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Capabilities of the Generic Systems Assessment Model

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by
Peter D. Howard

Report Date
July 1992

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Section I

INTRODUCTION

The automated electric power and environmental control Systems Assessment Model (SAM) determines the heating, cooling and electric power requirements of a variety of military shelter and tent systems. By using steady state or hour-by-hour temperature profiles, the SAM establishes 24-hour cooling or heating requirements. Its database includes all standard Army shelters and tents but has the flexibility to allow the user to create a new rigid-wall shelter or tent or to modify characteristics already defined in the model.

SAM includes the standard environments per Army Regulation (AR) 70-38 and also allows the user to change internal or external temperature, humidity or wind speed. Routines allow the user to enter and edit equipment and configurations, edit shelter characteristics and environments, conduct steady-state and transient analyses, produce output reports, and perform database maintenance.

The SAM's dual capability allows:

- **Steady-state analysis** to determine cooling, heating and electric power requirements for any given set of input assumptions; and
- **Transient analysis** to provide the user a 24 hour, hour-by-hour plot of shelter exterior and interior temperatures when given specific heater, air conditioner, and environmental conditions or any other user-specified input.

The SAM will calculate total system weight from entered data. A weight estimate is calculated for the air conditioner, heater, and generator from values of military-standard (MIL-STD) equipment if no value is entered.

Section II

GENERAL DESCRIPTION

SYSTEM CAPABILITIES

Generic-SAM (Shelter System Assessment Model) is a dynamic tool that determines the heating, cooling, electric power, and weight requirements for user selected system configurations of equipment housed in several types of rigid-wall shelters and tents. It gives the user two main options:

- A transient analysis that computes an hourly interior temperature profile from a given hourly exterior temperature profile.
- A steady-state analysis that determines the cooling or heating load in BTUH, power in kilowatts, and individual and combined weights of the resulting air conditioner or heater, generator, equipment, and shelter.

Generic-SAM is driven by a primary set of data tables. The database consists of:

- Equipment characteristics—weight, voltage, power consumption, and duty cycle.
- Shelter characteristics—dimensions, thermal properties, and absorptivity.
- Configuration characteristics—equipment and people housed in one of the available rigid-wall or tent shelter types.
- Environment characteristics—temperature, humidity, and wind.

Shelter-SAM contains characteristics data for the following types of shelters as well as some equipment data:

- General purpose tents—small, medium, and large;
- ISO shelters—single sided and one- or two-side expandable;
- Maintenance, SICPS, and Temper tents; and
- S-250, S-280, and SICPS shelters.

SAM OPERATION

The user follows a step-by-step procedure to perform an analysis, using the data entry screens and menus in the software to describe equipment and shelter characteristics, define a configuration and load it with equipment, specify environmental parameters, and run steady-state or transient analyses or both. To perform analysis:

1. **Enter equipment data.** This includes values such as weight, kilowatts, heat rejection factor, start-up factor, and usage rate of the equipment being analyzed.
2. **Describe the shelter structure.** Each structure is described by data which affects environmental control like surface area, solar absorptency, and insulation values. The set of structures the user can use is not limited to those listed in the SAM. With careful consideration, modify a shelter's parameters and new shelters can be defined. The generic shelter and tent categories are provided for experimentation with alternative shelter types.
3. **Define a configuration by assigning a structure type, mount, surrounding ground type, personnel loading, and equipment list.** Personnel loading includes the number of persons and the weight, BTUs, and ventilation requirement per person. The equipment list is defined by entering the quantity of each piece of equipment in the configuration.
4. **Specify the parameters of the external environment(s).**
5. **Estimate the heating or cooling requirement necessary for the configuration by running the steady-state program.** The model computes BTUs and kW's required, air conditioner and generator weight, and total configuration weight. The user can view the results on-screen or print a copy. Shelter-SAM automatically saves the parameters and results in a run log file.
6. **Run the transient program.** Shelter-SAM will display the hourly interior and exterior temperatures on-screen in tabular or graphic form, or print a report of the results. It automatically saves the run parameters and results in a run log file.

Section III

STEADY-STATE ANALYSIS

The analytical technique for the steady-state thermal analysis, initially developed by the VSE Corporation for the Belvoir Research, Development and Engineering Center under contract DAAK70-86-D-0023, is presented in VSE Report No. VSE/ASG/0016-87/12RD, 31 March 1987. The following discussion draws on that report.

