

UNCLASSIFIED

AD NUMBER
AD809208
NEW LIMITATION CHANGE
TO Approved for public release, distribution unlimited
FROM Distribution authorized to DoD and DoD contractors only; Administrative/Operational Use; DEC 1966. Other requests shall be referred to Office of Civil Defense, Attn: Department of the Army-OSA, Washington, DC.
AUTHORITY
OCD ltr, 27 Oct 1972

THIS PAGE IS UNCLASSIFIED

NATIONAL BUREAU OF STANDARDS REPORT

9473

**Comparison of Digital Computer Simulations of
Thermal Environment in Occupied Underground
Protective Structures With Observed Conditions**

By

T. Kusuda and P. R. Achenbach
Building Research Division
National Bureau of Standards

December 1956



U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

809208L

THE NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards¹ provides measurement and technical information services essential to the efficiency and effectiveness of the work of the Nation's scientists and engineers. The Bureau serves also as a focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. To accomplish this mission, the Bureau is organized into three institutes covering broad program areas of research and services:

THE INSTITUTE FOR BASIC STANDARDS . . . provides the central basis within the United States for a complete and consistent system of physical measurements, coordinates that system with the measurement systems of other nations, and furnishes essential services leading to accurate and uniform physical measurements throughout the Nation's scientific community, industry, and commerce. This Institute comprises a series of divisions, each serving a classical subject matter area:

—Applied Mathematics—Electricity—Metrology—Mechanics—Heat—Atomic Physics—Physical Chemistry—Radiation Physics—Laboratory Astrophysics²—Radio Standards Laboratory,³ which includes Radio Standards Physics and Radio Standards Engineering—Office of Standard Reference Data.

THE INSTITUTE FOR MATERIALS RESEARCH . . . conducts materials research and provides associated materials services including mainly reference materials and data on the properties of materials. Beyond its direct interest to the Nation's scientists and engineers, this Institute yields services which are essential to the advancement of technology in industry and commerce. This Institute is organized primarily by technical fields:

—Analytical Chemistry—Metallurgy—Reactor Radiations—Polymers—Inorganic Materials—Cryogenics²—Materials Evaluation Laboratory—Office of Standard Reference Materials.

THE INSTITUTE FOR APPLIED TECHNOLOGY . . . provides technical services to promote the use of available technology and to facilitate technological innovation in industry and government. The principal elements of this Institute are:

—Building Research—Electronic Instrumentation—Textile and Apparel Technology Center—Technical Analysis—Center for Computer Sciences and Technology—Office of Weights and Measures—Office of Engineering Standards Services—Office of Invention and Innovation—Clearinghouse for Federal Scientific and Technical Information.³

¹ Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D. C., 20234.

² Located at Boulder, Colorado, 80302.

³ Located at 5285 Port Royal Road, Springfield, Virginia, 22151.

ERRATA

NOTE: First number indicate page, second number indicates line

VI 21

Change $V^2 = \frac{Z^2}{2X^2} + \frac{Z^2}{2Y^2} + \frac{Z^2}{2Z^2}$ to $V^2 = \frac{\partial^2}{\partial X^2} + \frac{\partial^2}{\partial Y^2} + \frac{\partial^2}{\partial Z^2}$

6 4 Change N_g to h_g

69 10 Change t_a to t'_a

69 12 Change T_v to t'_v

71 2 Change "references 5 and 6" to "references 12 and 13"

72 18 Change " $i + 1, t_w, i + 1$ " to " $(i + 1)$ th row, $t_w, i + 1$ "

72 19 Change $(t_i - t_s)$ to $(t_i - t_{sc})$

SUMMARY
OF
RESEARCH REPORT

COMPARISON OF DIGITAL COMPUTER SIMULATIONS OF THERMAL ENVIRONMENT
IN OCCUPIED UNDERGROUND PROTECTIVE STRUCTURES WITH OBSERVED CONDITIONS

by

T. Kusuda
P. R. Achenbach

December 1966

CUT ALONG THIS LINE

Prepared for
Office of Civil Defense
Department of the Army-OSA
under
Control No. OCD-OS-62-44
Unit 1211A

This is a summary of a report which has been reviewed in the
Office of Civil Defense and approved for issuance. Approval
does not signify that the contents necessarily reflect the
views and policies of the Office of Civil Defense.

Summary prepared by
National Bureau of Standards
December 1966

The National Bureau of Standards has been engaged in the heat transfer analysis of underground installations for the past several years. This report covers a part of the Bureau's activities related to the computer simulation of the thermal environment for prototype shelters.

The computer was used basically to simulate energy balance in the shelter living space and to analyze heat conduction from the shelter walls (including ceiling and floor) to the surrounding earth.

For the heat conduction analysis, finite difference techniques were employed; using a three dimensional model in some cases and a one dimensional model for the remainder.

Digital computer programs were developed and applied to seven different prototype shelters for which temperature and humidity records with simulated occupants were available as a result of studies by the National Bureau of Standards and by the University of Florida. In the seven shelters used for the investigation, twelve different operating conditions were analyzed. Of these twelve conditions, ten were under summer operation and two under moderate winter conditions.

Generally the agreement between the computed and observed thermal environment on these prototype shelters was surprisingly good, in spite of the fact that numerous simplifications were involved in describing the complex shelter heat transfer system for computer analysis. Two inherent uncertainties exist, which influence the final reliability of the calculations. The first involves the description of the actual complex system by mathematical language (or operational uncertainty). The second is related to the accuracy of input data used for the calculations, (or data uncertainty). Often, these are interrelated.

In this study, the following four different computer models were studied and two of them were extensively utilized for the comparison of calculated thermal environment with the observed data in the prototype shelters.

M-(1) Three-dimensional rectangular model with composite walls and with separate initial temperature patterns normal to the six bounding surfaces.

M-(2) Three-dimensional rectangular model with homogeneous heat conduction medium having separate initial temperature patterns normal to the six boundary surfaces.

M-(3) One-dimensional compound model for six composite wall systems.

M-(4) One-dimensional compound heat conduction model, same as M-(3) except that the roof region was assumed adiabatic.

To simulate the initial earth temperature distribution, the following three modes were employed:

I-(1) Earth temperature gradients normal to the six bounding surfaces.

I-(2) Earth temperature gradient normal only to the ground surface.

I-(3) Initial earth temperature constant around the shelter.

One of the factors not well established for calculating the shelter heat transfer is the heat exchange between the shelter air and the inner surfaces, between the occupants and the surfaces, and among the surfaces.

The analysis of simultaneous exchange for radiative and convective energy among occupants, air and inner surfaces of a shelter is very complex, and it requires the solution of a set of integral equations which are difficult to solve for even very simple geometrics. Therefore conventional combined heat transfer coefficients for radiation and convection were used in the analysis. Several numerical values and combination of these combined coefficients were assigned to the six interior surfaces to study the overall effect on shelter thermal environment.

Findings

- 1) A soil analysis of the earth around most of the prototype shelters indicated that the thermal diffusivity and thermal conductivity were in the neighborhood of $0.02 \text{ ft}^2/\text{hr}$ and $0.75 \text{ Btu/hr, (ft)}^2, ^\circ\text{F/ft}$ respectively. These values, in turn, seem to result in a good agreement between the calculated and the observed earth temperature change surrounding prototype shelters.
- 2) The following combined heat transfer coefficients at the shelter inner surfaces produced satisfactory simulation of the shelter summer environment for most of the prototype shelters.

1.0 Btu/hr. (ft^2) , $(^\circ\text{F})$ for vertical walls

1.5 Btu/hr. (ft^2) , $(^\circ\text{F})$ for the ceiling

0.5 Btu/hr. (ft^2) , $(^\circ\text{F})$ for the floor

Although there may be some other values and other combinations of these values that might have resulted in a slightly better simulation than those used in this analysis, these three values can be considered representative design heat transfer coefficients in the underground cavities.

- 3) For larger shelters, the one-dimensional and compound model (M-(3)) will probably be adequate for calculating the shelter thermal environment. The complicated three-dimensional model, therefore, may not be required for the calculation simulating the 14-day occupancy of many large community shelters. For small shelters (such as family shelters similar to the NBS shelter), however, it is recommended that the three-dimensional model be used for the accurate calculation.

CUT ALONG THIS LINE

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT

4212436

NBS REPORT

9473

Comparison of Digital Computer Simulations of Thermal Environment in Occupied Underground Protective Structures With Observed Conditions

By

T. Kusuda and P. R. Achenbach
Building Research Division
National Bureau of Standards

December 1966

Prepared for
Office of Civil Defense
Department of the Army-OSA
under
Control No. OCD-OS-62-44
Unit 1211A

This report has been reviewed in the Office of Civil Defense and approved for issuance. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

IMPORTANT NOTICE

NATIONAL BUREAU OF STANDARDS REPORTS are usually preliminary or progress accounting documents intended for use within the Government. Before material in the reports is formally published it is subjected to additional evaluation and review. For this reason, the publication, reprinting, reproduction, or open literature listing of this Report, either in whole or in part, is not authorized unless permission is obtained in writing from the Office of the Director, National Bureau of Standards, Washington, D.C. 20234. Such permission is not needed, however, by the Government agency for which the Report has been specifically prepared if that agency wishes to reproduce additional copies for its own use.



U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

TABLE OF CONTENTS

Nomenclature	Page
1. Introduction	1
2. Basic Heat Transfer Relations	3
3. Description of Computer Programs	9
4. Description of Prototype Shelters	15
4.1. NBS Shelter	15
4.2. Summerlin Shelter	17
4.3. Broyles Shelter	20
4.4. Napier Shelter	18
4.5. Reading Shelter	22
4.6. Ft. Belvoir 200-Man Shelter	24
4.7. Ft. Belvoir 1000-Man Shelter	26
5. Shelter Calculations	27
6. Conclusions	66
7. Appendix (Air Conditioning Subroutine)	69
8. References	73
9. Fortran Listing of Program M-(1), M-(2), and M-(4)	C-1/C-54
10. Sample Output of Program M-(4)	O-1/O-9

NOMENCLATURE

Unless otherwise defined in the text, the symbols used in this report are summarized, as follows:

<u>Symbols</u>		<u>Dimensions</u>
a	shelter dimension (half of the inside length)	ft
b	shelter dimension (half of the inside width)	ft
C_p	specific heat of moist air	Btu/lb, °F
c	shelter height	ft
d	shelter depth, distance between the earth surface and the ceiling of the shelter	ft
G	flow rate of ventilation air	CFM
h_g	ground surface heat transfer coefficient	Btu/hr, ft ² , °F
h_K or h	inner surface heat transfer coefficient of K th exposure	Btu/hr, ft ² , °F
k	thermal conductivity of solid	Btu/hr, ft, °F
L_E	Lewis Relation = $\frac{h_K}{\sigma C_p}$	dimensionless
P_{vs}	saturated vapor pressure of water at temp. t	inches Hg
P_v	vapor pressure of water in the air at dew point temperature	inches Hg
P_B	barometric pressure	inches, Hg
Q_{VS}	sensible heat released by the ventilation air	Btu/hr
Q_{VL}	latent heat released by the ventilation air	Btu/hr
Q_{GS}	sensible heat generated in the shelter by simulated occupants	Btu/hr
Q_{GL}	latent heat generated in the shelter by simulated occupants	Btu/hr
Q_{WSK}	sensible heat released by the shelter inner surface of K th exposure	Btu/hr
Q_{WLK}	latent heat released by the shelter inner surface of K th exposure	Btu/hr
Q_{MS}	sensible heat generated in the shelter by things other than simulated occupants	Btu/hr

<u>Symbols</u>		<u>Dimensions</u>
Q_{ML}	latent heat generated in the shelter by things other than simulated occupants	Btu/hr
Q_{SUN}	solar radiation intensity at the earth's surface	Btu/hr, ft ²
S_K	inner surface area of K th exposure	ft ²
t	temperature	°F
W_s	humidity ratio	lb of water vapor/ lb dry air
W_s	humidity ratio of air saturated by water vapor	lb of water vapor/ lb of dry air
X_K (K = 1,6)	coordinate system used for shelter heat transfer	ft
$X_{K,0}$ (K = 1,6)	coordinates of the system boundaries	ft
α_K	thermal diffusivity of earth in the region surrounding K th exposure	ft ² /hr
η	albedo of earth surface	dimensionless
θ	time coordinate	hr
λ	latent heat of vaporization of water	Btu/lb
σ	water vapor transfer coefficient (lb/(hr)(ft ²))(lb/lb dry air)	
ρ	density of moist air	lb/ft ³
ΔX_K	finite difference length along X_K	ft
$\Delta \theta$	finite difference time	hr
Σ	summation symbol	

Subscripts

Unless otherwise stated, the following rules of subscripting will apply to all of the variables.

- a shelter space properties
- o outdoor air properties

Subscripts--continued

v ventilation air properties

c concrete property

g ground surface properties

= deep underground

K innersurface exposure index

K = 1 = North

2 = South

3 = East

4 = West

5 = Floor

6 = Roof

In some cases, the subscript W is used to denote the wall properties instead of K being 1, 2, 3, and 4.

The subscripts R and F are employed in the same manner, denoting, respectively, the properties pertaining to roof and floor regions.

S sensible heat property

s saturated air property

L latent heat property

Operational Symbols

$$v^2 = \frac{v_x^2}{2x} + \frac{v_y^2}{2y} + \frac{v_z^2}{2z}$$

CAPTIONS FOR FIGURES

- Fig. 1. Schematic diagram of the matrix used for computer program M-(1).
- Fig. 2. Schematic diagram of the heat conduction region used for computer program M-(2).
- Fig. 3. Inner surface heat transfer coefficient frequency distribution.
- Fig. 4. Inner surface heat transfer coefficient vs temperature difference between the air and inner surface of the shelter.
- Fig. 5. Comparison of the calculated and observed shelter air temperatures and relative humidities of test 1 for NBS family shelter (computer program M-(1)).
- Fig. 6. Comparison of the calculated and observed shelter inner surface temperatures for test 1 of NBS family shelter (computer program M-(1)).
- Fig. 7. Comparison of the calculated and observed shelter air temperatures and relative humidities for test 2 of NBS family shelter (computer program M-(1)).
- Fig. 8. Comparison of the calculated and observed shelter air temperatures and relative humidities for test 3 of NBS family shelter (computer program M-(1)).
- Fig. 9. Comparison of the calculated and observed shelter air temperatures and relative humidities for test 3 of NBS family shelter (computer program M-(2)).
- Fig. 10. Comparison of the calculated and observed air temperatures and relative humidities for test 4 of NBS family shelter (computer program M-(2)).

CAPTIONS FOR FIGURES (cont'd)

- Fig. 11. Comparison of the calculated and observed shelter air temperatures and relative humidities for test 5 of NBS family shelter (computer program M-(2)).
- Fig. 12. Comparison of the calculated and observed shelter air temperatures for summer condition test for Summerlin shelter (computer program M-(2)).
- Fig. 13. Comparison of the calculated and observed shelter air relative humidities for summer condition test for Summerlin shelter (computer program M-(2)).
- Fig. 14. Comparison of the calculated and observed earth temperatures surrounding Summerlin shelter during summer test conditions (computer program M-(2)).
- Fig. 15. Comparison of the calculated and observed shelter air temperatures and relative humidities during moderate weather condition test for Summerlin shelter (computer program M-(2)).
- Fig. 16. Comparison of the calculated and observed shelter air temperatures for Broyles shelter (computer program M-(2)).
- Fig. 17. Comparison of the calculated and observed shelter relative humidities for Broyles shelter (computer program M-(2)).
- Fig. 18. Comparison of the calculated and observed shelter air temperatures for Napier shelter (computer program M-(2)).
- Fig. 19. Comparison of the calculated and observed shelter relative humidities for Napier shelter (computer program M-(2)).
- Fig. 20. Comparison of the calculated and observed shelter air temperatures and relative humidities for Reading shelter (computer program M-(2)).

CAPTIONS FOR FIGURES (cont'd)

- Fig. 21.** Observed moisture balance of Reading shelter.
- Fig. 22.** Comparison of the calculated and observed earth temperatures outside Reading shelter walls (computer program M-(2)).
- Fig. 23.** Comparison of the calculated and observed earth temperatures outside Reading shelter ceiling and floor (computer program M-(2)).
- Fig. 24.** Comparison of the calculated and observed shelter air temperatures and effective temperatures of Ft. Belvoir 200-man shelter (computer program M-(4)).
- Fig. 25.** Comparison of the calculated and observed shelter air temperatures and effective temperatures of Ft. Belvoir 1000-man shelter (computer program M-(4)).

COMPARISON OF DIGITAL COMPUTER SIMULATIONS OF THERMAL ENVIRONMENT
IN OCCUPIED UNDERGROUND PROTECTIVE STRUCTURES WITH OBSERVED CONDITIONS

By

T. Kusuda and P. R. Achenbach

1. INTRODUCTION

This report compares digital computer calculations of thermal environment for underground protective shelters with observed conditions of temperature and humidity. Several digital computer programs have been developed by the National Bureau of Standards for the purpose of simulating the heat transfer of underground structures. These computer programs were applied to 7 shelters, whose thermal environment under simulated conditions of occupation had been observed experimentally. Since the thermal environment in underground protective structures may become extremely unfavorable, particularly during the summer occupancy period, for large areas of the United States, the majority of prototype shelters mentioned herein were tested under summer climatic conditions. Of the 7 shelters whose thermal environments were calculated and compared with experimental observations, 12 different test conditions were included, 2 of which were under moderate winter conditions.

Analytical and experimental studies of various shelters have shown that the temperature and humidity within the occupied underground shelter depend on many parameters, which may be classified as follows:

1. Structural characteristics.
 - a. Size and shape.
 - b. Physical and thermal properties of construction material.

2. Site characteristics.

- a. Physical and thermal properties of earth surrounding the shelter.
- c. Thickness of earth cover.
- d. Type of earth surface and landscape.
- e. Neighboring buildings and installations.

3. Climatic factors.

- a. Earth temperature.
- b. Psychrometric condition of outdoor air.
- c. Solar radiation.
- d. Precipitation.

4. Operational characteristics.

- a. Ventilation rate.
- b. Psychrometric condition of ventilation air
- c. Density of Occupancy.
- d. Activity of Occupancy.
- e. Heat and moisture release by equipment in shelter.
- f. Emergency condition such as sealed up or surface fire conditions.

Testing of underground structures to cover even a small portion of all of the possible combinations of the above parameters is a formidable and expensive task. However, the number of tests could be drastically decreased, and the efficiency of testing improved, if the effect of various parameters in the thermal environment of a shelter could be predicted by computation. The mathematical formulation of such a computation should take into account a majority of the important parameters so the sensitivity of the overall thermal environment to the several parameters could be studied individually

or simultaneously with others. The mathematical procedures should be simple enough so the computation time (or computer cost) would be reasonable. Finally, and most important, the computed results should be reliable.

Some previous computations of the thermal environment in shelters have been reported which take into account simulated human metabolism, ventilation effects, and heat transfer in the earth [1,2,3], but there have been very few actual comparisons between calculations and observations for a given system over a substantial period of time. It is fortunate that the observed results of six of the seven shelters covered by this study were so well documented by reports of the University of Florida [4], thus making possible comprehensive comparisons between the calculated thermal environment and the observed results.

2. BASIC HEAT TRANSFER RELATIONS

Since the details of the numerical technique employed for the heat transfer of underground protective structures have been reported previously [1], only basic mathematical formulations employed for all of our computer programs are given here:

2.1. Shelter air heat balance.

$$\sum_{K=1}^6 Q_{WSK} + Q_{VS} + Q_{GS} + Q_{MS} = 0$$

$$\sum_{K=1}^6 Q_{WLK} + Q_{VL} + Q_{GL} + Q_{ML} = 0$$

where

$$Q_{WSK} = h_K (r_K - t_a) S_K$$

$$Q_{WLK} = \left(\frac{h_K \lambda}{C_P L_c} \right) (W_K - W_a) S_K \quad \text{for } W_a < W_K$$

$$= 0 \quad \text{for } W_a \geq W_K$$

$$Q_{VS} = (1.08) (G) (t_v - t_a)$$

$$Q_{VL} = (4.5) (G) (W_v - W_a)$$

Q_{GS}	= 330	Btu/hr, person	60 °F
	300		70 °F
	220		80 °F
	115		90 °F
	0		100 °F
	-140		110 °F
	-280		120 °F

Q_{GL}	= 70	Btu/hr, person	60 °F
	100		70 °F
	180		80 °F
	285		90 °F
	400		100 °F
	540		110 °F
	680		120 °F

2.2. Shelter Inner Surfaces.

$$Q_{WSK} + Q_{WLK} = -k_K \int_{S_K} \frac{\partial t}{\partial x_K} dS_K$$

2.3. Concrete (or inner wall) heat conduction.

$$\frac{\partial^2 t_c}{\partial x_K^2} = \frac{1}{\alpha_{CK}} \frac{\partial t_c}{\partial \theta}$$

2.4. Boundary between the concrete (or inner wall), and earth.

$$t_c = t_g$$

$$k_{CK} \frac{\partial t_c}{\partial X_K} = k_{CG} \frac{\partial t_g}{\partial X_K}$$

2.5. Earth heat conduction.

$$\frac{\partial t_g}{\partial \theta} = \alpha_g \nabla^2 t_g \text{ for three-dimensional model}$$

$$\frac{\partial t_g}{\partial \theta} = \alpha_g \frac{\partial^2 t_g}{\partial X_K^2}, K=1 \text{ to } 6 \text{ for one-dimensional model}$$

2.6. Earth boundary conditions.

2.6.1 Four-wall region $\frac{\partial t_g}{\partial X_K} = 0$ at $X_K =$ (some large distance)

$$K = 1, 2, 3, 4.$$

2.6.2 Floor region $t_g = t_{g_m}$ at $X_K =$ (some large distance)

$$\text{where } K = 5$$

2.6.3 Roof region

$$\text{where } K = 6$$

Radiation model $-\frac{\partial t_g}{\partial X_K} = h_g (t_g - t_o) + Q_{rad}$

(a) equilibrium model $t_g = t_o$

(b) adiabatic model $\frac{\partial t_g}{\partial X_K} = 0$

(c) solar-heat model

$$Q_{rad} = (1 - \eta) Q_{sol} \text{ during the solar irradiation}$$

$$Q_{rad} = 0 \text{ during no solar irradiation}$$

This solar heat model is essentially the same as the sol-air temperature concept and ignores the direct radiation heat exchange between earth surface and sky, but it does include the effective radiation heat exchange between the earth surface and ambient air by adjusting the value of N_g . According to the last equation, however, the earth surface temperature never becomes lower than the air temperature, which is not always the case.

2.7. Psychrometric calculations.

Taking advantage of the large memory of the high speed digital computer of the National Bureau of Standards, all the psychrometric calculations were performed using the thermodynamic properties of moist air published by Goff and Gratch.

The thermodynamic properties of dry air and those of saturated air at one standard atmospheric pressure, such as the following, were tabulated as temperature functions by Goff and Gratch [5].

W_g = humidity ratio of the saturated moist air (lb/lb of dry air).

h_a = enthalpy of dry air (Btu/lb of dry air).

h_g = enthalpy of the saturated moist air (Btu/lb of dry air).

h_w = enthalpy of the water (Btu/lb of water).

V_a = volume of the dry air (cu ft/lb of dry air).

V_g = volume of the saturated moist air (cu ft/lb of dry air).

f_g = factors related to the relative humidity and degree (dimensionless) of saturation.

These properties were read into the computer for the temperature range from 30 °F to 120 °F at every one degree increment, except that the humidity ratio, W_g , was programmed for the temperature range from -20 °F to 120 °F at every one degree increment.

The following psychrometric symbols and formulas are used to derive the desired properties from given sets of properties, such as dry- and wet-bulb temperatures:

P_v = partial water vapor pressure in moist air (in. Hg).

P_B = barometric pressure (in. Hg).

P_{vs} = partial water vapor pressure in saturated air (in. Hg.).

ϕ = relative humidity, as a fraction

μ = degree of saturation.

W = humidity ratio of moist air (lb/lb of dry air).

V = volume of moist air (cu ft/lb of dry air).

W_s^* = W_s evaluated at the thermodynamic wet-bulb temperature (lb/lb of dry air).

h_w^* = h_w evaluated at the thermodynamic wet-bulb temperature (Btu/lb of water).

h_s^* = h_s evaluated at the thermodynamic wet-bulb temperature (Btu/lb of dry air).

$$W = 0.622 \frac{P_v}{P_B - P_v} \quad 2.7-1$$

$$\phi = \frac{P_v}{P_{vs}} \quad 2.7-2$$

$$\mu = \frac{\phi(1 - f \frac{P_v}{P_B})}{1 - \phi f \frac{P_v}{P_B}} \quad 2.7-3$$

$$W = \mu W_s \quad 2.7-4$$

$$V = \mu(V_s - V_a) + V_a \quad 2.7-5$$

$$h = \mu(h_g - h_a) + h_a \quad 2.7-6$$

$$h + (W_g^* - W)h_w^* = h_g^* \quad 2.7-7$$

The last formula represents the thermodynamic wet-bulb temperature relation for given h and W of moist air.

The psychrometric calculations of thermal environment begin, usually, with input data for dry- and wet-bulb temperature of moist air. These two temperature data are sufficient to describe the complete thermodynamic state of the moist air at one standard atmosphere. The actual calculations involving heat- and mass-balance within a given thermal system are, however, more readily performed with the dry-bulb temperature and the humidity ratio, as seen in equations of shelter heat balance. The method used during this study to obtain the humidity ratio of moist air from its dry- and wet-bulb data is described as follows:

The thermodynamic wet-bulb temperature relation 2.7-7 can be expanded by the use of enthalpy expression 2.7-6.

$$\frac{W}{W_g(t)} [h_g(t) - h_a(t)] + h_a(t) + [W_g^*(t') - W]h_w(t') = h_g^*(t') \quad 2.7-8$$

In the above expression, $W_g(t)$, $h_g(t)$, and $h_a(t)$ are thermodynamic properties at dry-bulb temperature t , while $W_g^*(t')$, $h_g^*(t')$, and $h_w^*(t')$ are thermodynamic properties evaluated at wet-bulb temperature t' .

Rearranging the terms in equation 2.7-8, the humidity ratio W for dry- and wet-bulb temperatures t and t' can be expressed as

$$W = \frac{h_g^*(t') - h_a(t) - h_w^*(t')W_g^*(t')}{h_g(t) - h_a(t) - h_w^*(t')W_g(t)} W_g(t) \quad 2.7-9$$

The calculation of the thermodynamic wet-bulb temperature from a given dry-bulb temperature and humidity ratio is also possible from

2.7-8 by an iterative technique. The iterative technique found successful during the course of this investigation is the inverse interpolation formula [6] of Newton applied to Goff and Gratch tables.

2.8. Effective temperature of shelter air.

For some of the shelter analyses, effective temperatures have been calculated from dry- and wet-bulb temperatures assuming an air velocity of less than 20 fpm. The effective temperature chart of the ASHVE* has been stored in the computer memory in a tabular format, and a table-searching and interpolative subroutine used to calculate the effective temperature.

3. DESCRIPTION OF COMPUTER PROGRAMS

3.1. Computer models.

Basically four different computer programs have been developed during this study. All the programs, however, essentially employ the time-iteration technique for solving transient heat conduction equations and they are designated as follows:

- M-(1) Three-dimensional model with composite walls and with separate initial temperature pattern normal to the six boundary surfaces.
- M-(2) Three-dimensional model with homogeneous heat conduction medium having separate initial temperature patterns normal to the six boundary surfaces.
- M-(3) One-dimensional compound heat conduction model for composite regions treating the six exposures separately.
- M-(4) One-dimensional compound heat conduction model for six composite regions assuming an adiabatic roof.

Each program has advantages and disadvantages, as discussed in the following pages.

* ASHVE Guide 1950 Chapter 6

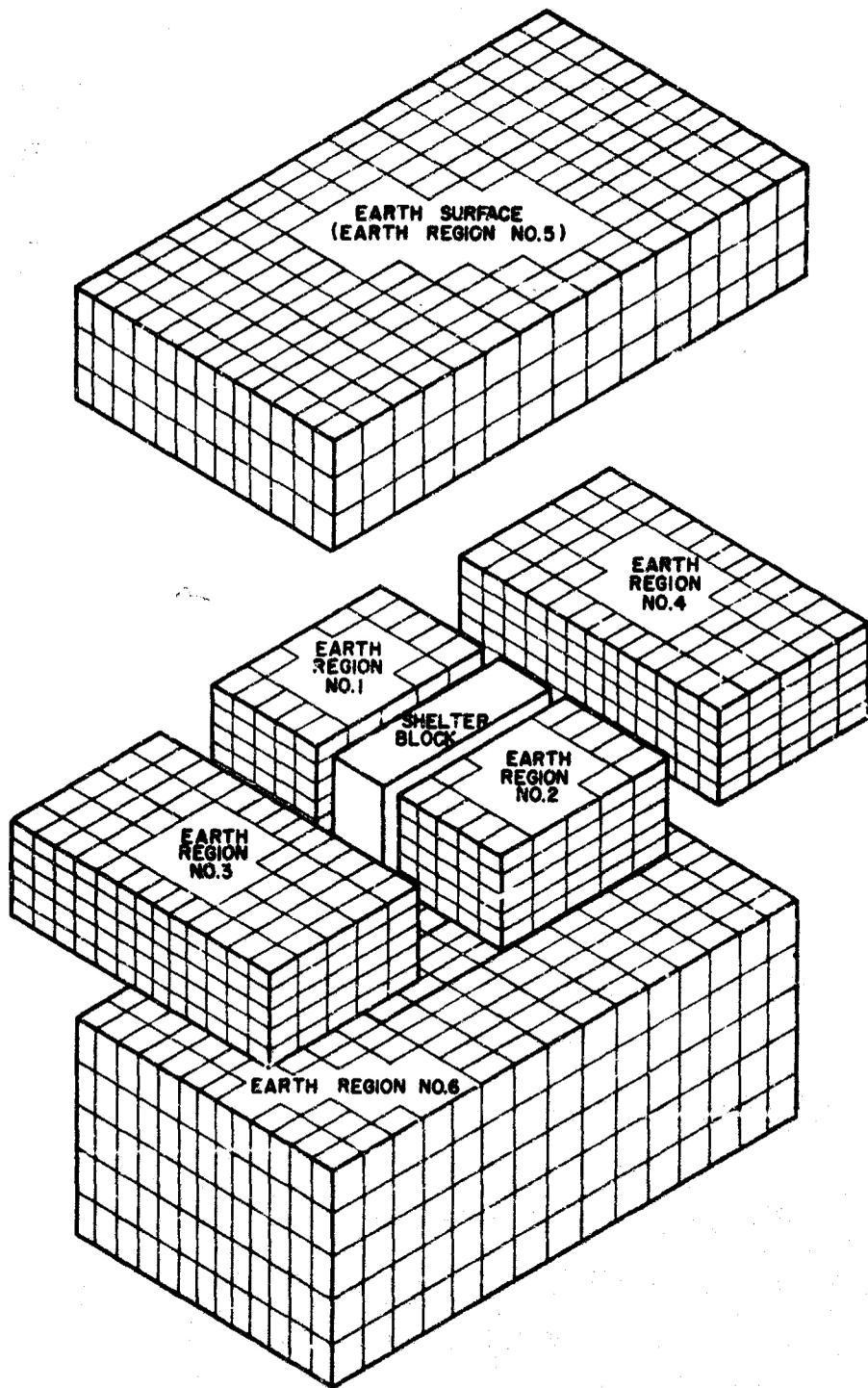
M-(1). This program has been described in reference [2], and was used to evaluate the NBS family shelter. The earth temperature field surrounding the shelter was divided into 6 blocks, such as shown in Figure 1. This block system enabled the program to account for situations in which some wall region(s) may be considerably different from the others in heat transfer properties and earth temperature.

The initial temperature in each block was programmed only in the direction normal to the wall surface, however, because the temperature profiles were usually known only along those directions.

Temperature calculations for the entire earth region surrounding the shelter were made with time-iterative techniques on three-dimensional finite difference equations. The concrete wall (including floor and ceiling) temperatures were calculated by one-dimensional finite difference equations separately for each wall, assuming that lateral temperature variation on the interior surface for a given wall could be neglected. Each inner wall-surface temperature was determined by surface heat balance equation 2.2, including vapor condensation but excluding condensate re-evaporation. The shelter psychrometric condition, dry-bulb temperature, dew-point temperature, and relative humidity were then evaluated, based upon the total heat balance equation 2.1.

M-(2). In this model, thermal properties or heat transfer characteristics around the shelter air space all were assumed homogeneous. In other words, no distinction in thermal properties was made from the concrete wall to the soil, or from one wall region to the other, as in Model M-(1).

The earth temperature initialization was performed only in the direction normal to the earth surface. The finite difference scheme employed for the three-dimensional time-iteration solution of the heat



**DIAGRAM OF HEAT TRANSFER MATRIX
AROUND FAMILY SHELTER
(SCHEMATIC)**

Fig. 1 Schematic diagram of the matrix used for computer program M-(1).

conduction equation is shown in figure 2. The homogeneity assumption of the heat conduction equation mentioned makes it possible to analyze only a one-quarter segment of the shelter, because of the symmetric nature of the entire system. The details of this program have been described in reference [1]. This program was applied to the NBS 6-man family shelter, the Summerlin shelter, the Broyles shelter, the Napier shelter, and the Reading shelter, for the purpose of comparing the calculated shelter thermal environment with the experimentally observed data.

M-(3). The three-dimensional effect on earth heat conduction around the shelter becomes less and less significant as the shelter size increases. A one-dimensional compound system was developed primarily for large shelters, where a major portion of the heat flow is always normal to the shelter walls, ceiling, and floor. This program is identical with M-(1), except that the corner region of earth and concrete is ignored, and the one-dimensional finite difference equation was used for earth temperature determinations. Comparison with the two previous programs indicates that the earth temperature computation scheme was drastically simplified in the model. The program was applied to the Summerlin and Reading shelters.

M-(4). This program was a modification of M-(3), to simulate basement type shelters such as the two at Ft. Belvoir. The heat transfer in the ceiling region of basement shelters will be much less significant than that in wall and floor regions. Thus, in this program, the outer face of the ceiling layer was assumed adiabatic.

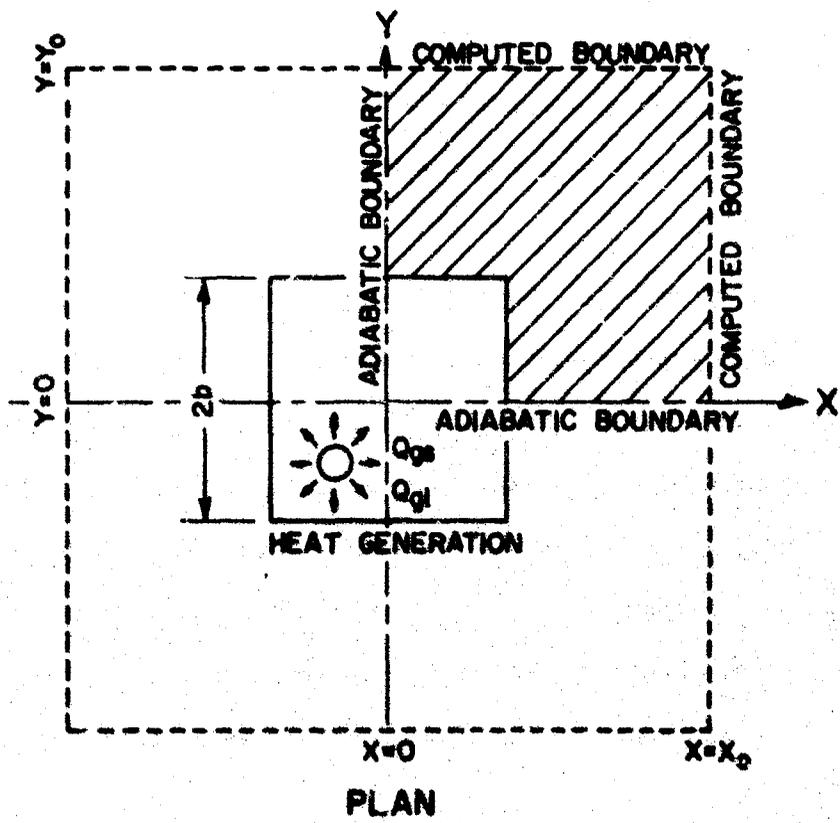
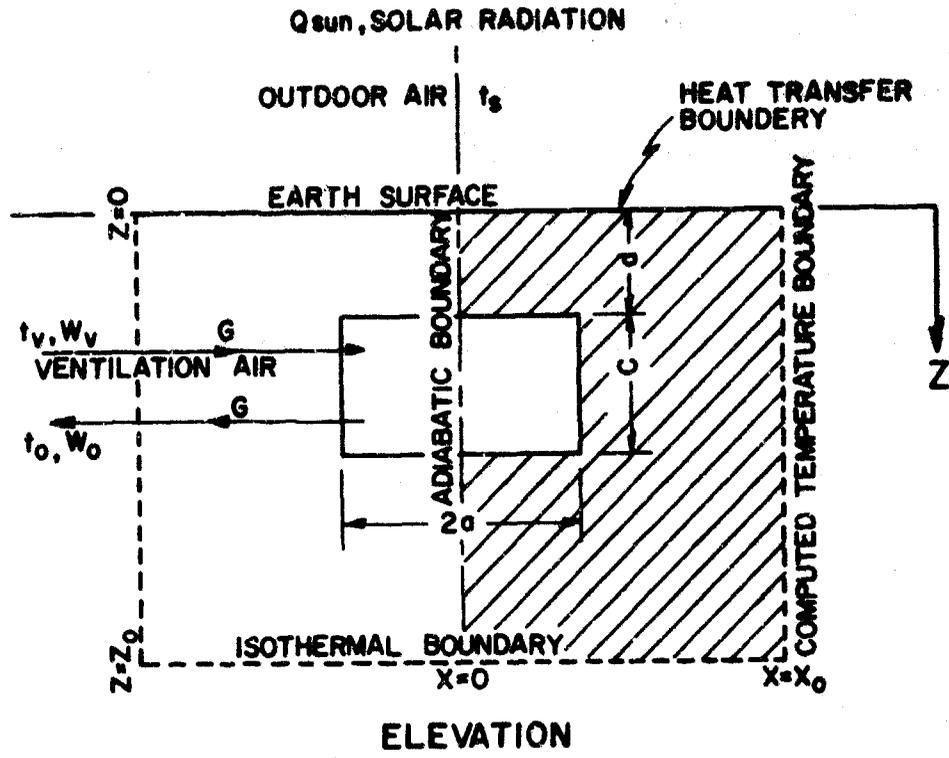


Fig. 2 Schematic diagram of the heat conduction region used for computer program M-(2).

