R 452

Technical Report

TUNNEL VENTILATION AND HEAT-LOAD SURVEY — BYRD STATION, ANTARCTICA, 1965

July 1966

NAVAL FACILITIES ENGINEERING COMMAND

U. S. NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

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TUNNEL VENTILATION AND HEAT-LOAD SURVEY — BYRD STATION, ANTARCTICA, 1965

Technical Report R-452

Y-F015-11-01-163

by

C. R. Hoffman

ABSTRACT

A ventilation and heat-load survey was conducted in the undersnow tunnels at Byrd Station, Antarctica, in late December 1965. This work was performed to obtain current information on tunnel cooling requirements and to obtain data for tunnel cooling system design.

The survey showed that average tunnel temperatures are 5 to 6°F lower than during a similar survey conducted in 1963, but are still as much as 18°F higher than the desired temperature of 0°F.

Doors originally installed at tunnel entrances have deformed and become inoperative, allowing the free circulation of warm surface air throughout the undersnow camp.

It was concluded that tunnel temperatures in the undersnow camp can be reduced by installation of airtight bulkheads and suitable selfclosing doors to prevent the inflow of warm, surface air and reduce cross-circulation between tunnels. All tunnels except L-7, which contains the communications galley and generator buildings, can be adequately cooled by drawing cold air from tunnel walls. A cooling system based on the U. S. Naval Facilities Engineering Command's air-plenum concept appears to be the most suitable means of cooling tunnel L-7.

CONTENTS

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INTRODUCTION

The structural integrity and useful life of the undersnow camp at Byrd Station, Antarctica, is dependent upon the rate of snow deformation in the tunnel walls and roof arches. Studies of the structural properties of snow have shown that load-bearing characteristics improve and rate of deformation decreases as the snow temperature decreases. Several systems have been proposed for maintaining low temperatures in the snow tunnels during the critical summer months.

This report presents the results of a ventilation and heat load study conducted at Byrd Station during December 1965 and recommendations regarding construction of a cold-air-plenum system for lowering tunnel air temperatures.

BACKGROUND

Byrd Station, Antarctica, is an undersnow camp designed by the U. S. Naval Facilities Engineering Command (NFEC)* and constructed by Navy Seabees during the antarctic summers of 1960-61 and 1961-62. The Station consists of a network of tunnels containing prefabricated buildings and other equipment. While most facilities are in the tunnels, some small buildings are elevated above the surface. A few scientific facilities which require freedom from electromagnetic disturbance are located a mile or more from the Station without subsurface communication. The general layout of the tunnel complex is shown in Figure 1.

The tunnels were constructed by excavating trenches in the snow, placing timber sills on the abutments and roofing the trenches with corrugated steel arches. Snow was backfilled to the peak of the arch to provide a smooth undisturbed surface to drifting snow. Entrance to and from the surface was by vehicle ramps at the end of tunnels M-1 and L-3, or by vertical escape shafts from the lateral tunnels.

In designing the undersnow camp, tunnel ventilation and cooling were known to be of great importance in minimizing deformation of snow tunnels. Operating instructions for Byrd Station reportedly specified 0°F as the maximum desired tunnel temperature. Systems for cooling the tunnels during the critical summer months were based on utilization of the immense heat sink on which the camp is built. Because of the insulating properties of snow, the temperatures at depths below 25 feet remain constant and are equivalent to the mean annual temperature for the specific location. At Byrd Station, where mean monthly temperatures range from +5°F in December to

*Formerly the U. S. Navy Bureau of Yards and Docks.

-35°F in July and August, the snow temperature at that depth is -19°F. During most of the year, surface temperatures are below 0°F and large quantities of cold air flow naturally through the porous snow or tunnel openings to maintain tunnel air temperatures near the desired 0°F level. In the summer months, however, surface temperatures rise above 0°F and the warmer air is unsuitable for tunnel ventilation.

