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EVALUATION OF SOLAR COLLECTORS FOR HEAT PUMP APPLICATIONS

Final Report

By
Gary Skartvedt
Donald Pedreyra
Dr. Robert McMordie
James Kidd
Jerome Anderson
Richard Jones

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August 1980

Work Performed Under Contract No. AC04-78CS35351

American Heliothermal Corporation
Denver, Colorado

U.S. Department of Energy

Solar Energy

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Department of Energy
Albuquerque Operations Office
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Denver, Colorado 80222

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I. INTRODUCTION AND SUMMARY

This study is part of a comprehensive solar energy R & D program which was defined and initiated under the National Program Plan for Research and Development in Solar Heating and Cooling, published by the Energy Research and Development Administration (ERDA) in November, 1976. The study is one of several projects, primarily analytical, which were aimed at defining the most promising configurations and applications for simple, flat plate, non-concentrating solar collectors.

A. STUDY OBJECTIVES

Although solar collectors have been integrated with heat pump systems in a variety of ways, no systematic evaluation had been conducted to identify the most cost-effective combinations of solar collectors with heat pumps using both water and ground-coupled thermal storage, and how the best of these configurations compare with other available non-solar heat pump options. The objectives of this study were designed to provide a detailed exploration of this question with respect to residential heating and cooling using commercially available, reversible electric heat pumps. The specific objectives of the study are as follows:

1. Develop a detailed heat-pump system simulation computer model which includes options for solar collectors, water storage and ground-coupled storage.

2. Using the simulation model, exercise various promising heat pump configurations against typical residential heating and cooling loads to determine the annual electric power consumed by each system.

3. Compare the thermal performance and cost effectiveness of each water-source heat pump configuration against a conventional residential air-to-air heat pump.

4. Evaluate the potential economic utility of low-cost, flat plate solar collectors, water storage and ground-coupled thermal storage as the heat source/sink for heat pump systems for space heating and cooling.

5. Conduct an experimental determination of effective night sky temperatures and convective heat transfer coefficients for surfaces with dimensions representative of flat plate solar collectors.

B. BACKGROUND

Heat pumps have been in use for heating and cooling buildings for many years. Because heat pumps can extract energy from low-temperature sources, the use of solar collectors in series with heat pumps (to collect energy at lower temperatures and correspondingly higher efficiencies), is an intuitively attractive idea. Numerous studies have shown, however, that in most applications use of conventional, glazed, flat plate collectors as the sole source of energy for a heat pump is not as cost-effective as the use of the same collectors in parallel with a conventional air-to-air heat pump. This is particularly true if a large energy storage reservoir, such as a swimming pool, is not available as a source and sink for the heat pump.

Based on these results, the subject study was initiated to evaluate the potential utility of very low cost (possibly unglazed and uninsulated) solar collectors to serve as both heat collection and rejection devices for a liquid-source heat pump.

The study approach consisted of exercising a detailed analytical simulation of the complete heat pump/solar collector/storage system against heating and cooling loads derived for typical single-family residences in eight U.S. cities. The performance of each system was measured against that of a conventional air-to-air heat pump operating against the same loads. In addition to evaluation of solar collector options, the study included consideration of water tanks and buried pipe grids to provide thermal storage.

As a supplement to the analytical tasks, the study included an experimental determination of night sky temperature and convective heat transfer coefficients for surfaces with dimensions typical of solar collectors. It became apparent during the early phases of the system analysis effort that accurate estimation of the heat collection capability of unglazed collectors is highly dependent on film coefficients, and heat rejection rates depend on both film coeffecents and effective night sky temperatures. Review of the literature indicated that the available correlations for convective film coefficients are based on characteristic dimensions which are quite small in comparison to solar collector dimensions, and that extensive data on effective night sky temperature, particularly with clouds, is not available.

Because of the lack of experimental convection data for large exposed surfaces, and the lack of correlated sky temperature data, a simple experiment was designed to characterize the radiative and convective losses from collector sized surfaces. The experiments were conducted "in situ" by placing the test apparutus on the roofs of houses in the Denver, Colorado, area.

C. SUMMARY OF RESULTS AND CONCLUSIONS

1. Performance and Cost-Effectiveness of Residential Heat Pump Systems -

The annual electric power consumption of various configurations of solar-assisted, water-storage coupled and ground-coupled heat pump systems were compared to the power consumed by a conventional air-to-air heat pump operating against the same residential thermal loads in eight U.S. cities. The results show that none of the solar-assisted configurations are economically competitive with the reference air-to-air system. Ground-coupled, water-source heat pumps, however, are economically viable and competitive with standard air-to-air units in moderate and warm climate areas.

The annual system COP (coefficient of performance defined as the total annual heating and cooling load divided by the total annual electrical energy consumed by the heating and cooling system) for the air-to-air heat pump ranged from a low of 1.66 in Minneapolis, to a maximum of 2.22 in Miami. None of the solar-assisted or ground-coupled configurations studied had COP's equal to or greater than the air-to-air system in Boston or Minneapolis. The highest water-source heat pump COP's (2.60) were produced in Miami by two different configurations, one consisting of 300 ft^2 of unglazed solar collectors and 500 ft of ground pipe, the other consisting of 1000 ft of buried pipe with no solar collectors.

The relative cost-effectiveness of the various solar-assisted, water storage and ground-coupled systems was compared to the reference air-to-air system assuming a simple ten-year payback and average electricity cost of six cents per kilowatt-hour. A simple cost model was devised based on the assumption that the installed costs of the air-to-air and water-source systems are equal except for the solar collectors, water storage tank, and/or ground pipe network which are added cost items for the water-source systems. Using this model, the "allowable installed costs" of the solar collectors, water tank and ground piping were determined based on the amount of annual energy saved over the reference air-to-air system and the simple ten-year payback assumption.

The allowable costs for solar collectors were at least an order of magnitude below realistic values for all configurations studied. The "best" figures were $0.36/sq ft for unglazed collectors in Atlanta, and $1.78/sq ft for glazed units in Denver. Although the cost model used to produce these results is quite simple, it is doubtful that a more sophisticated approach would alter the numbers sufficiently to make flat plate solar collectors of almost any conceivable design an economically attractive heat source/sink for residential water-source heat pumps.

The allowable cost of buried pipe networks, however, falls in a realistic range in four of the cities studied, based on reported costs for developmental systems currently being installed. These values, in $/ft, are 2.00 in Miami, 2.24 in Phoenix, 2.32 in Atlanta, and 1.04 in Los Angeles. Based on these results, use of the soil as a heat source/sink for residential water-source heat pumps is attractive from both economic and energy-conservation standpoints, and deserves further study and optimization.

The performance of a configuration consisting of a water storage tank and an outdoor fan coil was surprisingly efficient in the cooling mode compared to the air-to-air reference system. In Miami the annual COP of this system was 2.52 compared to 2.22 for the air-to-air heat pump. The improved efficiency is apparently due to the ability to reject energy from the water storage tank at night and provide a lower temperature heat sink (than outdoor ambient) during the day when the cooling load peaks. The cost-effectiveness of this configuration is marginal, however, since the allowable cost of the water storage tank which offsets the electricity savings is $897, slightly less than the assumed baseline installed cost of $1200 for the 600 gallon storage tank.

2. Convective Film Coefficients for Large Surfaces - The following correlations, derived from the test data, are recommended for predicting the convection film coefficients for heated flat surfaces facing upward in the outdoor ambient air stream at moderate tilt angles up from the horizontal:

$$Nu = 1.93\ Re^{0.48}Pr^{0.33} \qquad \text{(measurable wind condition)}$$

$$Nu = 1.48\ (GrPr)^{0.272} \qquad \text{(negligible wind condition)}$$

Both values should be checked for moderate wind conditions, and the larger value used.

3. Effective Night Sky Temperature - The recommended correlation, derived from the test data, for estimating night sky temperature under clear sky conditions is:

$$T_{sky} = -41.9 + 0.8\, T_{ambient} \qquad (T \text{ in } ^{o}F)$$

Useful correlations could not be derived for sky temperature as a function of either moisture content in the air, or the amount and type of cloud cover.

D. RECOMMENDED FUTURE ACTIVITIES

1. **Heat Pump Studies** - Results of the performance and cost-effectiveness evaluations conducted in this study indicate that ground-coupled heat pump systems may be attractive in mild climate areas. It would appear that use of anti-freeze in the ground circuit (not considered in this study) may significantly improve the performance of the ground-coupled systems in more severe climate areas. It would also appear that the performance of the ground-coupled systems can be improved by optimizing the size of the various components, and the system control strategies. The system simulation computer model developed under this study could be effectively used to further evaluate and optimize both air-to-air and ground-coupled heat pump performance. The simulation model could also be used to explore the cooling performance obtainable with various water-storage configurations using the outdoor fan coil as the heat rejection device. These systems may have added economic benefits because of the ability to generate chilled water at night using off-peak power.

2. **Synthetic Weather Model** - The synthetic weather model developed during this study has broad application to all types of analytical simulations in the areas of building energy consumption analysis, and both active and passive solar system design. The model has the potential to produce realistic hourly weather using only monthly average values as input. Although the model has been checked against limited samples of real weather data, a full-scale validation effort using weather data from a variety of different locations would suggest improvements to the model and would provide a statistical basis for its accuracy.

3. **Film Coefficient/Night Sky Temperature Experiment** - The data obtained from the experimental program demonstrated the viability of the basic test article design. In order to improve the accuracy of the data correlations, and broaden their applicability, a larger data sample from different climatic regions is required. To obtain such a sample, a second-generation experiment should be designed and fabricated in sufficient quantity to permit simultaneous test operations in three or four locations.

II. FLAT-PLATE COLLECTOR EVALUATION

Assessment of the potential utility of flat-plate solar collectors as both collectors and rejectors of energy for residential heat pumps required the development of detailed information on a variety of commercially available collectors which might be promising candidates. This was initiated by identifying the currently active manufacturers of flat plate collectors, and requesting from them detailed technical and cost data on their products. The responses were then screened by calculating a nominal heating figure-of-merit to determine those configurations which provided the most Btu/$ in the temperature range suitable to available liquid-source heat pumps. At the same time, an investigation was made into the potential night-time heat rejection capability of both glazed and unglazed collectors. Based on these results, it was determined that only unglazed configurations had sufficient heat rejection capability to justify consideration as both collection and rejection devices. A commercially available plastic unglazed configuration was selected as the baseline for the system performance simulation runs, and a detailed analysis was conducted to determine how the performance of unglazed absorbers might be optimized for the heat pump application. The methodology and results of these investigations are described in the following sections.

A. SOLICITATION OF MANUFACTURER'S DATA

A review of published solar equipment catalogs produced a list of 110 suppliers and/or manufacturers who were solicited for design and cost information. The form of the information request is shown in Figure II-1. Twenty responses were received which were sufficiently complete to justify inclusion in the detailed screening and evaluation process. The data obtained in the twenty responses is summarized in Table II-1.

B. PERFORMANCE/COST FIGURE OF MERIT

In order to assess the relative cost effectiveness of the twenty candidate collector configurations, a simple figure-of-merit (FOM) was defined to measure the heating Btu's provided per square-foot cost of each collector. The FOM is based on the predicted day-long energy that would be collected by each collector during the heating season (November through March) assuming a tilt angle of 50^{o}, inlet temperatures of 80, 110 and 140^{o}F, and 67% possible sunshine. The daily average collected energy is then multiplied by the number of days in the heating season and the estimated collector life (20 years for purposes of this comparison), and divided by the collector cost.

Calculated values of FOM for each of the candidate collector configurations are plotted in Figure II-2 (collector numbers correspond to those in Table II-1). As indicated by these results, very little difference is observed between collectors at the high or intermediate inlet temperatures, (140 and 110^{o}F), but a significant difference exists at an inlet temperature of 80^{o}F, particularly for the lower-cost collectors. This is not an unexpected result. It simply indicates that at inlet temperatures not far above ambient, the costs associated with insulating and glazing a collector may not be justified by the additional solar energy captured.

Solar Collector Data

1.	Collector aperture area	________	Ft^2
2.	No. and type of transparent covers	________	
3.	Absorber plate to cover spacing	________	In.
4.	Cover to cover spacing	________	In.
5.	Back insulation area	________	Ft^2
6.	Back insulation thickness	________	In.
7.	Type of back insulation	________	
8.	Thermal conductivity of back insulation	________	Btu/hr-ft-^oF
9.	Recommended flowrate of working fluid	________	lbm/hr
10.	Type of working fluid . . . . . ________________		
11.	Perimeter of fluid channel	________	In.
12.	Cross-sectional area of fluid channel	________	$In.^2$
13.	Number of parallel channels	________	
14.	Length of absorber channels	________	In.
15.	Channel spacing, centerline to centerline . . .	________	In.
16.	Thickness of absorber plate	________	In.
17.	Absorber material . . . . ________________		
18.	Thermal conductivity of absorber material . . .	________	Btu/hr-ft-^oF
19.	Absorber IR emissivity	________	
20.	Absorber solar absorptivity	________	
21.	Inside cover IR emissivity	________	
22.	Inside cover solar transmissivity	________	
23.	Outside cover IR emissivity	________	
24.	Outside cover solar transmissivity	________	

25. Collector cost (To Manufacture $__________/per collector
(To Distributor $__________/per collector
(To Dealer $__________/per collector
(To User $__________/per collector
26. Typical Installation Cost $__________/per collector
27. Brief description of collector frame and thermal standoffs between frame and absorber plate and between frame and covers ______________________________

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____

____

FIGURE II-1. Data Solicited from Collector Manufacturers

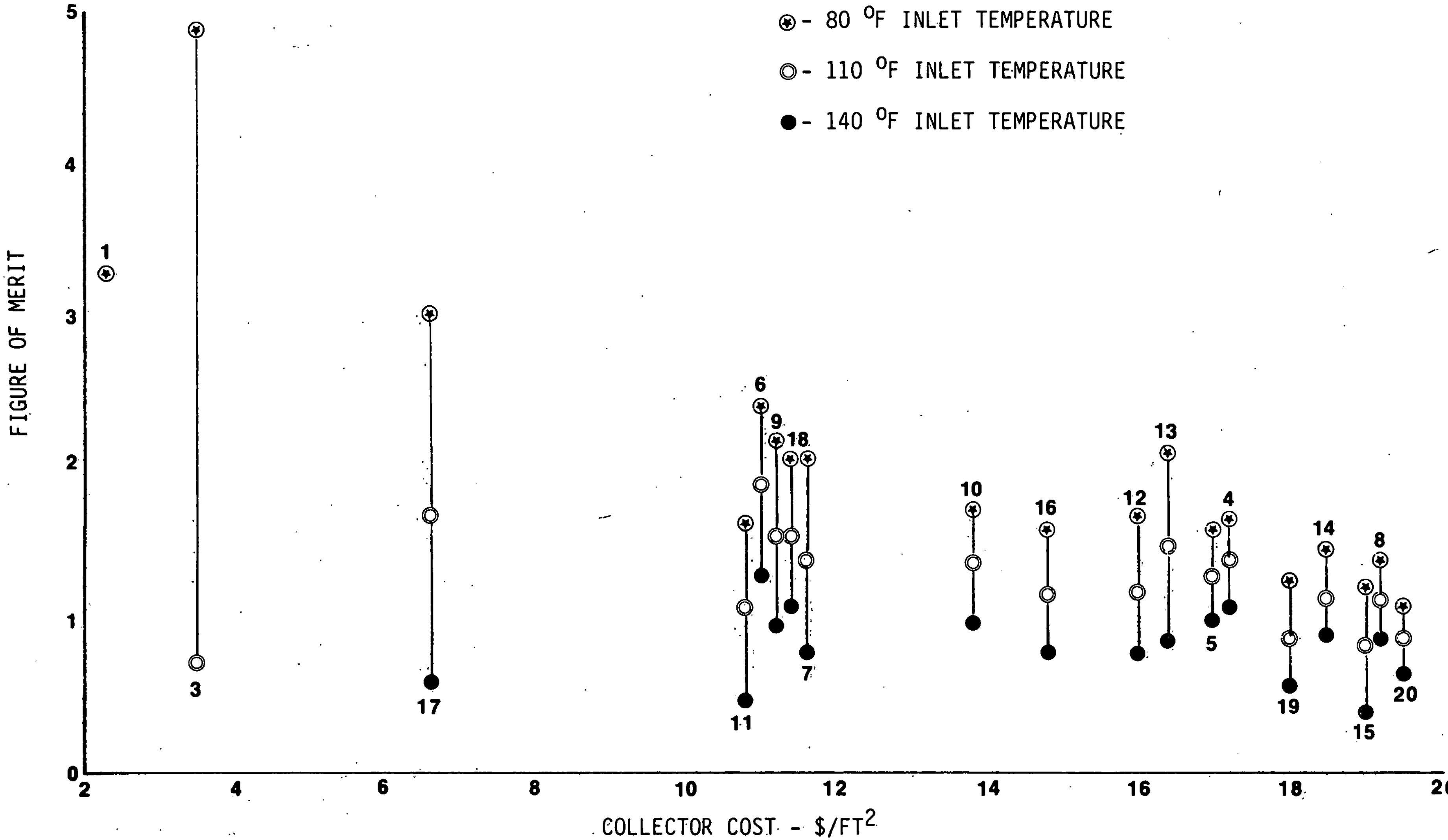
TABLE II-1. COLLECTOR MANUFACTURER'S DATA

Collector Mfgr.	Fluid	Cost $/ft^2$	Absorber Materials Coating	Plate	Waterways	Glazing (If any)	Backside Insulation	Housing Material
1. Wojcik Industries	Liq	2.43	Poly-ethylene	Same	Same	None	None	None
2. Solarator	Liq	3.40	Polyvinyl-chloride	Same	Same	None	Poly-urethane	Fiberboard or Plywood
3. Solheater 10-101	Liq	3.50	Poly-propylene	Same	Same	None	None	None
4. Cole 306-1S	Liq	17.15	Black Chrome	Copper	Copper	Single Glass	Fiber-glass	Galvanized Steel
5. Cole 406 AT	Liq	16.96	Not Spec.	Alum.	Copper	Outer Acrylic Inner FEP Teflon	Not Spec.	Galvanized Steel
6. Ying Mfg SP480	Liq	11.00	Epoxy Paint	Alum.	Stainless Steel	Single Polycarbonate	Urethane	Extruded Alum.
7. American Solar Heat Corp.	Liq	11.48	Flat Black	Copper	Copper	Single Fiberglass	Polyurethane	Alum.
8. Solar Dev. Inc. SD6	Liq	19.18	Black Chrome	Copper	Copper	Single Glass	Celotex Thermax	Alum.
9. Columbia Chase Corp. 3494	Liq	11.26	Black Paint	Copper	Copper	Single Fiberglass	Fiberglass	Molded Fiberglass
10. Solar Energy Comp. Inc	Liq	13.80	Black Chrome	Copper	Copper	Single Kalwall	ASTM C665	Wood
11. Kalwall Corp.	Air	10.74	Flat Black	Alum.	Alum.	Single Kalwall	Fiberglass	Alum.
12. Calmac	Liq	16.06	EPDM	Same	Same	Single FRP Teflon	Isocyanurate	Extruded ABS

TABLE II-1. COLLECTOR MANUFACTURER'S DATA (CONT)

Collector Mfgr.	Fluid	Cost $/Ft^2	Absorber Materials Coating	Plate	Waterways	Glazing (If any)	Backside Insulation	Housing Material
13. Colt Model A-151	Liq	16.37	Selective Black	Alum.	Alum.	Single Glass	Fiberglass	Alum.
14. Sol Heet Model 750	Liq	18.50	Not Spec.	Alum.	Copper	Single Glass	Fiberglass	Redwood
15. Continental Baseline	Air	19.13	Black Paint	Steel	Steel	Double Glass	Not Spec.	Galvanized Steel
16. Miromit Model 200	Liq	14.78	Black Nickel	Steel	Steel	Single Glass	Rockwool	Galvanized Steel
17. Sun Bank	Liq	6.65	Acrylic Film	ABS	Epoxy Paint	None	None	ABS
18. Intertech. Corp. Mark V	Liq	11.37	Black Paint	Alum.	Copper	Single Glass	Fiberglass, Urethane	Galvanized Steel
19. Energy Syst. Model 111-S	Liq	17.95	Black Paint	Alum.	Copper	Single Glass	Fiberglass	Galvanized Steel
20. Energy Syst. Model 111-D	Liq	19.44	Black Paint	Alum.	Copper	Double Glass	Fiberglass	Galvanized Steel

FIGURE II-2. PERFORMANCE/COST FIGURE OF MERIT



C. NOCTURNAL HEAT REJECTION ANALYSIS

Analyses were conducted to determine the heat rejection characteristics of flat plate solar collectors at night. These studies were performed prior to the sky temperature film coefficient experimental program, and so do not incorporate any of the correlations derived from the test data (see Section VI). Two separate computer programs were developed, one for an unglazed collector and one for a collector with a single transparent cover. The derivation of the equations and the results are described in the following paragraphs.

In both analyses, the forced convection film coefficient used is given by:

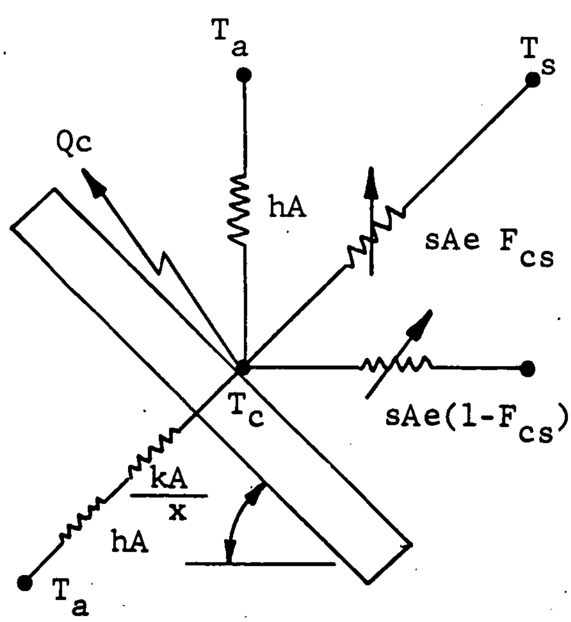
$$h = 1.0 + 0.3V, \quad \text{Btu/hr-ft}^2\text{-}^\circ\text{F} \qquad \text{(II-1)}$$

Where: V = Wind Speed, mph

Based on the results of the test program, this equation yields film coefficient values which are low in most cases for surfaces with characteristic lengths typical of solar collectors. The results of the analyses (plotted in Figures II-3 through II-5) do provide insights, however, into the relative behavior of solar collectors in a night-cooling mode. For example, it is apparent from the performance curves that a drastic decrease in heat rejection occurs when a single transparent cover is placed over a collector. The curves also show the relative sensitivities to sky temperature, ambient temperature, wind speed and collector temperature.

Night Cooling Mode - No Transparent Cover

Development of Equations



$$hA(Ta-Tc) + sAeFcs(Ts^4-Tc^4) + sAe(1-Fcs)(Ta^4-Tc^4) +$$

$$A(Ta-Tc)/(1/h+x/k) + Qc = 0 \qquad \text{(II-2)}$$

$$Qc/A = h(Tc-Ta) + seFcs(Tc^4-Ts^4) + se(1-Fcs)(Tc^4-Ta^4) + (Tc-Ta)/(1/h+x/k) \qquad \text{(II-3)}$$

Where: Qc/A = Collector energy loss, $Btu/hr\text{-}ft^2$

h = Film coefficient, $Btu/hr\text{-}ft^2\text{-}^oF$

Ta = Ambient temperature, ^oR

Tc = Collector average temperature, ^oR

Ts = Effective sky temperature, ^oR

s = Stefan-Boltzmann constant

e = Collector emissivity

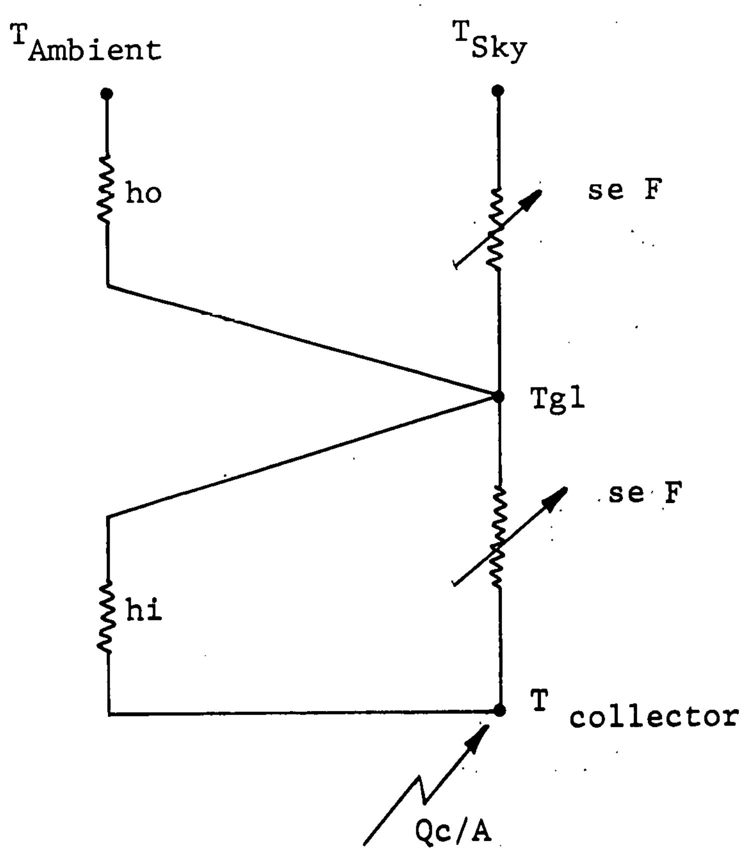
Fcs = View factor, collector to sky

x = thickness of back insulation, ft

k = Conductivity of back insulation, $Btu/hr\text{-}ft\text{-}^oF$

h = 1.0 + 0.3V, V = wind speed in mph

Night Cooling Mode - One Glass Cover



Assume: $e = 1.0$, $Fcs = 1.0$

$$Qc/A + s(Tgl^4 - Tc^4) + hi(Tgl - Tc) = 0 \quad \text{(II-4)}$$

$$s(Tc^4 - Tgl^4) + s(Ts^4 - Tgl^4) + hi(Tc - Tgl) + ho(Ta - Tgl) = 0 \quad \text{(II-5)}$$

Where: Tgl = Glass temperature, ^oR

ho = 1.0 + 0.3V, Btu/hr-ft^2-^oF

hi = Nuk/d, k = air conductivity, d = gap space

Nu = 1.0 for Gr less than $2x10^3$

Nu = $0.0507Gr^{0.4}$ for Gr between $2x10^3$ and $5x10^4$

Nu = 3.8 for Gr greater than $5x10^4$

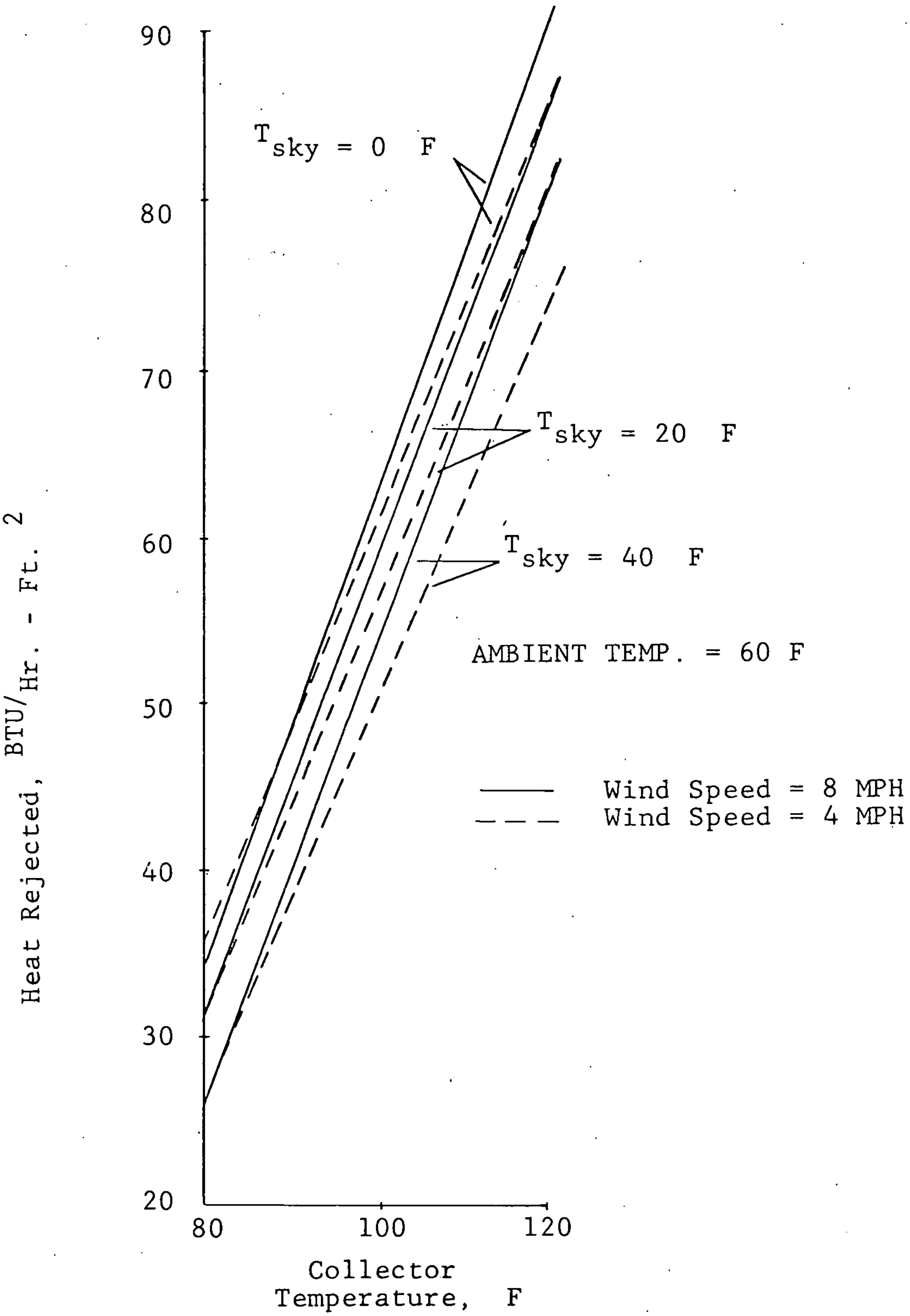


FIGURE II-3. NIGHT COOLING MODE, SINGLE GLAZING, AMBIENT TEMPERATURE = 60 Deg F

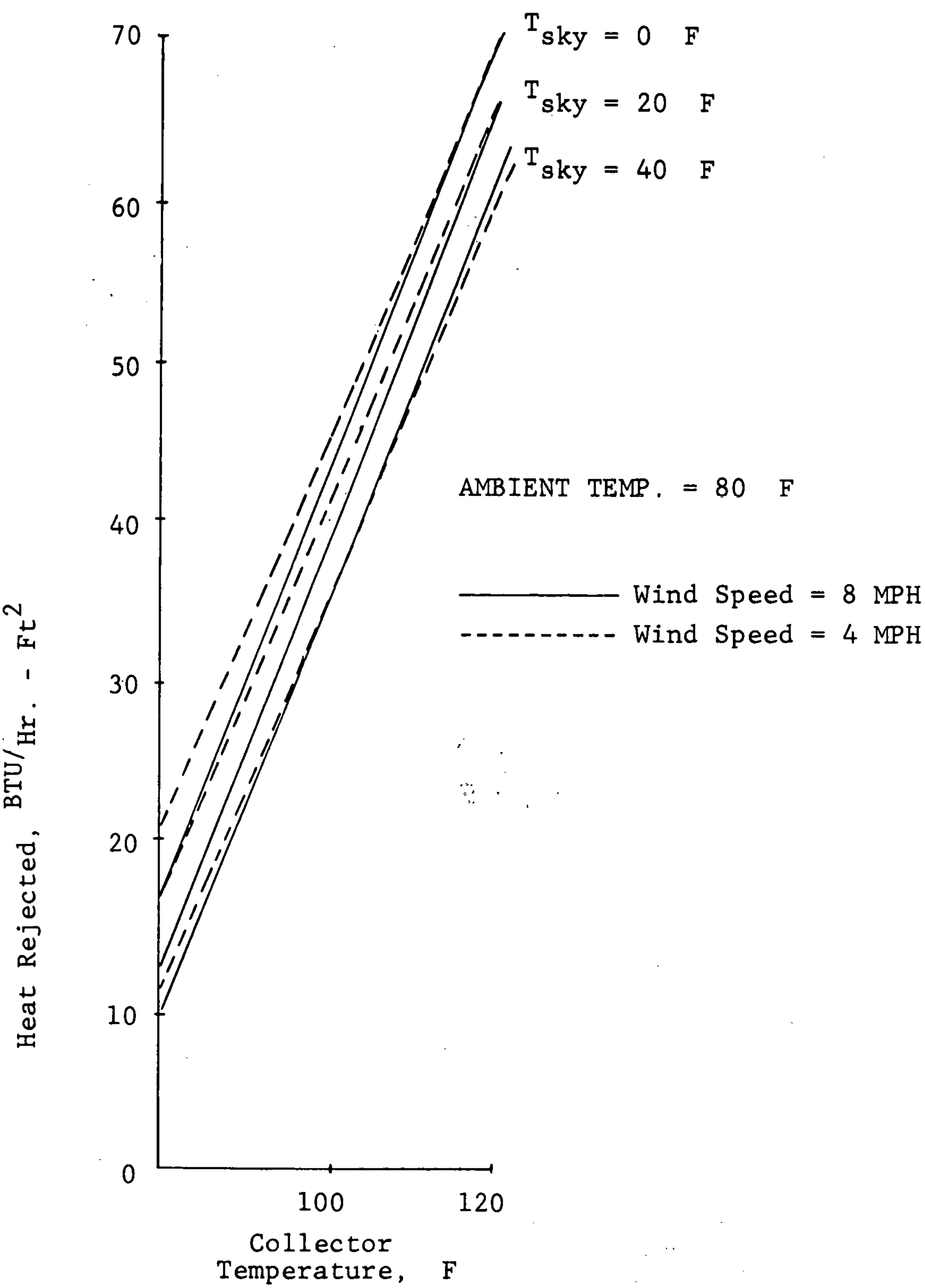


FIGURE II-4. NIGHT COOLING MODE, SINGLE GLAZING, AMBIENT TEMPERATURE = 80 Deg F

Emissivity = 0.95, Tilt Angle = 20^0, Back Insulation Thickness = 3"
Back Insulation Conductivity = 0.03 Btu/hr-ft-^{0}F

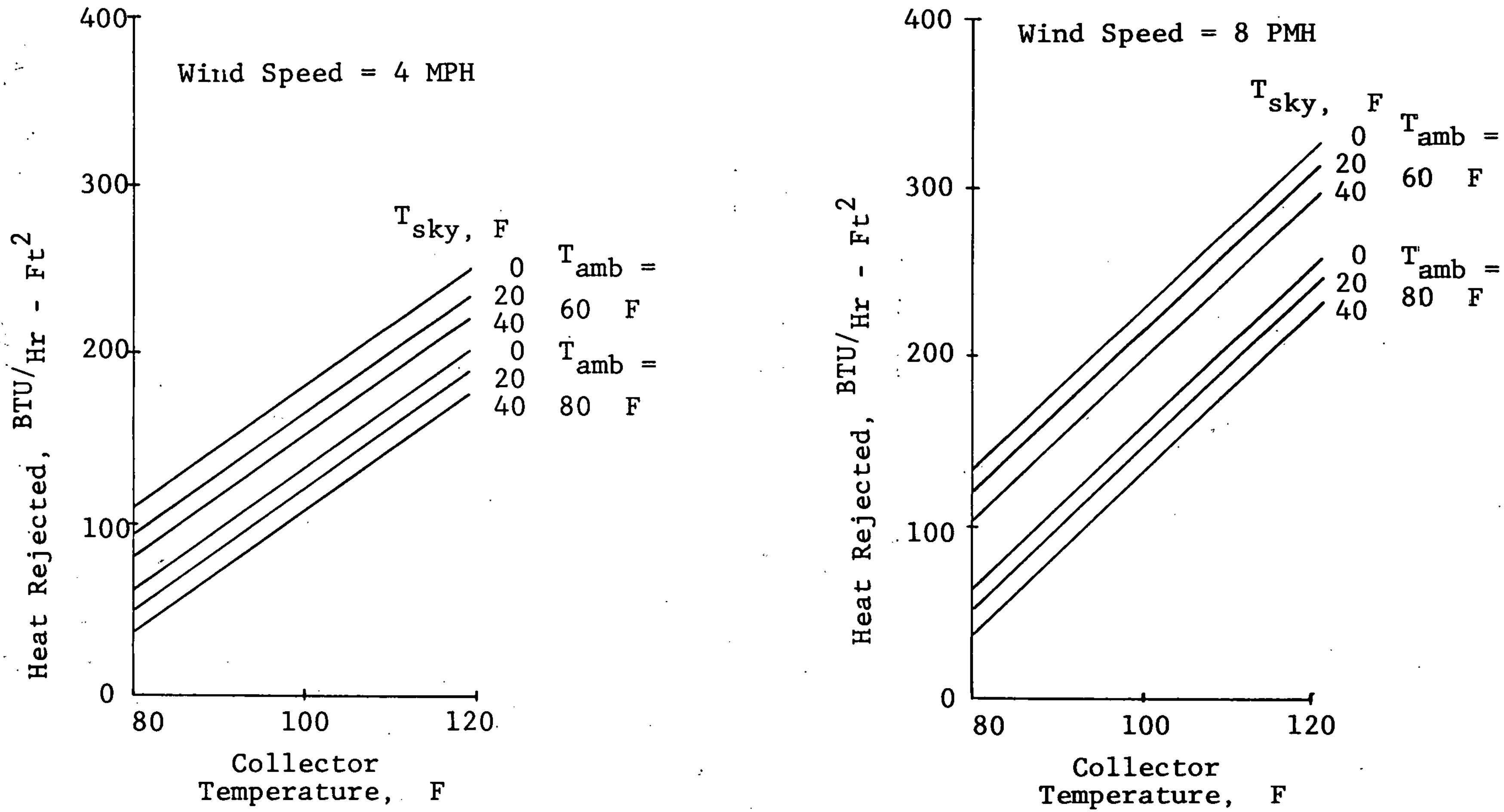


FIGURE II-5. NIGHT COOLING MODE, NO TRANSPARENT GLAZING

D. UNGLAZED COLLECTOR OPTIMIZATION

Based on the results of the FOM and the night heat rejection analyses, a commercially available extruded plastic absorber ("SolaRoll") was selected as the baseline configuration for an optimization analysis. The objective of this investigation was to calculate the thermal efficiency of the configuration as manufactured, and to determine if significant improvements can be achieved by changing the geometry. The geometry of the baseline SolaRoll configuration is shown in Figure II-6.