The calculation of the psychrometric condition of shelter air for this program was designed so that dry- and wet-bulb and dew-point temperature, as well as shelter effective temperature, can be computed with or without the air conditioning system turned on. The details of the air conditioning calculations used in this program are described in the appendix. This program was applied to 200-man and 1000-man shelters of Ft. Belvoir, which were tested by the University of Florida.

3.2. Initialization of earth temperature surrounding a protective shelter.

Accurate heat transfer calculations for the early part of an occupancy period for these shelters are extremely difficult, because of the uncertainty about the earth temperature distribution around the shelter. Particularly for the shelters that had been installed with only a shallow earth cover, the temperature variation from roof region to the floor region, from one wall region to another, and from corner to flat surface region was quite appreciable, and very complex to approximate mathematically.

In order to simulate this complex and three-dimensional pattern of the initial earth temperature around the shelter, assuming that such three-dimensional patterns are important, the earth temperature program becomes highly, and perhaps unnecessarily, complicated. Therefore, during the study, a simplification was made by selecting three initial temperature patterns, as follows:

- 1. Earth temperature gradients are always in a direction normal to four walls, floor, and roof surfaces - block mode.

- I-2. Predominant earth temperature gradient is always along a vertical path, from the surface downward - vertical mode.
- I-3. Earth temperature is virtually constant all around the shelter - constant mode.

These three modes of the initial earth temperature patterns have been employed during the calculation, and presented in this report.

However, it is important to remember that the detailed earth temperature profile data surrounding shelters seldom will be available, even when it is important, for the majority of actual shelters. For most of the thermal environment calculations of underground structures, it is usually assumed that the earth has a single value of temperature. This uncertainty in the initial earth temperatures is one of the sources of error in predicting the thermal environment of shelters, particularly for the early period of shelter occupancy.

4. DESCRIPTION OF PROTOTYPE SHELTERS

Brief descriptions of the prototype shelters used for this analysis and their characteristics are given. If the mathematical simulation of shelter thermal environment is to be most effective, it is necessary to secure accurate information regarding many parameters related to structural, site, climatic, and operational characteristics of shelters.

4.1. NBS shelter.

The family size shelter in Washington, D. C., tested by the National Bureau of Standards, was constructed according to Bulletin MP-15

of the Office of Civil Defense [3] with some small modifications. It was a concrete wall shelter with external dimensions of 12 feet long, 9 feet 4 inches wide, and 7 feet 6 inches high (not including hatch), placed in an excavation and covered with 2 feet 3 inches of earth. The interior dimensions of the shelter area were 10 feet 8 inches long, 8 feet wide, and 6 feet 6 inches high. A 2-foot-wide hatchway was installed on the north side of the occupancy area and separated from the 8- by 8-foot living space by an 8-inch-thick concrete shielding wall. The earth surface over the shelter was grass covered and partially in the shade of neighboring trees. The soil around the shelter was mostly loam and clay; its density averaged about 109 lb/ft^3 , and its moisture content averaged about 15 percent (dry weight basis).

Ventilation air was controlled in a neighboring equipment house to specified conditions and ducted into the shelter through an inlet at the mid-height of the shielding wall facing the occupied area, and the shelter air was exhausted through an outlet located on the opposite wall of the hatchway.

Six simulated occupants (SIMOC) were carefully designed and constructed to produce sensible and latent portions of metabolic heat as functions of shelter area temperature (details of SIMOC are found in reference [3]). Four SIMOC's had a nominal heat output of 400 Btu/hr, and the other two had heat outputs of 200 and 600 Btu/hr, respectively.

Complete psychrometric observations were made at the ventilation air inlet, the exhaust air outlet, and at the 5-foot level above the

geometrical center of the shelter floor. Temperature observations obtained during this test included earth temperatures around the shelter to a maximum distance of 4 feet away from the exterior surface of the concrete wall for all four walls and the floor. In the shelter roof region, earth temperature was studied with four thermocouples located 6 inches, 12 inches, 18 inches, and 24 inches from the external surface of the shelter ceiling.

Five tests were conducted with variations in test duration, ventilation rate, number of occupants, ventilation air condition, and surrounding earth temperature. Test 1 was conducted with no occupants, with 42 cfm of ventilation air. Tests 2, 3, and 4 were each conducted with six SIMOC's, and with ventilation air rates of 0, 18, and 42 cfm, respectively. Test 5 was undertaken to simulate winter conditions of occupancy, ventilation air, and earth temperature, using six SIMOC's and 18 cfm ventilation air.

4.2. Summerlin shelter [4].

This shelter was a welded steel structure located entirely below the finished grade line, with a 30-inch earth cover over the roof, in a rural area of Gainesville, Fla., and thermally isolated from other buildings. The occupancy area dimensions were 23 feet 7 inches long, and 7 feet 8 inches wide. The shelter roof was arched over the wall, and the maximum ceiling height at the middle of the arch was 7 feet 2 1/4 inches. A 4- by 3-foot hatchway was located at one end of the shelter. The earth around the shelter was a mixture of sand and loam, and the earth cover was bare at the time of the shelter environmental tests. The moisture content (dry weight basis) of the soil samples analyzed ranged from 9 percent to 19 percent; their dry density ranged from 103 lb/ft³ to 111 lb/ft³.

Ventilation air conditions were generated in an equipment trailer located outside the shelter, and supplied to the shelter by a flexible tube passing through the entrance hatch. The ventilation air inlet was near the north end of the shelter, and shelter air was exhausted from a stack located at the southeast corner.

Two series of environmental tests were conducted, using 18 SIMOC's (ref. 3) of NBS 400 Btu/hr type; one during July 1962 with ventilation air of 200 cfm and typical Florida summer outdoor psychrometric conditions; and the other during April 1963 with ventilation rates of 54 and 216 cfm at August and April psychrometric conditions. The simulated August psychrometric conditions used for the tests were diurnal cycles of 96 °F maximum dry-bulb temperature, 80 °F minimum dry-bulb temperature, and 79.8 °F average dewpoint temperature. The simulated April psychrometric conditions used for the test were diurnal cycles of 76 °F maximum dry-bulb temperature, 61 °F minimum dry-bulb temperature, and 59.5 °F average dewpoint temperature.

4.3. The Broyles shelter [4].

The Broyles Shelter, at Gainesville, Fla., was so constructed that a portion of the shelter was below grade, and 3 feet of earth was mounded around the above-grade portion. The interior of the shelter had a ceiling height of 7.33 feet, and the floor area measured 16 by 7.75 feet, for a total area of 124 square feet. The floor, placed on a plastic membrane, was of waterproof concrete reinforced with 1/2-inch steel rods on 12-inch centers. The walls were hollow concrete blocks with conventional mortar joints, and the cavities were filled with waterproof cement as the walls were constructed. The roof was a concrete slab reinforced with 3/8-inch

steel rods on 12-inch centers. The concrete was treated with a water-proofing material at the time it was mixed. This shelter was shaded by surrounding trees, and a heavy layer of sod and green grass covered it and the surrounding ground. The surrounding earth was a mixture of sand and loam, whose dry density ranged from 95 lb/ft³ to 104 lb/ft³, and moisture content from 1 percent to 12.5 percent.

For most of the thermal environment test period, 12 SIMOC's (ref. 3) of NBS 400 Btu/hr type were employed. The ventilation air was processed outside the shelter to simulate diurnal cyclic conditions of 96 °F maximum dry-bulb temperature, 80 °F minimum dry-bulb temperature, and 70 °F average dew-point temperature, and was forced into the shelter by a fan through an air supply duct that was laid along the inside surface of the longitudinal shelter wall, and which had four equally spaced outlets. The shelter air was exhausted through two outlets located at opposite ends of the shelter.

In addition to the regular psychrometric measurements of inlet ventilation air, shelter exhaust air, and shelter air at the geometrical center, several measurements were made of the shelter inner wall surface temperature and surrounding earth temperature.

The shelter was tested in four successive phases:

Phase 1: A ventilation rate of 3 cfm per person was supplied, and a fan-and-coil unit simultaneously cooled the recirculated air by 4 gpm of well water at an inlet water temperature of 71.5 °F. During the first two days, sensible and latent heat was removed from the shelter by this fan-and-coil unit at a rate of 6440 Btu/hr. This cooling capacity exceeded the total heat supplied to the SIMOC's by 4800 Btu/hr.

Phase 2. The well-water coil was cut off and 10 cfm per person of ventilation air was supplied for a period of 12 days.

Phases 3 and 4. These two phases were operated under the same conditions as phase 2, except that the ventilation rate in phase 3 was 6 cfm per person (for 48 hours) and in phase 4 was 3 cfm per person (for 48 hours).

4.4. Napier shelter [4].

The Napier shelter was a 100-occupant community shelter designed for a group of residents in a subdivision adjoining the city of Gainesville, Fla. The floor level was 5 feet below grade and 30 inches of earth covered the roof. The floor slab was wire-mesh reinforced, 4-inch-thick concrete poured over a waterproof plastic membrane. The walls were of 8-inch-thick hollow concrete blocks, whose cavities had reinforcing rods placed vertically through them at selected intervals and were then filled with concrete. Outside dimensions were 20 feet wide and 85 feet long. The interior floor area was 1561 square feet. Reinforced prestressed concrete T-beams placed on top of the shelter walls, each in contact with the beams parallel to it, formed its roof. The surrounding earth was mostly clay, whose dry density varied from 76 lb/ft³ to 109 lb/ft³, while the moisture content ranged from 3.4 percent to 34.2 percent (dry weight basis). The earth surface over the shelter was bare with several patches of weeds.

For this test, 100 SIMOC's (ref. 3) of NBS 400 Btu/hr type were employed. The ventilation air was conditioned in the equipment trailer outside the shelter to represent a diurnal cycle of a Florida summer: 96 °F maximum dry-bulb temperature, 80 °F minimum dry-bulb temperature,

and 73 °F average dewpoint temperature. It was forced into the shelter at two stations at the ceiling level in the south wall, approximately 8 feet from the southwest and southeast corners of the shelter. The ventilation air was discharged in the direction of the north wall; and after passing through the main chamber was exhausted through the entry doorway and entry chamber. Regular psychrometric measurements were made of shelter air, ventilation air, and exhaust air. In order to study the three-dimensional earth temperature profile during the simulated occupancy period of the shelter, numerous measurements of earth temperature were made around the northwest and southwest corner regions.

The test was conducted in six phases:

Phase 1. Ventilation rate was maintained at 3 cfm per person for 48 hours, during which a well-water coil using 12 gpm of 72.2 °F water was in operation. The measured total cooling capacity of the well-water coil during the phase averaged 20,700 Btu/hr, amounting to 51.6 percent of the total heat released by SIMOC's.

Phase 2. Ventilation air rate was increased to 6 cfm per person and the well water coil was shut off for this period of 97 hours.

Phase 3. With all other conditions being identical with those of phase 2, 30 NBS SIMOC's were replaced by one MASS SIMOC of MRD [4] for 42 hours. (One MASS SIMOC has an adjustable output from 1-40 SIMOC's of NBS 400 Btu/hr type.)

Phase 4. The MASS SIMOC was replaced by 30 NBS SIMOC's for 51 hours.

Phase 5. Ventilation air rate was increased to 8.05 cfm per person with 100 NBS SIMOC's for 116 hours.

Phase 6. The total ventilation rate remained at 805 cfm and 100 NBS SIMOC's were used together with 1 MASS SIMOC for 36 hours, representing a total of 140 occupants.

4.5. Reading shelter [4].

This was a community shelter located in a park owned by the city of Reading, Pa. It was constructed in a hillside to take advantage of a thick earth cover, and was basically a rectangular parallelepiped 56 feet long, 17 feet 4 inches wide, with a ceiling height of 7 feet 8 inches. The ends of the shelter were connected to separate tunnel-like entry corridors so that two right angle turns were formed in each of these passageways. The floor was 4 feet 6 inches below the grade level that existed prior to construction, and the roof and all sides had a minimum earth covering of 30 inches. All bearing walls, the roof, and the floor were constructed of concrete reinforced with steel bars. Waterproofing was applied to the external surfaces of the shelter during construction. There were many internal partition walls constructed of hollow concrete blocks with mortar filled voids, for rooms of various purposes, such as storage, first aid, mechanical equipment, and lavatory. The surrounding earth was sandy loam of dry density between 89 lb/ft³ and 121 lb/ft³, and moisture content between 10 percent and 22 percent (dry weight basis). The earth surface at the time of testing was grass under snow. Ventilation air artificially created in an equipment trailer outside the shelter was carried to the shelter through a duct connected to a stack that under normal shelter operation would be utilized as an exhaust stack. A temporary distribution duct for ventilation air supply was installed at the ceiling level along the west wall of the shelter.

Three air outlets were installed in the temporary duct at equally spaced intervals. The air was exhausted through a stack located in the center of the ceiling of the equipment room, which was almost longitudinally at the opposite end from the air supply duct.

The ventilation air conditions used for this test varied considerably; however, the dry-bulb temperature was generally maintained between 32 and 40 °F, with an average dewpoint temperature of 30 °F. The simulated occupants used were two MASS SIMOC's (ref 4), which were capable of producing sensible and latent metabolic heat equivalent to 120 sedentary adults.

Psychrometric observation stations were located at the ventilation air inlet, geometric center of the shelter, and exhaust air outlet. Thermocouples were used to measure interior surface temperatures and several ground temperatures extending downward 45 inches distance from the top of the floor slab and horizontally from the outside surface of the west wall. The roof region ground temperature was also measured at several distances from the outside surface.

The test was divided into seven phases, described as follows:

Phase 1. Ventilation at the rate of 150 cfm was supplied to the shelter in the manner described previously, and the two MASS SIMOC's were adjusted to deliver heat and moisture equivalent to a total of 50 sedentary adults. This phase continued from February 26 to March 4, 1963.

Phase 2. Ventilation rate was then decreased to 75 cfm, or 1.5 cfm per person, with operating conditions identical to those of phase 1. This phase lasted approximately 5 days.

Phase 3. The mass SIMOC's were readjusted to produce total equivalent metabolic heat for 100 occupants. The total ventilation air rate was 150 cfm during this phase of study, lasting three days.

Phase 4. During the three-day period that followed phase 3, from March 12 to 14, shelter occupancy was 50 simulated occupants. The ventilation air at a rate of 831 cfm was supplied by the blower that originally had been installed in the shelter as a part of the permanent facilities. The shelter's own air handling systems provided the distribution and exhaust of the shelter air. The purpose of this phase of the test was to determine if the original equipment for supplying air, and the air distribution and venting systems were adequate.

Phase 5. During this phase, ventilation air at the rate of 718 cfm was supplied for 50 simulated occupants. The air distribution and exhaust systems were changed during this phase, details of which are not important for the purpose of this report.

Phases 6 & 7. These phases were conducted for sealed-up conditions without ventilation for 50 simulated occupants for 24 hours, and 100 simulated occupants for 58 hours, respectively.

4.6. Ft. Belvoir 200-man shelter.

This was an experimental 200-man shelter designed and built by the Protective Structures Development Center at Ft. Belvoir, Va. It was a two-story reinforced concrete structure with one story below ground level. Because the building had been occupied by personnel of the Protective Structures Development Center prior to the environmental testing, the temperature and humidity had been comfort conditioned. Only the basement area was used for the shelter environment test, while the upper

floor area was heated to simulate an adiabatic roof condition. The shelter walls were 10 inches thick, the floor slab 6 inches thick, and the ceiling-floor slab 8 inches thick. There was a 12-inch-thick fill of gravel between the external surface of concrete of the basement and the earth on all sides, except the north end. The earth around the shelter was a mixture of sand and clay, its dry density varying from 85 lb/ft³ to 120 lb/ft³ and its moisture content from 9 percent to 23 percent (dry weight basis). The earth surface was composed of sod on all sides of the shelter, except for a portion of the north end where a bituminous concrete driveway was located. Interior dimensions were 37 feet 2 inches by 37 feet 2 inches, with a ceiling height of 9 feet 6 inches. Excluding a first aid room and stairwell, a net usable floor area of 1032 square feet was available for 100 simulated occupants. There were two family-type basement shelters that were built for display purposes in the test room, one of sand-filled concrete block walls and the other a triangular-shaped wooden lean-to filled with sand and sand bags. They may have had a considerable effect in absorbing heat during the first few days of the environmental test.

The temperature- and humidity-controlled ventilation air (dry-bulb cycles 93 °F ~ 76 °F and wet-bulb 78 °F ~ 74 °F were in phase with maximum at 2 p.m. and minimum at 4 a.m.) was produced in the equipment trailer parked outside the shelter and introduced into the shelter from ceiling level near the center of the occupied space. The exhaust outlet was also in the ceiling, approximately 12 feet from the air inlet. The thermal environment of the lower shelter space was measured with 100 SIMOC's of the NBS type (ref. 3).

The test was conducted in five phases, in which the ventilation air rates were 3 cfm per person for the first phase (6 days), 6 cfm per person for the second phase (2 days), 9 cfm per person for the third phase (3 days), 18 cfm per person for the fourth phase (2 days), and 27 cfm per person for the fifth phase (4½ days).

Psychrometric measurements were made at the ventilation air inlet, air exhaust, east geometric center, and west geometric center of the shelter. Temperature measurements were obtained of various inner surfaces, together with surrounding earth temperatures to a distance of 4 feet from the external surface of the concrete structure.

4.7. Ft. Belvoir 1000-man shelter.

This shelter was built by the Protective Structures Development Center at Ft. Belvoir, Va. It was a two-story reinforced concrete building with one story below ground level. Prior to testing the building had been occupied by personnel of the Protective Structures Development Center, and its thermal environment had been controlled at a comfort air condition by a central heating and cooling plant. Only the basement area was used for test, while the upper floor level was heated to simulate an adiabatic roof condition. The usable floor area of the basement was 5400 ft² and was given a simulated occupancy of 11 MASS SIMOC's (ref. 4). The shelter walls were 10 inches thick, the floor 6 inches thick, and the ceiling-floor slab 8½ inches thick. The interior dimensions were 74 feet 4 inches by 74 feet 4 inches, with a ceiling height of 9 feet 6 inches. The surrounding earth was sandy clay and ranged in moisture content from 10 to 20 percent (dry weight basis), and in dry density from 86 lb/ft³ to 104 lb/ft³ depending upon the depth, as well as upon

the location around the shelter. During the backfilling and mounding operations, a 12-inch-thick fill of gravel was placed adjacent to all the basement walls.

The ventilation air was conditioned by the equipment trailer to yield a local design diurnal cycle of dry-bulb temperature, 94 °F maximum, 76 °F minimum, and wet-bulb temperature, 78 °F maximum, 74 °F minimum. The maximum and minimum conditions of dry- and wet-bulb temperatures were both at 2 p.m. and 4 a.m., respectively. The ventilation air inlet and exhaust air outlet were both near a corner of the space and separated from each other by approximately 12 feet for most of the test period.

The test was divided into four major phases, excluding an initial short period of purging. Phase 1 was a sealed-up-condition test of approximately 8 hours without ventilation, whereas the ventilation rates for remaining phases were varied from 16.8 cfm per person for $3\frac{1}{2}$ days, to 5 cfm per person for 1 day. The shelter thermal environment was measured by dry- and wet-bulb thermometers at the exhaust duct, the northeast area, the southwest area, and the geometric center of the shelter, and numerous thermocouple temperature readings were taken for many parts of the wall surface and the earth region extending outward normally to the walls and floor to a distance of 4 feet from the exterior surfaces.

5. SHELTER CALCULATIONS

As discussed in section 2 of this report, the calculated shelter thermal environment is affected by several parameters, such as thermal conductivity and thermal diffusivity of surrounding walls and earth,

and heat transfer coefficients along the inner surfaces of the shelter and the ground surface. Based upon the characteristics of prototype shelters and their test conditions described in the previous section, table 1 is prepared to summarize the parameters used for the shelter calculations. However, many of the heat transfer parameters selected for the computation cannot be too precise. The following considerations were given for assigning numerical values to the parameters listed in table 1.

5.1. Physical dimensions (size and heat transfer area).

The size of the shelter is expressed in the overall internal dimensions, which are the overall external dimensions less the thickness of walls, ceiling, and floor. The heat transfer area used for the computation was calculated from the internal dimension only, thus ignoring the complex pattern of partitioning and, consequently, the heat absorption by partition walls or columns.

5.2. Simulated occupants.

The simulated occupants (SIMOC's) used for the experiment were designed to simulate the heat output of human bodies and each generated a total heat of 400 Btu/hr, regardless of temperature. The sensible heat component was regulated according to the shelter air temperature in the manner described in section 2. The number of active SIMOC's was varied during some tests (Napier and Reading shelters) by turning the power off and on to a part of them. For this reason, the area per person data shown in Table 1 for these tests are not constant.

In order to simulate the change in number of SIMOC's during some of the tests, the NBS computer program was constructed to take the number of occupants as a time variable instead of a constant.

Table 1. UNDERGROUND FALLOUT SHELTER CALCULATIONS

Tented Shelters	FBI Shelter, Washington, D. C.					Summary of Results As of February 1965					Reading, Pa.	Ft. Belvoir, Virginia 200-mu	Ft. Belvoir, Virginia 1000-900
	1	2	3	4	5	Summerlin, Fla.	Boyles, Fla.	Mapler, Fla.	55x16x7.66	37.17x17.17x9.5			
400 Btu equiv. SHROUSE	0	6	6	6	6	18	12	100 ~ 140	50 ~ 100	100	540		
Floor Area	14.3					10.3	10.7	15.6 ~ 11.1	17.6 ~ 8.8	13.8	10.2		
Floor/Floor													
Total Surface	65					65	50	46.8 ~ 33.4	57 ~ 28.5	43.8	25.7		
Ventilation (Total)	65					65	50	46.8 ~ 33.4	57 ~ 28.5	43.8	25.7		
Soil Type	Loam-Clay					Loam-Clay	1 ~ 10 Sand	2 ~ 8.4 Clay	1.5 ~ 3 Clay	3 ~ 27 Sand-Clay	5 ~ 16.7 Sand		
Density: lb/ft ³	92 ~ 115					103 ~ 128	99 ~ 104	76 ~ 109	89 ~ 122	90 ~ 110	86 ~ 104		
Water Cont.:	16 ~ 21					10 ~ 20	1 ~ 12	34 ~ 34	10 ~ 22	10 ~ 24	10 ~ 21		
Average Outdoor Temp. °F	80	87	78-85	55	55	82	85	82	6 ~ 40	60	85		
Initial Earth Temp. °F	70	68	67	65	65	61	63	60	36	74 ~ 68	72 ~ 69		
Ventilation Air	80	82	82	44	44	87	86	67	32 ~ 40	93 ~ 78	93 ~ 78		
Avg. RH, %	68	68	68	33	33	72	70	73	30	73	70		
Parameters:	0.026	0.026	0.022	0.022	0.030	0.022	0.029	0.025	0.022	0.02	0.02		
h _w Btu/hr, ft ²	0.75	0.75	0.75	0.75	0.75	0.75	0.65	0.75	0.75	0.75	0.75		
h _c Btu/hr, ft ²	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45		
h _f Btu/hr, ft ²	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6		
h _g Btu/hr, ft ²	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.43	1.5	1.5		
h _t Btu/hr, ft ²	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.37	0.5	0.5		
Computer	1	1	1.6	1.6	1.6	2.6	2.6	2	2.6	4	4		

/ α = Thermal diffusivity of soil
 k = Thermal conductivity of soil
 h_w = Wall surface heat transfer coefficient
 h_c = Ceiling surface heat transfer coefficient
 h_f = Floor surface heat transfer coefficient
 h_g = Floor surface heat transfer coefficient
 h_t = Approximate average for the test period

5.3. Ventilation air.

Observed hourly data on dry-bulb and dewpoint temperatures or dry-bulb and wet-bulb temperatures of the supply air duct were used as the input data, either in the 2-hour step or the 4-hour step calculations. Since the University of Florida varied the ventilation air rate during their tests, the computer program was designed to accept the ventilation rate as time dependent input data. These variations of the number of SIMOC's and ventilation rates during the tests are the reason that the per capita ventilation rate indicated in table 1 was not a constant for some of the tests.

The ventilation air temperature and humidity conditions were varied with respect to time, closely following a prescribed diurnal cyclic pattern in most cases. The entries in table 1 show approximate ranges of the temperature levels employed during the test, whereas actual hourly values were used in the calculations.

5.4. Thermal properties of earth and wall.

For all of the prototype shelters, soil samples were taken from several representative spots around the shelter at selected depths and were analyzed with respect to soil classification, dry density, and water content (dry weight basis); their typical characteristics are shown in table 1. The thermal conductivities and diffusivities of various types of soils are usually presented as functions of moisture content [5,6]. Such charts were consulted in arriving at the values of thermal conductivity, k , and thermal diffusivity, α , in table 1.

For the NBS shelter, the thermal diffusivity value of $0.026 \text{ ft}^2/\text{hr}$. for tests 1 and 2 was estimated from a phase angle shift of the earth temperature cycles at two different depths. The diffusivity values of

0.022 ft²/hr for tests 3 and 4, and 0.03 ft²/hr for test 5 were evaluated by a numerical technique similar to that reported by Beck [7]. The method is basically a reversed use of finite difference solutions of the heat conduction equation for a semi-infinite solid. For the case of composite wall models, the thermal diffusivity and conductivity of concrete were assumed as 0.036 ft²/hr and 1.1 Btu/hr ft² (deg F/ft), respectively.

5.5. Surface Heat Transfer Coefficients.

The surface heat transfer coefficient consists of a radiative portion and a convective portion. For the heat transfer at the interior shelter surfaces, the radiation portion plays a predominant role, since the air velocity over the shelter inner surface usually is very small. In addition, the surface heat transfer coefficient along any one of the vertical walls at a given time would vary considerably from the bottom to the top, due to the varying nature of layer pattern, as well as that of the radiation heat exchange geometry and air velocity, and also because of the difference in local temperature distribution. However, it is probable that the local variation of the surface heat transfer coefficient along a given surface may be of the same order of magnitude as the convective heat transfer coefficient itself. Several attempts were made during this study to obtain the surface heat transfer coefficients for the experimental observations of the shelter wall heat conduction. Since the NBS test shelter was equipped with a heat flow meter at the geometric center of each of all the inner surfaces, and since the inner surface temperatures and shelter air temperatures were simultaneously measured, it was possible to calculate the heat transfer coefficients. However, the accuracy of this procedure is questionable, because (a) the heat flow meter reading

at the geometric center of an inner surface did not necessarily yield an average heat transfer coefficient for the entire surface, because of the local variation of heat flow, and (b) where condensation of shelter air moisture was taking place simultaneously, the heat flow meter would read the total heat flux, which is not proportional to the temperature difference between the surface and air. In fact, these difficulties were realized in the NBS shelter, since the ratio agreement between the shelter total heat conduction estimated by the heat balance, and the heat conduction based upon the heat flow meter ranged from 52 percent to 108 percent in various tests [2].

Nevertheless, the values of heat transfer coefficients listed for the NBS shelter tests 1, 2, 3, and 4, and the Summerlin shelter test were estimated from the test 3 data of the heat flow meter readings, adjusted by the vapor transfer due to the difference of air humidity ratio between the air and the wet surface, and the Lewis relation of heat and mass transfer.

A low value for the floor coefficient was observed. This result was to be expected since the floor surface was typically colder than the air immediately above it and the downward convection heat transfer rate would be very low under these conditions. Moreover the effective heat transfer area of the floor was considerably reduced by the presence of simulated occupants. The same values for the surface coefficient were applied to the test 5 condition of the NBS shelter, but the agreement between the observed and calculated inner surface temperatures was rather poor when this low value of the surface coefficient was used.

Several other combinations of the surface heat transfer coefficients for NBS test 5 were tried and the results are summarized in table 2, which will be elaborated later in this section. For the many other prototype shelters, heat flow meter readings were not included, or were not usable, so that the detailed heat transfer analysis on the surface by surface basis was discarded. However, the average heat transfer coefficients for the entire inner surface were obtained from the sensible heat balance calculation for the Summerlin shelter during the moderate weather condition test, the NBS test 3, the NBS test 5, the Ft. Belvior 1000-man shelter, and the Napier shelter.

As indicated in figures 3 and 4, the result of this analysis on the overall sensible inner surface heat transfer coefficient shows a greatly fluctuating pattern. The accuracy of the calculated values of the surface heat transfer coefficient is inherently related to the accuracy of measuring air and surface temperatures. Since radiation would usually be present and wetted surfaces are sometimes involved, the error in temperature measurement could easily be a significant part of the observed temperature difference for differences of 2 °F or less. A significant trend can be observed, however, from Figure 3 and 4 that the overall inner surface sensible heat transfer coefficient seems to increase as the temperature difference between the air and inner surface decreases. The majority of the sensible heat transfer coefficients are in the neighborhood of 1.0, except for the Napier shelter. Nevertheless, the inner surface heat transfer coefficients selected for the Proyles and Napier shelters of table 1 are somewhat arbitrary, whereas those given to the Reading and Ft. Belvior shelters are estimated from ref. 8, which was not available prior to the last three shelter calculations. The possible effects of the various

Table 2. EFFECT OF INNER SURFACE HEAT CONDUCTANCE
FOR NBS SHELTER TEST 5

Inner Surface Conductance	t_{wall}		t_{roof}		t_{floor}		t_{air}		R.H.		WG		
	h_w	h_R	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.			
7 days	2.0	1.0	55.0	54.23	56.6	55.82	54.5	55.21	58.8	56.97	90.0	77.61	0.
	2.0	1.0		55.28		56.60		56.06		58.01		75.12	0.
	1.0	1.5		55.74		58.23		56.87		60.38		72.28	0.
	1.0	1.5		56.45		58.79		56.46		61.22		85.89	0.
	1.0	1.0		55.79		57.96		57.43		60.38		72.27	0.
	2.5	1.0		54.06		55.49		54.78		56.36		79.32	0.
	2.5	1.0		56.54		58.97		56.78		58.76		74.22	1.0
	1.21	1.43		55.99		58.16		56.04		60.23		72.45	0.
	1.0	1.5	✓	56.62		59.03		55.94		61.55		85.43	0.
	14 days	2.0	1.0	59.0	55.69	59.8	55.18	57.3	56.75	62.3	58.22	88.5	76.27
2.0		1.0		56.61		55.87		57.56		59.13		75.10	0.
1.0		1.5		57.21		57.81		58.46		61.35		72.34	0.
1.0		1.5		57.47		58.15		57.87		61.81		71.78	0.
1.0		1.0		57.29		57.23		58.98		61.48		72.19	0.
2.5		1.0		55.41		54.78		56.29		57.58		77.05	0.
2.5		1.0		58.67		59.71		58.91		60.73		73.11	1.0
1.21		1.43		57.33		57.64		57.68		61.13		72.62	0.
1.0		1.5	✓	57.64		58.37		57.33		62.09		71.43	0.

Thermal Conductivity $k = 0.75$ Btu/hr, ft. °F, thermal diffusivity $\alpha = 0.03$ ft²/hr
 Earth Surface Heat Transfer Coefficient, $h_G = 5.0$ Btu/hr ft² °F
 Lewis Relation = 1

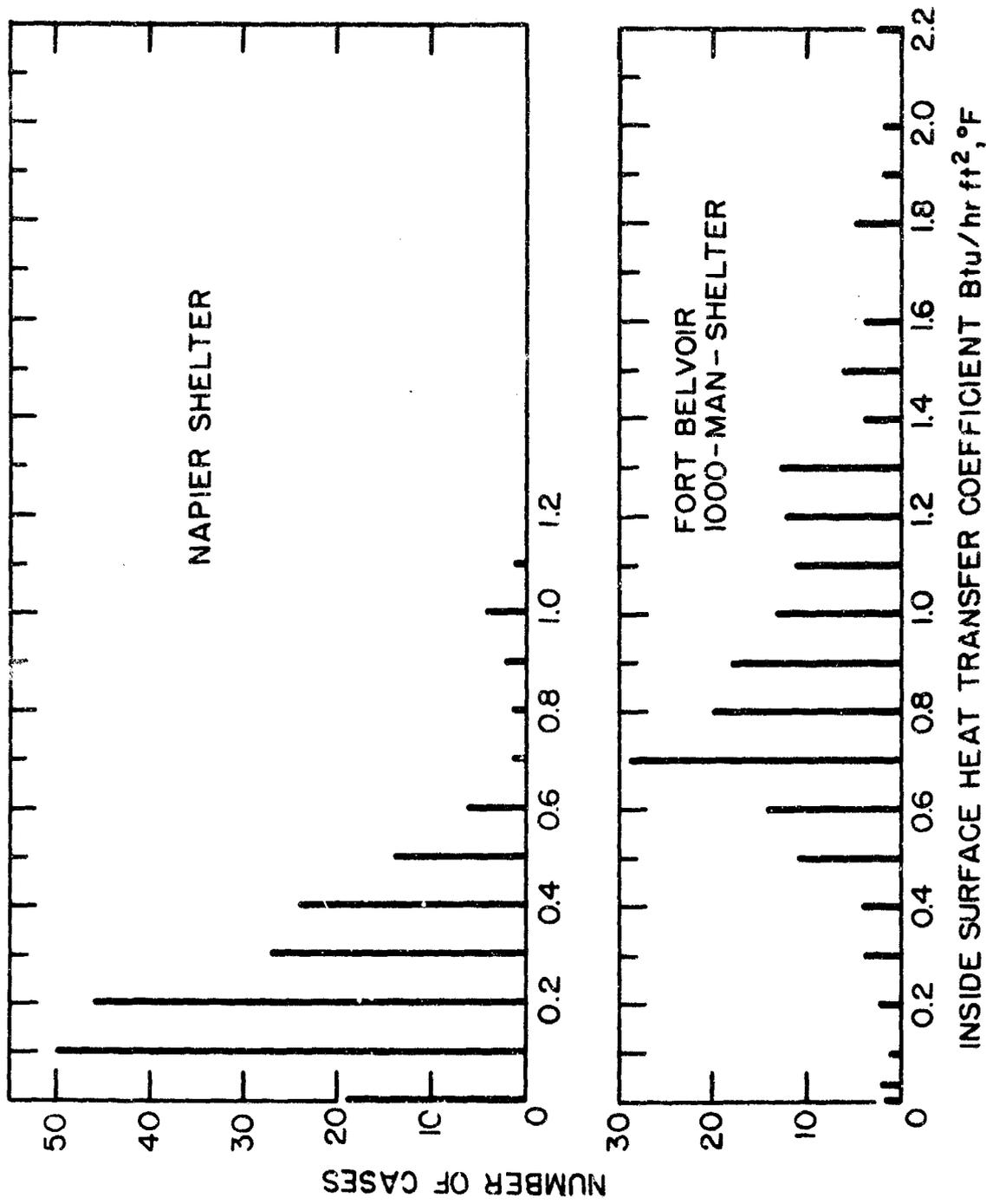


Figure 3. Inner surface heat transfer coefficient frequency distribut.