STRUCTURAL THERMAL LOAD ANALYTICAL APPROACH— GENERAL SURFACES

The generation of structural thermal loads involves solving complex heat transfer equations governing the flow of heat between the environment and the structure under consideration. The interior environment of a structure should be maintained within a range conducive to an efficient work environment. The interior temperature of the structure is one of the known parameters of the heat transfer equations.

The external environmental conditions can vary widely with locale. Extreme climactic conditions, set forth in AR 70-38, or any intermediate conditions also become a set of known parameters. With the interior and exterior conditions defined, a heat balance equation is developed for each surface of the shelter. Heat flows to and from the surfaces of the shelter in a variety of modes. If the surface temperature is stable, not increasing or decreasing, then the total heat flow, positive and negative, must be zero for that surface since the heat flowing toward a surface equals the heat flowing away from it. Since the same surface area is used for each term, they cancel each other, and the equation becomes a heat flux balance.

There are three primary modes of heat transfer: radiation, convection, and conduction. The heat balance equations include the following terms:

- Solar (Short Wave) Radiation,
 - Direct Solar Radiation,
 - Diffuse Sky Radiation, and
 - Ground Reflected Solar Radiation.
- Thermal (Long Wave) Radiation (Proportional to the difference between the fourth power of the absolute temperatures of the two bodies),
 - Radiation to/from the atmosphere, and
 - Radiation to/from the ground.

- Convection,
 - Forced convection due to wind velocity, and
 - Natural convection due to air buoyancy.
- Conduction.

The temperature of the surface is adjusted iteratively until the terms of the heat flux balance equation sum to zero. The term in the equation which is the heat flux between the surface and the interior is multiplied by the area of the surface to get the heat flow between the surface and the interior. Each surface of the shelter is analyzed in this way, and the heat flows are totaled to generate the total structural thermal load for the shelter.

INFILTRATION/VENTILATION LOAD

Infiltration is one of two potential sources of outside air. It happens from wind penetration into the shelter cover or through vestibule entrance ways during normal use. One change per hour is normally used for shelters.

The second outside air source is ventilation. In a working environment, with no smoking, the minimum ventilation requirement is 10 CFM of fresh air per occupant. This value is currently being used as the default value.

As an example, the C-100 A/C delivers 200 CFM with fresh air damper fully open at maximum fan speed against a 1.0 in. H₂O back pressure. The make-up ventilation air effectively over-pressurizes the shelter, minimizing any tendency toward infiltration. The shelters will be subjected to ventilation CFM only. The latent infiltration/ventilation load is calculated utilizing algorithms of the psychrometric thermodynamic relationships.

METHOD OF SOLUTION OF THE HEAT BALANCE EQUATIONS

The heat balance equations are polynomials, with a fourth power term due to long wave radiation. The most efficient way to solve polynomials is the Newton-Raphson method. The solution estimate for each successive iteration is modified by the derivative of the polynomial at the previous estimate. This results in rapid convergence to the solution.

Section IV

TRANSIENT ANALYSIS

GENERAL

The transient analysis algorithms are simplified in comparison to the steady-state algorithms. Averaging techniques are used which eliminate the higher order effects of radiative heat transfer. The lumped capacity method of transient analysis is utilized. In this method, the exterior surroundings are treated as a body at ambient temperature. The shelter roof, sides, ends, and floor are treated as a second body at a temperature which is averaged to include the effect of solar loading on the roof and the effect of appropriate heat transfer coefficients between each surface and ambient. The third body is the shelter interior including the equipment and occupants as well as ventilation air coming through the CB filter.

The modified perimeter method of estimating the heat loss or gain through the floor was used in this analysis. The modified perimeter method is a variation of the ASHRAE standard perimeter method. The standard perimeter method estimates area for calculating heat loss through the floor for the structure at a distance of two feet inside the walls of the structure. The modified perimeter method estimates the area through which the heat loss is calculated as the ratio of the difference between outside and instantaneous inside temperature and the difference between outside and desired inside temperature, multiplied by the area as calculated by the two foot perimeter rule. As the instantaneous inside temperature approaches the desired inside temperature, then the ratio approaches one and the calculation simplifies to the standard ASHRAE method.