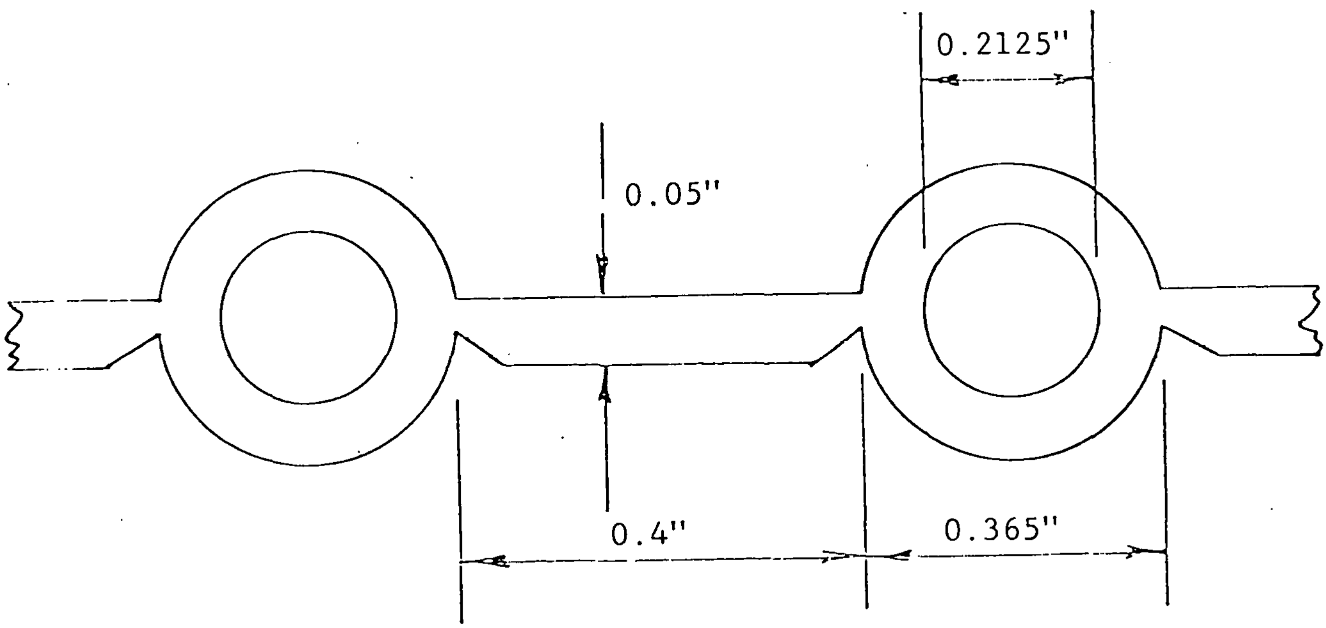


FIGURE II-6. SOLAROLL ABSORBER GEOMETRY

The first step in the investigation was to calculate the performance of the fins which interconnect the tubes of the absorber. Assuming one-dimensional heat transfer, an approximate equation for the fin effectiveness is given by:

$$N_1 = \tanh((B_{ie})^{\frac{1}{2}} l/t)/(B_{ie})^{\frac{1}{2}} l/t) \qquad \text{(II-6)}$$

$$(B_{ie}) = (seFTb^3 + h)t/k \qquad \text{(II-7)}$$

Where: B_{ie} = effective Biot Number

k = conductivity of fin material

t = fin thickness

l = fin length

e = IR emissivity of fin material

F = view factor between fin and sky

Tb = temperature of base of fin

s = Stefan-Boltzmann constant

h = convection film coefficient

If the fin is metallic and thin, then equation II-6 represents the effectiveness quite well. However, if the fin is a low-conductivity plastic, a question arises as to the adequacy of the one-dimensional heat transfer assumption. To investigate this, a two-dimensional fin efficiency equation was derived:

$$N_2 = 2/(B_i l/t) \quad (\sin B_n \tanh(B_n l/t))/(B_n + \tfrac{1}{2}\sin(2B_n)) \qquad \text{(II-8)}$$

Where: $B_i = ht/k$

$B_n = B_i/\tan B_n$

Results of the one and two-dimensional fin effectiveness equations are compared for various fin thickness-to-length ratios and Biot Numbers in Figure II-7. The conclusion drawn from this comparison is that the one-dimensional heat transfer assumption is valid for Biot Numbers of 0.01 or less, but significant error is introduced as Biot Number increases. It turns out that plastic absorbers of the type shown in Figure II-6 have Biot Numbers associated with their fins on the order of 1.0. Based on these results, a finite-element, two-dimensional computer model was developed to optimize the plastic absorber geometry.

A nodal diagram of the two-dimensional computer model is show in Figure II-8. The input variables to the model are listed as follows:

Fin length
Fin width
Tube outside diameter
Incident radiation
Surface emissivity
Surface absorptivity
Fin material conductivity
Wind velocity
Working fluid mass rate of flow
Working fluid temperature
Ambient temperature
Effective sky temperature

The program contains 67 nodes interconnected by 118 conductors. Internal film coefficients are calculated for either laminar or turbulent flow depending on which flow regime exists. The external film coefficient is calculated using Sparrow's equation (Ref. II-1). Results obtained using the model are plotted in Figure II-9. Inspection of these results shows that improved performance can be obtained by maintaining the fin thickness constant (compare curve A with curve B). The baseline SolaRoll configuration "pinches" the fin to a narrow cross-section adjacent to the tubes. It is apparent that this reduction in fin material blocks the heat transfer between fin and working fluid to a noticeable extent. Curve C shows the performance with a uniform fin (no pinch) which is half the length of the baseline design. Curve D shows the

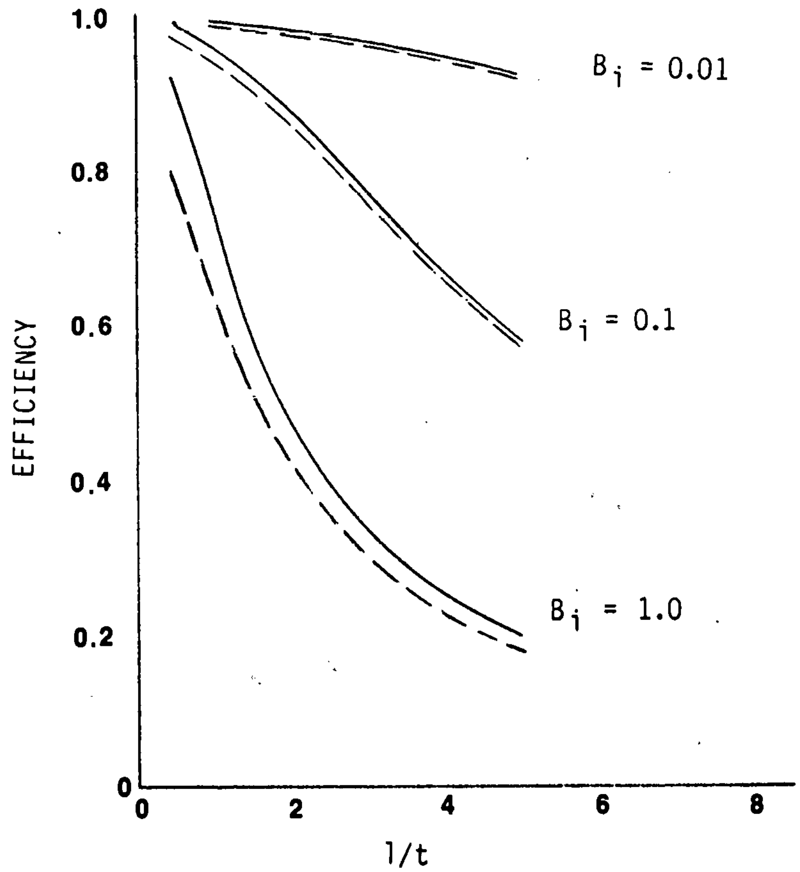


FIGURE II-7. FIN EFFICIENCY VS. BIOT NUMBER

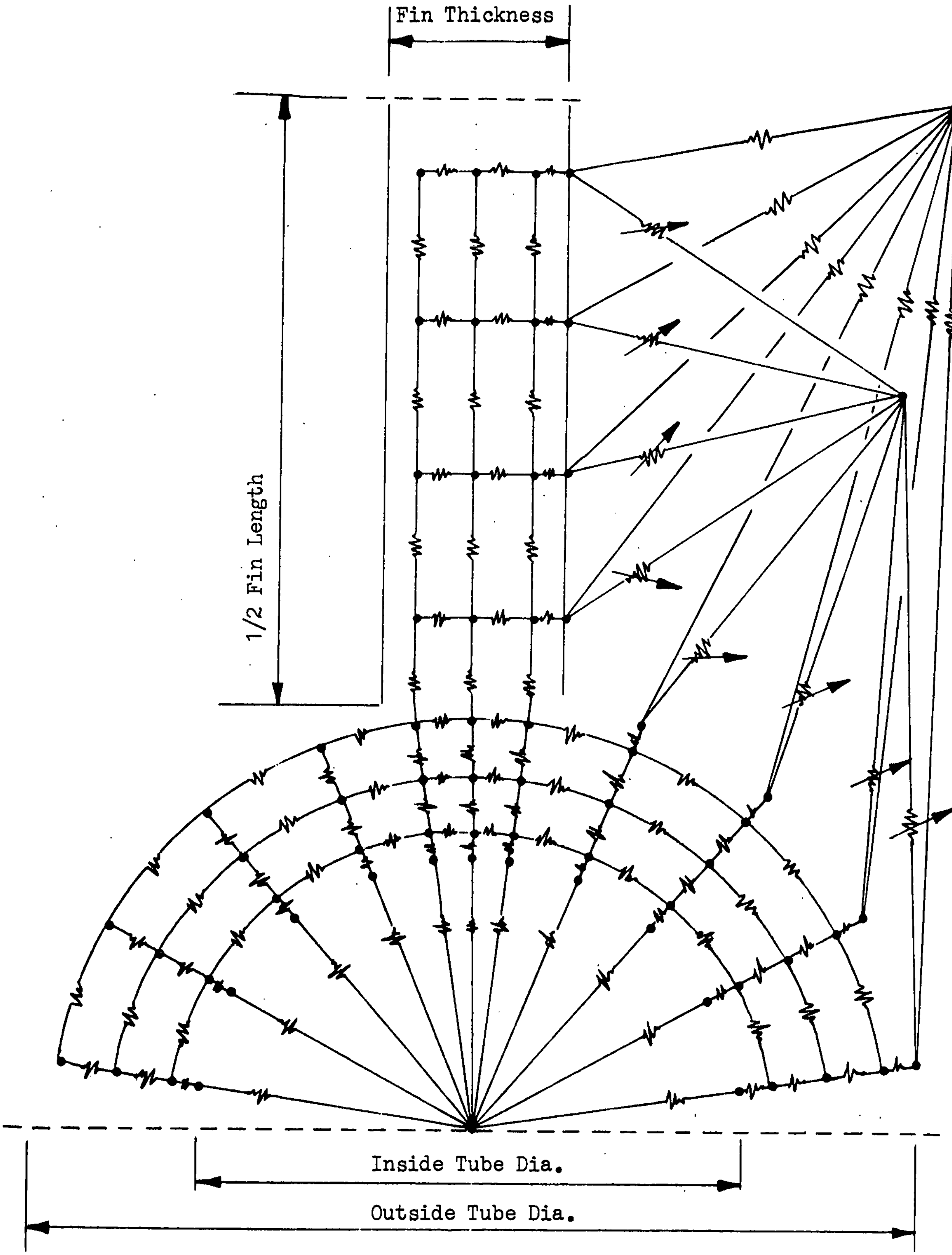
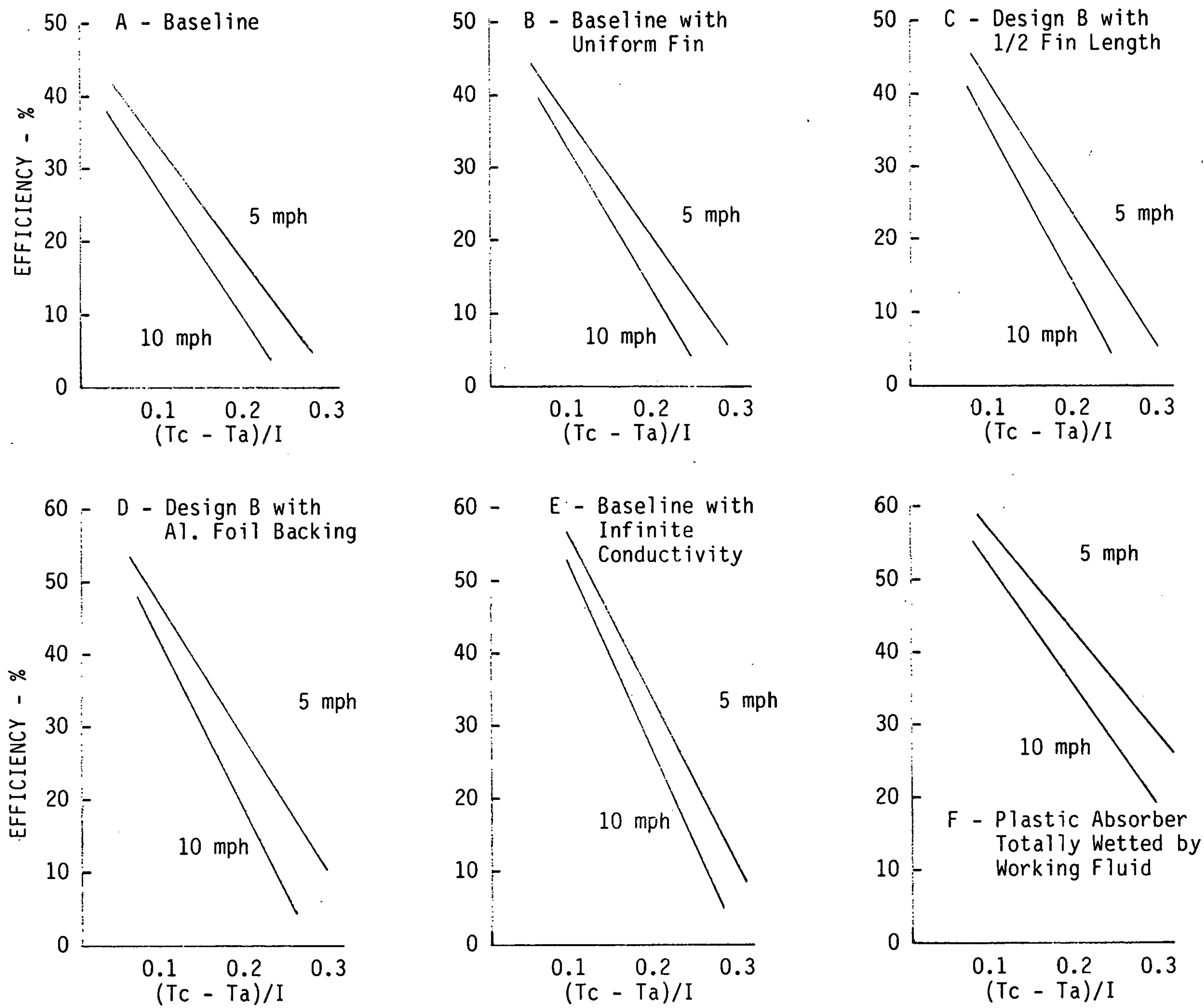


FIGURE II-8. TWO-DIMENSIONAL COMPUTER MODEL

FIGURE II-9. PERFORMANCE OF IMPROVED PLASTIC ABSORBERS



effect of backing the absorber with aluminum foil. This case assumes uniform fin thickness with 0.01 thick aluminum bonded to the plastic with a 0.005 inch thick adhesive.

Curves E and F represent the upper bound conditions, or the best heating performance that can be expected from simple unglazed, uninsulated collectors. For curve E, the conductivity of the baseline absorber was assumed to be infinite instead of the 0.1 Btu/hr-ft-^{o}F value typical of plastic absorbers. Curve F represents the performance of a plastic absorber in which the working fluid wets the entire surface. For this case, the wall thickness was assumed to be the same as the tube wall thickness of the baseline configuration, 0.05", and the thermal conductivity was assumed to be 0.1 Btu/hr-ft-^{o}F.

Comparison of the performance data for the various configurations indicates that the performance of the baseline configuration can be significantly improved. At moderate values of the abscissa (Tc-Ta)/I, the baseline collector efficiency is roughly half that of the theoretical upper limit cases (curves E and F). Of the possible practical modifications, the most promising would appear to be a shorter fin of uniform thickness. At an abscissa of 0.1, this modification would improve the efficiency of the baseline by a factor of 1.3.

It should also be noted that these results indicate a strong sensitivity to wind velocity, as would be expected with unglazed collectors. The correlation of film coefficient data from the test program (Section VI) suggests that the coefficients used in this analysis are low by about 50% for surfaces with characteristic dimensions typical of solar collectors. The wind velocities in Figure II-9, therefore, should possibly be 2.2 and 4.4 mph instead of the 5 and 10 mph shown.

III. HEAT PUMP SYSTEM CONFIGURATIONS

Four candidate solar-assisted heat pump systems were designed and evaluated as a first step toward defining the particular system configuration to be used in the year-long system performance simulations. The systems are all based on the use of a water-to-air heat pump in order to be able to couple the heat pump directly to either a water storage tank, or a water (or water-glycol) solar collector circuit, or both. The systems are also relatively complex due to the desire to use the solar collectors in both the heat collection and rejection modes. The four systems are shown in schematic form in Figures III-1 through III-4. The significant features of each of the four preliminary candidate systems are described as follows:

A. CANDIDATE WATER-SOURCE HEAT PUMP SYSTEMS

System #1 is a conventional series solar-assisted heat pump configuration in which all energy provided by the solar collectors goes into a water storage tank which is the only source of energy for the heat pump in the heating mode. The heat pump transfers energy to (or from) the residence space heating (or cooling) load through a conventional refrigerant/air coil in the forced air distribution duct. An electric resistance element in the duct provides auxiliary backup energy if the heat pump cannot satisfy the total heating demand. The only element in this system which might be considered novel is the desuperheat condenser coil which preheats the domestic water whenever the heat pump compressor is operating. The desuperheat condensor is an energy-effective means of heating domestic water and is included in all of the system configurations considered in the study.

System #2 employs a special type of heat transfer coil which allows an interface between air, refrigerant, and water or water/glycol; (an example of such a coil is the "TRI-AX" unit manufactured by Carrier Corporation). In system #2, a TRI-AX coil is installed in the collector circuit to permit the heat pump to collect and reject energy directly to the outside air in addition to the solar collectors. The addition of the TRI-AX coil provides improved system flexibility and efficiency, but adds cost and complexity.

System #3 employs two TRI-AX coils, one in the collector circuit and one in the distribution air duct. The coil in the air duct permits the heating or cooling load to be satisfied by either the heat pump or a water storage tank. This provides even greater flexibility and efficiency, but again at the expense of increased system cost and complexity.

System #4 is similar to System #3 except that the solar collector circuit has direct access to the water storage tank and the heat pump refrigerant circuit does not.

During review and evaluation of the candidate systems, it became apparent that conventional series, solar-assisted, water-source systems have the inherent problem of heat source starvation during periods of poor availability of solar energy. A review of recent DOE-sponsored work at Brookhaven National Laboratory indicated that coupling the ground to the heat pump as an energy source offered a promising means of alleviating the heat starvation problem. The primary design choice involved in selection of a ground-coupled

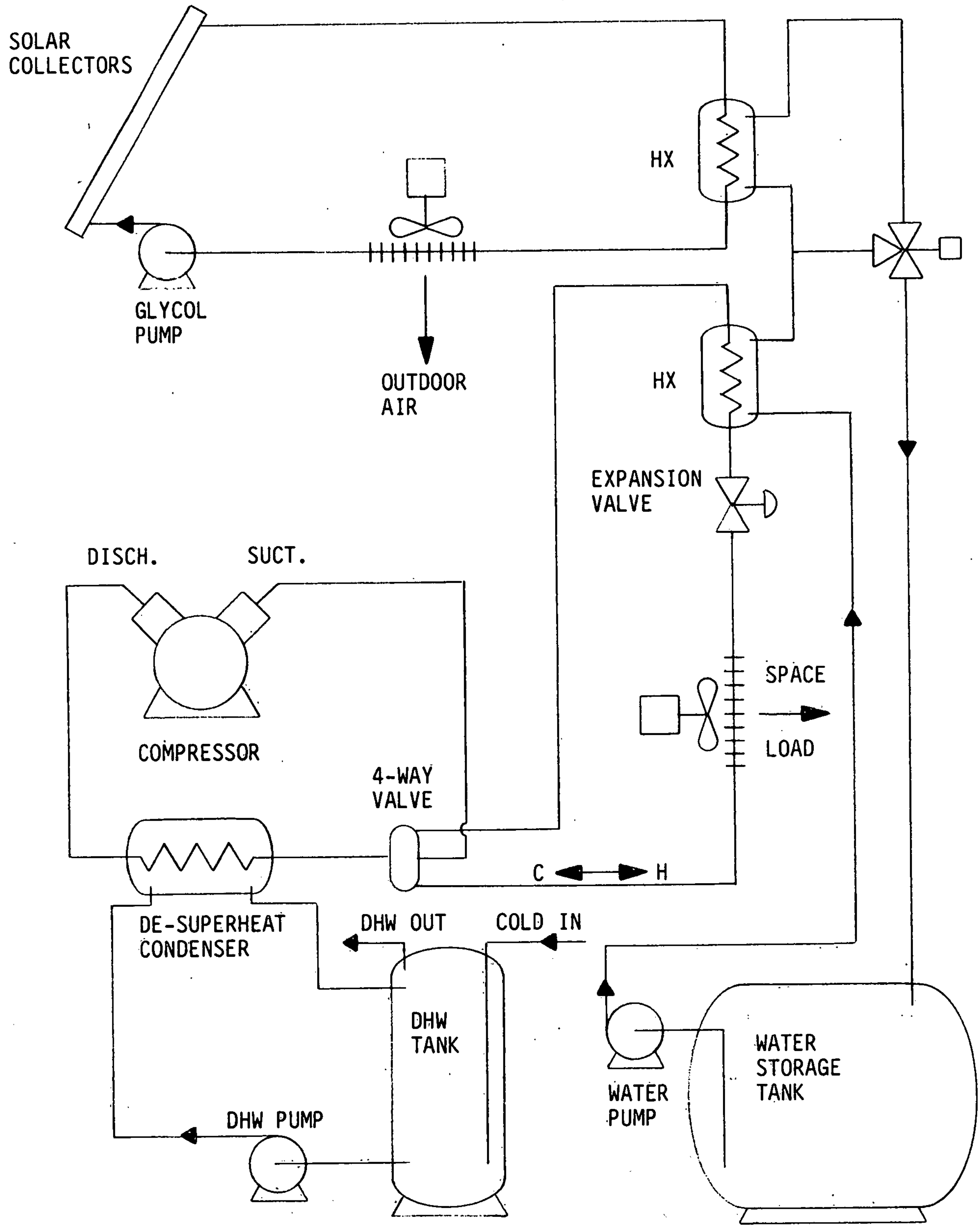


FIGURE III-1. SYSTEM #1

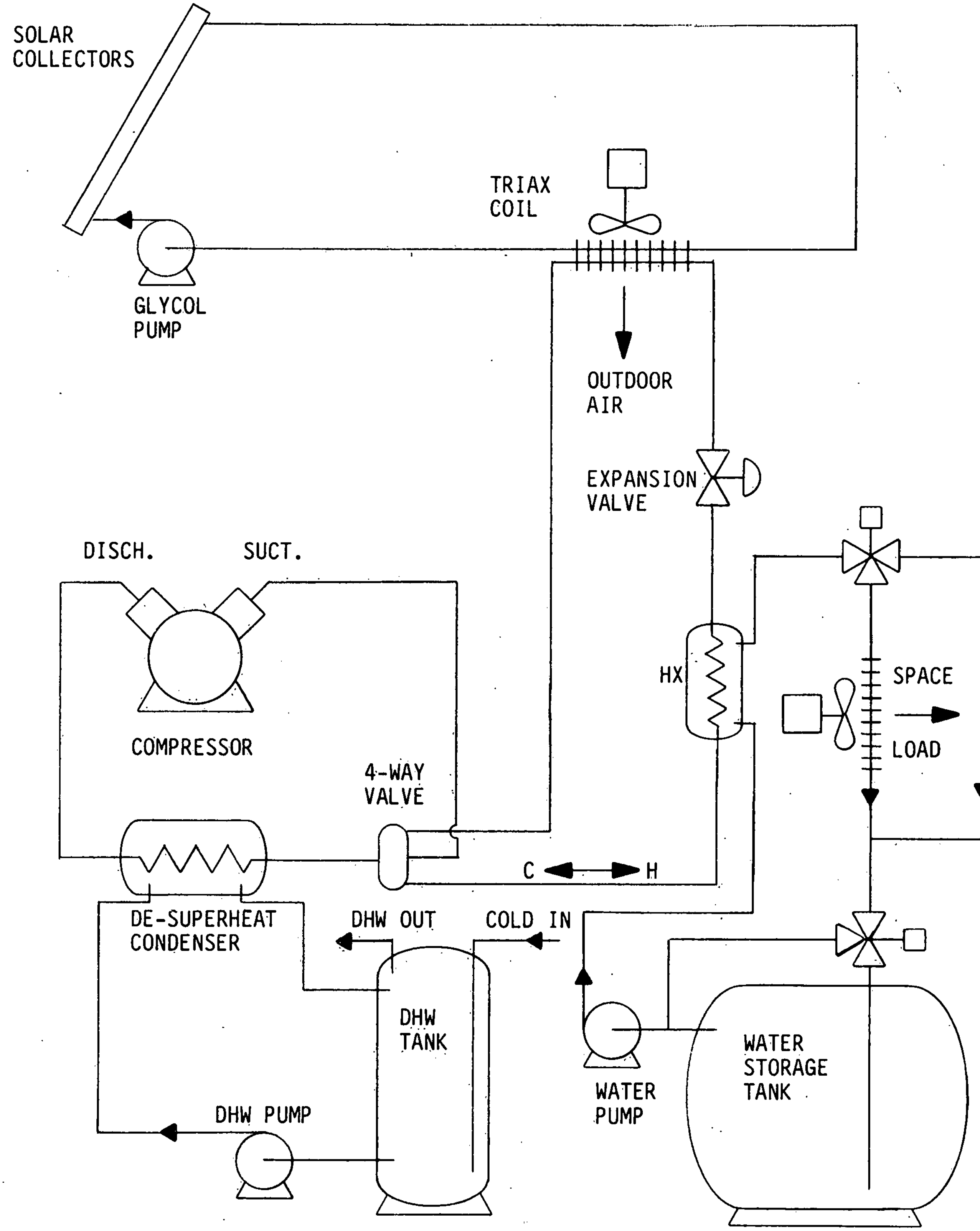


FIGURE III-2. SYSTEM #2

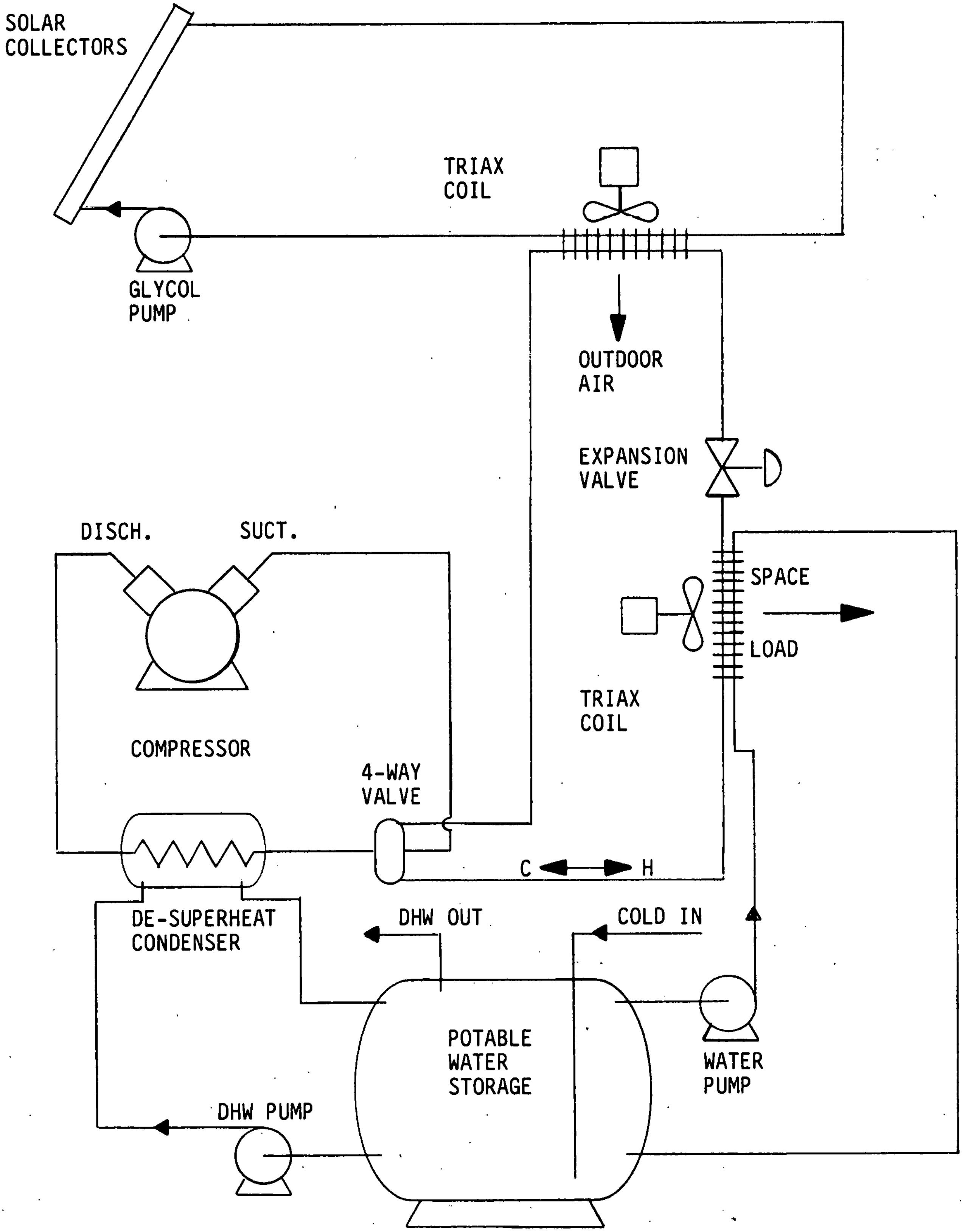


FIGURE III-3. SYSTEM #3

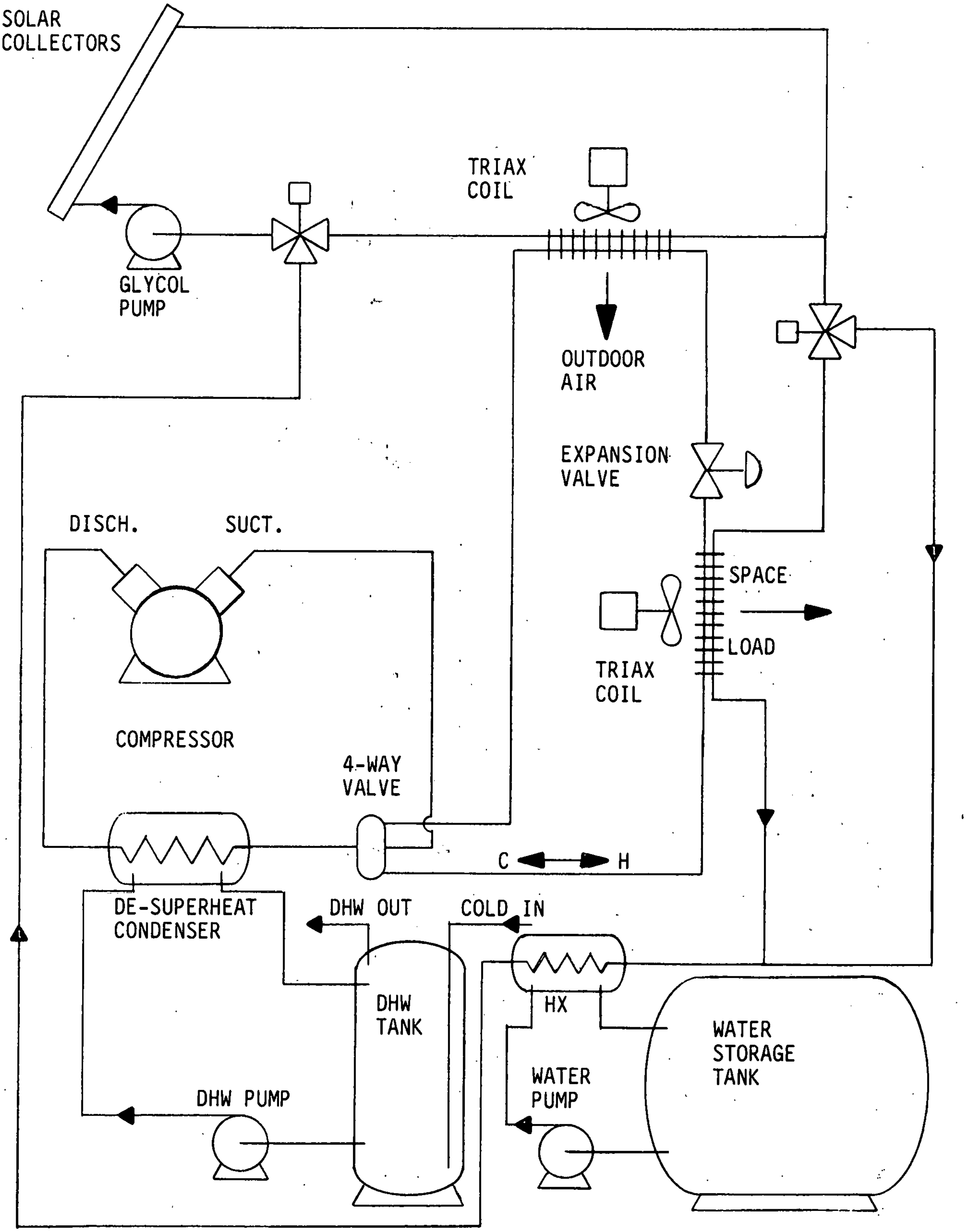


FIGURE III-4. SYSTEM #4

configuration is whether to couple the heat pump refrigerant circuit to the solar collector water/glycol circuit, the water storage/ground circuit, or both. Preliminary performance simulations for these configuration options for the Denver residence indicated only small differences in annual performance. Based on these results, and the desire to provide maximum sensitivity to collector heat rejection capability, a configuration was selected in which the heat pump refrigerant circuit is coupled to the collector water/glycol circuit. The collector circuit is coupled to the ground, water storage, or both.

This system was then compared to the earlier candidate designs which employed the TRI-AX coils, (systems #2, 3, and 4). Although the TRI-AX coils are commercially available units, their use introduces a degree of complexity into the system hardware and controls that was not considered appropriate for residential applications. The dual water/glycol-air source systems were discarded, therefore, in favor of the simpler design (from the standpoint of the heat pump and its controls) using a water tank or the ground as the energy source/sink. The selected baseline system is described in the following section.

B. BASELINE WATER-SOURCE HEAT PUMP CONFIGURATION

The system configuration selected for the year-long performance simulation computer runs is shown schematically in Figure III-5. The system is comprised of conventional hardware modules sized to be compatible with a standard reversible three-ton residential heat pump. Details of the system hardware are presented in the following paragraphs.

1. Solar Collectors - Flat plate solar collectors are connected to a water/glycol circuit that couples them thermally to one side of the heat pump's freon circuit, an outdoor air fan coil, and a water-to-water heat exchanger in the water storage/ground circuit. Depending on control inputs, the collector circuit may bypass the collectors and/or the water-to-water heat exchanger. The size of the collector array was set at a nominal value of 300 ft^2. This value was selected simply because it is an array size which reasonably can be accommodated on the typical residences (approximately 1800 ft^2) considered in the study. Increments of plus or minus 150 ft^2 were used to investigate effects of array size on annual performance.

The baseline collector configuration selected for the performance simulations is an unglazed, uninsulated plastic absorber. Details of the geometry and thermal performance of the baseline collector are given in Section II.D. Performance of a glazed, insulated collector array was evaluated in those cities which have significant space heating requirements. The glazed collector configuration used in the analysis is a single-glazed unit with a selective absorber surface. The ASHRAE 93-77 performance data for the glazed unit is an intercept of 0.73, and a slope of 0.87.

2. Water Storage - The water storage module is an insulated storage tank with a nominal assumed capacity of 600 gallons. This value was selected as compatible with the nominal 300 ft^2 collector array, and as a reasonable size for installation in the typical residences. A maximum value of 1200 gallons and a minimum of zero (no water storage) were used to explore sensitivities.

3. Ground Storage - The ground thermal storage system consists of four-inch diameter plastic pipe buried at a depth of four feet, (except in Minneap-

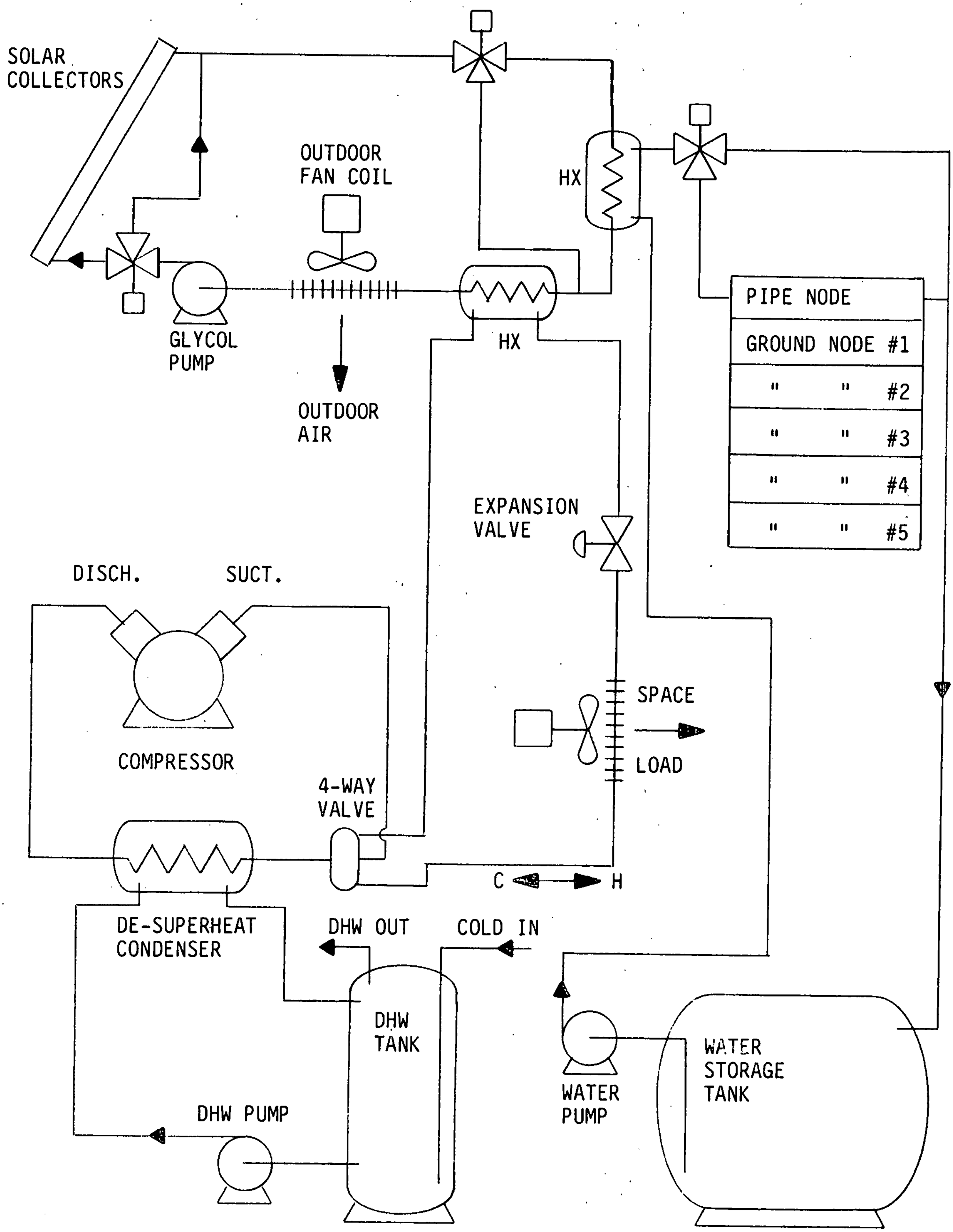


FIGURE III-5. BASELINE WATER-SOURCE HEAT PUMP SYSTEM olis where the depth was increased to six feet to prevent freezing). The nominal length was assumed to be 500 ft with values of 1000 ft and zero (no ground coupling) used to determine sensitivities.

