Arctic hut heating and ventilation trials

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CANADA

ARCTIC HUT HEATING AND VENTILATION TRIALS

BY

A. D. KENT AND A. G. WILSON

(A JOINT PROJECT OF THE DIRECTORATE OF ENGINEER DEVELOPMENT, DND (ARMY) AND THE DIVISION OF BUILDING RESEARCH, NRC)

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PREFACE

This paper describes and gives the results of a comprehensive study of the heating and ventilation of a prefabricated Army arctic hut carried out in the field during the winter of 1950-51. It is considerably longer than the usual research paper despite the substantial condensation of the results which has already been made, and in addition is of interest to a limited number of the readers of any one scientific or technical journal. On the other hand it contains much valuable information not available elsewhere for those interested in the performance of camp-type buildings heated with space heaters. In view of this the Division has adopted the unusual course of issuing this paper in the Research Paper series even though it has not first been published elsewhere.

The trials were instituted by the Directorate of Engineer Development, Department of National Defence (Army) as part of a program of development of the arctic hut, and were carried out co-operatively with the Division of Building Research. Consequently, many persons in both agencies had a share in the work and contributed directly or indirectly to the development of the information now made public. Assistance was also given in the analysis of fuels by the Fuels and Lubricants Laboratory of the Division of Mechanical Engineering, NRC, and by the Mines Branch, Department of Mines and Technical Surveys.

The authors are mechanical engineers and research officers with the Building Services Section of the Division of Building Research. Both of them were involved in the planning and direction of the work throughout the project and in addition, Mr. Kent was actively engaged in the field operation.

Ottawa
January 1961

N. B. Hutcheon,
Assistant Director.

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ARCTIC HUT

HEATING AND VENTILATION TRIALS

by

A. D. Kent and A. G. Wilson

In 1950 the Directorate of Engineer Development, Department of National Defence (Army) completed the development of the Mark 3 version of the Prefabricated Arctic Hut, following which a prototype underwent a series of trials to determine its general suitability for troop accommodation in the Arctic. These trials included transportation, assembly and disassembly, occupancy, structure, materials, and heating and ventilation.

The Division was privileged to assist the Directorate in the planning, instrumentation, supervision, and analysis of records of the heating and ventilation trials which were conducted from October 1950 to April 1951 at Donjek River Camp, Yukon Territory.

The purpose of the heating and ventilation trials was to test the occupied hut under field operating conditions, and specifically to determine the following for different degrees of severity of weather conditions and different methods of hut ventilation.

(a) Comfort conditions of the hut environment as characterized by the air temperature, relative humidity, surface temperature, air velocity and air quality.

(b) Heat inputs and heat losses of the hut and its contents.

(c) Performance and adequacy of the heating and ventilation system.

(d) Probable influence of the hut floor heat losses on permafrost below the hut.

This paper gives a general account of these trials and the results obtained. Item (d) will be the subject of a separate report.

2. THE ERECTION SITE

Donjek River Camp is a Royal Canadian Engineers' road maintenance camp located on the wooded southwest slope of a mountain overlooking the Donjek River basin at Mile 1130 on the Northwest Highway System, 214 miles northwest of Whitehorse, Yukon Territory. The hut was erected at the south end of the camp with northeast – southwest orientation facing a large clearing to the southeast (Fig. 1). The nearest adjacent hut was situated 25 to 30 ft to the northwest; there was virtually no shading from the sun by nearby trees.

The ground at the erection site of the hut consisted of loose sandy silt to a depth of approximately 6 in., with permafrost below. There was no grass or other ground cover below the hut.

3. ARCTIC HUT CONSTRUCTION

The arctic hut (Mk. 3) is a prefabricated rectangular flat roof structure consisting of a basic unit 44 ft long by 18 ft wide and 8 ft high to which are appended two storm porches, one at either end entrance. The hut is designed to be erected directly on the ground with no fixed foundations but uses bearing pads on the underside of floor beams, shaped to suit the contours of the ground. Walls, roof, and floor of the structure are of prefabricated plywood panel construction, supported by aluminum extrusion roof girders and floor beams, and fastened together by special connectors for easy and rapid assembly. Panels containing windows are interchangeable with standard wall panels to give flexibility in arrangement of natural lighting. Non-loadbearing partition panels can be incorporated for versatility of interior room layout. A special roof panel is designed to accommodate the roof vent or "jack", which provides an outlet for both the heater flue gases and ventilation air, this special panel being interchangeable with any standard roof panel, for flexibility in heater location.

Wall panels are approximately 8 by 4 ft by 3-1/8 in., consisting of interior and exterior sheets of 1/4 in. exterior grade plywood glued and nailed to a 2 5/8-in. wood framework, the interior sheet having a painted vapour barrier on the non-exposed face. Insulation in the panels is 2 5/8-in. of glass wool. The edges of each panel are fitted with an aluminum spline and spline recess, each running the full length of the panel, the latter fitted with a 1/4-in. rubber strip bonded to the aluminum.

The upper half of each window panel is framed to accommodate two window openings. The lower opening contains two fixed windows each 32 in. long by 12 in. high, equipped with three sheets of clear cellulose acetate plastic, and an exterior storm sash with two sheets of vinyl chloride acetate resin plastic. The upper opening contains an openable window, with two sheets of plastic in a transom sash hinged at the lower edge to open inwards, and an exterior removable storm sash with single plastic sheet. The storm sash for the upper window contains eight 1-in. diameter holes with a wooden cover pivotted at one end and equipped with a spring steel closure.

The floor panels are approximately 9 by 4 ft by 3 3/8 in. and are similar to the wall panels in general construction and insulation except that the 1/4-in. interior plywood face is replaced by a 1/2-in. composite board consisting of 1/4-in. plywood with 1/8-in. hardboard faces on either side.

Roof panels are approximately 10 by 4 ft by 3 3/16 in.; their general construction is similar to that of the wall panels except that 5/16-in. plywood is used in place of 1/4-in. on the exterior face of the panel. When assembled, the roof panels leave a 9-in. overhang along the sides of the hut.

4. DONJEK PROTOTYPE HUT

Figure 2 is an interior view of the barrack portion of the hut during occupancy. The 3- by 3-in. wooden posts visible in the photograph were installed to serve as thermocouple supports. The interior arrangement of the prototype hut erected at the Donjek site is shown in Fig. 3. It was divided into two sections. The larger section, constituting approximately three-quarters of the hut, was arranged to accommodate twelve men; the remainder served as an instrument room and sleeping quarters for the two non-commissioned officers in charge of the trials.

Lavatory, shower and toilet facilities along with laundry equipment were in a special hut elsewhere in the camp. Electrical power was supplied at 60 cycles, single phase, 110 to 220 volts by the camp diesel-driven generator.

5. HEATING AND VENTILATION EQUIPMENT

Heating was provided by a single oil-fired "pot-type" space heater with a domestic circulator cabinet located approximately in the centre of the hut. This was equipped with a fuel tank of 5-gal (U.S.) capacity and a float-type fuel regulator with an eight position dial. The heater was vented to a 6-in. flue pipe terminating in a transition piece at the 7-in. opening of the roof "jack". An automatic draft regulator was installed in the flue pipe. Manufacturer's specifications for the space heater were as follows:

Over-all Size, in.			Height to Centre of Vent Outlet, in.	Fuel Burning rate, quarts per hour			Btu Output per hour
height	width	depth		at low	at high	avg	
40 1/2	30	38 1/4	30 3/4	1/3	2.2	1.1	55,000

Accessories to the heater were: an automatic fuel control, used as an alternative to manual operation of the fuel regulator, whereby on heat demand of an electric thermostat the fuel valve is repositioned by an electric relay from a "pilot flame"setting to the setting previously established manually on the fuel regulator dial, and on satisfaction of the thermostat the fuel valve reverts to the low or pilot position; and a circulating fan, located under the heat transfer surfaces of the heater, driven by a 1/40-hp 110-volt 60-cycle motor and having a rated capacity of 18,000 cu ft of warm air per hr, by which some of the heated air is drawn downward and discharged into the room horizontally through a grille a few inches above floor level.

Ventilation of the hut was by natural forces only, without the use of fans. The main provision for air exhaust was in the special metal roof "jack" (Fig. 4) containing an 11 1/4-in. square opening, concentric with the 7-in. flue gas outlet, which passed through the roof and terminated in a metal cowling for protection against precipitation. For air supply a 4-in. diameter hole was provided in the floor directly below the heater. Both of these openings could be closed from inside the hut by metal covers. For additional or alternative ventilation the openable portion of the windows could be used.

6. METHODS OF TEST

The trials were planned to obtain maximum information on the behaviour of the hut under all weather conditions and with the heating and ventilation equipment operated in different ways, that is, using various combinations of heater accessories and ventilation openings.

Since dry bulb temperature was the most important element of the weather, the general classification of weather severity was made as follows:

Moderate weather	-	Approx. 10°F and above
Moderately severe weather	-	Approx. 10° to -20°F
Severe weather	-	Approx. -20°F and below

The various combinations of ventilation openings used for the trials were as follows:

Condition	Roof Vent	Floor Opening	Windows
1	closed	closed	closed
2	closed	closed	open
3	open	closed	closed
4	open	open	closed
5	open	closed	open
6	open	open	open

Normal operation of the heating equipment was considered to be manual fuel control with heat distribution by natural convection, since the hut was intended for use in northern locations where electric power might not be available. The use of the electric thermostat for fuel control and the heater circulating fan was to be restricted to special trials (designated by suffixes T and F) to be compared with the standard trials having the same ventilation arrangement.

During the trials the room thermostat was used more extensively than originally planned to achieve closer air temperature control and more stabilized test conditions.

To study the crawl space temperature and its probable effect on permafrost, a short series of trials, designated as series A, was run with the perimeter of the crawl space open; for succeeding trials, series B, the perimeter was closed by banking-up of snow except for a small hole left in the banking to admit fresh air for conditions 4 and 6 when the floor opening was in use. The results of the crawl space temperature measurements will be the subject of a separate report.

The trials were scheduled to provide as nearly as practicable at least one trial under each of conditions 1 to 6 under each of the three basic weather classifications. The schedule called for two three-day trials and one non-trial day (Sunday) per week, with additional non-trial days at Christmas and New Year's. During the trials, however, it was found advisable to reduce the duration of condition 1 trials to two days each because of the unpleasant air conditions resulting from the reduced ventilation. Each trial day was considered as beginning at 0800 hr on the date of the trial and continuing until the following day at 0800 hr. Over the 161-day period from 25 October 1950 to 3 April 1951, there were 6 trials with the crawl space banked and 38 trials with it unbanked.

7. METEOROLOGICAL RECORDS

During the heating and ventilation trials the following meteorological records were obtained using standard weather instruments.

Outside air (dry bulb) temperature
Outside air relative humidity
Wind (speed) and direction
Depth of snow cover on roof
General weather observations.

The records for the duration of the trials are shown in Fig. 5.

8. ENVIRONMENTAL RECORDS

(a) Room Air Temperature and Relative Humidity at Control Point

The temperature and relative humidity of the room air were continuously recorded at the "control point" with a hygro-thermograph, with check readings once a week by means of a sling psychrometer. The daily average air temperature and relative humidity recorded at the control point are shown in Fig. 6.

(b) Room Air Temperature Distribution

To obtain the air temperature distribution throughout the hut, dry-bulb temperatures were recorded by means of 24-gauge copper-constantan thermocouples located at the 2-, 30-, 60- and 95-in. elevations above the floor at locations 1 to 10 shown in Fig. 3. The 30-in. level at location 1 was taken as the "control point". At locations 11 and 12 in the south and north porches respectively, temperatures were recorded at the 84-in. level only.

The thermocouple leads were connected through a multiple-bank switchboard to a strip-chart type recording potentiometer. This was a sixteen-point instrument with a temperature range of -80°F to 160°F operating with a one-minute print interval.

The 64 thermocouples were arranged in three banks for connection to the recorder. The bank containing the thermocouples recording the more important temperatures remained connected to the recorder for most of the daily test period. Three times daily at 0800, 1600, and 2200 hr, the other banks were switched in consecutively for 16 min each, to record the remaining temperatures.

The original trial directive called for the air temperature at the "control point" (30-in. elevation at location 1) to be maintained as closely as possible to 70°F for the duration of the trials. This was adhered to for the early trials but it was found that the temperature distribution in the hut was such that in fairly severe weather the temperature at the level of the upper bunks was uncomfortably warm for sleeping. Beginning 4 December, therefore, the control point temperature for the night period, (2200 hr to 0800 hr the following day) was reduced to 65°F.

It was originally intended that the full set of 48 temperatures recorded at each of the three periods of bank change, 0800, 1600, and 2200 hr would be used in determining the temperature distribution within the barrack room and instrument room of the hut under the different trial conditions. In analysis of the records, however, it was found that in many trials the temperature readings at 0800 hr and 2200 hr coincided with changes in setting of the fuel register of the heater (under manual control) and changes in setting of the thermostat (under thermostatic control) so that temperatures in the hut were rising or falling during these periods. Furthermore, at these two periods of the day, the hut temperature variations were affected by the opening and closing of the doors of the hut due to the normal movements of the personnel. Consequently the only full set of 48 temperature readings which could be relied upon to indicate the temperature pattern under reasonably steady conditions were those recorded at 1600 hr (4 p.m.). These 4 p.m. readings, when plotted for each trial day using room air (dry-bulb) temperature as abscissa and elevation above the floor as ordinate, resulted in curves of vertical temperature gradient for each of the ten room locations. Figures 7 to 11 inclusive have been selected to indicate how vertical room temperature gradients were affected by the severity of the weather, the use of the heater circulating fan, and the degree of ventilation provided.