Transient calculations rely on accurate thermal mass data. There are four types of thermal mass which must be considered as follows:

- Air mass within the shelter and the mass of fresh air introduced through infiltration/ventilation—this is considered in its entirety.
- Equipment mass within the shelter —Inclusion of this mass is left at the operator's discretion. Exclusion will result in a more rapid approach to the preset internal temperature and rapid cycling of the heating/cooling device. Inclusion results in a slower approach to the preset internal temperature and less frequent cycling of the heating/cooling device.
- Shelter mass—Results of tests of the maintenance tent at Fort Drum, February 1990, indicate that the complete shelter mass should not be used as the lumped mass. Since the exterior of the tent remains near the outside

ambient temperature, if the tent or shelter is heavily insulated, only a portion of its mass is subjected to varying temperature. Using the Fort Drum results, a linear equation was developed to approximate the effect of "U" factor on shelter thermal mass.

- Ground mass—Although ground conductivity is incorporated through the perimeter method, thermal mass is not. This is because the effective depth is considered negligible in determining transient inside air temperature. If the time required to effect a significant depth of ground is desired, another set of differential equations must be solved, a triple mass system instead of a double mass system.

METHOD OF SOLUTION OF TRANSIENT ANALYSIS

The computer program is used to generate interior temperatures of the shelter at one minute time increments for set exterior conditions. After each one minute time period, the equations are solved again, using the previous minute's calculation of instantaneous internal temperature as the new initial interior temperature and a new set of exterior conditions. The exterior conditions correspond to user-defined situations. Tabulations are listed on an hourly basis; linear interpolation is used to generate minute-by-minute changes in the exterior conditions for solution of the equations.

In the air conditioning mode, when the interior temperature starts to drop below an operator set value, the program simulates a thermostat by cycling the heat flow removed by the air conditioner from the specified BTU/HR for the run to zero until the interior temperature rises above the preset value. Similarly, in the heating mode, when the interior temperature starts increasing above an operator set value, the heat flow added by the heater is cycled from the specified BTU/HR for the run to zero until the interior temperature falls below the preset value.

HEAT TRANSFER EQUATIONS

A complete listing of the heat transfer equations utilized in Shelter SAM are not listed in this document but are available from the System Assessment Team, Belvoir RD&E Center, Fort Belvoir, Va.

ELECTRICAL POWER CALCULATIONS

Shelter-SAM uses a statistical approximation method to determine the electric power required in a given configuration. The text is based on "Logistics Electric Power Requirements for Army Systems," Draft Report, BDM International, Inc., May 1988. This report was prepared for the U.S. Army Belvoir RD&E Center, Fort Belvoir, Va.

THE DEMAND ASSUMPTION

The demand factor is the ratio of the maximum amount of power that must be provided to adequately power the connected load to the algebraic total of the connected load. Demand factors lie between zero (a load that is never on) and one (a load that is always on). Most loads are intermittent, such as lights or a radio transmitter, and the demand factor will fall between these extremes.

Underlying the demand factor is the concept that all items do not operate simultaneously. You can statistically compute the expected distribution of the total powered load, and then specify a level that gives high statistical assurance, say 99 percent, that sufficient power will be available.

The demand factor for otherwise identical loads can vary. For example, for large systems with many loads, the demand factor can approach the average fractional usage. For small systems, the same load with the same usage would require a demand factor of essentially one.

Correct calculation of the demand factor requires data on all individual loads connected to the power source. In Shelter-SAM, this data is in the equipment table and consists of the kW and usage rate for each piece of equipment. All else being equal, circuits with more loads have lower demand factors than those with fewer loads. Shelter-SAM uses two methods of calculating the demand factor: statistically precise method for small systems and an approximate method for larger systems. Both methods require a preliminary tabulation of all loads on the generator.

Both of the computational techniques assume that loads are randomly on or off. This random assumption is important. One must be very careful to treat grouped or ganged loads (i.e., several loads always operating together, often on a common switch as in a radio set) and alternative loads that never operate together (e.g., heating and cooling devices) in the appropriate way. Alternative loads may use an either/or switch. Grouped loads should be treated as one large load; with alternative loads, the smaller load should be ignored.

Section V

DISCUSSION

In the past, heating, cooling and electric power requirements required exhaustive manual calculations since the Army deploys shelter systems to varying climates with multiple configurations. Obviously, the dynamic character of these conditions would best be assessed using a flexible, interactive computer model. In 1989, the System Assessment Team developed such a computerized power system assessment model for the Deployable Medical Systems (DEPMEDS). Further refinement of computational techniques was achieved in the second generation model developed for the Standardized Integrated Command Post System (SICPS). The third iteration, Shelter-SAM, has the ability to analyze all standard Army shelters and tents and also one-of-a-kind nonstandard shelters.