As shown in the schematic, a three-way valve was provided to permit bypassing the ground storage when ground temperatures are such that useful energy can not be collected or rejected. This control logic was used only in some of the Denver simulations in which both water storage and ground coupling were installed in the system. Results of these runs indicated that only slight improvements in annual performance were achieved by the presence of both water and ground storage, and that the performance increases did not come close to justifying the cost of installation of both storage systems. Based on these results the three-way valve and bypass were eliminated and all subsequent simulations for the remaining seven cities included water storage or ground coupling, but never both together.

4. Outdoor Fan Coil - An outdoor liquid-to-air fan coil unit is incorporated in the collector/water storage/ground circuit to provide adequate heat rejection capability when the water or ground storage temperatures reach levels which significantly reduce heat pump capacity. The fan coil has a 1/3 hp motor, and is rated at 36000 Btuh with 100 ^{o}F inlet glycol temperature and 70^{o}F ambient air.

5. Heat Pump - The heat pump configuration selected for the study is intended to be representative of unitary (i.e., factory as opposed to field assembled), electrically powered units currently manufactured and sold for residential applications. Although the extremes, or design values, of the heating and cooling loads vary widely for the eight cities selected for the study, the heat pump was sized at a nominal rating of three tons. The three-ton capacity reflects a size close to what would be chosen by current practice for the typical residences in the cities with the higher heating and cooling requirements (Minneapolis, Denver, Phoenix, and Miami), but is a larger unit than probably would be selected for the other cities. The oversized unit would likely provide poorer performance (lower annual COP) because of greater transient cycling losses than a smaller unit in the mild-climate cities. This should not significantly affect the study results, however, since in each city the various water-source configurations are compared to a reference air-to-air heat pump of comparable size.

In addition to the conventional expansion device, four-way reversing valve, evaporator, and condenser, the heat pump includes a desuperheating condenser on the compressor discharge upstream of the four-way valve. The desuperheater is coupled to a pumped domestic hot water circuit such that the domestic hot water is pre-heated whenever the heat pump operates in either the heating or cooling mode.

C. AIR-TO-AIR HEAT PUMP REFERENCE SYSTEM

In order to assess the relative performance and cost effectiveness of the various water-source heat pump configurations, an air-to-air system was designed to provide a reference baseline against which to measure the water-source systems. The air-to-air system is shown schematically in Figure III-6. It consists of an indoor section (compressor, four-way valve, expansion device, distribution air duct coil, and desuperheat condenser) which is identical in size and performance to the indoor sections of all of the various water-source

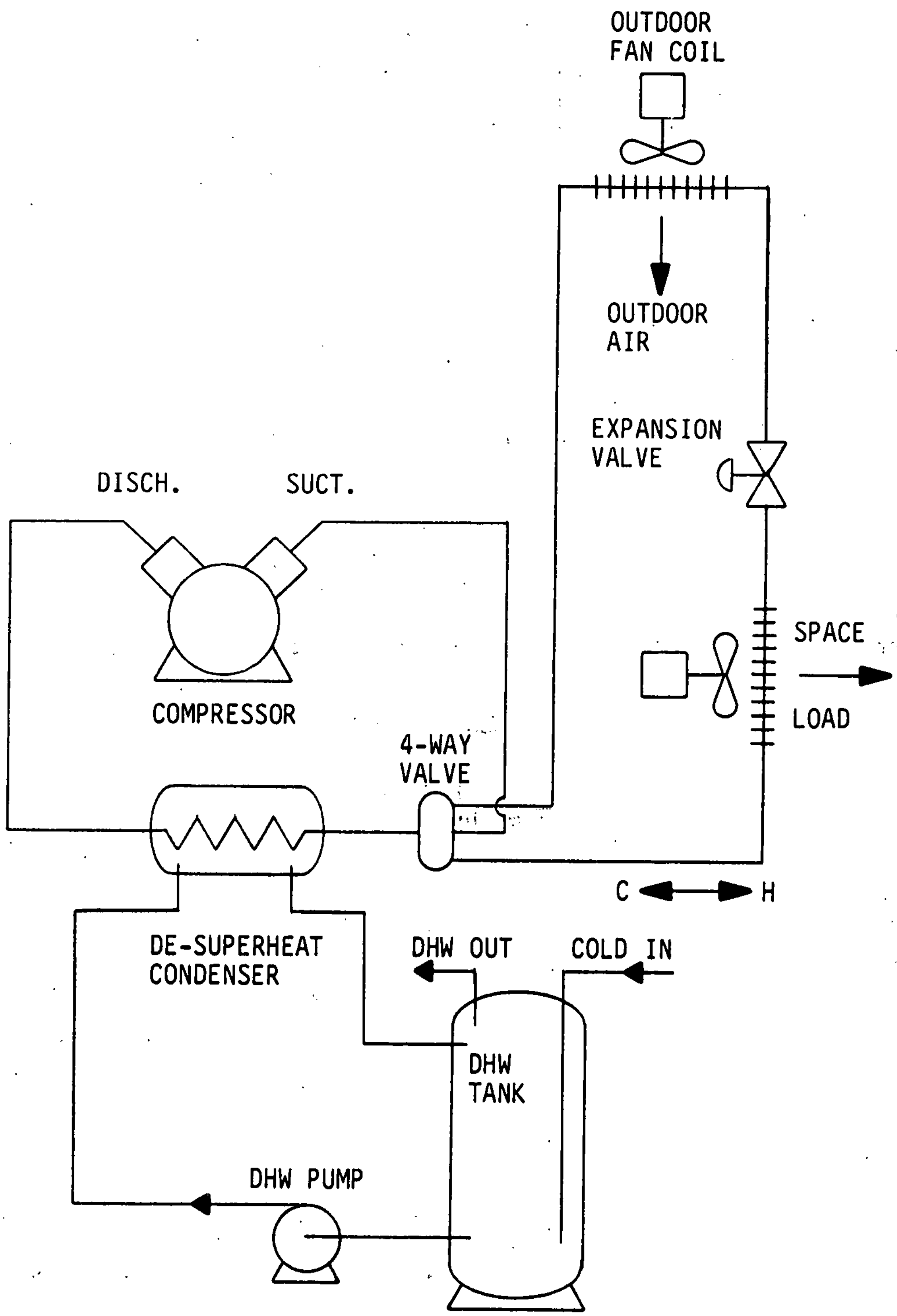


FIGURE III-6. REFERENCE AIR-TO-AIR HEAT PUMP SYSTEM configurations. The outdoor coil replaces the solar collector circuit, water storage, and ground circuit of the water-source systems.

A non-sophisticated timed defrost cycle was assumed for the air-to-air system. Although many manufacturers offer heat pumps which employ various sensing techniques to determine the extent of outdoor coil blockage by ice, and initiate defrost accordingly, the timed cycle triggered by outside ambient temperature is still the most common approach found in lower priced units. A timed cycle of 10 minutes of defrost during each 90 minutes of operation whenever the outside temperature is less than 40°F was used in all of the air-to-air system performance simulations.

IV. PERFORMANCE SIMULATION COMPUTER MODEL

A detailed computer model was developed to calculate the annual performance of the various water-source heat pump configurations and the reference air-to-air system in the eight selected cities. The model consists of three basic routines:

A synthetic weather routine which generates hourly weather parameters which are used to calculate the building heating and cooling loads, and provide the weather environment for the outdoor portions of the various heat pump systems.

A building heat load routine which generates the hourly heating and cooling loads for the typical residences in the eight selected cities.

A heat pump system simulation model, including the solar collectors, water storage, and ground storage, which exercises the various heat pump configurations against the building heating and cooling loads to determine the electrical power consumed by each system.

The analytical approach used to develop each section of the performance simulation model is described in the following paragraphs. A complete listing of the basic-language program is included as Appendix C.

A. SYNTHETIC WEATHER MODEL

The synthetic weather routine generates hourly weather parameters which vary in a cyclic random manner, but which converge on the monthly average values from the U. S. Climatic Atlas for the appropriate location. The basic methodology used to calculate each parameter is as follows:

1. Dry Bulb Temperature - The daily average ambient dry bulb temperature is assumed to vary randomly about the monthly average, and the hourly value varies sinusoidally about the daily average with a minimum at 3:00 AM and a maximum at 3:00 PM. The magnitude of the daily swing is adjusted by a random number which is correlated with sky clearness, such that large day-night swings tend to occur with clear (rather than cloudy) days. The basic equations used to generate the dry bulb temperatures are as follows:

$$T_{aved} = 2T_{avem} - T_{maxm} + .25(R_2 - 0.5)(T_{maxm} - T_{avem}) \qquad \text{(IV-1)}$$

$$T_{swc} = 2R_1(T_{maxm} - T_{avem}) \qquad \text{(IV-2)}$$

$$T_{amb} = T_{aved} + T_{swc}\text{COS}(15(T - 15)) \qquad \text{(IV-3)}$$

Where: T_{avem} = Monthly average temperature from Climatic Atlas

T_{maxm} = Monthly average maximum temperature from Climatic Atlas

R_1, R_2 = Random numbers selected daily

T = Hour of the day

2. Dew Point Temperature - Dew point temperature is calculated using a procedure similar to that for ambient temperature except that dew point temperature is never permitted to exceed ambient dry bulb temperature.

$$T_{dpad} = T_{dpam} + 0.5R_3(T_{aved} - T_{avem}) \quad \text{(IV-4)}$$

$$T_{dp} = T_{dpad} + 0.25R_4T_{swc} \quad \text{(IV-5)}$$

Where: T_{dpam} = Monthly average dew point from Climatic Atlas

R_3, R_4 = Random numbers selected daily

3. Solar Insolation - This is calculated by degrading the ASHRAE clear day insolation profile for the appropriate latitude in a random manner assuming an S-shaped cumulative probability distribution, i.e., days are more likely to be either mostly cloudy or clear rather than "one-half" clear. It should be noted that no attempt is made to allow for abrupt cloudiness variations within a given day. Each day is predetermined to be either clear or some degree of cloudy, and the hourly profile is degraded accordingly throughout the day. The daily total insolation calculated for a horizontal surface converges each month on the monthly average values taken from the Climatic Atlas for the appropriate city. The basic equations used are as follows:

$$P = H_a/H_c \quad \text{(IV-6)}$$

$$P_p = (P - 0.35)/0.65 \quad \text{(IV-7)}$$

$$P_s = 1 - P_p \quad \text{(IV-8)}$$

If R_1 greater than P_s:

$$R_s = P_p + P_s/90\text{ArcCOS}((1 - R_1)/P_p) \quad \text{(IV-9)}$$

If R_1 less than P_s:

$$R_s = R_1(P_p/P_s)(1 - \text{COS}(90R_1/P_s)) \quad \text{(IV-10)}$$

$$C_1 = 0.65R_s + 0.35 \quad \text{(IV-11)}$$

$$S_{bs} = I_{dn}R_s\text{COS(Theta)} \quad \text{(IV-12)}$$

$$S_{ds} = I_{dn}(C_1C + \text{SIN(Beta)})((C_1 - R_s)F_{ss}) \quad \text{(IV-13)}$$

$$S_{gs} = I_{th}R_{hog}C_1F_{sg} \quad \text{(IV-14)}$$

Where: H_a = Monthly average day-long insolation on a horizontal surface from Climatic Atlas

H_c = ASHRAE-method calculated clear day insolation on a horizontal surface

I_{dn} = ASHRAE-method clear day direct beam insolation

Theta = Incident angle of direct beam on surface of interest

C = ASHRAE-method monthly constant for diffuse radiation

Beta = Incident angle of direct beam on horizontal surface

F_{ss} = View factor from surface of interest to sky

I_{th} = ASHRAE-method clear day total radiation on a horizontal surface

R_{hog} = Ground reflectance

F_{sg} = View factor from surface of interest to ground

S_{bs} = Direct beam insolation on surface of interest

S_{ds} = Diffuse insolation on surface of interest

S_{gs} = Ground-reflected insolation on surface of interest

4. Effective Sky Temperature -

$$T_{sky} = ((T_{amb} + 460)^4 - 2.14^{10})^{0.25} - 460 \quad \text{(IV-15)}$$

5. Wind Velocity -

$$V_{wd} = V_{wave}(8.306R_5{}^3 - 9.95R_5{}^2 + 4.158R_5 - 0.0763) \quad \text{(IV-16)}$$

$$V_w = V_{wd}(1.5 - R_{nd}) \quad \text{(IV-17)}$$

Where: V_{wave} = Monthly average wind velocity from Climatic Atlas

R_5 = Random number selected daily

R_{nd} = Random number selected hourly

Since the finite number of random numbers used do not always average to 0.5, smoothing factors are applied to all the calculated weather parameters to assure that their monthly average values match those from the Climatic Atlas. Complete details of the synthetic weather calculations may be found in the program listing in Appendix C.

B. BUILDING HEAT LOAD MODEL

The heat load routine was developed to calculate hourly heating and cooling loads for the typical residences in each of the eight cities using the synthetic weather parameters described in the preceding section. Characteristics of the generic single-family residence defined for each city, and the basic methodology used to calculate the thermal loads are described in the following paragraphs.

1. Building Characteristics - The design and structural features selected for the "typical" residence in each city are intended to be representative of the detached single-family residence currently being built for middle and upper-middle income families. The design characteristics used are based primarily on results of a nation-wide builder survey conducted for HUD by

Hittman Associates, Inc., (Ref. IV-1).

The buildings defined are all of wood frame construction except for the Miami house, which has solid masonry walls with a built-up roof. Conditioned living space varies from 1200 in Boston to 1850 ft^2 in the Denver house. Wall insulation R values in the frame houses range from 10 to 13 $hr\text{-}ft^2\text{-}^oF/Btu$. Ceiling and roof R values range from 14 to 21. Double-glazed windows and full basements were assumed for the Minneapolis and Boston houses. The major characteristics of the residence defined for each city are listed in Table IV-1.

2. Thermal Load Calculation Method - Hourly heating and cooling load profiles were calculated for each city using the appropriate building design characteristics and the hourly synthetic weather parameters. Heat transfer through walls and roofs were computed using the response factor method defined in the 1977 ASHRAE Fundamentals Handbook. Internal thermal mass of the building is simulated by a single node connected by air-convection conductors to the walls, internal air, and heat sources and sinks (occupants, appliances, lights, solar flux through windows, and heat pump). Infiltration is computed as a function of wind velocity and the difference between indoor and outdoor dry bulb temperature.

Solar gains through windows are calculated using the hourly values of direct beam and diffuse radiation from the synthetic weather routine modified for absorption and reflection due to the window glazing (Ref. IV-2). Draperies were assumed behind 70% of the window area. Thermostat set points were assumed to be 72^{o}F for heating and 78^{o}F cooling, with a heating night setback to 65^{o}F. Both humidification and dehumidification latent loads are included as required to maintain indoor humidity ratios of 0.006 lb. water/lb. air in the winter, and 0.009 lb. water/lb. air in the summer.

Daily profiles were assumed for internal heating or cooling loads generated by lights, appliances, occupants, and energy required for heating domestic hot water. No adjustments were made in these profiles for weekends or holidays. The daily totals assumed for each item are as follows:

Lights - 5.47 KWH/day

Appliances - 16.2 KWH/day

Occupants - 2 Adults, 2 Children
7.49 KWH/day Sensible Load
3.56 KWH/day Latent Load

Domestic Hot Water - 80 Gal/day

Annual and seasonal heating and cooling loads are tabulated for each city in Table V-1. Monthly values are tabulated in Appendix B. A complete listing of the basic-language heat load computer routine is included in Appendix C.

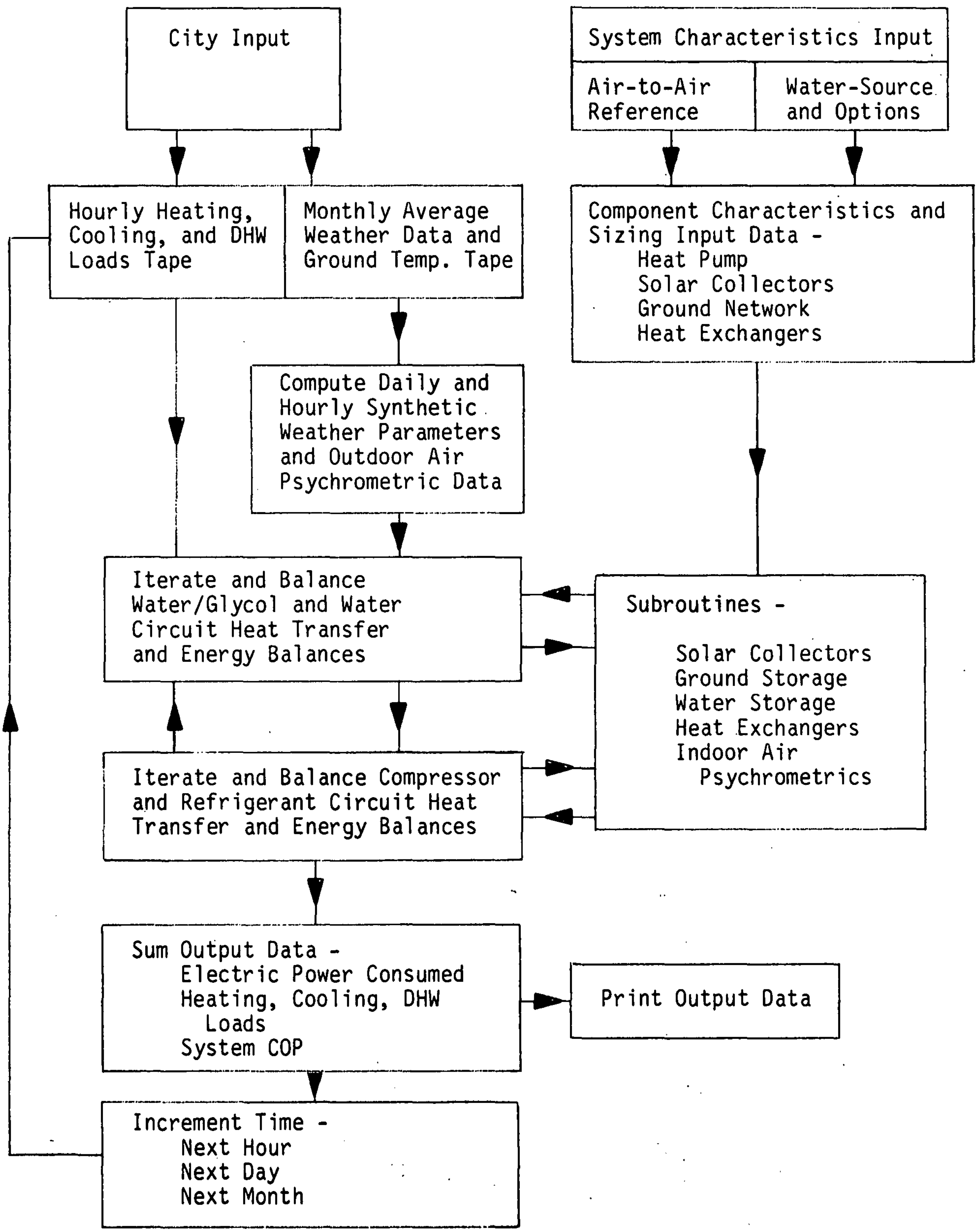
C. HEAT PUMP SYSTEM SIMULATION MODEL

The solar-assisted, water-source heat pump computer model is shown in block-diagram form in Figure IV-1. As shown, the heat pump performance analysis part of the model receives input from the synthetic weather and building heat load routines described above, and from the input blocks which

TABLE IV-1. DESIGN CHARACTERISTICS OF GENERIC RESIDENCES

	DENVER	BOSTON	MINNEAPOLIS	BALTIMORE	MIAMI	PHOENIX	ATLANTA	LOS ANGELES
Building Type	Split Level	Split Level	Ranch	2-Story	Ranch	Ranch	2-Story	Ranch
Frame	Wood	Wood	Wood	Wood	Block	Wood	Wood	Wood
Basement	Partial	Full	Full	Full	Slab on Grade	Slab on Grade	Slab on Grade	Slab on Grade
Living Area - ft^2	1852	1200	1457	1695	1705	1705	1700	1705
Window Area - ft^2								
North	102	61	60	83	74	102	83	102
East	0	0	24	48	24	24	48	24
South	128	82	101	84	92	112	84	112
West	0	0	0	0	0	12	0	12
Glazing Type	Single	Double	Double	Single	Single	Single	Single	Single
Exterior Siding	Brick Veneer	Wood	Wood	Wood	Stucco	Stucco	Brick Veneer	Stucco
Wall Area - ft^2	1484	1179	1230	1897	986	1317	1721	1317
Wall R Value	13	12	13	12	3	12	13	12
Roof Material	Asphalt Shingle	Asphalt Shingle	Asphalt Shingle	Asphalt Shingle	Built-up	Asphalt Shingle	Asphalt Shingle	Asphalt Shingle
Roof R Value	14	16	19	16	15	14	21	14
Attached Garage	Yes	Yes	Yes	No	Yes	No	Yes	No

FIGURE IV-1. HEAT PUMP SYSTEM SIMULATION MODEL BLOCK DIAGRAM



prescribe the physical characteristics of the system components. Given the input data, the model assumes a set of conditions for the water/glycol circuit (refer to Figure III-5 in Section III.B) at the beginning of each hour (based on the end conditions for the previous hour) and iterates between the water/glycol circuit, the refrigerant circuit, and the water/ground storage circuit until a consistent set of heat transfer rates and energy balances is obtained for all three circuits, and the building heating or cooling load is satisfied. The model then tabulates all of the electrical energy used by the various components in the system (including space heating or DHW resistance auxiliary if required) and proceeds to the next hour.

The analytical descriptions of the solar collectors, water storage tank, and various heat exchangers in the system were constructed in a conventional manner. Particular attention was given, however, to development of detailed, accurate models of the heat pump compressor and the ground thermal storage network. The basic approach used to model these elements is described in the following paragraphs.

1. Heat Pump Compressor Analytical Model - Operation of the heat pump compressor and the refrigerant circuit is simulated by a series of bi-variant second-order polynomial equations of the general form:

$$Y = A + Bx + Cx^2 + Dz + Exz + Fx^2z + Gz^2 + Hz^2x + Ix^2z^2 \qquad \text{(IV-18)}$$

The specific performance parameters computed using this equation are as follows:

$$Q_{elec} = f_1(x,z) \qquad \text{(IV-19)}$$

Where: Q_{elec} = Electrical energy used by compressor motor, Btu/hr

x = Saturated condensing temperature in condenser modified by line losses, ^{o}F

z = Saturated suction temperature in evaporator modified by line losses, ^{o}F

$$Q_{evap} = f_2(x,z) \qquad \text{(IV-20)}$$

Where: Q_{evap} = Heat transferred to refrigerant in evaporator, Btu/hr

x and z are the same variables used in previous equation

$$T_{sv} = f_3(x,z) \qquad \text{(IV-21)}$$

Where: T_{sv} = Temperature of superheated vapor leaving compressor, ^{o}F

x = Saturated condensing temperature, ^{o}F

z = Enthalpy of refrigerant leaving compressor, Btu/lb

$$H_{shv} = f_4(x,z) \quad \text{(IV-22)}$$

Where: H_{shv} = Enthalpy of refrigerant leaving desuperheater condenser, Btu/lb

x = Saturated condensing temperature, ^oF

z = Temperature of refrigerant leaving desuperheater condenser, ^oF

The nine constants for equations IV-19 through IV-22 were determined by regression analysis curve fitting of test data obtained from a conventional reciprocating three-ton compressor. The constants are listed as follows:

	Q_{elec}	Q_{evap}	T_{sv}	H_{shv}
A	10132	33064	-749.1	95.64
B	-57.67	-198.2	2.049	0.176
C	0.2333	0.04768	0.01322	-0.002156
D	-410.1	323.6	8.197	0.1971
E	8.62	1.513	-0.02691	-0.000835
F	-0.03287	-0.01232	-0.000126	0.00000957
G	4.188	8.569	-0.009312	0.000000115
H	-0.09016	0.03652	0.0000893	0.000000964
I	0.000429	-0.000432	0.00000032	-0.000000012

Equations IV-19 through IV-22, together with appropriate heat transfer rate equations and refrigerant equations of state, are solved iteratively each hour to define the performance of the system. For example, if space heating by the heat pump is required during a given hour, a trial estimate of Q_{evap} is made based on conditions in the glycol side of the evaporator obtained from an initial balance of the water and water/glycol circuits. An estimate of evaporator saturated suction temperature is made based on Q_{evap} and the water/glycol inlet temperature. Using this value and the saturated condensing temperature from the previous hour, estimates of Q_{evap} and Q_{elec} are calculated from equations IV-19 and IV-20. Refrigerant enthalpies entering and leaving the evaporator are also calculated from the estimates of saturated evaporator and condensing temperatures and appropriate equations of state. The refrigerant mass flowrate is then calculated from the enthalpy change and the estimate of Q_{evap}. Enthalpy leaving the compressor is then estimated by adding the energy (less line and compressor losses) added by the evaporator (Q_{evap}) and the compressor (Q_{elec}) to the enthalpy leaving the condenser. The temperature of the superheated vapor leaving the compressor is calculated using equation IV-21 and the estimates of saturated condensing temperature and enthalpy leaving the compressor. If the domestic water requires heat, the temperature of the refrigerant leaving the desuperheater is estimated based on the domestic water temperature and the refrigerant mass flow. Enthalpy leaving the desuperheater is then calculated from equation IV-22.

The procedure is repeated until changes in all variables are reduced below specified convergence limits. When the steady-state output of the heat pump has been defined in this manner, the output is compared to the load required during the particular hour and the heat pump operation is reduced to the fraction of the hour required to satisfy the load.

Cycling transient losses are simulated by assuming that approximately 300 watt-hours of electricity are expended without useful output during each start-up of the heat pump. For the water-source configurations, this energy contributes to space heating during the heating season since the compressor is assumed to be inside the house. For the reference air-to-air unit, the compressor is assumed to be outside and the 300 watt-hour start-up loss is lost to the ambient under all conditions. Defrost cycle penalties for the air-to-air unit are assumed to occur whenever the outside ambient is less than 40^{o}F. This penalty consists of a reversal of the heat pump for 0.1 of each hour with appropriate cycling loss, plus turn on of a 1500 watt auxiliary resistance heater while the heat pump is reversed.

Calculated performance of the simulated air-to-air heat pump system was compared to values published by the manufacturer of a commercially available three-ton unit. The particular unit selected for comparison and the simulation have comparably sized indoor and outdoor coils (1275 cfm airflow through indoor coil, 1800 cfm through outdoor coil). The performance of the commercial unit and calculated values from the simulation at similar operating conditions (no domestic water heat load in the desuperheat condenser) are shown in the following table:

Heating Capacity - Btu/hr	30500	26226
Outdoor Ambient - ^{o}F	35	35
Total Power Consumption - KW	4.41	2.85
System COP	2.03	2.69
Cooling Capacity - Btu/hr	36900	34394
Outdoor Ambient - ^{o}F	80	80
Total Power Consumption - KW	4.74	3.98
System EER - Btu/hr/Watt	7.78	8.64

The above comparison indicates that the efficiency of the simulation air-to-air heat pump is slightly better than that of the example commercial unit in both the heating and cooling modes. This may in part be due to the assumption of a thermostatically controlled expansion valve in the simulation heat pump, as opposed to a fixed capillary device in the commercial unit. In the heating mode the manufacturer's data also normally includes a derated COP to account for defrost cycle penalties which are included in the simulation model, but on a discrete cycle basis, and are not included in the calculated heating mode performance listed above. The comparison shows that the simulation produces steady-state results (which do not include any domestic water load in the desuperheater) for the reference air-to-air system that are representitive of what can be expected from state-of-the-art residential units. Inclusion of the domestic water desuperheater improves the net operating COP's of the system in both the heating and cooling modes.

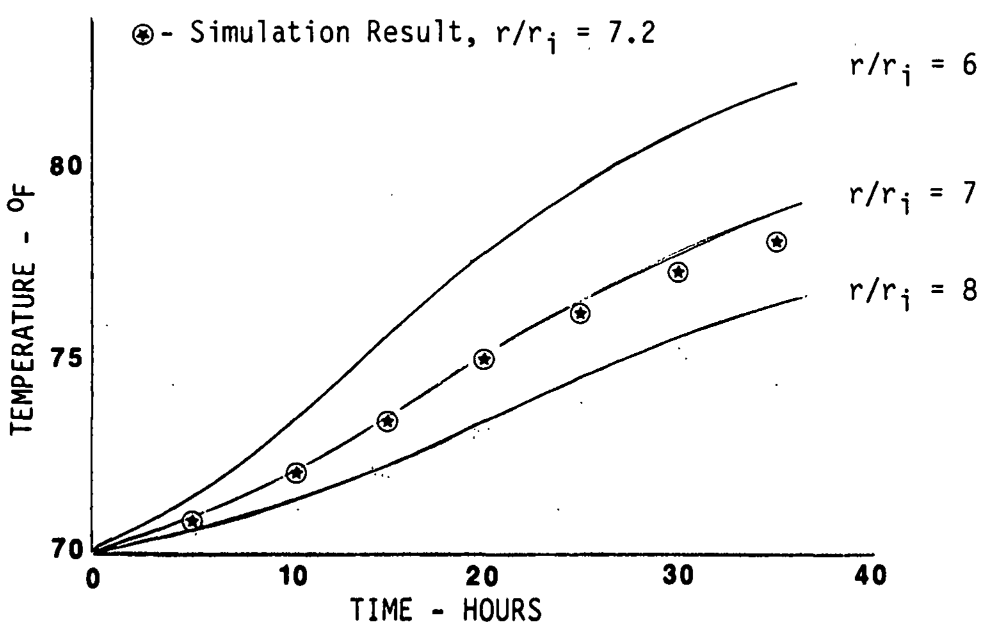
Complete listings of the basic language programs for both the reference air-to-air heat pump simulation model and the water-source system models are included in Appendix C.

2. **Ground-coupled Thermal Storage Simulation Model** - A six-node finite-element computer model, consisting of one pipe node and five ground nodes, was constructed to permit reasonably accurate simulation of the transient temperature gradients in the soil surrounding the buried pipe network caused by the addition and extraction of energy. The ground nodes are defined as five annular cylinders of equal thickness which surround the 4-inch diameter pipe and just extend to the surface. The pipe was assumed to be buried 4 feet deep in each city except Minneapolis where a 6-foot depth was assumed. Boundary conditions for the ground nodes were derived from the monthly average ground temperatures at various depths for the eight cities of interest. These temperatures, which approximate a sine wave about an annual average temperature with a minimum in March and a maximum in September, are imposed in the simulation as the far-field ground temperature at the beginning of each month.

Probably the most critical assumption influencing the performance and effectiveness of the ground-coupled thermal storage is that of thermal conductivity of the soil surrounding the buried pipe. In real soil, this can vary significantly from one type of soil to another, and can vary by orders of magnitude depending on moisture content. For purposes of this study, thermal conductivity of the soil was assumed to be a constant value of 0.7 Btu/hr-ft-^{o}F. This value is representative of relatively dry, loose earth, and may be on the low side for any type of soil with even small quantities of moisture.

In order to test the accuracy and validity of the six-node model used in the simulation, a closed form, two-dimensional analytical model was constructed and compared to the simulation for a step change in pipe temperature. Results of this comparison are plotted in Figure IV-2 for various values of r/r_i which is the ratio of distance from the pipe to the radius of the pipe. These data indicate that the temperatures calculated by the simple six-node model in the simulation track the more exact solution reasonably accurately, at least for the conditions of the example. Details of the ground-coupling model used in the simulation may be found in the program listing in Appendix B.

FIGURE IV-2. SIMULATION GROUND TEMPERATURES VS. ANALYTICAL SOLUTION



V. PERFORMANCE SIMULATION RESULTS

A series of year-long performance simulation computer runs was made for each of the eight selected cities using the model described in Section IV. The initial runs were made for Denver and included various combinations of the "nominal" size collector array, water storage, and ground storage, as well as variations in each to explore sensitivities. Run matrices for the remaining cities were developed based on the Denver results. The Denver runs clearly showed, for example, that although system performance was improved slightly by including both water storage and ground storage, the additional free energy obtained in no way justified the added cost of a system which incorporated both storage systems.

The Denver results also tended to justify the nominal values selected for the various system elements, at least for the Denver climate and thermal loads. Increases in size of the collector array and the storage elements did improve performance, but only marginally. The nominal sizes are all beyond the "knee" of the annual performance curves. Based on these results, the run matrices were designed to provide a basis of comparison for the performance and cost effectiveness of the nominally sized water-source heat pump options against the air-to-air reference heat pump in each city.

A. TABULATED THERMAL PERFORMANCE RESULTS

An annual and seasonal summary of the heating and cooling loads and the system electrical power consumption for each run is tabulated in Table V-1. All values of loads and power consumption are in units of kilowatt hours. The COP values (coefficient of performance) are defined as the sum of the loads (heating, cooling, and DHW) divided by the electrical power consumed by the heat pump, auxiliary resistance heaters, air fans, and liquid pumps. The last line in each table is the annual COP of the particular water-source system divided by the annual COP of the reference air-to-air system. This figure can be viewed as a figure-of-merit for the water-source system. For example, a COP ratio of 1.2 means that the air-to-air reference requires 1.2 times the electrical power to satisfy the annual heating and cooling repuirements compared to that particular water-source configuration. The seasonal values are included to provide some insight into the performance of the various configurations during the heating and cooling extremes in each location. A complete tabulation of all results, monthly and annually, is included as Appendix B.

Inspection of the tabulated results clearly shows that none of the water-source configurations analyzed are significantly better performers than the reference air-to-air system, and in the cities where the bulk of the thermal load is space heating (Denver, Boston, Baltimore, and Minneapolis) the performance of the air-to-air system is superior in almost every case. The best water-source system thermal performance (compared to the air-to-air referance system) occurs in Atlanta and Los Angeles, where the heating and cooling loads are balanced, and where the ground storage appears to be particularly effective both as a heat source and sink.