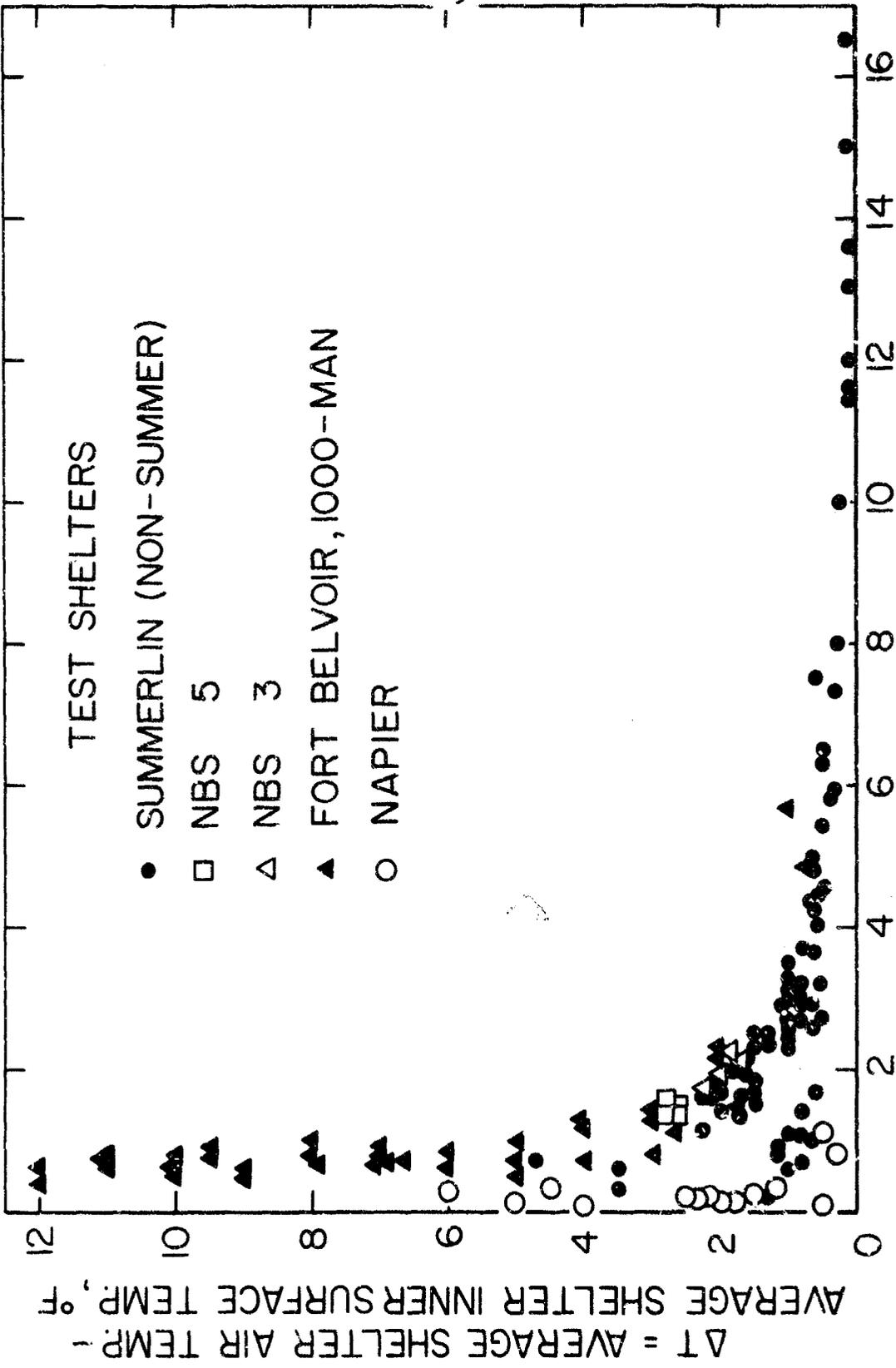


Figure 4. Inner surface heat transfer coefficient vs. temperature difference between the air and inner surface of the shelter.

surface heat transfer coefficients upon calculations of the shelter thermal environment can be seen in table 2, which illustrates a result of sensitivity analyses of inner surface heat transfer coefficients using computer program M-(2) on the NBS shelter.

In table 2, the calculated shelter surface temperatures, shelter air temperatures, and shelter air relative humidities are compared with the observed data at the end of the seventh and fourteenth day on test 5 of the NBS shelter. The symbol WG in table 2 is zero when solar heat input to the ground surface above the shelter is ignored, while it is one when the entire solar heat effect is assumed absorbed by the ground surface. If they are compared at an identical condition, the calculated shelter air temperature at the fourteenth day became approximately 3 °F higher when solar heat input was considered than when it was ignored.

For the fourteenth day results, the interior surface temperature agreement between the observed and calculated is better with rather high values of surface conductances, while better air temperature agreement is obtained with relatively low values of surface conductance. The combination of $h_w = 1.21$, $h_R = 1.4^2$, and $h_F = 0.57$ is obtained from reference [10] on the basis that the simulated occupants obstruct each wall from seeing each other. As far as the shelter air temperature is concerned, a combination of $h_w = 1.0$, $h_R = 1.5$, and $h_F = 0.3$ yielded the best agreement, which was also true for NBS tests 3 and 4.

5.6. Outdoor conditions.

Outdoor air conditions during the prototype shelter test periods were not the same as the ventilation air conditions, as would usually be the case for actual non-air-conditioned shelters. The ventilation air conditions were selected and programmed according to certain climactic criteria to simulate typical operating conditions of a shelter, regardless of the actual climatic condition during the test period.

The outdoor air temperatures used for the calculations in this report were recorded separately during the test, averages of which are shown in table 1.

The NBS tests included observations of solar energy at the shelter roof surface, but the tests conducted by the University of Florida did not have these data. Therefore, the inclusion of solar energy data for the shelters tested by the University of Florida was accomplished by using data supplied by Flanigan [11].

5.7. Initial earth temperature.

As described in section 3, the computer model M-(1) incorporated an earth temperature distribution normal to the surface in the six surrounding blocks. The NBS test shelter included these observations and they were used for the M-(1) calculation of this shelter. The M-(2) calculation provided for only a vertical or depthwise distribution of initial earth temperature. The observed data on roof region temperatures, average of the wall regions, and observed distribution of floor region were used to arrive at a depthwise distribution of the earth temperature. Average earth temperatures of the wall, roof, and floor regions were used for the calculations employing M-(3) and M-(4) models. Table 1 shows the overall average values of initial earth temperature which were used for the calculations in these latter two models.

5.8. Comparison between the computed and observed shelter thermal environments

Figures 5 through 25 represent some of the results obtained by computer analysis of thermal environment, together with the observed data. Figures 5, 6, 7, and 8 compare the calculated shelter thermal environments with the observed data for tests 1, 2, and 3 on the NBS

AIR PROPERTIES INSIDE UNDERGROUND SHELTER
42 CFM VENTILATING AIR - NO OCCUPANTS
TEST NO.1

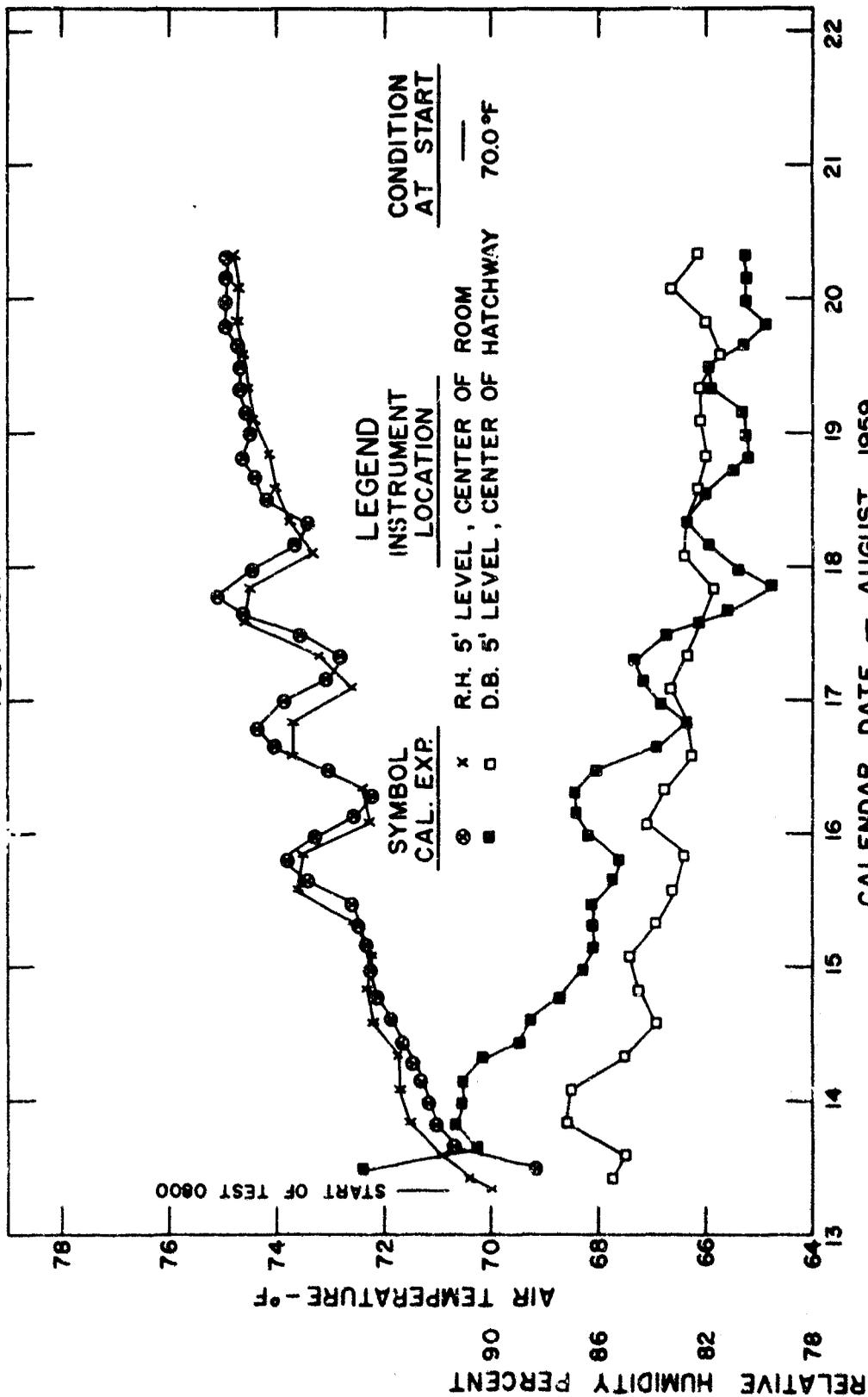
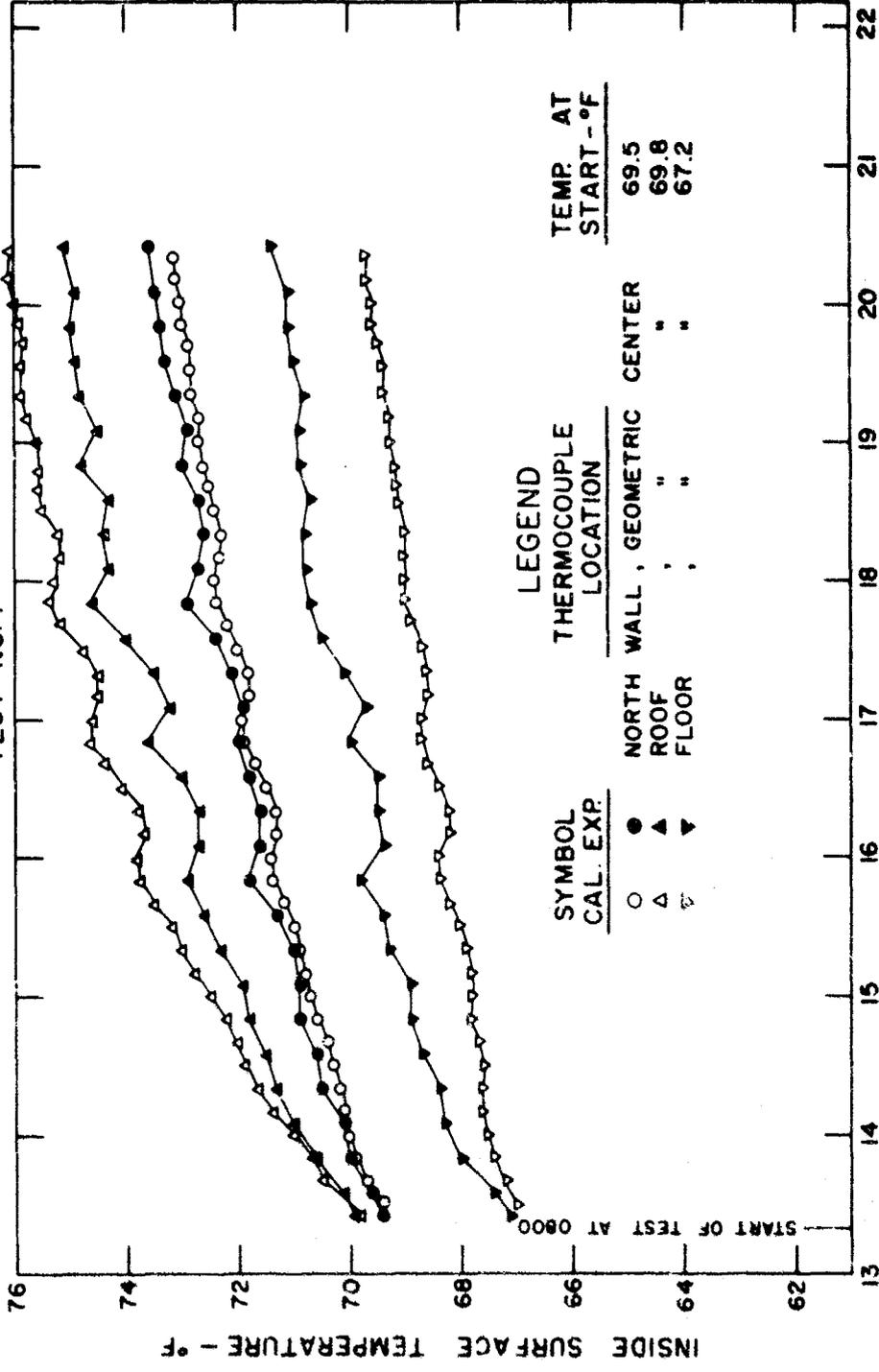


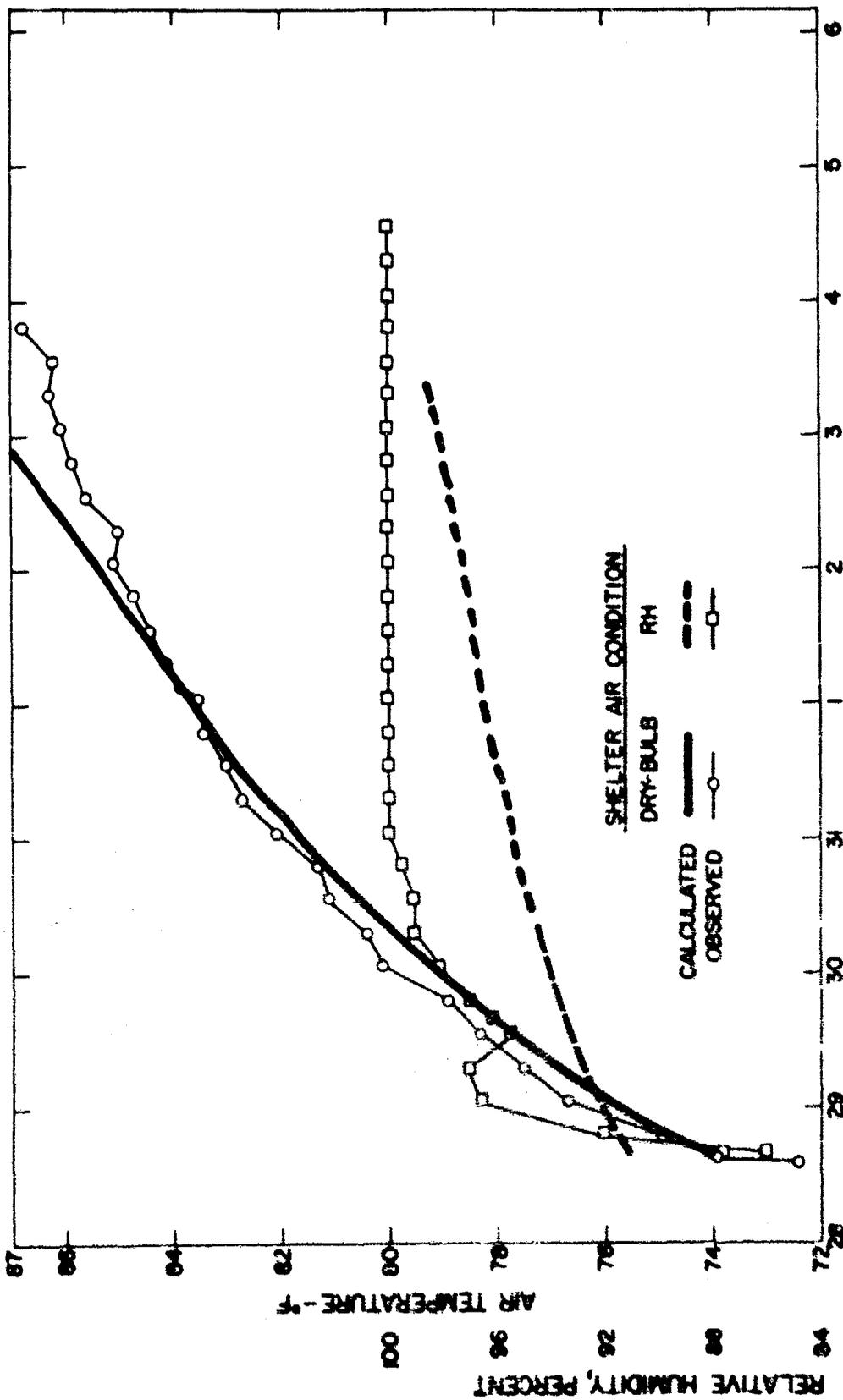
Fig. 5 Comparison of the calculated and observed shelter air temperatures and relative humidity of test 1 for NBS family shelter (computer program M-(1)).

INSIDE SURFACE TEMPERATURES OF UNDERGROUND SHELTER
 42 CUBIC FEET PER MINUTE VENTILATING AIR - NO OCCUPANTS
 TEST NO. 1



CALENDAR DATE - AUGUST, 1959

Fig. 6 Comparison of the calculated and observed shelter inner surface temperatures for test 1 of NBS family shelter (computer program X-(1)).



CALENDAR DATE, AUGUST AND SEPTEMBER, 1959

Fig. 7 Comparison of the calculated and observed shelter air temperatures and relative humidities for test 2 of NBS family shelter (computer program M-(1)).

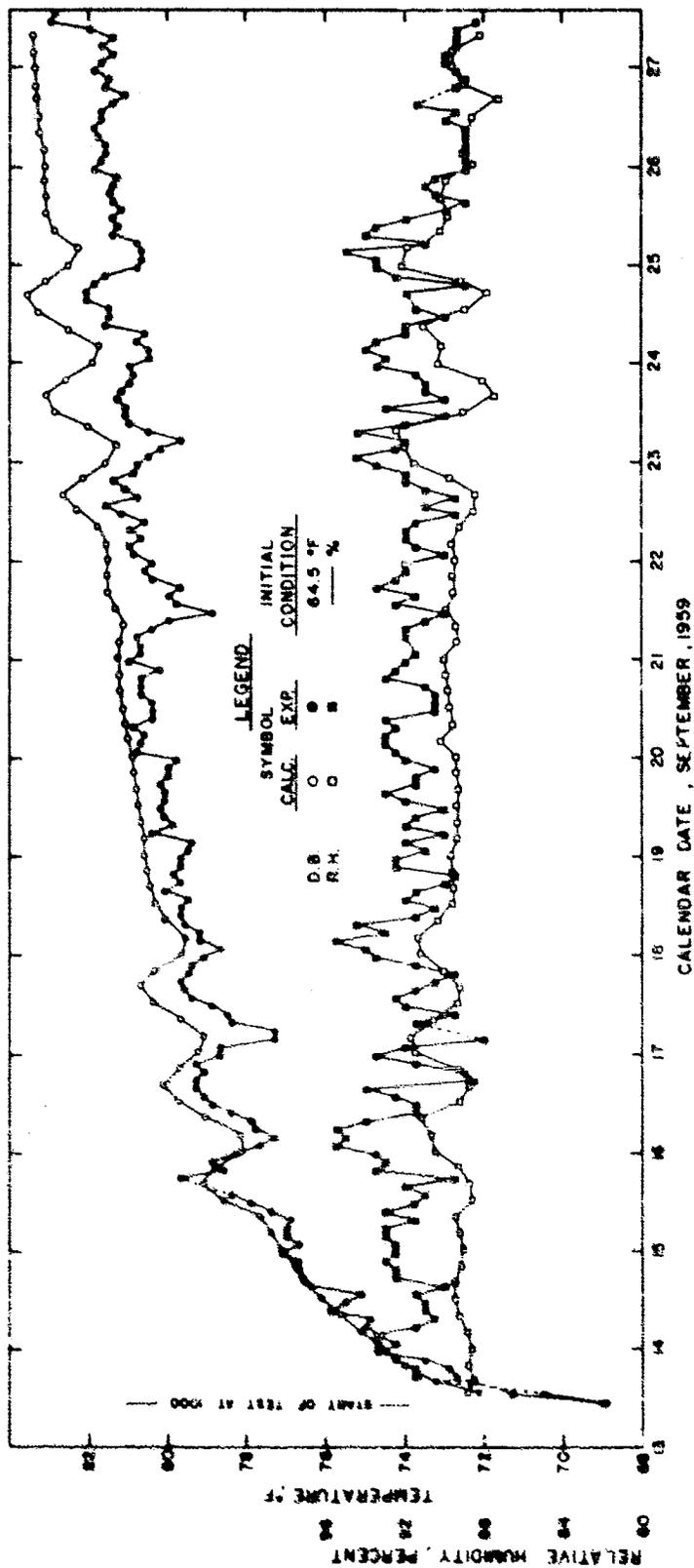


Fig. 8 Comparison of the calculated and observed shelter air temperatures and relative humidity for test 3 of NBS family shelter (computer program M-(1)).

family shelter. The M-(1) computer program was used for these comparisons. Computed shelter air temperatures agreed with the observed within approximately 2 °F for the entire period of shelter occupancy. Agreement between computed and observed relative humidities was good for tests 1 and 3, and somewhat poorer for test 2 using the M-(1) program. Figure 7 represents a sealed-up condition with 6 occupants, as indicated in table 1. A very good agreement in calculated and observed air temperature for the first 4-day period is shown in figure 7. However, the calculated relative humidity was as much as 6 percent lower than the observed during the second day of test, and did not quite attain the saturated condition that was observed during the test, even after 48 hours of sealed-up condition.

Figures 9, 10, and 11 compare temperatures and humidities obtained by computer program M-(2) with the observed conditions for NBS shelter tests 3, 4, and 5. Figures 8 and 9, both for test 3 condition, show that computer program M-(1), the temperature-block model, results in better agreement with the observed shelter temperatures for the first two days than that by program M-(2), the homogeneous-earth model. This was expected, because program M-(1), as explained before, is considerably more elaborate in accounting for a complex nature of initial earth temperature distribution around the shelter than program M-(2), and also takes into account the differences in thermal properties of the concrete and the earth.

A. However, the agreement between the calculated and observed air temperature at the 5-foot level in the shelter was somewhat better using the M-(2) program than the M-(1) program during the last 4 or 5 days of test 3.

The agreement of the computed shelter air temperature with the observed condition for test 4 of the NBS shelter became poorer toward the end of the test. The lowering of the computed shelter temperature during the second week of the test was caused primarily by a decrease in outdoor temperature. This temperature decrease averaged approximately 15 degrees, beginning on October 12 and continuing to the end of the test period. The detailed report [3] on these tests indicates a steady and significant decline of earth temperature during this period. The curves on figure 10 shows that the observed shelter air temperature was not affected as significantly by this cool spell as the computer model indicated that it would be.

The sudden and irregular drop of the calculated relative humidity for the NBS test 5 condition shown in figure 11 is not reflected by the observed data. It is probable that the relative humidity in the shelter was sustained at a high level by drying of the shelter walls. The moisture balance between the supply and exhaust air indicated that this evaporation amounted to approximately 2 to 2.5 lb/day during this winter test condition where extremely dry ventilation air was employed. As indicated earlier, the computer program developed for this analysis had no provision for taking this drying process into consideration. Table 2 indicates that the calculated air temperature at the end of 14 days in the NBS test shelter test 5 condition is in better agreement with the observed value when solar heat effect was not included for the ground surface heat exchange than when it was included. The ground surface was quite wet during this test period because of a snow prior to the test. This implies that during this particular test period the solar heat was mostly absorbed by evaporation of water on or near the earth's surface

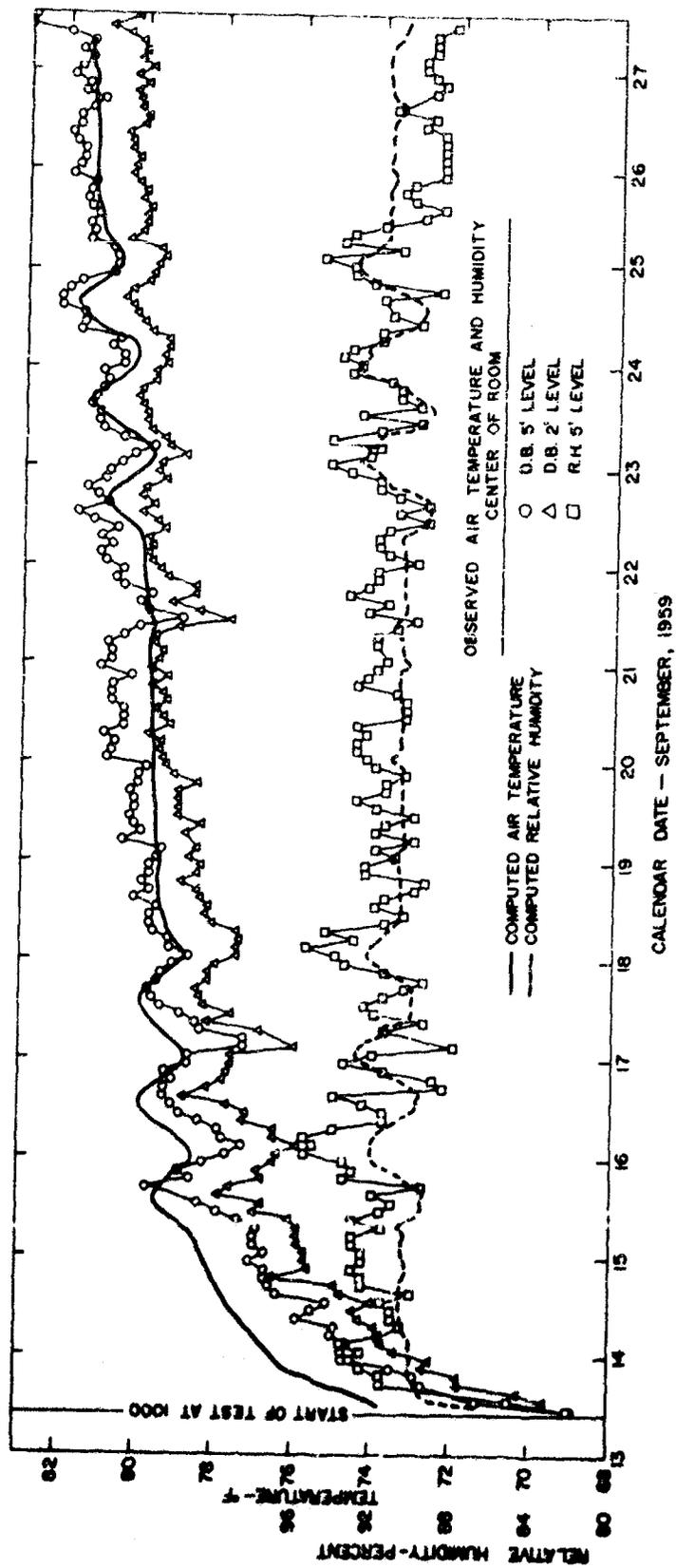


Fig. 9 Same as Fig. 8 but using computer program M-(2).

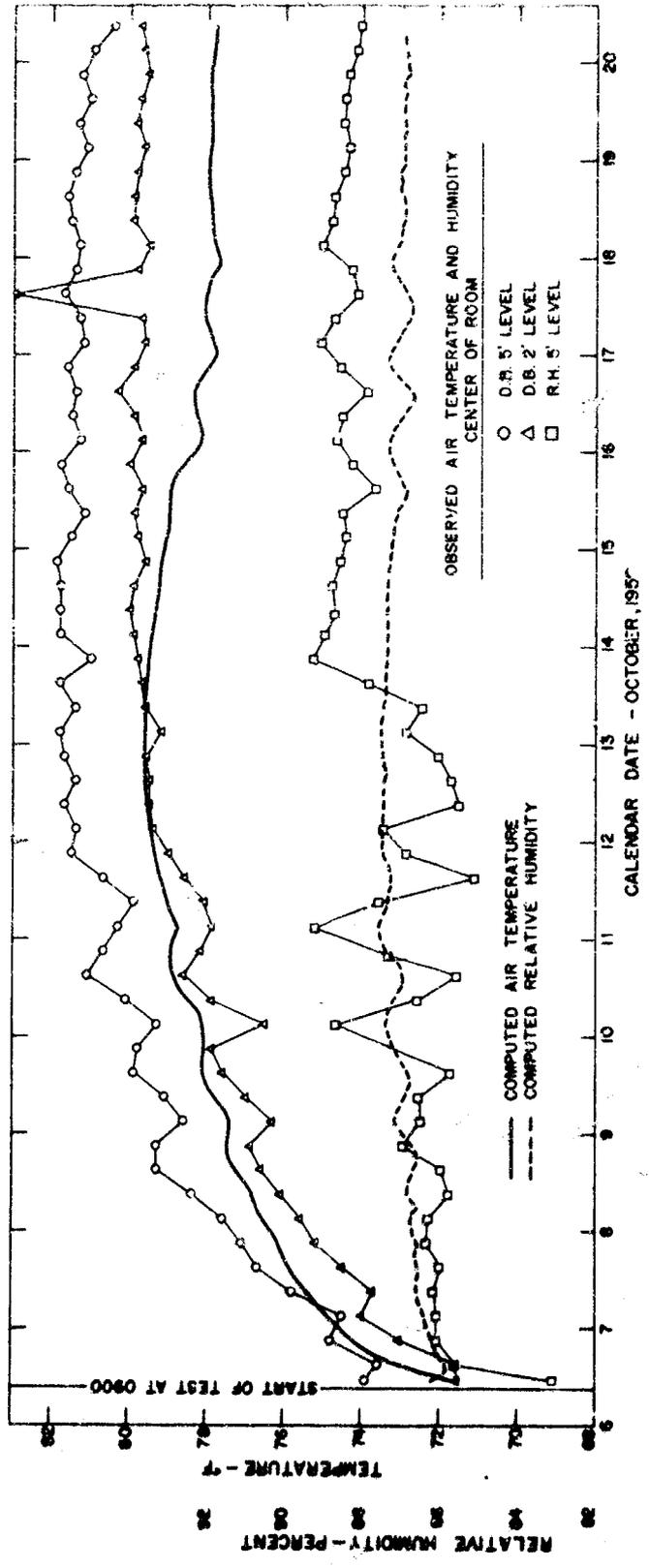


Fig. 10 Comparison of the calculated and observed air temperatures and relative humidities for test 4 of NBS family shelter (computer program N-(2)).

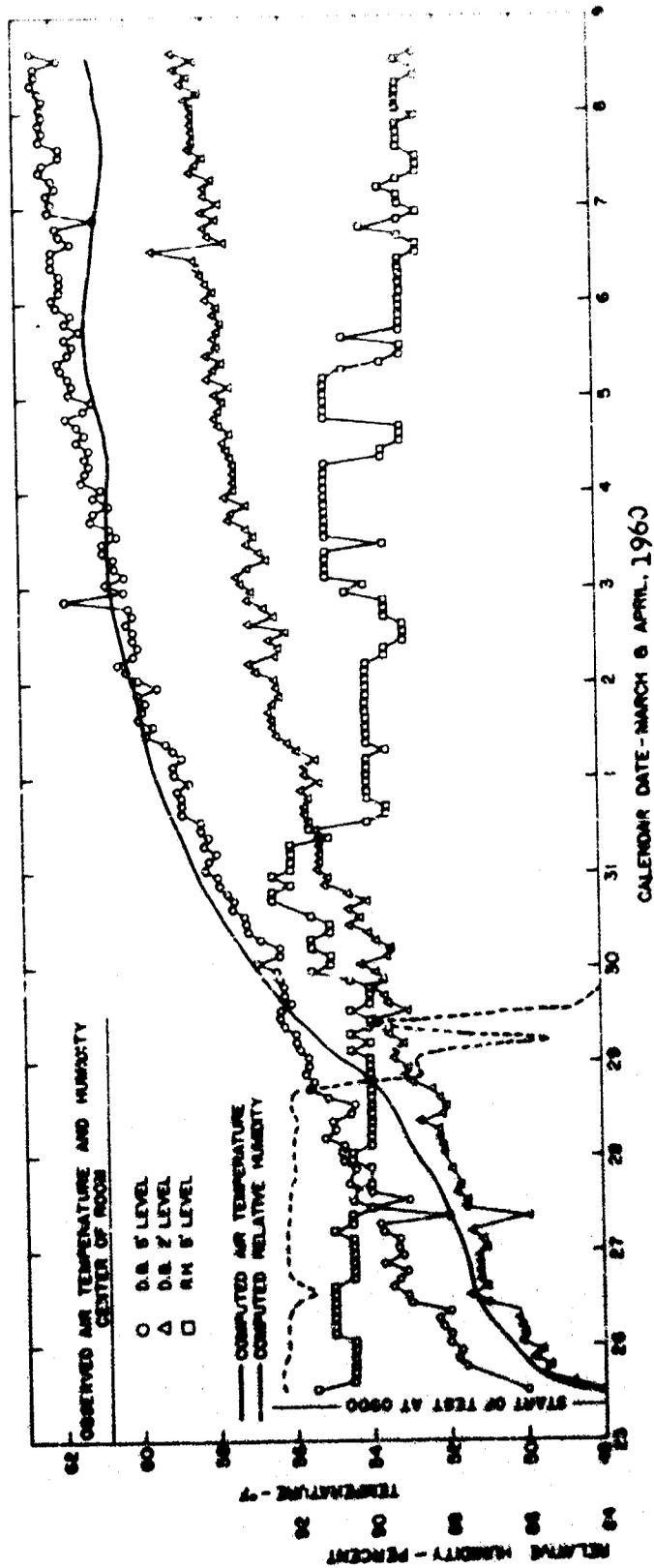


Fig. 11 Comparison of the calculated and observed shelter air temperatures and relative humidities for test 5 of NBS family shelter (computer program M-(2)).

and did not cause appreciable temperature rise in the ground. Similar moisture evaporation near the earth's surface also explains the small earth temperature rise near the surface for other test conditions, such as the Summerlin, Broyles, and Napier shelters, some of which will be illustrated later.

Figure 12 compares calculated (M-(2) program) and observed air temperatures in the Summerlin shelter for its summer condition test. Although the overall trend of the actual temperature is closely followed by the calculation, the computed amplitude of the diurnal temperature variation within the shelter is considerably smaller than the observed. The relative humidity calculation for the summer test condition of the Summerlin shelter is shown in figure 13. For the first five days, the calculated relative humidity was higher than the observed. This discrepancy may be due to the fact that there were cool regions in the shelter interior surfaces where more condensation of water vapor was taking place than was determined by the calculation which was based upon average surface temperatures of each exposure. Some of the high peaks in the computed relative humidity during the last three days were not registered in the observed record. Figure 14 compares the calculated earth temperature surrounding the Summerlin shelter during the summer test period with the observed. The agreement between calculated and observed values was quite good for the south and east walls. The earth temperature under the floor was not observed during the test because this was a privately owned shelter and it was decided that the water-tightness of the floor should not be jeopardized by making a hole through it. The calculated roof region temperature was much higher than the observed values. As mentioned before, this discrepancy is assumed to be caused by partial utilization of solar energy by surface evaporation of ground moisture,

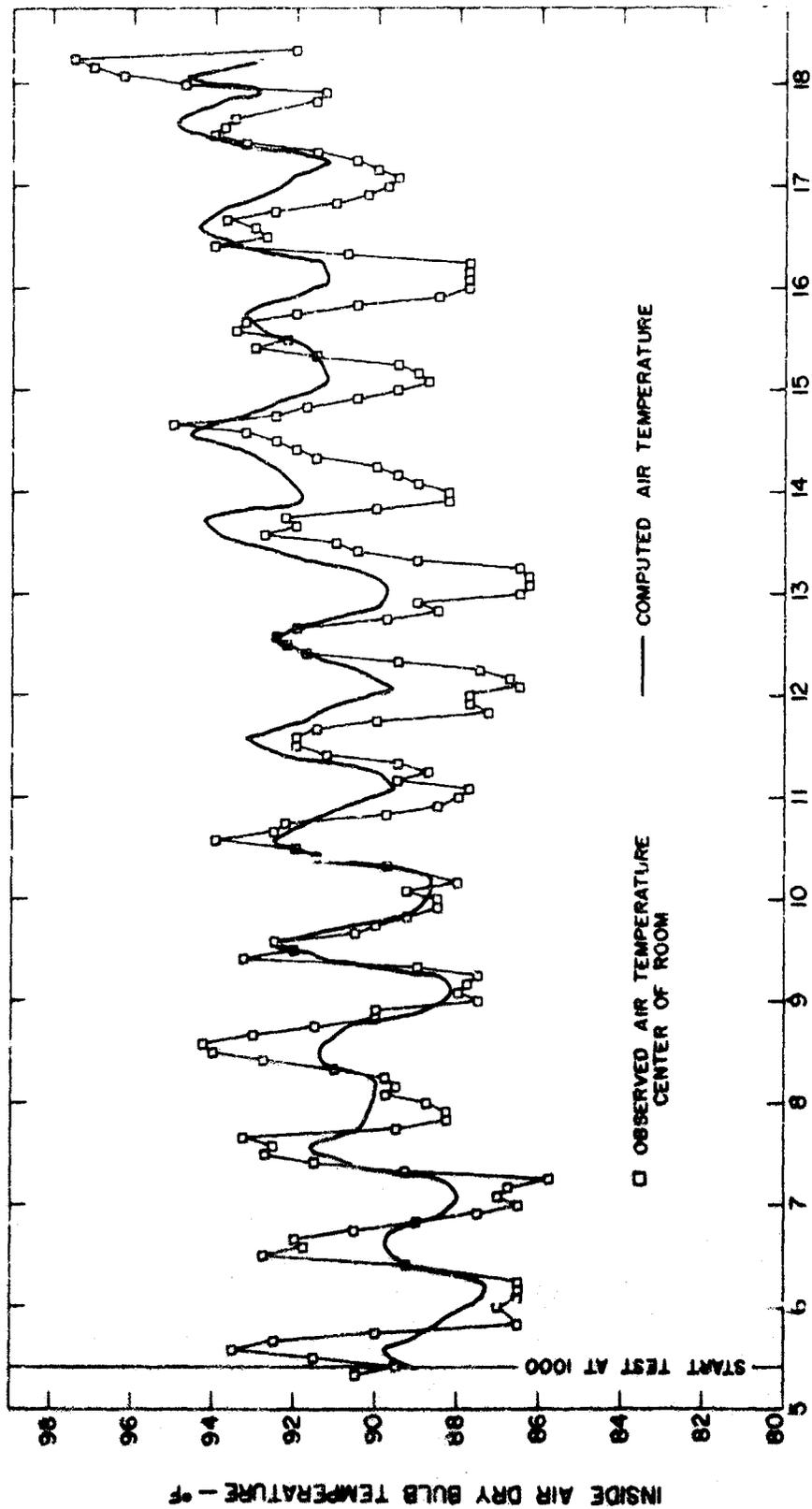


Fig. 12 Comparison of the calculated and observed shelter air temperatures for Summerlin Shelter (computer program M-(2)).