The benefit of having a dynamic tool that determines shelter system heating, cooling, and electric power requirements is its ability to show the user the logistic burden or benefit of a configuration change. For illustrative purposes, we will take a look at the requirements for a conceptual system housed in an S-250 shelter. The operational requirements are as follows:

- Hot-Dry Climate
 - 120°F outside temperature
 - 3% outside humidity
 - 8.9 mph wind speed
 - 231.0 (BTU/HR/FT²) average solar load
 - 145.0°F ground temperature
- Shelter S-250
 - 50°F minimum interior temperature
 - 90°F maximum interior temperature
 - 8% inside humidity
 - No solar shading
- No CBR
- Two operators
- 40 CFM minimum ventilation
- Mission equipment load from .5kW to 2.5 kW
- AC utility power (no converters)

Using the steady state portion of the model, adding the above conditions, and fixing all variables except mission equipment load, the air conditioning requirement is 9192 BTUs for .5 kW and 16018 BTUs for 2.5 kW mission equipment. Figure 1 shows the user that to utilize a MIL-STD 9,000 BTU environmental control unit, the mission equipment load must be under .5 kW. If the mission equipment load exceeds .5 kW, the next available MIL-STD environmental control unit is the 18,000 BTU unit. The 18K BTU environmental control unit would provide enough cooling until the mission load exceeds 3 kW. The logistic burden greatly increases with larger environmental control units. The steady state power draw of the 9K BTU unit is a nominal 2.5 kW, and the steady state power draw of the 18K BTU unit is a nominal 4.5 kW. Including the mission equipment load and the start-up peak load of the environmental control unit, the power requirement for the total system would increase from a 5 kW generator to a 10 kW generator if the ECU were changed from a 9K BTU to a 18k BTU unit. This example illustrates the model's capability to perform multiple analyses to present to the user so the impact of configuration changes can be assessed.

S-250 Hot Dry kW vs BTU's Cooling

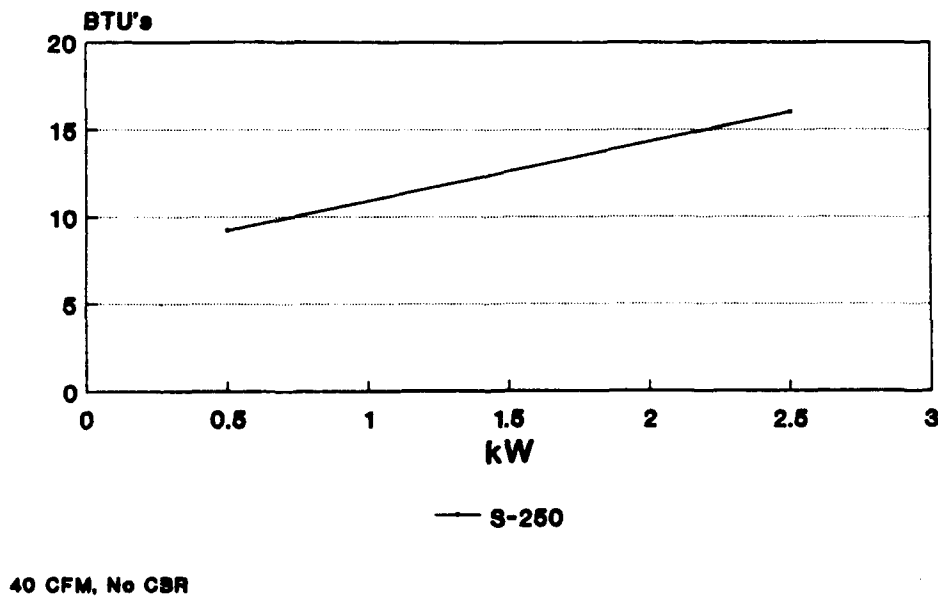


Figure 1

Using the numbers derived from the steady state analysis, the transient analysis portion of the model can be exercised to predict the performance of both the environmental control units.

Figure 2 displays the internal and external temperature of the S-250 shelter with 2.5 kW of mission load equipment and the 18,000 BTU environmental control unit in a hot dry climate as defined by AR 70-38. The steady state portion of the model had predicted a cooling load of 16018 BTUs per hour. The 18,000 BTU can maintain the highest acceptable interior temperature (90°F) throughout the 24 hour period.