In the colder locations, the water-source systems require a significant amount of auxiliary resistance space heating energy during the coldest months even though the capacity of the heat pump is relatively large. This is because the storage (either water tank or ground, or both) become depleted, i.e., drop

TABLE V-1, SIMULATION RESULTS

DENVER		ANNUAL	HEATING SEASON (Dec, Jan, Feb)	COOLING SEASON (July, Aug)
	Heating Load (KWH)	26292	13769	139
	Cooling Load (KWH)	1566	0	1189
	DHW Load (KWH)	4848	1414	676

CONFIGURATION -	1	2	3	4	5	6	7	Air-to-Air
Coll Area - Sq Ft	300	300	300	300	300	150	450	
Stor Vol - Gal	600	600	1200	0	0	0	0	
Ground Lngth - Ft	500	0	0	1000	500	500	500	
ELECTRICITY CONSUMED - KWH (COP)								
Annual	15292 (2.14)	17369 (1.88)	16578 (1.97)	17160 (1.91)	16787 (1.93)	20145 (1.62)	14781 (2.21)	16787 (1.95)
Heating Season	8892 (1.71)	10121 (1.50)	9693 (1.57)	9885 (1.54)	9707 (1.56)	11582 (1.31)	8168 (1.86)	8192 (1.85)
Cooling Season	756 (2.65)	888 (2.26)	873 (2.30)	764 (2.62)	797 (2.51)	774 (2.59)	827 (2.42)	1042 (1.92)
(Annual COP)/(Air-to-Air COP) ..	1.098	0.966	1.013	0.978	0.991	0.833	1.136	

TABLE V-1, SIMULATION RESULTS

		ANNUAL	HEATING SEASON (Dec, Jan, Feb)	COOLING SEASON (July, Aug)
DENVER	Heating Load (KWH)	26292	13769	139
	Cooling Load (KWH)	1566	0	1189
	DHW Load (KWH)	4848	1414	676

CONFIGURATION -	8	9	10	Air-to-Air
Coll Area - Sq Ft	0	300-G	300-G	
Stor Vol - Gal	0	0	600	
Ground Lngth - Ft	500	500	0	
ELECTRICITY CONSUMED - KWH (COP)				
Annual	23035 (1.42)	14573 (2.24)	13897 (2.35)	16787 (1.95)
Heating Season	13201 (1.15)	8065 (1.88)	7790 (1.95)	8192 (1.85)
Cooling Season	769 (2.61)	835 (2.40)	891 (2.25)	1042 (1.92)
(Annual COP)/(Air-to-Air COP)	0.729	1.152	1.208	

TABLE V-1, SIMULATION RESULTS

BOSTON	ANNUAL	HEATING SEASON (Dec, Jan, Feb)	COOLING SEASON (July, Aug)
Heating Load (KWH)	15393	10143	0
Cooling Load (KWH)	3123	0	2027
DHW Load (KWH)	4705	1430	593

CONFIGURATION -	1	2	3	4	5	6	7	Air-to-Air
Coll Area - Sq Ft	300	300	0	150	450	300-G	300-G	
Stor Vol - Gal	600	0	0	0	0	0	600	
Ground Lngth - Ft	0	500	500	500	500	500	0	
ELECTRICITY CONSUMED - KWH (COP)								
Annual	14019 (1.66)	12382 (1.88)	15176 (1.53)	13810 (1.68)	11567 (2.01)	11493 (2.02)	12559 (1.85)	10756 (2.16)
Heating Season	9244 (1.25)	7698 (1.50)	10081 (1.15)	8921 (1.30)	6997 (1.65)	6916 (1.67)	8047 (1.44)	5065 (2.28)
Cooling Season	1069 (2.45)	926 (2.83)	901 (2.91)	910 (2.88)	943 (2.78)	950 (2.76)	1078 (2.43)	1205 (2.17)
(Annual COP)/(Air-to-Air COP) ..	0.767	0.869	0.709	0.779	0.930	0.936	0.856	

TABLE V-1, SIMULATION RESULTS

		ANNUAL	HEATING SEASON (Dec, Jan, Feb)	COOLING SEASON (July, Aug)
MINNEAPOLIS	Heating Load (KWH)	40948	23600	114
	Cooling Load (KWH)	2038	0	1513
	DHW Load (KWH)	4684	1481	521

CONFIGURATION -	1	2	3	4	5	6	Air-to-Air
Coll Area - Sq Ft	300	300	300-G	300-G	300	0	
Stor Vol - Gal	600	0	0	600	0	0	
Ground Lngth - Ft	0	500	500	0	1000	500	
ELECTRICITY CONSUMED - KWH (COP)							
Annual	36478 (1.31)	36715 (1.30)	34459 (1.38)	33855 (1.41)	37219 (1.28)	40955 (1.16)	28655 (1.66)
Heating Season	23123 (1.08)	23044 (1.09)	21966 (1.14)	21801 (1.15)	23172 (1.08)	25082 (1.00)	17563 (1.43)
Cooling Season	928 (2.32)	774 (2.78)	778 (2.76)	931 (2.31)	761 (2.82)	769 (2.79)	1088 (1.97)
(Annual COP)/(Air-to-Air COP) ..	0.786	0.780	0.832	0.846	0.770	0.700	

TABLE V-1, SIMULATION RESULTS

BALTIMORE	ANNUAL	HEATING SEASON (Dec, Jan, Feb)	COOLING SEASON (July, Aug)
Heating Load (KWH)	18550	12103	1
Cooling Load (KWH)	5863	0	3370
DHW Load (KWH)	4253	1331	569

CONFIGURATION -	1	2	3	4	5	6	7	Air-to-Air
Coll Area - Sq Ft	300	300	0	150	450	300-G	300-G	
Stor Vol - Gal	0	600	0	0	0	0	600	
Ground Lngth - Ft	500	0	500	500	500	500	0	
ELECTRICITY CONSUMED - KWH (COP)								
Annual	14641 (1.96)	16115 (1.78)	17202 (1.67)	15713 (1.82)	13740 (2.09)	13720 (2.09)	14617 (1.96)	13752 (2.08)
Heating Season	8531 (1.57)	10047 (1.34)	10760 (1.25)	9454 (1.42)	7868 (1.71)	7844 (1.71)	8876 (1.51)	6422 (2.09)
Cooling Season	1394 (2.83)	1529 (2.58)	1361 (2.89)	1373 (2.87)	1412 (2.79)	1430 (2.76)	1536 (2.56)	1743 (2.26)
(Annual COP)/(Air-to-Air COP) ..	0.939	0.853	0.799	0.875	1.001	1.002	0.941	

TABLE V-1, SIMULATION RESULTS

		ANNUAL	HEATING SEASON (Dec, Jan, Feb)	COOLING SEASON (July, Aug)
MIAMI	Heating Load (KWH)	41	40	0
	Cooling Load (KWH)	24123	1510	7128
	DHW Load (KWH)	3525	868	598

CONFIGURATION -	1	2	3	4	5	Air-to-Air
Coll Area - Sq Ft	300	300	0	0	0	
Stor Vol - Gal	600	0	0	0	600	
Ground Lngth - Ft	0	500	500	1000	0	
ELECTRICITY CONSUMED - KWH (COP)						
Annual	10789 (2.57)	10648 (2.60)	10791 (2.57)	10625 (2.61)	10982 (2.52)	12477 (2.22)
Heating Season	1113 (2.17)	1217 (1.99)	1226 (1.97)	1226 (1.97)	1132 (2.14)	1318 (1.84)
Cooling Season	2980 (2.59)	2857 (2.70)	2901 (2.66)	2835 (2.73)	3038 (2.54)	3430 (2.25)
(Annual COP)/(Air-to-Air COP) ..	1.156	1.172	1.156	1.174	1.136	

TABLE V-1, SIMULATION RESULTS

		ANNUAL	HEATING SEASON (Dec, Jan, Feb)	COOLING SEASON (July, Aug)
PHOENIX	Heating Load (KWH)	2718	2183	0
	Cooling Load (KWH)	17451	132	7353
	DHW Load (KWH)	4266	1215	610

CONFIGURATION -	1	2	3	4	Air-to-Air
Coll Area - Sq Ft	300	300	0	0	
Stor Vol - Gal	600	0	0	0	
Ground Lngth - Ft	0	500	500	1000	
ELECTRICITY CONSUMED - KWH (COP)					
Annual	10437 (2.34)	10286 (2.38)	10280 (2.38)	9866 (2.48)	12147 (2.01)
Heating Season	1361 (2.59)	1596 (2.21)	1690 (2.09)	1714 (2.06)	2154 (1.64)
Cooling Season	3590 (2.22)	3337 (2.39)	3331 (2.39)	3153 (2.53)	3812 (2.09)
(Annual COP)/(Air-to-Air COP) ..	1.164	1.181	1.182	1.231	

TABLE V-1, SIMULATION RESULTS

ATLANTA		ANNUAL	HEATING SEASON (Dec, Jan, Feb)	COOLING SEASON (July, Aug)
	Heating Load (KWH)	7009	5433	0
	Cooling Load (KWH)	11705	0	5560
	DHW Load (KWH)	3912	1281	455

CONFIGURATION -	1	2	3	4	5	Air-to-Air
Coll Area - Sq Ft	300	300	0	0	150	
Stor Vol - Gal	600	0	0	0	0	
Ground Lngth - Ft	0	500	500	1000	500	
ELECTRICITY CONSUMED - KWH (COP)						
Annual	8957 (2.53)	8885 (2.55)	9200 (2.46)	8808 (2.57)	8999 (2.51)	11140 (2.03)
Heating Season	2767 (2.43)	2709 (2.48)	2985 (2.25)	2811 (2.39)	2811 (2.39)	3553 (1.89)
Cooling Season	2287 (2.63)	2186 (2.75)	2195 (2.74)	2092 (2.87)	2190 (2.75)	2670 (2.25)
(Annual COP)/(Air-to-Air COP) ..	1.244	1.254	1.211	1.265	1.238	

TABLE V-1, SIMULATION RESULTS

		ANNUAL	HEATING SEASON (Dec, Jan, Feb)	COOLING SEASON (July, Aug)
LOS ANGELES	Heating Load (KWH)	2089	1467	0
	Cooling Load (KWH)	3638	41	1872
	DHW Load (KWH)	3943	1187	539

CONFIGURATION -	1	2	3	4	Air-to-Air
Coll Area - Sq Ft	300	300	0	0	
Stor Vol - Gal	600	0	0	0	
Ground Lngth - Ft	0	500	500	1000	
ELECTRICITY CONSUMED - KWH (COP)					
Annual	4250 (2.28)	4488 (2.15)	4452 (2.17)	4336 (2.23)	5321 (1.82)
Heating Season	1000 (2.69)	1068 (2.52)	1161 (2.32)	1159 (2.32)	1500 (1.80)
Cooling Season	1004 (2.40)	1018 (2.37)	953 (2.53)	889 (2.71)	1122 (2.15)
(Annual COP)/(Air-to-Air COP) ..	1.252	1.186	1.195	1.227	

to 35^{o}F. This suggests the possibilty of using a water/glycol fluid in the ground pipe grid to extend the useful temperature range and permit extraction of heat of fusion by freezing the moisture in the surrounding soil. Use of anti-freeze fluid to couple the ground storage was not included in any of the runs made in the study, but it appears that this might significantly enhance the performance of the ground-coupled systems in cold climate areas.

One result of interest which was not expected is the effectiveness of the outdoor fan coil in rejecting heat in the warmer cities. The fan coil was added to the system early in the study when it became apparent that neither the solar collectors nor the ground network were capable of rejecting sufficient energy to satisfy the cooling loads during long periods of time under severe conditions. The fan coil by itself (without either water storage or ground storage) is not as effective as the as the air-to-air unit since it is more efficient to evaporate refrigerant directly in the outdoor coil if no storage is available to the system. Incorporation of a water storage tank, however, provides a configuration which has better thermal performance than the air-to-air system in the cooling mode (reference the Miami Configuration #5 results, page V-7). It appears that the COP of the fan coil/water storage system is better than the air-to-air unit because the fan coil can dump energy from the storage tank during the night. This provides a heat sink at a temperature lower than that of the ambient air for the heat pump to operate against during the peak cooling loads during the day. These results suggest configurations in which the heat pump is coupled directly to the storage so that chilled water for the next day's cooling load can be produced at night. This would further reduce the daytime operation of the heat pump and might provide even better annual COP's in cities which have primarily cooling loads.

B. SYSTEM COST EFFECTIVENESS

A simple set of cost assumptions was devised to provide some insight into the basic question of whether either solar collectors or ground-coupled thermal storage can be cost-effective compared to a conventional air-to-air residential heat pump system. While the cost model must be viewed as a very rough approximation, it has purposely been kept simple so that the reader can easily make his own adjustment. The assumptions are as follows:

1. The installed cost of the reference air-to-air system is the same as for the water-source systems except for the solar collectors, the ground pipe grid, and/or the water storage tank which are all "extras" over and above the cost of the air-to-air system.

2. The installed cost of a water storage tank, if any, is $2.00 per gallon, or $1200 for the nominal-size tank.

3. The current average cost of residential electricity in each city is $0.06 per kilowatt hour.

4. The "allowable cost" of solar collectors and/or ground storage is based on a simple 10-year payback from the annual saving in electricity compared to the reference air-to-air system.

These assumptions were used to compute what the solar collectors and ground storage network could cost in order to justify their increment of installed cost over and above the air-to-air system. The results are shown in matrix form in Table V-2.

As may be seen from Table V-2, solar collectors can not be installed in any configuration for anything close to realistic costs in any of the eight locations studied. Even if the cost model assumptions are grossly in error, it does not appear that solar collectors can be made to be economically attractive in any of the configurations analyzed. Ground-coupled thermal storage, on the other hand, appears to be competitive in the cities with moderate or warm climates at allowable installed costs which are close to those currently being reported for real systems The Table also shows that buried pipe lengths greater than the nominal value of 500 feet improve thermal performance, but at diminished economic returns.

TABLE V-2. ALLOWABLE INSTALLED COST

	Solar Collectors - $/sq ft		Ground Storage - $/ft	
	Glazed	Unglazed	500 ft	1000 ft
Denver	1.78	*	*	*
Boston	*	*	*	*
Minneapolis	*	*	*	*
Baltimore	*	*	*	*
Miami	*	*	2.00	1.11
Phoenix	*	*	2.24	1.37
Atlanta	*	0.36	2.32	1.40
Los Angeles	*	*	1.04	0.59

* - Allowable cost is zero or negative

The allowable cost of the water storage tank for the Miami configuration with the outdoor fan coil and 600 gallon tank is $897 compared to the assumed baseline installed cost of $1200 used in the simple cost model. This indicates that although the system has a better annual COP than the air-to-air unit, it may be marginal from an economic standpoint. The potential to use off-peak power at night, however, could make significant additional cost savings available to this configuration in warm climate areas with peak and off-peak electric rate differentials.

VI. FILM COEFFICIENT/NIGHT SKY TEMPERATURE EXPERIMENT

The two correlations most commonly used today for calculating convection heat transfer film coefficients are by Jerges (reported by McAdams, Ref. VI-1), and by Sparrow (Ref. II-1). When these correlations are compared, the Jerges coefficient is three to four times the Sparrow coefficient for characteristic dimensions typical of solar collector size surfaces (12 to 18 feet). It would appear that the Sparrow correlation is superior since it is based on more recent data, and incorporates a characteristic length (which the Jerges equation does not). The Sparrow correlation, however, was based on wind tunnel testing using a small test article (3 by 3 inches), and was necessarily influenced by turbulence levels which may or may not be representative of those present in outside ambient air streams. Since neither available correlation may be applicable to outdoor-mounted solar collector arrays, a simple test program was conceived which would provide not only "in situ" film coefficient data, but also estimates of effective night sky temperature.

The interest in night sky temperature arose because it is the other controlling parameter (in addition to convective film coefficient) in predicting the nocturnal heat rejection capability of unglazed flat plate collectors. A literature survey was made to review the available data on sky temperature and correlations (if any) of the effects of cloud cover. Two of several references were selected for detailed review (Feigelson, Ref. VI-2, Kondratyev, Ref. VI-3). These summarized the available data and offered some quantitative discussion of the various factors which affect sky temperature.

Data presented by Feigelson indicate a net radiated flux of 33 Btu/ft^2 for a clear night sky, and a reduction to 6.6 Btu/ft^2 caused by a stratus cloud layer 1000 ft thick covering the entire sky. Kondratyev presents an equation which attempts to quantify the effects of cloud cover:

$$F_n = F_o(1-0.024n-0.004n^2) \qquad (VI-1)$$

Where: F_n = net radiation with cloud cover

F_o = clear sky net radiation of a surface

n = amount of cloud cover

One obvious difficulty with this equation is that it does not account for effects that are likely to be caused by different types of cloud cover. A better approximation of cloud effects might be obtained from the following equation from Kondratyev:

$$F_n = F_o((1-(C_l N_l + C_m N_m + C_a N_a)) \qquad (VI-2)$$

Where: C_l = coefficient for low-level clouds

N_l = fraction of low cloud cover

C_m = coefficient for middle-level clouds

N_m = fraction of middle cloud cover

C_a = coefficient for upper-level clouds

N_a = fraction of upper cloud cover

Recommended coefficients for the different cloud levels at latitude 40^o during the six warm months of the year are:

$C_l = 0.78$

$C_m = 0.65$

$C_a = 0.19$

These coefficients suggest, as might be expected intuitively, a strong dependence of effective night sky temperature on both the amount and type of cloud cover. Based on this, the experimental program was designed to provide sky temperature on clear nights as well as during various conditions of cloud cover.

A. EXPERIMENT DESIGN

The basic concept underlying the experimental program is that both film coefficient and sky temperature can be derived by measuring the energy rejected to the night sky by two flat plates having different emissivities. Assuming a view factor between the flat plates and the sky of unity (this is not a requirement of the actual experiment), and the back sides of the plates adiabatic, the following equations may be written:

$$Q_1 = Ase_1(T_{p1}{}^4 - T_s{}^4) + hA(T_{p1} - T_a) \quad \text{(VI-3)}$$

$$Q_2 = Ase_2(T_{p2}{}^4 - T_s{}^4) + hA(T_{p2} - T_a) \quad \text{(VI-4)}$$

Where: Q_1 = Heat input to plate 1

Q_2 = Heat input to plate 2

A = Area of plates

e_1 = emissivity of plate 1

e_2 = emissivity of plate 2

T_{p1} = Temperature of plate 1

T_{p2} = Temperature of plate 2

T_s = Night sky temperature

T_a = Ambient temperature

h = convective film coefficient

s = Stefan-Boltzmann constant

If the plate emissivities are known; and heat input, plate temperatures, and ambient temperature are measured; then simultaneous solution of the above equations will yield values of film coefficient and effective sky temperature.

The test instruments designed to mechanize the above equations consist of two six-inch square by 1/8 inch thick copper plates exposed to the ambient on one side and heavily insulated on the other side. On the insulated side of each plate an electric heating element is attached, and thermocouples are imbedded in each plate. One plate's exposed surface is painted black, while the other is plated with chromium. The two six-inch square plates are flush-mounted in a 2 ft. by 6 ft. by 6-inch thick glass-foam block of insulation. In order to determine if the heated starting length has a significant effect on film coefficient, a larger copper plate, 20 by 60 by 1/8 inches is similarly equipped with heaters and thermocouples and mounted in an identical block of insulation. The larger copper plate is painted black. With effective sky temperature derived from the two smaller plates, the film coefficient determined from the large plate may be compared with that for the smaller plates. Two identical sets of test instruments were fabricated and instrumented. Each set of two insulation blocks (one containing the two small copper plates, the other the large plate) were mounted together with a one-foot gap between filled in with a flat board. This provides a total flat area presented to the ambient airstream 5 feet wide by 6 feet high.

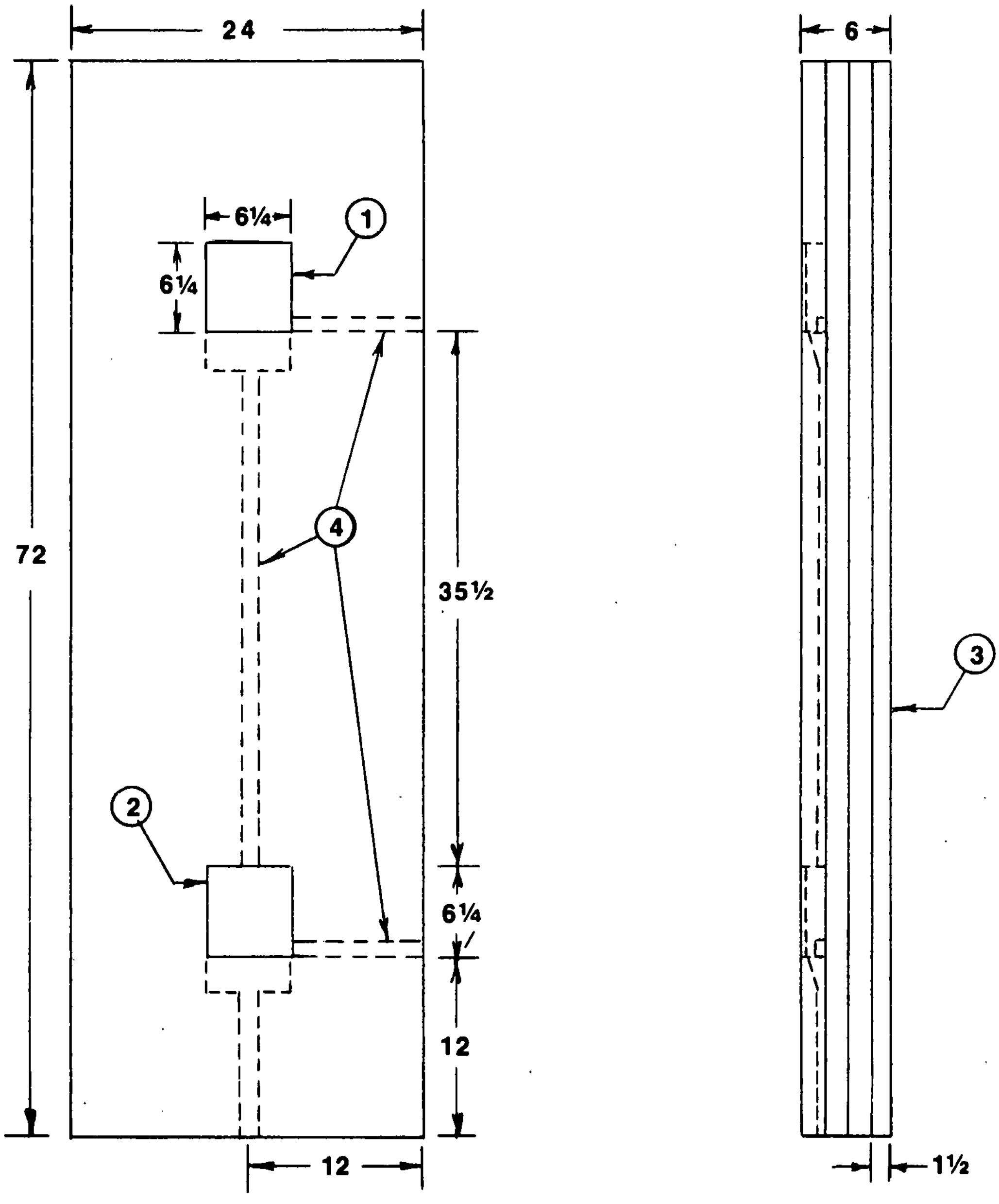
One of the test instrument assemblies was mounted on the roof of a residence near Denver, Colorado. The roof faces southwest and has a slope of 18^{o} from horizontal. The other assembly was ground-mounted near Denver with the same orientation and slope as the roof-mounted unit. Sketches of the test instrument components and assemblies are shown in Figures VI-1 and VI-2, and photographs of the field installations are shown in Figure VI-3.

B. INSTRUMENTATION AND DATA REDUCTION

1. Instrumentation - Twenty thermocouples were used in each instrument assembly. Five on each of the six-by-six inch plates and ten on the large plate. The thermocouple wires were joined with a weld bead and peened into holes drilled into the back of the copper plates. The holes were 3/32 inches deep resulting location of the bead 1/32 inch from the front surface of the plate. The thermocouples were connected through a Doric 405A multipoint selector to a Doric 410A Trendicator which reads temperatures in degrees F. All thermocouples were calibrated in boiling water and an ice bath.

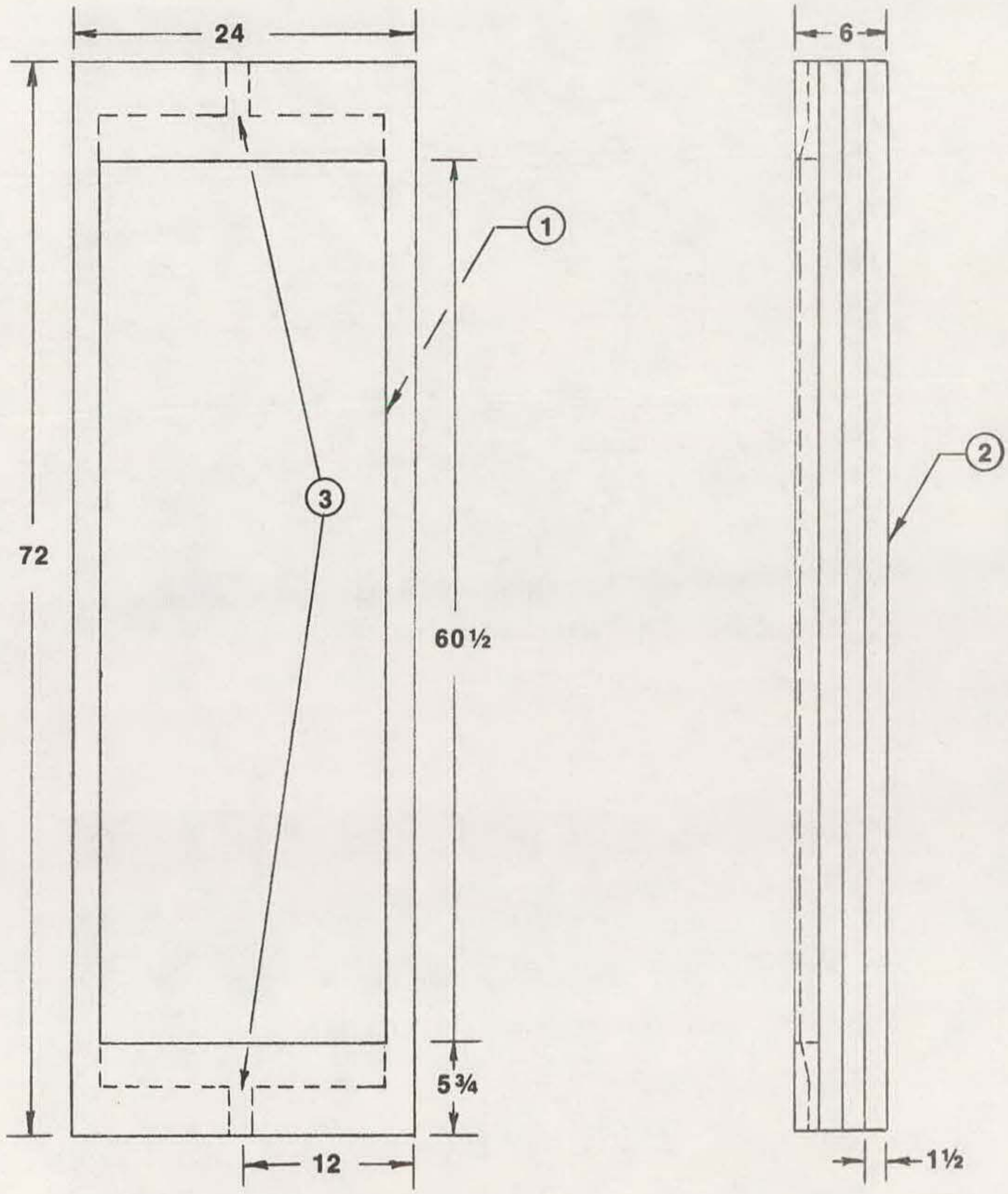
Heater power was supplied and controlled through a Staco Variable Autotransformer. Heater circuit resistance (including the complete power lead of approximately 80 ft. in length) was measured using a Simpson Model 460 Series 3 digital multimeter. Voltage applied to each of the three heaters was read using the multimeter during each data run. Ambient dry and wet bulb temperatures were measured during each test using a Taylor Instrument Co. sling psychrometer. Wind velocity, wind direction, barometric pressure and ambient dry bulb temperature were read from a Texas Electronics Mark IV-T Weatherminder weather station. Emissivity of reference samples of the black paint and chrome plating were measured with a Lyon emissometer.

FIGURE VI-1. TEST INSTRUMENT - SMALL PLATES, HIGH AND LOW EMISSIVITY



NOTES: 1. Chrome-Plated Copper Plate with Heater Bonded to Rear Face
2. Black-Painted Copper Plate wuth Heater Bonded to Rear Face
3. Glass-Foam Insulation Board
4. Lead-Out Groove for Heater and Thermocouple Wire

FIGURE VI-2. TEST INSTRUMENT - LARGE PLATE, HIGH EMISSIVITY



NOTES: 1. Black-Painted Copper Plate with Heater Bonded to Rear Face
2. Glass-Foam Insulation Board
3. Lead-Out Groove for Heater and Thermocouple Wire

FIGURE VI-3. FIELD INSTALLATIONS OF TEST INSTRUMENTS

Roof-mounted Experiment

Ground-Mounted Experiment

2. Data Reduction - An energy balance on each of the copper plates is given by:

$$Q+h(T_a-T_p)+seF_{ps}(T_s{}^4-T_p{}^4)+se(1-F_{ps})(T_a{}^4-T_p{}^4)$$
$$+k/x(T_a-T_p) = 0 \qquad (VI-5)$$

Where:

Q = Energy input into plate, Btu/hr-ft^2

h = Film coefficient, Btu/hr-ft^2-^{o}F

s = Stefan-Boltzmann constant, Btu/hr-ft^2-^{o}R^4

e = Plate emissivity

F_{ps} = View factor of plate to sky

k = Conductivity of back insulation, Btu/hr-ft-^{o}F

x = Thickness of back insulation, ft

T_a = Ambient temperature, ^{o}R

T_s = Sky temperature, ^{o}R

Rearranging equation VI-5 and using the subscripts b for the small high-emissivity plate, s for the small low-emissivity plate, and l for the large high-emissivity plate gives:

$$h(T_a-T_{pb})+T_s{}^4se_bF_{ps}+Q_b-se_bF_{ps}T_{pb}{}^4+se_b(1-F_{ps})(T_a{}^4-T_{pb}{}^4)$$
$$+k/x(T_a-T_{pb}) = 0 \qquad (VI-6)$$

$$h(T_a-T_{ps})+T_s{}^4se_sF_{ps}+Q_s-se_sF_{ps}T_{ps}{}^4+se_s(1-F_{ps})(T_a{}^4-T_{ps}{}^4)$$
$$+k/x(T_a-T_{ps}) = 0 \qquad (VI-7)$$

Or:

$$hB_1+T_s{}^4C_1 = D_1 \qquad (VI-8)$$
$$hB_2+T_s{}^4C_2 = D_2 \qquad (VI-9)$$

Where:

$B_1 = T_a-T_{pb}$

$C_1 = se_bF_{ps}$

$D_1 = -Q_b+se_sF_{ps}T_{pb}{}^4-se_b(1-F_{ps})(T_a{}^4-T_{pb}{}^4)-k/x(T_a-T_{pb})$

$B_2 = T_a-T_{ps}$

$C_2 = se_sF_{ps}$

$D_2 = -Q_s+se_sF_{ps}T_{ps}{}^4-se_s(1-F_{ps})(T_a{}^4-T_{ps}{}^4)-k/x(T_a-T_{ps})$

Then:

$$h = (D_1C_2-D_2C_1)/(B_1C_2-B_2C_1) \qquad (VI-10)$$

$$T_s^4 = (B_1D_2-B_2D_1)/(B_1C_2-B_2C_1) \quad \text{(VI-11)}$$

$$h_1 = (-T_s^4 se_b F_{ps} - Q_1 + se_b F_{ps} T_{p1}^4 - se_b(1-F_{ps})(T_a^4 - T_{p1}^4) - k/x(T_a - T_{p1}))/(T_a - T_{p1}) \quad \text{(VI-12)}$$

Having determined the film coefficients from equations VI-10 and VI-12, the final step in the data reduction process was to calculate the Nusselt, Reynolds, and Grashof numbers to correlate the data. For these calculations, air density was corrected for pressure and temperature; air viscosity, coefficient of expansion, and thermal conductivity were corrected for temperature. Air specific heat was assumed to be constant. Characteristic length of the small plates was 6 inches, while that of the large plate was varied with wind direction by assuming it to be the distance travelled by the wind moving across the plate. For a zero wind condition (free convection), the characteristic length of the large plate was assumed to be the plate length of 60 inches.

3. Uncertainty Analyses - Several analyses were conducted to guide the design of the test instruments, and to determine the accuracy to be expected from the test results. Results of these analyses are summarized as follows:

* As plate temperature increases above ambient (with increasing heater input power, the uncertainty in film coefficient decreases while the sky temperature uncertainty increases. A temperature difference of 30°F was selected as the nominal target test condition. At this temperature difference, the uncertainty in film coefficient is ±6% and the uncertainty in sky temperature is ±11°F.

* A conduction analysis of the copper plates indicated that the maximum temperature difference due to temperature gradients in the plane of the plates would be on the order of 0.03 °F under typical heater power input conditions.

* A nine-node finite element model was constructed to investigate transient effects due to changes in wind velocity and during test start-up. Results indicated that approximately two hours are required to approach steady-state conditions after the initial step change in heater power. After reaching steady-state conditions, it requires 15 minutes for the plate to return to within 1°F of the steady-state value after a step change in wind speed.

C. EXPERIMENTAL RESULTS

1. Forced Convection Film Coefficients - Excluding zero wind conditions, 314 data points were recorded during a one-month period (3/19/80 to 4/18/80). Of these data points, 23 were judged to have steady wind conditions (direction and speed reasonably stable prior to and during the data recording interval). The reduced data for these 23 points are listed in Table VI-1.

The data in Table VI-1 were correlated using linear regression assuming an equation of the form $Nu = CRe^nPr^{0.33}$. The correlation yielded the following results for the various combinations of roof and ground mounted instruments, and large and small plates:

Roof-mounted small plate -	$Nu = 1.776\ Re^{0.458} Pr^{0.33}$	(VI-13)
Roof-mounted large plate -	$Nu = 0.773\ Re^{0.556} Pr^{0.33}$	(VI-14)
Combined roof-mounted -	$Nu = 0.74\ Re^{0.555} Pr^{0.33}$	(VI-15)
Ground-mounted small plate -	$Nu = 25.3\ Re^{0.173} Pr^{0.33}$	(VI-16)
Ground-mounted large plate -	$Nu = 371.8\ Re^{0.0223} Pr^{0.33}$	(VI-17)
Combined ground mounted -	$Nu = 2.32\ Re^{0.478} Pr^{0.33}$	(VI-18)
Combined, all data -	$Nu = 1.93\ Re^{0.480} Pr^{0.33}$	(VI-19)

The correlated results listed above all appear reasonable except for the individual ground-mounted plate equations. Considered individually, these data points were scattered to a degree that meaningful correlations could not be obtained. The combined data, however, yield an equation which appears reasonable although with a lower correlation coefficient (0.719) than was obtained for the combined roof-mounted data (0.943).

The equations by Sparrow previously cited can be arranged to yield:

$$Nu = 0.931\ Re^{0.5} Pr^{0.33} \qquad \text{(VI-20)}$$

Over the range of Reynolds numbers typical of outdoor-mounted solar collectors, the combined roof-mounted Nusselt Numbers and corresponding film coefficients are 1.5 times Sparrow's results, and the combined ground-mounted data are higher by a factor of 1.93. It may be that the higher values of film coefficients derived from the simulated solar collector test instruments are due to turbulence present in the ambient outdoor air stream. This hypothesis appears to be supported by the higher Nusselt numbers derived from the ground-mounted data; higher levels of small-scale turbulence which could influence the boundary layers on the test plates would be expected closer to the ground.

2. Free Convection Film Coefficients - A total of 44 data points were recorded during zero wind velocity conditions. Of these, 10 were judged to be at near steady-state conditions. These data points are summarized in Table VI-2. These results were correlated using linear regression assuming an equation of the form $Nu = C(GrPr)^n$. The resulting equation (correlation coefficient = 0.959) is:

$$Nu = 1.48\ (GrPr)^{0.272} \qquad \text{(VI-21)}$$

Typical test conditions produced Grashof-Prandtl number products in the laminar range for the small plates and in the turbulent or laminar-turbulent transition range for the large plates. The Nusselt Numbers derived from the test results were compared with free convection correlations from the literature (Ref. VI-1). This showed that the test-derived film coefficients are 3 to 4 times as large as those predicted by the published correlations for both the laminar and turbulent regimes. The test data may indicate that true free convection conditions are rarely if ever experienced in outdoor ambient conditions on exposed surfaces of a size typical of solar collectors.

3. **Night Sky Temperatures** - Results derived from the test data for night sky temperature are summarized in Table VI-3. The data are categorized by clear sky conditions or by the estimated amount and type of cloud cover. For the clear sky conditions, the mean difference between the ground level ambient temperature and the sky temperature is 48.9^{o}F with a standard deviation of $\pm$12.6^{o}F. The maximum observed difference is 67.6^{o}F, and the least observed difference is 25.3^{o}F for the clear sky condition. Although the range of ambient temperature for the clear sky data samples was small (32 to 51^{o}F), a linear correlation of sky temperature versus ambient temperature produced the following equation:

$$Tsky = -41.9 + 0.7974Tamb \quad (T \text{ in } ^{o}F) \qquad \text{(VI-22)}$$

As might be expected, considerable scatter was observed in the data for the overcast conditions. For this case, the mean difference between ambient and sky temperature is 25.5^{o}, with a standard deviation of $\pm$18.4^{o}F. The maximum observed difference is 44.4^{o}F and the minimum difference is 1.2^{o}F. The best-fit linear correlation for the overcast sky temperature data is:

$$Tsky = -36.8 + 1.23Tamb \quad (T \text{ in } ^{o}F) \qquad \text{(VI-23)}$$

Over the limited range of ambient temperatures represented in the sky temperature data samples, the correlations derived from the test data compare to correlations found in the literature (for clear sky conditions) as shown in the following tabulation (T in ^{o}F):

Tamb	Tsky-1	Tsky-2	Tsky-3	Tsky-4	Tsky-5
30	-18.0	0.1	19.2	-12.0	-24.0
40	-10.0	12.4	29.2	1.7	-9.7
50	-2.0	24.7	39.2	15.7	3.7

Where: Tamb = Ambient Temperature

Tsky-1 = Experiment clear sky correlation (equation VI-22)

Tsky-2 = Experiment overcast correlation (equation VI-23)

Tsky-3 = Tamb - 10.8^{o}F (Whillier, 1967)

Tsky-4 = $0.0413(Tamb+460)^{1.5}$ (Swinbank, 1963)

TSky-5 = $((Tamb+460)^{4}-2.14E10)^{0.25}-460$ (From equations by Kondratyev, Ref. VI-3)

For the clear sky conditions, an attempt was made to correlate sky temperature as a function of water vapor in the ambient air. An equation was obtained of the form:

$$(Tamb - Tsky) = 53 - 2.43(10^{4})H \qquad \text{(VI-24)}$$

TABLE VI-1. FORCED-CONVECTION RESULTS

Date	Time	Test Location	Small Plates Nusselt Number	Small Plates Reynolds Number	Large Plate Nusselt Number	Large Plate Reynolds Number
3/19/80	2050	Roof	70.3	$3.679*10^3$	165.8	$1.249*10^4$
3/20	2050	"	140.8	$2.134*10^4$	338.3	$9.929*10^4$
3/20	2115	"	140.7	$2.334*10^4$	671.8	$2.008*10^5$
3/21	2033	"	101.6	$9.250*10^3$	177.6	$3.302*10^4$
3/21	2045	"	86.3	$3.660*10^3$	415.4	$3.176*10^4$
4/4	2123	"	79.3	$7.481*10^3$	133.7	$2.496*10^4$
4/4	2134	"	100.6	$1.137*10^4$	165.1	$3.772*10^4$
4/7	2004	"	323.9	$1.001*10^5$	666.4	$3.316*10^5$
4/7	2134	"	137.6	$1.903*10^4$	836.1	$1.911*10^5$
4/15	2048	"	235.0	$4.638*10^4$	661.3	$2.180*10^5$
4/15	2102	"	214.1	$2.782*10^4$	450.2	$9.985*10^4$
3/21	1930	Ground	101.3	$5.271*10^3$	218.5	$1.824*10^4$
3/26	2110	"	124.0	$1.333*10^4$	447.5	$4.580*10^4$
3/30	0120	"	134.5	$9.780*10^3$	569.8	$4.100*10^4$
3/31	0015	"	89.2	$3.692*10^3$	525.8	$2.018*10^4$
4/5	0020	"	141.4	$5.704*10^3$	587.7	$2.379*10^4$
4/5	2255	"	126.3	$5.496*10^3$	865.9	$3.638*10^4$
4/7	2150	"	162.0	$4.115*10^4$	233.2	$1.415*10^5$
4/8	2350	"	131.3	$3.853*10^3$	363.5	$1.609*10^4$
4/12	2335	"	113.0	$3.896*10^3$	446.2	$2.579*10^4$
4/14	2110	"	82.1	$5.424*10^3$	224.5	$3.618*10^4$
4/16	2240	"	103.2	$1.139*10^4$	350.0	$7.621*10^4$
4/18	2330	"	157.0	$2.214*10^4$	714.6	$1.484*10^5$

TABLE VI-2. FREE-CONVECTION RESULTS

Date	Time	Test Location	Small Plates Nusselt Number	Small Plates Grashof Number	Large Plates Nusselt Number	Large Plates Grashof Number
4/14/80	2100	Roof	63.23	$3.568*10^6$	375.3	$3.192*10^9$
4/9	2033	"	75.91	$2.248*10^6$	366.6	$2.102*10^9$
4/10	2039	"	82.77	$2.913*10^6$	555.7	$2.929*10^9$
3/31	0035	Ground	84.13	$3.214*10^6$	914.8	$3.237*10^9$
4/6	2135	"	80.33	$2.791*10^6$	973.2	$2.854*10^9$
4/9	2045	"	67.10	$1.985*10^6$	402.2	$2.072*10^9$
4/13	2355	"	90.19	$2.276*10^6$	530.0	$2.261*10^9$
4/14	2050	"	69.89	$2.135*10^6$	288.7	$2.006*10^9$
4/15	2350	"	59.03	$2.640*10^6$	340.6	$2.376*10^9$
4/16	2330	"	88.64	$2.241*10^6$	514.9	$2.063*10^9$

TABLE VI-3. SKY TEMPERATURE RESULTS

Date	Time	Location	Tsky Deg-F	Tamb Deg-F	H2O Vapor - lb/ft^3 air $(x10^{-4})$	Cloud Cover - %, Height, Type
3/19/80	2050	Roof	6.2	39	2.241	30%, Middle
3/20	2050	"	-11.3	40	1.976	Clear
3/20	2115	"	-8.1	39.5	1.976	Clear
3/21	2033	"	2.6	49	2.149	Clear
3/21	2045	"	9.9	48.5	2.149	Clear
4/4	2100	"	-4.8	40	1.946	80% High, Thin
4/4	2123	"	-7.7	39.5	1.946	Clear
4/4	2134	"	-11.7	39	1.946	Clear
4/7	2004	"	-17.6	34.5	1.197	Clear
4/7	2134	"	-34.1	33.5	1.197	Clear
4/9	2033	"	-3.5	51	1.861	Clear
4/10	2039	"	36.8	38	2.945	70% Middle, 30% High
4/15	2048	"	39.2	57.5	2.317	70% Middle
4/15	2102	"	31.7	57	2.317	80% Middle
3/21/80	1930	Ground	-16.3	46	2.087	Clear
3/31	0015	"	-2.1	31	2.123	100%, Middle, Thin
3/31	0035	"	-14.4	30	2.565	100%, Middle, Thin
4/5	0020	"	5.1	35	2.595	Clear
4/5	2255	"	29.1	43	2.238	80%, Middle, Thin
4/8	2350	"	-7.4	32	0.804	Clear
4/9	2045	"	11.5	49	1.919	75%, Middle, Thin
4/12	2335	"	0.3	28	1.343	70%, Middle, Thin
4/13	2355	"	-19.8	32	0.538	Clear
4/14	2050	"	-16.3	49	2.057	Clear
4/14	2110	"	-14.3	49	2.057	Clear
4/15	2350	"	27.7	51	2.192	100%, Middle, Thin
4/16	2330	"	-15.1	40	1.249	Clear
4/18	2330	"	24.7	50	1.476	Clear

where H is lbs of water vapor per cubic foot of air. The correlation coefficient for this equation is -0.104, however, which is indicative of the scatter in the data.