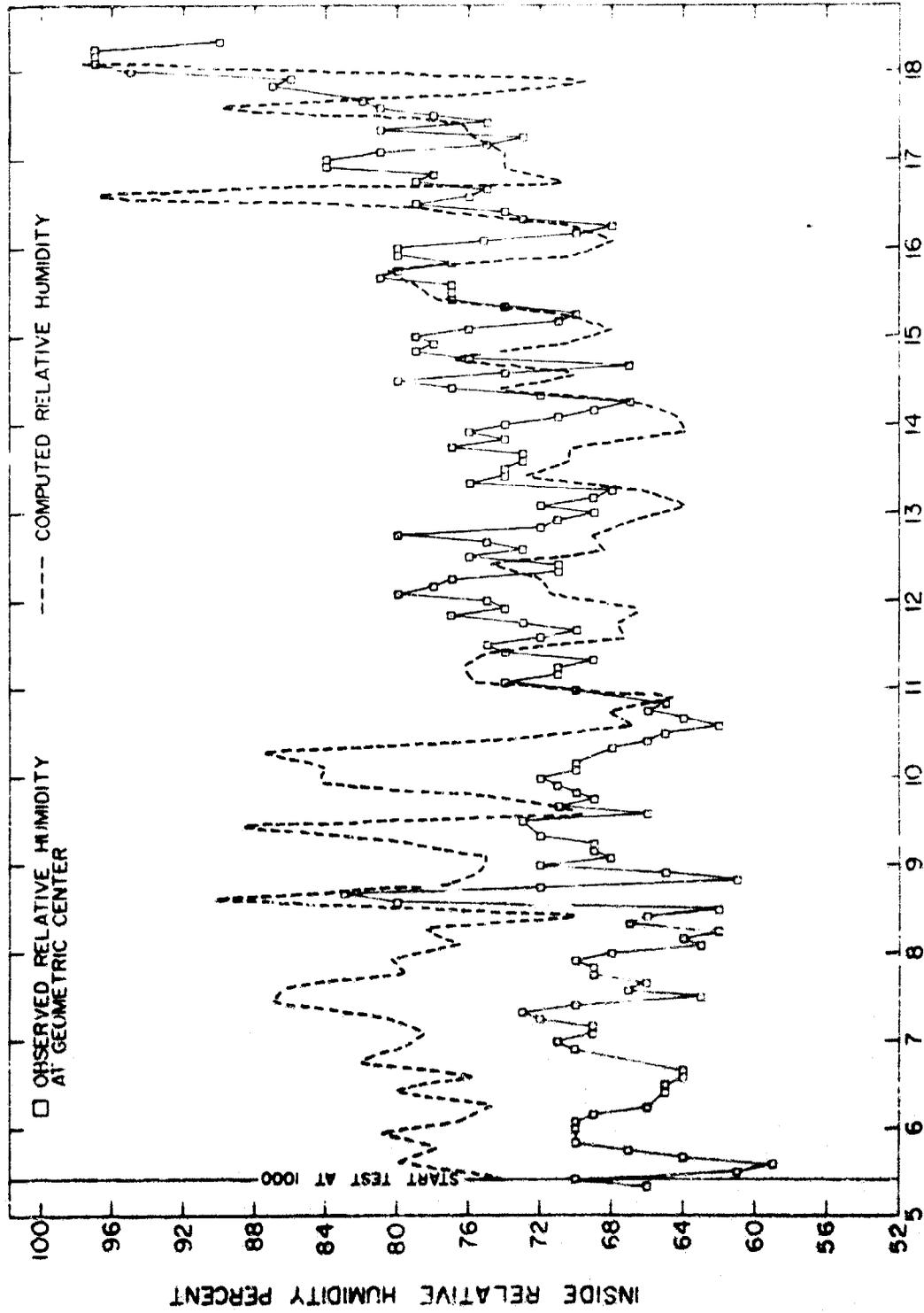


Fig. 13. Comparison of the calculated and observed shelter air relative humidities for summer condition test for Summerlin Shelter (computer program M-(2)).

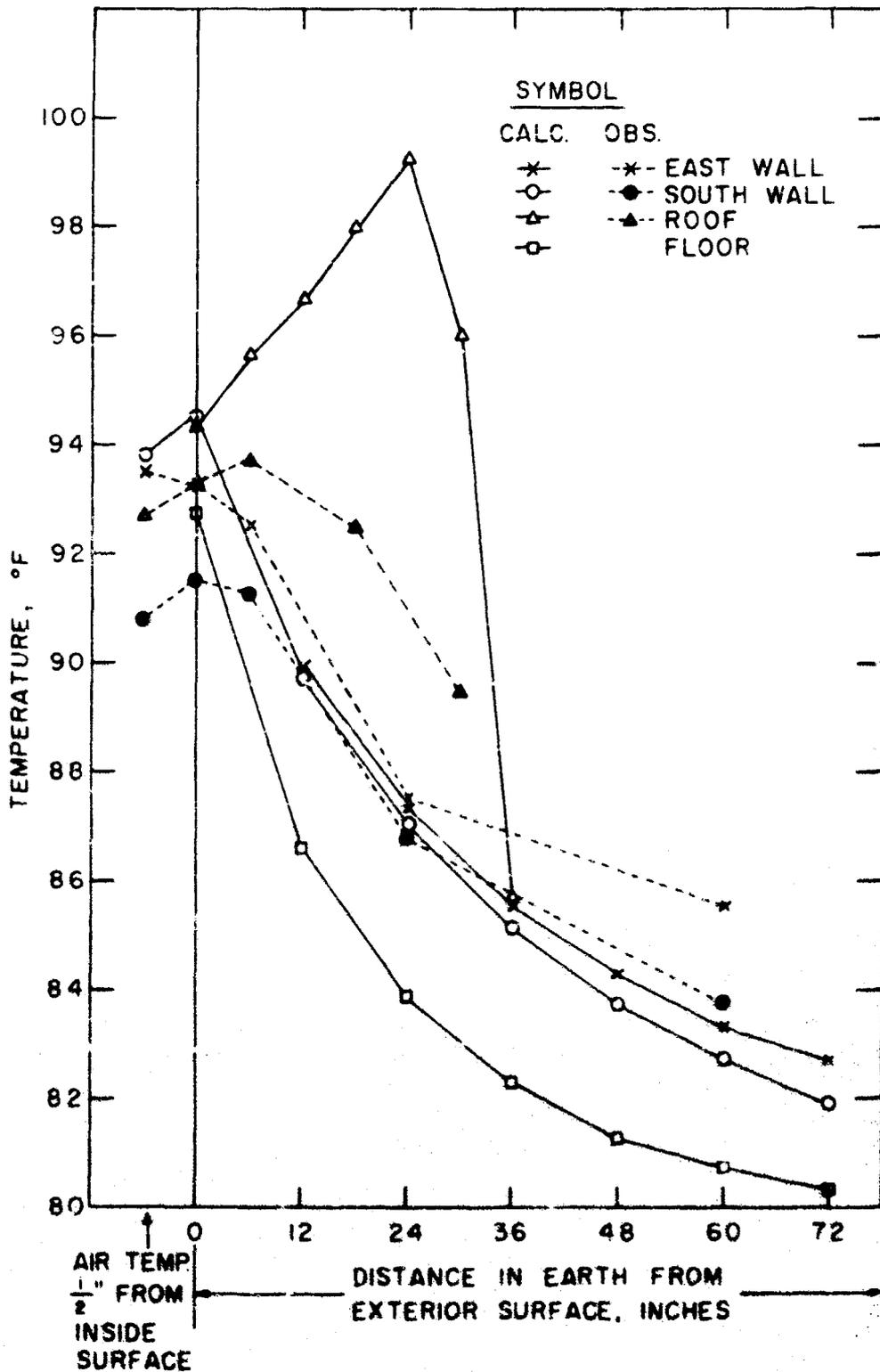


Fig. 14. Comparison of the calculated and observed earth temperatures surrounding Sumnerlin Shelter during summer test conditions (computer program M-(2)).

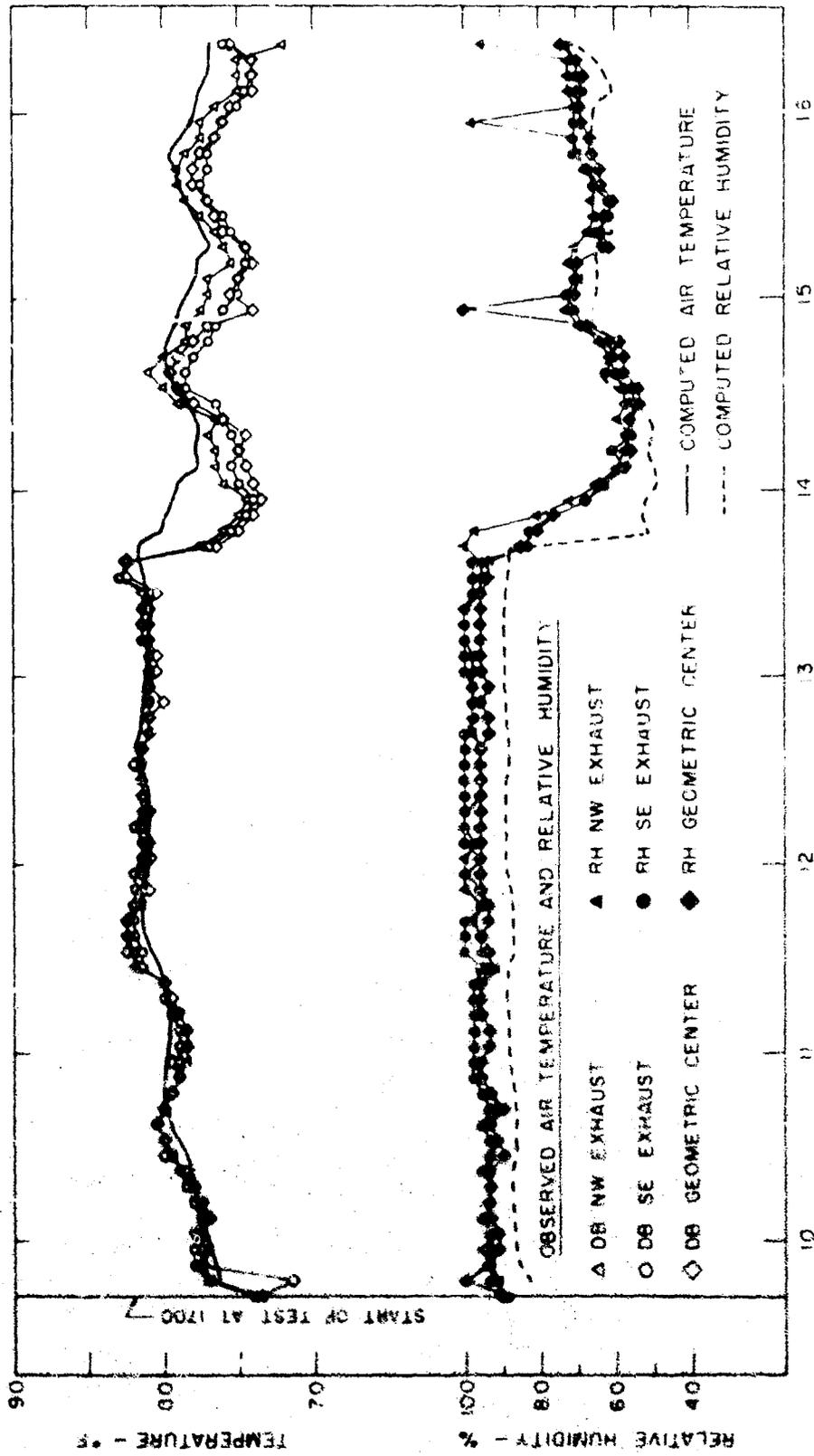


Fig. 15. Comparison of the calculated and observed shelter air temperatures and relative humidities during winter condition test for Summerlin Shelter (computer program M-(2)).

resulting in less temperature rise in the interior of the earth than calculated. It was found for all other shelters for which the ground surface was not dry and bare, the inclusion of solar heat in the calculation usually gave higher shelter temperatures, as well as higher roof region temperatures, than observed values.

Figure 15 compares the computed Summerlin shelter thermal environment with the observed condition for a moderate climatic condition. Although the computed temperature amplitude was again lower than the observed, the agreement between the computed and the observed data is very good and was better than for the hot summer test condition. Three high peaks of the observed shelter relative humidity during the last two days of the test were not reproduced by the calculation and they may represent instrumentation errors. Essentially identical results were obtained when the calculations were repeated by M-(3) or one-dimensional compound model on Summerlin shelter.

Figures 16 and 17 compare calculated results with observed temperature and relative humidities of the Broyles shelter. As described in section 4-C, this shelter was conditioned by a cooling coil using well water during the first two days. In figure 16, a dashed curve shows the computed result without consideration of the cooling coil, thus yielding much higher shelter temperatures during the first two days of the test. The last 2-day portion of figure 16 was not simulated by the computer, so the comparison between the calculated and the observed shelter temperature without air conditioning should be made between August 1 and 16. However, an adjustment was made later to account for the observed cooling capacity of the coil by making Q_{MS} and Q_{ML} negative in the equation for miscellaneous heat load in section 2. The first 2-day portion of the Broyles shelter calculation was repeated with this adjustment and the

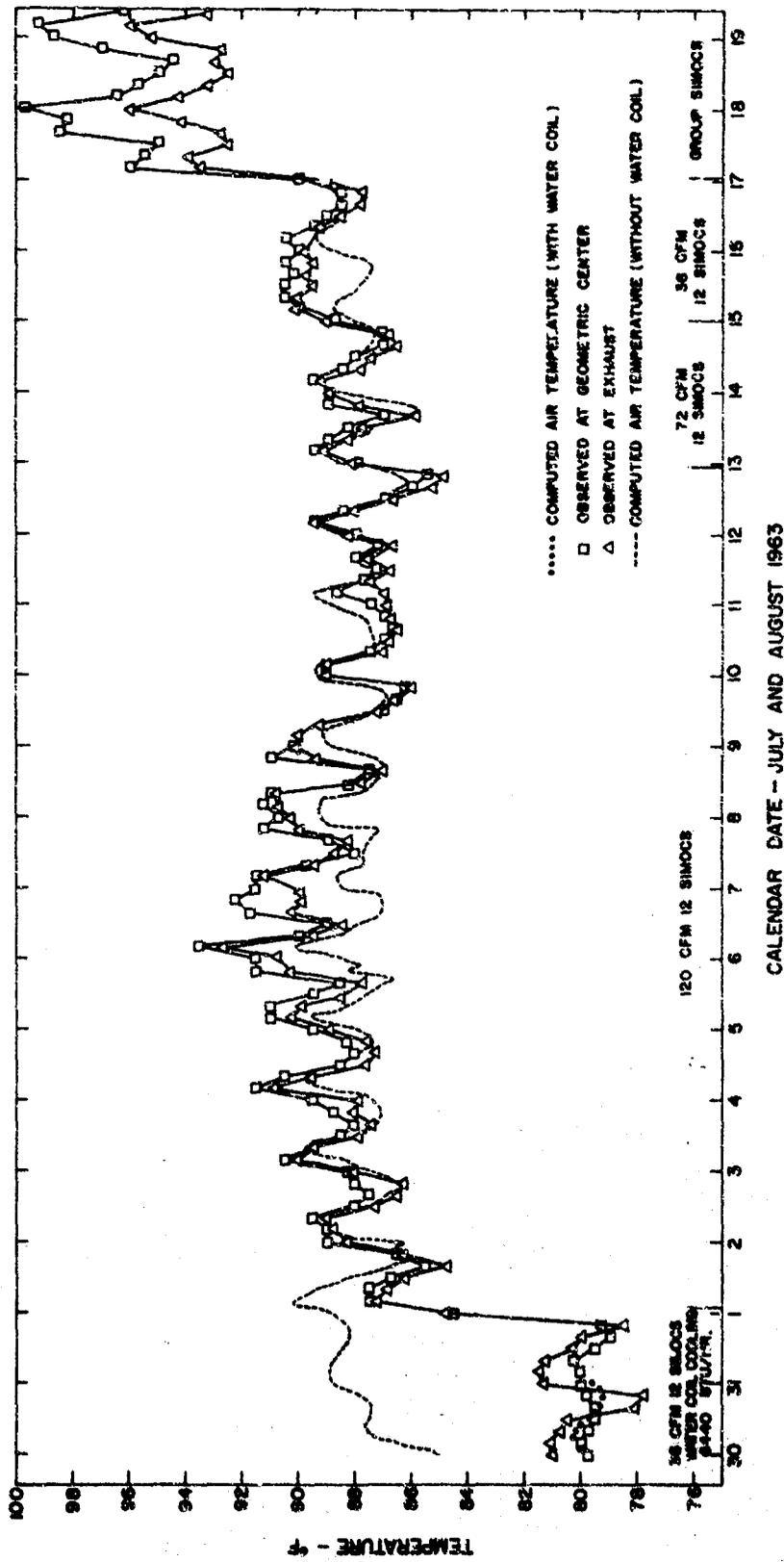


Fig. 16. Comparison of the calculated and observed shelter air temperatures for Broyles Shelter (computer program M-(2)).

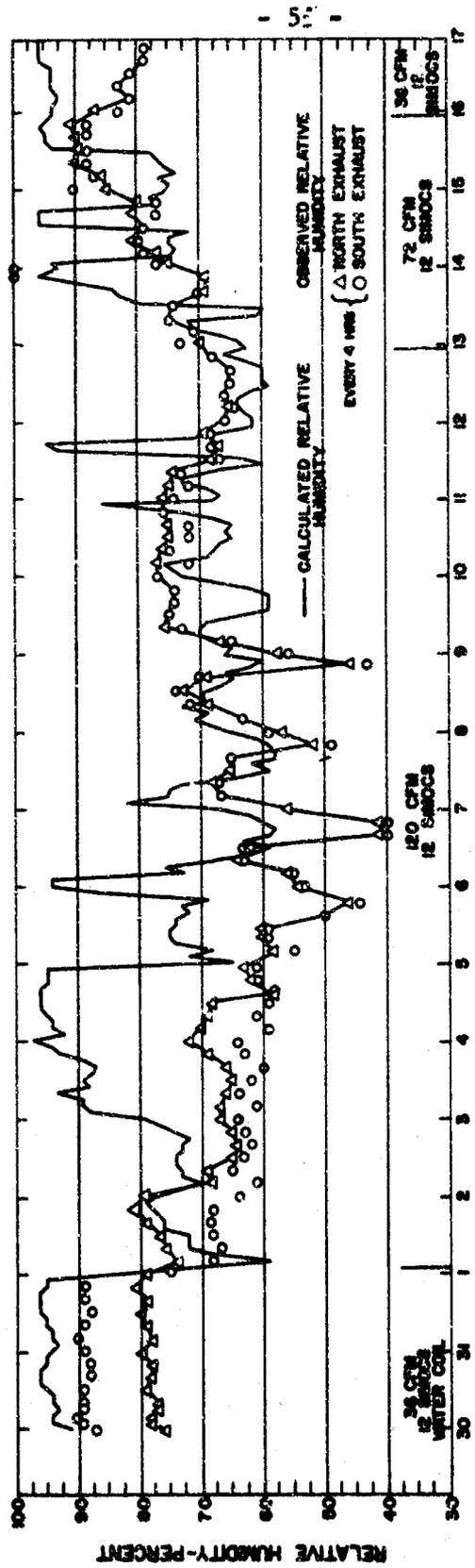


Fig. 17 Comparison of the calculated and observed shelter relative humidities for Broyles Shelter (computer program M-(2)).

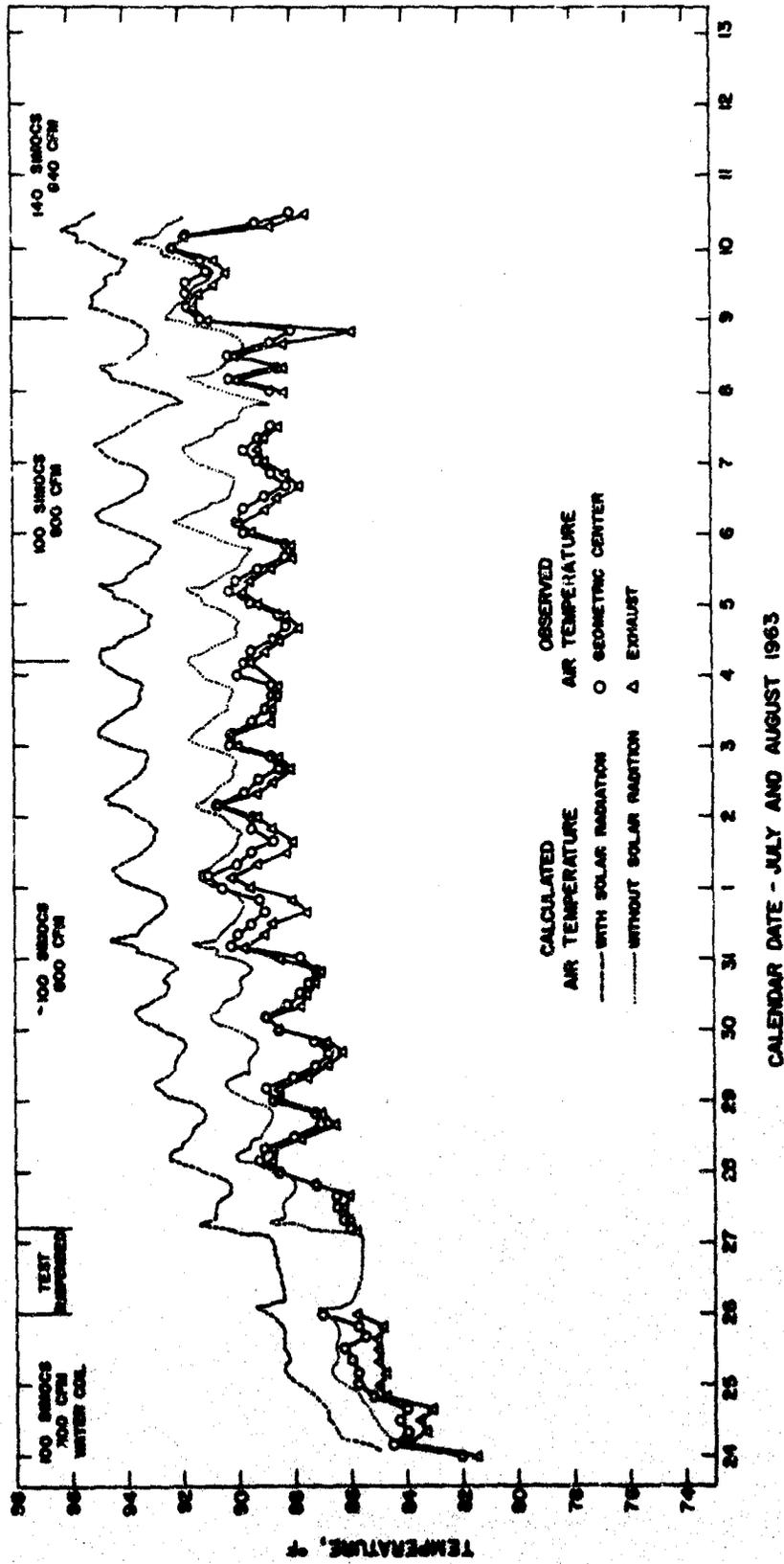


Fig. 18. Comparison of the calculated and observed shelter air temperatures for Napier Shelter (computer program M-(2)).

results are shown by solid dots on figure 16. The adjusted and calculated shelter air temperatures for this initial 2-day period agree very well with observed temperatures obtained at the geometric center of the shelter

Figure 17 compares the calculated and observed relative humidities in the Broyles shelter. The large disagreement of the computed relative humidities during August 2 to 7 cannot be explained adequately by the available data. The agreement of the computed relative humidities with the observed values for this test were generally very poor, and the same trend was also observed in the Napier shelter comparison, as shown in figure 19.

The Napier shelter temperature comparison was satisfactory if the solar heat input to the ground surface is ignored, as seen from figure 18. The inclusion of the solar heat in the calculation caused the computed shelter air temperature to be approximately 3 to 4 degrees higher than the observed temperature.

By contrast, figure 20 shows excellent agreement between the calculated and observed temperature and relative humidity during the winter test condition for the Reading shelter. For this shelter, nearly 80 percent of the total heat generated was conducted into the surrounding earth. The moisture balance of the test results is shown in figure 21, indicating the continuous condensation of water vapor on the inner surfaces of the shelter during the first ten days of the test. The ventilation rate was either 3 cfm or $1\frac{1}{2}$ cfm per person during this period. The excellent agreement between the computed thermal environment with the observed condition during the first 10-day period is a good demonstration that the computer simulation technique was valid. However, in

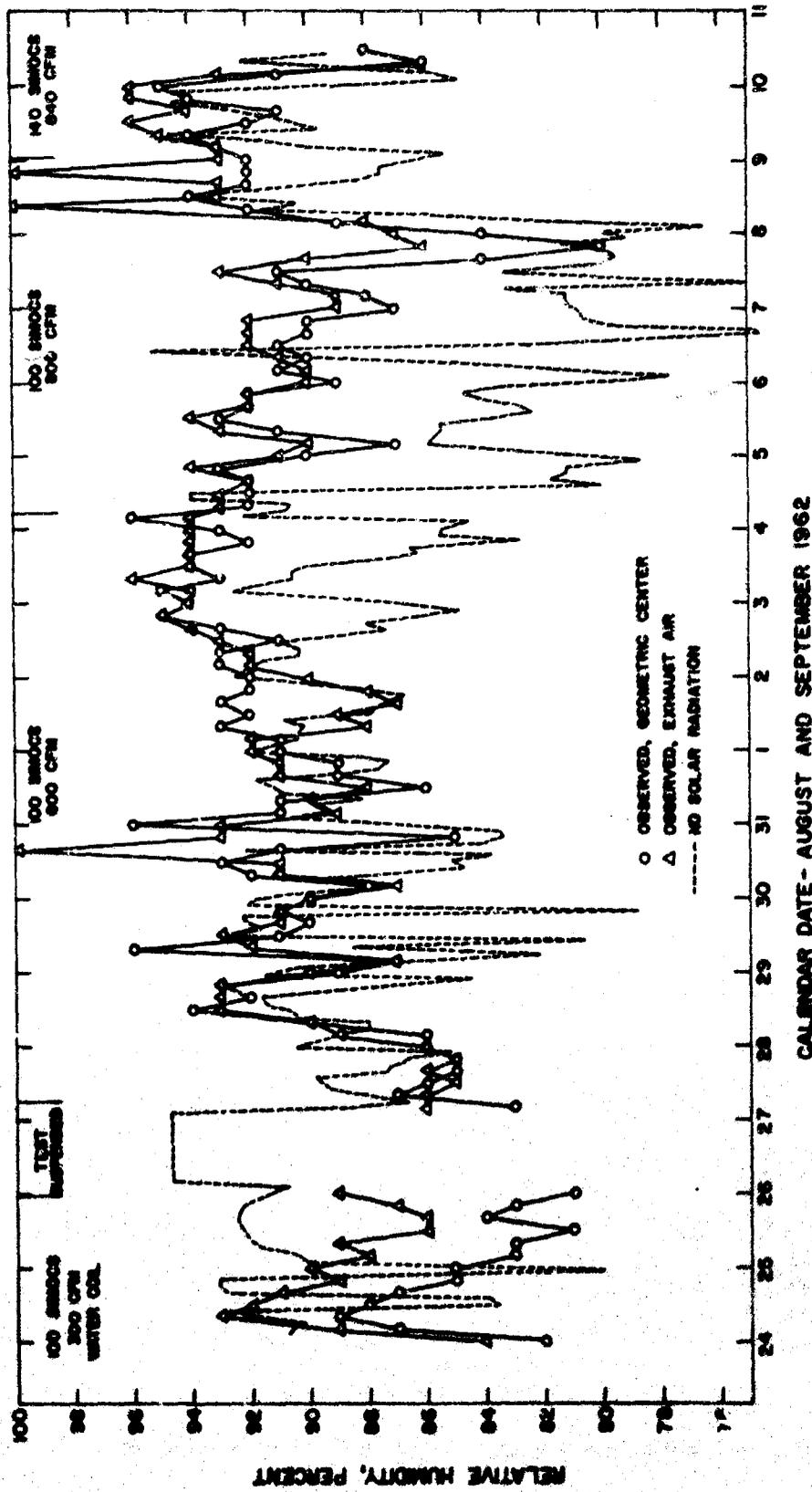


Fig. 19 Comparison of the calculated and observed shelter relative humidities for Napier Shelter (computer program M-(2)).

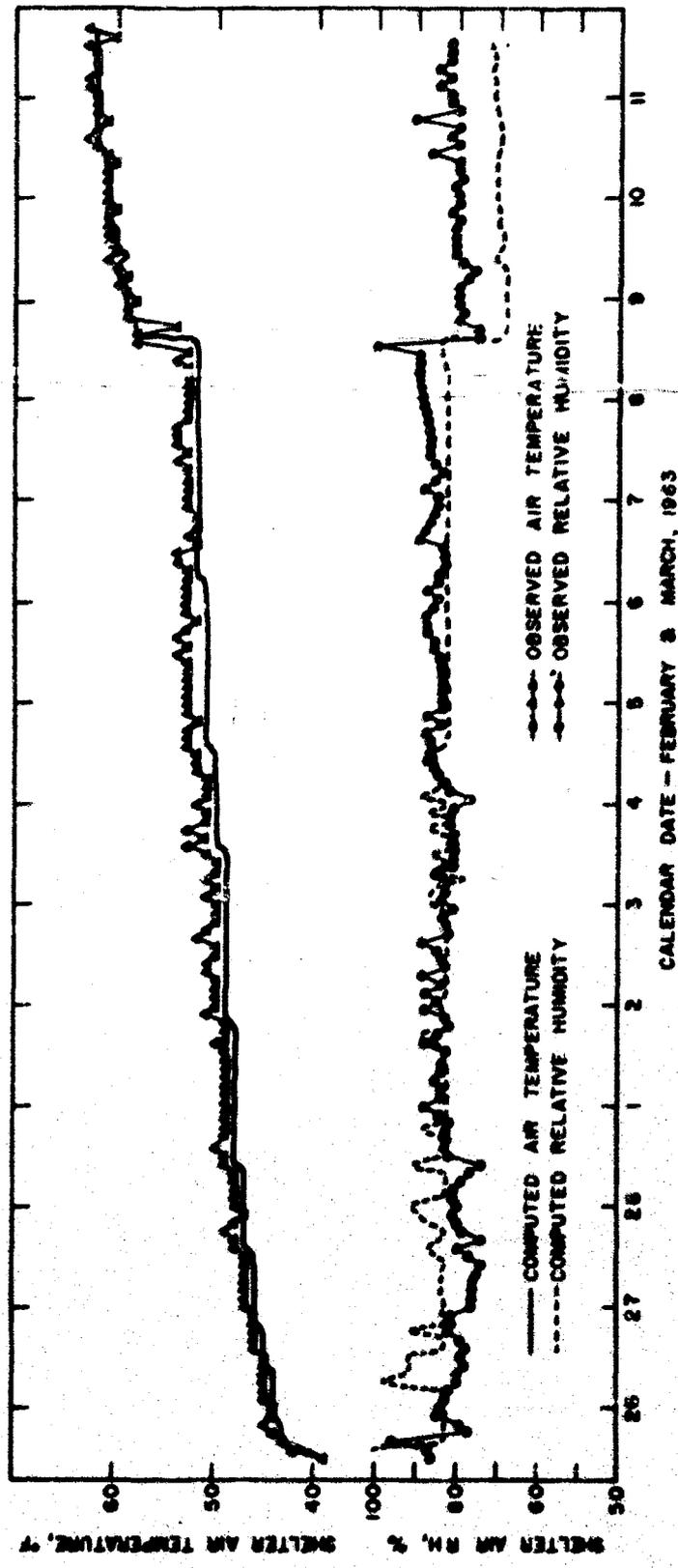


Fig. 20 Comparison of the calculated and observed shelter air temperatures and relative humidities for Reading Shelter (computer program M-(2)).

figure 20, the computed relative humidity is approximately 10 percent lower than the observed during the last three days. During this period, the simulated occupants were increased from the equivalent of 50 to 100. In figure 21, the indicated moisture balance within the Reading shelter during this period shows that the ventilation air actually carried out more water vapor than was produced by all of the simulated occupants. This proves that the shelter wall was drying out during the period. As mentioned before, the computer program does not have provision for simulating the drying process of concrete walls; therefore, the computed relative humidity was lower than the observed.

Figures 22 and 23 compare the computed and observed earth temperatures surrounding the Reading shelter. Being in the midst of winter, the undisturbed earth temperature was relatively low and the ground surface was snow covered during this period. Two computer models M-(2) (symmetrical and three-dimensional) and M-(3) (one-dimensional and compound), were applied to the Reading shelter calculation, resulting in practically identical thermal environments. The ground temperature profiles were computed and compared with the observed profiles for other prototype shelters and the agreement between the calculated and observed results were generally similar to those shown in figures 22 and 23 for the Reading shelter.

The computer Model M-(4), basically a one-dimensional and compound system with the top surface of the roof being adiabatic, was employed to compute the thermal environments of the Ft. Belvoir 200-man and 1000-man basement-type shelters. These results are shown graphically in Figures 24 and 25. Instead of comparing the relative humidity, as in cases of other shelters, effective temperatures were compared, in addition to the dry-bulb temperature comparison. The computed and observed results agreed almost

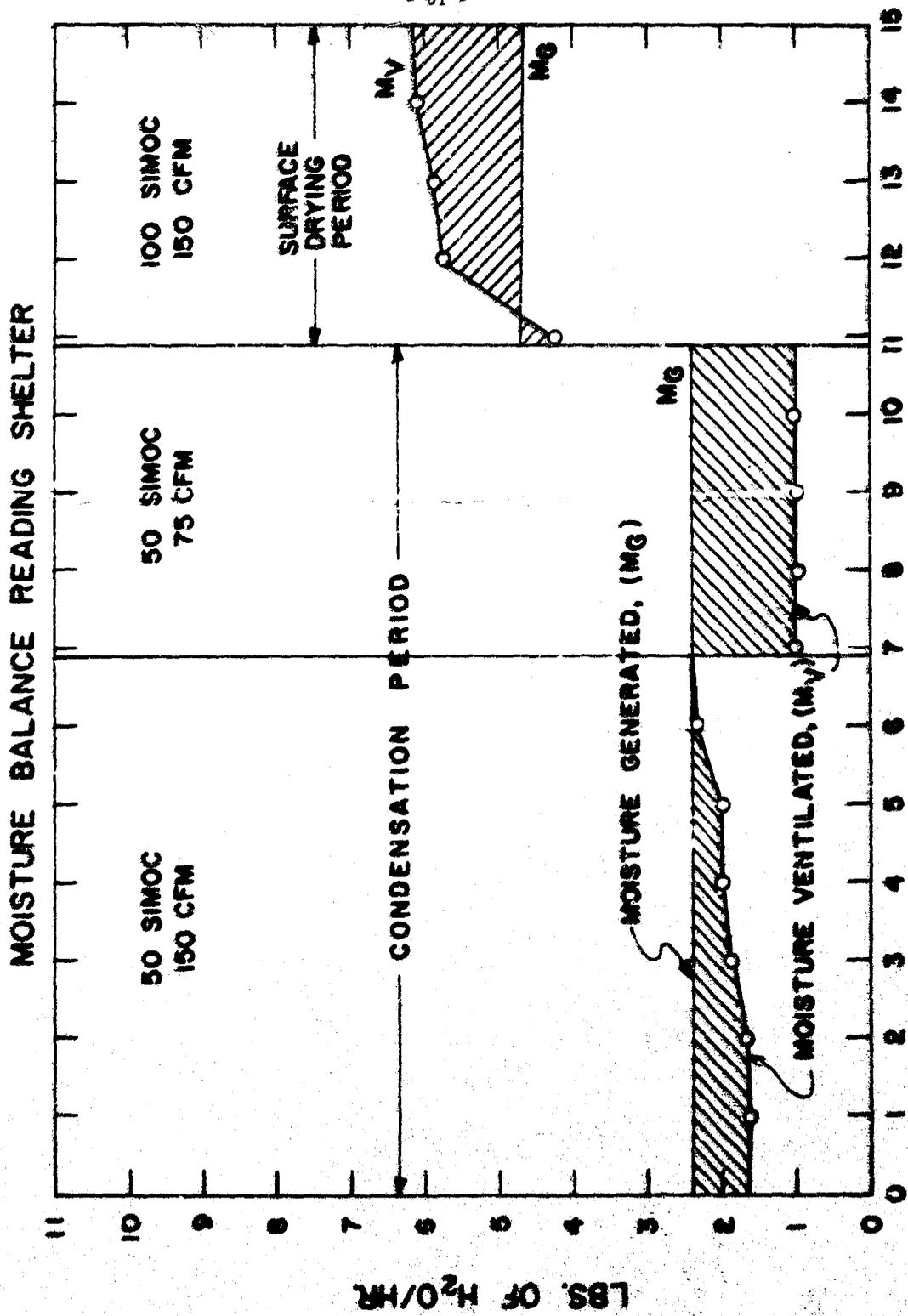


FIG. 21 Observed moisture balance of feeding Shelter.