To further illustrate the distribution of temperatures throughout the hut, the temperatures in Figs. 8 and 9 for locations 1 to 7 have been replotted in Figs. 12 and 13 as isothermal lines along the longitudinal and transverse centre lines of the barrack room.

(c) Surface Temperatures

Measurements were also made, with a contact pyrometer, of the inside surface temperatures of typical panels of the enclosure under a variety of weather conditions. Differences between air and surface temperatures were quite small, notably for the windows. Surface temperature gradients in the vicinity of framing were also small. Surface temperatures obtained with this instrument are relatively crude and are likely to be somewhat higher than the true surface temperatures.

(d) Air Quality

No regular measurements were made to assess the air quality in the hut during the heating and ventilation trials. Observations of odour intensity were made during the trials, however, and it was noted that the hut remained comparatively odour free except during all condition 1 trials and some condition 2 trials. Under condition 1, with all vents and windows closed, there was a serious accumulation of odours from tobacco smoke, perspiration, and oily clothing, so objectionable that condition 1 trials were reduced to two-day's instead of three-day's duration. The odour intensity under condition 2 was not as great but in most trials was objectionable and there were complaints from the hut occupants of "not enough fresh air" particularly for sleeping.

As a health precaution during condition 1 trials the air in the hut was sampled and analyzed with an Orsat apparatus about every three hours. There was no undue rise in the CO_2 content of the air. For further safety, a portable CO indicator using yellow-to-green capsules was used to sample the air at various positions in the room near the heater, samples being taken once every hour throughout the trial. No significant amount of CO was detected.

9. VENTILATION RATE

With the instrumentation available it was not possible to measure the over-all rate of air change in the hut. Measurements were made, however, to estimate the air exhausted through the roof vent and flue pipe, the latter consisting of air through the draft regulator and air for combustion.

To determine the air exhausted through the roof vent a vane-type anemometer was mounted in one corner of the roof jack, approximately midway between the square outer casing and the flue pipe. The number of feet of air passing through the anemometer was obtained for each trial day. Estimation of air flow from the anemometer readings was subject to considerable error because of the irregularity of the cross-section of the vent opening and the location of the anemometer which was near the entrance of the roof jack to facilitate reading of the dials. Comparison of early trials with roof vent open and closed showed that the calculated air flow through the roof vent based on anemometer readings was much higher than the heat balance could justify. A correction factor, equal to 0.5, was therefore established.

The temperature of the air passing out the roof vent was given by the average of the recorded readings of two thermocouples mounted in the lower section of the roof vent, one in each of two corners. These were protected against direct radiation from the flue pipe by cylindrical metal shields open at both ends. A flat ring of sheet metal, approximately 12 in. in diameter was assembled around the flue pipe a short distance below the lower section of the roof vent to assist in mixing the higher-velocity higher-temperature air rising next to the flue pipe with the lower-velocity lower-temperature room air, and to give steadier readings of exhaust air temperature and velocity. Average temperature of the air passing through the roof vent varied between a maximum of 140°F during severe weather and a minimum of 72°F in moderate weather with an over-all average for the 161-day period of approximately 105°F.

A vane-type anemometer similar to that used for measuring air passing through the roof vent was used to determine the feet of air passing through the draft regulator. Since the draft regulator presented an irregularly shaped opening, a special entrance pipe of circular cross-section was fabricated and installed over the frame of the draft regulator. The anemometer was mounted in the throat of this circular opening as shown in Fig. 2. Temperature of the draft regulator air was given by readings of adjacent room air temperature thermocouples.

The air used for combustion was determined by calculation from records of flue gas composition and the ultimate analysis of the fuel using the relationship:

$$A_t = \frac{3.04\ (N_2)_v C}{(CO_2)_v + (CO)_v}$$

where A_t = Total weight of air, including excess, (lb per lb of fuel)

$(N_2)_v$ = Nitrogen in flue gas (per cent by vol)

$(CO_2)_v$ = Carbon dioxide in flue gas (per cent by vol)

$(CO)_v$ = Carbon monoxide in flue gas (per cent by vol)

C = Weight of carbon in fuel (lb per lb of fuel).

Flue gas analyses were made three times during each trial day with an Orsat apparatus to obtain records of CO_2, O_2, and CO. Since the analyses showed changes in proportions of the various gases for different fuel consumption rates, it was necessary to inter-relate the value of A_t with fuel consumption. From a large number of flue gas analyses on various trial days the value of the total weight of combustion air (A_t) was found and plotted against the fuel consumption rate for each instance. From these many points, a curve was plotted to give the relation between A_t and fuel consumption rate. Then for each increment of fuel consumption for any one trial day a value of A_t was found from the curve and the corresponding volume of combustion air calculated. The summation of these increments then gave the total volume of combustion air for each trial day. This is shown in Fig. 14.

The volume of air, referred to a density of 0.075 lb per cu ft exhausted through the roof vent and flue pipe was totalled for each trial day and the average measured ventilation rate for the hut computed on this basis. The results are shown in Fig. 6. It should be noted that this does not include air exfiltration through cracks or openings in the structure or through open windows. Values of the measured ventilation rate were plotted against inside-outside temperature difference. Although the results showed a wide scatter there was a general increase in measured ventilation rate with decreasing outside temperature for most trial conditions. A straight line relation was assumed and curves drawn through the points by the method of least squares (Fig. 15).

10. HEAT BALANCE

A heat balance for the hut was determined for each trial day. The three main components of the total heat input to the hut were: the heat content of the fuel oil burned in the heater, the heat equivalent of electrical energy used in the hut, mainly for lighting purposes, and the body heat emitted by the occupants of the hut. No account was taken of heat gain due to solar radiation through the windows.

To measure fuel consumption the fuel tank was equipped with a simple float-rod device calibrated in tenths of gallons. This was read at the beginning and end of each trial day and before and after each manual filling of the tank.

An 8-oz sample of the fuel was drawn from the large storage tank after each filling by tank truck, the samples later being sent to Ottawa laboratories for ultimate analysis and for heat content and density determinations. The heat content and density respectively were 18,500 Btu per lb and 6.94 lb per cu ft up to 9 January and 18,440 Btu per lb and 7.10 lb per cu ft for the rest of the trials.

Fuel consumption for the 161-day trial period is shown graphically in Fig. 16. For comparison with the fuel consumption curve, the curve of degree-days (65°F base) for the trial period has been included and a fairly close relation is apparent.

To measure electrical power consumption, a standard multiple dial watt-hour meter was installed which registered the total power supplied to the hut. Readings were taken three times a day immediately following fuel readings, and at the beginning and end of each trial. All electrical energy consumed was converted into heat units for heat balance purposes. Daily electricity consumption in the hut is shown in Fig. 16.

An estimate of the daily heat input from personnel was made based on their occupancy habits. It was assumed that personnel would emit heat at the rate of 400 Btu per hr per man during waking hours and 300 Btu per hr during sleeping hours.

For all trials the proportion of the total daily heat input attributable to personnel varied from 2 to 8 per cent with a rough average of 6 per cent whereas the electrical heat input was approximately 3 to 12 per cent with a rough average of 8 per cent.

The various heat losses entering into the heat balance calculations for the hut were as follows:

Heat loss through roof vent.- The heat required to raise the temperature of the ventilation air passing out the roof vent from outside temperature to room temperature.

Heat loss through draft regulator.- The heat required to raise the temperature of the air passing through the draft regulator from outside temperature to room temperature.

Heat loss to combustion air.- The heat required to raise the temperature of the air used by the heater for combustion from outside temperature to room temperature.

Heat loss to flue gas.- The heat contained in the combustion gases passing up the stack, relative to room temperature.

Heat loss through structure.- The heat loss by heat transmission through the walls (including windows and doors), roof and floor of the hut.

Unaccounted for heat losses occurred due to air infiltration and, during many of the trials, ventilation air through open windows.

The heat losses attributable to air entering the roof vent, draft regulator, and heater were calculated individually from the records of air volume and temperature previously referred to.

(a) Heat Loss to Flue Gas

Values of percentage CO_2 were obtained from analysis of the flue gas made three times daily with the draft regulator adjusted to give the draft recommended by the manufacturer. Flue gas temperatures were taken at the same intervals by means of a mercury-in-glass laboratory thermometer mounted in the flue below the draft regulator. From these CO_2 and temperature readings the combustion efficiency was determined from curves given in Chapter 14 of the 1955 ASHAE "Guide", published by the American Society of Heating and Air Conditioning Engineers.

Since a close record of fuel consumption was kept, it was possible to relate the rate of fuel consumption to the heater combustion efficiency as determined from the instantaneous flue gas analyses and temperatures, over a wide range of values from low heater setting to high heater setting. From the combustion efficiency curve thus established for the heater (Fig. 17), combustion efficiencies were found for each increment of fuel consumption, over the entire day, assuming that for any one heater setting the fuel rate was essentially constant. The heat loss to flue gas for each increment was then readily determined and the increments totalled for each trial day.

(b) Heat Loss Through the Structure (H_s)

The total heat loss by transmission through the structure comprised losses through the roof, walls, windows and doors, and the floor. These were calculated for each day of the trials, and were based on the average temperature difference between the air inside and outside of each building component, multiplied by the area and by the calculated over-all heat transmission coefficient of each component.

The over-all heat transmission coefficients ("U" values) for the building sections were calculated using procedures and thermal coefficients given in Chapter 9 of the 1955 ASHAE Guide. These values are given in Table I.

The U values of the roof panel with different amounts of snow cover were also calculated and the appropriate value used, based on snow depth measurements. Table I gives the value for an 8-inch snow cover.

In obtaining the average inside air temperature adjacent to any component a "weighted" average was established by first dividing the interior surfaces of the hut into ten zones, the average inside air temperature value for each zone being based on the readings of adjacent thermocouples. In certain zones where thermocouples had not been installed the temperatures used were those of zones having similar temperatures as indicated by the pattern of isotherms. Two thermocouples were used to obtain crawl space air temperatures.

Heat transmission through the structure was calculated for each trial day. No account was taken of heat storage in the structure since its effect was small when considered over the several days of each trial condition. The heat losses through the components as a percentage of the total calculated heat loss through the structure were as follows: roof, 28 to 41 per cent; walls, windows and doors, 41 to 59 per cent; floor with crawl space unbanked, 19 to 25 per cent; floor with crawl space banked, 8 to 21 per cent. The total calculated heat loss through the structure is shown in Fig. 18.

The average distribution of the measured heat losses during severe weather with the hut perimeter banked is shown in Table II. The draft regulator heat loss was less than 1 per cent in each instance.

The heat unaccounted for varied quite widely from day to day. This was inevitable because, in addition to errors in measurement, no account was taken of such factors as infiltration, ventilation through open windows, heat storage, and solar and night sky radiation exchange. The difference between total heat input and total heat loss was generally less than 10 per cent and in most instances less than 5 per cent. It was often negative, especially under severe weather conditions.

A direct linear relation between the total daily heat requirements and inside-outside temperature difference was apparent from plotted results. This is shown in Fig. 19, the curves having been located by the method of least squares.

11. DISCUSSION OF RESULTS

(a) Environment

A study of temperature gradient curves such as those shown in Figs. 7 to 11 leads to the following observations with regard to the horizontal temperature distribution within the hut. At the 2-in. level, temperatures ranged from 42 to 68°F for severe weather trials. Temperatures for moderately severe and moderate weather were within the range of 49 to 70°F. At the 30-in. level room air temperatures were within the range of 60 to 75°F in all trials. The variation in air temperature throughout the hut at this level was approximately 11 degrees for severe weather trials, 8 degrees for moderately severe weather, and 5 degrees for moderate weather.

At the 60-in. level, air temperatures ranged from 67 to 80°F in all trials, but in individual trials the variation throughout the hut rarely exceeded 7 degrees regardless of the severity of the weather. As was the case at the 30-in. level, locations 9 and 3 at the 60-in. level showed in many trials the highest and lowest temperature readings although the temperature at location 10 in the instrument room was lower than that of location 9 on some occasions.

At the 95-in. level, air temperatures for the majority of locations in all trials were between 70 and 95°F, although for the severe weather trials the temperature at some locations, notably location 6, reached as high as 117°F. The extreme temperatures at location 6 were due to the aluminum beams of the roof structure which pocketed hot air rising from the heater and channelled it across the room. The use of the heater fan, as illustrated in Fig. 9, resulted in a marked decrease in air temperatures at the 95-in. level.

In general the greatest air temperature gradient from floor to ceiling was found at locations 6 and 7, due mainly to the pocketing of hot air as previously mentioned. The smallest gradient of each trial was shown by location 10 except in the severe weather trial when the fan was in operation (Fig. 9).

When the fan was not in operation the vertical air temperature gradients between the 30- and 60-in. levels were much less than between either the 2- and 30-in. levels or the 60- and 95-in. levels, being approximately 5 degrees for severe weather, 4 degrees for moderately severe weather, and 3 degrees for moderate weather.

The over-all gradient from floor to ceiling increased with increasing severity of weather and with increasing ventilation rate from conditions 1 to 6, except when the fan was in operation. The use of the fan greatly minimized the vertical temperature gradients throughout the hut.

Under similar conditions of weather and ventilation, the mean room air temperature gradient was greater when the perimeter of the crawl space was not banked than when it was banked.