D. CONCLUSIONS AND RECOMMENDATIONS

1. Convection Film Coefficients - The film coefficient data appear to be reasonably consistent with available published results. Recognizing that the data samples are limited, and were obtained under somewhat uncontrolled transient outdoor conditions, the following equations are recommended for predicting the convection film coefficients for heated flat surfaces facing upward in the ambient air stream at moderate tilt angles up from the horizontal:

$$Nu = 1.93\ Re^{0.48} Pr^{0.33} \quad \text{(measurable wind condition)} \qquad \text{(VI-25)}$$

$$Nu = 1.48\ (GrPr)^{0.272} \quad \text{(negligible wind condition)} \qquad \text{(VI-26)}$$

Both values should be checked for moderate wind conditions. The larger value should be used since the free convection value likely represents a lower bound.

2. Night Sky Temperatures - The sky temperature data show a considerable amount of scatter for both the clear sky and overcast conditions. During the period in which data were taken, the ground ambient temperature did not vary over a sufficient range to permit derivation of a broadly applicable correlation of sky temperature as a function of ambient temperature. The recommendated equation for clear sky conditions (recognizing that the data are based on conditions in Denver, Colorado, during March and April) is:

$$T_{sky} = -41.9 + 0.8 T_{amb} \quad (T \text{ in } {}^{o}F) \qquad \text{(VI-27)}$$

Useful correlations could not be obtained for sky temperaure as a function of moisture content in the air, or versus the type and amount of cloud cover.

3. Recommended Future Activities - The data obtained from the experimental program yielded usable results and demonstrated the viability of the basic test article design. In order to improve the accuracy of the data correlations, and broaden their applicability, a significantly larger data sample acquired in several different climatic regions will be required. In order to obtain such a data sample, a second-generation experiment should be designed and fabricated in sufficient quantity to permit simultaneous test operations in three or four locations. The new design should incorporate automatic data recording and reduction capability to minimize the cost of handling the anticipated large quantity of data.

VII. REFERENCES

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Appendix A
Tabulated Weather Data

Weather data for the eight cities analyzed is presented in the following tabulation. There are twelve values for each variable; one for each month from January through December. Each variable is defined below.

H = Total hemispheric mean daily solar radiation (Langleys)
Tave = Mean ambient temperature (F)
Tmax = Mean of all maximum ambient temperatures (F)
Tdpa = Mean dew point temperature (F)
Ttap = Average domestic water tap temperature (F)
Dd = Heating degree days, 65 F base (F/days)
Vm = Mean wind velocity (miles/hour)
P = Fraction of clear day solar radiation

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PHOENIX ARIZONA; LAT = 33.5

H	277	373	492	639	726	743	675	622	547	428	312	253
Tave	51	55	60	68	76	85	91	89	84	72	60	53
Tmax	64	69	75	84	93	102	105	102	98	88	75	66
Tdpa	33	33	33	35	36	42	58	60	53	44	36	33
Ttap	48	48	50	52	57	59	63	75	79	69	59	54
Dd	428	292	1875	60	0	0	0	0	0	17	182	388
Vm	4	5	6	6	6	6	6	6	5	5	5	4
P	.83	.84	.89	.95	.95	.95	.95	.95	.95	.95	.94	.87

LOS ANGELES CALIF; LAT = 33.93

H	251	329	439	529	559	575	626	564	456	357	272	230
Tave	55	56	57	59	62	65	69	70	69	65	60	57
Tmax	64	64	64	66	68	70	75	76	76	73	70	67
Tdpa	40	43	45	49	52	55	59	59	58	53	46	42
Ttap	50	50	54	63	68	73	74	76	75	69	61	55
Dd	331	270	267	195	114	71	19	15	23	77	158	279
Vm	7	6	6	6	6	6	6	5	5	6	7	4
P	.77	.75	.80	.82	.80	.80	.90	.89	.86	.83	.84	.81

DENVER COLO; LAT = 39.75

H	228	306	415	510	579	638	616	554	468	353	240	199
Tave	30	33	37	48	57	66	73	72	63	52	39	33
Tmax	44	46	50	61	70	80	87	86	78	67	53	46
Tdpa	12	16	17	24	35	42	47	46	37	27	19	14
Ttap	39	40	43	49	55	60	63	64	63	56	45	37
Dd	1088	902	868	525	253	80	0	0	120	408	768	1004
Vm	10	11	12	13	10	10	9	9	9	10	10	10
P	.88	.81	.82	.83	.84	.89	.90	.91	.95	.95	.93	.92

BALTIMORE MD.; LAT = 38.95

H	155	221	305	396	466	516	493	439	364	272	177	131
Tave	32	34	42	53	63	71	75	74	67	56	45	34
Tmax	41	43	53	65	75	83	86	85	79	68	56	43
Tdpa	25	25	29	40	52	61	65	64	59	48	36	26
Ttap	42	42	52	56	63	67	67	78	79	68	55	46
Dd	1020	874	719	357	131	5	0	0	43	291	609	961
Vm	11	11	12	11	10	9	9	8	9	9	10	10
P	.58	.58	.60	.64	.67	.72	.72	.72	.74	.72	.66	.58

MIAMI FLORIDA; LAT = 25.8

H	287	356	435	504	500	463	478	442	395	353	303	276
Tave	67	68	71	75	78	81	82	83	82	78	72	68
Tmax	76	77	80	83	85	88	89	90	88	85	80	77
Tdpa	57	59	61	63	68	72	73	74	74	69	63	58
Ttap	70	70	70	70	70	70	70	70	70	70	70	70
Dd	53	67	17	0	0	0	0	0	0	0	13	56
Vm	9	10	10	10	9	8	8	7	8	9	9	9
P	.68	.69	.72	.76	.72	.66	.69	.68	.67	.70	.73	.73

ATLANTA GEORGIA; LAT = 33.65

H	195	263	354	457	503	519	492	463	386	326	240	183
Tave	42	45	51	61	69	76	78	78	72	62	51	44
Tmax	51	55	61	71	79	85	87	86	81	73	62	53
Tdpa	34	34	39	48	57	65	68	67	62	51	40	34
Ttap	43	48	53	59	72	78	84	80	78	70	60	48
Dd	701	560	443	144	27	0	0	0	8	137	408	667
Vm	11	12	12	11	9	8	8	8	8	9	10	10
P	.59	.60	.64	.71	.72	.72	.71	.73	.72	.75	.73	.63

BOSTON MASS; LAT = 42.37

H	129	193	276	360	440	493	475	403	342	241	136	109
Tave	29	30	38	49	59	68	73	71	65	55	45	33
Tmax	36	38	45	56	67	77	81	79	72	63	52	39
Tdpa	19	19	25	34	44	55	60	60	53	44	34	22
Ttap	32	36	39	52	58	71	74	67	60	56	48	45
Dd	1110	969	834	492	218	27	0	8	76	301	594	992
Vm	13	14	12	14	12	11	10	10	11	10	13	13
P	.56	.56	.57	.59	.64	.69	.69	.67	.74	.71	.60	.59

MINNEAPOLIS MINN; LAT = 44.88

H	126	207	299	391	471	523	534	458	340	233	130	96
Tave	12	17	28	45	57	67	72	70	60	50	32	19
Tmax	21	26	37	56	68	77	82	81	71	61	41	27
Tdpa	6	10	20	32	43	55	60	59	50	40	25	13
Ttap	32	32	35	41	61	69	80	73	68	60	50	40
Dd	1637	1358	1138	597	271	65	11	21	173	472	978	1438
Vm	11	11	12	13	12	11	9	9	10	11	12	11
P	.63	.65	.65	.66	.69	.73	.79	.78	.77	.75	.66	.62

APPENDIX B

TABULATED SIMULATION RESULTS

Note: All tabulated figures are in units of Kilowatt Hours, except Net Coeff. of Performance, which is defined as the sum of heating, cooling and DHW energy required (lines 1 through 3), divided by the electrical power consumed (heat pump, fans, pumps, resistance auxiliary for space heat and DHW; lines 4 through 7).

APPENDIX B - TABULATED SIMULATION RESULTS

DENVER - Coll Area = 300 Sq Ft; Ground Lngth = 500 Ft; Stor Vol = 600 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	4957	4083	3934	2177	765	180	65	74	417	1556	3354	4730	26292
Space Cooling Energy Req'd ...	0	0	0	0	2	188	664	526	179	8	0	0	1566
DHW Energy Req'd	485	432	461	411	389	347	341	335	330	383	435	497	4848
KWH for Heat Pump Comp.	669	674	839	592	282	200	278	250	247	456	864	835	6187
Resist. KWH for Space Heat ...	2667	1737	972	25	0	0	0	0	1	11	253	1820	7486
Resist. KWH for DHW	78	48	3	0	0	0	0	0	0	0	0	48	177
KWH for Pumps	84	86	113	122	107	100	107	105	115	120	125	101	1286
KWH for Fans	14	15	22	15	3	9	8	9	16	7	19	18	156
Fan Energy lost to Atmos.	0	1	5	5	1	7	4	6	12	1	1	0	45
Energy Coll. from Ground	209	193	168	3	0	3	0	0	57	3	536	666	1839
Energy Rejected to Ground	0	0	0	0	268	628	870	781	480	217	0	0	3241
Energy Coll. by Solar Panels .	1713	1724	2177	1796	1429	362	126	177	497	1823	1856	1707	15389
Energy Rej. by Solar Panels ..	0	0	0	0	0	21	11	7	23	0	0	0	62
Energy Rejected by Fan Coil ..	18	-25	-127	-64	190	-246	-130	-168	-156	117	-36	7	-620
Net Coeff. of Performance	1.55	1.76	2.26	3.44	2.94	2.31	2.73	2.57	2.44	3.27	3.00	1.85	2.14

DENVER - Coll Area = 300 Sq Ft; Ground Lngth = 0 Ft; Stor Vol = 600 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	4957	4083	3934	2177	765	180	65	74	417	1556	3354	4730	26292
Space Cooling Energy Req'd ...	0	0	0	0	2	188	664	526	179	8	0	0	1566
DHW Energy Req'd	485	432	461	411	389	347	341	335	330	383	435	497	4848
KWH for Heat Pump Comp.	583	572	771	592	285	202	301	261	246	454	710	599	5578
Resist. KWH for Space Heat ...	2996	2118	1239	25	0	0	0	0	2	1	876	2748	10006
Resist. KWH for DHW	96	66	12	0	0	0	0	0	0	0	3	72	249
KWH for Pumps	76	77	106	122	107	129	140	138	132	120	111	80	1339
KWH for Fans	12	13	23	15	4	19	25	23	23	6	19	14	196
Fan Energy lost to Atmos.	0	1	7	5	1	17	21	20	20	1	5	1	100
Energy Coll. from Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected to Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Coll. by Solar Panels .	1694	1646	2163	1795	1180	338	117	165	487	1652	1831	1691	14762
Energy Rej. by Solar Panels ..	0	0	0	0	0	193	278	270	158	1	0	0	901
Energy Rejected by Fan Coil ..	13	-19	-132	-65	354	225	532	411	170	213	-128	-24	1550
Net Coeff. of Performance	1.45	1.59	2.04	3.44	2.92	2.05	2.29	2.22	2.30	3.34	2.20	1.49	1.88

APPENDIX B - TABULATED SIMULATION RESULTS

DENVER - Coll Area = 300 Sq Ft; Ground Lngth = 0 Ft; Stor Vol = 1200 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	4957	4083	3934	2177	765	180	65	74	417	1556	3354	4730	26292
Space Cooling Energy Req'd ...	0	0	0	0	2	188	664	526	179	8	0	0	1566
DHW Energy Req'd	485	432	461	411	389	347	341	335	330	383	435	497	4848
KWH for Heat Pump Comp.	635	651	858	593	287	201	296	257	245	451	772	662	5910
Resist. KWH for Space Heat ...	2845	1863	959	25	0	0	0	0	1	0	666	2547	8908
Resist. KWH for DHW	84	54	6	0	0	0	0	0	0	0	0	60	204
KWH for Pumps	80	83	113	122	107	128	138	139	131	120	115	85	1362
KWH for Fans	13	15	24	15	3	17	23	21	21	6	19	16	194
Fan Energy lost to Atmos.	0	1	6	6	0	15	18	17	17	1	4	2	89
Energy Coll. from Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected to Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Coll. by Solar Panels .	1804	1802	2337	1863	1169	331	113	160	488	1675	1916	1820	15479
Energy Rej. by Solar Panels ..	0	0	0	0	0	201	261	258	162	1	0	0	883
Energy Rejected by Fan Coil ..	10	-34	-156	-65	277	318	521	418	192	157	-96	-31	1510
Net Coeff. of Performance	1.49	1.69	2.24	3.42	2.91	2.07	2.34	2.24	2.33	3.37	2.41	1.55	1.97

DENVER - Coll Area = 300 Sq Ft; Ground Lngth = 1000 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	4957	4083	3934	2177	765	180	65	74	417	1556	3354	4730	26292
Space Cooling Energy Req'd ...	0	0	0	0	2	188	664	526	179	8	0	0	1566
DHW Energy Req'd	485	432	461	411	389	347	341	335	330	383	435	497	4848
KWH for Heat Pump Comp.	446	469	680	604	297	202	283	251	246	472	894	958	5803
Resist. KWH for Space Heat ...	3559	2605	1692	189	3	0	0	0	1	81	212	1388	9730
Resist. KWH for DHW	105	51	9	0	0	0	0	0	0	0	0	18	183
KWH for Pumps	66	69	98	120	107	105	108	106	117	120	126	112	1257
KWH for Fans	9	10	17	28	25	11	8	8	15	15	19	21	187
Fan Energy lost to Atmos.	1	1	3	16	21	9	4	5	12	6	0	0	79
Energy Coll. from Ground	187	292	600	423	51	65	49	28	154	462	1480	1623	5415
Energy Rejected to Ground	680	760	1032	1490	2140	517	893	786	456	1668	809	561	11792
Energy Coll. by Solar Panels .	1750	1766	2242	2359	2468	352	122	174	487	2362	1853	1704	17640
Energy Rej. by Solar Panels ..	0	0	0	0	0	23	12	11	29	0	0	0	74
Energy Rejected by Fan Coil ..	-7	-17	-100	-367	-376	-153	-86	-120	-46	-89	8	21	-1331
Net Coeff. of Performance	1.30	1.41	1.76	2.75	2.67	2.25	2.68	2.56	2.44	2.83	3.03	2.09	1.91

APPENDIX B - TABULATED SIMULATION RESULTS

DENVER - Coll Area = 300 Sq Ft; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	4957	4083	3934	2177	765	180	65	74	417	1556	3354	4730	26292
Space Cooling Energy Req'd ...	0	0	0	0	2	188	664	526	179	8	0	0	1566
DHW Energy Req'd	485	432	461	411	389	347	341	335	330	383	435	497	4848
KWH for Heat Pump Comp.	441	507	682	606	294	201	288	255	245	466	882	974	5844
Resist. KWH for Space Heat ...	3551	2452	1675	168	2	0	0	0	1	67	215	1315	9447
Resist. KWH for DHW	120	48	9	0	0	0	0	0	0	0	0	9	186
KWH for Pumps	65	72	98	120	107	112	114	119	129	120	126	113	1296
KWH for Fans	9	11	16	23	13	11	9	12	18	9	18	21	173
Fan Energy lost to Atmos.	0	1	2	11	9	9	6	8	15	1	0	0	64
Energy Coll. from Ground	216	401	666	516	85	113	85	81	289	546	1557	1715	6271
Energy Rejected to Ground	663	732	994	1362	1770	398	829	679	354	1466	775	544	10564
Energy Coll. by Solar Panels .	1717	1752	2183	2272	2321	341	117	166	471	2202	1766	1659	16969
Energy Rej. by Solar Panels ..	0	0	0	0	0	34	25	47	129	0	0	0	235
Energy Rejected by Fan Coil ..	5	-10	-72	-253	-119	0	6	13	91	19	23	25	-270
Net Coeff. of Performance	1.30	1.46	1.77	2.82	2.77	2.21	2.60	2.42	2.36	2.94	3.05	2.15	1.93

DENVER - Coll Area = 150 Sq Ft; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	4957	4083	3934	2177	765	180	65	74	417	1556	3354	4730	26292
Space Cooling Energy Req'd ...	0	0	0	0	2	188	664	526	179	8	0	0	1566
DHW Energy Req'd	485	432	461	411	389	347	341	335	330	383	435	497	4848
KWH for Heat Pump Comp.	321	326	502	559	300	202	287	254	248	475	729	670	4875
Resist. KWH for Space Heat ...	4007	3119	2409	394	6	0	0	0	1	89	914	2544	13485
Resist. KWH for DHW	177	123	33	0	0	0	0	0	0	0	0	63	396
KWH for Pumps	52	55	80	115	107	105	109	108	121	120	111	85	1170
KWH for Fans	10	12	22	38	35	11	8	9	17	21	18	16	219
Fan Energy lost to Atmos.	4	6	11	27	31	8	4	6	14	13	3	2	130
Energy Coll. from Ground	155	175	329	378	67	62	55	40	187	546	1299	1053	4347
Energy Rejected to Ground	206	273	423	857	1339	416	842	699	303	841	347	173	6718
Energy Coll. by Solar Panels .	827	824	1122	1251	1310	183	62	89	252	1274	1002	919	9115
Energy Rej. by Solar Panels ..	0	0	0	0	0	12	7	8	16	0	0	0	42
Energy Rejected by Fan Coil ..	-103	-163	-332	-735	-704	-214	-79	-99	-74	-260	-75	-59	-2897
Net Coeff. of Performance	1.19	1.24	1.44	2.34	2.58	2.25	2.65	2.52	2.39	2.76	2.14	1.55	1.62

APPENDIX B - TABULATED SIMULATION RESULTS

DENVER - Coll Area = 450 Sq Ft; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	4957	4083	3934	2177	765	180	65	74	417	1556	3354	4730	26292
Space Cooling Energy Req'd ...	0	0	0	0	2	188	664	526	179	8	0	0	1566
DHW Energy Req'd	485	432	461	411	389	347	341	335	330	383	435	497	4848
KWH for Heat Pump Comp.	583	643	837	611	290	200	290	257	243	464	868	1180	6467
Resist. KWH for Space Heat ...	3022	1907	1023	102	0	0	0	0	0	45	157	407	6664
Resist. KWH for DHW	63	18	3	0	0	0	0	0	0	0	0	3	87
KWH for Pumps	78	84	113	121	107	122	124	130	134	120	126	132	1391
KWH for Fans	12	13	18	16	4	12	13	14	19	8	16	24	172
Fan Energy lost to Atmos.	0	0	1	4	0	10	9	11	16	1	0	0	54
Energy Coll. from Ground	408	671	914	558	100	204	142	160	424	524	1519	2117	7742
Energy Rejected to Ground	1116	1172	1520	1885	2285	425	805	672	417	1992	1122	807	14215
Energy Coll. by Solar Panels .	2434	2384	3007	3000	2996	467	163	228	653	2844	2249	2199	22626
Energy Rej. by Solar Panels ..	0	0	0	0	0	171	122	171	249	0	0	0	713
Energy Rejected by Fan Coil ..	31	22	2	-72	46	63	48	51	228	83	52	44	598
Net Coeff. of Performance	1.45	1.70	2.20	3.04	2.87	2.15	2.51	2.33	2.34	3.06	3.24	2.99	2.21

DENVER - Coll Area = 0 Sq Ft; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	4957	4083	3934	2177	765	180	65	74	417	1556	3354	4730	26292
Space Cooling Energy Req'd ...	0	0	0	0	2	188	664	526	179	8	0	0	1566
DHW Energy Req'd	485	432	461	411	389	347	341	335	330	383	435	497	4848
KWH for Heat Pump Comp.	173	228	352	512	305	203	286	255	249	473	546	361	3942
Resist. KWH for Space Heat ...	4448	3424	2926	624	11	0	0	0	4	125	1648	3602	16813
Resist. KWH for DHW	327	222	132	3	0	0	0	0	0	0	39	234	957
KWH for Pumps	33	43	62	109	107	101	108	105	115	120	91	57	1053
KWH for Fans	13	18	28	43	40	10	8	8	16	36	30	19	270
Fan Energy lost to Atmos.	9	13	21	33	36	8	4	5	13	27	19	11	200
Energy Coll. from Ground	128	132	198	267	75	38	36	20	154	527	906	600	3084
Energy Rejected to Ground	20	47	123	534	1047	390	841	700	265	489	71	26	4553
Energy Coll. by Solar Panels .	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rej. by Solar Panels ..	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected by Fan Coil ..	-348	-508	-840	-1598	-1702	-385	-155	-203	-310	-1166	-616	-397	-8228
Net Coeff. of Performance	1.09	1.15	1.26	2.01	2.49	2.27	2.67	2.54	2.41	2.58	1.61	1.22	1.42

DENVER - Coll Area = 300 Sq Ft, Glazed; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	4957	4083	3934	2177	765	180	65	74	417	1556	3354	4730	26292
Space Cooling Energy Req'd ...	0	0	0	0	2	188	664	526	179	8	0	0	1566
DHW Energy Req'd	485	432	461	411	389	347	341	335	330	383	435	497	4848
KWH for Heat Pump Comp.	597	639	866	610	290	200	292	257	243	464	863	1185	6506
Resist. KWH for Space Heat ...	2971	1910	897	99	0	0	0	0	0	40	148	344	6410
Resist. KWH for DHW	54	21	0	0	0	0	0	0	0	0	0	0	75
KWH for Pumps	79	84	115	121	107	126	126	131	136	120	126	132	1407
KWH for Fans	12	13	19	16	4	13	13	15	20	8	16	24	174
Fan Energy lost to Atmos.	0	0	1	4	0	11	9	12	17	1	0	0	56
Energy Coll. from Ground	421	657	1002	570	103	229	159	183	470	522	1505	2141	7964
Energy Rejected to Ground	1223	1275	1642	2001	2420	412	782	652	411	2178	1273	914	15181
Energy Coll. by Solar Panels .	2577	2501	3153	3126	3141	470	162	230	661	3051	2436	2350	23861
Energy Rej. by Solar Panels ..	0	0	0	0	0	75	71	93	146	0	0	0	386
Energy Rejected by Fan Coil ..	35	32	6	-59	59	207	144	172	396	97	59	50	1199
Net Coeff. of Performance	1.47	1.69	2.32	3.06	2.88	2.11	2.48	2.31	2.32	3.08	3.28	3.10	2.24

DENVER - Coll Area = 300 Sq Ft, Glazed; Ground Lngth = 0 Ft; Stor Vol = 600 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	4957	4083	3934	2177	765	180	65	74	417	1556	3354	4730	26292
Space Cooling Energy Req'd ...	0	0	0	0	2	188	664	526	179	8	0	0	1566
DHW Energy Req'd	485	432	461	411	389	347	341	335	330	383	435	497	4848
KWH for Heat Pump Comp.	809	800	905	589	289	202	301	261	246	464	831	821	6518
Resist. KWH for Space Heat ...	2010	1105	499	6	0	0	0	0	1	0	208	1764	5594
Resist. KWH for DHW	48	45	6	0	0	0	0	0	0	0	0	42	141
KWH for Pumps	96	98	121	122	107	134	141	139	133	120	124	101	1439
KWH for Fans	17	17	18	11	6	20	25	23	24	8	17	16	204
Fan Energy lost to Atmos.	1	1	2	3	3	18	22	20	21	3	2	0	98
Energy Coll. from Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected to Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Coll. by Solar Panels .	2493	2448	2970	2274	1688	483	167	237	694	2203	2525	2478	20662
Energy Rej. by Solar Panels ..	0	0	0	0	0	118	151	170	156	1	0	0	597
Energy Rejected by Fan Coil ..	28	7	20	397	895	446	712	583	378	758	4	25	4253
Net Coeff. of Performance	1.83	2.19	2.84	3.55	2.88	2.01	2.29	2.20	2.29	3.29	3.21	1.90	2.35

APPENDIX B - TABULATED SIMULATION RESULTS

DENVER - REFERENCE AIR-TO-AIR SYSTEM

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	4957	4083	3934	2177	765	180	65	74	417	1556	3354	4730	26292
Space Cooling Energy Req'd ...	0	0	0	0	2	188	664	526	179	8	0	0	1566
DHW Energy Req'd	485	432	461	411	389	347	341	335	330	383	435	497	4848
KWH for Heat Pump Comp.	1442	1278	1338	926	519	400	537	486	455	739	1200	1438	10760
Resist. KWH for Space Heat ...	1504	1039	757	217	37	2	0	0	17	165	582	1294	5617
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Inside Fan	35	30	29	16	6	2	5	4	4	11	25	33	201
KWH for Outside Fan	35	30	30	17	7	4	6	5	5	12	25	33	209
Energy Coll. from Ambient	2899	2575	2721	1806	837	195	69	84	389	1336	2403	2909	18224
Energy Rej. to Ambient	0	0	0	0	1	35	597	436	55	6	0	0	1131
Net Coeff. of Performance	1.80	1.90	2.04	2.20	2.04	1.75	1.96	1.89	1.92	2.10	2.07	1.87	1.95

APPENDIX B - TABULATED SIMULATION RESULTS

BOSTON - Coll Area = 300 Sq Ft; Ground Lngth = 0 Ft; Stor Vol = 600 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	3669	3108	2152	808	122	4	0	0	0	510	1653	3366	15393
Space Cooling Energy Req'd ...	0	0	0	0	71	662	1103	924	350	13	0	0	3123
DHW Energy Req'd	527	454	485	394	371	284	275	317	347	383	417	449	4705
KWH for Heat Pump Comp.	224	297	507	294	174	259	380	341	208	226	478	307	3696
Resist. KWH for Space Heat ...	2976	2177	568	8	0	0	0	0	0	0	91	2381	8201
Resist. KWH for DHW	327	195	6	0	0	0	0	0	0	0	0	201	729
KWH for Pumps	35	47	107	106	96	136	142	139	121	103	116	51	1200
KWH for Fans	5	8	23	4	5	25	36	31	15	3	23	14	193
Fan Energy lost to Atmos.	1	2	13	1	4	22	30	26	13	1	14	7	134
Energy Coll. from Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected to Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Coll. by Solar Panels .	624	815	1320	917	835	3	0	0	4	865	961	735	7080
Energy Rej. by Solar Panels ..	0	0	0	0	17	538	647	742	274	0	0	0	2219
Energy Rejected by Fan Coil ..	-3	-19	-175	115	667	251	706	353	107	252	-343	-112	1798
Net Coeff. of Performance	1.18	1.31	2.18	2.91	2.06	2.26	2.47	2.43	2.03	2.73	2.92	1.29	1.66

BOSTON - Coll Area = 300 Sq Ft; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	3669	3108	2152	808	122	4	0	0	0	510	1653	3366	15393
Space Cooling Energy Req'd ...	0	0	0	0	71	662	1103	924	350	13	0	0	3123
DHW Energy Req'd	527	454	485	394	371	284	275	317	347	383	417	449	4705
KWH for Heat Pump Comp.	214	281	496	292	169	249	353	330	206	230	469	868	4159
Resist. KWH for Space Heat ...	3038	2285	658	52	0	0	0	0	0	9	79	304	6425
Resist. KWH for DHW	303	171	6	0	0	0	0	0	0	0	0	0	480
KWH for Pumps	34	47	105	106	96	105	113	116	120	103	116	124	1186
KWH for Fans	4	6	19	21	18	4	7	8	11	4	9	19	132
Fan Energy lost to Atmos.	0	0	8	16	18	1	2	3	9	1	0	0	59
Energy Coll. from Ground	134	188	417	73	2	28	13	26	164	183	872	1928	4030
Energy Rejected to Ground	221	270	610	1165	1605	779	1304	1017	328	971	304	197	8768
Energy Coll. by Solar Panels .	692	863	1357	1552	1591	4	0	0	3	1372	825	767	9028
Energy Rej. by Solar Panels ..	0	0	0	0	0	13	21	58	127	0	0	0	218
Energy Rejected by Fan Coil ..	6	7	-195	-292	-174	-33	-18	7	48	55	20	16	-553
Net Coeff. of Performance	1.17	1.28	2.05	2.55	1.99	2.65	2.91	2.73	2.07	2.62	3.07	2.90	1.88

APPENDIX B - TABULATED SIMULATION RESULTS

BOSTON - Coll Area = 0 Sq Ft; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	3669	3108	2152	808	122	4	0	0	0	510	1653	3366	15393
Space Cooling Energy Req'd ...	0	0	0	0	71	662	1103	924	350	13	0	0	3123
DHW Energy Req'd	527	454	485	394	371	284	275	317	347	383	417	449	4705
KWH for Heat Pump Comp.	71	76	421	294	172	243	346	326	207	238	484	402	3282
Resist. KWH for Space Heat ...	3471	2892	969	80	0	0	0	0	0	18	107	2023	9561
Resist. KWH for DHW	450	375	48	0	0	0	0	0	0	0	0	210	1083
KWH for Pumps	12	14	89	106	96	103	107	111	111	103	116	62	1031
KWH for Fans	5	7	37	42	35	4	5	6	6	29	30	11	218
Fan Energy lost to Atmos.	3	6	28	36	35	0	0	1	5	26	20	2	163
Energy Coll. from Ground	86	78	277	57	2	14	3	13	75	154	913	1065	2738
Energy Rejected to Ground	0	0	61	609	1081	797	1331	1092	380	251	5	0	5604
Energy Coll. by Solar Panels .	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rej. by Solar Panels ..	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected by Fan Coil ..	-103	-125	-879	-1276	-1232	-62	-50	-32	21	-602	-439	-52	-4831
Net Coeff. of Performance	1.05	1.06	1.69	2.30	1.86	2.71	3.00	2.80	2.15	2.33	2.81	1.41	1.53

BOSTON - Coll Area = 150 Sq Ft; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	3669	3108	2152	808	122	4	0	0	0	510	1653	3366	15393
Space Cooling Energy Req'd ...	0	0	0	0	71	662	1103	924	350	13	0	0	3123
DHW Energy Req'd	527	454	485	394	371	284	275	317	347	383	417	449	4705
KWH for Heat Pump Comp.	121	143	460	294	171	244	349	327	207	232	478	695	3722
Resist. KWH for Space Heat ...	3345	2714	824	62	0	0	0	0	0	20	98	1004	8067
Resist. KWH for DHW	381	291	15	0	0	0	0	0	0	0	0	54	741
KWH for Pumps	21	27	98	106	96	104	110	113	115	103	116	102	1111
KWH for Fans	3	4	30	35	33	4	6	6	8	10	11	15	168
Fan Energy lost to Atmos.	1	1	20	30	32	1	1	2	7	7	1	0	104
Energy Coll. from Ground	76	85	320	57	1	19	4	15	105	176	951	1575	3386
Energy Rejected to Ground	51	75	275	830	1302	791	1321	1068	359	529	123	64	6787
Energy Coll. by Solar Panels .	275	341	726	864	879	2	0	0	2	803	502	430	4824
Energy Rej. by Solar Panels ..	0	0	0	0	0	4	6	11	70	0	0	0	91
Energy Rejected by Fan Coil ..	-25	-33	-459	-647	-580	-51	-40	-16	9	-59	-15	4	-1911
Net Coeff. of Performance	1.08	1.12	1.85	2.42	1.89	2.70	2.97	2.78	2.11	2.48	2.94	2.04	1.68

BOSTON - Coll Area = 450 Sq Ft; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	3669	3108	2152	808	122	4	0	0	0	510	1653	3366	15393
Space Cooling Energy Req'd ...	0	0	0	0	71	662	1103	924	350	13	0	0	3123
DHW Energy Req'd	527	454	485	394	371	284	275	317	347	383	417	449	4705
KWH for Heat Pump Comp.	313	382	517	290	169	251	357	331	206	232	464	880	4394
Resist. KWH for Space Heat ...	2724	1925	544	45	0	0	0	0	0	3	63	178	5483
Resist. KWH for DHW	225	105	3	0	0	0	0	0	0	0	0	0	333
KWH for Pumps	47	60	110	106	96	111	115	121	125	103	116	127	1238
KWH for Fans	6	8	14	13	10	6	8	10	13	4	8	18	120
Fan Energy lost to Atmos.	0	0	3	8	9	2	3	6	11	1	0	0	43
Energy Coll. from Ground	213	278	501	100	3	47	30	55	243	174	842	1946	4434
Energy Rejected to Ground	390	473	946	1512	1907	756	1266	946	302	1319	450	305	10571
Energy Coll. by Solar Panels .	1073	1293	1841	2061	2095	5	0	0	4	1778	1034	974	12160
Energy Rej. by Solar Panels ..	0	0	0	0	3	39	58	149	211	0	0	0	460
Energy Rejected by Fan Coil ..	14	18	-64	-103	25	-10	4	26	69	94	33	27	131
Net Coeff. of Performance	1.27	1.44	2.22	2.64	2.06	2.58	2.87	2.68	2.03	2.65	3.17	3.17	2.01

BOSTON - Coll Area = 300 Sq Ft, Glazed; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	3669	3108	2152	808	122	4	0	0	0	510	1653	3366	15393
Space Cooling Energy Req'd ...	0	0	0	0	71	662	1103	924	350	13	0	0	3123
DHW Energy Req'd	527	454	485	394	371	284	275	317	347	383	417	449	4705
KWH for Heat Pump Comp.	309	407	516	289	169	252	358	332	207	233	463	874	4410
Resist. KWH for Space Heat ...	2724	1833	542	46	0	0	0	0	0	2	57	171	5376
Resist. KWH for DHW	234	96	3	0	0	0	0	0	0	0	0	0	333
KWH for Pumps	47	63	111	106	96	113	115	124	128	103	116	127	1250
KWH for Fans	6	8	13	13	8	7	9	13	16	4	8	18	124
Fan Energy lost to Atmos.	0	0	3	8	8	4	3	8	14	1	0	0	48
Energy Coll. from Ground	224	331	519	105	4	42	24	50	239	173	821	1932	4465
Energy Rejected to Ground	433	525	1025	1594	1965	749	1258	947	296	1454	525	355	11126
Energy Coll. by Solar Panels .	1102	1368	1920	2149	2182	5	0	0	4	1926	1142	1054	12854
Energy Rej. by Solar Panels ..	0	0	0	0	2	26	41	76	100	0	0	0	247
Energy Rejected by Fan Coil ..	16	19	-51	-95	54	13	25	90	190	108	38	32	440
Net Coeff. of Performance	1.26	1.48	2.22	2.65	2.07	2.55	2.86	2.65	1.99	2.65	3.21	3.20	2.02

APPENDIX B - TABULATED SIMULATION RESULTS

BOSTON - Coll Area = 300 Sq Ft, Glazed; Ground Lngth = 0 Ft; Stor Vol = 600 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	3669	3108	2152	808	122	4	0	0	0	510	1653	3366	15393
Space Cooling Energy Req'd ...	0	0	0	0	71	662	1103	924	350	13	0	0	3123
DHW Energy Req'd	527	454	485	394	371	284	275	317	347	383	417	449	4705
KWH for Heat Pump Comp.	336	430	538	277	182	258	379	340	206	231	465	429	4072
Resist. KWH for Space Heat ...	2549	1653	328	0	0	0	0	0	0	0	60	1899	6490
Resist. KWH for DHW	261	123	0	0	0	0	0	0	0	0	0	153	537
KWH for Pumps	51	66	115	106	96	139	144	144	125	103	116	67	1270
KWH for Fans	7	8	14	4	6	27	38	34	16	4	15	16	190
Fan Energy lost to Atmos.	0	0	4	1	5	24	33	29	14	2	6	7	125
Energy Coll. from Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected to Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Coll. by Solar Panels .	1008	1282	1730	1173	1177	4	0	0	5	1186	1241	1113	9920
Energy Rej. by Solar Panels ..	0	0	0	0	6	121	139	159	105	0	0	0	531
Energy Rejected by Fan Coil ..	13	19	-9	355	1040	686	1213	934	277	559	-109	-105	4876
Net Coeff. of Performance	1.31	1.56	2.65	3.10	1.99	2.24	2.46	2.40	2.02	2.68	3.15	1.49	1.85

BOSTON - REFERENCE AIR-TO-AIR SYSTEM

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	3669	3108	2152	808	122	4	0	0	0	510	1653	3366	15393
Space Cooling Energy Req'd ...	0	0	0	0	71	662	1103	924	350	13	0	0	3123
DHW Energy Req'd	527	454	485	394	371	284	275	317	347	383	417	449	4705
KWH for Heat Pump Comp.	1365	1162	905	513	340	472	617	564	400	430	768	1252	8789
Resist. KWH for Space Heat ...	413	350	227	113	1	0	0	0	0	59	150	340	1655
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Inside Fan	34	28	18	6	1	4	6	5	2	4	13	30	151
KWH for Outside Fan	34	28	19	7	3	5	7	6	4	5	13	30	160
Energy Coll. from Ambient	2778	2367	1808	823	308	4	0	0	1	617	1476	2587	12772
Energy Rej. to Ambient	0	0	0	0	54	585	1133	860	170	11	0	0	2813
Net Coeff. of Performance	2.27	2.27	2.26	1.88	1.63	1.98	2.19	2.16	1.72	1.82	2.19	2.31	2.16

APPENDIX B - TABULATED SIMULATION RESULTS

MINNEAPOLIS - Coll Area = 300 Sq Ft; Ground Lngth = 0 Ft; Stor Vol = 600 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	8752	6953	5645	2552	743	96	45	69	729	2228	5239	7896	40948
Space Cooling Energy Req'd ...	0	0	0	0	35	399	912	601	90	0	0	0	2038
DHW Energy Req'd	527	476	509	458	353	295	239	281	301	359	406	479	4684
KWH for Heat Pump Comp.	210	284	425	684	274	219	336	263	270	601	374	183	4124
Resist. KWH for Space Heat ...	8029	5961	4210	133	0	0	0	0	0	0	3980	7263	29577
Resist. KWH for DHW	414	321	213	0	0	0	0	0	0	0	174	381	1503
KWH for Pumps	18	28	51	136	134	128	142	136	128	144	47	18	1111
KWH for Fans	4	6	8	26	5	15	30	21	6	21	15	4	163
Fan Energy lost to Atmos.	0	0	0	12	2	13	25	17	3	10	6	0	91
Energy Coll. from Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected to Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Coll. by Solar Panels .	607	842	1268	1688	1095	18	6	12	1086	1529	908	533	9593
Energy Rej. by Solar Panels ..	0	0	0	0	0	313	486	373	7	0	0	0	1178
Energy Rejected by Fan Coil ..	8	13	13	-354	367	126	631	303	534	-264	-139	6	1243
Net Coeff. of Performance	1.07	1.13	1.25	3.08	2.73	2.18	2.36	2.26	2.77	3.38	1.23	1.07	1.31