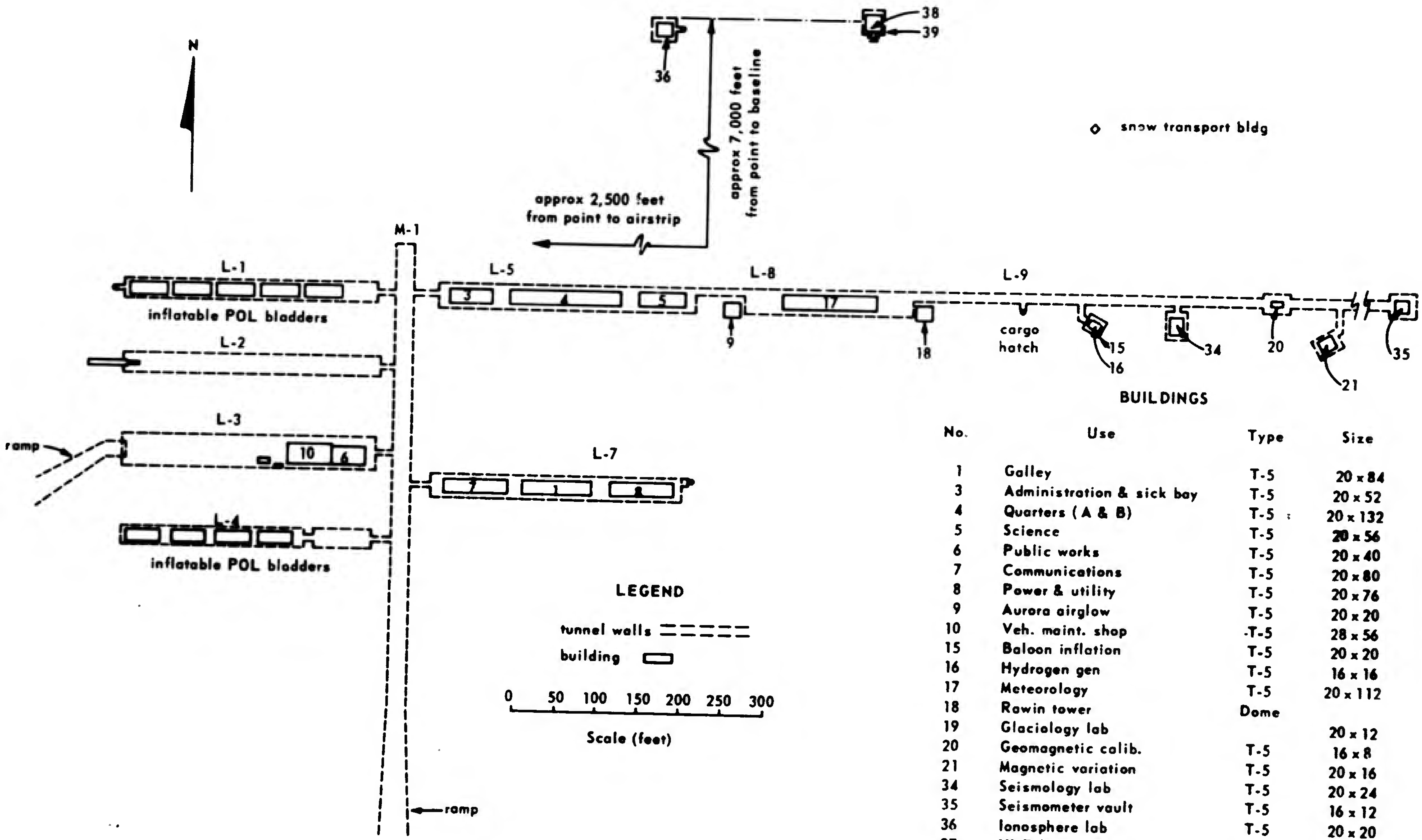
Ventilation at Byrd Station was originally designed for horizontal circulation, with floor-level fans at lateral tunnel entrances discharging into the central corridor M-1. This was changed during camp construction with the installation of surface-ducted exhaust fans at the arch crown in all tunnels where heat is liberated. Air wells were also installed in the tunnel floors. These consisted of a high-pressure axial blower mounted over a 16-inch-diameter, 40-foot-deep hole. When operating, they draw air from the tunnel downward through the porous cold snow floor and discharge the cooled air back to the tunnel via the fan. Many of the air wells in the original installation were inoperative because of fan damage incurred in transit. Those which were operated were found unsatisfactory because the cooling capacity of the units was inadequate, and the tunnel floor near the air well was softened by the absorbed heat.

Tunnel cooling and ventilation studies were conducted by the U. S. Army Cold Regions Research and Engineering Laboratory (CRREL) in 1961-62 during the first summer of occupancy and again in late January 1963.[1] The temperature and air flow information obtained during the 1963 studies (Figures 2 and 3) showed generally unsatisfactory tunnel temperatures during the summer months. The entrance of warm surface air and inadequate ventilation in tunnels with high heat gain resulted in temperatures in the tunnels as much as 23°F higher than the desired 0°F. As a result, a number of operational and maintenance recommendations were made for improving tunnel cooling. In addition, a tunnel cooling method was proposed to supplant the inadequate air wells.

The cooling system proposed by CRREL after the 1963 study was described as follows:

Pressure in the closed tunnels would be reduced by means of the arch crown exhaust fans so that cold air would flow out of the snow walls and floor. With seepage across the extensive snow area, large volumes of cold air could flow while seepage velocities in the snow pores remained low. In general, the highest seepage velocities of cold air would occur near the top of the walls because of the lower snow density. This higher seepage rate was considered by CRREL to be satisfactory since the arch seats are critical deformation zones. No action was taken on the proposed cooling method and therefore conditions remained relatively unchanged.

In 1965, NFEC proposed an air-plenum system for tunnel cooling. In this system, a small room would be excavated in the snow behind the tunnel wall and at the same elevation as the tunnel floor. A passageway of minimum dimension would connect the room and tunnel, and would be fitted with an airtight bulkhead. A fan mounted in the bulkhead would pull cold air from the snow walls and ceiling of the plenum room for delivery through a duct to the tunnel. Figure 4 shows a plan for proposed plenum location in tunnel L-7 which houses the generator building, mess hall and galley, and communications and shipstore buildings.



BUILDINGS

No.	Use	Type	Size
1	Galley	T-5	20 x 84
3	Administration & sick bay	T-5	20 x 52
4	Quarters (A & B)	T-5	20 x 132
5	Science	T-5	20 x 56
6	Public works	T-5	20 x 40
7	Communications	T-5	20 x 80
8	Power & utility	T-5	20 x 76
9	Aurora airglow	T-5	20 x 20
10	Veh. maint. shop	T-5	28 x 56
15	Baloon inflation	T-5	20 x 20
16	Hydrogen gen	T-5	16 x 16
17	Meteorology	T-5	20 x 112
18	Rawin tower	Dome	
19	Glaciology lab		20 x 12
20	Geomagnetic calib.	T-5	16 x 8
21	Magnetic variation	T-5	20 x 16
34	Seismology lab	T-5	20 x 24
35	Seismometer vault	T-5	16 x 12
36	Ionosphere lab	T-5	20 x 20
37	VLF (whistler)		15 x 10
38	Radio noise lab	T-5	20 x 20
39	Gen. noise lab	T-5	16 x 16

Figure 1. Plot plan of Byrd Station, Antarctica. Conditions as of DF65.