Surface temperatures of the selected floor panel were considerably higher toward the centre line of the hut than at the wall end. This is believed to be due in part to the proximity of the panel to the heater. Floor surface temperatures varied from 48 to 64°F at the wall end of the panels and from 58 to 74°F at the hut centre line. Floor temperatures were higher with the hut perimeter banked than with it unbanked. In moderate weather this difference was from 1 to 8°F while under more severe weather conditions the increase due to banking was from 4 to as high as 13 degrees.

Relative humidity varied directly with the number of occupants, since the amount of moisture within the hut was mainly due to the respiration and perspiration of the occupants, and to a small degree to the melting and evaporation of snow from the floor and from clothing after personnel had entered from outside. Also, the relative humidity was strongly influenced by the degree of hut ventilation afforded by the various trial conditions. These relationships between number of occupants, ventilation rate, and relative humidity are more evident from a study of Fig. 6. Where ventilation rate and number of occupants remained roughly constant, the rises and falls in inside relative humidity can be attributed to corresponding sharp rises and falls in the outdoor air temperature which occurred usually about one day previous.

(b) Ventilation Rate

Measured ventilation rate of the hut varied from a minimum under condition 1 (roof vent, floor opening, and windows closed) to a maximum under condition 6 (roof vent, floor opening, and windows open).

The roof vent was responsible for the major part of the total measured ventilation. On days when the roof vent was closed the air required for combustion was the major component. Air quantities through the draft regulator were so small as to be insignificant except on trial days when the roof vent was closed.

From Fig. 15 it is apparent that under conditions 1 and 2 the measured ventilation rate was more or less independent of outside temperature conditions; with the roof vent open (conditions 3 to 6), however, ventilation rate increased with decreasing outside temperature.

As has been indicated ventilation rate measurements were necessarily crude. Exfiltration, through cracks in the construction around windows and doors, was probably a negligible component of the total air change, in view of the tightness of construction and weather stripping and the air exhaust provided by the roof jack in most trials. However, the correction factor of 0.5 applied to the roof jack anemometer took such exfiltration into account to some extent since it was selected to give the best agreement on the heat balance for the many trials in which windows were closed.

Ventilation rate measurements ignored exfiltration through doors during use and through open windows. The volume of such exfiltration will depend on what exfiltration exists through other openings and upon the wind and outdoor temperature conditions.

The increase in measured ventilation rate due to open windows with the roof vent open can be seen in Fig. 15 by comparing curves 3 and 4 with 5 and 6. Comparison of the corresponding curves in Fig. 19 provides a crude index of the increase in actual ventilation rate due to open windows. For example, at an inside-outside temperature difference of 100°F, the ventilation air volume corresponding to the difference in heat inputs between curves 3 and 5 or 4 and 6 of Fig. 19 is approximately 55,000 cu ft per day. This compares with a difference in measured ventilation rate in Fig. 15 of about 30,000 cu ft per day. Thus the unmeasured air volume due to exfiltration through doors and windows was roughly 25,000 cu ft per day under these conditions.

Comparison of curves 1 and 2 in Fig. 15 indicates that opening of windows had little effect on measured ventilation rates under "buttoned-up" conditions. However, the open windows did in fact provide a substantial amount of ventilation as indicated by the difference in heat requirements for the same two conditions shown in curves 1 and 2 of Fig. 19.

(c) Heat Requirements

Figure 19 shows that the daily heat input was a minimum under condition 1 and increased as the means for ventilation were increased. The influence of the floor opening on the daily heat input appeared to be slight, the difference between curves 3 and 4 and again between 5 and 6 probably being due to errors in measurement and scatter of points. Comparing curves 3 and 3-F, the operation of the circulating fan appeared to have reduced input requirements to some extent, at least at the higher inside-outside air temperature differences.

Since there were only a few trials for each condition number in which the hut perimeter was left unbanked, the number of points was insufficient to plot a curve in each case. The records show, however, that the heat inputs for the unbanked perimeter trials, when compared with those of the corresponding trials when the hut perimeter was banked, were consistently higher for similar weather conditions.

It should be kept in mind that the daily heat input in Fig. 19 includes the full heat equivalent of the fuel burned, heat in the flue gas having been regarded as a heat loss for purposes of this analysis. Thus the heat available for heating the hut was less than the heat input value by the amount of the flue gas loss.

Table II shows that the structure accounted for the largest percentage of the total heat loss under all trial conditions. These heat losses through the structure obtained from calculated U values, are shown as curves in Fig. 18. Structural heat losses for condition 1 trials can also be determined by subtracting other heat losses from the heat input figures. Values obtained in this way have been plotted as individual points in Fig. 18. The results at the extreme left were obtained with no snow cover, while those at the centre and extreme right were obtained with from 2 to 8 in. of snow on the roof. Agreement with the curves based on calculated figures is reasonably good.

(d) Heating System Performance

In general, the performance of the heating system in the hut under test was satisfactory throughout the full trial period.

The capacity of the heater was adequate to ensure proper temperatures in the hut under all weather conditions experienced. Indeed, there was sufficient reserve capacity to provide reasonably quick warm-up of the hut from cool to comfortable temperatures even during the most severe weather.

On the whole, the heating system was easy to operate and to maintain. Under manual operation of the heater, however, some difficulty was experienced in adjusting the fuel regulator to give the proper control point air temperature at all times. Considerable judgment had to be exercised in adjusting the setting for the night period, taking into account the existing control point temperature and whether it required raising or lowering, and allowing for any weather change that might be expected to occur during the night. It is not surprising therefore that on some occasions under manual control the early morning temperature at the control point was considerably higher or lower than the temperature called for in the trial schedule.

When the heater was under thermostatic control, with the thermostat located at the control point and with setting difficulties of manual operation eliminated, the air temperature at the control point remained relatively constant, departing from the desired temperature by no more than about two degrees. One necessary precaution, however, was to adjust the "high-fire" setting sufficiently high to take care of the maximum heat demand.

Another difficulty encountered under both thermostatic and manual operation was that in milder weather the flame would tend to go out on very low fuel setting, resulting in considerably reduced air temperature, especially during the night period when the heater was unattended. Before relighting the heater the operator was obliged to drain most of the accumulated fuel from the pot.

At very low fuel setting the reduced combustion efficiency was accompanied by a gradual sooting up of the heater and flue-pipe -- a characteristic of most pot-type space heaters -- and by the middle of the trial series the accumulation was sufficient to warrant partial dismantling and complete cleaning of the heater and flue-pipe. By the end of the series the combustion surfaces were again coated to the point where cleaning was advisable.

(e) Ventilation System Performance

The arrangement for ventilating the hut, consisting of the roof vent opening around the flue-pipe outlet and the small floor opening below the heater, was adequate for proper ventilation under the conditions of occupancy of the trials even in the mildest winter weather.

The importance of the floor opening in the satisfactory performance of the system is questionable since adequate ventilation was achieved with this opening blocked off, but the measured ventilation was increased slightly by its being used.

The heat input curves for the trials showed that the small window openings of the storm windows provide some ventilation of the occupied hut even under low wind velocity conditions. These window openings alone (condition 2) were not sufficient, however, to maintain adequate ventilation for the removal of all odours under the conditions of occupancy, with the low wind velocities experienced.

(f) Comfort Reactions

There were no complaints about temperature from the normally clothed occupants during waking hours. For sleeping, however, it was found necessary to lower the control point temperature to 65°F to reduce complaints of overheating mainly from those occupying the upper bunks. Even with this reduced night temperature setting there were occasions when occupants of the upper bunks closest to the heater were uncomfortably warm, and since there were no complaints of sleeping conditions being too cold at the level of the lower bunks, it is believed that a control point temperature of 60°F might have been acceptable to all.

The use of the heater fan was generally favoured by the occupants since the vertical temperature gradient was reduced, but some objected to the fan noise when trying to sleep.

Relative humidity varied widely throughout the hut. For a control point temperature of 70°F and a relative humidity of 20 per cent, the calculated relative humidity gradient under the most extreme gradient conditions of temperature (40°F at the floor and 100°F at the ceiling) would be about 8 per cent relative humidity at the ceiling and 50 per cent at the floor. Even greater extremes occurred, however, since the relative humidity at the control point varied from a maximum of 40 per cent to a minimum of 13 per cent. Complaints of the occupants concerning "dryness" of the air were rare and were accompanied by complaints of uncomfortably high temperature usually in connection with sleeping conditions in the upper bunks. There were no complaints that the relative humidity was too high.

It is generally agreed by authorities on ventilation that in an occupied building the minimum ventilation rate depends upon the amount of fresh air necessary to clear the air of objectionable odours. This was confirmed in the arctic hut trials, where, under condition 1 with all vents and windows closed, there was no appreciable build-up of carbon dioxide or depletion of oxygen measured but there was a decided increase in odour intensity. During one of the two-day trials, the odour from men's clothing, some of which had been oil-soaked from their work during the day, coupled with usual body odours and tobacco smoke, was so obnoxious that on the second day of the trial the test was terminated after 12 hours. Ventilation rate under these conditions was approximately one tenth of an air change per hour or roughly 1.3 cu ft of fresh air per minute per man. Under condition 2 (windows open but all vents closed) the odour intensity was considerably lower than for condition 1, for although the measured ventilation rate showed very little increase, the heat input showed there was considerable unmeasured air change. Under these conditions there were fewer complaints about odour and stuffiness.

During all trial conditions except Nos. 1 and 2 there were no objections to the air quality in the hut, although the measured rate of air change on some occasions was as low as one-third of an air change per hour. This corresponds to approximately 4.5 cu ft per minute per person of fresh air with an occupancy of 8 men. The actual ventilation rate on these occasions may have been slightly higher due to extraneous exfiltration.

12. CONCLUSION

The heating and ventilation trials of the arctic hut (Mk. 3) at Donjek Camp showed that, within the limits of the occupancy schedule of the trials, the hut was able to provide comfortable accommodation for as many as 14 men under the most severe weather conditions encountered even without the aid of electrical services. Construction of the hut and its component panels was such that heat losses of the hut were low and all inside surfaces, including windows, remained at temperatures sufficiently high to ensure acceptable conditions. With the relative humidities experienced during the trials there was no surface condensation or frosting except in the unheated porches and in severe weather on the nail heads of the lower portion of the corner wall panels in the instrument room.

The heating system had adequate capacity to maintain acceptable temperatures throughout the hut even in the coldest weather. Temperature distribution throughout the hut was good considering the simplicity of the heating system, but air temperatures near the ceiling were too high for comfortable sleeping in the upper bunks especially during severe weather. It is believed that the roof structure, by its configuration, prevented proper distribution of heated air from the centrally placed heater to the ends of the barrack room during trials when the heater was operated with no fan. Had the ceiling been flat, better horizontal and vertical temperature gradients would have been achieved, with consequently improved comfort conditions.

Heater efficiency was good and resulted in economical fuel consumption. There was no heating system maintenance required other than the cleaning of the heater and flue-pipe once throughout the trial period and the draining of the heater combustion chamber before relighting the fire on two occasions when the flame went out during the night.

The ventilation system, without the aid of electrical appliances, was able to maintain an acceptable draught-free atmosphere without accumulation of odours, provided that the roof vent remained open, and without reducing the relative humidity in the hut to an uncomfortable level. No maintenance of the system was required throughout the trials.

Where electricity is available, it can be used to increase the degree of comfort and economize on fuel consumption by means of a thermostatic fuel regulator and a heater circulating fan.

TABLE I

CALCULATED U VALUES OF BUILDING SECTIONS

	SECTION	U VALUE, Btu/sq ft hr °:
1.	Wall panel	0.102
2.	Window panel (without storm sash)	0.184
3.	Window panel (with storm sash)	0.148
4.	Weighted average of 1 and 2	0.123
5.	Weighted average of 1 and 3	0.144
6.	Floor panel (hut perimeter banked)	0.096
7.	Floor panel (hut perimeter unbanked)	0.104
8.	Roof panel (without snow)	0.106
9.	Roof panel (8-inch snow cover)	0.071

TABLE II

SUMMARY OF HEAT LOSSES (PER CENT)

HUT PERIMETER BANKED - SEVERE WEATHER

HEAT LOSSES	Cond. 1	Cond. 2	Cond. 3	Cond. 3-F	Cond. 4	Cond. 5	Cond. 6
Roof Vent	0	0	15-17	19-20	13-17	19-27	20-27
Flue Gas	18-20	20-22	19-21	17-18	18-23	16-22	17-21
Combustion Air	4	4	3	3	3	3	3
Structure	76-78	74-76	60-62	59-60	59-62	52-60	52-57

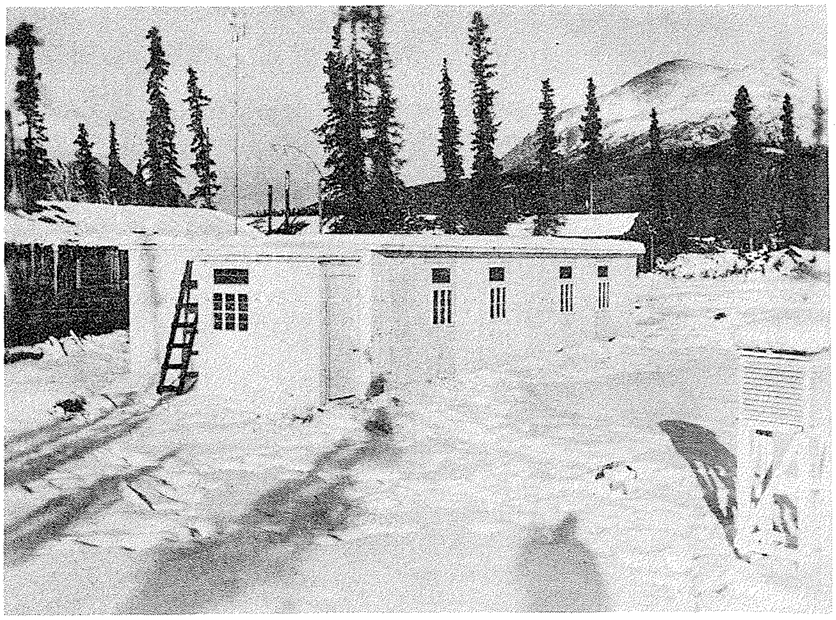


Figure 1 View facing north (February 1951). (D.E.D. photo)