MINNEAPOLIS - Coll Area = 300 Sq Ft; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	8752	6953	5645	2552	743	96	45	69	729	2228	5239	7896	40948
Space Cooling Energy Req'd ...	0	0	0	0	35	399	912	601	90	0	0	0	2038
DHW Energy Req'd	527	476	509	458	353	295	239	281	301	359	406	479	4684
KWH for Heat Pump Comp.	191	225	338	553	291	217	300	251	287	583	556	282	4074
Resist. KWH for Space Heat ...	8093	6180	4536	773	12	0	0	0	0	204	3339	6911	30049
Resist. KWH for DHW	420	333	249	0	0	0	0	0	0	0	84	330	1416
KWH for Pumps	17	23	43	120	134	102	106	105	128	139	64	26	1007
KWH for Fans	4	5	7	32	30	6	6	6	26	28	12	6	171
Fan Energy lost to Atmos.	0	0	0	21	25	4	1	3	22	17	1	0	95
Energy Coll. from Ground	21	18	89	265	108	23	5	5	158	693	745	287	2418
Energy Rejected to Ground	64	157	418	1087	1865	614	1152	813	1649	1067	159	53	9094
Energy Coll. by Solar Panels .	608	813	1325	1763	1855	40	14	23	1570	1603	988	603	11206
Energy Rej. by Solar Panels ..	0	0	0	0	0	3	2	0	0	0	0	0	5
Energy Rejected by Fan Coil ..	9	12	14	-611	-532	-223	-100	-176	-450	-421	-18	11	-2483
Net Coeff. of Performance	1.06	1.10	1.19	2.04	2.42	2.43	2.90	2.63	2.54	2.71	1.39	1.11	1.30

APPENDIX B - TABULATED SIMULATION RESULTS

MINNEAPOLIS - Coll Area = 300 Sq Ft, Glazed; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	8752	6953	5645	2552	743	96	45	69	729	2228	5239	7896	40948
Space Cooling Energy Req'd ...	0	0	0	0	35	399	912	601	90	0	0	0	2038
DHW Energy Req'd	527	476	509	458	353	295	239	281	301	359	406	479	4684
KWH for Heat Pump Comp.	261	345	480	594	294	218	302	251	285	617	700	434	4785
Resist. KWH for Space Heat ...	7814	5730	4025	600	0	0	0	0	0	45	2748	6352	27315
Resist. KWH for DHW	384	270	162	0	0	0	0	0	0	0	54	261	1131
KWH for Pumps	23	33	58	125	134	103	107	105	128	143	79	38	1076
KWH for Fans	5	7	9	25	21	6	6	6	19	21	15	9	152
Fan Energy lost to Atmos.	0	0	0	13	17	4	2	3	15	8	0	0	62
Energy Coll. from Ground	21	61	148	408	142	28	9	7	203	859	1016	534	3438
Energy Rejected to Ground	253	408	812	1565	2314	570	1142	778	2036	1529	372	181	11957
Energy Coll. by Solar Panels .	1044	1419	2122	2461	2555	49	17	26	2205	2245	1415	961	16520
Energy Rej. by Solar Panels ..	0	0	0	0	0	4	4	2	0	0	0	0	10
Energy Rejected by Fan Coil ..	18	25	31	-373	-258	-161	-81	-135	-156	-205	12	21	-1260
Net Coeff. of Performance	1.09	1.16	1.30	2.24	2.52	2.42	2.88	2.62	2.58	3.13	1.57	1.18	1.38

MINNEAPOLIS - Coll Area = 300 Sq Ft, Glazed; Ground Lngth = 0 Ft; Stor Vol = 600 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	8752	6953	5645	2552	743	96	45	69	729	2228	5239	7896	40948
Space Cooling Energy Req'd ...	0	0	0	0	35	399	912	601	90	0	0	0	2038
DHW Energy Req'd	527	476	509	458	353	295	239	281	301	359	406	479	4684
KWH for Heat Pump Comp.	349	459	645	682	280	218	336	263	279	574	515	288	4889
Resist. KWH for Space Heat ...	7492	5300	3328	24	0	0	0	0	0	0	3423	6866	26434
Resist. KWH for DHW	360	234	135	0	0	0	0	0	0	0	120	333	1182
KWH for Pumps	29	42	73	138	134	131	143	137	128	144	61	27	1190
KWH for Fans	7	9	13	17	6	16	31	21	7	11	15	6	160
Fan Energy lost to Atmos.	0	0	0	5	3	14	26	18	4	2	4	0	76
Energy Coll. from Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected to Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Coll. by Solar Panels .	1060	1403	2038	2072	1467	27	9	17	1507	1907	1424	867	13800
Energy Rej. by Solar Panels ..	0	0	0	0	0	99	144	136	4	0	0	0	383
Energy Rejected by Fan Coil ..	19	26	31	-77	767	345	973	543	948	86	-58	13	3617
Net Coeff. of Performance	1.13	1.23	1.47	3.49	2.70	2.17	2.34	2.26	2.70	3.55	1.37	1.11	1.41

APPENDIX B - TABULATED SIMULATION RESULTS

MINNEAPOLIS - Coll Area = 300 Sq Ft; Ground Lngth = 1000 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	8752	6953	5645	2552	743	96	45	69	729	2228	5239	7896	40948
Space Cooling Energy Req'd ...	0	0	0	0	35	399	912	601	90	0	0	0	2038
DHW Energy Req'd	527	476	509	458	353	295	239	281	301	359	406	479	4684
KWH for Heat Pump Comp.	189	218	325	568	293	216	291	247	287	590	455	248	3928
Resist. KWH for Space Heat ...	8101	6205	4585	795	13	0	0	0	0	193	3687	7032	30612
Resist. KWH for DHW	420	342	255	3	0	0	0	0	0	0	135	342	1497
KWH for Pumps	16	22	42	119	134	102	105	104	128	139	55	23	991
KWH for Fans	4	4	6	35	36	7	6	7	32	36	10	5	191
Fan Energy lost to Atmos.	0	0	0	24	32	4	2	4	27	24	1	0	119
Energy Coll. from Ground	17	11	69	198	74	17	2	3	91	534	462	189	1669
Energy Rejected to Ground	69	166	437	1228	2257	676	1199	903	2095	1287	175	57	10547
Energy Coll. by Solar Panels .	610	805	1320	1822	1955	44	16	25	1673	1703	989	602	11566
Energy Rej. by Solar Panels ..	0	0	0	0	0	1	0	0	0	0	0	0	1
Energy Rejected by Fan Coil ..	9	11	11	-733	-853	-286	-154	-266	-864	-703	-25	10	-3844
Net Coeff. of Performance	1.06	1.09	1.18	1.98	2.38	2.44	2.97	2.65	2.51	2.70	1.30	1.10	1.28

MINNEAPOLIS - Coll Area = 0 Sq Ft; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	8752	6953	5645	2552	743	96	45	69	729	2228	5239	7896	40948
Space Cooling Energy Req'd ...	0	0	0	0	35	399	912	601	90	0	0	0	2038
DHW Energy Req'd	527	476	509	458	353	295	239	281	301	359	406	479	4684
KWH for Heat Pump Comp.	0	0	61	531	292	214	297	251	288	549	201	0	2685
Resist. KWH for Space Heat ...	8752	6953	5465	929	24	6	0	0	0	379	4573	7896	34977
Resist. KWH for DHW	525	477	453	3	0	0	0	0	0	0	282	480	2220
KWH for Pumps	0	0	10	114	133	101	105	104	128	134	26	0	857
KWH for Fans	0	0	7	46	44	7	6	6	40	47	11	0	215
Fan Energy lost to Atmos.	0	0	6	35	40	4	1	3	36	36	6	0	168
Energy Coll. from Ground	0	0	42	155	67	18	3	4	101	462	299	1	1152
Energy Rejected to Ground	0	0	0	392	1202	638	1165	833	1011	425	0	0	5665
Energy Coll. by Solar Panels .	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rej. by Solar Panels ..	0	0	0	0	0	-0	0	0	0	0	0	0	-0
Energy Rejected by Fan Coil ..	0	0	-122	-1660	-1748	-290	-131	-218	-1436	-1480	-261	0	-7347
Net Coeff. of Performance	1.00	1.00	1.03	1.85	2.29	2.41	2.93	2.63	2.45	2.33	1.11	1.00	1.16

MINNEAPOLIS - REFERENCE AIR-TO-AIR SYSTEM

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	8752	6953	5645	2552	743	96	45	69	729	2228	5239	7896	40948
Space Cooling Energy Req'd ...	0	0	0	0	35	399	912	601	90	0	0	0	2038
DHW Energy Req'd	527	476	509	458	353	295	239	281	301	359	406	479	4684
KWH for Heat Pump Comp.	1556	1463	1676	1115	576	433	575	493	553	1016	1666	1653	12776
Resist. KWH for Space Heat ...	5160	3521	1535	117	0	0	0	0	0	35	1007	3951	15326
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Inside Fan	45	40	42	21	6	3	6	4	6	17	40	45	273
KWH for Outside Fan	45	40	42	21	7	4	6	5	6	18	40	45	280
Energy Coll. from Ambient	2907	2790	3384	2206	810	76	36	55	757	1962	3447	3183	21613
Energy Rej. to Ambient	0	0	0	0	31	265	926	510	86	0	0	0	1819
Net Coeff. of Performance	1.36	1.47	1.87	2.36	1.92	1.80	2.04	1.90	1.98	2.38	2.05	1.47	1.66

BALTIMORE - Coll Area = 300 Sq Ft; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	4394	3512	2523	721	115	10	1	0	88	779	2208	4198	18550
Space Cooling Energy Req'd ...	0	0	0	50	410	1330	1849	1521	604	98	0	0	5863
DHW Energy Req'd	467	422	407	371	341	307	317	251	237	311	377	443	4253
KWH for Heat Pump Comp.	326	379	508	281	242	430	598	504	262	281	562	1011	5386
Resist. KWH for Space Heat ...	3370	2347	892	93	1	0	0	0	0	81	185	542	7512
Resist. KWH for DHW	192	81	0	0	0	0	0	0	0	0	0	3	276
KWH for Pumps	51	63	108	104	110	111	122	132	130	108	120	124	1284
KWH for Fans	10	11	23	20	9	10	17	21	20	7	11	22	183
Fan Energy lost to Atmos.	3	3	13	16	6	3	7	13	16	3	0	0	86
Energy Coll. from Ground	211	255	438	114	70	39	59	127	369	292	1145	2314	5435
Energy Rejected to Ground	305	389	872	1435	521	1544	2060	1558	609	953	457	230	10932
Energy Coll. by Solar Panels .	904	1083	1527	1618	79	6	4	0	41	1315	1022	862	8460
Energy Rej. by Solar Panels ..	0	0	0	0	32	45	224	431	391	1	0	0	1124
Energy Rejected by Fan Coil ..	-103	-103	-317	-268	-90	5	34	43	90	143	29	14	-522
Net Coeff. of Performance	1.23	1.37	1.91	2.29	2.39	2.99	2.94	2.70	2.25	2.49	2.94	2.73	1.96

BALTIMORE - Coll Area = 300 Sq Ft; Ground Lngth = 0 Ft; Stor Vol = 600 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	4394	3512	2523	721	115	10	1	0	88	779	2208	4198	18550
Space Cooling Energy Req'd ...	0	0	0	50	410	1330	1849	1521	604	98	0	0	5863
DHW Energy Req'd	467	422	407	371	341	307	317	251	237	311	377	443	4253
KWH for Heat Pump Comp.	364	418	575	283	242	467	642	520	255	291	540	418	5016
Resist. KWH for Space Heat ...	3214	2153	550	9	1	0	0	0	0	10	337	2822	9096
Resist. KWH for DHW	186	96	0	0	0	0	0	0	0	0	0	147	429
KWH for Pumps	52	65	117	104	128	138	143	142	128	108	117	61	1304
KWH for Fans	16	16	24	5	17	35	44	39	23	6	23	20	270
Fan Energy lost to Atmos.	8	7	13	2	15	28	34	30	19	3	13	11	185
Energy Coll. from Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected to Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Coll. by Solar Panels .	885	1024	1491	1062	72	6	4	0	43	1063	1240	866	7758
Energy Rej. by Solar Panels ..	0	0	0	5	317	645	712	821	447	6	0	0	2954
Energy Rejected by Fan Coil ..	-156	-162	-253	413	122	958	1621	1116	294	449	-292	-300	3809
Net Coeff. of Performance	1.27	1.43	2.31	2.85	2.23	2.58	2.62	2.53	2.29	2.85	2.54	1.34	1.78

APPENDIX B - TABULATED SIMULATION RESULTS

BALTIMORE - Coll Area = 0 Sq Ft; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	4394	3512	2523	721	115	10	1	0	88	779	2208	4198	18550
Space Cooling Energy Req'd ...	0	0	0	50	410	1330	1849	1521	604	98	0	0	5863
DHW Energy Req'd	467	422	407	371	341	307	317	251	237	311	377	443	4253
KWH for Heat Pump Comp.	164	253	445	275	238	423	585	494	259	280	580	571	4568
Resist. KWH for Space Heat ...	3900	2766	1190	137	2	0	0	0	0	108	216	2277	10597
Resist. KWH for DHW	321	192	0	0	0	0	0	0	0	0	0	117	630
KWH for Pumps	30	45	99	103	103	105	119	130	130	108	120	78	1170
KWH for Fans	11	19	40	35	8	8	14	20	19	19	25	17	237
Fan Energy lost to Atmos.	8	13	30	31	5	1	5	12	15	15	13	4	156
Energy Coll. from Ground	134	180	247	93	40	16	24	50	255	417	1411	1490	4357
Energy Rejected to Ground	4	22	258	874	564	1581	2180	1721	654	212	13	1	8080
Energy Coll. by Solar Panels .	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rej. by Solar Panels ..	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected by Fan Coil ..	-313	-514	-1200	-1305	-226	-25	82	224	277	-271	-249	-106	-3625
Net Coeff. of Performance	1.10	1.20	1.65	2.08	2.46	3.07	3.02	2.75	2.28	2.30	2.75	1.52	1.67

BALTIMORE - Coll Area =150 Sq Ft; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	4394	3512	2523	721	115	10	1	0	88	779	2208	4198	18550
Space Cooling Energy Req'd ...	0	0	0	50	410	1330	1849	1521	604	98	0	0	5863
DHW Energy Req'd	467	422	407	371	341	307	317	251	237	311	377	443	4253
KWH for Heat Pump Comp.	270	305	478	278	238	425	590	499	261	280	571	854	5051
Resist. KWH for Space Heat ...	3560	2595	1042	111	1	0	0	0	0	94	202	1202	8809
Resist. KWH for DHW	237	144	0	0	0	0	0	0	0	0	0	33	414
KWH for Pumps	43	53	103	103	106	108	119	130	130	108	120	108	1234
KWH for Fans	13	16	34	32	8	9	15	20	19	6	11	19	206
Fan Energy lost to Atmos.	8	10	24	28	6	3	6	12	16	2	0	0	115
Energy Coll. from Ground	189	179	312	95	47	23	38	81	307	326	1254	2016	4868
Energy Rejected to Ground	96	149	502	1110	555	1566	2133	1648	635	555	196	85	9228
Energy Coll. by Solar Panels .	412	509	841	892	42	3	2	0	21	756	607	481	4567
Energy Rej. by Solar Panels ..	0	0	0	0	10	16	94	219	196	0	0	0	535
Energy Rejected by Fan Coil ..	-241	-287	-643	-673	-176	-12	59	115	172	34	9	-5	-1649
Net Coeff. of Performance	1.18	1.26	1.77	2.18	2.44	3.04	2.99	2.73	2.27	2.43	2.86	2.09	1.82

BALTIMORE - Coll Area = 450 Sq Ft; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	4394	3512	2523	721	115	10	1	0	88	779	2208	4198	18550
Space Cooling Energy Req'd ...	0	0	0	50	410	1330	1849	1521	604	98	0	0	5863
DHW Energy Req'd	467	422	407	371	341	307	317	251	237	311	377	443	4253
KWH for Heat Pump Comp.	396	462	583	283	241	434	605	508	264	283	557	1051	5667
Resist. KWH for Space Heat ...	3121	2032	585	79	0	0	0	0	0	70	173	317	6380
Resist. KWH for DHW	144	42	3	0	0	0	0	0	0	0	0	0	189
KWH for Pumps	59	73	116	104	115	112	125	134	132	108	120	128	1328
KWH for Fans	10	11	18	13	10	11	18	23	21	7	10	22	176
Fan Energy lost to Atmos.	1	1	6	9	7	4	9	15	18	3	0	0	75
Energy Coll. from Ground	245	372	611	124	108	59	82	176	435	275	1098	2358	5943
Energy Rejected to Ground	510	638	1236	1770	480	1512	1979	1480	588	1283	676	354	12505
Energy Coll. by Solar Panels .	1357	1551	2096	2162	105	8	5	0	57	1742	1320	1119	11524
Energy Rej. by Solar Panels ..	0	0	0	0	68	93	282	467	440	2	0	0	1353
Energy Rejected by Fan Coil ..	-46	-30	-163	-60	-13	17	89	139	155	212	42	25	369
Net Coeff. of Performance	1.30	1.50	2.24	2.38	2.37	2.96	2.90	2.67	2.23	2.53	3.00	3.05	2.09

BALTIMORE - Coll Area = 300 Sq Ft, Glazed; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	4394	3512	2523	721	115	10	1	0	88	779	2208	4198	18550
Space Cooling Energy Req'd ...	0	0	0	50	410	1330	1849	1521	604	98	0	0	5863
DHW Energy Req'd	467	422	407	371	341	307	317	251	237	311	377	443	4253
KWH for Heat Pump Comp.	390	468	587	283	242	435	608	511	265	284	554	1044	5671
Resist. KWH for Space Heat ...	3140	2004	566	80	0	0	0	0	0	68	167	309	6334
Resist. KWH for DHW	147	42	3	0	0	0	0	0	0	0	0	0	192
KWH for Pumps	58	73	117	104	117	113	127	136	135	108	120	128	1338
KWH for Fans	9	11	18	13	11	12	21	27	24	7	10	22	185
Fan Energy lost to Atmos.	1	1	6	8	8	5	11	19	21	3	0	0	84
Energy Coll. from Ground	259	401	645	130	103	50	71	156	417	273	1075	2356	5938
Energy Rejected to Ground	557	695	1315	1834	473	1506	2004	1499	577	1400	780	406	13043
Energy Coll. by Solar Panels .	1376	1604	2170	2243	101	8	5	0	56	1890	1462	1193	12108
Energy Rej. by Solar Panels ..	0	0	0	0	37	50	96	138	152	1	0	0	475
Energy Rejected by Fan Coil ..	-44	-26	-151	-36	11	63	244	427	428	240	49	30	1237
Net Coeff. of Performance	1.30	1.51	2.27	2.38	2.35	2.94	2.87	2.63	2.19	2.55	3.04	3.09	2.09

APPENDIX B - TABULATED SIMULATION RESULTS

BALTIMORE - Coll Area = 300 Sq Ft, Glazed; Ground Lngth = 0 Ft; Stor Vol = 600 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	4394	3512	2523	721	115	10	1	0	88	779	2208	4198	18550
Space Cooling Energy Req'd ...	0	0	0	50	410	1330	1849	1521	604	98	0	0	5863
DHW Energy Req'd	467	422	407	371	341	307	317	251	237	311	377	443	4253
KWH for Heat Pump Comp.	479	536	604	289	242	468	643	522	256	300	546	526	5415
Resist. KWH for Space Heat ...	2722	1639	311	0	0	0	0	0	0	2	200	2362	7237
Resist. KWH for DHW	162	63	0	0	0	0	0	0	0	0	0	120	345
KWH for Pumps	65	79	121	104	134	139	143	143	132	108	119	72	1360
KWH for Fans	16	14	15	6	19	37	45	40	24	7	14	21	260
Fan Energy lost to Atmos.	6	4	4	3	16	29	35	32	21	4	4	10	170
Energy Coll. from Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected to Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Coll. by Solar Panels .	1323	1537	1950	1364	99	8	5	0	59	1421	1597	1261	10626
Energy Rej. by Solar Panels ..	0	0	0	1	95	146	161	188	154	3	0	0	749
Energy Rejected by Fan Coil ..	-104	-56	-41	734	395	1460	2171	1750	608	790	-66	-243	7402
Net Coeff. of Performance	1.41	1.69	2.78	2.86	2.19	2.56	2.61	2.51	2.25	2.84	2.94	1.50	1.96

BALTIMORE - REFERENCE AIR-TO-AIR SYSTEM

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	4394	3512	2523	721	115	10	1	0	88	779	2208	4198	18550
Space Cooling Energy Req'd ...	0	0	0	50	410	1330	1849	1521	604	98	0	0	5863
DHW Energy Req'd	467	422	407	371	341	307	317	251	237	311	377	443	4253
KWH for Heat Pump Comp.	1455	1219	991	472	446	707	917	785	472	483	887	1413	10249
Resist. KWH for Space Heat ...	825	587	362	151	6	0	0	0	1	170	311	734	3147
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Inside Fan	34	28	19	5	3	8	11	9	4	5	16	32	175
KWH for Outside Fan	34	28	19	6	4	8	11	9	5	6	16	33	182
Energy Coll. from Ambient	2998	2493	1946	678	100	9	2	0	77	670	1739	2914	13628
Energy Rej. to Ambient	0	0	0	47	265	1391	2052	1681	570	100	0	0	6107
Net Coeff. of Performance	2.07	2.11	2.11	1.80	1.88	2.28	2.31	2.21	1.93	1.79	2.10	2.10	2.08

MIAMI - Coll Area = 300 Sq Ft; Ground Lngth = 0 Ft; Stor Vol = 600 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	30	3	0	0	0	0	0	0	0	0	0	7	41
Space Cooling Energy Req'd ...	417	500	1096	1599	2510	3188	3520	3607	3367	2488	1236	593	24123
DHW Energy Req'd	299	270	299	289	299	289	299	299	289	299	289	299	3525
KWH for Heat Pump Comp.	213	220	391	547	847	1115	1259	1307	1195	856	435	259	8645
Resist. KWH for Space Heat ...	0	0	0	0	0	0	0	0	0	0	0	0	0
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Pumps	124	119	139	138	143	139	143	144	139	143	137	129	1637
KWH for Fans	15	16	30	40	54	60	63	64	61	52	32	19	507
Fan Energy lost to Atmos.	13	14	24	32	41	42	44	44	42	38	25	16	377
Energy Coll. from Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected to Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Coll. by Solar Panels .	20	10	0	0	0	0	0	0	0	0	0	9	38
Energy Rej. by Solar Panels ..	396	449	817	723	901	1041	1012	1051	1174	1101	829	426	9920
Energy Rejected by Fan Coil ..	89	140	498	1282	2306	3118	3645	3722	3264	2124	708	294	21189
Net Coeff. of Performance	2.12	2.18	2.49	2.60	2.69	2.65	2.61	2.58	2.62	2.65	2.53	2.21	2.57

MIAMI - Coll Area = 300 Sq Ft; Ground Lngth = 0 Ft; Stor Vol = 600 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	30	3	0	0	0	0	0	0	0	0	0	7	41
Space Cooling Energy Req'd ...	417	500	1096	1599	2510	3188	3520	3607	3367	2488	1236	593	24123
DHW Energy Req'd	299	270	299	289	299	289	299	299	289	299	289	299	3525
KWH for Heat Pump Comp.	218	223	390	535	810	1056	1195	1248	1161	849	441	264	8391
Resist. KWH for Space Heat ...	0	0	0	0	0	0	0	0	0	0	0	0	0
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Pumps	143	130	141	135	143	139	143	143	139	143	139	143	1682
KWH for Fans	26	24	30	37	54	59	64	64	62	58	50	46	575
Fan Energy lost to Atmos.	24	21	25	28	41	42	45	45	43	44	43	42	446
Energy Coll. from Ground	498	426	269	187	98	75	101	140	221	562	938	1205	4723
Energy Rejected to Ground	247	294	648	934	1140	1218	1180	1041	755	445	162	111	8174
Energy Coll. by Solar Panels .	18	8	0	0	0	0	0	0	0	0	0	6	32
Energy Rej. by Solar Panels ..	608	677	729	552	706	829	811	871	1031	1032	941	936	9723
Energy Rejected by Fan Coil ..	118	46	218	667	1404	2118	2687	2943	2828	2288	1375	862	17554
Net Coeff. of Performance	1.93	2.06	2.48	2.67	2.79	2.77	2.73	2.68	2.69	2.66	2.43	1.98	2.60

APPENDIX B - TABULATED SIMULATION RESULTS

MIAMI - Coll Area = 0 Sq Ft; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	30	3	0	0	0	0	0	0	0	0	0	7	41
Space Cooling Energy Req'd ...	417	500	1096	1599	2510	3188	3520	3607	3367	2488	1236	593	24123
DHW Energy Req'd	299	270	299	289	299	289	299	299	289	299	289	299	3525
KWH for Heat Pump Comp.	217	224	392	536	817	1071	1215	1272	1187	865	446	266	8511
Resist. KWH for Space Heat ...	0	0	0	0	0	0	0	0	0	0	0	0	0
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Pumps	144	130	144	138	142	139	143	143	138	142	139	143	1686
KWH for Fans	29	27	37	41	55	60	64	64	62	58	50	47	594
Fan Energy lost to Atmos.	27	24	31	33	42	43	45	45	43	44	43	44	464
Energy Coll. from Ground	421	362	225	168	75	45	65	100	161	498	914	1200	4236
Energy Rejected to Ground	258	310	669	934	1162	1263	1211	1065	777	422	134	92	8296
Energy Coll. by Solar Panels .	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rej. by Solar Panels ..	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected by Fan Coil ..	622	627	886	1190	2081	2894	3448	3770	3801	3289	2326	1808	26745
Net Coeff. of Performance	1.92	2.03	2.44	2.64	2.77	2.74	2.69	2.64	2.64	2.62	2.40	1.97	2.57

MIAMI - Coll Area = 0 Sq Ft; Ground Lngth = 1000 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	30	3	0	0	0	0	0	0	0	0	0	7	41
Space Cooling Energy Req'd ...	417	500	1096	1599	2510	3188	3520	3607	3367	2488	1236	593	24123
DHW Energy Req'd	299	270	299	289	299	289	299	299	289	299	289	299	3525
KWH for Heat Pump Comp.	217	224	390	534	813	1055	1186	1236	1153	847	442	266	8366
Resist. KWH for Space Heat ...	0	0	0	0	0	0	0	0	0	0	0	0	0
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Pumps	144	130	143	136	143	139	144	144	139	143	138	144	1686
KWH for Fans	28	27	34	36	49	56	62	64	61	58	50	47	573
Fan Energy lost to Atmos.	27	25	28	28	36	39	42	44	43	45	43	44	444
Energy Coll. from Ground	461	394	211	132	45	19	32	32	73	358	853	1311	3922
Energy Rejected to Ground	282	337	793	1206	1640	1829	1799	1610	1218	643	170	90	11614
Energy Coll. by Solar Panels .	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rej. by Solar Panels ..	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected by Fan Coil ..	640	635	743	909	1557	2270	2764	3126	3238	2911	2226	1922	22942
Net Coeff. of Performance	1.92	2.03	2.46	2.67	2.79	2.78	2.75	2.71	2.70	2.66	2.42	1.97	2.61

APPENDIX B - TABULATED SIMULATION RESULTS

MIAMI - Coll Area = 0 Sq Ft; Ground Lngth = 0 Ft; Stor Vol = 600 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	30	3	0	0	0	0	0	0	0	0	0	7	41
Space Cooling Energy Req'd ...	417	500	1096	1599	2510	3188	3520	3607	3367	2488	1236	593	24123
DHW Energy Req'd	299	270	299	289	299	289	299	299	289	299	289	299	3525
KWH for Heat Pump Comp.	215	222	396	552	858	1138	1287	1336	1227	868	439	261	8800
Resist. KWH for Space Heat ...	0	0	0	0	0	0	0	0	0	0	0	0	0
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Pumps	125	122	142	139	143	139	143	144	138	142	138	132	1648
KWH for Fans	16	19	34	43	56	61	64	65	62	55	37	21	533
Fan Energy lost to Atmos.	14	16	28	34	42	43	44	45	43	41	30	18	401
Energy Coll. from Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected to Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Coll. by Solar Panels .	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rej. by Solar Panels ..	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected by Fan Coil ..	432	582	1315	2008	3215	4179	4674	4797	4467	3226	1546	714	31155
Net Coeff. of Performance	2.10	2.13	2.44	2.57	2.66	2.60	2.56	2.53	2.56	2.61	2.49	2.18	2.52

MIAMI - REFERENCE AIR-TO-AIR SYSTEM

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	30	3	0	0	0	0	0	0	0	0	0	7	41
Space Cooling Energy Req'd ...	417	500	1096	1599	2510	3188	3520	3607	3367	2488	1236	593	24123
DHW Energy Req'd	299	270	299	289	299	289	299	299	289	299	289	299	3525
KWH for Heat Pump Comp.	419	408	630	814	1185	1489	1646	1697	1570	1177	673	471	12180
Resist. KWH for Space Heat ...	0	0	0	0	0	0	0	0	0	0	0	0	0
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Inside Fan	2	3	6	9	15	19	21	22	21	15	7	3	145
KWH for Outside Fan	4	4	7	10	15	19	21	22	21	15	8	4	151
Energy Coll. from Ambient	30	5	0	0	0	0	0	0	0	0	0	8	43
Energy Rej. to Ambient	296	402	1101	1760	2925	3851	4296	4432	4105	2904	1283	505	27863
Net Coeff. of Performance	1.75	1.87	2.17	2.27	2.31	2.28	2.26	2.24	2.27	2.31	2.22	1.88	2.22

APPENDIX B - TABULATED SIMULATION RESULTS

PHOENIX - Coll Area = 300 Sq Ft; Ground Lngth = 0 Ft; Stor Vol = 600 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	895	493	233	68	0	0	0	0	0	15	220	795	2718
Space Cooling Energy Req'd ...	11	78	230	814	1827	2632	3786	3567	2679	1487	296	44	17451
DHW Energy Req'd	431	389	419	394	377	353	341	269	237	305	353	395	4266
KWH for Heat Pump Comp.	313	268	297	360	686	1095	1660	1514	1087	562	285	309	8436
Resist. KWH for Space Heat ...	86	25	0	0	0	0	0	0	0	0	0	63	175
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Pumps	98	88	96	135	143	138	144	144	139	142	93	98	1457
KWH for Fans	4	5	9	25	42	51	66	64	53	36	10	4	369
Fan Energy lost to Atmos.	1	3	7	20	31	35	41	41	37	28	7	1	253
Energy Coll. from Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected to Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Coll. by Solar Panels .	1103	1128	1418	62	0	0	0	0	0	4	1311	1105	6132
Energy Rej. by Solar Panels ..	11	49	290	241	450	452	599	573	583	429	95	51	3824
Energy Rejected by Fan Coil ..	245	649	1185	716	1806	3020	4598	4329	3092	1469	1270	370	22749
Net Coeff. of Performance	2.67	2.49	2.20	2.45	2.53	2.33	2.21	2.23	2.28	2.44	2.24	2.60	2.34

PHOENIX - Coll Area = 300 Sq Ft; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	895	493	233	68	0	0	0	0	0	15	220	795	2718
Space Cooling Energy Req'd ...	11	78	230	814	1827	2632	3786	3567	2679	1487	296	44	17451
DHW Energy Req'd	431	389	419	394	377	353	341	269	237	305	353	395	4266
KWH for Heat Pump Comp.	280	243	258	367	677	1038	1524	1403	1048	590	260	287	7978
Resist. KWH for Space Heat ...	288	92	6	0	0	0	0	0	0	0	2	106	495
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Pumps	98	88	96	134	139	138	144	144	139	143	93	98	1453
KWH for Fans	7	5	8	21	31	42	59	63	57	50	10	4	360
Fan Energy lost to Atmos.	3	2	6	16	21	27	36	42	41	41	7	1	246
Energy Coll. from Ground	161	99	41	443	265	224	149	239	557	1312	260	393	4146
Energy Rejected to Ground	1388	1487	1857	795	1750	2319	2578	1791	1104	491	920	788	17266
Energy Coll. by Solar Panels .	1845	1837	2127	59	0	0	0	0	0	2	1398	1269	8539
Energy Rej. by Solar Panels ..	0	6	53	162	237	220	320	348	418	486	49	27	2325
Energy Rejected by Fan Coil ..	-24	58	204	402	533	1094	2239	2892	2656	2251	757	199	13260
Net Coeff. of Performance	1.99	2.24	2.39	2.44	2.60	2.45	2.39	2.38	2.34	2.31	2.38	2.49	2.38

APPENDIX B - TABULATED SIMULATION RESULTS

PHOENIX - Coll Area = 0 Sq Ft; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	895	493	233	68	0	0	0	0	0	15	220	795	2718
Space Cooling Energy Req'd ...	11	78	230	814	1827	2632	3786	3567	2679	1487	296	44	17451
DHW Energy Req'd	431	389	419	394	377	353	341	269	237	305	353	395	4266
KWH for Heat Pump Comp.	284	242	256	357	647	1022	1524	1401	1047	590	247	281	7900
Resist. KWH for Space Heat ...	299	108	18	1	0	0	0	0	0	0	4	132	562
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Pumps	98	88	96	122	128	135	144	144	139	143	93	98	1428
KWH for Fans	30	25	25	15	21	34	55	62	57	49	10	5	390
Fan Energy lost to Atmos.	27	23	23	10	11	18	32	41	41	40	7	1	277
Energy Coll. from Ground	183	108	56	226	122	123	98	162	449	1168	430	720	3846
Energy Rejected to Ground	420	551	795	888	2038	2767	3045	2066	1255	546	28	4	14401
Energy Coll. by Solar Panels .	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rej. by Solar Panels ..	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected by Fan Coil ..	-866	-807	-788	175	309	720	2026	2868	2790	2531	466	92	9518
Net Coeff. of Performance	1.88	2.07	2.23	2.58	2.77	2.51	2.39	2.39	2.35	2.31	2.46	2.39	2.38

PHOENIX - Coll Area = 0 Sq Ft; Ground Lngth = 1000 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	895	493	233	68	0	0	0	0	0	15	220	795	2718
Space Cooling Energy Req'd ...	11	78	230	814	1827	2632	3786	3567	2679	1487	296	44	17451
DHW Energy Req'd	431	389	419	394	377	353	341	269	237	305	353	395	4266
KWH for Heat Pump Comp.	279	241	255	350	599	892	1412	1388	1037	588	247	278	7567
Resist. KWH for Space Heat ...	316	109	16	1	0	0	0	0	0	0	5	145	592
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Pumps	98	88	96	117	121	125	142	143	139	144	93	98	1403
KWH for Fans	30	26	28	12	15	19	29	39	45	43	11	5	303
Fan Energy lost to Atmos.	26	24	25	8	5	4	7	18	28	35	8	2	192
Energy Coll. from Ground	175	96	36	171	46	30	15	21	198	854	320	681	2644
Energy Rejected to Ground	471	640	952	904	2142	3224	4711	3980	2451	1004	69	10	20556
Energy Coll. by Solar Panels .	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rej. by Solar Panels ..	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected by Fan Coil ..	-912	-916	-975	91	75	95	276	792	1318	1740	319	59	1965
Net Coeff. of Performance	1.85	2.07	2.24	2.66	3.00	2.88	2.61	2.44	2.39	2.33	2.44	2.34	2.48

APPENDIX B - TABULATED SIMULATION RESULTS

PHOENIX - REFERENCE AIR-TO-AIR SYSTEM

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	895	493	233	68	0	0	0	0	0	15	220	795	2718
Space Cooling Energy Req'd ...	11	78	230	814	1827	2632	3786	3567	2679	1487	296	44	17451
DHW Energy Req'd	431	389	419	394	377	353	341	269	237	305	353	395	4266
KWH for Heat Pump Comp.	466	394	420	601	982	1365	1918	1797	1353	838	403	454	10992
Resist. KWH for Space Heat ...	371	154	38	3	0	0	0	0	0	0	33	288	887
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Inside Fan	4	3	3	5	11	17	25	23	18	9	3	4	129
KWH for Outside Fan	6	5	4	7	12	18	25	23	18	10	4	6	139
Energy Coll. from Ambient	697	505	373	61	0	0	0	0	0	13	322	654	2626
Energy Rej. to Ambient	9	78	236	743	2059	3137	4697	4476	3301	1675	314	47	20774
Net Coeff. of Performance	1.58	1.73	1.89	2.07	2.19	2.13	2.10	2.08	2.10	2.11	1.96	1.64	2.01

ATLANTA - Coll Area = 300 Sq Ft; Ground Lngth = 0 Ft; Stor Vol = 600 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	2080	1453	768	69	0	0	0	0	0	38	699	1900	7009
Space Cooling Energy Req'd ...	0	0	6	309	1353	2239	2865	2696	1747	487	1	0	11705
DHW Energy Req'd	461	389	401	353	287	243	215	239	243	299	347	431	3912
KWH for Heat Pump Comp.	511	379	278	215	453	747	970	916	608	244	247	482	6052
Resist. KWH for Space Heat ...	454	239	35	2	0	0	0	0	0	0	30	325	1087
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Pumps	113	102	102	119	141	139	143	143	138	130	97	113	1482
KWH for Fans	23	8	3	13	38	51	58	56	44	19	3	18	335
Fan Energy lost to Atmos.	13	2	0	11	30	38	42	42	34	16	0	9	241
Energy Coll. from Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected to Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Coll. by Solar Panels .	1197	1092	999	40	0	0	0	0	0	22	883	1112	5348
Energy Rej. by Solar Panels ..	0	0	118	284	780	704	926	871	906	398	102	0	5089
Energy Rejected by Fan Coil ..	-255	-4	110	73	854	2170	2861	2658	1372	195	66	-169	9933
Net Coeff. of Performance	2.31	2.53	2.81	2.09	2.60	2.65	2.63	2.63	2.52	2.10	2.78	2.48	2.53