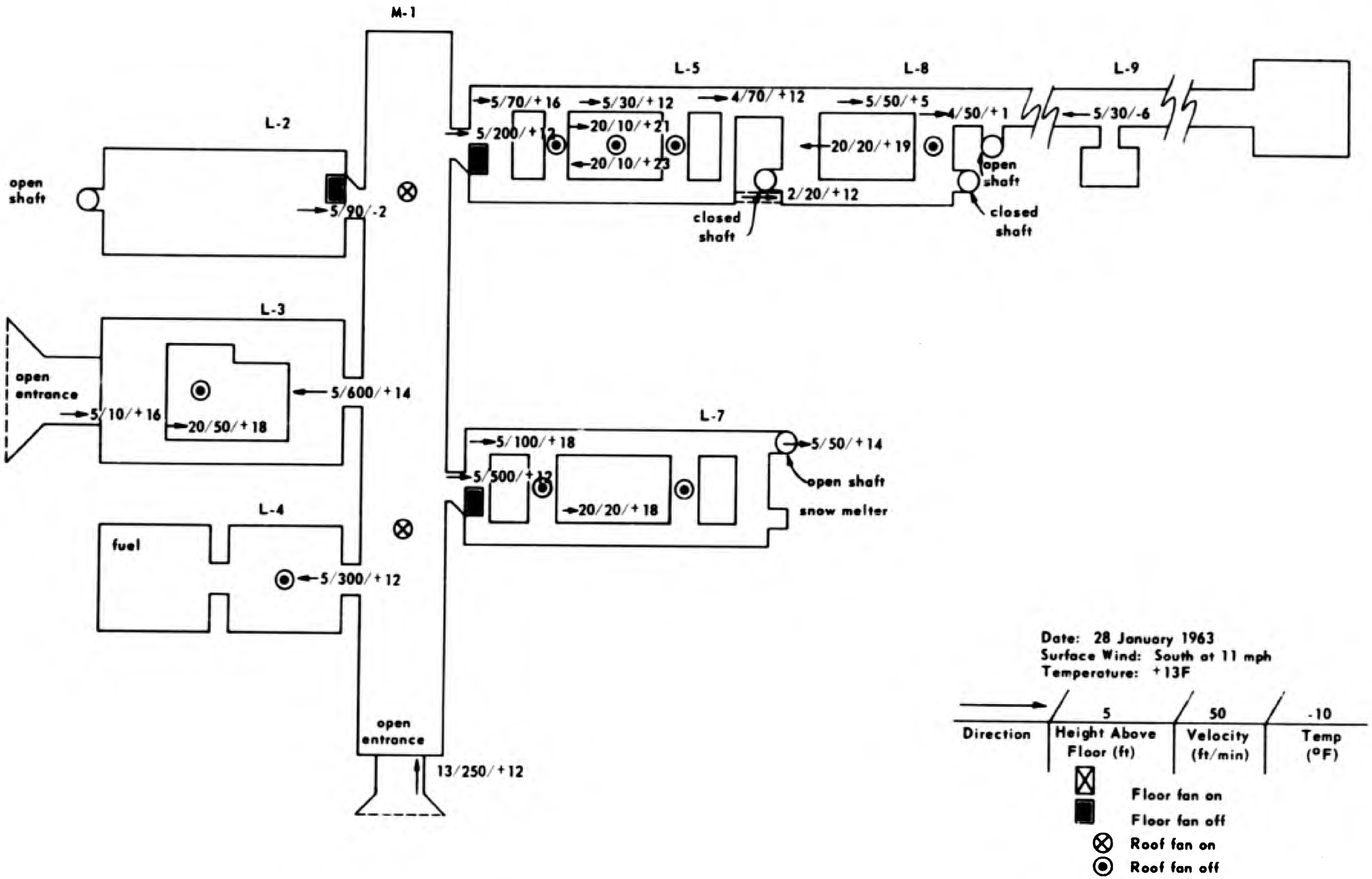


Figure 2. Air-temperature and air-velocity measurements taken with exhaust fans shut down as far as possible; Byrd Station, Antarctica, summer, 1963.