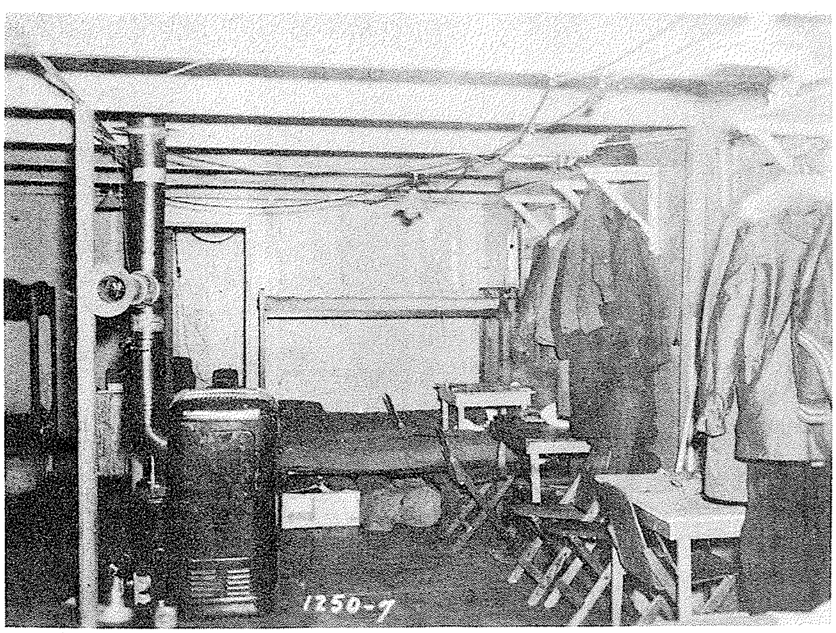
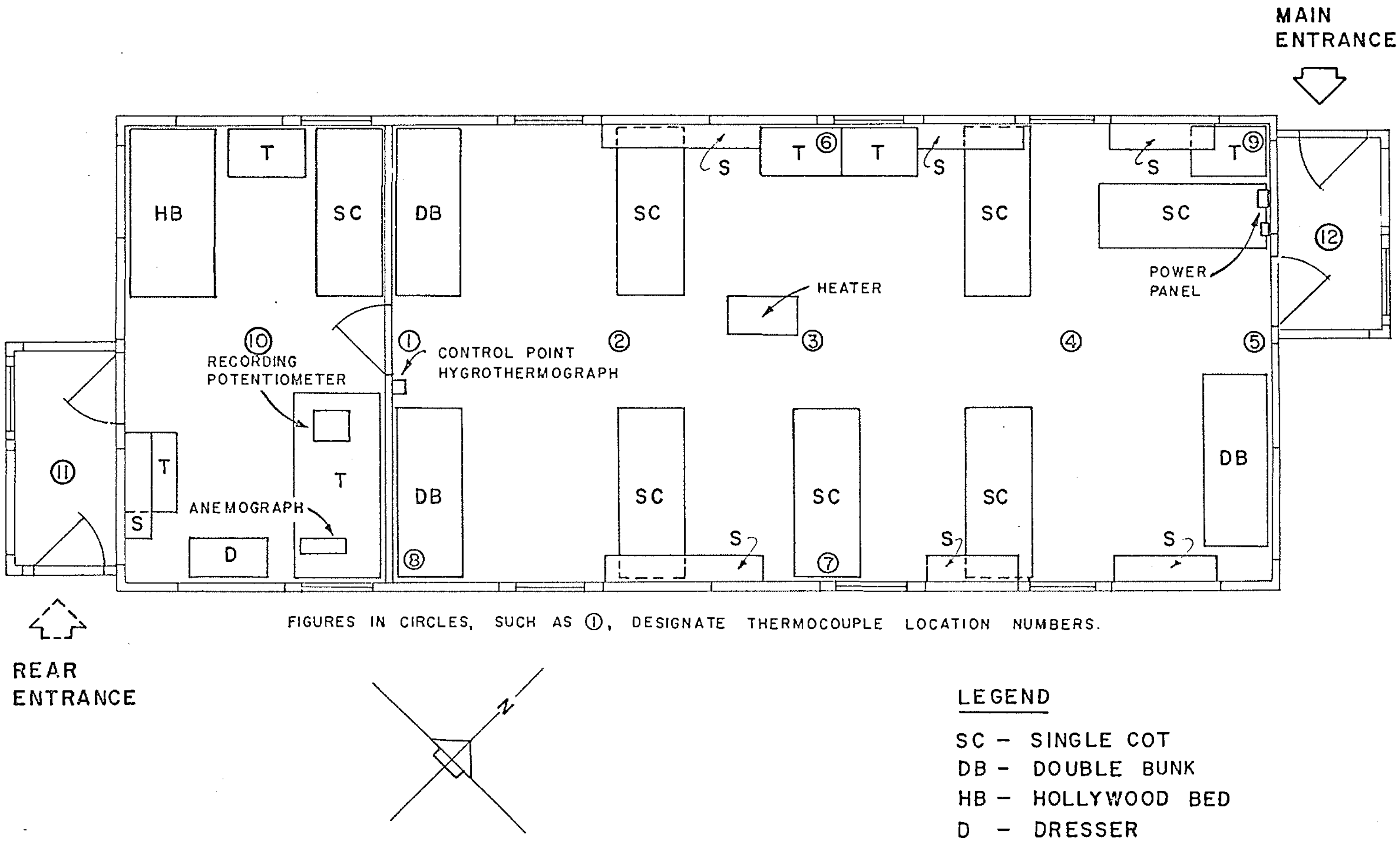


Figure 2 Interior view, west side looking south. (D.E.D. photo)



FIGURES IN CIRCLES, SUCH AS ①, DESIGNATE THERMOCOUPLE LOCATION NUMBERS.

LEGEND

SC – SINGLE COT
DB – DOUBLE BUNK
HB – HOLLYWOOD BED
D – DRESSER
T – TABLE
S – SHELF AND CLOTHES RACK

FIGURE 3

FLOOR PLAN OF HUT SHOWING LAYOUT OF FURNISHINGS

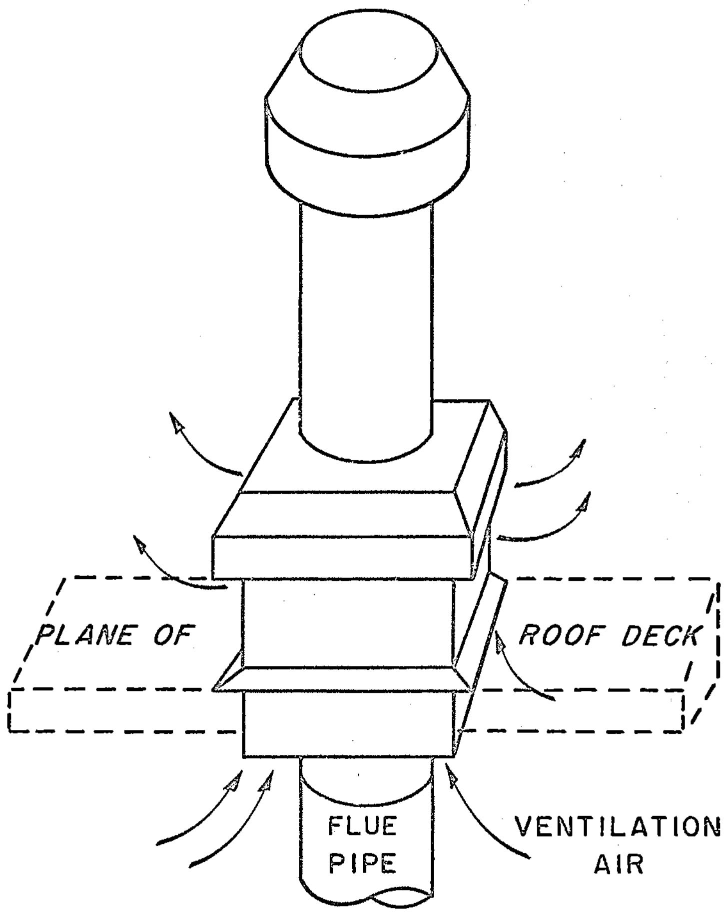


FIGURE 4

ROOF JACK ARCTIC HUT (MK.3)