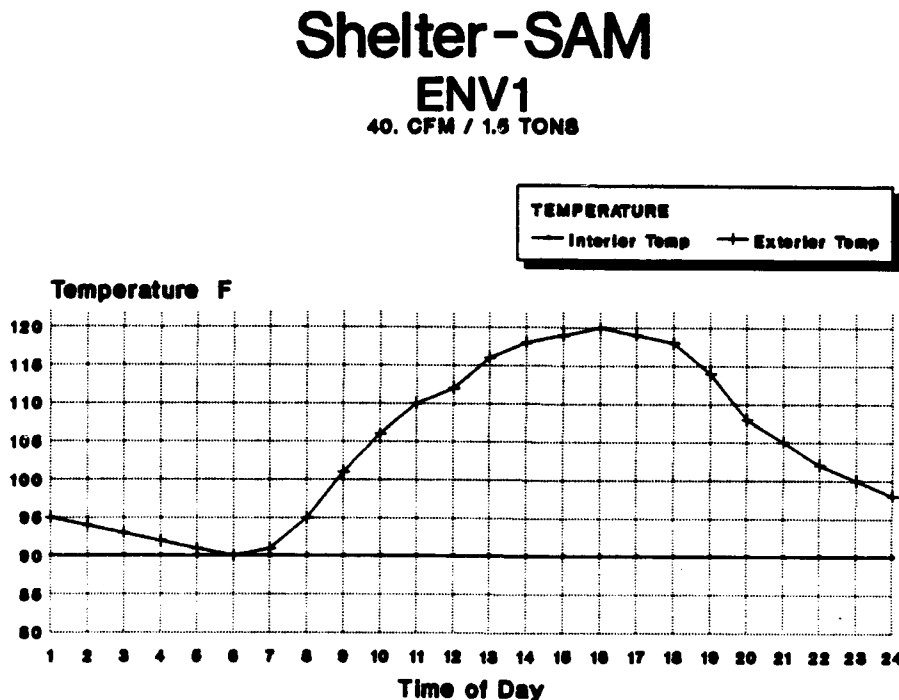


Figure 2

Figure 3 displays the internal and external temperature of the S-250 shelter with 0.5 kW of mission load equipment and the 9,000 BTU environmental control unit in a hot dry climate as defined by AR 70-38. The steady state portion of the model had predicted a cooling load of 9192 BTUs per hour. The 9,000 BTU cannot maintain the highest acceptable interior temperature (90 °F) throughout the 24 hour period. Figure 3 graphically illustrates to the user that solar shading and/or load management must be utilized to reduce the cooling requirement during the peak temperatures or the 90°F interior temperature will be exceeded and mission performance degraded.

Shelter-SAM

ENV1

40. CFM / 0.75 TONS

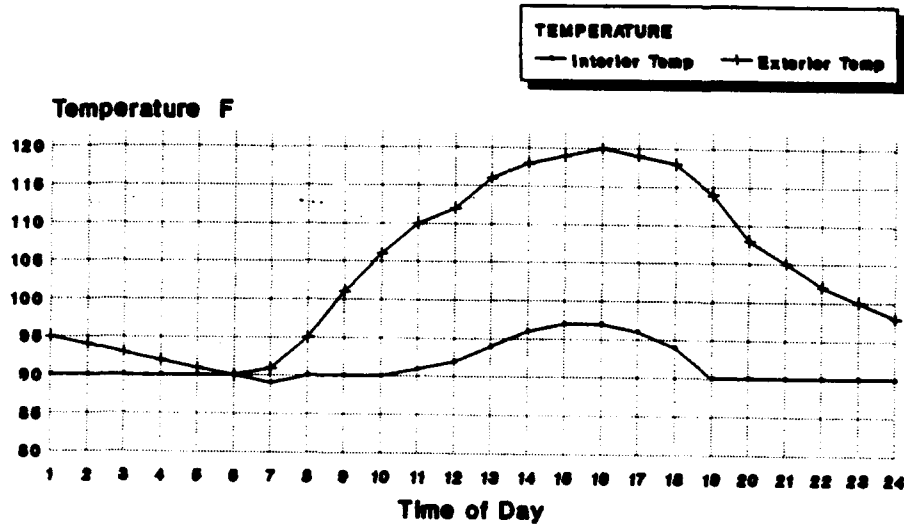


Figure 3

Section VI

INPUT DATA REQUIREMENTS

EQUIPMENT DATA SUMMARY

Generic-SAM allows the user to define a configuration that consists of a given list of equipment and parameters. Once defined, the configuration can be quickly accessed. New configuration can be developed quickly by modifying existing ones. For each piece of equipment in a shelter, for a given configuration, you must provide:

- Equipment name,
- National stock number (NSN),
- Weight in pounds,
- Kilowatts (kW),
- Voltage (V),
- Mission criticality rating,
- Power type (DC, AC utility, AC precise),
- Equipment type (heater only, air conditioner only, other),
- Phase,
- Start-up factor,
- Heat rejection factor,
- Usage rate (duty cycle),
- Capacitance (heat capacitance of the primary material from which the equipment is made),
- Manufacturer's name (optional),
- Part number (optional),
- Line Item Number (optional).