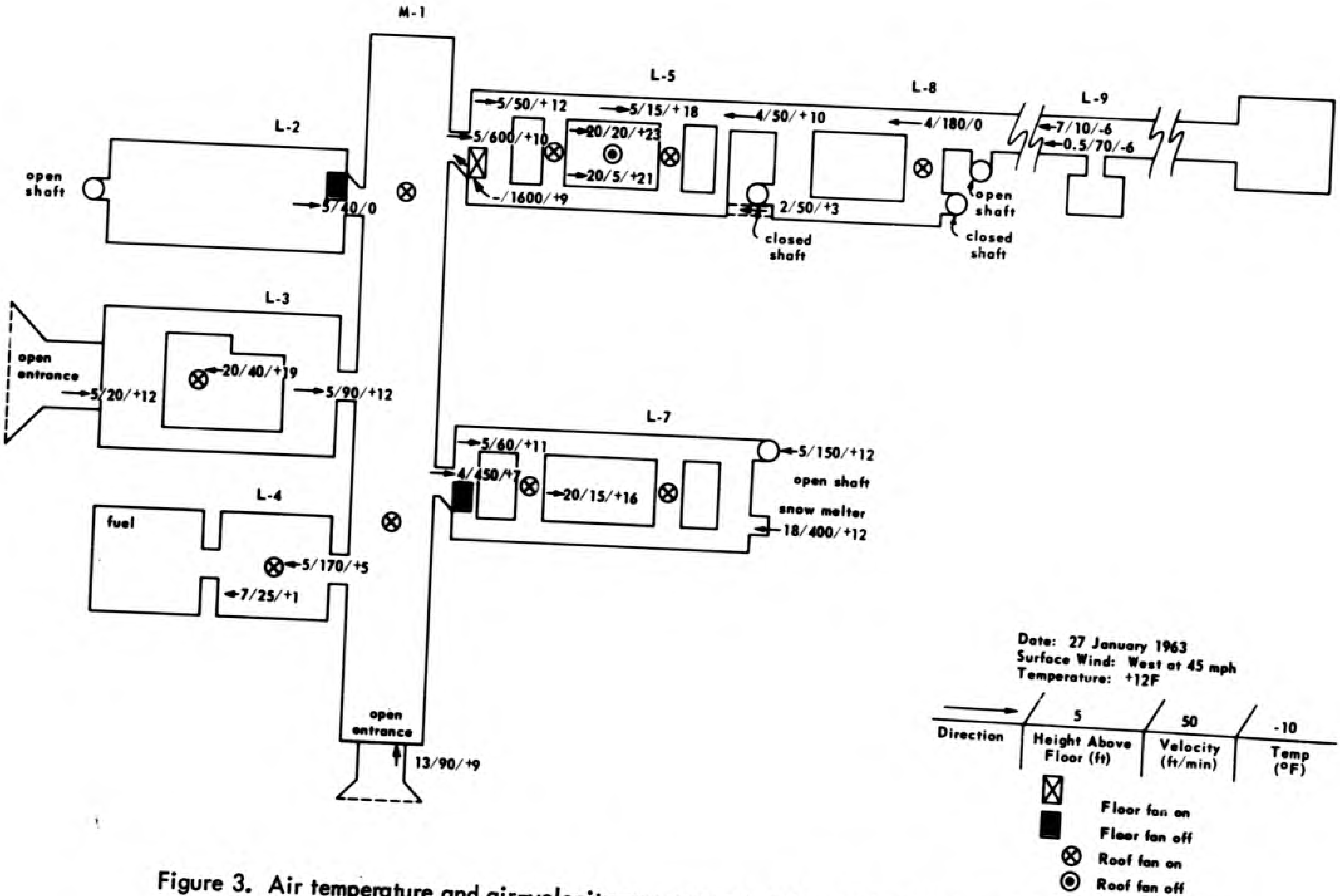


Figure 3. Air temperature and air-velocity measurements taken with hatches and doorways open and exhaust fans operating; Byrd Station, Antarctica, summer, 1963.

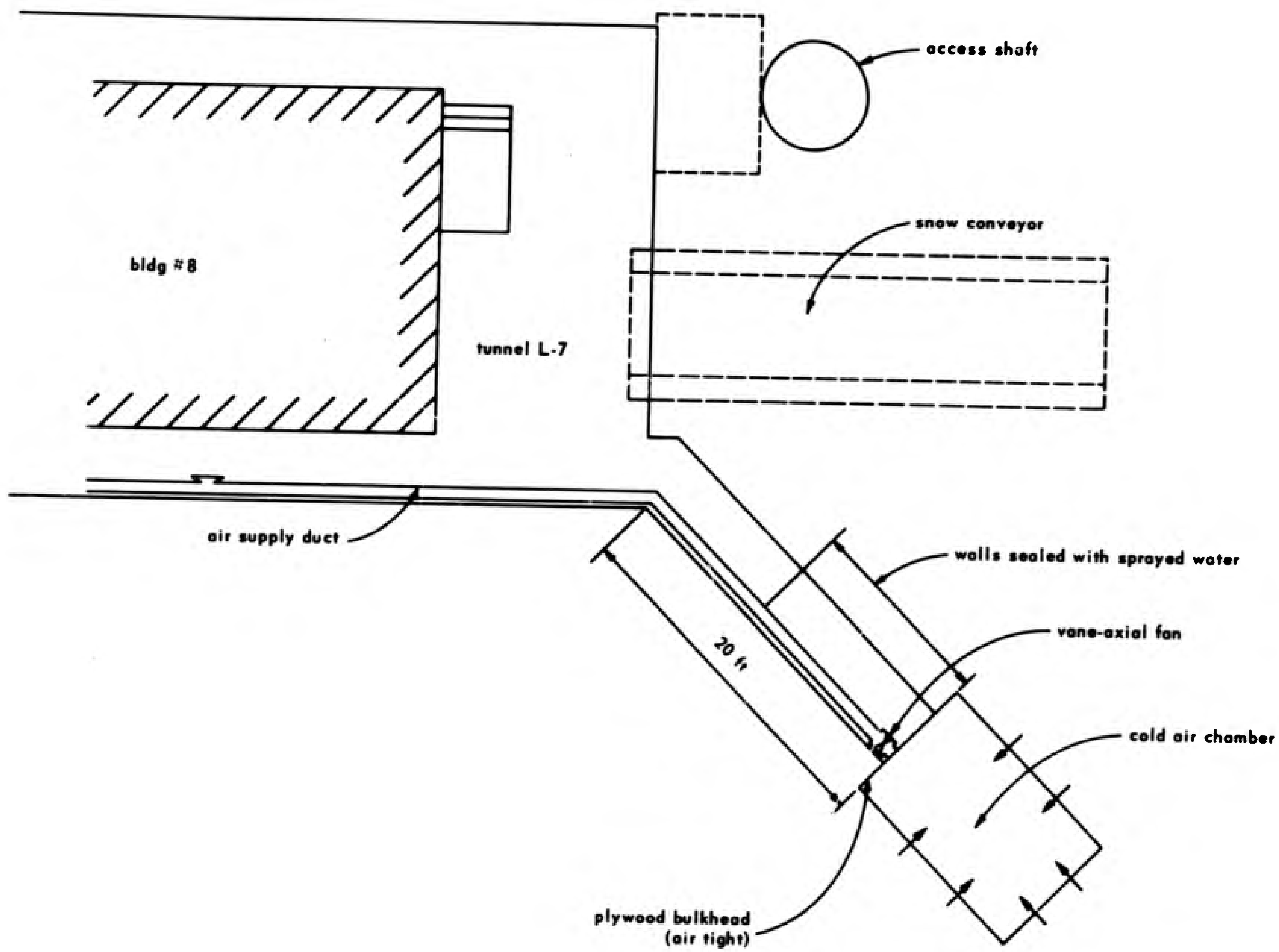


Figure 4. Plan of NFEC-proposed cold-air plenum chamber.

During Deep Freeze 66, NFEC sponsored a ventilation and heat-load study to obtain current information for evaluation of the cooling plenum concept[2] and to obtain data for cooling systems design. Study of the plenum concept showed the system to be practical. The ventilation and heat-load information required for tunnel cooling system design is discussed in the following section of this report.

VENTILATION AND HEAT LOAD

The study of tunnel ventilation at Byrd Station was conducted in late December and, for ease of comparison, was patterned after ventilation studies conducted by CRREL personnel in late January 1963.[1] Air velocity measurements were made with an Alnor heated thermocouple annemometer having a range of 10 to 2,000 fpm in two scales and an advertised accuracy of 3%. Temperature measurements were made with mercury thermometers and Taylor dial thermometers. The results of the study are shown in Figures 5 and 6. One set of measurements was made with all fans running; another set was made the next day with all fans shut down. In addition to velocity and temperature measurements, observations were made on air movement and heat load within the tunnels.