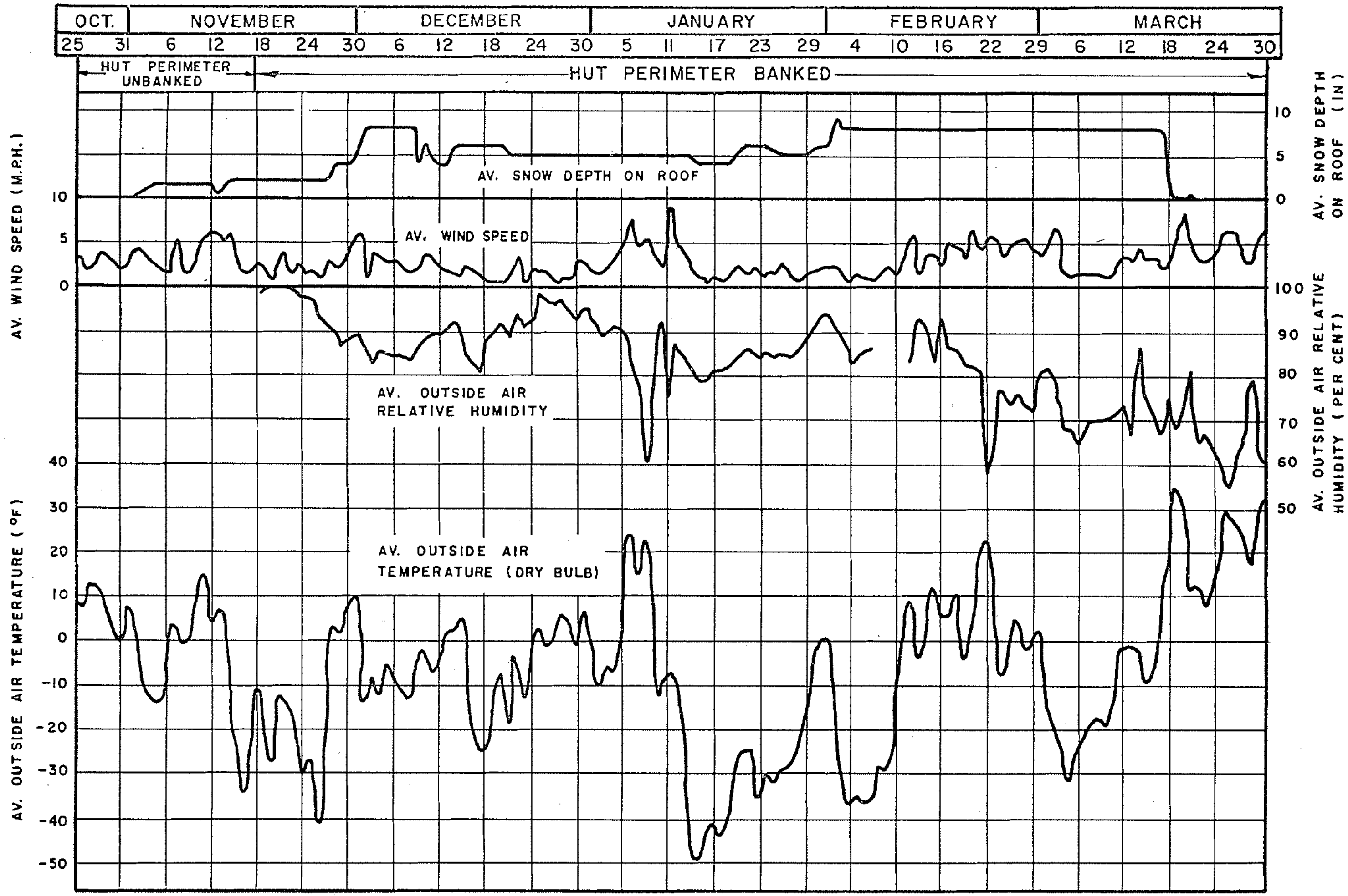


FIGURE 5 METEOROLOGICAL RECORDS

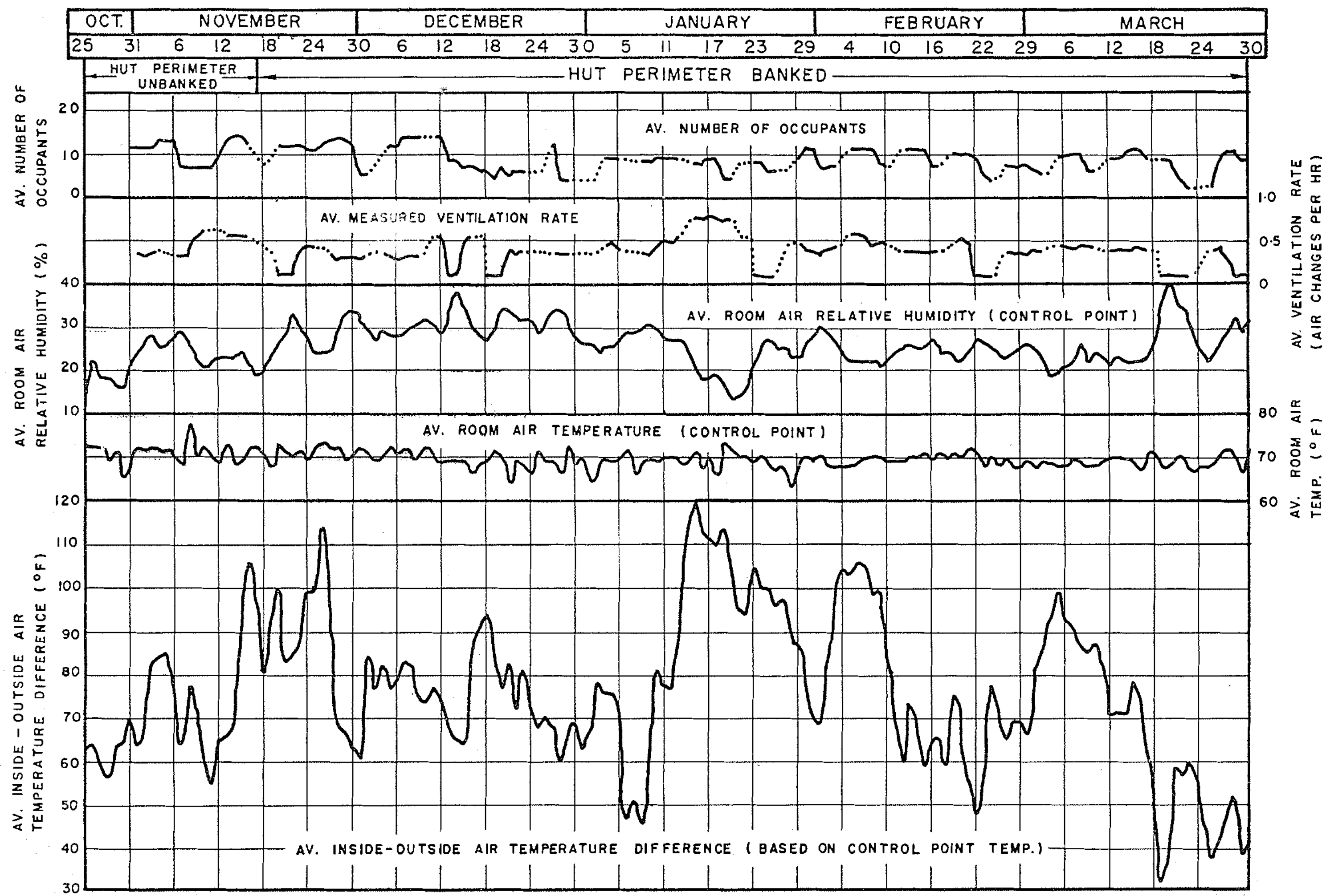


FIGURE 6 ENVIRONMENTAL RECORDS

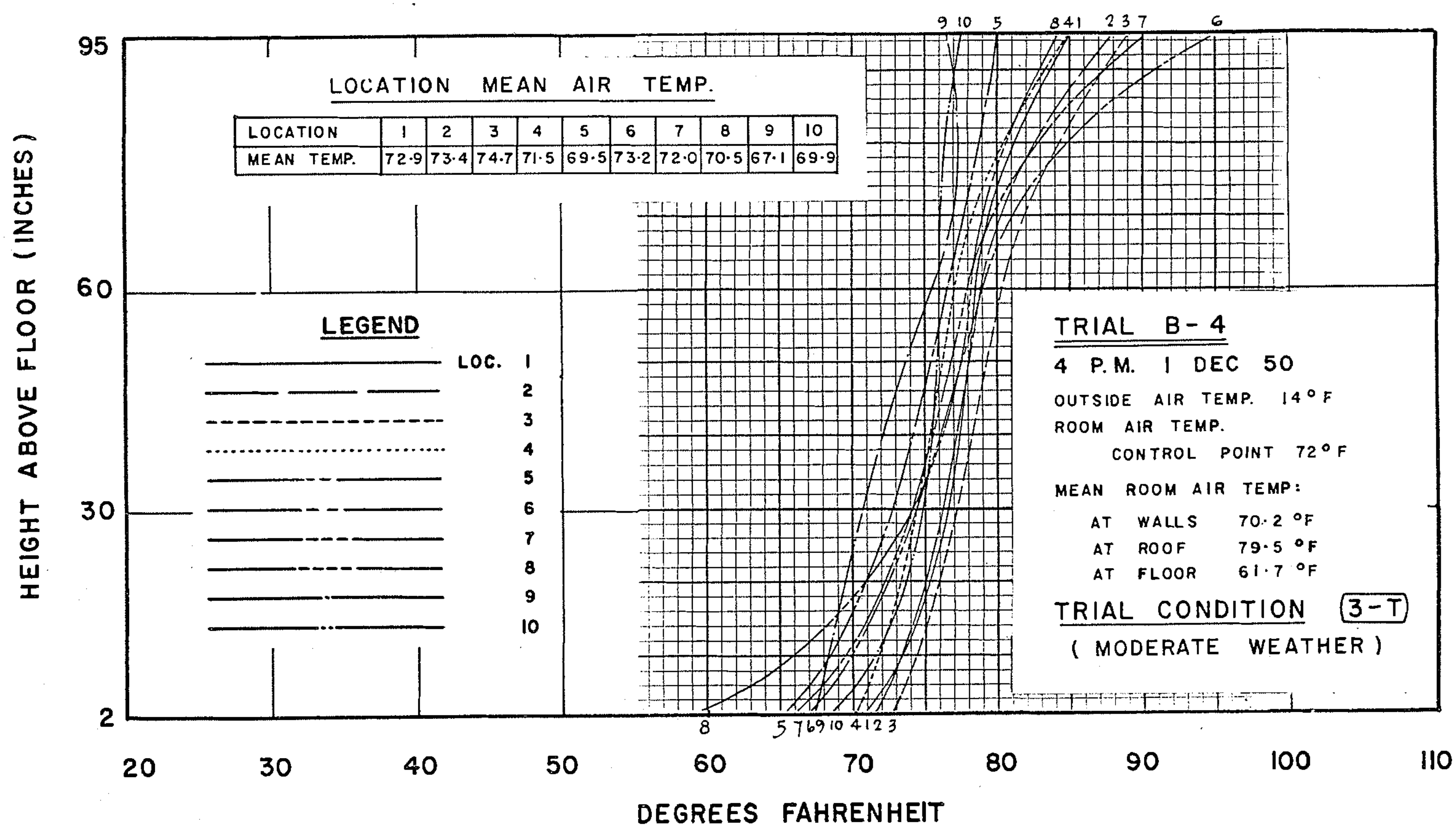


FIGURE 7

ROOM AIR VERTICAL TEMPERATURE GRADIENTS

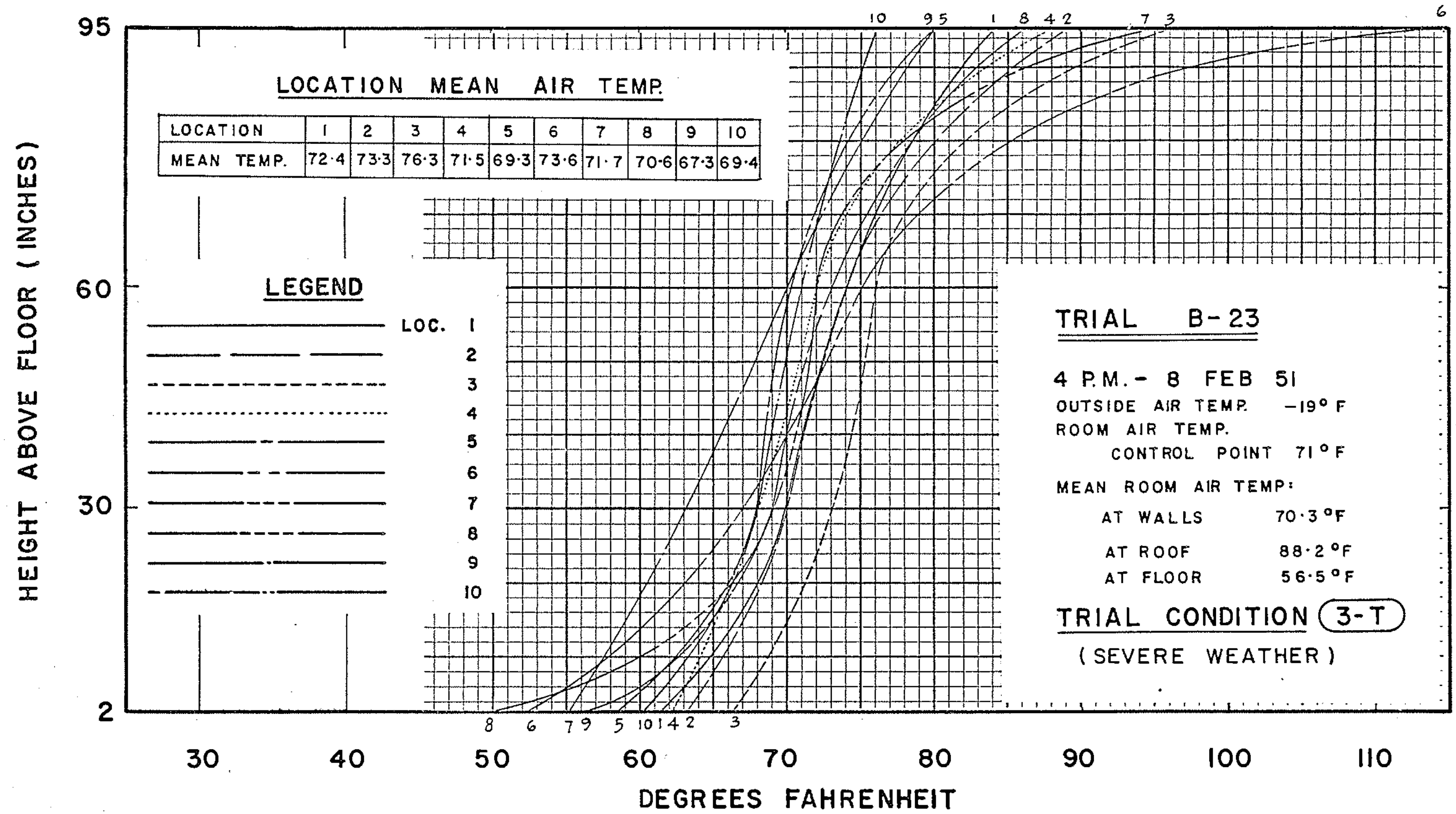


FIGURE 8

ROOM AIR VERTICAL TEMPERATURE GRADIENTS

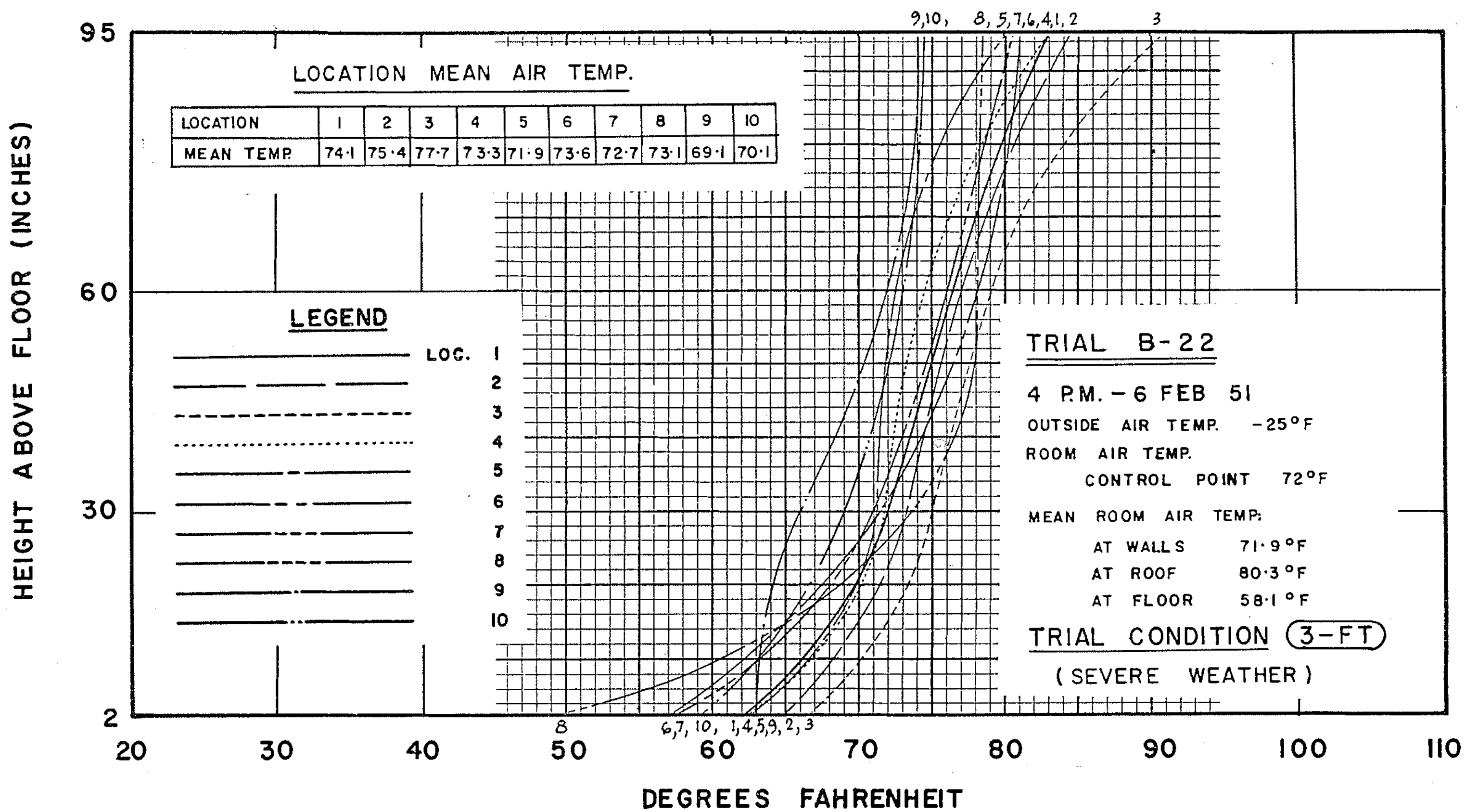