ATLANTA - Coll Area = 300 Sq Ft; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	2080	1453	768	69	0	0	0	0	0	38	699	1900	7009
Space Cooling Energy Req'd ...	0	0	6	309	1353	2239	2865	2696	1747	487	1	0	11705
DHW Energy Req'd	461	389	401	353	287	243	215	239	243	299	347	431	3912
KWH for Heat Pump Comp.	539	384	261	214	437	717	921	874	565	238	235	477	5866
Resist. KWH for Space Heat ...	371	299	175	3	0	0	0	0	0	0	125	281	1254
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Pumps	115	102	102	121	123	132	143	143	139	143	97	114	1477
KWH for Fans	12	8	4	12	16	30	49	55	50	39	3	8	288
Fan Energy lost to Atmos.	1	1	1	10	9	18	34	40	41	36	0	0	193
Energy Coll. from Ground	825	493	176	255	71	55	81	142	388	1063	258	1018	4826
Energy Rejected to Ground	533	693	1154	308	1382	2000	1859	1360	636	184	775	428	11310
Energy Coll. by Solar Panels .	1174	1251	1630	39	0	0	0	0	0	13	1157	875	6141
Energy Rej. by Solar Panels ..	0	0	18	161	290	465	677	656	801	792	64	0	3923
Energy Rejected by Fan Coil ..	-27	4	20	57	19	391	1195	1573	1162	642	26	42	5104
Net Coeff. of Performance	2.45	2.32	2.17	2.08	2.84	2.82	2.77	2.74	2.64	1.96	2.28	2.65	2.55

ATLANTA - Coll Area = 0 Sq Ft; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	2080	1453	768	69	0	0	0	0	0	38	699	1900	7009
Space Cooling Energy Req'd ...	0	0	6	309	1353	2239	2865	2696	1747	487	1	0	11705
DHW Energy Req'd	461	389	401	353	287	243	215	239	243	299	347	431	3912
KWH for Heat Pump Comp.	512	371	265	212	428	712	929	879	570	238	235	487	5840
Resist. KWH for Space Heat ...	518	395	195	4	0	0	0	0	0	0	141	308	1562
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Pumps	113	100	102	111	119	130	143	143	139	143	97	114	1455
KWH for Fans	30	29	33	9	13	26	47	54	50	40	3	9	343
Fan Energy lost to Atmos.	20	22	29	7	6	14	31	40	41	37	0	0	248
Energy Coll. from Ground	947	513	152	122	18	15	41	84	278	925	572	1394	5062
Energy Rejected to Ground	41	122	369	346	1551	2378	2235	1587	745	193	0	0	9564
Energy Coll. by Solar Panels .	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rej. by Solar Panels ..	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected by Fan Coil ..	-474	-582	-816	-11	79	449	1449	1942	1739	1270	16	8	5072
Net Coeff. of Performance	2.16	2.06	1.98	2.17	2.93	2.86	2.75	2.73	2.62	1.96	2.20	2.54	2.46

ATLANTA - Coll Area = 0 Sq Ft; Ground Lngth = 1000 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	2080	1453	768	69	0	0	0	0	0	38	699	1900	7009
Space Cooling Energy Req'd ...	0	0	6	309	1353	2239	2865	2696	1747	487	1	0	11705
DHW Energy Req'd	461	389	401	353	287	243	215	239	243	299	347	431	3912
KWH for Heat Pump Comp.	547	388	265	211	416	661	891	868	568	237	234	484	5771
Resist. KWH for Space Heat ...	374	322	194	4	0	0	0	0	0	0	150	305	1348
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Pumps	115	102	102	112	113	120	140	140	139	144	97	114	1439
KWH for Fans	26	26	32	9	9	13	22	31	35	32	4	9	251
Fan Energy lost to Atmos.	15	18	28	8	2	2	7	17	26	29	1	0	155
Energy Coll. from Ground	1180	663	178	129	7	1	3	7	115	736	552	1402	4975
Energy Rejected to Ground	20	81	350	347	1597	2741	3424	2882	1506	338	1	0	13285
Energy Coll. by Solar Panels .	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rej. by Solar Panels ..	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected by Fan Coil ..	-316	-446	-778	-6	1	38	260	573	806	938	5	11	1088
Net Coeff. of Performance	2.39	2.20	1.98	2.18	3.05	3.13	2.93	2.82	2.68	2.00	2.16	2.56	2.57

ATLANTA - Coll Area = 150 Sq Ft; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	2080	1453	768	69	0	0	0	0	0	38	699	1900	7009
Space Cooling Energy Req'd ...	0	0	6	309	1353	2239	2865	2696	1747	487	1	0	11705
DHW Energy Req'd	461	389	401	353	287	243	215	239	243	299	347	431	3912
KWH for Heat Pump Comp.	533	383	263	213	432	714	925	876	568	238	234	480	5860
Resist. KWH for Space Heat ...	420	328	191	3	0	0	0	0	0	0	132	293	1368
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Pumps	115	101	102	115	120	130	143	143	139	143	97	114	1464
KWH for Fans	18	17	16	10	14	27	48	54	50	39	3	8	307
Fan Energy lost to Atmos.	8	10	12	8	7	15	33	40	41	36	0	0	212
Energy Coll. from Ground	883	501	161	166	35	29	55	109	327	992	306	1110	4676
Energy Rejected to Ground	235	339	654	330	1490	2221	2071	1486	693	191	359	188	10255
Energy Coll. by Solar Panels .	653	710	942	20	0	0	0	0	0	7	664	514	3512
Energy Rej. by Solar Panels ..	0	0	0	58	111	254	383	375	456	463	33	0	2132
Energy Rejected by Fan Coil ..	-149	-153	-155	16	51	363	1280	1713	1406	888	24	28	5312
Net Coeff. of Performance	2.34	2.22	2.06	2.14	2.90	2.85	2.76	2.73	2.63	1.96	2.25	2.60	2.51

ATLANTA - REFERENCE AIR-TO-AIR SYSTEM

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	2080	1453	768	69	0	0	0	0	0	38	699	1900	7009
Space Cooling Energy Req'd ...	0	0	6	309	1353	2239	2865	2696	1747	487	1	0	11705
DHW Energy Req'd	461	389	401	353	287	243	215	239	243	299	347	431	3912
KWH for Heat Pump Comp.	825	623	458	401	701	1057	1342	1261	846	438	409	768	9131
Resist. KWH for Space Heat ...	457	369	251	5	0	0	0	0	0	1	250	435	1770
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Inside Fan	14	9	4	2	8	13	17	16	10	3	4	12	115
KWH for Outside Fan	15	10	6	4	8	13	17	16	11	4	5	13	124
Energy Coll. from Ambient	1580	1116	678	59	0	0	0	0	0	37	586	1441	5499
Energy Rej. to Ambient	0	0	5	125	1433	2629	3488	3240	1974	383	0	0	13277
Net Coeff. of Performance	1.94	1.82	1.63	1.78	2.29	2.29	2.24	2.27	2.30	1.85	1.57	1.90	2.03

APPENDIX B - TABULATED SIMULATION RESULTS

LOS ANGELES - Coll Area = 300 Sq Ft; Ground Lngth = 0 Ft; Stor Vol = 600 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	667	415	343	140	2	0	0	0	0	5	132	385	2089
Space Cooling Energy Req'd ...	1	5	1	0	65	244	914	958	879	469	66	35	3638
DHW Energy Req'd	419	379	395	330	311	272	275	263	260	305	342	389	3943
KWH for Heat Pump Comp.	264	213	209	149	133	154	314	332	314	223	166	226	2700
Resist. KWH for Space Heat ...	4	0	0	0	0	0	0	0	0	0	0	0	4
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Pumps	100	88	97	93	110	125	143	143	136	132	111	98	1377
KWH for Fans	3	2	3	2	6	15	35	36	32	20	10	3	168
Fan Energy lost to Atmos.	0	1	1	2	5	14	30	31	28	18	9	2	142
Energy Coll. from Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected to Ground	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Coll. by Solar Panels .	953	820	981	910	1	0	0	0	0	2	68	933	4670
Energy Rej. by Solar Panels ..	0	7	7	0	56	178	336	373	411	297	47	51	1763
Energy Rejected by Fan Coil ..	176	342	515	657	60	70	754	792	665	245	-90	406	4591
Net Coeff. of Performance	2.93	2.63	2.39	1.92	1.52	1.76	2.41	2.39	2.36	2.07	1.88	2.47	2.28

LOS ANGELES - Coll Area = 300 Sq Ft; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	667	415	343	140	2	0	0	0	0	5	132	385	2089
Space Cooling Energy Req'd ...	1	5	1	0	65	244	914	958	879	469	66	35	3638
DHW Energy Req'd	419	379	395	330	311	272	275	263	260	305	342	389	3943
KWH for Heat Pump Comp.	263	208	198	134	131	157	318	333	317	231	164	216	2669
Resist. KWH for Space Heat ...	66	12	0	0	0	0	0	0	0	0	0	9	87
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Pumps	100	88	97	93	144	139	143	143	139	144	139	98	1466
KWH for Fans	4	2	2	1	38	33	40	41	39	35	26	3	265
Fan Energy lost to Atmos.	0	0	0	0	37	31	35	36	35	32	25	1	235
Energy Coll. from Ground	207	120	75	22	875	491	268	269	348	602	810	159	4246
Energy Rejected to Ground	1107	1115	1428	1482	22	121	470	501	434	270	46	1026	8022
Energy Coll. by Solar Panels .	1571	1524	1863	1776	2	0	0	0	0	1	55	1404	8197
Energy Rej. by Solar Panels ..	0	1	2	0	530	345	271	293	400	442	480	19	2783
Energy Rejected by Fan Coil ..	26	52	62	69	359	289	611	643	588	430	240	101	3469
Net Coeff. of Performance	2.51	2.57	2.49	2.07	1.21	1.57	2.38	2.36	2.30	1.91	1.64	2.48	2.16

LOS ANGELES - Coll Area = 0 Sq Ft; Ground Lngth = 500 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	667	415	343	140	2	0	0	0	0	5	132	385	2089
Space Cooling Energy Req'd ...	1	5	1	0	65	244	914	958	879	469	66	35	3638
DHW Energy Req'd	419	379	395	330	311	272	275	263	260	305	342	389	3943
KWH for Heat Pump Comp.	266	213	206	139	132	157	318	336	320	231	165	221	2706
Resist. KWH for Space Heat ...	81	21	2	0	0	0	0	0	0	0	0	13	117
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Pumps	100	88	97	93	122	111	126	134	134	140	139	98	1382
KWH for Fans	25	23	25	25	8	7	16	23	29	28	23	13	248
Fan Energy lost to Atmos.	22	20	23	25	8	6	11	18	25	26	21	11	217
Energy Coll. from Ground	304	201	160	59	139	67	50	62	139	355	611	331	2480
Energy Rejected to Ground	120	149	167	240	77	275	992	948	724	384	54	92	4219
Energy Coll. by Solar Panels .	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rej. by Solar Panels ..	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected by Fan Coil ..	-445	-409	-437	-419	68	30	139	255	466	492	457	-167	30
Net Coeff. of Performance	2.30	2.31	2.23	1.83	1.44	1.88	2.58	2.48	2.36	1.95	1.66	2.35	2.17

LOS ANGELES - Coll Area = 0 Sq Ft; Ground Lngth = 1000 Ft; Stor Vol = 0 Gal

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	667	415	343	140	2	0	0	0	0	5	132	385	2089
Space Cooling Energy Req'd ...	1	5	1	0	65	244	914	958	879	469	66	35	3638
DHW Energy Req'd	419	379	395	330	311	272	275	263	260	305	342	389	3943
KWH for Heat Pump Comp.	266	213	206	139	132	157	312	327	314	229	165	221	2682
Resist. KWH for Space Heat ...	80	21	2	0	0	0	0	0	0	0	0	13	116
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Pumps	100	88	97	93	122	108	115	117	125	139	138	98	1339
KWH for Fans	24	21	24	25	8	6	8	10	15	20	21	15	199
Fan Energy lost to Atmos.	20	19	23	24	8	5	4	5	11	17	19	13	169
Energy Coll. from Ground	347	226	179	60	142	62	30	21	63	240	569	315	2257
Energy Rejected to Ground	110	142	166	269	76	277	1054	1117	990	491	54	112	4857
Energy Coll. by Solar Panels .	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rej. by Solar Panels ..	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy Rejected by Fan Coil ..	-402	-386	-423	-448	74	20	39	39	129	281	410	-201	-866
Net Coeff. of Performance	2.31	2.32	2.24	1.83	1.44	1.91	2.73	2.69	2.51	2.01	1.67	2.33	2.23

APPENDIX B - TABULATED SIMULATION RESULTS

LOS ANGELES - REFERENCE AIR-TO-AIR SYSTEM

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
Space Heating Energy Req'd ...	667	415	343	140	2	0	0	0	0	5	132	385	2089
Space Cooling Energy Req'd ...	1	5	1	0	65	244	914	958	879	469	66	35	3638
DHW Energy Req'd	419	379	395	330	311	272	275	263	260	305	342	389	3943
KWH for Heat Pump Comp.	456	380	394	313	311	335	541	559	533	428	326	408	4984
Resist. KWH for Space Heat ...	149	52	18	0	0	0	0	0	0	0	0	33	252
Resist. KWH for DHW	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH for Inside Fan	4	3	2	1	0	1	5	5	5	3	1	3	35
KWH for Outside Fan	6	4	4	2	2	2	6	6	6	4	3	4	51
Energy Coll. from Ambient	695	539	519	328	2	0	0	0	0	5	313	532	2933
Energy Rej. to Ambient	1	4	0	0	-138	94	871	945	859	352	65	35	3090
Net Coeff. of Performance	1.77	1.82	1.77	1.48	1.21	1.53	2.16	2.14	2.10	1.79	1.64	1.81	1.82

Appendix C
Computer Program Listings

Due to limitations in the device used to print these listings the normal BASIC symbols used for greater than, less than, not equal, less than or equal to, greater than or equal to, and to the power, have been changed to conventional FORTRAN notation as follows.

.LT. = Less than
.GT. = Greater than
.LE. = Less than or equal to
.GE. = Greater than or equal to
.NE. = Not equal
** = To the power ie 4**2 is four squared

```
5    REM **************** PROGRAM HTLD *********************
6    REM THIS PROGRAM CALCULATES HOURLY HEATING AND COOLING LOADS FOR A
7    REM BUILDING USING TRANSFER FUNCTIONS FOR WALLS AND OTHER ASHRAE
8    REM METHODS FOR WINDOWS, BASEMENTS AND SLAB ON GRADE
10   PRINTER IS 0
30   PRINT LIN(2)
40   OPTION BASE 1
50   STANDARD
60   DEG
70   PRINTER IS 0
80   INPUT "ENTER JOB TITLE/CUSTOMER",J$
90   INPUT "ENTER DATE",D$
100  PRINT TAB(30),J$;TAB(65),D$
110  BEEP
120  DISP "INSERT 'Weath FILE #1' IN T14"
130  PAUSE
140  Rhog=.2
150  DIM A(12),B(12),C(12),Dmo(12),Dec(12),Az(4)
160  DIM S(96),Sh(25),Trf(96),Te(24),Nb(4),Ind(12),Nd(4),Q(24),Cn(4),Pap(24),Ppl
(24),Plt(24),Thst(24),Trwf(6),Awnd(4),Bn(24),Dn(24),Awll(4),E(7),Mn$(12)
170  DIM Qs(24),Sinaz(4),Cosaz(4),Sinb(24),Idnt(24),Shmt(12),Shcl(12)
180  DIM R1f(12),R2f(12),R3f(12),R4f(12),R5f(12),Pf(12),Tmtp(24)
190  INPUT "ELEVATION ABOVE SEA LEVEL IN FEET",Elev
200  PRINT "ELEVATION ABOVE SEA LEVEL IN FEET =";Elev;"Feet"
210  INPUT "MEAN AMBIENT TEMP FOR YEAR",Tmamb
220  PRINT "MEAN AMBIENT TEMP FOR YEAR =";Tmamb;"Deg F"
230  INPUT "AMPLITUDE OF GROUND TEMP SWING",Amgrn
240  PRINT "AMPLITUDE OF GROUND TEMP SWING =";Amgrn;"Deg F"
250  INPUT "SOLAR ABSORBTIVITY OF WALLS",Alpha
260  PRINT "SOLAR ABSORBTIVITY OF WALLS =";Alpha
270  Alfdho=Alpha/3
280  INPUT "INITIAL TEMPERATURE OF AIR IN HOUSE",Tao
290  PRINT "INITIAL TEMPERATURE OF AIR IN HOUSE =";Tao;"Deg F"
300  Tair=Tao
310  INPUT "INITIAL TEMPERATURE OF HOUSE MASS",To
320  PRINT "INITIAL TEMPERATURE OF HOUSE MASS =";To;"Deg F"
330  Tmass=To
340  INPUT "INSIDE SUMMER HUMIDITY RATIO",Hrs
350  PRINT "INSIDE SUMMER HUMIDITY RATIO =";Hrs;"  lb water/lb air"
360  INPUT "INSIDE WINTER HUMIDITY RATIO",Hrw
370  PRINT "INSIDE WINTER HUMIDITY RATIO =";Hrw;"  lb water/lb air"
380  INPUT "BASEMENT U FACTOR",Bsnf
390  PRINT "BASEMENT U FACTOR =";Bsnf;"  Btu/(Hr-F)"
400  INPUT "WINDOW U FACTOR ",Wndu
410  PRINT "WINDOW U FACTOR  =";Wndu;"  Btu/(Hr-sqft-F)"
420  INPUT "VOLUME OF HOUSE",Volhs
430  PRINT "VOLUME OF HOUSE =";Volhs;"Cubic feet"
440  INPUT "ROOF UA FACTOR",Urf
450  PRINT "ROOF UA FACTOR =";Urf;"Btu/(Hr-F)"
460  INPUT "CONCRETE SLAB ON GRADE FACTOR",Slbf
470  PRINT "CONCRETE SLAB ON GRADE FACTOR =";Slbf;"Btu/(Hr-ft-F)"
480  INPUT "GARAGE TO HOUSE UA FACTOR ",Gua
490  PRINT "GARAGE TO HOUSE UA FACTOR =";Gua;"Btu/F"
500  INPUT "MASS TIMES SPECIFIC HEAT OF HOUSE",Mcp
```

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510  PRINT "MASS TIMES SPECIFIC HEAT OF HOUSE =";Mcp;"  Btu/F"
520  INPUT "CONDUCTANCE BETWEEN HOUSE AIR AND MASS",Ga
530  PRINT "CONDUCTANCE BETWEEN HOUSE AIR AND MASS =";Ga;"Btu/F"
540  INPUT "CONDUCTANCE BETWEEN HEAT/COOL SOURCE AND AIR",Uhc
550  PRINT "CONDUCTANCE BETWEEN HEAT/COOL SOURCE AND AIR =";Uhc;"Btu/F"
560  INPUT "DOOR UA",Dua
570  PRINT "DOOR UA= ";Dua;"Btu/(Hr-F)"
580  INPUT "WALL TRANSFER FUNCTION 'C' COEFF, Cn",Cn(1)
590  INPUT "WALL TRANSFER FUNCTION No OF 'B' COEFFS, Nb AND EACH Bn(Nb)",Nb(1),
Bn(1),Bn(2),Bn(3),Bn(4),Bn(5),Bn(6)
600  INPUT "WALL TRANSFER FUNCTION No OF 'D' COEFFS, Nd AND EACH Dn(Nd)",Nd(1),
Dn(1),Dn(2),Dn(3),Dn(4),Dn(5),Dn(6)
610  Tawnd=0
620  FOR Zz=1 TO 4
630  ON Zz GOTO 640,660,680,700
640  INPUT "FOR WALL 1 Az, Awll, Awnd",Az(Zz),Awll(Zz),Awnd(Zz)
650  GOTO 710
660  INPUT "FOR WALL 2 Az, Awll, Awnd",Az(Zz),Awll(Zz),Awnd(Zz)
670  GOTO 710
680  INPUT "FOR WALL 3 Az, Awll, Awnd",Az(Zz),Awll(Zz),Awnd(Zz)
690  GOTO 710
700  INPUT "FOR WALL 4 Az, Awll, Awnd",Az(Zz),Awll(Zz),Awnd(Zz)
710  Cn(Zz)=Cn(1)
720  Nb(Zz)=Nb(1)
730  Nd(Zz)=Nd(1)
740  Sinaz(Zz)=SIN(Az(Zz))
750  Cosaz(Zz)=COS(Az(Zz))
760  Tawnd=Tawnd+Awnd(Zz)
770  FOR Zzn=1 TO 6
780  Zb=(Zz-1)*6+Zzn
790  Bn(Zb)=Bn(Zzn)
800  Dn(Zb)=Dn(Zzn)
810  NEXT Zzn
820  NEXT Zz
830  PRINT TAB(34);"Wall Number"
840  PRINT TAB(23);"1";TAB(33),"2";TAB(43),"3";TAB(53),"4"
850  PRINT "Azimuth Angle";TAB(20),Az(1);TAB(30),Az(2);TAB(40),Az(3);TAB(50),Az
(4)
860  PRINT "Wall Area Sqft";TAB(20),Awll(1);TAB(30),Awll(2);TAB(40),Awll(3);TAB
(50),Awll(4)
870  PRINT "Window Area Sqft";TAB(20),Awnd(1);TAB(30),Awnd(2);TAB(40),Awnd(3);T
AB(50),Awnd(4)
880  PRINT "Wall Cn factor";TAB(20),Cn(1);TAB(30),Cn(2);TAB(40),Cn(3);TAB(50),C
n(4)
890  PRINT "Wall Bn factor"
900  PRINT "           n=1";TAB(20),Bn(1);TAB(30),Bn(7);TAB(40),Bn(13);TAB(50),
Bn(19)
910  PRINT "           n=2";TAB(20),Bn(2);TAB(30),Bn(8);TAB(40),Bn(14);TAB(50),
Bn(20)
920  PRINT "           n=3";TAB(20),Bn(3);TAB(30),Bn(9);TAB(40),Bn(15);TAB(50),
Bn(21)
930  PRINT "           n=4";TAB(20),Bn(4);TAB(30),Bn(10);TAB(40),Bn(16);TAB(50)
,Bn(22)
940  PRINT "           n=5";TAB(20),Bn(5);TAB(30),Bn(11);TAB(40),Bn(17);TAB(50)
,Bn(23)
```

```
950  PRINT "            n=6";TAB(20),Bn(6);TAB(30),Bn(12);TAB(40),Bn(18);TAB(50)
,Bn(24)
960  PRINT "Wall Dn factors"
970  PRINT "            n=1";TAB(20),Dn(1);TAB(30),Dn(7);TAB(40),Dn(13);TAB(50),
Dn(19)
980  PRINT "            n=2";TAB(20),Dn(2);TAB(30),Dn(8);TAB(40),Dn(14);TAB(50),
Dn(20)
990  PRINT "            n=3";TAB(20),Dn(3);TAB(30),Dn(9);TAB(40),Dn(15);TAB(50),
Dn(21)
1000 PRINT "            n=4";TAB(20),Dn(4);TAB(30),Dn(10);TAB(40),Dn(16);TAB(50)
,Dn(22)
1010 PRINT "            n=5";TAB(20),Dn(5);TAB(30),Dn(11);TAB(40),Dn(17);TAB(50)
,Dn(23)
1020 PRINT "            n=6";TAB(20),Dn(6);TAB(30),Dn(12);TAB(40),Dn(18);TAB(50)
,Dn(24)
1030 RESTORE 1050
1040 MAT READ A,B,C,Dmo,Dec
1050 DATA 390,385,376,360,350,345,344,351,365,378,387,391,.142,.144,.156,.18,.1
96,.205,.207,.201,.177,.16,.149,.142,.058,.06,.071,.097,.121,.134,.136
1060 DATA .122,.092,.073,.063,.057,31,28,31,30,31,30,31,31,30,31,30,31,-20.08,-
10.8,0.0,11.6,20.,23.45,20.6,12.3,0.0,-10.5,-19.8,-23.45
1070 DATA 708,708,708,708,708,1998,3038,3981,2392,2565,2392,3682,2392,2014,2014
,2171,2047,2786,3004,3446,4218,2596,2974,2093
1080 DATA 1331,1331,1331,1331,1331,1331,1331,1331,544,544,544,544,544,544,544,9
06,906,1331,1331,1331,1331,1331,1331,1331
1090 DATA 0,0,0,0,0,0,2941,2941,69,69,69,69,69,69,69,69,69,69,69,1520,1520,3000
,3000,3000
1100 DATA 65,65,65,65,65,65,72,72,72,72,72,72,72,72,72,72,72,72,72,72,72,72,72,
72
1110 MAT READ Pap,Ppl,Plt,Thst
1120 PRINT "     Heat Gain Profiles  Btu/hr                         Heating"
1130 PRINT " Hour    Appliances      Lights      People          Thermostat Pro
file Deg F"
1140 PRINT "-----   -----------     -------     -------        ---------------
-------"
1150 DATA 1.0224,.9503,.9744,1.0121,1.0004,1.0316,1.1078,.9809,1.0821,.9830,.86
93,1.0706
1160 DATA 1.093,.976,.8443,1.0078,1.122,1.0674,.9133,1.021,.8638,.9056,.8845,.9
54
1170 DATA .8911,.9626,.8958,.9037,.9787,1.0049,1.0855,1.0548,.9479,.8744,.9647,
1.1239
1180 DATA .9434,1.0983,1.1632,.9472,.9873,1.2305,1.1512,.9837,1.0675,.998,1.186
6,1.0278
1190 DATA .8978,.8259,1.0913,1.0204,.9429,.8811,.853,1.1793,.9759,.995,1.0434,.
9938
1200 DATA 1.0548,1.0059,1.0259,1.0422,1.0436,1.0352,1.0338,1.0165,1.012,.9780,.
9565,1.0138
1210 MAT READ R1f,R2f,R3f,R4f,R5f,Pf
1220 FOR Z=1 TO 24
1230 PRINT TAB(2),Z;TAB(12),Pap(Z);TAB(26),Plt(Z);TAB(39),Ppl(Z);TAB(60),Thst(Z)
1240 NEXT Z
1250 DATA  6,5,4,3,2,1,6,5,4,3,2,1
1260 MAT READ Ind
1270 Fd=.8  !GLASS TRANSMITTANCE FOR DIFFUSE RADIATION
1280 DATA -.00885,2.71235,-.62062,-7.07329,9.75995,-3.89922
```

```
1290 MAT READ Trwf
1300 DATA JAN,FEB,MAR,APRIL,MAY,JUNE,JULY,AUG,SEPT,OCT,NOV,DEC
1310 READ Mn$(*)
1311 FOR T=1 TO 24
1312 Tmtp(T)=COS(15*(T-15))
1313 NEXT T
1320 Tcst=78
1330 Ina=.25
1340 Inb=.02165
1350 Inc=.00833
1360 Qhmax=99999
1370 Qcmax=-50000
1380 Detprint=0
1390 ASSIGN "Weath:T14" TO #1
1400 SHORT Tave(12),Tmax(12),Tdpa(12),Vm(12),P(12)
1410 INPUT "ENTER ID NUMBER OF DESIRED CITY ",Lo
1420 Lr=10*Lo
1430 READ #1,Lr;Lo$,L1
1440 READ #1,Lr+2;Tave(*)
1450 READ #1,Lr+3;Tmax(*)
1460 READ #1,Lr+4;Tdpa(*)
1470 READ #1,Lr+7;Vm(*)
1480 READ #1,Lr+8;P(*)
1481 READ #1,Lr+9;Pf(*)
1490 PRINT "WEATHER DATA SOURCE:";TAB(37),Lo$;LIN(1)
1500 FIXED 2
1510 DISP "REMOVE WEATHER TAPE AND INSERT LOAD STORAGE TAPE IN T14"
1520 PAUSE
1530 ASSIGN "LOADS:T14" TO #2
1540 INPUT "ENTER CITY POSITION ON LOAD TAPE",Cit
1550 Lr=(Cit-1)*370+1
1560 SHORT Load(24)
1570 PRINT #2,Lr;Lo$,L1
1580 Lr=Lr+1
1590 Cosl=COS(L1)
1600 Sinl=SIN(L1)
1610 Tcst=78
1620 Fss=.5
1630 Fsg=.5
1640 Tanl=TAN(L1)*-1
1650 Pb=2116.8*(1-Elev*6.88E-6)**5.26!  Barometric Pressure
1660 Qcy=0
1670 Qhy=0
1680 MAT Q=ZER
1690 MAT Te=ZER
1700 MAT Shmt=ZER
1710 MAT Shcl=ZER
1720 Day=0
1730 PRINT "                HEAT LOAD/LOSS SUMMARY IN THOUSAND BTU"
1740 PRINT "                                          GAR,"
1750 PRINT "                          SOLAR           DOOR"
1760 PRINT "            LOAD          THRU            AND"
1770 PRINT " MONTH   HEAT   COOL   WINDOW   ROOF   SLAB   BSMT   WALL   WNDOW   I
NFL   LATENT"
1780 PRINT " -----   ----   ----   ------   ----   ----   ----   ----   -----   -
```

```
---   ------"
1790 FOR M=1 TO 12
1800 Tand=TAN(Dec(M))
1810 Hp=ACS(Tanl*Tand)!  FIND SUN RISE HOUR ANGLE
1820 RANDOMIZE 2*PI/180/M
1830 MAT S=ZER
1840 MAT Sh=ZER
1850 Sinlsind=Sinl*SIN(Dec(M))
1860 Cosdec=COS(Dec(M))
1870 Coslcosd=Cosl*Cosdec
1880 IF Detprint=0 THEN 1900
1890 PRINT "Cosdec=";Cosdec;"Coslcosd=";Coslcosd;"Sinlsind=";Sinlsind
1900 FOR T=1 TO 24! CALC CLEAR SKY SOLAR VALUES FOR EACH HOUR OF DAY
1910 H=15*(T-12)!  FIND HOUR ANGLE FOR TIME T
1920 IF ABS(H) .GE. ABS(Hp) THEN Dark! IF SUN NOT UP OMIT SOLAR CALCS
1930 Cosh=COS(H)
1940 Sinbeta=Coslcosd*Cosh+Sinlsind
1950 Cosw=Cosdec*SIN(H)
1960 Coss=(1-Sinbeta**2-Cosw**2)**.5
1970 IF Cosh .LT. -Tand/Tanl THEN Coss=-Coss
1980 Idn=A(M)/EXP(B(M)/Sinbeta)!  DIRECT NORMAL SOLAR INTENSITY
1990 Sinb(T)=Sinbeta
2000 Idnt(T)=Idn
2010 Sh(T)=Idn*(C(M)+Sinbeta)!  TOTAL SOLAR ON HORIZONTAL SURFACE
2020 Shcl(M)=Shcl(M)+Sh(T)
2030 IF Detprint=0 THEN 2060
2040 PRINT "T=";T;"H=";H;"Cosw=";Cosw;"Coss=";Coss;"Sinbeta=";Sinbeta
2050 PRINT "Idn=";Idn;"Ids=";Ids;"Sh=";Sh(T);"Idg=";Idg
2060 FOR Saz=1 TO 4! FOR EACH AZ ANGLE FIND SOLAR ON VERTICAL SURFACE AND WINDOW
2070 Sazt=Saz+4*(T-1)
2080 Costheta=Sinaz(Saz)*Cosw+Cosaz(Saz)*Coss
2090 IF Costheta .LE. 0 THEN Shade
2100 Trw=Trwf(1)
2110 FOR Jz=1 TO 5! FIND WINDOW TRANSMITTANCE FOR BEAM RADIATION
2120 Trw=Trw+Trwf(Jz+1)*Costheta**Jz
2130 NEXT Jz
2140 Trf(Sazt)=Trw
2150 S(Sazt)=Idn*Costheta   ! TOTAL BEAM SOLAR INCIDENT ON VERTICAL SURFACE
2180 GOTO Rec
2190 Shade: S(Sazt)=Ids+Idg! TOTAL SOLAR ON SHADED VERTICAL SURFACE
2200 IF Detprint=0 THEN 2220
2210 PRINT "Saz=";Saz;"S(Sazt)=";S(Sazt);"Costheta=";Costheta
2220 Rec: NEXT Saz
2230 GOTO Endy
2240 Dark: Sh(T)=0
2250 Endy: NEXT T
2260 Qcm=0
2270 Qhm=0
2280 Mlroof=Mgroof=Mlslab=Mgslab=Mlbsmt=Mgbsmt=Mlwal=Mgwal=Mlwnd=Mgwnd=Mlinfl=M
ginfl=Mllatent=Mglatent=Msolwnd=0
2290 Pp=(Pf(M)*P(M)-.35)/.65
2300 FOR Dm=1 TO Dmo(M)
2310 R1=RND*R1f(M)
2320 R2=RND*R2f(M)
2330 R3=RND*R3f(M)
```

```
2340 R4=RND*R4f(M)
2350 R5=RND*R5f(M)
2360 Ps=1-Pp
2370 IF R1 .LT. Ps THEN Les
2380 IF R1 .GE. Ps THEN Great
2390 Les:Rs=R1*Pp/Ps*(1-COS(90*R1/Ps))
2400 GOTO End
2410 Great:Rs=Pp+Ps/90*ACS((1-R1)/Pp)
2420 End:Tavedp=Taved
2422 Tswcp=Tswc
2423 R2=.5+ABS(R2-.5)*.25*SGN(R2-.5)
2425 Taved=2*Tave(M)-Tmax(M)+2*R2*(Tmax(M)-Tave(M))
2430 Tdpad=Tdpa(M)+.5*R3*(Taved-Tave(M))
2440 Vmd=Vm(M)*(8.306*R5**3-9.95*R5**2+4.158*R5-.0763)
2450 Tswc=R1*(Tmax(M)-Tave(M))*2
2451 PRINTER IS 0
2460 Day=Day+1
2463 IF Day .GT. 1 THEN 2470
2465 Tavedp=Taved
2468 Tswcp=Tswc
2470 Cl=.65*Rs+.35
2480 Ccl=Cl*C(M)
2490 Tgrnd=Tmamb+Amgrn*SIN(Day*.986-90)! GROUND TEMP
2500 IF Detprint=0 THEN 2520
2510 PRINT "Pd=";Pd;"Rs=";Rs;"Taved=";Taved;"Vmd=";Vmd;"Tswc=";Tswc;"Idvf=";Idv
f;"Ibvf=";Ibvf;"Tgrnd=";Tgrnd;"Day=";Day
2520 FOR Tq=1 TO 4
2530 FOR K=1 TO 6
2540 T=6*(Tq-1)+K!  TIME OF DAY
2550 Rhoar=Pb/53.3/(Tair+460)!  AIR DENSITY
2560 V=Vmd*(1.5-RND)!   WIND VELOCITY
2570 IF V .LT. 0 THEN V=0
2580 Hc=.4*V**.5 ! OUTSIDE SURFACE HEAT TRANSFER COEFF
2590 IF Hc .LT. .45 THEN Hc=.45
2595 IF T .GT. 3 THEN 2605
2598 Tavd=Tavedp
2600 Tswcn=Tswcp
2602 GOTO 2610
2605 Tavd=Taved
2607 Tswcn=Tswc
2610 Tamb=Tavd+Tswcn*Tmtp(T)
2612 IF T .NE. 3 THEN 2622
2615 Tend=Tamb
2617 Dt=Tend-Taved-Tswc*Tmtp(T)
2620 Tcc=Dt/4
2622 IF T .GT. 8 THEN 2632
2625 IF T .LT. 4 THEN 2660
2627 Tamb=Tamb+Dt*(1-(T-4)/5)
2630 GOTO 2660
2632 IF T .GT. 21 THEN 2660
2635 Tamb=Tamb-Tcc
2660 Tdp=Tdpad+.25*R4*Tswcn*Tmtp(T) !   DEW POINT TEMP
2670 IF Tdp .GT. Tamb THEN Tdp=Tamb
2680 Qlatent=0
2690 Solwnd=0
```

```
2700 Sumtr=0
2710 IF Sh(T) .LE. 0 THEN 2750
2720 Scd=Idnt(T)*(Ccl+Sinb(T)*(Cl-Rs))*Fss
2730 Idg=Sh(T)*Rhog*Fsg*Cl
2740 Sd=Scd+Idg
2750 Ntp=6-K
2760 Nqp=7-K
2790 FOR Saz=1 TO 4! FOR EACH AZ ANGLE FIND HEAT TRANSFERED THRU WALLS AND WIND
OWS
2800 Sazt=Saz+4*(T-1)
2810 IF Sh(T) .LE. 0 THEN Zsol! IF SUN NOT UP OMIT SOLAR CALCS
2820 Sb=S(Sazt)*Rs
2830 Swnd=(.485*Sb*Trf(Sazt)+.685*Sd*Fd)*Awnd(Saz) ! TOTAL SOLAR THROUGH WINDOW
2840 Solwnd=Solwnd+Swnd
2850 Zsol: Sum1=0
2860 Sazm16=(Saz-1)*6
2870 Ite=Sazm16+K
2880 Sol=Sb+Sd
2890 Te(Ite)=Tamb+Alfdho*Sol! FIND SOL-AIR TEMP
2900 Nb1=Nb(Saz)
2910 FOR L=1 TO Nb1
2920 Nt=Ntp+L
2930 Idx=Ind(Nt)+Sazm16
2940 Ib=Sazm16+L
2950 Sum1=Sum1+Bn(Ib)*Te(Idx)! SUM UP B TRANSFER FUNCTION PRODUCTS
2960 NEXT L
2970 Nq2=Nd(Saz)-1
2980 FOR L=1 TO Nq2
2990 Nqq=Nqp+L
3000 Idx=Ind(Nqq)+Sazm16
3010 Id=Sazmm16+L+1
3020 Sum1=Sum1-Dn(Id)*Q(Idx)/Awll(Saz)! SUM UP D TRANSFER FUNCTION PRODUCTS
3030 NEXT L
3040 Sum1=(Sum1-Tair*Cn(Saz))*Awll(Saz)! TOTAL HEAT TRANSFER THRU WALL
3050 Sumtr=Sumtr+Sum1
3060 Q(Ite)=Sum1
3090 NEXT Saz
3100 IF Sh(T) .GT. 0 THEN Shmt(M)=Shmt(M)+Cl*Sh(T)  !SUM UP TOTAL SOLAR ON HORI
ZONTAL SURFACE
3110 Deltat=Tair-Tamb
3120 Qroof=Urf*Deltat
3130 Qslab=Slbf*Deltat+Dua*Deltat
3140 Qbsmt=Bsnf*(Tair-Tgrnd)
3150 Qgar=Gua*Deltat
3160 Qwndc=1/(1/Wndu+1/Hc)*Tawnd*Deltat
3170 Winfl=Volhs*Rhoar*(Ina+Inb*V+Inc*ABS(Deltat))! WEIGHT OF AIR INFILTRATED
3180 Qinfl=Winfl*.24*Deltat! INFILTRATION LOSS/GAIN
3190 Qppl=Ppl(T)*.6   ! SENSIBLE HEAT GAIN FOR PEOPLE
3200 Qlatent=0
3210 Qair=(Qppl+Pap(T)+Plt(T)-Qroof-Qslab-Qbsmt-Qwndc+Sumtr-Qgar)*.4-Qinfl
3220 Qbsmt=Qbsmt+Qgar
3230 Qmass=Solwnd-.6*(Qroof+Qslab+Qbsmt+Qwndc-Sumtr+Qgar-Qppl-Pap(T)-Plt(T))
3240 Tsns=(Tair+Tmass)/2!  THERMOSTAT SENSING TEMP
3250 IF Hi .GT. 0 THEN Tsns=Tsns-1 !THERMOSTAT DEAD BAND
3260 IF Hi .LT. 0 THEN Tsns=Tsns+1 !THERMOSTAT DEAD BAND
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```
3270 IF Tsns .GT. Thst(T) THEN Cool!  TEST FOR HEATING
3280 Thc=Thst(T)!  SET HEAT SOURCE TEMP FOR HEATING THEARMOSTAT
3290 Ghc=Uhc!    TURN ON FURNACE
3300 Hi=1!   SET FLAG FOR HEATING
3310 GOTO Solvt
3320 Cool: IF Tsns .LT. Tcst THEN Float!  TEST FOR COOLING
3330 Thc=Tcst!  SET SOURCE TEMP FOR COOLING THERMASTAT
3340 Ghc=Uhc!  TURN ON REFRIGERATION SYSTEM
3350 Hi=-1!   SET FLAG FOR COOLING
3360 GOTO Solvt
3370 Float: Ghc=0!  TURN OFF ALL AIR CONDITIONING EQUIPMENT
3380 Hi=0!   SET FLAG FOR NO HEATING OR COOLING
3390 Solvt: G1=(Ghc+Ga)/Ga
3400 Tmass=(Ghc*Thc+G1*(Mcp*To+Qmass)+Qair)/(G1*Mcp+Ghc)!NEW HOUSE MASS TEMP
3410 Tair=(Qair+Ghc*Thc+Ga*Tmass)/(Ghc+Ga) !  NEW HOUSE AIR TEMP
3420 Qhc=Ghc*(Thc-Tair)!  HEATING OR COOLING REQUIRED
3430 IF Hi .GT. 0 THEN Heat
3440 IF Hi .LT. 0 THEN Refrig
3450 GOTO Ok
3460 Heat: IF Qhc .LT. 0 THEN 3500
3462 IF Qhc .LE. Qhmax THEN Latent
3465 Tmass=To+(Qair+Qhmax+Qmass)/Mcp
3466 Tair=Tmass+(Qair+Qhmax)/Ga
3467 Qhc=Qhmax
3470 GOTO Latent
3500 Hi=0
3510 Ghc=0
3520 GOTO Solvt
3530 Refrig: IF Qhc .GT. 0 THEN 3570
3540 IF Qhc .GE. Qcmax THEN Latent
3545 Tmass=To+(Qair+Qcmax+Qmass)/Mcp
3550 Tair=Tmass+(Qair+Qcmax)/Ga
3551 Qhc=Qcmax
3560 GOTO Latent
3570 Hi=0
3580 Ghc=0
3590 GOTO Solvt
3600 Latent: IF Tdp .LT. 32 THEN Pv=9.65E-69*(Tdp+460)**25! FIND WATER VAPOR PRESS
3610 IF Tdp .GT. 32 THEN Pv=6.75E-50*(Tdp+460)**18
3620 Hr=.622*Pv/(Pb*.01413-Pv)!   FIND HUMIDITY RATIO
3630 IF (Hi .GT. 0) AND (Hr .LT. Hrw) THEN Qlatent=Winfl*(Hrw-Hr)*1075!  INFIL L
ATENT HEAT
3640 IF (Hi .LT. 0) AND (Hr .GT. Hrs) THEN Qlatent=Winfl*(Hrs-Hr)*1075!  INFIL L
ATENT HEAT
3650 IF Hi .LT. 0 THEN Qlatent=Qlatent-Ppl(T)*.475
3660 Ok:Load=INT(Qhc/100)
3670 Cloadl=Qlatent/100000
3680 Load(T)=Load+Cloadl
3690 Qhc=Qhc+Qlatent
3700 Qs(T)=Qhc
3710 To=Tmass!  SAVE OLD HOUSE MASS TEMP
3720 Tao=Tair!  SAVE OLD HOUSE AIR TEMP
3730 IF Qhc .LT. 0 THEN Qcm=Qcm+Qhc
3740 IF Qhc .GT. 0 THEN Qhm=Qhm+Qhc
3780 Msolwnd=Msolwnd+Solwnd
```