Air Velocity and Temperature

Comparison of the velocity and temperature data obtained during this study (Figures 5 and 6) and that obtained during the 1963 study (Figures 2 and 3) show an average decrease in tunnel temperatures of 5 to 6°F. This may be partially attributed to slightly cooler surface temperature or to the study being made 4 weeks earlier in the summer. However, the principal factor resulting in lower temperatures is believed to be the closing of the vehicle ramp at the south end of M-1, which partially eliminated the circulation of warmer, surface air through the tunnels.

Fuel tunnels L-1 and L-4, supply tunnel L-2, and seismic tunnel L-9 continued to be the coldest locations in the undersnow camp and were as much as 12°F below the 0°F target temperature. Operation of the arch crown exhaust fan in the antechamber of fuel tunnel L-4 is detrimental to tunnel cooling, since it draws in warmer air from M-1. When this fan was shut down, direction of air flow reversed and the tunnel entrance temperature dropped from +1°F to -10°F.

Tunnels L-5, L-8, and L-9 which are, in effect, one continuous tunnel partitioned by wide snow firewalls, illustrate the effect of air seepage through tunnel walls and the effect of various internal heat sources on tunnel temperature. Tunnel L-9 at the extreme outward end of the three-tunnel complex is the coldest location (-13°F) and is only 6 degrees warmer than the minimum in-situ snow temperature at tunnel depth. Air flows out of this dead-end tunnel into L-8 and contributes significantly to reducing its temperature. With the arch crown fans operating in L-5 and

L-8, air enters through the open escape hatch in L-9. This hatch is used extensively by scientific personnel going to and from the surface. Because of the difficulty of opening and closing this hatch and the inherent danger in performing the operation while hanging on the vertical ladder, the shaft is seldom closed. As the air flows from L-9 to L-8 and L-5, then into M-1, it is progressively warmed by heat lost from the consecutive buildings. When the arch crown fan are shut down, the air flow is reversed, flowing from M-1 into L-5, L-8 and L-9 and exiting by gravity flow to the surface through the fan shafts and open escape hatch.

The maintenance tunnel (L-3) with the large vehicle ramp open to the surface is a few degrees warmer than the surface temperature. The effectiveness of the arch crown fan in this tunnel is questionable in view of the large inflow of surface air.

It was found that tunnel L-7, containing the communications, mess hall, and generator buildings, is the warmest tunnel in the undersnow camp and is nearly 10°F above the desired temperature. The heat loss from the three buildings and the large inflow of warm air from M-1 are the major cause of temperature elevation.

The surface air intake for cooling the generator engines is inadequate at warmer surface temperatures. When required, ports are opened in the generator building and additional engine cooling air is obtained directly from the tunnel. This is basically undesirable because it requires the induction of surface air to the tunnel to make up for the air used for cooling. Under present conditions, this is of little importance because of the large quantities of surface air already entering the tunnel.

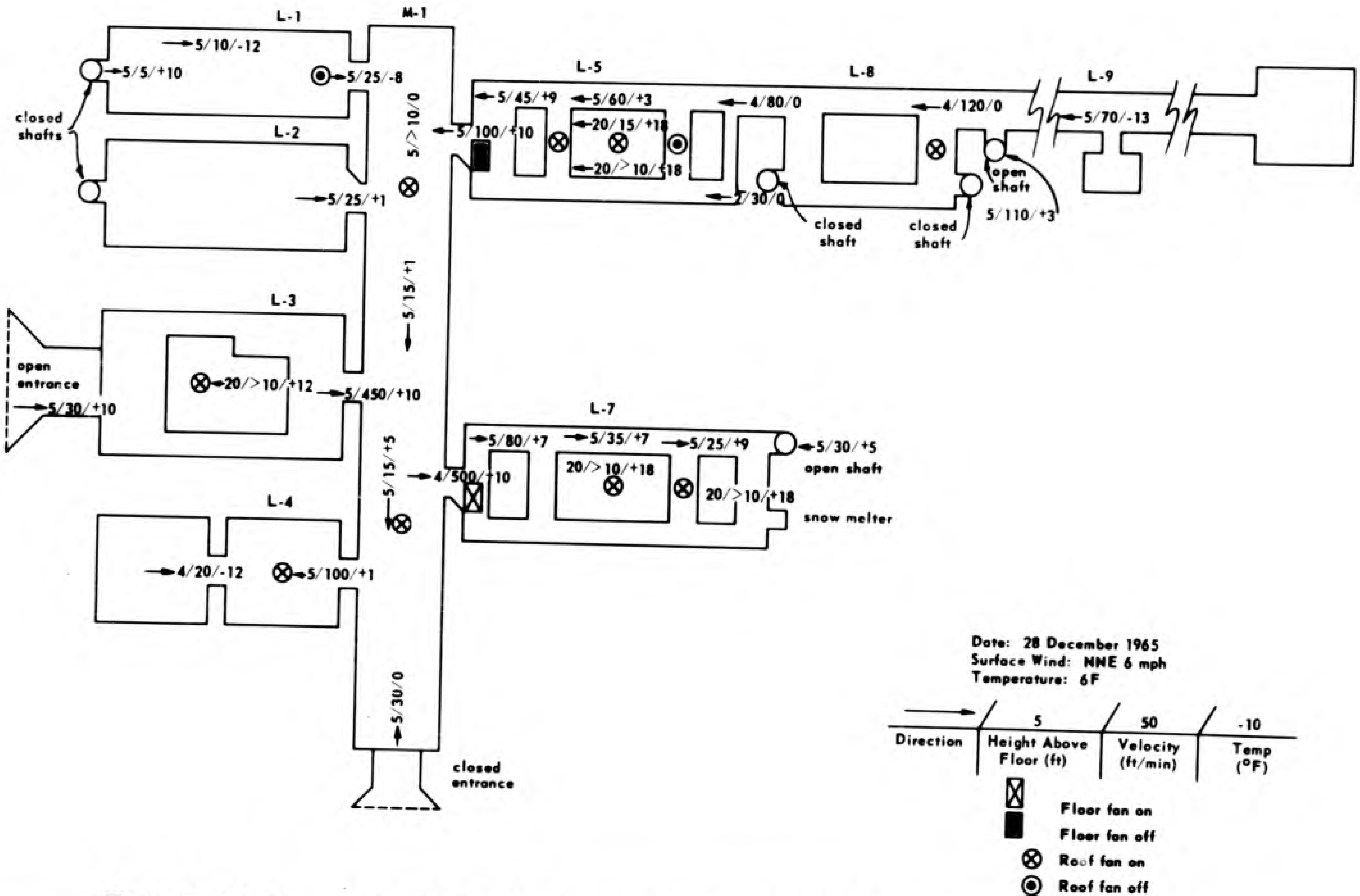


Figure 5. Air-temperature and air-velocity measurements taken with exhaust fans operating; Byrd Station, Antarctica, summer, 1965.