FIGURE 9

ROOM AIR VERTICAL TEMPERATURE GRADIENTS

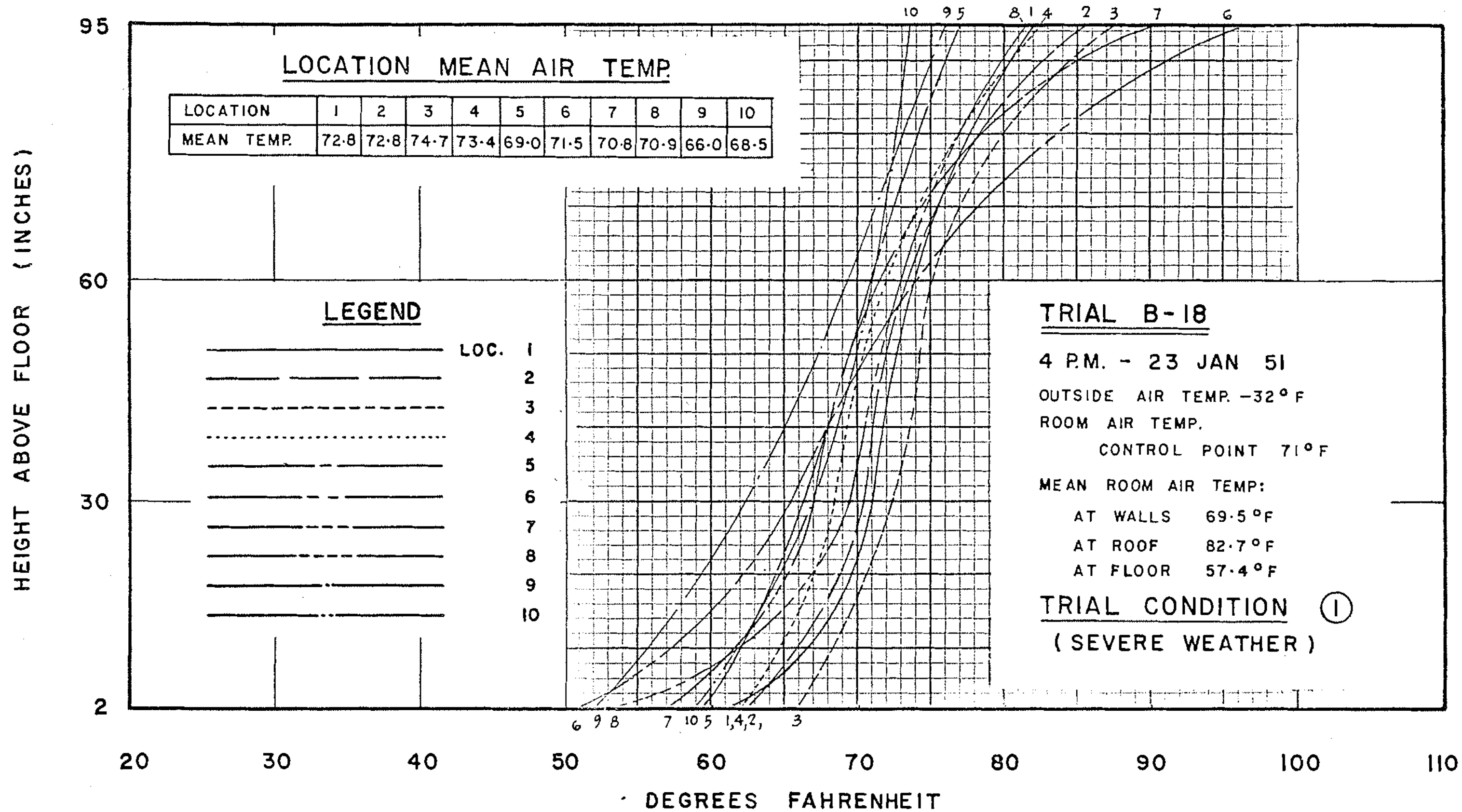


FIGURE 10

ROOM AIR VERTICAL TEMPERATURE GRADIENTS

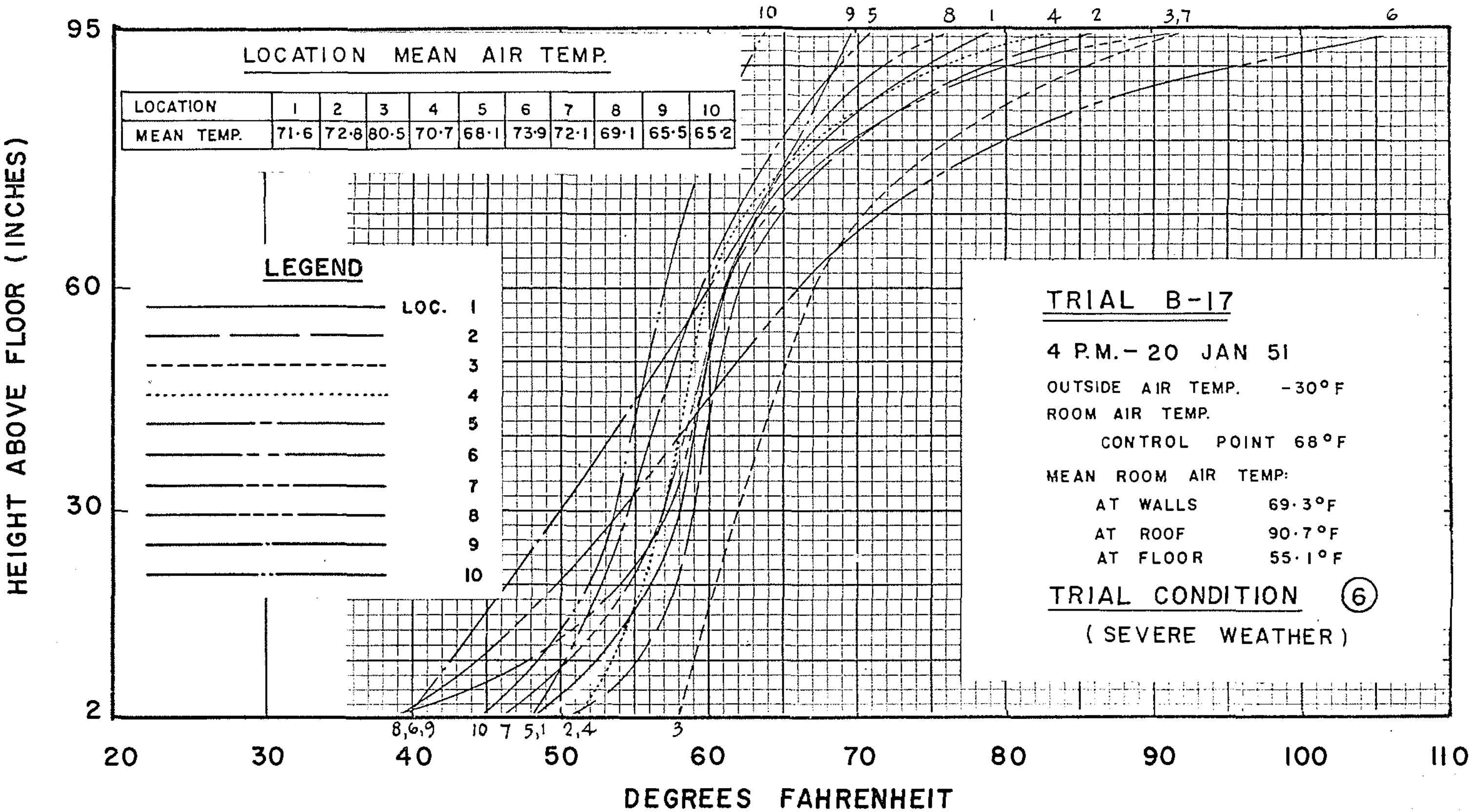


FIGURE 11

ROOM AIR VERTICAL TEMPERATURE GRADIENTS

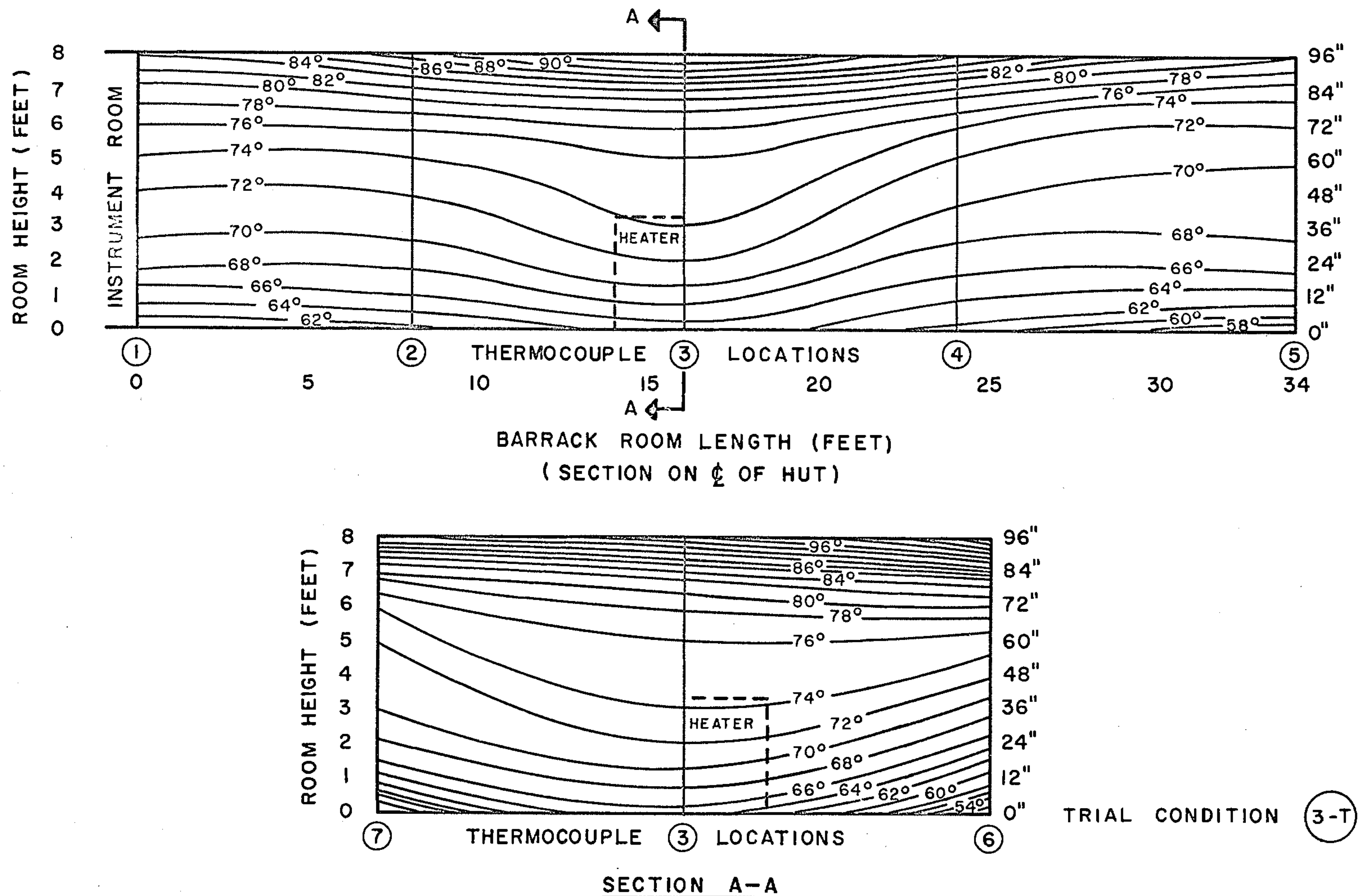


FIGURE 12

ROOM AIR TEMPERATURE DISTRIBUTION, 4 P.M. 9 FEB. 51

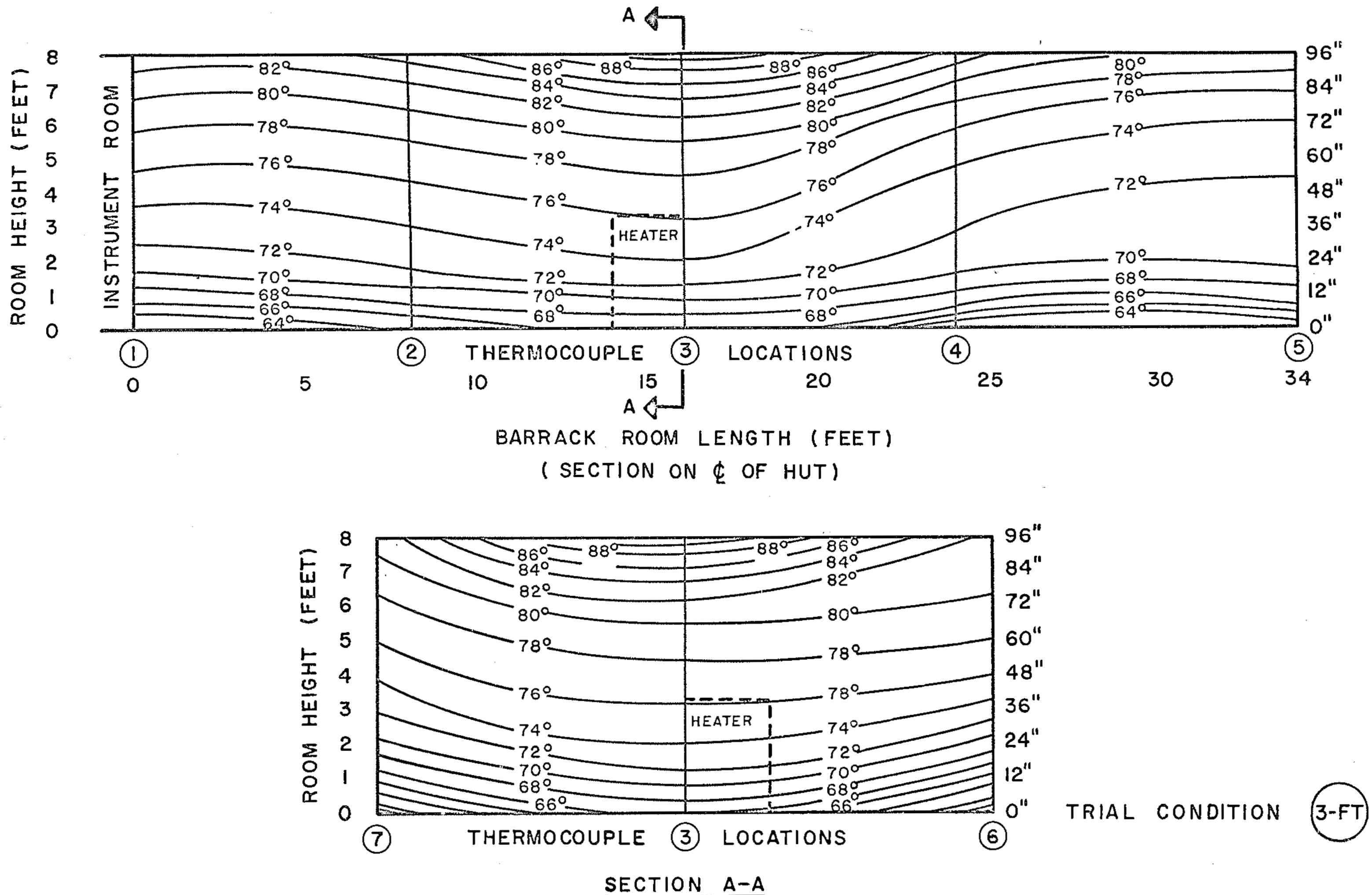