SHELTER-SAM DATA SUMMARY

Shelter-SAM lets you modify:

- Surface areas (square feet) and length and width (feet),
- U-Factor (BTU/hour/square feet/degrees Fahrenheit),
- Solar absorbcency,
- Angle with respect to horizontal,
- Areas of any uninsulated surfaces penetrated by conduits [holes].

- Heat capacity of primary shelter material (BTU/pound/degrees Fahrenheit),
- Volume (cubic feet),
- Weight (pounds),
- Percent of tent roof covered by a fly if one is present, and
- Height of fly above roof (inches), if one is present.

The first five characteristics are defined up to eight different surfaces that may be used to define a structure.

CONFIGURATION DATA SUMMARY

Basic Heating, Ventilating, and Air Conditioning (HVAC) and power analyses usually are done on a variety of configurations for a shelter. In Generic-SAM, you must provide:

- Name,
- Description,
- Structure used,
- Type of ground around shelter,
- Position of shelter (mounted on the ground or elevated),
- Interior humidity,
- Number of personnel in the shelter,
- Sensible and latent loads,
- Ventilation required per person, and
- Weight per person.

The data that changes from configuration to configuration is usually the equipment in the shelter and/or the additional data required for the transient or steady-state runs as listed below.

ENVIRONMENT DATA SUMMARY

Generic-SAM already contains the following data elements on the eight standard environments from AR 70-38, *Research, Development, Test and Evaluation of Materiel for Extreme Climactic Conditions*:

- Ambient temperature,
- Ambient humidity,
- Ground temperature,
- Wind velocity,
- Solar loading.

These data are stored for each hour of the day (except for wind velocity) for use in transient analyses and as single values representative of extremes for steady-state analyses. These values may be modified for individual analyses.

CONVERSION EQUATION DATA

Generic-SAM contains two tables of conversion factors. In the first, six factors convert:

- AC utility to DC,
- DC to AC precise,
- AC utility to AC precise,
- AC precise to AC utility,
- AC precise to DC,
- DC to AC utility,

The second table contains a multiplier and increment to compute estimated values for:

- Air conditioner weight from BTU,
- Power required for heating/cooling from BTUs, and
- Generator weight from the kW required.

ADDITIONAL DATA REQUIRED FOR A STEADY-STATE ANALYSIS

When a steady-state analysis is run, the following parameters must be specified:

- Configuration,
- Generator type and location of the converters,
- Environment,
- CFM for CBR or no CBR cases,
- Maximum interior temperature,
- Minimum interior temperature.

ADDITIONAL DATA REQUIRED FOR A TRANSIENT ANALYSIS

When a transient analysis is run, the following parameters must be specified:

- Configuration,
- Generator type and location of the converters,
- Environment,

- Temperature of the night sky,
- Time of day the run is to begin,
- Interior temperature and relative humidity at start time,
- CFM for CBR or no CBR cases,
- BTU capacity of the air conditioner to be used,
- Temperature at which the AC should be turned on,
- Temperature at which the heat should be turned off,
- Wind velocity,
- Vehicle speed,
- Direction of the vehicle with respect to the wind.

Section VII

OUTPUT PRODUCED BY SHELTER-SAM

The output produced by Shelter-SAM consists of five different files:

- Reports of various types of input data set up for transient and steady-state runs,
- Transient-run result graphs for on-screen viewing,
- Run result files for on-screen viewing,
- Run log files for printing, and
- Harvard Graphics interface files for plotting transient run results.

The run log files contain all of the parameters of the transient run or a steady-state run. Shelter-SAM stores run log files for the ten most recent transient and steady-state runs. The discussion contains sample data for both runs for an S-250 shelter under selected conditions.

Section VIII

Summary

The Generic-SAM model is capable of rapidly analyzing heating, cooling and electric power requirements for multiple configurations of all Army standard shelter systems. It also has the flexibility to perform analysis of non-standard shelter system requirements when the appropriate assumptions are utilized. This dynamic interactive computer model allows the user to graphically present impact of configuration changes to the system manager in a timely manner. It replaces the tedious and labor intensive manual calculation requirements for every configuration or climactic scenario change.

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