For use with ventilation tests a reliable and sensitive method for measuring low velocity air flows was needed. Because the pressure available to cause air flow is very small, the method of measuring the air that flows into the shelter has to be such that there is little or no pressure drop. This eliminates an orifice which, by its nature, requires a pressure drop.

Personnel from Electronics Research, Montana State College, were consulted concerning the possibility of measuring air flow in a duct using a thermistor probe. Since this group had previously conducted apparently successful research on thermistors, they agreed to design and build the necessary circuitry and thermistor probe.

The thermistor circuit used was a temperature-compensating Wheatstone-bridge circuit using transistors to maintain constant current. Several bead-type thermistors were tried in this circuit without success. Much time was spent trying to develop a reliable anemometer from the thermistors, but the problem of temperature compensation was not completely solved.

Details of the thermistor anemometry, including calibration procedures, can be found in the appendix.

Another unsuccessful attempt to measure air flow was made using a hot-wire anemometer. The instrument was neither sensitive enough nor accurate enough at low air velocities.

In search for an instrument or method to measure air flow through the shelter, Professor Drummond suggested that we could design a special thermocouple device consisting of two thermocouples wired in series set one behind the other in the air flow stream. Between them should be a common resistor giving off a constant quantity of heat. The thermocouples sense the increase in air temperature caused by heating the resistor and produce a voltage output which depends on air velocity. A sketch of the simple anemometer is shown in Figure 2a on page 8. Figure 2b shows in part the thermocouple and resistor wiring diagrams. Assumptions concerning the design parameters of the meter are:

1. Flow rate range expected to be measured in one 8 in. intake duct is 10 to 150 cfm at actual conditions (70°F and 25 in. Hg.)
2. Anemometer will be installed in one of the 1 in. aluminum foil tubes and placed in the center of the intake duct.
3. Accuracy in measurement of air temperature difference at the highest anticipated flow is limited to 1°F using iron-constantan thermocouples.
4. A maximum input of 40 volts d.c. is available as supply voltage.
5. The specific heat of air throughout the expected flow range is constant at 0.24 Btu/lb °F.

Calculations for the required size of resistor are given below. The reader is referred to any standard text on thermodynamics or heat transfer if a more complete explanation of the basic equations is desired.

The weight of air per minute flowing through the 8 in. intake duct (w_8) is given by the perfect gas law as:

$$w_8 = \frac{P_B(\text{in. Hg}) \times V(\text{ft}^3/\text{min}) \times 0.491(\text{psi/in. Hg}) \times 144(\text{in}^2/\text{ft}^2)}{R(\text{ft-lb/lb °F abs}) \times T_a(\text{°F abs})}$$