FIGURE 13

ROOM AIR TEMPERATURE DISTRIBUTION, 4 P.M. 6 FEB. 51

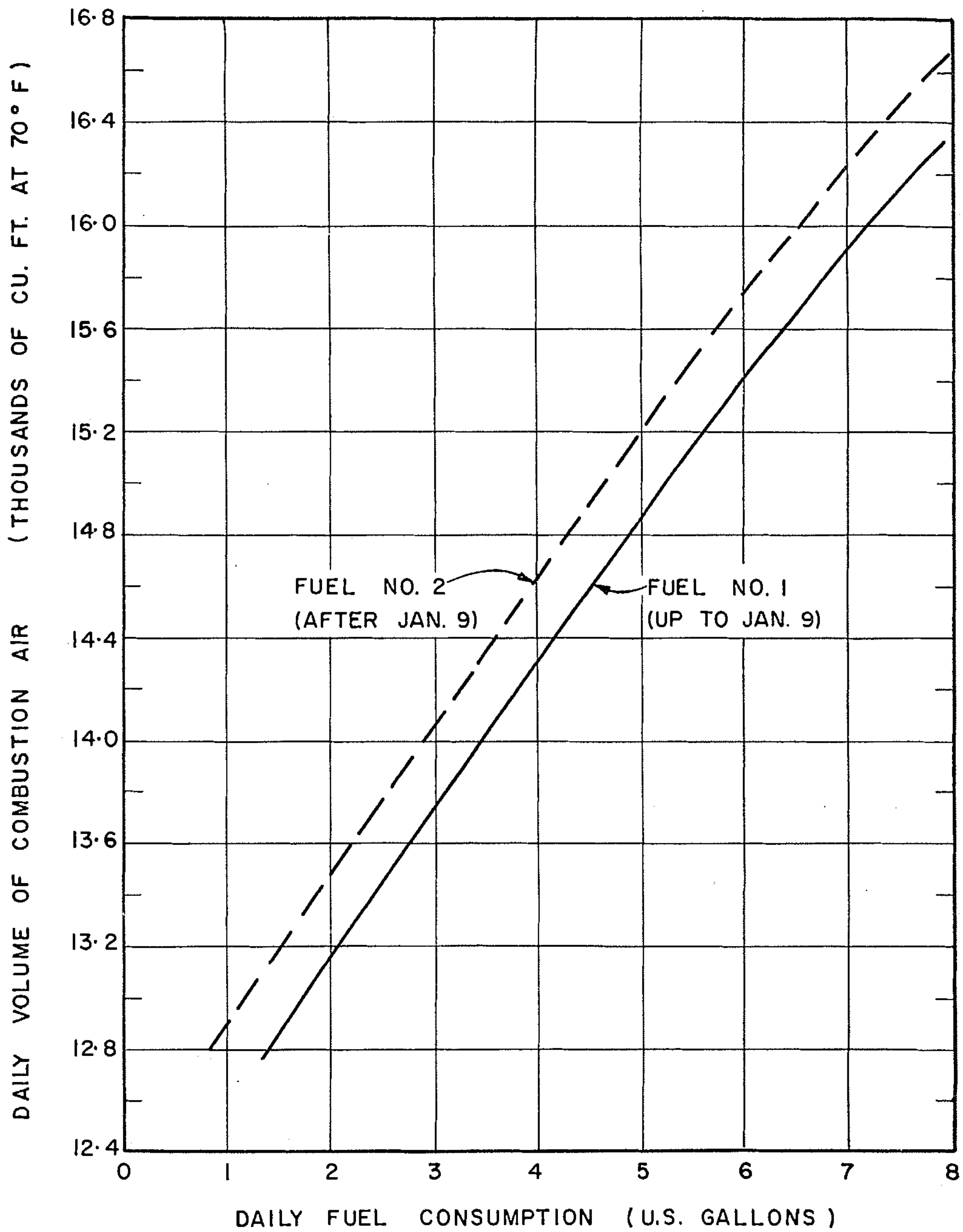


FIGURE 14

DAILY VOLUME OF COMBUSTION AIR VS. DAILY FUEL CONSUMPTION

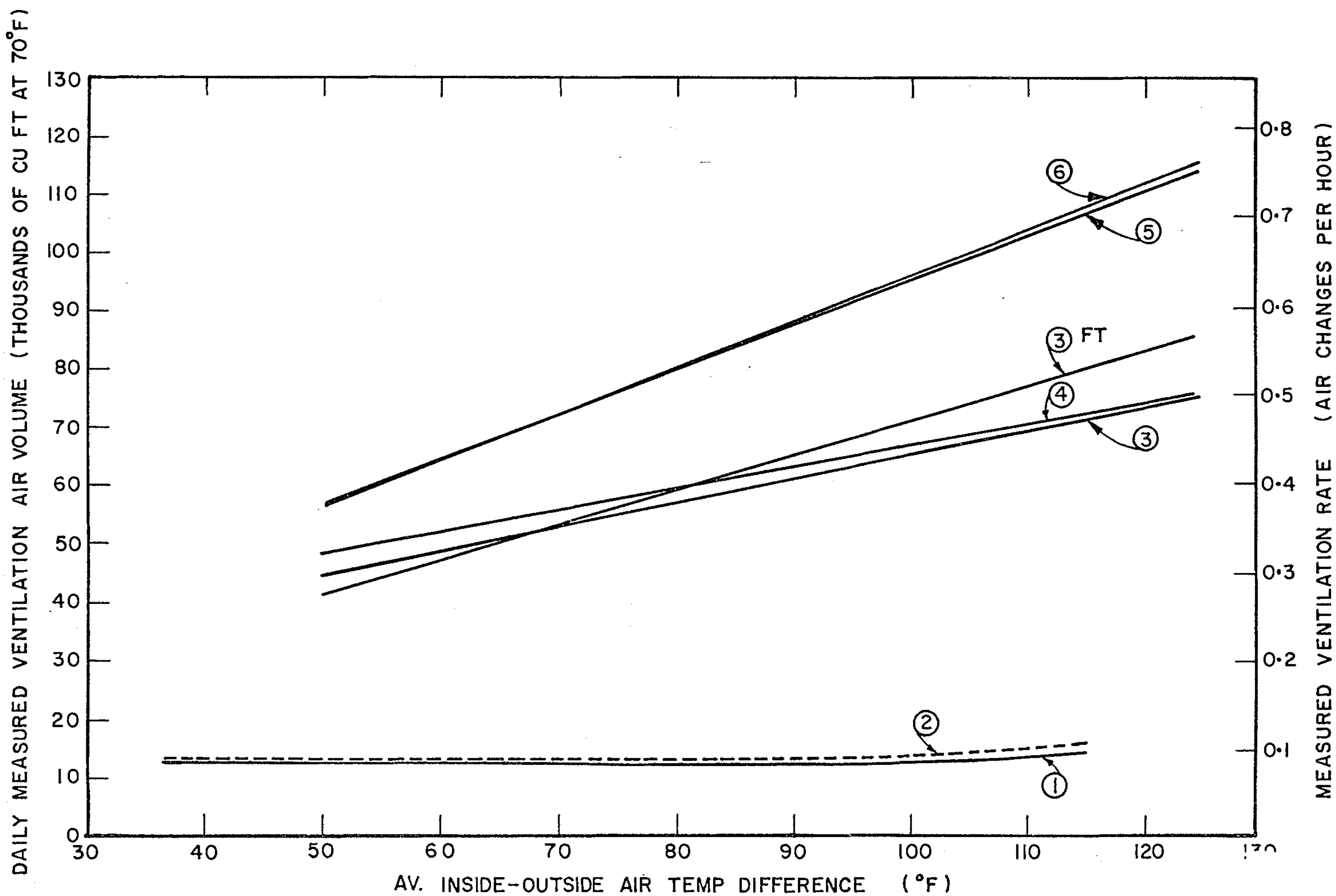


FIGURE 15

MEASURED VENTILATION RATE VS. INSIDE-OUTSIDE AIR TEMPERATURE DIFFERENCE

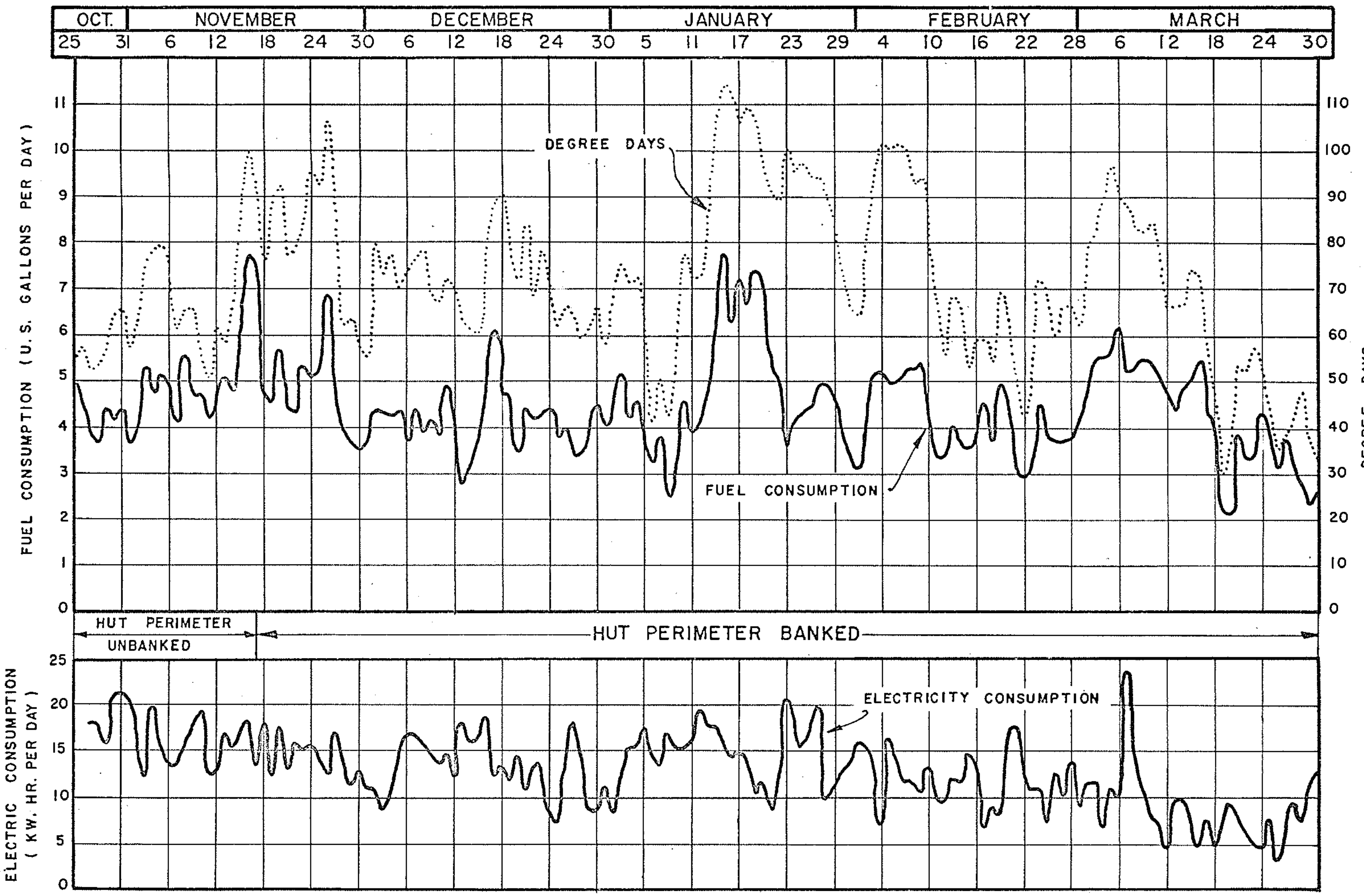


FIGURE 16 FUEL AND ELECTRICITY CONSUMPTION