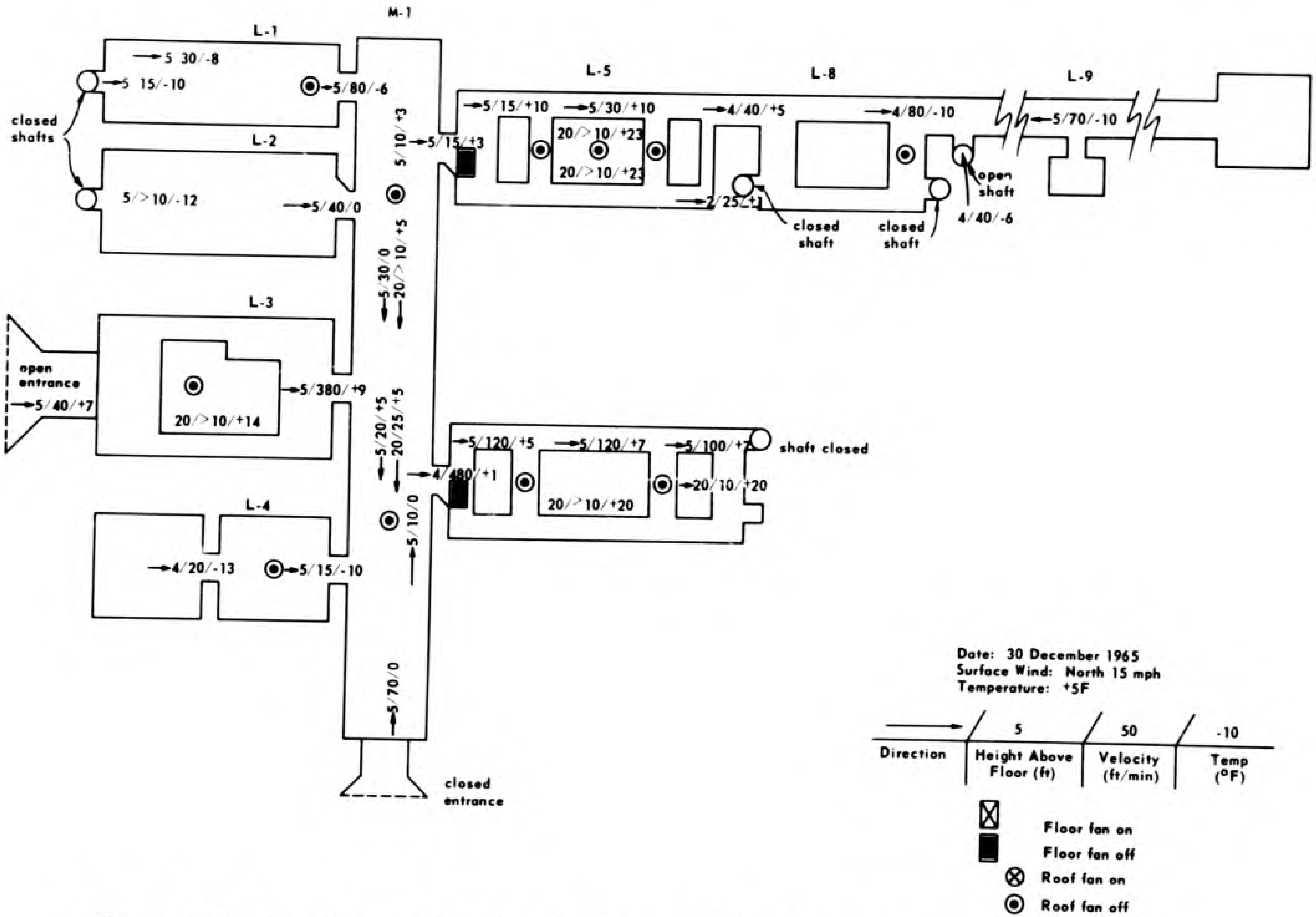


Figure 6. Air-temperature and air-velocity measurements taken with exhaust fans shut down; Byrd Station, Antarctica, summer, 1965.

Air Movement and Heat Load

During the study, the following observations were made on air movement and heat load within the tunnels:

Tunnel L-1 (fuel storage)

Inflow:	Probably by seepage through snow walls and by leakage around closed escape hatch
Outflow:	Through doorless passage to M-1
Heat Load:	None
Comments:	Improved closure on the escape hatch could reduce flow of surface air into tunnel. This tunnel was excavated during Deep Freeze 65 and was never fitted with a door to M-1 either for fire stop or air flow control

Tunnel L-2 (material storage)

Inflow:	Probably by seepage through snow walls
Outflow:	Through poor fitting door and perforated bulkhead to M-1
Heat Load:	None
Comments:	Original bulkhead fan discharging into M-1 has been removed. Opening remains. No air was observed entering the cargo shaft

Tunnel L-3 (maintenance)

Inflow:	Down equipment ramp
Outflow:	Arch crown fan and to M-1 via doorless passage
Heat Load:	Loss from maintenance buildings and running vehicles and inflow of warm air from surface via vehicle ramp
Comments:	A temporary door was installed in the passage between M-1 and L-3 during the preceding winter to reduce inflow of cold air and increase personal comfort. Door was not in place during study.