READING SHELTER EARTH TEMPERATURE ON THE 14th DAY OF THE TEST

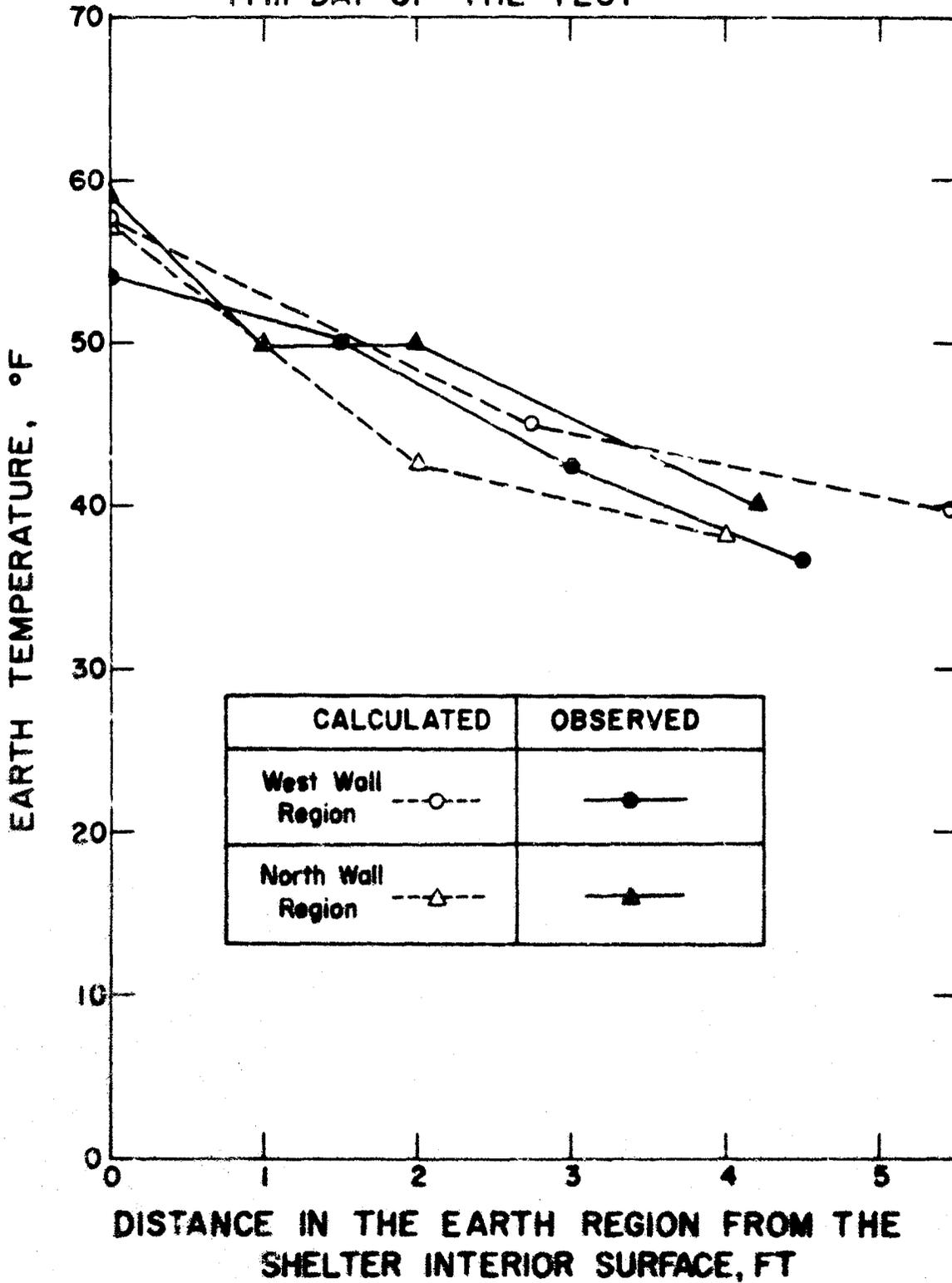


Fig. 22 Comparison of the calculated and observed earth temperatures outside Reading Shelter walls (computer program M-(2)).

READING SHELTER EARTH TEMPERATURE ON THE 14th DAY OF THE TEST

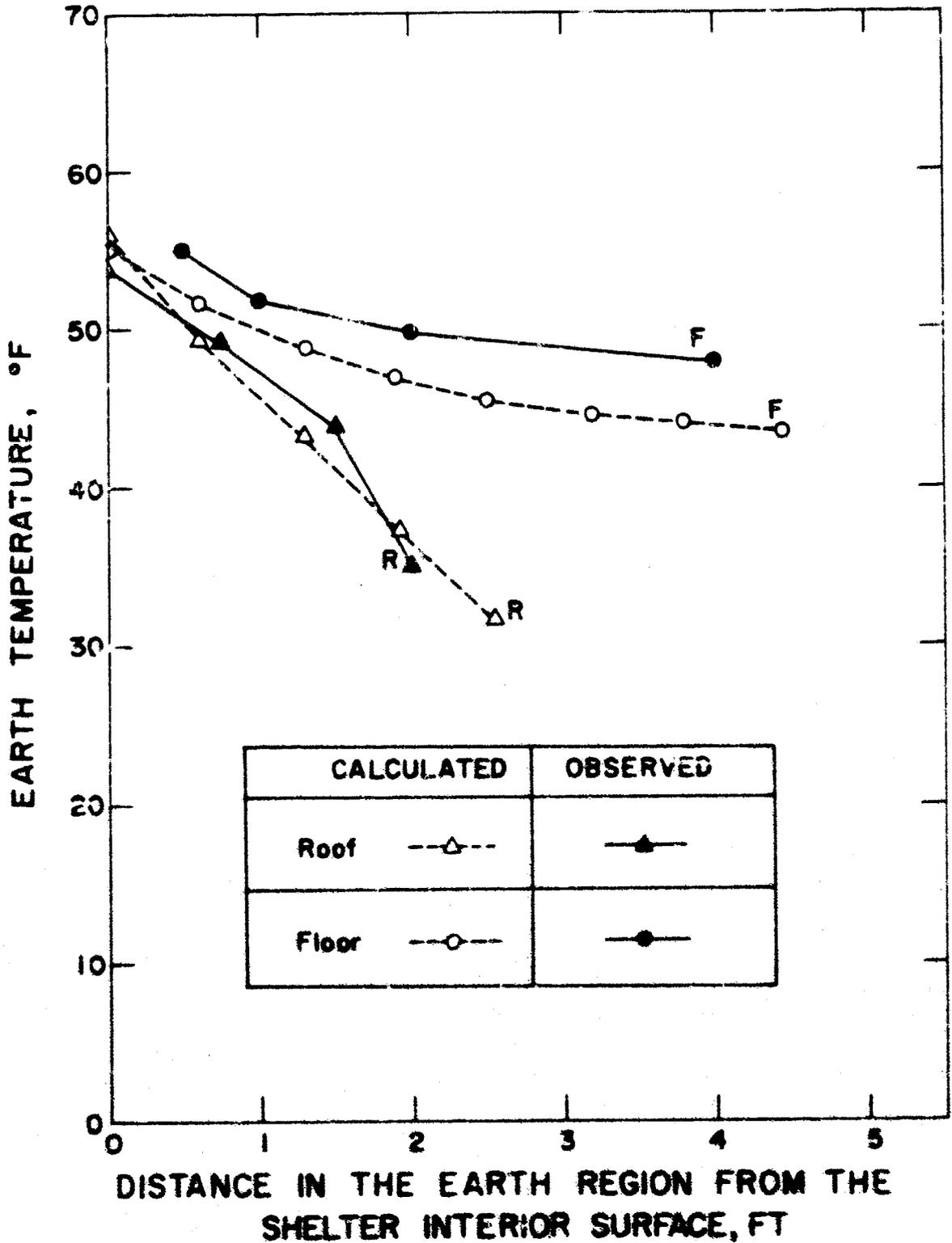
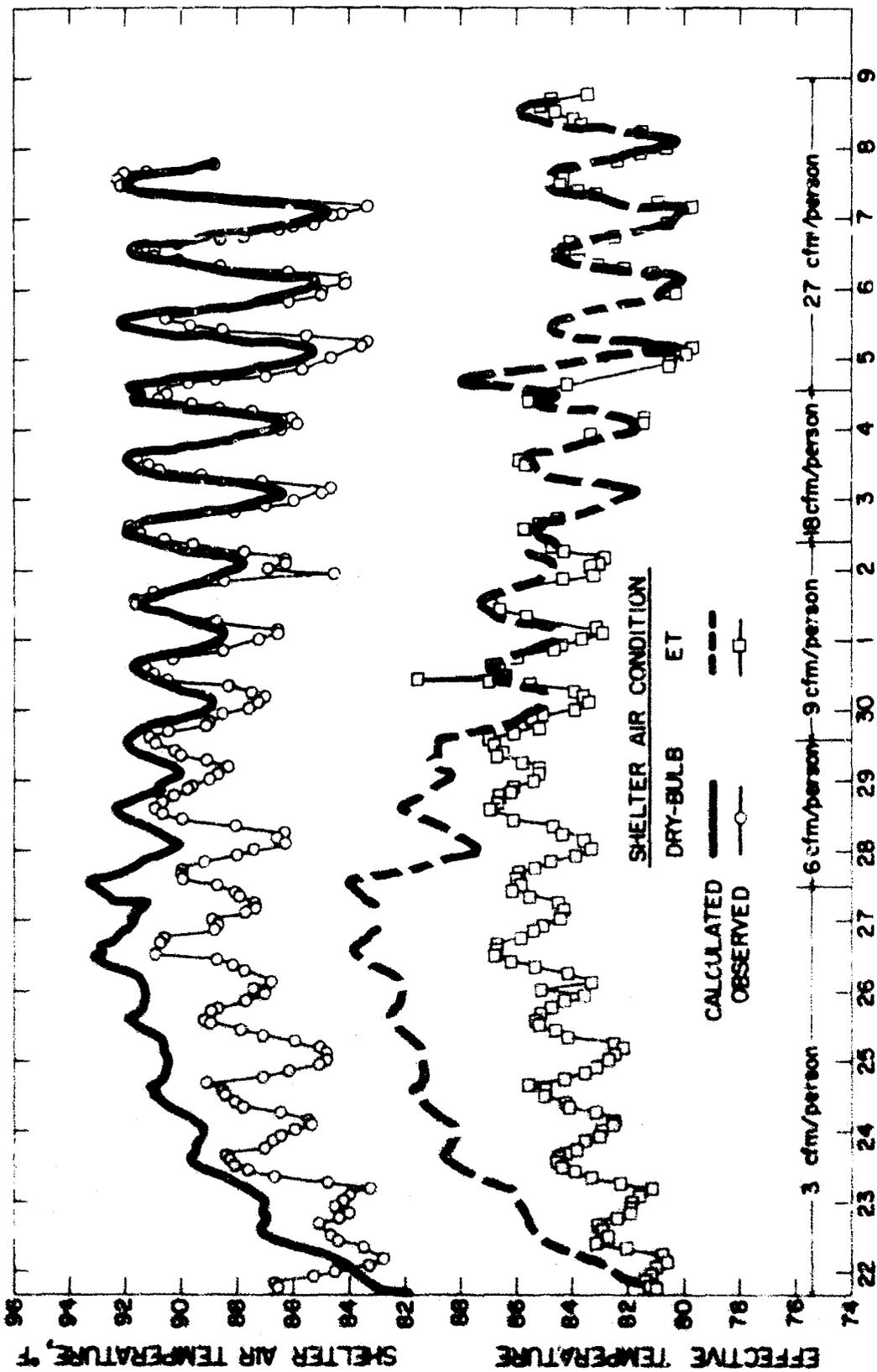
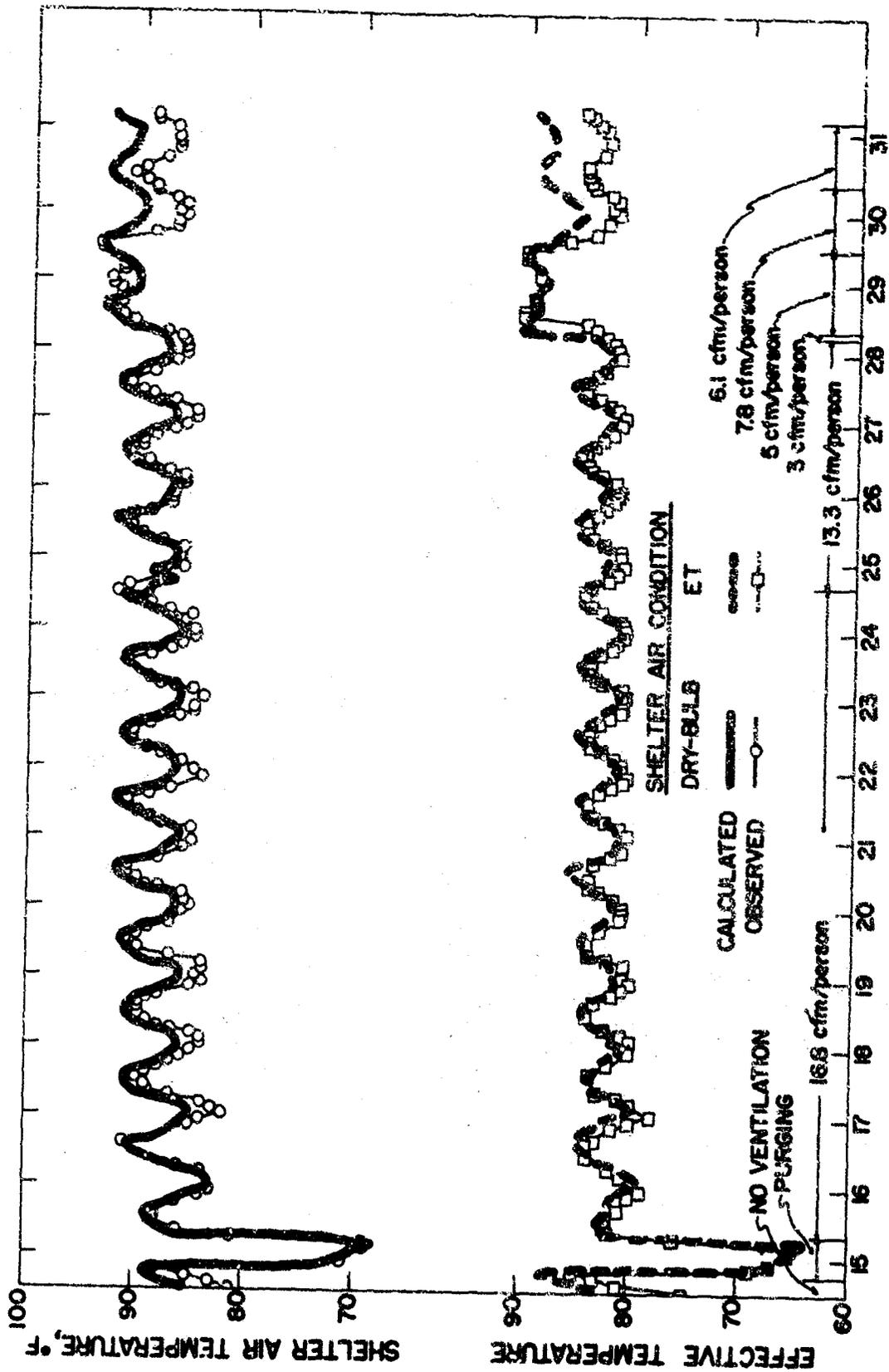


Fig. 23 Comparison of the calculated and observed earth temperature outside Reading Shelter ceiling and floor (computer program M-(2)).



CALENDAR DATE, SEPTEMBER AND OCTOBER, 1963

Fig. 24 Comparison of the calculated and observed shelter air temperatures and effective temperatures of Ft. Belvoir 200-man shelter. (computer program 24- (4)).



CALENDAR DATE, OCTOBER 1963

Fig. 25 Comparison of the calculated and observed shelter air temperatures and effective temperatures of Ft. Belvoir 1000-man shelter (computer program M-(4)).

perfectly for the 1000-man shelter. Higher and less fluctuating dry-bulb and effective temperatures were calculated for the 200-man shelter than were observed, particularly during the first seven days of the test period. By comparison it appeared that the observed temperatures reflected shelter diurnal cycles corresponding to a higher ventilation air rate than the indicated 3 cfm per person. It also should be realized that the geometrical relationship between the inlet for the ventilation air and the stations for room temperature measurement and the mixing effects in the intervening space would have an effect in the amplitude of the temperature variations observed in any of the shelters.

6. CONCLUSIONS

Except for a very few cases, such as for the Napier shelter and the NBS shelter test 4 conditions, the computer simulation based upon a finite difference solution of the heat conduction equation for the calculation of the thermal environment of underground protective shelters has been found generally satisfactory. Good agreement between calculated and observed thermal conditions was obtained for tests 2 and 3 in the NBS shelter, the Summerlin shelter, the Reading shelter, and the Ft. Belvoir 1000-man shelter. This agreement coincided with well-controlled test conditions, and where input parameters were known more accurately than in other cases. However, for this type of analysis there are two inherent uncertainties which influence the accuracy of the calculations.

The first uncertainty stems from simplification of the actual environmental system when constructing the mathematical model. The

complexity of the system including construction details of interior partitions, foundations, wall supports and reinforcing; the heterogeneous temperatures, thermal properties, and types of the surrounding earth; and space variation of conditioning air and its convective pattern in the shelter, makes an accurate mathematical description of the system very difficult. Therefore, the simulated computer model is a simplified version of the actual system that is suited to the mathematical handling of the problem. The magnitude of the error due to this uncertainty has not been evaluated, but it is a part of the differences between calculated and observed temperature and humidity conditions shown in this report for seven different shelters.

The second uncertainty is closely related to the first, and concerns the reliability of input data. It is almost impossible to acquire complete three-dimensional information on earth thermal properties and temperature, and if such information were available, it would be difficult to use as computer input data. Therefore, when a homogeneous heat conduction model is employed for a system surrounded by earth of heterogeneous characteristics and temperature, the choice of proper input values becomes very difficult. The uncertainty involved in evaluating the interior surface heat transfer coefficients is equally as difficult, as discussed in section 5.

Thus the simplification of the physical characteristics of the real shelter-earth system employed in creating an analytical model and the uncertainties in the thermal properties of the materials involved, became the principal approximations incorporated into the computer

analysis of the thermal environment in shelters. In spite of these uncertainties, good agreement between computed and observed results was achieved for many of the shelters described in this report.

In addition to these general comments, these specific conclusions are emphasized, as follows:

(a) Soil analysis of most of the prototype shelters indicated that thermal diffusivity and thermal conductivity are in the neighborhood of $0.02 \text{ ft}^2/\text{hr}$ and $0.75 \text{ Btu/hr ft}^2 (\text{deg F/ft})$, respectively. These values, in turn, seem to result in fairly good agreement of earth temperature change during the test period for most of the shelters.

(b) Heat conductance at the shelter inner surfaces for most of the summer shelter conditions may be approximated by the following:

1.0 Btu/hr ft^2 deg F for vertical walls.

1.5 Btu/hr ft^2 deg F for the ceiling.

0.5 Btu/hr ft^2 deg F for the floor.

Although there may be some other values and other combinations of these values that may have resulted in a slightly better simulation than those used in the analysis, these three values can be considered representative design heat transfer coefficients in the underground cavities.

(c) For large shelters, the one-dimensional, compound 6-directional model M-(3) will probably be adequate for calculating the shelter heat transfer. Thus, the complicated 3-dimensional model may not be required, at least for the heat transfer calculation of less than 14-day occupancy. For small shelters (such as a family shelter similar to the NBS shelter), however, it is recommended that the three-dimensional model be used for the accurate calculations.

7. APPENDIX

7.1 Air-conditioning subroutine.

Program M-(4) employs a subroutine for air conditioning the shelter. This subroutine enables the computer program to include the heat and vapor absorbing capacity of a given cooling system (a fan-and-coil unit) in the shelter heat balance equation of 2.1. The row by row account of the cooling coil performance is considered for the cross-counter flow circuited coil circulating the well water. The input data required for this subroutine are:

- Shelter air dry-bulb temperature, t_a °F
- Shelter air wet-bulb temperature, $t_{a,w}$ °F
- Ventilation air dry-bulb temperature, t_v °F
- Ventilation air wet-bulb temperature, $T_{v,w}$ °F
- Inlet coolant temperature, t_w °F
- Recirculation air rate, CFM_R
- Contact factor of air conditioning coil per row, C_f
- Thermal resistance between the solid-air inter-
face and the coolant, k_v °F, ft² hr/Btu
- Estimated temperature rise due to fan heat, Δt_f
- Coolant heat content, G_w Btu/hr, °F

The contact factor per row C_f , mentioned above, is a function of air face velocity across the given air cooling coil, air-side heat transfer coefficient of the coil surface, and the amount of total heat transfer surface. The factor may be estimated by the following expressions:

$$C_f = 1 - e^{-\left(\frac{f_a S_p}{1.08 \text{ CFM}_t}\right)}$$

7-1

where f_a = air side heat transfer coefficient, Btu/hr ft² °F.

S_p = air side heat transfer surface of the coil per row, ft²

$\text{CFM}_t = \text{CFM}_{Rt} + \text{CFM} = \text{total air flow rate.}$

The thermal resistance value R_w may be estimated by the following expression:

$$\frac{1}{R_w} = \frac{S_p}{S_t} \frac{1}{f_w} + \Sigma r$$

7-2

where S_t = coolant side heat transfer surface of the coil per row, ft²

f_w = heat transfer coefficient of coolant, Btu/hr, ft² °F.

Σr = sum of all other heat resistance between the coolant side surface and air side surface, such as thermal resistance due to tube wall, finish bond, finish metal (depending upon the effectiveness of finish). and condensate film thickness.

The temperature rise due to fan heat can be estimated by total power input to the fan and air flow rate, assuming that all the fan heat will be expended to raise the air stream temperature. The value of Δt_f usually does not exceed 3 °F.

The coolant heat G_w is the coolant mass flow rate multiplied by the coolant specific heat. In the case of a direct expansion refrigerant coil, where the coolant temperature change in the coil is very small, G_w is considered infinity, or a very large number. The details of the cal-

culative procedure on C_f and R_w , and their design value can be found in references 5 and 6.

First, the air inlet condition to the air cooling coil is calculated by the following equation:

$$t_1 = \frac{(CFM)_R(t_a) + (CFM)(t_v)}{CFM_R + CFM} \quad 7-3$$

$$W_1 = \frac{(CFM)_R(W_a) + (CFM)(W_v)}{(CFM)_R + CFM} \quad 7-4$$

where t_1 , W_1 , W_a , and W_v represent inlet air dry-bulb temperatures, inlet air humidity ratio, shelter air humidity ratio, and ventilation air humidity ratio, respectively. These humidity ratio values are calculated by a separate subroutine from dry- and wet-bulb temperatures, as explained in section 2.7.

The air conditioning coil is assumed to be of multi-row structure, and the overall direction of coolant is counter to that of air flow, although for individual rows the coolant is flowing perpendicular to the air stream. For simplicity, it is assumed that the coolant temperature, as well as air-side surface temperature of a row, changes by a step function. The heat and vapor transfer calculation of the counter-flow dehumidifying coil requires an iterative procedure, because, except for the direct expansion coil, the outlet condition of air or coolant is not previously known. In this report, the outlet coolant temperature, which is in the same side as the inlet air condition of the coil, is first approximated. The heat and vapor transfer, and subsequent reduction of air temperature,

air humidity, and change of the coolant fluid, are then calculated row by row. After the calculation is completed, the total net change in coolant temperature is subtracted from the outlet temperature of the coolant, yielding the calculated coolant temperature at the inlet condition. If the calculated coolant temperature at the coil coolant inlet is different from the actual, the calculation is repeated with a modified outlet coolant temperature until the calculated agrees with the given inlet temperature of the coolant flow. The general heat and vapor transfer relation used for this calculation is described for i row as follows:

$$C_f \left[1.08 \text{ CFM}(t_1 - t_{s1}) + 4.5 (\text{CFM})(\lambda)(W_1 - W_{s1}) \right] = \frac{S_p}{R_w}(t_{s1} - t_{w1}) \quad 7-5$$

W_{s1} in the above equation is the humidity ratio of the air saturated at the surface temperature, t_{s1} ; if $W_1 \leq W_{s1}$, the second term in the left hand side of the equation is set equal to zero. Since W_{s1} is a complicated function of t_{s1} , an iterative technique is required to solve t_{s1} from the above expression. After t_{s1} is obtained, the leaving air condition, t_{i+1} , W_{i+1} , from the i row, and entering coolant condition to the $i + 1$, $t_{w,i+1}$, are calculated by the following relations:

$$t_i - t_{i+1} = (t_i - t_s)(C_f) \quad 7-6$$

$$\begin{aligned} W_1 - W_{i+1} &= (W_1 - W_{s1})(C_f) \text{ if } W_1 > W_{s1} \\ &= 0 \quad \text{if } W_1 \leq W_{s1} \end{aligned} \quad 7-7$$

$$\frac{S_p}{R_w}(t_{s1} - t_{w1}) = (t_{w1} - t_{w,i+1})(G_w) \quad 7-8$$

Since all of the relations are linear, calculations of t_{i+1} , W_{i+1} , and $t_{w,i+1}$ are straightforward.

When the total number of rows is N and the properties in the air inlet point are specified by subscript 1, the properties of the air outlet condition should be specified by $N + 1$. Thus, the calculations will be iterated, as mentioned before, until $t_{w,N+1}$ becomes equal to t_w . The final results of the air conditioning capacity will be expressed as follows:

(1) Sensible cooling capacity, $Q_{AS} = (1.08)(CFM)(t_1 - t_{N+1} + \Delta t_f)$

(2) Latent cooling capacity, $Q_{AL} = (4.5)(CFM)(W_1 - W_{N+1})\lambda$.

With the value of Q_{AS} and Q_{AL} known, the shelter air condition for the next time period now can be calculated by adding Q_{AS} and Q_{AL} to the overall heat balance equation in (1).

8. REFERENCES

1. T. Kusuda and P. R. Achenbach, Numerical Analysis of the Thermal Environment of Occupied Underground Spaces with Finite Cover Using a Digital Computer, Trans. ASHRAE, 69, 439-452(1963).
2. P. R. Achenbach, T. Kusuda, and F. J. J. Drapeau, Mathematical Analysis of Thermal Environment in Underground Shelters, ASHRAE Sym. on Survival Shelters, 9-33(1962).
3. P. R. Achenbach, F. J. J. Drapeau, and C. W. Phillips, Studies of Environmental Factors in a Family-Size Underground Shelter, OCDM-NBS-60-1, National Bureau of Standards, Washington, D. C., 20234.
4. University of Florida OCD Reports, OCD-OS-116, Simulated Occupancy Test.

Summerlin shelter	Jul. 5, 1962 - Jul. 18, 1962
Second Summerlin test	Apr. 9, 1963 - Apr. 20, 1963
Broyles shelter	Jul. 30, 1962 - Aug. 19, 1962
Napier shelter	Aug. 24, 1962 - Sep. 10, 1962
Reading shelter	Feb. 25, 1963 - Mar. 18, 1963
200-man shelter at Ft. Belvoir,	Sep. 22, 1963 - Oct. 16, 1963
1000-man shelter at Ft. Belvoir,	Oct. 16, 1963 - Oct. 31, 1963
5. Guide and Data Book, Am. Soc. of Heating, Refrigerating and Air Conditioning Engineers, pp 30-37, 1961 Ed.
6. J. G. Scarborough, Numerical Mathematical Analysis, The Johns Hopkins Press, 1958.
7. J. D. Bottorff, An Investigation of Thermal Conductivity and Rate of Moisture Migration in Soils, Ph.D. Thesis of Purdue Univ. (1951).

8. Survival Shelters, Chap. 30, 1964 ASHRAE Guide and Data Book.
pp. 333-352.
9. J. V. Beck, Calculation of Thermal Diffusivity from Temperature Measurements, Jour. of Heat Transfer, Transactions ASME, 85, Series C, 181-182(1963).
10. F. W. Hutchinson, A Rational Re-evaluation of Surface Conductance of Still Air, ASHRAE Transactions, 105-109(1964).
11. F. M. Flanigan, Use of Hydraulic Analogue, ASHRAE Jour. (Aug. 1961).
12. S. N. Ludwig, Step-by-Step Procedure to Determine Evaporation Capacities, Air Conditioning, Heating, and Ventilating (Mar. 1961).
13. T. Kusuda, Coil Performance Solutions Without Trial and Error, Air Conditioning, Heating, and Ventilating (Jan. 1960).

Computer Programs

Fortran listings of the computer programs developed for the heat transfer studies in underground protective shelters during the contract research are attached in the following pages. Except for M-3 program, the computer symbols are explained according to input and output sequences at the beginning of each program.

A complete set of input data and illustrative examples of output format for program M-4 are also shown.

Program M-1 Input and Output Symbols

- KP1: A matrix index marking the interface of earth and north wall.
- KP2: A matrix index marking the interface of earth and south wall.
- KP3: A matrix index marking the end of earth block outside the south wall.
- KQ1: A matrix index marking the interface of earth and east wall.
- KQ2: A matrix index marking the interface of earth and west wall.
- KQ3: A matrix index marking the end of earth block outside the west wall.
- KR1: A matrix index marking the interface of earth and shelter roof.
- KR2: A matrix index marking the interface of earth and shelter floor.
- KR3: A matrix index marking the end of earth block below the shelter floor.
- KP: Nearest integer to $(KP1 + KP2)/2$.
- KQ: Nearest integer to $(KQ1 + KQ2)/2$.
- KR: Nearest integer to $(KR1 + KR2)/2$.
- NN: Number of time increments.
- LC: Number of matrix points for shelter inner-wall.
- WC: Work cell for determining type of initial earth temperature data.
- WC = -1. : Depthwise variation
= 0. : Homogeneous earth temperature
= 1. : Six directional variations.
- TGI: A constant initial earth temperature when WC = 0.

TG1(I), TG2(I), TG3(I), TG4(I), TG5(I), TG6(I): Initial earth temperature profiles in earth blocks outside of north, south, east, west, roof and floor, respectively. °F

TC(L,M): Initial temperature distribution of the shelter inner wall, °F.

S(M): Shelter inner wall surface area, ft².

D(M): Thickness of shelter inner wall, ft.

ZL(M): Thickness of the earth block, ft.

CK(M): Thermal conductivity of shelter wall, Btu/hr,ft, °F

CG(M): Thermal conductivity of earth block, Btu/hr,ft, °F

AC(M): Thermal diffusivity of shelter wall, ft²/hr.

AG(M): Thermal diffusivity of earth block, ft²/hr.

H(M): Heat transfer coefficient at the shelter inner surface, Btu/hr,ft², °F.

HD(M): Mass transfer coefficient at the shelter inner surface, lb/hr, ft²(lb/lb).

EH(H): Heat transfer coefficient at the external side of the earth block, Btu/hr, ft², °F.

DB(N): Outdoor air dry-bulb temperature, °F.

TV(CN): Ventilation air dry-bulb temperature, °F.

DPV(N): Ventilation air dew-point temperature, °F.

Q(N): Solar radiation, Btu/hr,ft².

A: Shelter length (internal dimension), ft.

B: Shelter width (internal dimension), ft.

C: Shelter height (internal dimension), ft.

ZN1: Number of 600 Btu/hr occupants.
ZN2: Number of 400 Btu/hr occupants
ZN3: Number of 200 Btu/hr occupants
TA: Shelter air temperature, °F.
DPA: Shelter air dew-point temperature, °F.
PB: Barometric pressure, in. Hg.
BS: Total sensible heat emitted by non-human heat source, Btu/hr
BL: Total latent heat generated by non-human heat source, Btu/hr.
DGX: Finite Difference, earth length for N-S. Coordinate direction,
ft.
DGY: Finite Difference, earth length for E-W. Coordinate direction,
ft.
DGZ: Finite Difference, earth length for roof-floor coordinate
direction, ft.
DGX1: Modification of DGX for $KP1 < I < KP2$, ft.
DGY1: Modification of DGY for $KR1 < J < KR2$, ft.
DT: Finite difference inner wall time, hr.
V: Total interior volume of the shelter, cu ft.
G: Ventilation air rate, cfm.
ZN: Run identification number.
DTT: Finite difference time for earth block, hr.
TG(I,J,K) : Earth temperature °F.
N: Number of time iterations (subscript).
TM: Elapsed time, hr.
QVS: Sensible Heat Exchanged with Ventilation Air, Btu/hr.

QVL: Latent Heat Exchanged with Ventilation Air, Btu/hr.
QGS: Sensible Heat Generated within the shelter, Btu/hr.
QGL: Latent Heat Generated within the shelter, Btu/hr.
QWST: Heat Transferred to the shelter inner surfaces, Btu/hr.
QWLT: Latent Heat Transferred to the shelter inner surfaces, Btu/hr.
TWCT: Water Vapor Collected on the shelter inner surfaces, lb/hr.

TQVS, TQVL, TQGS, TQGL, TQWST, TQWCT, TTWCT: Cumulative values for
QVS, QVL, QGS, QGL, QWST, QWLT and TWCT, respectively.

AT(N) = TA Calculated shelter air dry-bulb temperature, °F.

RH(N) = RHA: Calculated shelter air relative humidity, %.

DP(N) = DPA: Calculated shelter air dew-point temperature, °F.

Subscript M refers to exposures such that

- M = 1: North wall and its region
- 2: South wall and its region
- 3: East wall and its region
- 4: West wall and its region
- 5: Roof and its region
- 6: Floor and its region.

Subroutine:

GN: Computes the moisture saturated air vapor pressure for a given
temperature using Goff and Gratch formula.

FN: Computes the boundary temperature by a finite difference formula.