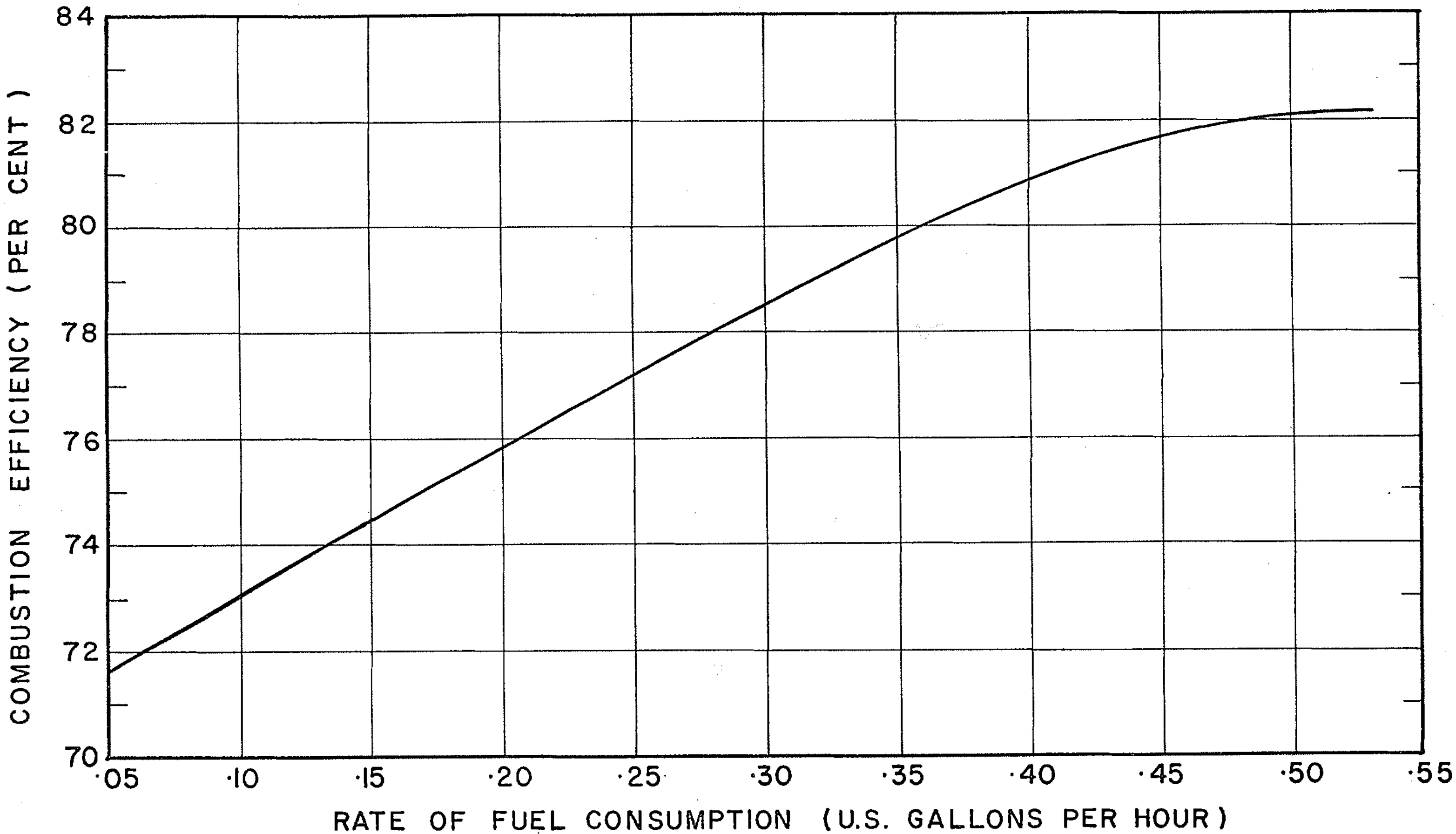


FIGURE 17

HEATER COMBUSTION EFFICIENCY VS. RATE OF FUEL CONSUMPTION

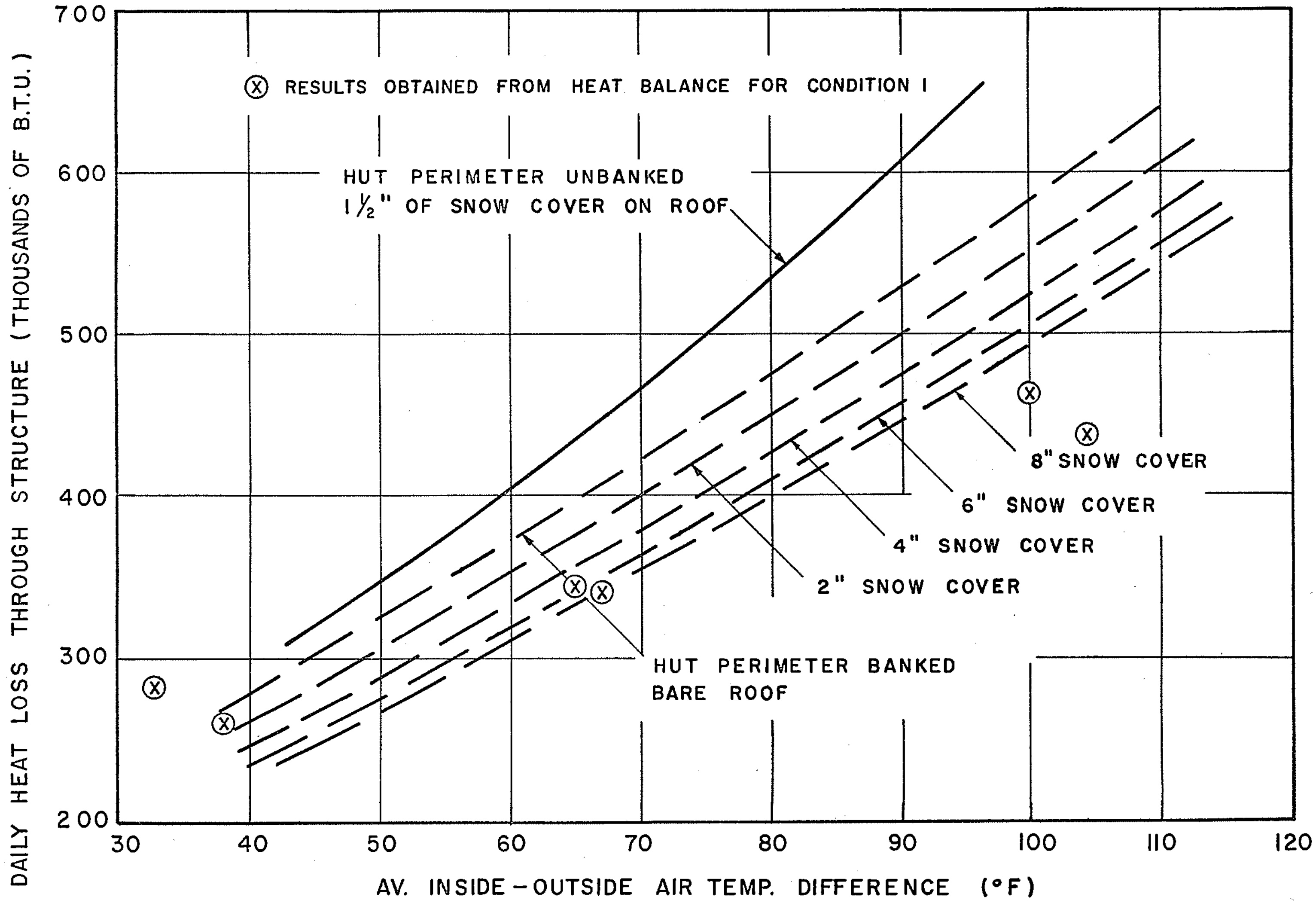


FIGURE 18

DAILY HEAT LOSS THROUGH STRUCTURE VS. INSIDE-OUTSIDE AIR TEMPERATURE DIFFERENCE

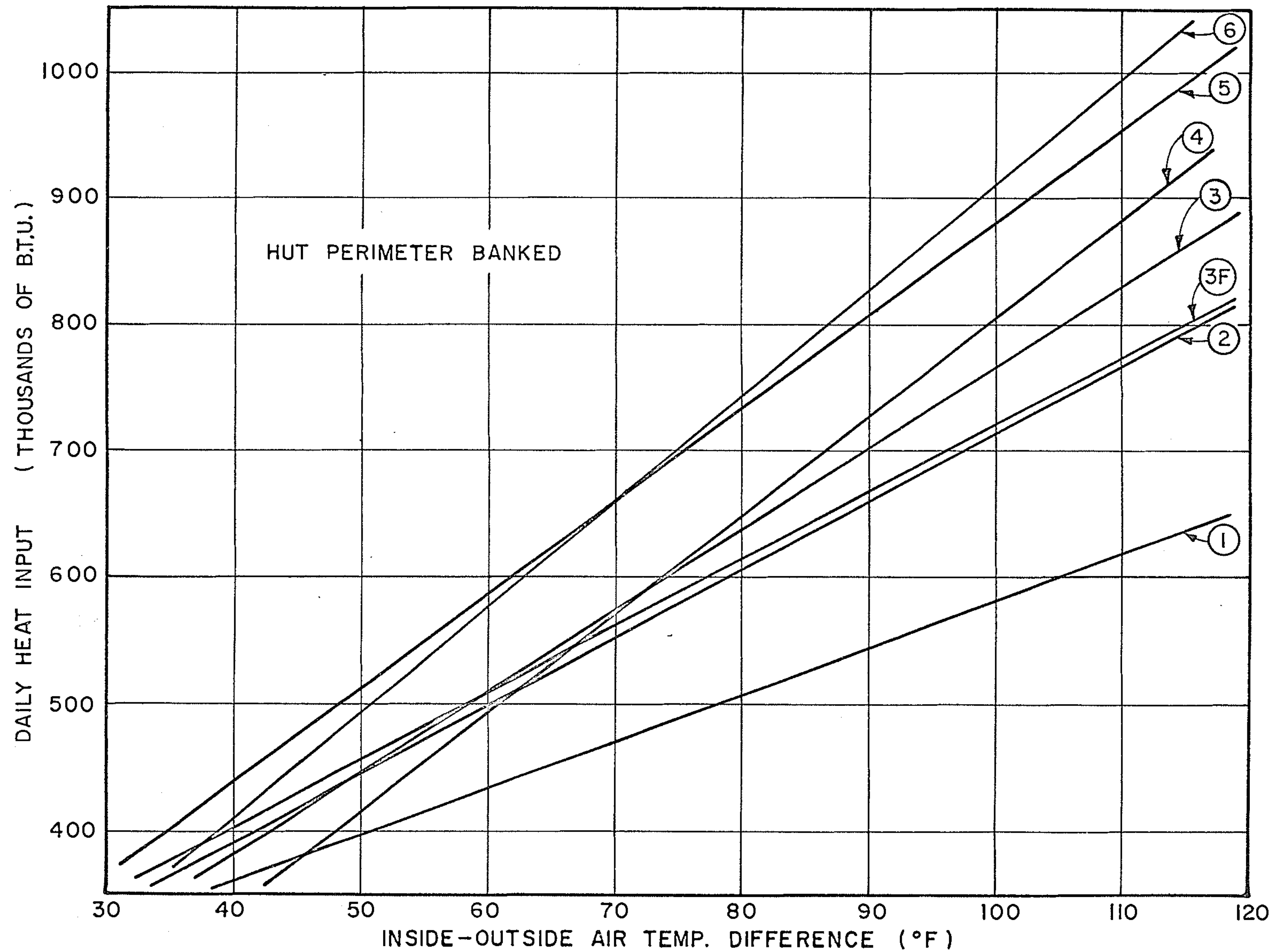


FIGURE 19

DAILY HEAT INPUT VS. INSIDE-OUTSIDE TEMPERATURE DIFFERENCE