Tunnel L-4 (fuel storage)

Inflow:	Probably seepage through tunnel walls and via warped door from M-1
Outflow:	Arch crown fan to surface
Heat Load:	None
Comments:	Fan at arch crown is not needed except for possible ventilation should fuel vapors accumulate in tunnel

Tunnel L-5 (quarters and administration)

Inflow: From L-8 via culvert passage and M-1 via passageway

Outflow: To M-1 via open door, miscellaneous opening in bulkhead and to surface via fans at arch crown

Heat Load: Heat loss from buildings, uninsulated furnace vent stacks on all buildings, open 7-inch-diameter hole through roof to quarters building

Comments: Door to M-1 does not close well. Bulkhead has number of large openings around waterlines, etc. Arch crown fan at east end of L-5 has been removed and duct to surface filled with snow

Tunnel L-7 (communications, galley, generators)

Inflow: From M-1 via open door, leakage around escape hatch, snow-melter door and annular space around engine exhaust ducts to surface

Outflow: Arch crown fan and generator engine radiator cooling duct system

Heat Load: Heat loss from buildings, uninsulated vent stacks on all furnaces. Galley range hood discharging directly to tunnel. Leakage from generator cooling air vent system

Comments: Floor fan operating in bulkhead to M-1 is ineffective because it operates against the natural flow of air and the discharged air reenters the tunnel through open door. Exhaust fan on galley range appears ineffective due to small vent size and makeshift fan arrangement. No condensation noted on tunnel walls in vicinity of galley. Arch crown fan at north end of tunnel restricted by to-surface duct extension of smaller size

Tunnel L-8 (scientific)

Inflow: From L-9 via culvert passage

Outflow: To L-5 via culvert passage and sewer trench and to surface via arch crown fan

Heat Load: Heat loss from buildings, uninsulated furnace vent stacks on all buildings. Broken vent stack on science building

Comments: None

Tunnel L-9 (science)

Inflow: Probably seepage through snow walls and through open escape hatch

Outflow: To L-8

Heat Load: Heat loss from seismic building. Inflow of surface air through open hatch

Comments: Relatively heavy traffic to surface via escape hatch and hazardous operation of hatch results in this passage being open almost continuously, allowing entrance of surface air and snow

TUNNEL COOLING

Cooling of undersnow tunnels requires the venting or absorbing of internally generated heat. Since the use of mechanical refrigeration for this purpose is beyond consideration economically, any air cooling undertaken is dependent on the use of the surrounding snowfields as a heat sink. Use of this heat sink appears feasible but careful design will be required because of:

1. The small temperature differential between the minimum snow temperature at tunnel depth and the desired tunnel temperature
2. The low heat absorbing capacity of a given volume of snow as represented by its low specific heat
3. The relatively poor thermal conductivity of the snow, which retards the dissipation of heat and the recovery of the sink

Laboratory studies have been made of the thermal conductivities of unconsolidated snow, its permeability, and thermal conductivity;[2,3,4] however, much of the information is not readily applicable to field conditions.

Before the design and construction of any tunnel cooling system for Byrd Station is undertaken, the uncontrolled circulation of warm surface air through the camp must be eliminated. Until this is done, no cooling system can be effective. Self-closing doors and impermeable bulkheads are needed at each lateral tunnel leading from M-1. Doors are also required at the bottom of the frequently used escape hatches in tunnel L-9 and probably L-7. Halting the inflow of surface air to L-3 is also highly desirable; however, no simple and practical closure system for the large vehicle ramp is visualized. An elevator, as proposed in the DF-66 Byrd Station Survey,[6] would fulfill the requirements but would require a major design and construction effort.

The light wood and steel frame doors installed during original camp construction (Figure 7) deformed and became inoperative after a short time because of pressures imposed on the casing by the surrounding snow.