QC: Computes the human metabolic heat by type of occupants as function
of temperature.

```

C UNDERGROUND FALLOUT SHELTER THERMAL ENVIRONMENT HEAT TRANSFER 11850000
C NATIONAL BUREAU OF STANDARDS PROJECT-10436 T.KUSUDA, 10.3 11850010
  DIMENSION TG(23,22,29),TC(10,6),QSUN(170,6),DB(170),TV(170)
  DIMENSION DPV(170),TG1(10),TG2(10),TG3(10),TG4(10),TG5(10) 11850030
  DIMENSION TG6(10),TGD(30),S(6),D(6),ZL(6),AG(6),AC(6),CK(6),CG(6) 11850040
  DIMENSION H(6),HD(6),HG(6),QWS(6),QWL(6),TQWS(6),TQWL(6),TWC(6) 11850050
  DIMENSION TTWC(6),QSUNT(6), AT(170),RH(170),DP(170),QSUNO(6) 11850060
  DIMENSION CD(6),E(6),Q(170)
  3 FORMAT(8F9.4) 11850070
  1 FORMAT(14I4,2F3.0) 11851
  99 READ 1,KP1,KP2,KP3,KQ1,KQ2,KQ3,KR1,KR2,KR3,KP,KQ,KR,NN,LC,KC 11851
  IF(WC) 2, 12,11 11850100
  12 READ 3,TGI 11850110
  GO TO 10 11850120
  2 GO TO 13 11850130
  11 READ 3,(TG1(I),I=1,KP1),(TG2(I),I=KP2,KP3),(TG3(J),J=1,KQ1) 11850140
  READ 3,(TG4(J),J=KQ2,KQ3),(TG5(K),K=1,KR1),(TG6(K),K=KR2,KR3) 11850150
  10 READ 3,((TC(L,M),L=1,LC),M=1,6) 11851
  READ 3,(S(M),M=1,6),(D(M),M=1,6),(ZL(M),M=1,6),(CK(M),M=1,6) 11850170
  READ 3,(CG(M),M=1,6),(AC(M),M=1,6),(AG(M),M=1,6),(H(M),M=1,6) 11850180
  READ 3,(HD(M),M=1,6),(HG(M),M=1,6) 11850190
  6 READ 3,(DB(N),N=1,NN),(TV(N),N=1,NN),(DPV(N),N=1,NN),(Q(N),N=1,NN) 11850400
  DO 55 M=1,6 11850410
  IF(HG(M))50,51,50 11850420
  51 DO 52 N=1,NN 11850430
  52 QSUN(N,M)=0. 11850440
  GO TO 55 11850450
  50 DO 54 N=1,NN 11850460
  54 QSUN(N,M)=C(N) 11850470
  5 CONTINUE 11850480
  9 READ 3,A,B,C,ZN1,ZN2,ZN3,TA,DPA,PB,BS,BL,DGX,DGY,DGZ,DGX1,DGY1,DT 11850490
  14 FORMAT(4F9.4) 11851
  READ 14,V,G,ZN,DTT] 11851
  GO TO 300 11850520
  13 READ 3,(TGC(K),K=1,KR3) 11850530
  GO TO 10 11850540
  15 FORMAT(43H1 UNDERGROUND FALLOUT SHELTER DATA) 11850550
  300 PRINT 15 11850560
  PRINT 16 11850570
  16 FORMAT(79H0 ZN A B C V G 11850580
  1 ZN1 ZN2 ZN3 DT) 11850590
  30 FORMAT(F9.0,F7.1,2F8.1,F10.0,F12.0,F7.0,3F6.2)
  PRINT 30,ZN,A,B,C,V,G,ZN1,ZN2,ZN3,DT 11850590
  PRINT 17 11850600
  17 FORMAT(64H0 M 1 2 3 4 5 11850610
  1 6) 11850620
  PRINT 18,(CK(M),M=1,6 ) 11850630
  18 FORMAT(10H0 CK(M) 6F10.3) 11850640
  19 FORMAT(10H0 CG(M) 6F10.3) 11850650
  20 FORMAT(10H0 AC(M) 6F10.3) 11850660
  21 FORMAT(10H0 AG(M) 6F10.3) 11850670
  22 FORMAT(10H0 D(M) 6F10.3) 11850680
  23 FORMAT(10H0 ZL(M) 6F10.3) 11850690
  24 FORMAT(10H0 S(M) 6F10.3) 11850700
  5 FORMAT(10H0 H(M) 6F10.3) 11850710
  26 FORMAT(10H0 HG(M) 6F10.3) 11850720
  27 FORMAT(10H0 HD(M) 6F10.3) 11850730
  PRINT19,(CG(M),M=1,6) 1185074
  PRINT20,(AC(M),M=1,6) 1185075
  PRINT21,(AG(M),M=1,6) 1185076

```

PRINT22,(D(M), M=1,6)	11850770
PRINT23,(ZL(M),M=1,6)	11850780
PRINT24,(S(M), M=1,6)	11850790
PRINT25,(H(M), M=1,6)	11850800
PRINT26,(HG(M),M=1,6)	11850810
PRINT27,(HD(M),M=1,6)	11850820
GO TO 100	11850830
C GROUND TEMPERATURE INITIALIZATION	11850840
100 IF(WC) 101,102,103	11850850
101 DO 104 I=1,KP3	11850860
DO 104 J=1,KQ3	11850870
DO 104 K=1,KR3	11850880
104 TG(I,J,K)=TGO(K)	11850890
GO TO 129	11850900
102 DO 105 I=1,KP3	11850910
DO 105 J=1,KQ3	11850920
DO 105 K=1,KR3	11850930
105 TG(I,J,K)=TGI	11850940
GO TO 129	11850950
103 DO 900 I=1,KP3	11850960
DO 900 J=1,KQ3	11850970
DO 900 K=1,KR3	11850980
IF(KP1-I) 111,106,106	11850990
106 IF(J-KQ1) 111,107,107	11851000
107 IF(KQ2-J) 111,108,108	11851010
108 IF(K-KR1) 111,109,109	11851020
109 IF(KR2-K) 111,110,110	11851030
110 TG(I,J,K) =TG1(I)	11851040
GO TO 900	11851050
111 IF(I-KP2) 117,112,112	11851060
112 IF(J-KQ1) 117,113,113	11851070
113 IF(KQ2-J) 117,114,114	11851080
114 IF(K-KR1) 117,115,115	11851090
115 IF(KR2-K) 117,116,116	11851100
116 TG(I,J,K) =TG2(I)	11851110
GO TO 900	11851120
117 IF(KQ1-J) 121,118,118	11851130
118 IF(K-KR1) 121,119,119	11851140
119 IF(KR2-K) 121,120,120	11851150
120 TG(I,J,K)=TG3(J)	11851160
GO TO 900	11851170
121 IF(J-KQ2) 125,122,122	11851180
122 IF(K-KR1) 125,123,123	11851190
123 IF(KR2-K) 125,124,124	11851200
124 TG(I,J,K)=TG4(J)	11851210
GO TO 900	11851220
125 IF(KR1-K) 127,126,126	11851230
126 TG(I,J,K)=TG5(K)	11851240
GO TO 900	11851250
127 IF(K-KR2) 900,128,128	11851260
128 TG(I,J,K)=TG6(K)	11851270
900 CONTINUE	11851280
1900 FORMAT(10F9.5)	
129 TM=0.0	
TQWST=0.	11851330
TQWLT=0.	11851340
TTWCT=0.	11851350
TQVS=0.	11851360
TQVL=0.	11851370
TQGS=0.	11851380

```

TQGL=0. 11851390
TTQSUN=0. 11851400
DO 152 M=1,6 11851410
TQMS(M)=0. 11851420
TQWL(M)=0. 11851430
TTWC(M)=0. 11851440
152 QSUNT(M)=0. 11851450
LLC=LC-1 11851
ZLC=LLC
C END OF INITIALIZATION 11851460
DO 800 N=1,NN 11851470
29 FORMAT (10F5.1) 11851
301 DO 28 M=1,6
28 PRINT 29, (TC(L,M),L=1,LC) 11851
PRINT 29, (TG(I,KQ,KR),I=1,KP1) 11851
PRINT 29, (TG(I,KQ,KR),I=KP2,KP3) 11851
PRINT 29, (TG(KP,J,KR),J=1,KQ1) 11851
PRINT 29, (TG(KP,J,KR),J=KQ2,KQ3) 11851
PRINT 29, (TG(KP,KQ,K),K=1,KR1) 11851
PRINT 29, (TG(KP,KQ,K),K=KR2,KR3) 11851
1501 FORMAT(16F5.1)
PRINT 1501, TG(1,1,1),TG(1,1,KR3),TG(1,KQ3,1),TG(1,KQ3,KR3),TG(KP3,1,1),TG(KP3,1,KR3),TG(KP3,KQ3,1),TG(KP3,KQ3,KR3),TG(KP1,KQ1,KR1),11851
TG(KP1,KQ1,KR2),TG(KP1,KQ2,KR1),TG(KP1,KQ2,KR2),TG(KP2,KQ1,KR1),TG(11851
1(KP2,KQ1,KR2),TG(KP2,KQ2,KR1),TG(KP2,KQ2,KR2) 11851
TM=TM+DTT 11851
PSV=GN(DPV(N)) 1185148
WV=0.622*PSV/(PB-PSV) 1185149
DTM=0. 11851
1..J5 DTM=DTM+DT 11851
DTA=0.2
TA1=40.0
IR=1 11851
405 QVS=1.08*G*(TA1-TV(N))
QGS=QG(TA1,ZN1,ZN2,ZN3,1.)+BS
QWST=0.
DO 153 M=1,6
UD(M)=D(M)/ZLC 11851
QWS(M)=H(M)*S(M)*(TA1-TC(1,M))
153 QWST=QWST+QWS(M)
GO TO (1153,406),IR 11851
1153 ZX=QGS-QVS-QWST 11851
IF(ZX) 400,401,402
402 TA1=TA1+DTA
ZX2=ABSF(ZX)
GO TO 405
400 TA2=TA1-DTA
ZX1=ABSF(ZX)
TA=(TA1*ZX2+TA2*ZX1)/(ZX1+ZX2)
IR=2 11851
TA1=TA 11851
GO TO 405
401 TA=TA1
406 DPA1=0.2
DPA1=40.0
IR=1 11851
409 PSA=GN(DPA1)
WA=0.622*PSA/(PB-PSA) 1185159
QVL=4780.*G*(WA-WV) 1185160
CWL1=0. 1185160
TWCT=0. 11851
DO 158 M=1,6 11851

```

157	PSW=GN(TC(1,M))	1105162
	WS=0.622*PSW/(PB-PSW)	1105163
	IF(WA-WS) 154,154,155	1105163
154	QWL(M)=0.	1105163
	GO TO 156	1105164
155	QWL(M)=1061.*ND(M)*S(M)*(WA-WS)	1105164
156	QWLT=QWLT+QWL(M)	1105164
	TWC(M)=QWL(M)/1061.	1105165
158	TWCT=TWCT+TWC(M)	1105165
	QGL=QG(TA,ZN1,ZN2,ZN3,0.)+BL	1105170
	GO TO (1158,413),IR	11051
1158	ZY=QGL-QVL-QWLT	11051
	IF(ZY) 410,411,412	
412	DPA1=DPA1+CDPA	
	ZY2=ABSF(ZY)	
	GO TO 409	
410	DPA2=DPA1-CDPA	
	ZY1=ABSF(ZY)	
	DPA=(DPA1+ZY2+DPA2+ZY1)/(ZY1+ZY2)	
	IR=2	11051
	DPA1=DPA	
	GO TO 409	11051
411	DPA=DPA1	
413	POA=GN(TA)	
	RHA=100.*PSA/POA	1105175
	DO 161 M=1,6	1105176
	TQWS(M)=TQWS(M)+QWS(M)*DT	1105176
	TQWL(M)=TQWL(M)+QWL(M)*DT	1105177
	ZW=CD(M)*(QWS(M)+QWL(M))/(CK(M)*S(M))+TC(2,M)	1105165
160	TC(1,M)=ZW	1105166
161	TTWC(M)=TTWC(M)+TWC(M)*DT	1105177
	TQWST=TQWST+QWST*DT	1105178
	TQWLT=TQWLT+QWLT*DT	1105178
	TTWCT=TTWCT+TWCT*DT	1105179
	TQGS=TQGS+QGS*DT	1105179
	TQGL=TQGL+QGL*DT	1105180
	TQVS=TQVS+QVS*DT	1105180
	TQVL=TQVL+QVL*DT	1105181
C	CONCRETE WALL TEMPERATURE DISTRIBUTION	1105202
	DO 164 M=1,6	1105203
	E(M)=AC(M)*DT/DD(M)**2	1105204
	DO 164 L=2,LLC	11051
164	TC(L,M)=E(M)*(TC(L-1,M)+TC(L+1,M)+(1./E(M)-2.)*TC(L,M))	1105206
	IF(DTM-DTT) 1405,1164,1164	11051
C	GROUND AND CONCRETE BOUNDARY TEMPERATURES	1105207
1164	DO 165 J=KQ1,KQ2	11051
	DO 165 K=KR1,KR2	1105209
	TG(KP1,J,K)=FN(CK(1),CG(1),TC(LLC,1),TG(KP1-1,J,K),DD(1),DGX,0.)	11051
165	TG(KP2,J,K)=FN(CK(2),CG(2),TC(LLC,2),TG(KP2+1,J,K),DD(2),DGX,0.)	11051
	DO 165 I=KP1,KP2	1105212
	DO 166 K=KR1,KR2	1105213
	TG(I,KQ1,K)=FN(CK(3),CG(3),TC(LLC,3),TG(I,KQ1-1,K),DD(3),DGY,0.)	11051
166	TG(I,KQ2,K)=FN(CK(4),CG(4),TC(LLC,4),TG(I,KQ2+1,K),DD(4),DGY,0.)	11051
	DO 167 I=KP1,KP2	1105216
	DO 167 J=KQ1,KQ2	1105217
	TG(I,J,KR1)=FN(CK(5),CG(5),TC(LLC,5),TG(I,J,KR1-1),DD(5),DGZ,0.)	11051
167	TG(I,J,KR2)=FN(CK(6),CG(6),TC(LLC,6),TG(I,J,KR2+1),DD(6),DGZ,0.)	11051
	TC(ILC,1)=TG(KP1,KQ,KR)	11051
	TC(ILC,2)=TG(KP2,KQ,KR)	11051
	TC(ILC,3)=TG(KP,KQ1,KR)	11051
	TC(ILC,4)=TG(KP,KQ2,KR)	11051
	TC(ILC,5)=TG(KP,KQ,KR1)	11051
	TC(ILC,6)=TG(KP,KQ,KR2)	11051
	PRINT 1900,(TC(ILC,M),M=1,6)	11051

C GROUND TEMPERATURES

KP4 = KP3-1	1185220
KQ4 = KQ3-1	1185220
KR4 = KR3-1	1185220
DO 600 I=2,KP4	1185221
DO 600 J=2,KQ4	1185222
DO 600 K=2,KR4	1185223
IF(KP1-I) 173,168,168	1185224
168 IF(J-KQ1) 173,169,169	1185225
169 IF(KQ2-J) 173,170,170	1185226
170 IF(K-KR1) 173,171,171	1185227
171 IF(KR2-K) 173,172,172	1185228
172 AGG=AG(1)	1185229
IF(I-KP1) 500,600,600	
173 IF(I-KP2) 179,174,174	1185231
174 IF(J-KQ1) 179,175,175	1185232
175 IF(KQ2-J) 179,176,176	1185233
176 IF(K-KR1) 179,177,177	1185234
177 IF(KR2-K) 179,178,178	1185235
178 AGG=AG(2)	1185236
IF(KP2-I) 500,600,600	
179 IF(KQ1-J) 183,180,180	1185238
180 IF(K-KR1) 183,181,181	1185239
181 IF(KR2-K) 183,182,182	1185240
182 AGG=AG(3)	1185241
IF(J-KQ1) 500,590,590	
590 IF(I-KP1) 500,580,580	
580 IF(KP2-I) 500,600,600	
183 IF(J-KQ2) 187,184,184	1185243
184 IF(K-KR1) 187,185,185	1185244
185 IF(KR2-K) 187,186,186	1185245
186 AGG=AG(4)	1185246
IF(KQ2-J) 500,570,570	
570 IF(I-KP1) 500,560,560	
560 IF(KP2-I) 500,600,600	
187 IF(KR1-K) 189,188,188	1185248
188 AGG=AG(5)	1185249
IF(K-KR1) 500,550,550	
550 IF(I-KP1) 500,540,540	
540 IF(J-KQ1) 500,530,530	
530 IF(KQ2-J) 500,520,520	
520 IF(KP2-I) 500,600,600	
189 IF(K-KR2) 600,190,190	1185251
190 AGG=AG(6)	1185252
IF(KR2-K) 500,521,521	
521 IF(I-KP1) 500,522,522	
522 IF(J-KQ1) 500,523,523	
523 IF(KQ2-J) 500,524,524	
524 IF(KP2-I) 500,600,600	
500 IF(I-KP1) 502,502,503	1185252
503 IF(KP2-I) 502,502,504	1185252
504 DGX=DGX1	1185252
502 IF(J-KQ1) 501,501,505	1185252
505 IF(KQ2-J) 501,501,506	1185252
6 DGY=DGY1	1185252
501 EGX=AGG*DTT/(DGX**2)	11851
EGY=ACG*DTT/(DGY**2)	11851
EGZ=ACG*DTT/(DGZ**2)	11851
T1=TG(I-1,J,K)	1185256
T2=TG(I+1,J,K)	1185257

```

T3=TG(I,J-1,K) 1185
T4=TG(I,J+1,K) 1185
T5=TG(I,J,K-1) 1185
T6=TG(I,J,K+1) 1185
XX=EGX*(T1+T2)+EGY*(T3+T4)+EGZ*(T5+T6) 1185
YY=1.-2.*(EGX+EGY+EGZ) 1185
TG(I,J,K)=XX+TG(I,J,K)*YY 1185
600 CONTINUE 1185
C GROUND SURFACE TEMPERATURES 1185
DO 191 J=1,KQ3 1185
DO 191 K=1,KR3 1185
TG(I,J,K)=FN(HG(1),CG(1),DB(N),TG(2,J,K),1.,DGX,QSUN(N,1)) 1185
191 TG(KP3,J,K)=FN(HG(2),CG(2),DB(N),TG(KP3-1,J,K),1.,DGX,QSUN(N,2)) 1185
DO 192 I=1,KP3 1185
DO 192 K=1,KR3 1185
TG(I,1,K)=FN(HG(3),CG(3),DB(N),TG(I,2,K),1.,DGY,QSUN(N,3)) 1185
192 TG(I,KQ3,K)=FN(HG(4),CG(4),DB(N),TG(I,KQ3-1,K),1.,DGY,QSUN(N,4)) 1185
DO 193 I=1,KP3 1185
DO 193 J=1,KQ3 1185
TG(I,J,1)=FN(HG(5),CG(5),DB(N),TG(I,J,2),1.,DGZ,QSUN(N,5)) 1185
193 TG(I,J,KR3)=TG(I,J,KR3) 1185

AT(N)=TA 1185
RH(N)=RHA 1185
DP(N)=CPA 1185
WRITE OUTPUT TAPE 81,29,(TC(1,M),M=1,6),TG(1,1,1),TG(1,1,KR3)
WRITE OUTPUT TAPE 81,1900,FM
195 FORMAT(10H0 QWS(M) 6F15.0) 1135
196 FORMAT(10H0 TQWS(M) 6F15.0) 1185
197 FORMAT(10H0 QWL(M) 6F15.0) 1185
198 FORMAT(10H0 TQWL(M) 6F15.0) 1185
199 FORMAT(10H0 TWC(M) 6F15.0) 1185
200 FORMAT(10H0 TTW(M) 6F15.0) 1185
201 FORMAT(10H0 TC(1,M) 6F15.1) 1185
202 FORMAT(100H0 1 2 3 1185
1 4 5 6 ) 1135
203 FORMAT(100H1 N TM QVS QVL QGS 1185
1 QGL QWST QWLT ) 1185
204 FORMAT(100H1 TWCT TQVS TQVL 1185
1 TQGS TQGL TQWST ) 1185
205 FORMAT(100H1 TQWLT TTWCT TQSUN 1185
1 TTQSUN ) 1185
206 FORMAT(11 3,1F6.1,6F15.0) 1185
207 FORMAT(6F 15.2) 1185
208 FORMAT(5F 15.0) 1185
302 PRINT 203 1185
PRINT 206, N, TM, QVS, QVL, QGS, QGL, QWST, QWLT 1185
PRINT 204 1185
PRINT 207, TWCT, TQVS, TQVL, TQGS, TQGL, TQWST 1185
PRINT 205 1185
PRINT 208, TQWLT, TTWCT, TQSUN, TTQSUN 1185
PRINT 202 1185
PRINT 195, (QWS(M),M=1,6) 1185
PRINT 196, (TQWS(M),M=1,6) 1185
PRINT 197, (QWL(M),M=1,6) 1185
PRINT 198, (TQWL(M),M=1,6) 1185

```

PRINT 199,(TWC(M),M=1.6)	1185317
PRINT 200,(TTWC(M),M=1.6)	1185318
PRINT 201,(TC(1,M),M=1.6)	1185319
PRINT 204	1185320
209 FORMAT(100H	1185320
1 TA TV(N) DPV(N) DB(W)	1185320
DPFA RHA	1185340
PRINT 29, AT(N),DP(N),RH(N)	1185340
800 PRINT 207,TV(N),DPV(N),DB(N),TA,DPA,RHA	11851
801 DIMENSION AA(2),BB(2),TN(170)	1185340
303 AA(1)=0.0	1185340
AA(2)=500.	1185340
BB(1)=100.	1185340
BB(2)=50.	1185340
TM=0.	1185340
DD 90 N=1, NN	1185340
TM=TM+DTT	1185340
90 TN(N)=TM	1185340
CALL PLOT (3,NN, TN,AT, NN,TN,DP,2,AA,BB)	1185340
CALL SYSTEM	1185341
GOTO 99	1185341
ENC	1185341

Program M-2 Input and Output Symbols

- IX1: A matrix index marking the boundary between the shelter air space and surrounding earth (longitudinal direction)
- IX2: A matrix index marking the end of earth region along the longitudinal direction.
- IY1: A matrix index marking the boundary between the shelter air space and surrounding earth (transverse direction).
- IY2: A matrix index marking the end of earth region along the transverse direction.
- IZ1: A matrix index marking the boundary between the shelter air and roof earth region.
- IZ2: A matrix index marking the boundary between the shelter air and floor earth region.
- IZ3: A matrix index marking the end of earth of shelter floor region.
- CG: Thermal conductivity of earth, Btu/hr,ft, °F.
- AG: Thermal diffusivity of earth, ft^2/hr .
- DT: Finite difference time, hr
- DX: Finite difference length along the longitudinal direction, ft.
- DY: Finite difference length along the transverse direction, ft.
- DZ: Finite difference length along the vertical axis, ft.
- DTG: Finite difference time for computing the ground surface heat exchange, (modification of DT), hr.
- A, B, C: Internal dimensions of shelter, ft.

CFM: Shelter ventilation air, cu.ft/min.

HV = (60) (specific heat of air)(density of air) = 1.08 for standard
air, Btu/hr, °F, CFM.

WG: Work cell for ground surface temperature calculation
if WG < 0, ground surface temperature = outdoor air temperature.
if WG > 0, ground surface temperature is computed by solar heat,
convection heat and conduction heat.

RUN: Run number.

HW: Vertical wall surface heat transfer coefficients, Btu/hr, ft², °F.

HR: Ceiling surface heat transfer coefficient, Btu/hr, ft², °F.

HF: Floor surface heat transfer coefficient, Btu/hr, ft², °F.

HG: Ground surface heat transfer coefficient, Btu/hr, ft², °F.

TSW, TSR, TSF: Initial surface temperatures of wall, ceiling and floor
respectively, °F.

TA: Shelter air temperature, °F.

DPA: Shelter air dew point temperature, °F.

ZN1: Number of 600 Btu/hr occupants.

ZN2: Number of 400 Btu/hr occupants.

ZN3: Number of 200 Btu/hr occupants.

BS: Sensible heat generated in the shelter by non-human source,
Btu/hr.

BL: Latent heat generated in the shelter by non-human source,
Btu/hr.

PB: Barometric pressure, in. hg.

L1: If positive, initial ground temperature varies with depth.

L2: If positive, outdoor thermal environment is constant.
 L3: If positive, ground temperature will be printed out only at the end of total time iteration.
 L4: If positive, ventilation air rate varies with time.
 L5: If positive, number of 600 Btu/hr occupants varies with time.
 L6: If positive, number of 400 Btu/hr occupants varies with time.
 L7: If positive, number of 200 Btu/hr occupants varies with time.
 L8: Strength of non-human heat source and sink will vary with time.
 NN: Total number of time iterations.
 PPT2: Work cell for two different kinds of data input formats.
 ZLW: Lewis number for wall = 1.
 ZLR: Lewis number for roof = 1.
 ZLF: Lewis number for floor = 1.
 TG ϕ : Constant initial earth temperature, when $L1 \leq 0$, °F
 TG(K) ϕ : Depthwise variation of initial earth temperature when $L1 > 0$, °F.
 DB ϕ : Constant outdoor air dry-bulb temperature, °F, when $L2 \leq 0$.
 TV ϕ : Constant ventilation air dry-bulb temperature, °F, when $L2 \leq 0$.
 QSUN ϕ : Constant solar radiation, Btu/hr, ft², when $L2 \leq 0$.
 DPV ϕ : Constant ventilation air dew-point temperature, °F, when $L2 \leq 0$.
 DB(N): Outdoor air dry-bulb temperature (time dependent), °F.
 TV(N): Ventilation air dry-bulb temperature (time dependent), °F.
 DPV(N): Ventilation air dew-point temperature (time dependent), °F.
 QSUN(N): Solar irradiation (time dependent), Btu/hr ft².
 DN(N): Ventilation air rate (time dependent), cfm.
 ZN1N(N): Number of 600 Btu/hr occupants (time dependent).

ZN2N(N): Number of 400 Btu/hr occupants (time dependent).

QN3N(N): Number of 200 Btu/hr occupants (time dependent).

BSS(N): Sensible heat due non-human heat source (time dependent), Btu/hr.

BLL(N): Latent heat due non-human heat source (time dependent), Btu/hr.

QX: Heat flux on wall normal to longitudinal axis, Btu/hr ft².

QY: Heat flux on wall normal to transverse axis, Btu/hr ft².

QYP: Heat flux on ceiling surface, Btu/hr ft².

QZF: Heat flux on floor surface, Btu/hr ft².

TM: Elapsed time, hr.

STM(N): Mean surface temperature, °F.

ST1(N): Average temperature of the surface normal to longitudinal axis, °F.

ST2(N): Average temperature of the surface normal to transverse axis, °F.

ST3(N): Average surface temperature of ceiling, °F.

ST4(N): Average surface temperature of floor, °F.

RHA(N): Shelter air relative humidity, %.

TAA(N): Shelter air dry-bulb temperature, °F.

Y(N): Elapsed time = TM, hr.

```

C SIMPLIFIED SYMMETRIC SHELTER HEAT TRANSFER ANALYSIS ,T.KUSUCA 118510
C RECTANGULAR PARALLELEPIPED SHALLOW UNDERGROUND 118510
C S=TOTL SHELTER HEAT TRANSFER SURFACE, SQ,FT 118510
C CFM=VENTILATION AIR RATE ,HV=1.08 SENSIBLE 118510
CG =TOTAL HEAT GENERATED INSIDE THE SHELTER 118510
WG =WORK CELL, IF WG=0.,GROUND SURFACE=DB(N),IF NONZERO,CALCULATE 118510
C IF L1=0 TGO(K)=TGCC 118510
C IF L2=0 DB(N)=DB0, TV(N)=TVO, QSUN(N)=QSUN0 118510
C IF L3=0 PRINT TEMPERATURE AT EVERY TIME INTERVAL 118510
C IF L4=1 READ CFM FOR EACH TIME PERIOD 11851B
C IF L5=1 READ ZN1 FOR EACH TIME PERIOD 11851B
C IF L6=1 READ ZN2 FOR EACH TIME PERIOD 11851B
C IF L7=1 READ ZN3 FOR EACH TIME PERIOD 11851B
C IF L8=1 READ BS AND BL FOR EACH TIME PERIOD 11851B
DIMENSION STM(300),ST1(300),ST2(300),ST3(300),ST4(300)
DIMENSION DPV(300),Y(300),EB(2),EC(2),RHA(300)
DIMENSION T(20,20,40),TGO(40),DB(300),TV(300),QSUN(300)
DIMENSION TAA(300),V(300),DN(300),ZN1N(300),ZN2N(300),ZN3N(300)
DIMENSION BSS(300),BLL(300)
500 FORMAT(72H 11851B
1 11851B
READ 500 11851B
PRINT 500 11851B
201 FORMAT(10F7.0) 118510
202 FORMAT(10I7) 118510
199 READ 202,IX1,IX2,IY1,IY2,IZ1,IZ2,IZ3 118510
READ 201,CG,AG,CT,DX,DY,DZ,DTG,A,B,C 118513
READ 201, CFM,HV,WG,RUN,HW,HR,HF,HG 118513
READ 201,TSW,TSR,TSF,TA,DPA 118513
READ 201,ZN1,ZN2,ZN3,BS,BL,PB
READ 202,L1,L2,L3,NN,L4, L5,L6,L7 118510
READ 201, CPT2
READ 201,ZLW,ZLR,ZLF
IF(L1) 203,203,204 118510
203 READ 201,TGO0 118510
DO 205 K=1,IZ3 118510
205 TGO(K)=TGO0 118510
GC TO 206 118510
204 READ 201,(TGO(K),K=1,IZ3) 118510
206 IF(L2) 207,207,208 118510
207 READ 201,DB0,TVO,QSUN0,DPV0 118510
DO 209 N=1,NN 118510
DB(N)=DB0 118510
TV(N)=TVO 118510
DPV(N)=DPV0 11851
209 QSUN(N)=QSUN0 118510
GC TO 210 118510
208 IF(OPT2) 401,400,401
400 READ 402,(DB(N),N=1,NN),(TV(N),N=1,NN),(DPV(N),N=1,NN),(QSUN(N),N=
11,NN)
402 FORMAT (8F9 )
GC TO 210
401 READ 201,(DB(N),N=1,NN) 118510
READ 201,(TV(N),N=1,NN) 11851
READ 201,(DPV(N),N=1,NN) 11851B
IF (WG) 61,61,60 11851B
60 READ 201,(QSUN(N),N=1,NN) 11851B
61 IF (L4) 63,63,62 11851B
62 READ 201,(DN(N),N=1,NN) 11851B
63 IF (L5) 65,65,64 11851B

```

```

64 READ 201,(ZM1N(N),N=1,NN) 118518
65 IF (L6) 67,67,66 118518
66 READ 201,(ZM2N(N),N=1,NN) 118518
67 ZF(L7) 69,69,68 118518
68 READ 201,(ZM3N(N),N=1,NN) 118518
69 READ 202, LB 118518
   IF(L8) 210,210,70 118518
70 READ 201,(BSS(N),N=1,NN) 118518
   READ 201,(BLL(N),N=1,NN) 118518
210 DO 300 K=1,IZ3 118510
   DO 300 J=1,IY2 118510
   DO 300 I=1,IX2 118510
211 IF(I-IX1) 212,216,216 118510
212 IF(J-IY1) 213,216,216 118510
213 IF(I-Z1-K) 214,216,216 118510
214 IF(K-IZ2) 215,216,216 118510
215 GO TO 300 118510
216 T(I,J,K)=TGD(K) 118510
300 CONTINUE 118510
   PRINT 217,RUN 118510
217 FORMAT(50H1 SYMMETRICAL SHELTER HEAT TRANSFER,RUN F3.0 )118510
   PRINT 218 118510
218 FORMAT(65H0 S CFM TA HV HW 118510
   I HG )118510
   SR=A*B 118513
   SF=SR 118513
   SW=(A+B)*2.*C 118513
   S=SW+SR*SF 118513
   PRINT 219,S,CFM,TA,HV,HW,HG 118513
650 FORMAT(100H0 WG HW HR HF ZJW )
   I ZLR ZLF DX DY DZ )
   PRINT 650
651 FORMAT(10F10.3)
   PRINT 651,WG,HW,HR,HF,ZLW,ZLR,ZLF,DX,DY,DZ
219 FORMAT(6F10.3) 118510
   PRINT 220 118510
220 FORMAT(55H0 DB(N) TV(N) QSUN(N) 118510
   DO 222 N=1,NN )118510
222 PRINT 221, DB(N),TV(N),QSUN(N) 118510
221 FORMAT(3F10.2) 118510
   READ 202,II,JJ,KK
C END OF DATA INPUT
   KX=IX2-1 118510
   KXX=IX1-1 118510
   KY=IY2-1 118510
   KYY=IY1-1 118510
   KZ=IZ3-1 118510
   KZI=IZ1-1 118510
   KZ2=IZ2-1 118510
   EX=AG*DT/(DX*DX) 118510
   EY=AG*DT/(DY*DY) 118510
   EZ=AG*DT/(DZ*DZ) 118510
   H1=HW*DX/CG 118513
   H2=HW*DY/CG 118513
   H3 =HR*DZ/CG 118513
   H4 =HF*DZ/CG 118513
   HGU=HG*DZ/CG 118510
   RO=1.-2.*EX*EY*EZ 118510
   RX=RO-2.*EX*H1
   RY=RO-2.*EY*H2

```

```

RZR=RO-2.*EZ*H3
RZF=RO-2.*EZ*H4
RG=1.-2.*(EZ)*(1.+HGU)*CTG/OT
TM=0.
END OF INITIALIZATION
PRINT 223
223 FCRMAT(100H0 RO RX RY RZR RZF 110510
1 HI HZ H3 H4
PRINT 229,RO,RX,RY,RZR,RZF,H1,H2,H3,H4
329 PRINT 228
228 FCRMAT(105H CG AG HGU DX OY 110510
1 DZ CT EX EY EZ 110510
PRINT 229,CG,AG,HGU,DX,DY,DZ,CT,EX,EY,EZ
229 FCRMAT(10F10.3) 110510
234 FCRMAT(20F6.1) 110510
XX=IX1
YY=IY1
ZZ=IZ2-IZ1
AA=CX*XX*2.
BB=DY*YY*2.
CC=DZ*ZZ
SX=AA*CC
SY=BB*CC
SZR=AA*BB
SZF=SZR
612 FCRMAT( 50H1 QX QY QZR QZF TM 110513
PRINT 612 110513
WA=W(DPA) 110513
WW=W(TSW) 110513
WR=W(TSR) 110513
WF=W(TSF) 110513
C START OF TIME ITERATION 110510
OO 907 N=1,NN 110510
IF (L4) 51,51,50 110510
50 CFM = ON(N) 110510
51 IF (L5) 53,53,52 110510
52 ZN1 = ZN1(N) 110510
53 IF (L6) 55,55,54 110510
54 ZN2 = ZN2(N) 110510
55 IF (L7) 71,71,56 110510
56 ZN3 = ZN3(N) 110510
71 IF (L8) 57,57,72 110510
72 BS=BSS(N) 110510
BL=BLL(N) 110510
57 TM=TM+DT 110510
IF(WA-WW)601,601,602 110513
602 ZZW=1061.*(WA-WW)/(TA-TSW+0.000C1)/0.243 110513
ZZW=ZZW/ZLW
GO TO 603 110513
601 ZZW=0.
603 IF(WA-WR)604,604,605 110513
605 ZZR=1061.*(WA-WR)/(TA-TSR+0.000C1)/0.243 110513
ZZR=ZZR/ZLR
GO TO 606 110513
604 ZZR=0.
606 IF(WA-WF)607,607,608 110513
608 ZZF=1061.*(WA-WF)/(TA-TSF+0.000C1)/0.243 110513
ZZF=ZZF/ZLF
GO TO 609 110513
607 ZZF=0.

```

```

609 TSM=(TSH*SW+TSR*SR+TSF*SF)/(SW+SR+SF) 118513
PW=TA
PR=TA
PF=TA
MX=H1*(1.+ZZW) 118513
MY=H2*(1.+ZZW) 118513
HZR=H3*(1.+ZZR) 118513
HZF=H4*(1.+ZZF) 118513
QUU=QSUN(N)*DZ/CG 118510
QS=CG(TA,ZN1,ZN2,ZN3,1.)+BS
TA1=TA+1.
CS1=CG(TA1,ZN1,ZN2,ZN3,1.)+BS
Y1=CS1-CS
Y2=CS+TA1-CS1*TA
CL=CG(TA,ZN1,ZN2,ZN3,0.)+BL
WV=WIDPV(N)
RX=RO-2.*EX*HX
RY=RO-2.*EY*HY
RZR=RO-2.*EZ*HZR
RZF=RO-2.*EZ*HZF
702 IF(L3)231,231,845
845 IF(N-NN) 245,231,231
231 PRINT 232 118511
232 FORMAT(50H1 EARTH TEMPERATURE ON Z-X PLANE AT J=1 118511
DC 235 K=1,I23 118511
235 PRINT 234,(T(I,1,K),I=1,IX2) 118511
PRINT 236 118511
236 FORMAT(50H1 EARTH TEMPERATURE ON Z-X PLANE AT J=J 118511
DC 237 K=1,I23 118511
237 PRINT 234,(T(I,J,K),I=1,IX2) 118511
PRINT 238 118511
238 FORMAT(50H1 EARTH TEMPERATURE ON Z-Y PLANE AT I=1 118511
DC 239 K=1,I23 118511
239 PRINT 234,(T(I,J,K),J=1,IY2) 118511
PRINT 240 118511
240 FORMAT(50H1 EARTH TEMPERATURE ON Z-Y PLANE AT I=II 118511
DC 241 K=1,I23 118511
241 PRINT 234,(T(II,J,K),J=1,IY2) 118511
PRINT 242 118511
242 FORMAT(50H1 EARTH TEMPERATURE ON X-Y PLANE AT K=KK 118511
DC 243 J=1,IY2 118511
243 PRINT 234,(T(II,J,KK),I=1,IX2) 118511
C EARTH TEMPERATURE BOUNDARIES 118511
245 DO 103 I=1,IX2 118511
DC 103 J=1,IY2 118511
IF(WG) 101,101,102 118511
101 T(I,J,1)=OB(N) 118511
GO TO 103 118511
102 TG = 0.
802 T(I,J,1)+2.*EZ*(T(I,J,2)+HGU*DB(N)+QUL)*DTG/DT+T(I,J,1)*RG
IF (TG-CF) 803,103,103
803 TG=YG+DTG
GO TO 802
103 T(I,J,23)=TGO(I23) 118511
YGO(I)=T(I2,1Y2,1)
UNDISTURBED EARTH TEMPERATURE
DC 104 I=2,KZ 118511
104 TGO(K)=EZ*(TGO(K-1)+TGO(K+1))+TGO(K)*(1.-2.*EZ) 118511
DC 105 K=2,KZ
DO 105 J=1,IY2 118511

```

105	T (IX2,J,K)=TGO(K)	118511
	DC 106 K=2,KZ	
	DO 106 I=1,IY2	
106	T(I,IY2,K)=TGO(K)	
	DC 900 K=2,KZ	118511
	DO 900 J=1,KY	118511
	DO 900 I=1,KX	118511
	P2=T(I+1,J,K)	118511
	P4=T(I,J+1,K)	118511
	P5=T(I,J,K-1)	118511
	P6=T(I,J,K+1)	118511
	IF(I-1) 1,1,2	118511
1	P1=P2	118511
	GO TO 3	118511
2	P1=T(I-1,J,K)	118511
3	IF(J-1) 4,4,3	118511
4	P3=P4	118511
	GO TO 6	118511
5	P3=T(I,J-1,K)	118511
6	PO=T(I,J,K)	118511
C	END OF PREPARATION	118511
	IFT(I-IX1) 7,11,11	118511
7	IF(J-IY1) 8,11,11	118511
8	IF(IZ1-K) 9,11,11	118511
9	IF(K-IZ2) 10,11,11	118511
10	GO TO 900	118511
11	IF(K-IZ1) 800,12,19	118511
12	IFT(I-IX1) 13,15,800	118511
13	IF(J-IY1) 14,18,800	118511
14	PO=EX*(P1+P2)+EY*(P3+P4)+2.*EZ*(P5+HZR*PR)+PO*RZR	118511
	GO TO 900	118511
15	IF(J-IY1) 16,17,800	118511
16	PO=(EX/3.)*(2.*P1+4.*P2)+EY*(P3+P4)+(EZ/3.)*(4.*P5+2.*P6)+PO*RO	118511
	GO TO 900	118511
17	PO=(EX/7.)*(6.*P1+8.*P2)+(EY/7.)*(6.*P3+8.*P4)+(EZ/7.)*(8.*P5+6.*P6)+PO*RO	118511
	GO TO 900	118511
18	PO=EX*(P1+P2)+(EY/3.)*(2.*P3+4.*P4)+(EZ/3.)*(4.*P5+2.*P6)+PO*RO	118511
	GO TO 900	118511
19	IFT(IZ2-K) 800,26,20	
20	IFT(I-IX1) 24,21, 800	118511
21	IF(J-IY1) 22,23, 800	118511
22	PO=EY*(P3+P4)+EZ*(P5+P6)+2.*EX*(P2+HX*PW)+PO*RX	118513
	GO TO 900	118511
23	PO=(EX/3.)*(2.*P1+4.*P2)+(EY/3.)*(2.*P3+4.*P4)+EZ*(P5+P6)+PO*RO	118511
	GO TO 900	118511
24	IF(J-IY1) 900,25, 800	118511
25	PO=EX*(P1+P2)+EZ*(P5+P6)+2.*EY*(P4+HY*PW)+PO*RY	118513
	GO TO 900	118511
26	IFT(I-IX1) 27,30,800	118511
27	IF(J-IY1) 28,29,800	118511
28	PO=EX*(P1+P2)+EY*(P3+P4)+2.*EZ*(P6+HZF*PF)+PO*RZF	118513
	GO TO 900	118511
29	PO=EX*(P1+P2)+(EY/3.)*(2.*P3+4.*P4)+(EZ/3.)*(2.*P5+4.*P6)+PO*RO	118511
	GO TO 900	118511
30	IF(J-IY1) 31,32,800	118511
31	PO=(EX/3.)*(2.*P1+4.*P2)+EY*(P3+P4)+(EZ/3.)*(2.*P5+4.*P6)+PO*RO	118511
	GO TO 900	118511
32	PO=(EX/7.)*(6.*P1+8.*P2)+(EY/7.)*(6.*P3+8.*P4)+(EZ/7.)*(8.*P5+6.*P6)+PO*RO	118511
	GO TO 900	118511

GC TO 900	110511
800 PC=EX*(P1+P2)+EY*(P3+P4)+EZ*(P5+P6)+PO*RO	110511
900 T(I,J,K)=PO	
910 ZT=0.	110511
ZN=0.	110511
DC 911 K=I21,I22	110511
DC 911 J=1,IY1	110511
ZT=ZT+T(I21,J,K)	110511
911 ZN=ZN+1.	110511
TSX=ZT/ZN	110511
ZT=0.	110511
ZN=0.	110511
DC 912 K=I21,I22	110511
DC 912 I=I,IX1	110511
ZT=ZT+T(I,IY1,K)	110511
912 ZN=ZN+1.	110511
TSY=ZT/ZN	110511
ZN=0.	110511
ZT=0.	110511
DC 913 I=1,IX1	110511
DC 913 J=1,IY1	110511
ZT=ZT+T(I,J,I21)	110511
913 ZN=ZN+1.	110511
TSZR=ZT/ZN	110511
ZN=0.	110511
ZT=0.	110511
DC 914 I=1,IX1	110511
DC 914 J=1,IY1	110511
ZT=ZT+T(I,J,I22)	110511
914 ZN=ZN+1.	110511
TSZF=ZT/ZN	110511
QX=HW*(1.+ZZW)*(PW-TSX)	110513
QY=HW*(1.+ZZW)*(PW-TSY)	110513
QZR=HR*(1.+ZZR)*(PR-TSZR)	110513
QZF=HF*(1.+ZZF)*(PF-TSZF)	110513
TSW=(TSX*SX+TSY*SY)/(SX+SY)	110513
TSF=TSZF	110513
TSR=TSZR	110513
TSM=(TSW*SW+TSR*SR+TSF*SF)/(SW+SR+SF)	110513
TA=(1.08*CFM+TV(T)+YZ+HW*TSW*SW+HR*TSR*SR+HF*YSF*SF)/(1.08*CFM-Y1)	110513
HW=SW+HR*SR+HF*SF	110513
QL=CG(TA,ZN1,ZN2,ZN3,0.)+BL	110513
WW=W(TSW)	110513
WR=W(TSR)	110513
WF=W(TSF)	110513
HW=HW/ZLW	
HR=HR/ZLR	
HF=HF/ZLF	
WA=(4780.*CFM*WV+QL+(1061.)*(WW*SW+HW*WR*SR+HR*WF*SF+HF))/0.243)/(4118513)	110513
I780.*CFM+(1061.)*(SW*HW+SR*HR+SF*HF)/0.243	110513
HW=HW*ZLW	
HR=HR*ZLR	
HF=HF*ZLF	
WS=W(TSP)	110513
IF(WA-WS) 610,610,611	110513
610 WA=(4780.*CFM*WV+QL)/(4780.*CFM)	110513
611 PSA = WA*PB/(WA+0.622)	110513
RHA(N)=100.*PSA/GW(TA)	
613 FORMAT(SF10.2)	110513
PRINT613,QX,QY,QZR,QZF,TA	110513

```

STM(N)=TSM
ST1(N)=TSX
ST2(N)=TSY
ST3(N)=TSZR
ST4(N)=TSZF
V(N)=TM
Y(N)=TM
907 TAA(N)=TA
PRINT 950
950 FCRPAT(100M1      TM      STM      ST1      ST2      ST3
1 ST4      RHA      TAA
DO 951 N=1,NN
951 PRINT 954,Y(N),STM(N),ST1(N),ST2(N),ST3(N),ST4(N),RHA(N),TAA(N)
954 FORMAT(8F10.2)
EB(1)=0.
EB(2)=500.
EC(1)=100.
EC(2)=40.
CALL PLOT(3,NN,Y,STM,NN,V,TAA,2,EB,EC)
901 CONTINUE
CALL SYSTEM
GC TO 199
END

```

118512'

118512'

118512'

Program M-4 Input and Output Symbols

NN: Total number of time iterations.

II: Number of ventilation air inlets where temperatures were observed.

JJ: Number of shelter air temperature stations.

KK: Total number of shelter inner surface temperature stations.

KWC: If ≤ 0 , Ft. Belvoir 1000-man shelter analysis.
If > 0 , Ft. Belvoir 200-man shelter analysis.

WC: If ≤ 0 , constant earth temperature, $TG\phi$, is read in.
If > 0 , six directional earth temperature profiles, $TG(I,M)$,
will be read in.

AI: If > 0 , air conditioning calculations are included.

WC1: If ≤ 0 , cfm varies with time.

WC2: If ≤ 0 , number of occupants varies with time.

$TG\phi$: Constant initial earth temperature, °F.

$TG(I,M)$: Six directional initial earth temperature profiles, °F.

$TC\phi(M)$: Initial inner wall temperatures, °F.

$TC(L,M)$: Initial temperature profile within the shelter inner walls, °F.

$S(K)$: Shelter inner surface area, ft^2 .

$DD(K)$: Finite difference length for inner wall, ft.

$DC(K)$: Finite difference length for earth region, ft.

$D(K)$: Thickness of the inner wall, ft.

$ZL(K)$: Thickness of the earth block, ft.

$AG(K)$: Thermal diffusivity of earth, ft^2/hr .

$AC(K)$: Thermal diffusivity of inner wall, ft^2/hr .

CK(K): Thermal conductivity of inner wall, Btu/hr ft, °F.
CG(K): Thermal conductivity of earth block, Btu/hr, ft, °F.
H(K): Heat transfer coefficient of the inner surface, Btu/hr, ft², °F.
HD(K): Vapor transfer coefficient of the inner surface, lb/hr, ft² (lb/lb).
DT: Finite difference time for inner wall temperature calculation, hr.
DTT: Finite difference times for earth temperature calculation, hr.
GS: Per capita sensible heat generation from non-human heat source,
Btu/hr, person.
GL: Per capita latent heat generation from non-human heat source,
Btu/hr, person.
GA: Recirculation air rate for conditioning, cu ft/min.
FR: Coil effectiveness of the air conditioner (dimensionless).
CF: Coil contact factor of the air conditioner (dimensionless).
DAIT: Coil leaving air temperature rise due to fan heat, °F.
TW1: Entering temperature of the coolant to the air conditioner
coil, °F.
XDB(N): Outdoor air dry-bulb temperature, °F.
TV(N): Ventilation air dry-bulb temperature, °F.
DPV(N): Ventilation air dew-point temperature, °F.
EG(K): Finite difference stability modulus for earth temperature
calculation, which should not exceed 0.5.
E(K): Finite difference stability modulus for shelter inner-wall
temperature calculation, which should not exceed 0.5.
EC(K): E(K).
TM: Elapsed time (hr).

QVS: Sensible heat carried out by ventilation air, Btu/hr.
QVL: Latent heat carried out by ventilation air, Btu/hr.
QGS: Sensible heat generated in the shelter, Btu/hr.
QGL: Latent heat generated in the shelter.
QWST: Sensible heat absorbed by shelter surface, Btu/hr.
QWLT: Latent heat absorbed by shelter surface, Btu/hr.
TWCT: Condensate collected in the shelter, lb/hr.
QAS: Sensible heat absorbed by the air conditioner, Btu/hr.
QAL: Latent heat absorbed by the air conditioner, Btu/hr.
TA: Shelter air dry-bulb temperature, °F.
DPA: Shelter air dew-point temperature, °F.
WBA: Shelter air wet-bulb temperature, °F.
RHA: Shelter air relative humidity, %.
EFS1: Shelter air effective temperature, °F.
TSM: Average shelter inner surface temperature, °F.
QWS(K): Sensible heat transferred to the Kth surface, Btu/hr.
QWL(K): Latent heat transferred to the Kth surface, Btu/hr.
TWC(K): Condensate collected onto the Kth surface, lb/hr.
FLX(K): Heat flux of the Kth surface, Btu/hr, ft².
TS(K): Average temperature of the Kth surface, °F.
TC(L,K): Temperature distribution in the Kth inner wall, °F.
TG(I,K): Temperature distribution in the Kth block of the earth.
TIME(N): Elapsed time for the observed date, hr.
CFM(N): Ventilation air rate used in the experiment (time dependent), cfm.
ZN(N): Number of occupants used in the experiments (time dependent).

X1: = DBV(N) - Observed ventilation air dry-bulb temperature, °F.
X2: = WBV(N) - Observed ventilation air wet-bulb temperature, °F.
DBS: Observed shelter dry-bulb temperature.
WBS: Observed shelter wet-bulb temperature.
ETS1: Shelter effective temperature based upon DBS and WBS.

Subscripts:

MwK = Type of wall exposure.

1. North wall
2. South wall
3. East wall
4. West wall
5. Floor
6. Roof

N = Time

L = Spatial matrix index for inner wall

I = Spatial matrix index for earth region

Subroutines:

(1) PREP: This subroutine is designed to accept observed data of prototype shelter and yield the psychrometrically processed mean shelter conditions in terms of temperature, humidity and heat flux. Following are the input data specific to this subroutine.

KWS: The first temperature entry for XWS table.

NWS: The total number of temperature entries for XWS table.

XWS(I): Saturated air humidity ratio table of Goff and Gratch, lb/lb.

XHA: The first temperature entry for XHA table.

NHA: The total number of temperature entries for XHA table.

XHA(I): Dry air enthalpy table of Goff and Gratch, Btu/lb.

KHS: The first temperature entry for moisture XHS table, °F.

NHS: The total number of temperature entries for XHS table.

XHS(I): Moisture saturated air enthalpy table of Goff and Gratch, Btu/lb.

KFS: The first temperature entry for the XFS table.

NFS: The total number of temperature entries for XFS table.

XFS(I): Factors relating the degree of saturation to the relative humidity.

KHW: The first temperature entry for the XHW table.

NHW: The total number of temperature entries for XHW table.

XHW(I): Liquid water enthalpy table of Goff and Gratch, Btu/lb.

KVA: The first temperature entry for the XVA table.

NVA: The total number of temperature entries for XVA table.

XVA(I): Dry air volume table of Goff and Gratch, cu ft/lb.

KVS: The first temperature entry for the XVS table.

NVS: The total number of temperature entries for XVS table.

XVS(I): Moisture saturated air volume table of Goff and Gratch, cu ft/lb.

KQS: The first temperature entry for the XQS table.

NQS: The total number of temperature entries for XQS table.

XQS(I): Per capita sensible heat table of human body, Btu/hr.

EDB(I): Dry-bulb temperature entries to ASHRAE effective temperature table, °F.

EWB(I): Wet-bulb temperature entries to ASHRAE effective temperature table, °F.

(2) STRCON: Subroutine to compute adiabatic shelter air conditions by accepting ventilation air dry- and wet-bulb temperatures and ventilation air flow rate.

(3) AIRCEN: Subroutine to compute sensible and latent heat absorption by accepting the following input data.

GA: Recirculation air rate, cfm.

CFM: Ventilation air rate, cfm.

DBS: Shelter air dry-bulb temperature, °F.

WBS: Shelter air wet-bulb temperature, °F.

DBV: Ventilation air dry-bulb temperature, °F.

WBV: Ventilation air wet-bulb temperature, °F.

TW1: Inlet temperature of the air conditioner coolant, °F.

E: Effectiveness of the air cooling coil.

CF: Contact factor of the air cooling coil.

DTA: Dry-bulb temperature rise of the air conditioner outlet air due to the fan heat, °F.

(4) FN: Boundary temperature calculation subroutine by a finite difference formula.

(5) EFTI: Subroutine for computing effective temperature by using the input data of dry- and wet-bulb temperatures.

(6) DBWBH: Subroutine for computing enthalpy of moist air using dry- and wet-bulb temperatures.

(7) DBWRH: Subroutine for calculating relative humidity for given dry- and wet-bulb temperatures and barometric pressure, PB (in. Hg).

- (8) DBWWBH: Subroutine to calculate wet-bulb temperatures and enthalpy of moist air based upon given values of the dry-bulb temperature and humidity ratio.
- (9) PV: Subroutine for calculating the vapor pressure in inches of Hg of saturated moist air at given temperatures.
- (10) DBWBDP: Subroutine for calculating the dew-point temperature and humidity ratio of moist air for given dry- and wet-bulb temperatures.
- (11) DBWPWB: Subroutine for calculating the wet-bulb temperature and humidity ratio when dry-bulb temperatures and dew-point temperatures are given.
- (12) TBLU: Table look-up and linear interpolation subroutine when the independent variable is incremented by unity.
- (13) XTBLU: Table look-up and linear interpretation subroutine when the incrementation of the independent variable is non-unity.

```

C ONE DIMENSIONAL SHELTER 11851003
C SUBROUTINE TO BE USED IN THE PROGRAM 11851004
C PREP(DT,II,JJ,KK,KWC,NN) 11851M03
C STRCON(DB,WB,G) ADIABATIC SHELTER AIR CONDITION CALCULATION
C AIRCON(GA,CFM,DBS,WBS,DBV,WBV,TWI,E,CF,QAS,QAL,DTA) 11851A02
C FUNCTION FN
C EFT1(DB,WB,EFX)
C DBWRH(DB,WB,H) GIVEN DB AND WB ,COMPUTE H 11851012
C DBWRH(DB,WB,PB,RH) GIVEN DB,WB,PB ,COMPUTE RH 11851014
C DBWBMH(DB,W,WB,H) GIVEN DB AND W ,COMPUTE WB AND H 11851011
C FUNCTION PV(X,PB) CALCULATE VAPOR PRESSURE FOR GIVEN DB AND PB 11851018
C DBHBP(DB,WB,DP,W) GIVEN DB AND WB ,COMPUTE DP AND W 11851010
C DBOPWB(DB,DP,WB,W) GIVEN DB AND DP, COMPUTE WB 11851013
C TBLU (X,KX,V,Y) KX=FIRST VARIABLE 11851015
C V=TABLE 11851016
C Y=VALUE FOR X 11851017
C XTBLU(X,DX,KX,LX,V,Y), DX=VARIABLE INCREMENT 11851005
C KX=FIRST VARIABLE 11851006
C LX=NUMBEROF ENTRIES 11851007
C V =TABLE 11851008
C Y =VALUE OBTAINED FOR X 11851009
C 1=NORTH,2=SOUTH,3=EAST,4=WEST,5=FLOOR,6=ROOF,J=ROOF MATRIX 11851008
C AI=0 - NO AIR CONDITIOING, +=AIR CONDITIONING
C WC=0-, CONSTANT TGO ,+=PROFILE 11851M12
C II =NUMBER OF VENTILATION TEMP. DATA 11851004
C JJ =NUMBER OF SHELTER TEMP. DATA 11851005
C KK =NUMBER OF WALL TEMP. DATA 11851006
C KWC += ZOOMAN INPUT ,0- =1000 MAN INPUT 11851007
C WCI=- OR 0 CFM VARIES
C WC2=- GR 0 ZN VARIES
C JT= FIRST ESTIMATE OF CONCRETE TIME
C DTT= EARTH TIME
C DIMENSICN XWS(150),XHA(150),XHS(150),XHW(150),XFS(150),XVA(150),XV 11851M04
C 1S(150),QS(50),CFM(300),ZM(300),
C 2DBV(300),DPV(300),WBV(300),DBC(3,300),WBC(2,300),PS(10,300),
C 3TV(300),DPC(300),LA(300,10),LB(300,10),XDB(300),EDB(100),EMB(100),
C 4ET(50,50),TWC(6),EC(6),EG(6),TS(6),TSS(6)
C 5 , TG(10,6),TC(5,6),S(6),D(6),DD(6),ZL(6),DG(6),AG(6),AC(6) 11851004
C 6,CK(6),CG(6),H(6),HD(6), QWS(6),QWL(6),TQWS(6),TQWL(6),TQW(6) 11851005
C 7, DX(6),CS(6),QW(6),FLX(6),E(6),AS(6),ES(6),TCO(6),TIME(300)
C COMMON XWS,XHA,XHS,XHW,XFS,KWS,KHA,KFS,KHW,KHS,EDB,EMB,ET, KET, 11851M09
C 1ET,QS,CO1,CO2,UO,TW,GS,GL,ZLEWS,CFM,DPS,DBS,WBS,ETS1,ETS2,WCC,CO3, 11851M10
C 2WCD,DPA,ZN,QG,QL,DBV,DPV,DBC,DPC,WBC, S,TA,DT,KWC,NN,XVA,
C 3XVS,XVA,KVS,PS,LA,LB,XDB,WBV,WCI,WC2 ,DTT
C 77 FORMAT(1H010F10.1)
C 1 FORMAT(10F7.0) 11851009
C 2 FORMAT(10I7) 11851010
C 12 FORMAT(43H1 UNDERGROUND FALLOUT SHELTER DATA ) 11851057
C 13 FORMAT(43H0 INITIAL EARTH TEMPERATURES ) 11851058
C 14 FORMAT(43H0 INITIAL CONCRETE WALL TEMPERATURE ) 11851059
C 15 FORMAT(43H1 TIME VARIABLES ) 11851060
C 16 FORMAT(43H0 DB(N) TV(N) DPV(N) QSUN(N) ) 11851061
C 17 FORMAT(4F10.1) 11851062
C 18 FORMAT(63H TG(1) TG(2) TG(3) TG(4) TG(5) TG(6) 11851063
C 1(6) ) 11851064
C 19 FORMAT(63H TC(1) TC(2) TC(3) TC(4) TC(5) TC(6) 11851065
C 1(6) ) 11851066
C 20 FORMAT(6F10.1) 11851067
C 124 FORMAT(43H1 PHYSICAL DATA USED FOR COMPUTATION ) 11851081
C 125 FORMAT(110H0S(K) D(K) ZL(K) CK(K) CG(K) AC(K) 11851082

```

```

1) AG(K) H(K) HD(K) )11851083
126 FORMAT(10F10.4) 11851084
64 FORMAT(16HO QWS(M) 6F15.1) 11851206
45 FORMAT(16HO QWL(M) 6F15.1) 11851207
8 FORMAT(16HO TWC(M) 6F15.1) 11851208
67 FORMAT(16HO FLX(M) 6F15.1) 11851209
68 FORMAT(16HO TS(M) 6F15.1) 11851210
69 FORMAT(14H CONC.TEMP. III, 6F15.1) 11851211
74 FORMAT(14H EARTH TEMP III, 6F15.1) 11851212
63 FORMAT(120H- EXPOSURES
1 3 4 5 1 2
203 FORMAT(100HO EG(1) EG(2) EG(3)
1 EG(4) EG(5) EG(6)
205 FORMAT(100HO EC(1) EC(2) EC(3)
1 EC(4) EC(5) EC(6)
204 FORMAT(10H 6F15.3)
210 FORMAT(50HO DBV DPV W8V CFM )11851M50
75 FORMAT(10F10.2)
76 FORMAT(60HO DBS DPS WBS RHS ET
2 TS )
7100 FORMAT(10H- )
62 FORMAT(10F10.0) 11851202
211 FORMAT(3F15.1)
158 FORMAT(50H- OBSERVED SHELTER CONDITION )11851M53
159 FORMAT(50H- CALCULATED SHELTER CONDITION )11851M55
5000 FORMAT(72H1
1
61 FORMAT(100HI TIME QVS QVL QGS QGL )
2 QWST QWLT TWCT QAS QAL
6000 FORMAT(50HI ADIABATIC SHELTER RESULTS )
7000 FORMAT(90HO TIME CFM ZN DBV W8V )
1 DBS WBS EFT )
7001 FORMAT(10F10.1)
8999 FORMAT(10F12.2)
READ 5000
PRINT 5000

READ 2, NN
READ 2, II, JJ, KK, KWC
59 READ 1, WC , AI , WC1, WC2 11851M33
PRINT 158
IF(WC) 3,3,4
3 READ 1, TGO 11851013
DO 5 M=1,5 11851M35
DO 5 I=1,10 11851015
5 TG(I, M)=TGO 11851016
GO TO 7 11851017
4 DO 1000 M=1,5 11851M38
1000 READ1, (TG(I, M), I=1, 10) 11851M36
7 READ1, (TCO(M), M=1, 6) 11851M37
DO 8 L=1,5 11851M39
DO 8 M=1,6 11851M40
8 TC(L, M)=TCO(M) 11851M41
11 READ 1, (S(K), K=1, 6) 11851043
READ 1, (GD(K), K=1, 6) 11851044
READ 1, (DG(K), K=1, 6) 11851045
READ 1, (D(K), K=1, 6) 11851046
READ 1, (ZL(K), K=1, 6) 11851047
READ 1, (AG(K), K=1, 6) 11851048
READ 1, (AC(K), K=1, 6) 11851049

```

READ 1,(CK(K),K=1,6)	11851050
READ 1,(CG(K),K=1,6)	11851051
READ 1,(HK(K),K=1,6)	11851052
READ 1,(HD(K),K=1,6)	11851053
PB=29.97	
READ 1,DT,DTT,GS,GL	
CO1=1.08	
CO2=4.5	
CO3=1050.	
UO=0.	
TW=70.	
ZLEMS=1.	
WCC=-1.0	
WCD=-1.0	
CALL PREP	
TIME(1)=0.	11851M15
DO 9 N=1,NN	
TV(N)=DBV(N)	
9 TIME(N)=TIME(N-1)+DTT	11851M31
IF(A1) 5005,5005,5006	
5006 READ 1, GA,ER,CF,DATT,TW1	
5005 CONTINUE	
PRINT 12	11851068
PRINT 13	11851069
PRINT 18	11851070
DO 21 I=1,10	11851071
21 PRINT 20,(TG(I,M),M=1,5)	
PRINT 14	11851073
PRINT 19	11851074
DO 22 L=1,5	11851075
22 PRINT 20,(TC(L,M),M=1,6)	11851076
PRINT 15	11851077
PRINT 16	11851078
DO 5015 N=1,NN	
5015 PRINT 20,XDB(N),TV(N),DPV(N)	
PRINT124	11851085
PRINT125	11851086
DO127 K=1,6	11851087
127 PRINT126,S(K),D(K),ZL(K),CK(K),CG(K),AC(K),AG(K),H(K),HD(K)	
26 DO 28 K=1,6	11851097
DX(K)=DD(K)	11851100
AS(K)=AC(K)	
28 CS(K)=CK(K)	11851101
DST=DT	11851102
DO 801 K=1,6	
801 E(K)=AC(K)*DT/(DD(K)*DD(K))	11851176
DO 802 K=1,5	
802 EG(K)=AG(K)*DTT/(DG(K)*DG(K))	11851184
ECMAX=E(1)	11851M16
JK=1	
DO 58 K=2,6	11851M17
IF(E(K)-ECMAX) 58,58,59	11851M18
59 ECMAX=E(K)	
JK=K	11851M20
58 CONTINUE	11851M21
IF(ECMAX-0.5) 91,91,92	11851M22
92 DST=0.4*DD(JK)*DD(JK)/AC(JK)	11851M23
DO 93 K=1,6	11851M24
93 E(K)=AC(K)*DST/(DD(K)*DD(K))	
91 CONTINUE	11851M26

```

PRINT 203
PRINT 204, (EG(K), K=1,5)
PRINT 205
PRINT 204, (E(K), K=1,6)
TM=0.
DO 202 K=1,6
201 TSS(K)=TC(2,K)
202 TS(K)=TC(i,K)
DO 800 N=1,NN
TM=TM+DTT
X1=DBV(N)
X2=WBV(N)
G=CFM(N)
ZP=DPV(N)
PSV=PV(ZP,PB)
WV=0.622*PSV/(PB-PSV)
11851105

DTM=0.
53 DTM=DTM+DST
IR=1
DTA=1.0
TA1=TA-20.
30 QVS=1.08*G*(TA1-TV(N))
11851108
11851111
11851109
11851112

CALL XTBLU(TA1,5.,60,9,QS,QGP)
QGS=(QGP+GS)*ZN(N)
IF(KTEST)6995,6995,6994
6994 CONTINUE
PRINT 8999,QGP,QGS
6995 CONTINUE
CALL OBDPWB(TA1,DPA,WBA,WT)
IF(AI) 5007,5007,5008
5008 CALL AIRCON(GA,G,TA1,WBA,X1,X2,TW1,ER,CF,QAS,QAL,DTAA)
GO TO 5009
5007 QAS=0.
QAL=0.
5009 CONTINUE

QWST=0.
DO 31 K=1,6
QWS(K) =H(K)*S(K)*(TA1-TS(K))
31 QWST= QWST +QWS(K)
11851114
11851115
11851116
11851117

GO TO (32,36),IR
32 ZX=QGS-QVS-QWST-QAS
11851118

```

```

IF(ZX) 34,35,33
33 TA1=TA1+DTA
ZX2=ABSF(ZX)
GO TO 30
34 TA2=TA1-DTA
ZX1=ABSF(ZX)
TA=(TA1+ZX2+TA2+ZX1)/(ZX1+ZX2)
IR=2
TA1=TA
GO TO 30
35 TA= TA1
36 DOPA=0.2
DPA1=DPA-10.
IR=1
37 PSA=PV(DPA1,PB)

```

11851120
11851121
11851122
11651123
11851124
11851125
11851126
11851127
11851128
11851129
11851130
11851131

11851133

```

WA=0.622*PSA/(PB-PSA)
QVL=4780.*G*(WA-WV)
CALL DBDPWB(TA,DPA1,WBA,WT)
IF(AI) 5010,5010,5011
5011 CALL AIRCONIGA,G,TA ,WBA,X1,X2,TW1,ER,CF,QAS,QAL,DTAA)
GO TO 5012
5010 QAS=0.
QAL=0.
5012 CONTINUE
QWLT=0.
TWCT=0.
DO 42 K=1,6
PSW=PV(TS(K),PB)
WS=0.622*PSW/(PB-PSW)
ZP=WA-WS
IF(ZP) 39,39,40
39 QWL(K)=0.
GO TO 41
40 QWL(K)=1061.*HD(K)*S(K)*ZP.
41 QWLT=QWLT+QWL(K)
TWC(K)=QWL(K)/1061.
42 TWCT=TWCT+TWC(K)
CALL XTBLU(TA,5.,60,9,QS,QGP)
QGL=(400.-QGP+GL)*ZN(N)

```

11851135
11851136

11851137
11651138
11851139

11851141
11851142
11851143
11851144
11851145
11851146
11851147
11851148
11851149

```

GO TO (43,47),IR
43 ZY=QGL-QVL-CWLT-QAL
IF(ZY) 45, 46,44
44 DPA1=DPA1+DOPA
ZY2=ABSF(ZY)
GO TO 37
45 DPA2=DPA1-DOPA
ZY1=ABSF(ZY)
DPA=(DPA1+ZY2+DPA2+ZY1)/(ZY1+ZY2)
IR=2
DPA1=DPA
GO TO 37

```

11851151

11851153
11851154
11851155
11851156
11851157
11851158
11851159
11851160
11851161
11851162

WB=WBA
CALL EFT1(DB,WB,EFS1)

```
DO 50 K=1,6 11851166
FLX(K)=(QWS(K)+QWL(K))/S(K) 11851167
ES(K)=AS(K)*DST/(DX(K)*DX(K))
TS(K)=2.*ES(K)*(FLX(K)*DX(K)/CS(K)+TSS(K)+TS(K)*(0.5*1./ES(K)-1.))
49 TC(1,K)=TS(K) 11851172
50 CONTINUE 11851173
IF(KTEST) 6985,6985,6984
6984 CONTINUE
PRINT 8999,(TS(K),K=1,6)
6985 CONTINUE
51 DO 52 L=2,4
DO 52 K=1,6
52 TC(L,K)=E(K)*(TC(L-1,K)+TC(L+1,K)+(1./E(K)-2.)*TC(L,K)) 11851178
DO 8002 K=1,6
8002 TC(L,K)=TC(2,K)

IF(DTM-DTT) 53,54,54 11851179
54 DO 55 K=1,5 11851180
TG(1,K)=FN(CK(K),CG(K),TC(4,K),TG(2,K),DD(K),DG(K),0.) 11851181
55 TC(5,K)=TG(1,K) 11851182
TG(1,6)=TC(4,6) 11851M46
TC(5,6)=TG(1,6) 11851M47
56 DO 57 I=2,9
DO 57 K=1,5
57 TG(I,K)=EG(K)*(TG(I-1,K)+TG(I+1,K)+(1./EG(K)-2.)*TG(I,K)) 11851186
60 PRINT 61 11851198
TSM=0.
DO 8001 K=1,6
8001 TSM=TSM+TS(K)
TSM=TSM/6.
PRINT 62 ,TM,QVS,QVL,QGS,QGL,QWST,QWLT,TWCT ,QAS,QAL
PRINT 159
PRINT 76
PRINT 75,TA,DPA,WBA,RHA,EFS1,TSM 11851M49
PRINT 63 11851203
PRINT 64,(QWS(K),K=1,6) 11851213
PRINT 65,(QWL(K),K=1,6) 11851214
PRINT 66,(TWC(K),K=1,6) 11851215
PRINT 67,(FLX(K),K=1,6) 11851216
PRINT 68,(TS(K),K=1,6) 11851217
PRINT 7100
71 DO 70 L=2,5 11851219
70 PRINT 69, L,(TC(L,K),K=1,6) 11851220
PRINT 7100
72 DO 73 I=1,10 11851221
```

73	PRINT 74,I,(TG(I,K),K=1,5)	11851222
	PRINT 210	
	PRINT 75,TV(N),DPV(N),WBV(N),CFM(N)	11851223
800	CONTINUE	
	PRINT 6000	
	PRINT 7000	
	DD 8000 N=1,NN	
	X1=DSV(N)	
	X2=WBV(N)	
	GM=CFM(N)	
	CALL SYRCON(X1,X2,GM)	
8000	PRINT 7001, TIME(N),CFM(N),ZN(N),X1,X2,DBS,WBS,ETS1	11851224
	CALL SYSTEM	
	END	

SUBROUTINE PREP

DIMENSION XWS(150),XHA(150),XHS(150),XHW(150),XFS(150),XVA(150),XV
 1S(150),QS(50),CFM(300),ZN(300),
 2DBV(300),DPV(300),DBC(3,300),DPC(300),PS(10,300)
 3 ,LA(300,10),LB(300,10),XDB(300),WBV(300),EDB(100),EWB(100
 4),ET(50,50),WBC(2,300),S(6)

COMMON XWS,XHA,XHS,XHW,XFS,KWS,KHA,KFS,KHW,KHS,EDB,EWB,ET, KET,N11851M0-9
 1ET,QS,CO1,CO2,UQ,TW,GS,GL,ZLEWS,CFM,DPS,DBS,WBS,ETS1,ETS2,WCC,CO3,11851M10
 2WCD,DPA,ZN,QG,QGL,DBV,DPV,DBC,DPC,WBC, S,TA,DT,KWC,NN,XVA,
 3XVS,KVA,KVS,PS,LA,LB,XDB,WBV,WC1,WC2 ,DTT

26	FORMAT(12OH0	TIME	DBV	WBV	DBS	WBS	HTX:
1	ET	QGT	QVT	QWT	QWS	TSM	
50	FORMAT(10I7)						11851002
52	FORMAT(7F10.1)						11851024
1	FORMAT(10F7.0)						11851011
2	FORMAT(10I7)						11851012
	READ 2,KWS,NWS						11851015
	READ 1,(XWS(I),I=1,NWS)						11851016
	READ 2,KHA,NHA						11851017
	READ 1,(XHA(I),I=1,NHA)						11851018
	READ 2,KHS,NHS						11851019
	READ 1,(XHS(I),I=1,NHS)						11851020
	READ 2,KFS,NFS						11851021
	READ 1,(XFS(I),I=1,NFS)						11851022
	READ 2,KHW,NHW						11851023
	READ 1,(XHW(I),I=1,NHW)						11851024
	READ 2,KVA,NVA						11851025
	READ 1,(XVA(I),I=1,NVA)						11851026
	READ 2,KVS,NVS						11851027
	READ 1,(XVS(I),I=1,NVS)						11851028
	READ 2,KQS,NQS						11851029
	READ 1,(QS(I),I=1,NQS)						11851030
	READ 1,(EDB(I),I=1,29)						
	READ 1,(EWB(I),I=1,30)						
	DO 73 I=1,29						
73	READ 1,(ET(I,J),J=1,30)						11851048
	IF(WC1) 4,6,5						
4	READ 1,(CFM(N),N=1,NN)						
	GO TO 6						
5	READ 1,CFM0						
	DO 7 N=1,NN						
7	CFM(N)=CFM0						
6	IF(WC2) 8,8,9						
8	READ 1,(ZN(N),N=1,NN)						
	GO TO 10						
9	READ 1,ZNO						
	DO 11 N=1,NN						
11	ZN(N)=ZNO						
10	CONTINUE						
28	FORMAT(12F10.2)						
	TIME=0.						11851018
	ST=S(1)+S(2)+S(3)+S(4)+S(5)+S(6)						
	IF(KWC) 61,61,62						11851F05
61	DO 300 N=1,NN						
	50,(LA(N,L),L=1,10)						
	READ 50,(LB(N,L),L=1,10)						
	GO TO 500						
50	READ 1,(DBV(N),N=1,240)						11851F09
	READ 1,(WBV(N),N=1,240)						11851F10
	READ 1,(DBC(I,N),N=1,240)						11851F12

READ 1, (WBC(1,N),N=1,240)	11851F13
READ 1, (DBC(2,N),N=1,240)	11851F14
READ 1, (WBC(2,N),N=1,240)	11851F15
READ 1, (DBC(3,N),N=1,240)	
READ 1, (XDB(N),N=1,240)	
DO 63 J=1,10	11851F18
63 READ 1, (PS(J,N),N=1,240)	11851F19
DO 600 N=1,240	
600 CFM(N)=CFM(N)/2.	
500 PRINT 26	11851014
DO 400 N=1,NN	
IF(KWC) 401,401,402	
401 DBV(N)=LA(N,1)/10	
X=DBV(N)	
WBV(N)=LA(N,2)/10	
Y=WBV(N)	
CALL DBWBDP(X,Y,Z,WQ)	11851010
DPV(N)=Z	
X=(LA(N,3)+LA(N,5)+LA(N,7)+LA(N,9))/40	11851012
DBSM=X	
Y=(LA(N,4)+LA(N,6)+LA(N,8)+LA(N,10))/40	11851014
WBSM=Y	
CALL DBWBDP(X,Y,Z,WQ)	11851016
DPSM=Z	
X=(LB(N,1)+LB(N,2)+LB(N,3)+LB(N,4)+LB(N,5)+LB(N,6)+LB(N,7)+LB(N,8)+LB(N,10))/90	11851018
IF(LB(N,4)) 53,53,54	11851019
53 X=X*9./8.	11851020
54 TSM=X	
XDB(N)=LB(N,9)/10	
GO TO 70	11851F07
402 X=DBV(N)	
Y=WBV(N)	
CALL DBWBDP(X,Y,Z,WD)	11851F23
DPV(N)=Z	
X=(DBC(1,N)+DBC(2,N)+DBC(3,N))/3.	
UBSM=X	
Y=(WBC(1,N)+WBC(2,N))/2.	
WBSM=Y	
CALL DBWBDP(X,Y,Z,WD)	11851F27
DPSM=Z	
SUM=0.	11851F31
SUN=0.	11851F32
DO 64 J=1,10	11851F23
IF(PS(J,N)) 64,64,66	11851F34
66 SUM=SUM+PS(J,N)	11851F35
SUN=SUN+1.	11851F36
64 CONTINUE	11851F37
67 TSM=SUM/SUN	
70 CONTINUE	11851F08
UPL(N)=UPSM	
TIME=TIME+DTT	
X=DBV(N)	
Y=DPV(N)	
Z=WBV(N)	
CALL TBLU(X,KWS,XWS,WSS)	11851106
CALL TBLU(Y,KWS,XWS,WSV)	11851107
CALL TBLU(X,KVA,XVA,VA1)	11851108
CALL TBLU(X,KVS,XVS,VS1)	11851109
V=VA1+(VS1-VA1)*WSV/WSS	11851110