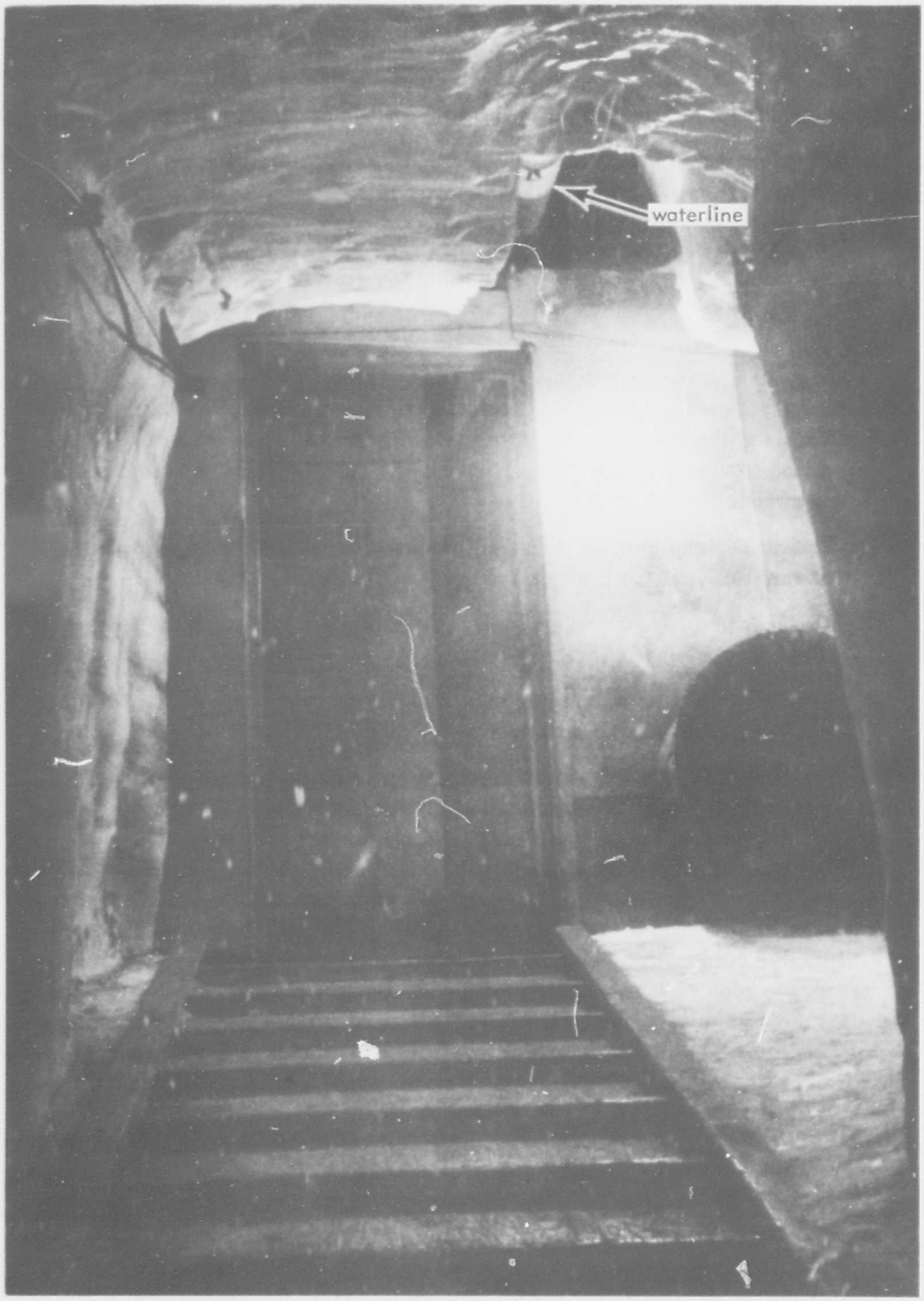


Figure 7. Typical passageway door showing bulkhead perforated by water-line and out-of-service ventilation fan.

Closure of the suggested passages requires a door design compatable with the slow but continuous deformation of the passageway walls. This might be accomplished by using:

1. A door casing of sufficient rigidity and strength to withstand the hydraulic pressures of the plastically deforming snow
2. A deformable diaphragm between the passage walls and door casing to absorb movement
3. A door system fitting against the face of the passageway bulkhead rather than set into the passage

With the undersnow camp compartmented into smaller zones and uncontrolled air flow between the main tunnel M-1 and the lateral tunnels eliminated, air cooling systems can be considered.

Tunnel L-7, in greatest need of cooling, poses severe requirements. The internal heat load in this tunnel results from heat lost from the galley, communications and generator buildings, and is estimated to be in excess of 200,000 Btuh based on a measured heat-loss coefficient of 0.158 Btuh/sq ft/°F[7] and a tunnel temperature of 0°F. Displacement of this heat during the period when surface temperatures are above 0°F requires a cooling system of considerable size. Drawing cold air from the snow walls by slight reduction of tunnel air pressure as outlined in the CRREL survey[1] is not considered suitable for cooling this tunnel because of the nearly unavoidable to-surface openings at the generator exhaust stacks, snow-melter chute, etc. A cooling system based on the proposed NFEC's plenum chamber concept appears to offer the greatest possibility of success in this area.

Cooling of the L-5, L-8, L-9 tunnel complex appears to present little problem. With a door at the passage to M-1 and at the escape hatch in L-8, the existing arch crown fans can be expected to draw cold air from the tunnel walls and provide the required cooling.

Tunnels L-1, L-2, L-4, and M-1, with negligible internal heat gain, should require no special cooling procedure following installation of doors. Existing arch crown exhaust fans can be operated if required to draw cold air from the tunnel walls.

Cooling of tunnel L-3 is considered impractical so long as the vehicle ramp is open to the surface. With this opening closed, the tunnel could be cooled.

FINDINGS

Study of Byrd Station ventilation and tunnel cooling requirements in December 1965 showed that:

1. Temperatures within the tunnels average 5 to 6°F lower than during the preceding study conducted in 1963.

2. Surface air enters the tunnels through the vehicle ramp and open escape hatches and flows uncontrolled through the camp.

3. Existing tunnel doors and bulkheads are in bad repair and are not capable of controlling airflow through the tunnels.

4. Tunnels containing heated buildings are as much as 17°F higher in temperature than the desired 0°F temperature.

5. Internal heat load within the tunnels can be reduced by:

   a. Insulation and proper maintenance of furnace vent stacks

   b. Replacement and surface venting of galley range exhaust hood

CONCLUSIONS

It is concluded that:

1. Installation of air-impermeable bulkheads with self-closing doors at tunnel entrances and frequently used escape hatches will:

   a. Halt inflow and uncontrolled circulation of warm air (important when surface temperatures are above 0°F)

   b. Compartmentize the camp for greater air circulation and temperature control by eliminating crossflow between tunnels

   c. Isolate high heat gain areas for more effective venting and tunnel cooling

2. Temperatures in the snow tunnels can be reduced by:

   a. Isolating the L-5, L-8, L-9 tunnel complex and drawing cold air through the snow walls with existing arch fans

   b. Isolating low-heat-gain tunnels L-1, L-2, L-4, and M-1 and drawing air through the snow walls with existing arch fans as required

   c. Isolating tunnel L-7 and installing a cooling system based on NFEC's plenum chamber concept

   d. Operating tunnel cooling systems during coldest winter weather to accelerate heat sink recovery and, if possible, cool the snow below its natural temperature

RECOMMENDATIONS

Based on the results of the ventilation and heat-load study, it is recommended that:

1. The inflow of warm surface air and crossflow of air between tunnels be eliminated with installation of impermeable bulkheads and self-closing doors at tunnel entrances and frequently used escape hatches.

2. Cooling of the snow tunnels be implemented as outlined, including construction of an experimental cold-air plenum adjoining tunnel L-7.

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Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) U. S. Naval Civil Engineering Laboratory Port Hueneme, California 93041	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Tunnel Ventilation and Heat-Load Survey — Byrd Station, Antarctica, 1965

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Survey December 1965

5. AUTHOR(S) (Last name, first name, initial)

Hoffman, C. R.

6. REPORT DATE July 1966	7a. TOTAL NO. OF PAGES 20	7b. NO. OF REFS 7
8a. CONTRACT OR GRANT NO. b. PROJECT NO. Y-F015-11-01-163 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) TR-452 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	

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DD FORM 1 JAN 64 1473 0101-807-6800

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14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.