CALL FBT1 (XX,ZZ,SET)	11851024
CALL TRLU(Y,Y,KWS,XWS,WSA)	11851113
CALL XTRLU (XX,5.,60,9,QS,QGS)	11851114
QGT=(400.+GS+GL)*ZN(N)	
QGS=QGS*7N(N)	11851118
WGL=(400.-QGS)*ZN(N)/1053.7	11851117
QVS=CFM(N)/V*0.24*60.*(XX-X)	11851115
WVL=CFM(N)/V*60.*(WSA-WSV)	11851116
QVT=QVS+WVL*1054.	11851026
QWS=QGS-QVS-GS	
QWT=QGT-QVT	
HTX=QWT/ST	11851027
RATIO=QWT/QGT	
PRINT 28,TIME,DBV(N),WBV(N),DBSM,WBSM,SET,QGT,QVT,QWT,QWS,TSM,	11851028
HTX	
400 CONTINUE	
TA=DBC(1,1)	
DPA=DPC(1)	
RETURN	
END	11851029

```

C   SHELTER AIR CONDITION CALCULATION                                11851E02
   SUBROUTINE STRCON(DB,WB,ZFM)
   DIMENSION XWS(150),XHA(150),XHS(150),XHW(150),XFS(150),
1EDB(100),EWB(100),ET(50,50),QS(50),CFM(300)                        11851E05
   COMMON XWS,XHA,XHS,XHW,XFS,KWS,KHA,KFS,KHW,KHS,CDB,EWB,ET,
3KET,NET,OS,CO1,CO2,UG,TW,GS,GL,ZLEWS,CFM,DPS,DBS,WBS,ETS1,ETS2  .11851028
4WCC,CO3,WCD
12 FORMAT(10H      ETS1 F10.2)
13 FORMAT(10H      ETS2 F10.2)
9  FORMAT(10H      QGL F10.2)
4  FORMAT(10H      DBS F10.2)
5  FORMAT(10H      QGS F10.2)
14 FORMAT(10H      DPS F10.2)
6  FORMAT(10H      TWS F10.2)
7  FORMAT(10H      DP F10.2)
11 FORMAT(10H     WBS F10.5)
10 FORMAT(10H     WA F10.5)
8  FORMAT(10H     WV F10.5)
   Y1=CO1*ZFM+UC
   Y2=CO1*ZFM*DB+UC*TW
   Y3=Y2/Y1
   IF(Y3-100.) 30,30,31
30 X1=Y3
3  X2=X1+0.5
   CALL XTBLU(X1,5.,60,9,QS,QS1)
   CALL XTBLU(X2,5.,60,9,QS,QS2)
   Z1=(QS1+GS)/Y1+Y3-X1
   Z2=(QS2+GS)/Y1+Y3-X2
   IF(Z2) 1,1,Z
2  X1=X2
   GO TO 3
1  Z2=ABS(Z2)
   DBS=X1+0.5*Z1/Z2/(1.+Z1/Z2)
   CALL XTBLU(DBS,5.,60,9,QS,QGS)
   GO TO 32
31 DBS=(1400.+GS+Y2)/(Y1+14.)
   QGS=-14.*(DBS-100.)
32 CONTINUE
   CALL TBLU(TW,KWS,XWS,TWS)
   CALL DBWBDP(DB,WB,DP,WV)
   QGL=400.-QGS
   ZF=ZLEWS*UD/0.243
   WA=((QGL+GL)/CO3+ZF*TWS+CO2*ZFM*WV)/(CO2*ZFM+ZF)
   IF(WCC) 19,20,20
20 PRINT 10,WA
19 CONTINUE
   IF(WA-TWS) 101,101,102
101 IF(WCD) 103,103,102
103 WA=WV+(QGL+GL)/(CO2*ZFM*CO3)
102 CALL DBWBDP(DBS,WA,WBS,H)
   IF(WCC) 21,22,22
22 PRINT 11,WBS
21 CONTINUE
   CALL DBWBDP(DBS,WBS,DPS,WA)
   IF(WCC) 23,24,24
   PRINT 14,DPS
   PRINT 10,WA
23 CONTINUE
   IF(WCC) 25,16,16
16 PRINT 4,DBS

```

```
PRINT 5,QGS  
PRINT 6,TWS  
PRINT 7, DP  
PRINT 8,WV  
PRINT 9,QGL  
PRINT 10,WA  
PRINT 11,WBS  
PRINT 14,DPS  
25 CONTINUE  
CALL EFT1(DBS,WBS,ETS1)  
IF(WCC) 15,17,17  
17 PRINT 12,ETS1  
15 RETURN  
END
```

```

FOR
SUBROUTINE AIRCON(GA,RW,SP,CF,GW,DBS,WBS,TWI,QAS,QAL,NROW) 11851001
C GA=AIR FLOW THROUGH COIL ,CFM 11851002
C GW=COOLANT FLOW (GPM/HR, * SPECIFIC HEAT) ,BTU/HR/DEG=500*GPM FOR H2O 11851004
C RW=COIL THERMAL RESISTANCE EXCLUDING AIR FILM RESISTANCE 11851005
C SP=COIL AIR SIDE HEAT TRANSFER SURFACE PER ROW 11851006
C CF=COIL CONTACT FACTOR PER ROW 11851007
C NROW= COIL ROWS 11851008
C DBS,WBS,=COIL INLET AIR DRY-AND WET-BULB TEMPERATURES 11851009
C TWI =COIL COOLANT ENTERING TEMPERATURE 11851010
C GAS =COIL SENSIBLE CAPACITY 11851011
C QAL =COIL LATENT CAPACITY 11851012
DIMENSION XWS(150),XHA(150),XHS(150),XHW(150),XFS(150),T(20),W(20) 11851013
1) ,TW(20),TAL(2),TWG(2),FGS(2) 11851014
COMMON XWS,XHA,XHS,XHW,XFS,KWS,KHA,KFS,KHW,KHS 11851015
T(1)=DBS 11851016
CALL DBWBDP(DBS,WBS,DPS,WX) 11851017
W(1)=WX 11851018
TWG(1)=DBS-1. 11851019
TWG(2)=TWG(1)-1. 11851020
A=SP/(RW*GA*CF*4.5) 11851021
7 DO 100 K=1,2 11851022
TW(1)=TWG(K) 11851023
DO 99 I=1,NROW 11851024
X=T(I) 11851025
Y=W(I) 11851026
Z=TW(I) 11851027
CALL SURFT(A,X,Y,Z,TSX,WSX) 11851028
T(I+1)=T(I)-(T(I)-TSX)*CF 11851029
Z=WSX-W(I) 11851030
IF(Z) 1,2,2 11851031
1 W(I+1)=W(I)-(W(I)-WSX)*CF 11851032
GO TO 3 11851033
2 W(I+1)=W(I) 11851034
3 TW(I+1)=TW(I)- (SP/(GW*RW))*(TSX-TW(I)) 11851035
99 CONTINUE 11851036
NZ=NROW+1 11851037
FGS(K)=TW(NZ)-TWI 11851038
100 TAL(K)=T(NZ) 11851039
TEST=FGS(1)*FGS(2) 11851040
IF(TEST) 4,5,6 11851041
6 TWG(1)=TWG(2) 11851042
TWG(2)=TWG(2)-1. 11851043
GO TO 7 11851044
5 TWL=TWG(1) 11851045
TL=TAL(2) 11851046
GO TO 98 11851047
4 C=ARCF(FGS(1)/FGS(2)) 11851048
TWL=(TWG(1)+TWG(2)*C)/(1.+C) 11851049
TL=(TAL(1)+TAL(2))/2. 11851050
98 GAS=1.08*GA*(DBS-TL) 11851051
QAL=GW*(TWL-TWI)-GAS 11851052
RETURN 11851053
END 11851054

```

		11851001
	SUBROUTINE SURFT(A,TA,WA,TW,TS,WS)	11851002
	SOLVE FOR TS FROM $0.243*(TA-TS)+1060.*(WA-WS)=A*(TS-TW)$	11851003
	DIMENSION XWS(150),XHA(150),XHS(150),XHW(150),XFS(150),Y(2),F(2)	11851004
	COMMON XWS,XHA,XHS,XHW,XFS,KWS,KHA,KFS,KHW,KHS	11851005
	Y(1)=TA	11851006
	Y(2)=TA-1.	11851007
5	DO 1 I=1,2	11851008
	P1=PV(Y(I),29.92)	11851009
	W=0.622*P1/(29.92-P1)	11851010
1	F(I)=A*(Y(I)-TW)-0.243*(TA-Y(I))+1060.*(WA-W)	11851011
	TEST=F(1)*F(2)	11851012
	IF(TEST) 2,3,4	11851013
4	Y(1)=Y(2)	11851014
	Y(2)=Y(2)-1.	11851015
	GO TO 5	11851016
3	TS=Y(2)	11851017
	GO TO 10	11851018
2	C=ABS(F(1)/F(2))	11851019
	TS=(Y(1)+Y(2)*C)/(1.+C)	11851020
10	P1=PV(TS,29.92)	11851021
	WS=0.622*P1/(29.92-P1)	11851022
	RETURN	11851023
	END	11851024

```
FUNCTION FN(X1,X2,Y1,Y2,Z1,Z2,Z3)
P1= X1*Y1/Z1 +X2*Y2/Z2 + Z3
P2= X1/Z1 + X2/Z2
FN=P1/P2
RETURN
END
```

```
11853720
11853730
11853740
11853750
11853760
```

EFFECTIVE TEMPERATURE CALCULATION

SUBROUTINE EFT1(DB,WB,EFX)

DIMENSION XWS(150),XHA(150),XHS(150),XHW(150),XFS(150),

FDB(100),EWB(100),ET(50,50)

COMMON XWS,XHA,XHS,XHW,XFS,KWS,KHA,KFS,KHW,KHS,EDB,EWD,ET,KET,NET

IF(DB-WB) 1,1,2

1 EFX=DB

GO TO 15

2 IF(DB-EDB(29)) 3,4,4

11851 44

3 EFX=0.

GO TO 15

4 IF(WB-EWB(30)) 3,5,5

5 IF(DB-EDB(1)) 6,6,7

7 EFX =100.

GO TO 15

6 IX=0

DO 8 I=1,29

IF(DB-EDB(I)) 9 ,10,10

11851 45

10 X1=EDB(I)

X2=EDB(I-1)

GO TO 11

9 IX=IX+1

8 CONTINUE

11 JY=0

DO 12 J=1,30

IF(WB-EWB(J)) 13,14,14

14 Y1=EWB(J)

Y2=EWB(J-1)

GO TO 15

13 JY=JY+1

12 CONTINUE

16 Z11=ET(IX+1,JY+1)

Z12=ET(IX,JY+1)

Z22=ET(IX,JY)

Z21=ET(IX+1,JY)

IF(Z11*Z12*Z22*Z21) 3,3,17

17 Z2=Z22+(DB-X2)*(Z21-Z22)/(X1-X2)

Z1=Z12+(DB-X2)*(Z11-Z12)/(X1-X2)

EFX =Z2+(WB-Y2)*(Z1-Z2)/(Y1-Y2)

15 RETURN

END

ENTHALPY CALCULATION BY DB AND WB	11851G02
SUBROUTINE DBWBH(DB,WB,H)	11851G03
DIMENSION XWS(150),XHA(150),XHS(150),XHW(150),XFS(150)	11851G04
COMMON XWS,XHA,XHS,XHW,XFS,KWS,KHA,KFS,KHW,KHS	11851G05
CALL TBLU (WB,KWS,XHS,WS)	11851G06
CALL TBLU (WB,KHW,XHW,MW)	11851G07
CALL TBLU (DB,KWS,XWS,WSS)	11851G08
CALL TBLU (DB,KHA,XHA,HA)	11851G09
CALL TBLU (WB,KHS,XHS,HS)	11851G10
CALL TBLU (DB,KHS,XHS,HSS)	11851G11
HAS=HSS-HA	11851G12
X=(HS-Hk*WS)*HAS-HA*HW*WSS	11851G13
Y=HAS-Hw*WSS	11851G14
H=X/Y	11851G15
RETURN	11851G16
END	

RELATIVE HUMIDITY CALCULATION BY DB AND WB	11851811
SUBROUTINE DHWRH(DB,WB,PB,RH)	11851812
DIMENSION XWS(150),XHA(150),XHS(150),XHW(150),XFS(150)	
COMMON XWS,XHA,XFS,XHW,XFS,KWS,KHA,KFS,KHW,KHS	11851814
CALL DBWBDP(DB,WB,DP,W)	
CALL TRLU(DB,KWS,XWS,WS)	11851817
ZM=W/WS	11851818
DBB=DB/10.	
CALL TBLU(DBB,KFS,XFS,FS)	
Z=PV(DB,PB)/PB	11851820
RH=100.*ZM/(1.-(1.-ZM)*FS*Z)	11851821
RETURN	11851822
END	

NET BULB CALCULATION BY DB AND W	11851F02
SUBROUTINE DBWBW(DB,W,WB,H)	
DIMENSION XWS(150),XHA(150),XHS(150),XHW(150),XFS(150)	
COMMON XWS,XHA,XHS,XHW,XFS,KWS,KHA,KFS,KHW,KHS	11851F05
CALL TBLU(DB,KHA,XHA,HA)	11851F06
CALL TBLU(DB,KHS,XHS,HS)	11851F07
CALL TBLU(DB,KWS,XWS,WS)	
IF(W-WS) 4,5,5	
5 WB=DB	
H=HS	
GO TO 6	
4 H=HA+W*(HS-HA)/WS	
X1=DB	11851F10
3 X2=X1-0.5	11851F11
CALL TBLU(X1,KHS,XHS,HS1)	11851F12
CALL TBLU(X2,KHS,XHS,HS2)	11851F13
CALL TBLU(X1,KWS,XWS,WS1)	11851F14
CALL TBLU(X2,KWS,XWS,WS2)	11851F15
CALL TBLU(X1,KHW,XHW,HW1)	11851F16
CALL TBLU(X2,KHW,XHW,HW2)	11851F17
Z1=HS1-HW1*(WS1-W)	11851F18
Z2=HS2-HW2*(WS2-W)	11851F19
IF(Z2-H) 1,1,2	
2 X1=X1-0.5	11851F21
GO TO 3	11851F22
1 WB=X2+0.5*(H-Z2)/(Z1-Z2)	
6 RETURN	
END	

VAPOR PRESSURE CALCULATION

FUNCTION PV(X,PB)
T=X+459.688
TS=671.689
TM1=-(7.90298)*(TS/T-1.)
TM2=(5.02808)*(LOG10(TS/T))
TM3=-(1.3816/(10.**7.))*(10.**((11.344*(1.-T/TS)))-1.)
TM4=(8.1328/1000.)*(10.**(-3.49149*(TS/T-1.))-1.)
ANS1=TM1+TM2+TM3+TM4
ANS2=10.**(ANS1)
PV=PB*ANS2
RETURN
END

11851H14
11851H15
11851H16
11851H17
11851H18
11851H19
11851H20
11851H21
11851H22
11851H23
11851H24
11851H25

DEW-POINT CALCULATION BY DB AND WB	11851002
SUBROUTINE DRRDRP(DB,WB,DP,W)	11851003
DIMENSION XWS(150),XHA(150),XHS(150),XHW(150),XFS(150)	11851004
COMMON XWS,XHA,XHS,XHW,XFS,KWS,KHA,KFS,KHW,KHS	11851005
IF(DB-WB) 1,1,2	11851006
1 DP=DB	11851007
CALL TBLU(DB,KWS,XWS,W)	11851008
GO TO 100	11851009
2 CALL TBLU(DB,KHA,XHA,HA)	11851010
IS FULL. GIVE ME ANOTHER A3 AND START.	
PERMANENT TAPE REDUNDANCY WAS DETECTED WHILE READING THE RECORD THAT PRODUCED	
CALL TBLU(DB,KHS,XHS,HS)	11851011
CALL TBLU(DB,KWS,XWS,WS)	11851012
CALL TBLU(WB,KHS,XHS,HSWB)	11851013
CALL TBLU(WB,KHW,XHW,HW)	11851014
CALL TBLU(WB,KWS,XWS,WSWB)	11851015
W=WS*(HSWB-HA-HW*WSWB)/(HS-HA-HW*WS)	11851016
Y1=WB	11851017
5 Y2=Y1-0.5	11851018
CALL TBLU(Y1,KWS,XWS,Z1)	11851019
CALL TBLU(Y2,KWS,XWS,Z2)	11851020
IF(Z2-W) 3,3,4	11851021
4 Y1=Y1-0.5	11851022
GO TO 5	11851023
3 DP=Y2+0.5*(W-Z2)/(Z1-Z2)	11851024
100 RETURN	11851025
END	

```
WET BULB CALCULATION BY DB AND DP          1185180
SUBROUTINE DBDPWB(DB,DP,WB,W)              1185180
DIMENSION XWS(150),XHA(150),XHS(150),XHW(150),XFS(150)
COMMON XWS,XHA,XHS,XHW,XFS,KWS,KHA,KFS,KHW,KHS          1185180
CALL TBLU(DP,KWS,XWS,W)                          1185180
CALL DBWBH(DB,W,WB,H)
RETURN                                          1185180
END
```

```
LINIER INTERPOLATION
SUBROUTINE TBLU(X,KX,V,Y)
DIMENSION V(150)
J=XINTF(X)
L=J-KX+2
LL=J-KX+1
VU=V(L)
VL=V(LL)
Y=(VU-VL)*(X-INTF(X))+VL
RETURN
END
```

```
11051H0
11051H0
11051H0
11051H0
11051H0
11051H0
11051H0
11051H0
11051H1
11051H1
```

```

SUBROUTINE XTBLU(X,DX,KX,LX,V,Y)
DIMENSION V(50)
J=XINTF(X)
M=KX+XINTF(DX)*(LX-1)
IF(J-KX) 1,2,2
1 Y=V(1)
GO TO 1C
2 IF(J-M ) 3,4,4
4 Y=V(LX)
GO TO 1C
3 DO 6 I=1,LX
Z=I
P=KX
Q=P+Z*DX
IF(X-Q) 5,5,6
5 Q1=V(I+1)
Q2=V(I)
Y=Q1-(Q1-Q2)*(Q-X)/DX
GO TO 1C
6 CONTINUE
10 RETURN
END

```

11851C0

11851C0
11851C0

11851C0
11851C0
11851C0
11851C1
11851C1

11851C2
11851C2

Sample Input and Output Data on M-4 Program

UNDERGROUND FALLCUT SHELTER DATA

INITIAL EARTH TEMPERATURES					
TG(1)	TC(2)	TG(3)	TG(4)	TG(5)	TG(6)
70.5	72.0	72.0	72.0	73.0	
70.0	72.0	72.0	72.0	72.0	
69.0	71.0	71.0	71.0	72.0	
67.0	70.0	70.0	70.0	71.0	
67.0	70.0	70.0	70.0	71.0	
67.0	70.0	70.0	70.0	70.0	
67.0	70.0	70.0	70.0	69.0	
67.0	69.0	69.0	69.0	68.0	
67.0	68.0	68.0	68.0	67.0	
67.0	67.0	67.0	67.0	67.0	

INITIAL CONCRETE WALL TEMPERATURE					
TC(1)	TC(2)	TC(3)	TC(4)	TC(5)	TC(6)
73.0	73.0	73.0	73.0	73.0	73.0
73.0	73.0	73.0	73.0	73.0	73.0
73.0	73.0	73.0	73.0	73.0	73.0
73.0	73.0	73.0	73.0	73.0	73.0
73.0	73.0	73.0	73.0	73.0	73.0

TIME VARIABLES

DR(N)	TV(N)	CPV(N)	QSUN(N)
70.0	76.0	57.2	
72.0	72.0	47.9	
74.0	74.0	61.9	
75.0	66.0	48.6	
77.0	68.0	55.0	
77.0	66.0	48.6	
76.0	64.0	48.2	
76.0	63.0	47.0	
75.0	62.0	43.5	
75.0	81.0	68.2	
75.0	91.0	71.8	
75.0	92.0	71.4	
77.0	93.0	71.0	
78.0	92.0	68.2	
79.0	88.0	69.9	
80.0	85.0	71.1	
80.0	81.0	71.3	
80.0	79.0	69.1	
80.0	77.0	68.4	
80.0	76.0	71.8	
80.0	79.0	70.6	
81.0	84.0	73.0	
81.0	87.0	71.9	
80.0	90.0	72.2	
82.0	92.0	71.4	
82.0	92.0	73.0	
83.0	88.0	73.0	
83.0	84.0	71.6	
83.0	82.0	72.3	
83.0	80.0	70.2	
83.0	79.0	69.1	
82.0	78.0	69.5	
82.0	80.0	70.2	
82.0	86.0	69.2	
82.0	91.0	71.8	
82.0	92.0	71.4	
83.0	92.0	69.8	
83.0	92.0	71.4	
84.0	88.0	71.4	
84.0	83.0	70.4	
84.0	81.0	69.8	
84.0	79.0	69.1	
84.0	80.0	71.7	
84.0	79.0	70.6	
84.0	81.0	71.3	
83.0	86.0	72.2	
83.0	90.0	70.6	
83.0	92.0	69.8	
84.0	92.0	71.4	
84.0	92.0	71.4	
85.0	88.0	71.4	
85.0	83.0	70.4	
85.0	80.0	70.2	
85.0	80.0	70.2	
84.0	79.0	72.1	
84.0	79.0	72.1	
84.0	79.0	72.1	

83.0	87.0	71.9
83.0	90.0	72.2
83.0	92.0	69.8
84.0	92.0	71.4
84.0	92.0	71.4
85.0	88.0	73.0
85.0	83.0	72.0
85.0	82.0	70.8
85.0	80.0	70.2
85.0	79.0	70.6
85.0	79.0	70.6
85.0	80.0	73.1
85.0	86.0	72.2
84.0	89.0	72.6
84.0	92.0	71.4
85.0	93.0	71.0
85.0	91.0	70.2
85.0	87.0	70.3
85.0	83.0	70.4
85.0	81.0	69.8
85.0	80.0	70.2
85.0	79.0	70.6
85.0	78.0	71.0
85.0	80.0	71.7
84.0	85.0	72.6
84.0	89.0	72.6
83.0	91.0	71.8
84.0	93.0	71.0
83.0	92.0	71.4
85.0	88.0	71.4
86.0	83.0	70.4
86.0	81.0	71.3
86.0	79.0	70.6
85.0	79.0	70.6
85.0	79.0	70.6
85.0	80.0	71.7
85.0	82.0	73.8
85.0	90.0	72.2
85.0	92.0	71.4
85.0	92.0	71.4
85.0	91.0	71.8
85.0	87.0	70.3
85.0	83.0	72.0
85.0	80.0	71.7
85.0	79.0	72.1
85.0	78.0	71.0
84.0	77.0	71.4
84.0	79.0	72.1
84.0	85.0	72.6
84.0	89.0	72.6
83.0	91.0	73.4
84.0	92.0	71.4
85.0	91.0	71.8
85.0	88.0	69.9
86.0	83.0	72.0
85.0	80.0	71.7
85.0	79.0	70.6
85.0	78.0	71.0
85.0	78.0	71.0
84.0	79.0	73.9

84.0	85.0	72.6
84.0	89.0	72.6
84.0	92.0	73.0
84.0	92.0	71.4
85.0	92.0	73.0
85.0	88.0	73.0
85.0	84.0	70.0
85.0	81.0	71.3
85.0	80.0	70.2
85.0	78.0	71.0
84.0	78.0	71.0
85.0	80.0	71.7
84.0	85.0	72.6
84.0	90.0	72.2
84.0	92.0	71.4
84.0	92.0	71.4
85.0	91.0	71.8
85.0	88.0	69.9
86.0	83.0	72.0
86.0	81.0	71.3
85.0	79.0	70.6
86.0	79.0	70.6
85.0	78.0	71.0
85.0	79.0	72.1
86.0	85.0	72.6
85.0	89.0	72.6
85.0	90.0	72.2
85.0	92.0	73.0
86.0	91.0	71.8
86.0	88.0	69.9
86.0	84.0	70.0
86.0	81.0	71.3
86.0	78.0	71.0
86.0	78.0	72.5
86.0	78.0	71.0
85.0	80.0	71.7
85.0	85.0	72.6
85.0	88.0	73.0
84.0	92.0	71.4
85.0	93.0	72.6
85.0	92.0	71.4
86.0	88.0	69.9
86.0	84.0	71.6
86.0	81.0	71.3
86.0	79.0	69.1
86.0	79.0	72.1
85.0	79.0	72.1
85.0	80.0	71.7
85.0	85.0	71.1
85.0	90.0	72.2
85.0	92.0	71.4
85.0	92.0	71.4
86.0	92.0	71.4
86.0	89.0	71.0
86.0	83.0	72.0
86.0	80.0	71.7
86.0	78.0	71.0
86.0	78.0	71.0
86.0	77.0	71.4
85.0	80.0	73.1

85.0	86.0	72.2
85.0	90.0	72.2
85.0	92.0	71.4
86.0	93.0	71.0
86.0	93.0	72.6
86.0	88.0	71.4
85.0	84.0	71.6
85.0	81.0	71.3
84.0	79.0	70.6
84.0	79.0	69.1
84.0	79.0	70.6
83.0	80.0	71.7
83.0	85.0	71.1
82.0	90.0	70.6
83.0	92.0	71.4
83.0	92.0	71.4
83.0	91.0	71.8
83.0	88.0	71.4
83.0	83.0	72.0
83.0	81.0	71.3
83.0	80.0	71.7
83.0	79.0	70.6
83.0	79.0	72.1
83.0	81.0	72.7
82.0	86.0	72.2
82.0	90.0	72.2

PHYSICAL DATA USED FOR COMPUTATION

(SK)	D(K)	7L(K)	CK(K)	CG(K)	AC(K)	AG(K)	H(K)	HD(K)
705.0000	0.8320	9.0000	1.1000	0.7500	0.0360	0.0170	1.0000	4.1000
705.0000	0.8320	9.0000	1.1000	0.7500	0.0360	0.0170	1.0000	4.1000
705.0000	0.8320	9.0000	1.1000	0.7500	0.0360	0.0170	1.0000	4.1000
705.0000	0.8320	9.0000	1.1000	0.7500	0.0360	0.0170	1.0000	4.1000
5520.0000	0.8320	9.0000	1.1000	0.7500	0.0360	0.0170	0.5000	2.0000
5520.0000	0.8320	9.0000	1.1000	0.7500	0.0360	0.0170	1.5000	6.2000

EG(1)	0.034	EG(2)	0.034	EG(3)	0.034	EG(4)	0.034	EG(5)	0.034
EC(1)	0.166	EC(2)	0.166	FC(3)	0.166	EC(4)	0.166	EC(5)	0.461
									EC(6)
									0.461

TIME 2. QVS 0. QVL 0. QGS 106991. QGL 109009. QMST 87773. QWLT 15897. TWCT 15. QAS 19190. QAL 90163.

CALCULATED SHELTER CONDITION

DBS 82.19 DPS 76.22 WBS 77.75 RBS 82.23 EBS 79.74 TS 75.67

EXPOSURES	1	2	3	4	5	6
QWS(M)	4678.7	4678.7	4678.7	4678.7	20201.7	48856.5
QWL(M)	1369.1	1369.1	1369.1	1369.1	10420.3	0.
TWC(M)	1.3	1.3	1.3	1.3	9.8	0.
FLX(M)	8.6	8.6	8.6	8.6	5.5	8.9
YS(M)	75.7	75.7	75.7	75.7	75.0	76.4
CONC. TEMP. 2	74.4	74.4	74.4	74.4	74.4	75.5
CONC. TEMP. 3	73.7	73.7	73.7	73.7	73.9	74.6
CONC. TEMP. 4	73.3	73.3	73.3	73.3	73.5	73.8
CONC. TEMP. 5	72.9	73.1	73.1	73.1	73.3	73.8
EARTH TEMP 1	72.9	73.1	73.1	73.1	73.3	73.3
EARTH TEMP 2	70.1	72.0	72.0	72.0	72.0	72.0
EARTH TEMP 3	69.C	71.0	71.0	71.0	71.0	71.0
EARTH TEMP 4	67.1	70.0	70.0	70.0	70.0	71.0
EARTH TEMP 5	67.C	70.0	70.0	70.0	70.0	70.0
EARTH TEMP 6	67.C	70.0	70.0	70.0	69.0	69.0
EARTH TEMP 7	67.C	69.0	69.0	69.0	68.0	68.0
EARTH TEMP 8	67.C	68.0	68.0	68.0	67.0	67.0
EARTH TEMP 9	67.C	67.0	67.0	67.0	67.0	67.0
EARTH TEMP 0	67.C	67.0	67.0	67.0	67.0	67.0

DRV 76.00 DPV 57.23 WBV 64.00 CFM 0.

TIME 24. -12+051. -370636. -123227. 92773. 41649. 0. 207623. 463408.

CALCULATED SHELTER CONDCITION

DBS DPS WBS RMS ET TS
 79.09 51.23 62.08 37.87 71.83 75.58

EXPOSURES	1	2	3	4	5	6
QWS(M)	2763.7	2473.7	2473.7	2473.7	12093.4	19370.5
QWL(M)	0.	0.	0.	0.	0.	0.
TWC(M)	0.	0.	0.	0.	0.	0.
FLX(M)	3.9	3.5	3.5	3.5	2.2	3.5
TS(M)	75.2	75.6	75.6	75.6	74.7	76.8

CONC. TEMP.	2	74.5	75.0	75.0	74.5	76.4
CONC. TEMP.	3	73.9	74.5	74.5	74.2	76.0
CONC. TEMP.	4	73.4	74.1	74.1	74.0	75.7
CONC. TEMP.	5	73.1	73.9	73.9	73.9	75.7

EARTH TEMP	1	73.1	73.9	73.9	73.9	73.9
EARTH TEMP	2	70.6	72.3	72.3	72.3	72.5
EARTH TEMP	3	68.9	71.1	71.1	71.1	71.9
EARTH TEMP	4	67.6	70.3	70.3	70.3	71.2
EARTH TEMP	5	67.1	70.1	70.1	70.1	70.8
EARTH TEMP	6	67.C	70.0	70.0	70.0	70.0
EARTH TEMP	7	67.C	69.7	69.7	69.7	69.0
EARTH TEMP	8	67.C	68.9	68.9	68.9	68.0
EARTH TEMP	9	67.C	68.0	68.0	68.0	67.3
EARTH TEMP	0	67.C	67.0	67.0	67.0	67.0

DBV WBS CFM
 92.00 77.00 9040.00

TIME 48. QVS -90920. QVL -573940. QCS 119939. QGL 90061. QWT 28741. QWLT C. THCT 0. QAS 191115. QAL 476000.

CALCULATED SHELTER CONCITION

DBS 79.77 DPS 52.00 WBS 62.67 RBS 33.10 ETS 72.41 TS 76.90

EXPOSURES	1	2	3	4	5	6
QWC(M)	2386.5	2034.8	2034.8	2034.8	11491.4	8759.1
QWL(M)	0.	0.	0.	0.	0.	0.
TWC(M)	0.	0.	0.	0.	0.	0.
FLX(M)	3.4	2.9	2.9	2.9	2.1	1.6
TS(M)	76.4	76.9	76.9	76.9	75.6	78.7
CONC. TEMP.	75.8	76.4	76.4	76.4	75.4	78.5
CONC. TEMP.	75.2	75.9	75.9	75.9	75.1	78.4
CONC. TEMP.	74.7	75.4	75.4	75.4	74.9	78.2
CONC. TEMP.	74.2	75.1	75.1	75.1	74.8	78.2
EARTH TEMP	74.2	75.1	75.1	75.1	74.8	78.5
EARTH TEMP	71.1	72.7	72.7	72.7	72.9	78.4
EARTH TEMP	69.2	71.3	71.3	71.3	71.9	78.2
EARTH TEMP	67.9	70.5	70.5	70.5	71.3	78.2
EARTH TEMP	67.3	70.1	70.1	70.1	70.7	78.2
EARTH TEMP	67.1	69.9	69.9	69.9	69.9	78.2
EARTH TEMP	67.0	68.5	68.5	68.5	68.0	78.2
EARTH TEMP	67.0	68.9	68.9	68.9	68.1	78.2
EARTH TEMP	67.0	68.0	68.0	68.0	67.4	78.2
EARTH TEMP	67.0	67.0	67.0	67.0	67.0	78.2

DBV 90.00 DPV 72.21 DBV 77.00 CFM 9040.00

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D		
<i>(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)</i>		
1. ORIGINATING ACTIVITY (Corporate author) National Bureau of Standards Institute for Applied Technology Washington, D. C. 20234		2a. REPORT SECURITY CLASSIFICATION N/A
		2b. GROUP N/A
3. REPORT TITLE COMPARISON OF DIGITAL COMPUTER SIMULATION OF THERMAL ENVIRONMENT IN OCCUPIED UNDERGROUND PROTECTIVE STRUCTURES WITH OBSERVED CONDITIONS		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Final Report - December, 1966		
5. AUTHOR(S) (Last name, first name, initial) Kusuda, Tamami Achenbach, Paul R.		
6. REPORT DATE October, 1966	7a. TOTAL NO. OF PAGES 140	7b. NO. OF REFS 13
8a. CONTRACT OR GRANT NO. OCD-OS-62-44	8b. ORIGINATOR'S REPORT NUMBER(S) N/A	
a. PROJECT NO. work unit 1211 A	8c. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) 9473	
c.		
d.		
10. AVAILABILITY/LIMITATION NOTICES Each transmittal of this document outside the Department of Defense must have prior approval of the Office of Civil Defense.		
11. SUPPLEMENTARY NOTES N/A	12. SPONSORING MILITARY ACTIVITY Office of Civil Defense Department of the Army - OSA	
13. ABSTRACT Digital computer programs for the calculation of underground shelter heat transfer are described with respect to their mathematical models, assumption, limitations, parameters, input data and computational techniques. The report also presents comparisons between the calculated shelter thermal environments with the observed for seven different prototype shelters. It has been found that the simple one-dimensional heat conduction model can accurately simulate the thermal environment in large shelters, although complex three dimensional heat conduction models may be needed for a small and shallow underground conduction.		

DD FORM 1473
1 JAN 64

Security Classification

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Underground Fallout Shelters, Thermal Environment, Digital Computer Simulation, Heat Transfer						

INSTRUCTIONS

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.
- 2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.
- 2b. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.
3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.
4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.
5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.
6. **REPORT DATE:** Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.
- 7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.
- 7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.
- 8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.
- 8b, 8c, & 8d. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.
- 9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.
- 9b. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:
 - (1) "Qualified requesters may obtain copies of this report from DDC."
 - (2) "Foreign announcement and dissemination of this report by DDC is not authorized."
 - (3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through _____."
 - (4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through _____."
 - (5) "All distribution of this report is controlled. Qualified DDC users shall request through _____."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.

12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring (paying for) the research and development. Include address.

13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

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, rules, and weights is optional.

Unclassified
Security Classification

CUT ALONG THIS LINE

COMPARISON OF DIGITAL COMPUTER SIMULATIONS OF
THERMAL ENVIRONMENT IN OCCUPIED UNDERGROUND PROTECTIVE
STRUCTURES WITH OBSERVED CONDITIONS

'UNCLASSIFIED'

NATIONAL BUREAU OF STANDARDS Dec 1966

140 pages OCD-OS-62-44 1211A

Four digital computer programs for simulating thermal environment in underground fallout shelters are described. The calculated temperature and humidity of seven prototype shelters are compared with the experimentally observed values.

COMPARISON OF DIGITAL COMPUTER SIMULATIONS OF
THERMAL ENVIRONMENT IN OCCUPIED UNDERGROUND PROTECTIVE
STRUCTURES WITH OBSERVED CONDITIONS

'UNCLASSIFIED'

NATIONAL BUREAU OF STANDARDS Dec 1966

140 pages OCD-OS-62-44 1211A

Four digital computer programs for simulating thermal environment in underground fallout shelters are described. The calculated temperature and humidity of seven prototype shelters are compared with the experimentally observed values.

COMPARISON OF DIGITAL COMPUTER SIMULATIONS OF
THERMAL ENVIRONMENT IN OCCUPIED UNDERGROUND PROTECTIVE
STRUCTURES WITH OBSERVED CONDITIONS

'UNCLASSIFIED'

NATIONAL BUREAU OF STANDARDS Dec 1966

140 pages OCD-OS-62-44 1211A

Four digital computer programs for simulating thermal environment in underground fallout shelters are described. The calculated temperature and humidity of seven prototype shelters are compared with the experimentally observed values.

COMPARISON OF DIGITAL COMPUTER SIMULATIONS OF
THERMAL ENVIRONMENT IN OCCUPIED UNDERGROUND PROTECTIVE
STRUCTURES WITH OBSERVED CONDITIONS

'UNCLASSIFIED'

NATIONAL BUREAU OF STANDARDS Dec 1966

140 pages OCD-OS-62-44 1211A

Four digital computer programs for simulating thermal environment in underground fallout shelters are described. The calculated temperature and humidity of seven prototype shelters are compared with the experimentally observed values.