```
3790 IF Qroof .GT. 0 THEN Mlroof=Mlroof-Qroof
3800 IF Qroof .LT. 0 THEN Mgroof=Mgroof-Qroof
3810 IF Qslab .GT. 0 THEN Mlslab=Mlslab-Qslab
3820 IF Qslab .LT. 0 THEN Mgslab=Mgslab-Qslab
3830 IF Qbsmt .GT. 0 THEN Mlbsmt=Mlbsmt-Qbsmt
3840 IF Qbsmt .LT. 0 THEN Mgbsmt=Mgbsmt-Qbsmt
3850 Sumtr=-Sumtr
3860 IF Sumtr .GT. 0 THEN Mlwal=Mlwal-Sumtr
3870 IF Sumtr .LT. 0 THEN Mgwal=Mgwal-Sumtr
3880 IF Qwndc .GT. 0 THEN Mlwnd=Mlwnd-Qwndc
3890 IF Qwndc .LT. 0 THEN Mgwnd=Mgwnd-Qwndc
3900 IF Qinfl .GT. 0 THEN Mlinfl=Mlinfl-Qinfl
3910 IF Qinfl .LT. 0 THEN Mginfl=Mginfl-Qinfl
3920 IF Qlatent .GT. 0 THEN Mllatent=Mllatent-Qlatent
3930 IF Qlatent .LT. 0 THEN Mglatent=Mglatent-Qlatent
3940 NEXT K
3950 NEXT Tq
3960 PRINT #2,Lr;Load(*)
3970 Lr=Lr+1
4020 NEXT Dm
4021 PRINTER IS 0
4030 IMAGE X5A2X,DDDDD.,DDDDDD.
4040 PRINT USING 4030;Mn$(M),Qhm/1000,Qcm/1000
4050 IMAGE "   GAIN",15X6D.,6D.,6D.,6D.,5D.,7D.,6D.,8D.
4060 PRINT USING 4050;Msolwnd/1000,Mgroof/1000,Mgslab/1000,Mgbsmt/1000,Mgwal/10
00,Mgwnd/1000,Mginfl/1000,Mglatent/1000
4070 IMAGE "   LOSS",22X6D.,6D.,6D.,5D.,7D.,6D.,8D.
4080 PRINT USING 4070;Mlroof/1000,Mlslab/1000,Mlbsmt/1000,Mlwal/1000,Mlwnd/1000
,Mlinfl/1000,Mllatent/1000
4090 Qcy=Qcy+Qcm
4100 Qhy=Qhy+Qhm
4110 Shmt(M)=Shmt(M)/Dmo(M)
4120 NEXT M
4130 IMAGE "TOTAL  ",6D.,6D.
4140 PRINT USING 4130;Qhy/1000,Qcy/1000
4150 PRINT LIN(3),"  AVERAGE SOLAR INSOLATION ON A HORIZONTAL SURFACE"
4160 PRINT USING "9X,12(5A)";Mn$(*)
4170 IMAGE "CLEAR",4X,12(5D)
4180 PRINT USING 4170;Shcl(*)
4190 IMAGE "PREDICTED",12(5D)
4200 PRINT USING 4190;Shmt(*)
4210 END
```

```
5    REM ***************PROGRAM INPUT **************************
6    REM THIS PROGRAM LOADS THE INPUT DATA FOR THE HPUMP PROGRAM
30   OPTION BASE 1
40   STANDARD
43   COM Qevapx,Qcondx,Qelecx,Way4,Ton,Ua3o,Ua4o,Kfwo,Kfgo,Tw3,Tg3,Td1,Frach,Fr
acd,Exf,Expuad,Ao1,Ao2,Ao3,Bo1,Bo2,Bo3,Co1,Co2,Co3,Do1,Do2,Do3,Eo1,Eo2,Eo3
44   COM Fo1,Fo2,Fo3,Go1,Go2,Go3,Ho1,Ho2,Ho3,Io1,Io2,Io3,Tf5x,Qevapxs,Tf4xs,Kfd
,Qdhw,Qa5,Fracc,W,Ao4,Bo4,Co4,Do4,Eo4,Fo4,Go4,Ho4,Io4
45   COM Tout(20),Tout1(20),Qf1(20),R1f(12),R2f(12),R3f(12),R4f(12),R5f(12),Trw
f(16),S(96),Sh(25),Sinb(24),Idnt(24),Trf(24),A(12),B(12),C(12),Dmo(13),Dec(12)
46   COM Mn$(12),Use(24),SHORT Tave(12),Tmax(12),Tdpa(12),Ttap(12),Vm(12),P(12)
,Pf(12),Load(24)
47   COM REAL Lo,Lr,Pamb,Tavyr,Opt1,Ua,Pf1,Dhw$,G,Gdhw,Cdhw,Tw,W1$,Twell,Qevap,
Qelec,Qcond,Cfm,Kfgwd,Ua1o,Ua34,Cfmo,Cfmi,Ua2o,Ua5o,Ua6h,Hum,Fua3,Qfan6,Qfan1
48   COM Kfdo,Rhx2,Hxf,Kfax,Opt2,Tilt,Ac,S,Sto$,Vs,Vst,Mcpsto,Tsto,Gnd$,Ua7o,Ff
4,Mcpgf,Tgnd,Lgnd,Dgnd,Do,Di,Rhognd,Cpgnd,Kpgnd,Depth,Apgnd,Qpumpo
49   COM Vpgnd,Mu,Rfilm,Rpvc,C1,R1,Delr,R2,R3,R4,R5,R6,R7,R8,R9,R10,R11,R12,R13
,Cf,C2,C4,C6,C8,C10,C12,Gf,G1x,G2,G3,G4,G5,G6,Tgn(12),Tgnx,Dz,Dpt,Lag,Col$(20)
50   DEG
90 Hpx:  PRINT LIN(2);TAB(18),"SOLAR/HEAT PUMP STUDY WITH LOW COST SOLAR COLLEC
TORS"
100  PRINT TAB(18),"----------------------------------------------------";LIN(2)
110  BEEP
120  DISP "INSERT 'Weath FILE #1' IN T14"
130  PAUSE
140  Day=0
150  Rhog=.2
160  Fd=.9
190  RESTORE 210
200  MAT READ Trwf
210  DATA .00001,3.0695,-3.671,1.4269,.39411,-.31951
240  RESTORE 260
250  MAT READ A,B,C,Dmo,Dec
260  DATA 390,385,376,360,350,345,344,351,365,378,387,391,.142,.144,.156,.18,.1
96,.205,.207,.201,.177,.16,.149,.142,.058,.06,.071,.097,.121,.134,.136
270  DATA .122,.092,.073,.063,.057,31,28,31,30,31,30,31,31,30,31,30,31,365,-20.
08,-10.8,0.0,11.6,20.,23.45,20.6,12.3,0.0,-10.5,-19.8,-23.45
280  DATA JAN,FEB,MAR,APRIL,MAY,JUNE,JULY,AUG,SEPT,OCT,NOV,DEC
290  READ Mn$(*)
300  RESTORE 320
310  MAT READ R1f,R2f,R3f,R4f,R5f
320  DATA 1.0224,.9503,.9744,1.0121,1.0004,1.0316,1.1078,.9809,1.0821,.983,.869
3,1.0706
330  DATA 1.093,.976,.8443,1.0078,1.122,1.0674,.9133,1.021,.8638,.9056,.8845,.954
340  DATA .8911,.9626,.8958,.9037,.9787,1.0049,1.0855,1.0548,.9479,.8744,.9647,
1.1239
350  DATA .9434,1.0983,1.1632,.9472,.9873,1.2305,1.1512,.9837,1.0675,.998,1.186
6,1.0278
360  DATA .8978,.8259,1.0913,1.0204,.9429,.8811,.853,1.1793,.9759,.995,1.0434,.
9938
380  RESTORE 400
390  MAT READ Use
400  DATA 0,0,0,0,0,0,.07,.07,.15,.07,.05,.04,.05,.08,.08,.02,.03,.04,.04,.1,.0
7,.04,0,0
410  ASSIGN "Weath:T14" TO #1
```

```
430  INPUT "ENTER ID NUMBER OF DESIRED CITY; ENTER U IF UNLISTED",Lo
440  Lr=10*Lo
450  READ #1,Lr;Lo$,L
460  READ #1,Lr+2;Tave(*)
470  READ #1,Lr+3;Tmax(*)
480  READ #1,Lr+4;Tdpa(*)
490  READ #1,Lr+5;Ttap(*)
500  READ #1,Lr+7;Vm(*)
510  READ #1,Lr+8;P(*)
520  READ #1,Lr+9;Pf(*)
530  PRINT "WEATHER DATA SOURCE:";Lo$
540  INPUT "ENTER THE LOCAL AMBIENT PRESSURE ,PSI",Pamb
550  PRINT "LOCAL AMBIENT PRESSURE =";Pamb;"psi (for psychrometric calculations)"
560  Tavyr=0!
570  FOR Tt=1 TO 12
580  Tavyr=Tavyr+Tave(Tt)/12
590  NEXT Tt
620  PRINTER IS 16
630  PRINT PAGE
640  PRINT "  OPTION 1: HOME HEAT LOSS/GAIN COMPUTED FROM UA FACTOR";LIN(2)
650  PRINT "  OPTION 2: HOME HEAT LOSS/GAIN READ FROM PRE-TAPED INPUT"
660  INPUT "ENTER HEAT LOAD OPTION, 1 OR 2",Opt1
670  PRINT PAGE
680  PRINTER IS 0
690  IF Opt1=2 THEN 750
700  FIXED 2
710  INPUT "ENTER UA - Btu/Hr/Deg F",Uaload
720  PRINT "SPACE HEATING LOSS FACTOR UA =";Uaload;"Btu/hr-deg-F"
730  INPUT "ENTER SPACE HEATING PROPORTIONALITY FACTOR",Pf1
740  PRINT "SPACE HEATING PROP FACTOR =";Pf1
750  Dhw=0
760  INPUT "DOES SOLAR/HEAT PUMP HEAT DHW - Y/N ?",Dhw$
770  IF UPC$(Dhw$)="N" THEN G=0
780  IF UPC$(Dhw$)="Y" THEN PRINT "HEAT PUMP ASSISTS WITH DHW "
790  IF UPC$(Dhw$)="N" THEN PRINT "HEAT PUMP DOES NOT ASSIST WITH DHW "
800  IF UPC$(Dhw$)="N" THEN 930
810  INPUT "ENTER DHW GALLONS PER DAY ",G
820  PRINT "DHW GALLONS PER DAY =";G;"gal/day"
830  INPUT "ENTER DHW TANK SIZE, GALLONS ",Gdhw
840  PRINT "DHW TANK SIZE =";Gdhw;"gallons"
850  Cdhw=62.4*Gdhw/7.481
860  INPUT "ENTER DESIRED HOT WATER TEMP - Deg F",Tw
870  PRINT "HOT WATER DELIVERY TEMPERATURE =";Tw;"deg-F"
880  INPUT "ENTER 'W' IF WELL WATER ;'M' IF MUNICIPAL",Wl$
890  IF UPC$(Wl$)="M" THEN 930
900  INPUT "WELL WATER TEMP = DEG-F",Twell
910  PRINT "WELL WATER TEMP =";Twell;"deg-F"
930  INPUT "ENTER HEAT PUMP CAPACITY - TONS (2, 2.5,OR 3 TON)",Ton
940  PRINT "HEAT PUMP SIZE =";Ton;"ton unit"
950  Qevap=10000*Ton
960  Qelec=3500*Ton
970  Qcond=13500*Ton
980  IF Ton=2 THEN RESTORE 1020
990  IF Ton=2.5 THEN RESTORE 1030
1000 IF Ton=3 THEN RESTORE 1040
```

```
1010 READ Ao1,Bo1,Co1,Do1,Eo1,Fo1,Go1,Ho1,Io1,Ao2,Bo2,Co2,Do2,Eo2,Fo2,Go2,Ho2,I
o2,Cfm,Kfgwd,Ua1o,Ua34,Qfan6
1020 DATA 30467,-281.4,.6949,131.4,3.166,-.01806,12.48,-.1066,.0003061,7014,-41
 .34,.2002,-318.5,5.962,-.02027,3.010,-.05638,.0002264,1200,2966,1400,1866,137
1030 DATA 37460,-348.2,.8561,-293.0,11.2,-.05341,18.48,-.1821,.0005914,8261,-47
 .87,.2134,-355.2,7.025,-.02531,3.481,-.0699,.0003073,1500,3708,1750,2172,171
1040 DATA 33064,-198.2,.04768,323.6,1.513,-.01232,8.569,.03652,-.0004321,10132,
-57.67,.2333,-410.1,8.62,-.03287,4.188,-.09016,.0004288,1800,4450,2100,2666,206
1050 RESTORE 1070
1060 READ Ao3,Bo3,Co3,Do3,Eo3,Fo3,Go3,Ho3,Io3,Ao4,Bo4,Co4,Do4,Eo4,Fo4,Go4,Ho4,I
o4
1070 DATA -749.1,2.049,.01322,8.197,-.02691,-.126E-3,-.009312,.8925E-4,.3156E-6
1080 DATA 95.64,.176,-.002156,.1971,-8.35E-4,9.568E-6,1.149E-7,9.637E-7,-1.18E-8
1090 Kfgo=Kfwo=Kfdo=Kfg=Kfw=Kfd=Kfgwd
1100 Cfmo=Cfmi=Cfm
1101 Qfan1=Qfan6
1102 Qpumpo=.14810*Kfgwd
1110 Ua1=Ua1o
1120 Ua2=Ua2o=900*Ton
1130 Ua3=Ua4=Ua3o=Ua4o=Ua34
1140 Ua5=Ua5o=Ua1o
1150 Ua6h=Ua1o
1160 Way4=0
1170 INPUT "ENTER 1 IF A 4-WAY VALVE IS USED, IF NONE THEN PRESS CONT",Way4
1180 IF Way4=0 THEN PRINT "NO 4-WAY VALVE IS USED, HEATING-ONLY HEAT PUMP"
1190 IF Way4=1 THEN PRINT "A 4-WAY VALVE IS USED, i.e., A REVERSING HEATING/COO
LING HEAT PUMP IS USED"
1200 Hum=0
1210 INPUT "ENTER 1 IF HOME IS HUMIDIFIED IN WINTER",Hum
1220 IF Hum=1 THEN PRINT "HOME IS HUMIDIFIED IN WINTER"
1230 IF Hum=0 THEN PRINT "HOME IS NOT HUMIDIFIED IN WINTER"
1250 Fua3=Fua4=0
1260 INPUT "ENTER 1 IF THE Ua3 HEAT EXCHANGER IS IN THE SYSTEM",Fua3
1270 Ua3o=Ua3=Fua3*Ua3o
1280 IF Fua3=1 THEN 1300
1290 IF Fua3=0 THEN Fua4=1
1300 Ua4o=Ua4=Fua4*Ua4o
1310 PRINTER IS 0
1320 FIXED 0
1330 PRINT "HEAT EXCHANGER UA FACTORS:"
1340 PRINT "  Ua1 = COLLECTOR GLYCOL-TO-AIR HEAT REJECTION HX UA FACTOR =";Ua1o
;"Btu/hr-deg-F"
1350 PRINT "  Ua2 = COLLECTOR GLYCOL-TO-WATER LOOP HX UA FACTOR =";Ua2o;"Btu/hr
-deg-F"
1360 PRINT "  Ua3 = COLLECTOR GLYCOL-TO-FREON LOOP HX UA FACTOR =";Ua3o;"Btu/hr
-deg-F"
1370 PRINT "  Ua4 = WATER LOOP-TO-FREON LOOP HX UA FACTOR =";Ua4o;"Btu/hr-deg-F"
1380 PRINT "  Ua5 = DHW LOOP-TO-FREON DESUPERHEAT HX UA FACTOR =";Ua5o;"Btu/hr-
deg-F"
1390 PRINT "  Ua6h= HOUSE AIR-TO-FREON CONDENSING HX UA FACTOR =";Ua6h;"Btu/hr-
deg-F"
1400 PRINT "  Ua6c= HOUSE AIR-TO-FREON EVAPORATING HX UA FACTOR IS COMPUTED WHE
N APPLICABLE"
1420 PRINT "THERMAL MASS FLOW RATES:"
1430 PRINT "  Kfg = GLYCOL LOOP Cp*MASS FLOW PRODUCT =";Kfgo;"Btu/hr-deg-F"
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1440 PRINT "  Kfw = WATER LOOP Cp*MASS FLOW PRODUCT =";Kfwo;"Btu/hr-deg-F"
1450 PRINT "  Kfd = DHW WATER LOOP Cp*MASS FLOW PRODUCT =";Kfdo;"Btu/hr-deg-F"
1460 PRINT "CFM FOR OUTSIDE AIR (HEAT REJECTION) FAN =";Cfmo;"cfm"
1470 PRINT "CFM FOR INSIDE AIR DUCT FAN =";Cfmi;"cfm"
1481 IF ABS((Kfgo-Kfwo)/Kfgo) .GT. .03 THEN 1484
1482 Rhx2=Ua2o/(1+Ua2o/Kfgo)
1483 GOTO 1488
1484 Hxf=EXP(Ua2o*(1/Kfgo-1/Kfwo))
1485 Rhx2=Kfgo*(1-Hxf)/(Kfgo/Kfwo-Hxf)
1488 Kfax=38.95*Cfmo*Pamb  !Cfmo*Pamb*60*.075*.24/14.696
1490 PRINTER IS 16
1500 PRINT PAGE
1510 PRINT "OPTION 1: SOLAROLL COLLECTOR";LIN(3)
1530 PRINT "OPTION 3: MIROMIT MODEL 210 COLLECTOR";LIN(3)
1550 INPUT "ENTER TYPE OF COLLECTOR,1,2,3,OR 4",Opt2
1560 PRINT PAGE
1570 PRINTER IS 0
1580 IF Opt2=1 THEN PRINT "COLLECTOR CONFIGURATION IS THE SOLAROLL CONCEPT"
1600 IF Opt2=3 THEN PRINT "COLLECTOR CONFIGURATION IS THE MIROMIT CONCEPT"
1630 FIXED 1
1640 INPUT "ENTER COLLECTOR TILT",Tilt
1650 PRINT "COLLECTOR TILT =";Tilt;"deg"
1660 INPUT "ENTER COLLECTOR AREA, SQ-FT",Ac
1670 PRINT "COLLECTOR AREA =";Ac;"sq-ft"
1671 INPUT "ENTER SMALLEST DIMENSION OF COLLECTOR ARRAY ,FT",S
1672 PRINT "SMALLEST DIMENSION OF COLLECTOR ARRAY = ";S;"FT"
1680 INPUT "ENTER COLLECTOR AZIM (0 IS SOUTH , WEST OF SOUTH IS POSITIVE)",Az
1690 PRINT "COLLECTOR AZIMUTH ANGLE =";Az;"deg"
1710 INPUT "IS A WATER STORAGE TANK USED ? - Y/N",Sto$
1720 IF UPC$(Sto$)="N" THEN Vs=Mcpsto=Tsto=0
1730 IF UPC$(Sto$)="N" THEN 1820
1740 PRINTER IS 0
1750 INPUT "ENTER STORAGE TANK VOLUME, GALLONS",Vst
1760 PRINT "STORAGE TANK VOLUME =";Vst;"gallons"
1770 Vs=Vst/7.481
1780 Mcpsto=62.4*Vs
1790 INPUT "ENTER INITIAL STORAGE TEMPERATURE, DEG-F",Tsto
1800 PRINT "INITIAL STORAGE TEMPERATURE =";Tsto;"deg-F"
1820 INPUT "IS GROUND COUPLING EMPLOYED, Y/N",Gnd$
1830 IF UPC$(Gnd$)="N" THEN Ua7=Ua7o=Ff4=Mcpgf=0
1840 IF UPC$(Gnd$)="N" THEN Tgnd=-100
1850 IF UPC$(Gnd$)="N" THEN 2840
1860 INPUT "ENTER LENGTH OF UNDERGROUND PIPE NETWORK, FEET",Lgnd
1870 PRINT "LENGTH OF UNDERGROUND PIPE NETWORK =";Lgnd;"ft"
1880 INPUT "ENTER DIAMETER OF UNDERGROUND PIPE, INCHES",Dgnd
1890 FIXED 3
1900 IF Dgnd=1 THEN 1970
1910 IF Dgnd=1.5 THEN 2000
1920 IF Dgnd=2 THEN 2030
1930 IF Dgnd=2.5 THEN 2060
1940 IF Dgnd=3 THEN 2090
1950 IF Dgnd=4 THEN 2120
1960 IF Dgnd=6 THEN 2150
1970 Do=1.315
1980 Di=1.195
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1990 GOTO 2170
2000 Do=1.900
2010 Di=1.740
2020 GOTO 2170
2030 Do=2.375
2040 Di=2.175
2050 GOTO 2170
2060 Do=2.875
2070 Di=2.635
2080 GOTO 2170
2090 Do=3.500
2100 Di=3.220
2110 GOTO 2170
2120 Do=4.500
2130 Di=4.100
2140 GOTO 2170
2150 Do=6.625
2160 Di=6.065
2170 PRINT "PVC UNDERGROUND PIPE DIAMETERS:  O.D.= ";Do;"inches   I.D.=";Di;"inc
hes"
2180 INPUT "ENTER DENSITY OF SURROUNDING SOIL, LB/CUBIC FT",Rhognd
2190 FIXED 1
2200 PRINT "DENSITY OF SURROUNDING SOIL =";Rhognd;"lb/cubic-ft"
2210 FIXED 4
2220 INPUT "ENTER SPECIFIC HEAT OF SURROUNDING SOIL, BTU/LB-DEG-F",Cpgnd
2230 PRINT "SPECIFIC HEAT OF SURROUNDING SOIL =";Cpgnd;"Btu/lb-deg-F"
2240 INPUT "ENTER CONDUCTIVITY OF SURROUNDING SOIL, BTU-FT/HR-DEG-F-SQFT",Kpgnd
2250 PRINT "CONDUCTIVITY OF SURROUNDING SOIL =";Kpgnd;"Btu-ft/hr-deg-F-sqft"
2260 FIXED 2
2270 INPUT "ENTER DEPTH OF PIPE NETWORK, FEET",Depth
2280 PRINT "DEPTH OF PIPE NETWORK =";Depth;"ft"
2290 INPUT "ENTER AVG. ANNUAL SOIL TEMPERATURE AT PIPE LEVEL, DEG-F",Tgnd
2300 PRINT "AVERAGE ANNUAL SOIL TEMPERATURE AT PIPE LEVEL =";Tgnd;"Deg-F"
2310 Apgnd=PI*Di**2/576
2320 Vpgnd=Kfw/(62.4*Apgnd)
2330 Mu=(1.73338E-3-2.30567E-5*Tgnd+1.2761E-7*Tgnd**2-2.53372E-10*Tgnd**3)*3600
2340 Rey=62.4*Di*Vpgnd/(12*Mu)
2350 IF Rey .LT. 2100 THEN Hgndf=7.098*(Kfw/.338/Lgnd)**.333 ! McADAMS P.232
2360 IF Rey .GT. 2100 THEN Hgndf=.2007*Rey**.8/Di
2370 Rfilm=12/(PI*Di*Lgnd*Hgndf)
2380 Rpvc=LOG(Do/Di)/(2*PI*.12*Lgnd)
2390 Ua7=Ua7o=1/(Rfilm+Rpvc)
2400 C1=PI*Di**2*Lgnd*62.4/576     ! THERMAL MASS OF FLUID IN PIPE
2410 R1=Do/24
2420 Delr=(Depth-R1)/12
2430 R2=R1+Delr
2440 R3=R2+Delr
2450 R4=R3+Delr
2460 R5=R4+Delr
2470 R6=R5+Delr
2480 R7=R6+Delr
2490 R8=R7+Delr
2500 R9=R8+Delr
2510 R10=R9+Delr
2520 R11=R10+Delr
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2530 R12=R11+Delr
2540 R13=R12+Delr
2550 Cf=Rhognd*Cpgnd*Lgnd*PI
2560 C2=Cf*(R3**2-R1**2)
2570 C4=Cf*(R5**2-R3**2)
2580 C6=Cf*(R7**2-R5**2)
2590 C8=Cf*(R9**2-R7**2)
2600 C10=Cf*(R11**2-R9**2)
2610 C12=Cf*(R13**2-R11**2)
2620 Gf=2*PI*Kpgnd*Lgnd
2630 G1x=Gf/LOG(R2/R1)
2640 G2=Gf/LOG(R4/R2)
2650 G3=Gf/LOG(R6/R4)
2660 G4=Gf/LOG(R8/R6)
2670 G5=Gf/LOG(R10/R8)
2680 G6=Gf/LOG(R12/R10)
2700 FOR M=1 TO 12
2710 Tgnx=Tave(M)/5
2720 Dz=45.0
2730 Dpt=Depth-R13*COS(Dz)
2740 Lag=INT(Dpt**.5)
2750 IF Lag=0 THEN Lag=1
2760 IF M .GT. Lag THEN Tgn=Tgnd+3*(Tave(M-Lag)-Tavyr)/(Dpt+1)
2770 IF M .LT. Lag+1 THEN Tgn=Tgnd+3*(Tave(M+12-Lag)-Tavyr)/(Dpt+1)
2780 Tgnx=Tgnx+Tgn/5
2790 Dz=Dz+45.0
2800 IF Dz .GT. 180 THEN 2820
2810 GOTO 2730
2820 Tgn(M)=Tgnx    ! AVG GROUND TEMP AROUND CIRCUM BOUNDRY
2830 NEXT M
2840 LOAD "HPUMP"
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```
1     REM ************** PROGRAM HPUMP ************************
5     REM THIS PROGRAM SIMULATES A LIQUID SOURCE SOLAR ASSISTED HEAT PUMP
10    REM INPUT FOR THIS PROGRAM IS SUPPLIED BY PROGRAM "INPUT" WHICH HAS TO BE
20    REM EXECUTED BEFORE ATTEMPTING TO RUN THIS PROGRAM
30    OPTION BASE 1
40    DIM Qgsum(5),Tg4(5),Qwsum(5),Tw1(5),Tmtp(24)
45    COM Qevapx,Qcondx,Qelecx,Way4,Ton,Ua3o,Ua4o,Kfwo,Kfgo,Tw3,Tg3,Td1,Frach,Fra
cd,Exf,Expuad,Ao1,Ao2,Ao3,Bo1,Bo2,Bo3,Co1,Co2,Co3,Do1,Do2,Do3,Eo1,Eo2,Eo3
50    COM Fo1,Fo2,Fo3,Go1,Go2,Go3,Ho1,Ho2,Ho3,Io1,Io2,Io3,Tf5x,Qevapxs,Tf4xs,Kfd,
Qdhw,Qa5,Fracc,W,Ao4,Bo4,Co4,Do4,Eo4,Fo4,Go4,Ho4,Io4
55    COM Tout(20),Tout1(20),Qf1(20),R1f(12),R2f(12),R3f(12),R4f(12),R5f(12),Trwf
(16),S(96),Sh(25),Sinb(24),Idnt(24),Trf(24),A(12),B(12),C(12),Dmo(13),Dec(12)
60    COM Mn$(12),Use(24),SHORT Tave(12),Tmax(12),Tdpa(12),Ttap(12),Vm(12),P(12),
Pf(12),Load(24)
65    COM REAL Lo,Lr,Pamb,Tavyr,Opt1,Ua,Pf1,Dhw$,G,Gdhw,Cdhw,Tw,W1$,Twell,Qevap,Q
elec,Qcond,Cfm,Kfgwd,Ua1o,Ua34,Cfmo,Cfmi,Ua2o,Ua5o,Ua6h,Hum,Fua3,Qfan6,Qfan1
70    COM Kfdo,Rhx2,Hxf,Kfax,Opt2,Tilt,Ac,S,Sto$,Vs,Vst,Mcpsto,Tsto,Gnd$,Ua7o,Ff4
,Mcpgf,Tgnd,Lgnd,Dgnd,Do,Di,Rhognd,Cpgnd,Kpgnd,Depth,Apgnd,Qpumpo
75    COM Vpgnd,Mu,Rfilm,Rpvc,C1,R1,Delr,R2,R3,R4,R5,R6,R7,R8,R9,R10,R11,R12,R13,
Cf,C2,C4,C6,C8,C10,C12,Gf,G1x,G2,G3,G4,G5,G6,Tgn(12),Tgnx,Dz,Dpt,Lag,Col$(20)
78    PRINTER IS 0
80    DEG
81    Runct=0
82    FOR T=1 TO 24
83    Tmtp(T)=COS(15*(T-15))
84    NEXT T
85    INPUT "TOTAL DAILY ENERGY FOR LIGHTS AND APPLIANCES IN BTU",Qlappl
86    PRINT "TOTAL DAILY ENERGY FOR LIGHTS AND APPLIANCES IN BTU= ";Qlappl
87 Tapeload:  BEEP
88    DISP "REMOVE PROGRAM CASSETT FROM T15. INSERT LOAD FILE IN T15
            REMOVE WEATHER TAPE FROM T14. INSERT RESULT TAPE IN T14"
89    PAUSE
90    ASSIGN "LOADS:T15" TO #2
91    INPUT "ENTER CITY POSITION ON LOAD TAPE",Cit
92    ASSIGN "RESLTS:T14" TO #3
93    INPUT "ENTER POSITION ON RESULTS TAPE",Citr
108   Hloady=Cloady=Qdhwly=Qelecy=Qreshy=Qresdy=Qpumpy=Qfany=Qa7cy=Qa7ry=Qcolly=Q
collry=Qaly=Yflag=Losty=Qfanly=0
109   Runct=Runct+1
115   Tgn2=Tgn4=Tgn6=Tgn8=Tgn10=Tgn12=Twpipe=Tgn(1)
120   IF UPC$(Sto$)="N" THEN Tsto=Twpipe
125   IF Ua3o .GT. 0 THEN Expuak=EXP(Ua3o/Kfgo)
130   IF Ua3o .GT. 0 THEN Expuak=EXP(Ua3o/Kfgo)
140   Exf=1/Expuak-1
145   IF Ua5o .GT. 0 THEN Expuad=EXP(Ua5o/Kfdo)
150   Tw1=Tw2=Tw3=Tw4=Tw1p=Tsto
155   Tg1=Tg2=Tg3=Tg4=Tend=Tabs=Tave(1)
160   Tf1=170
165   Tf2=140
170   Tf3=135
175   Tf4=Tf4x=140
180   Tf5=Tf5x=25
185   Tf6=25
190   Rsf=1.713E-9*.9*.5*(1+COS(Tilt))
195   Rgf=1.713E-9*.81*(1-.5*(1+COS(Tilt)))
```

```
197  Rhoads=.075*Pamb/14.7/S
200  IF Ua7o=0 THEN 202
201  G1=1/(1/Ua7o+1/G1x+1/Kfwo)
202  Time1=C1/Kfwo
203  Cpipe=C1/Time1
204  IF Cpipe .LT. C1 THEN Cpipe=C1
205  Qevap=Qcond=Qevapx=Qcondx=14000*Ton
210  Ua6=800*Ton
215  Tdhw=Td1=Tw
255  Lr=(Cit-1)*370+1
260  READ #2,Lr;Lo$,L1
265  PRINT "LOAD DATA FOR HOME IN ";Lo$
266  Lrrr=(Citr-1)*14+1
270  PRINT #3,Lrrr;Lo$,Ac,Opt2,Mcpsto,Lgnd
271  PRINT "Ac=";Ac;"Opt2=";Opt2;"Mcpsto=";Mcpsto;"Lgnd=";Lgnd;"Citr=";Citr
280 Rndweath: Cos1=COS(L1)
285  Sin1=SIN(L1)
290  Tan1=TAN(L1)*-1
295  Crejc=Hrejc=0
300  Lbsair=25000*.075*Pamb/14.696
305  Day=0
310  FOR M=1 TO 12
315  Cloadtm=Hloadm=Qdhw1m=Qelecm=Qreshm=Qresdm=Qpumpm=Qa7cm=Qa7rm=Qcollm=Qcollr
m=Qa1m=Qfanm=Qclnmt=Lntmt=Lostm=Qpim=Qstom=0
320  Tgn=Tgn(M)
325  RANDOMIZE 2*PI/180/M
330  Tand=TAN(Dec(M))
335  Hp=ACS(Tan1*Tand)
340  MAT S=ZER
345  MAT Sh=ZER
350  Sin1sind=Sin1*SIN(Dec(M))
355  Cosdec=COS(Dec(M))
360  Cos1cosd=Cos1*Cosdec
365  Fsg=(1-COS(Tilt))/2
370  Fss=1-Fsg
375  FOR T=1 TO 24
380  H=15*(T-12)
385  IF ABS(H) .GE. ABS(Hp) THEN Dark
390  Cosh=COS(H)
395  Sinbeta=Cos1cosd*Cosh+Sin1sind
400  Cosw=Cosdec*SIN(H)
405  Coss=(1-Sinbeta**2-Cosw**2)**.5
410  IF Cosh .LT. -Tand/Tan1 THEN Coss=-Coss
415  Idn=A(M)/EXP(B(M)/Sinbeta)
420  Sinb(T)=Sinbeta
425  Idnt(T)=Idn
430  Sh(T)=Idn*(C(M)+Sinbeta)
435  Sinwt=SIN(Tilt)
440  Costheta=COS(Tilt)*Sinbeta+SIN(Az)*Sinwt*Cosw+COS(Az)*Sinwt*Coss
445  IF Costheta .LE. 0 THEN Shade
450  Trw=Trwf(1)
455  FOR Jz=1 TO 5
460  Trw=Trw+Trwf(Jz+1)*Costheta**Jz
465  NEXT Jz
470  Trf(T)=Trw
```

```
475  S(T)=Idn*Costheta
480  GOTO Endy
485 Shade:  S(T)=0
490  GOTO Endy
495 Dark:  Sh(T)=0
500 Endy:  NEXT T
505  Pp=(Pf(M)*P(M)-.35)/.65
510  FOR Dm=1 TO Dmo(M)
515  Lr=Lr+1
520  R1=RND*R1f(M)
525  R2=RND*R2f(M)
530  R3=RND*R3f(M)
535  R4=RND*R4f(M)
540  R5=RND*R5f(M)
545  Ps=1-Pp
550  IF R1 .GT. Ps THEN Great
555 Les: Rs=R1*Pp/Ps*(1-COS(90*R1/Ps))
560  GOTO End
565 Great: Rs=Pp+Ps/90*ACS((1-R1)/Pp)
570 End: Tavedp=Taved
575  Tswcp=Tswc
580  R2=.5+ABS(R2-.5)*.25*SGN(R2-.5)
585  Taved=2*Tave(M)-Tmax(M)+2*R2*(Tmax(M)-Tave(M))
590  Tdpad=Tdpa(M)+.5*R3*(Taved-Tave(M))
595  Vmd=Vm(M)*(8.306*R5**3-9.95*R5**2+4.158*R5-.0763)
600  Tswc=R1*(Tmax(M)-Tave(M))*2
605  Day=Day+1
610  IF Day .GT. 1 THEN 625
615  Tavedp=Taved
620  Tswcp=Tswc
625  Cl=.65*Rs+.35
626  Rsfcl=Rsf*Cl
627  Rsfprgf=Rsfcl+Rgf+1.38753E-9
630  Ccl=Cl*C(M)
635  IF Opt1=1 THEN 665
640  READ #2,Lr;Load(*)
670  FOR T=1 TO 24
675  Twl=Tsto
676  Tf5x=Tf5
680  Qevap=Qcond=Qevapx=Qcondx=14000*Ton
685  Qsto=0
690  Vmph=Vmd*(1.5-RND)
695  IF Vmph .LT. 0 THEN Vmph=0
700  Hc=4.25*(Rhoads*V)**.5
705  IF Hc .LT. .45 THEN Hc=.45
710  IF T .GT. 3 THEN 730
715  Tavd=Tavedp
720  Tswcn=Tswcp
725  GOTO 740
730  Tavd=Taved
735  Tswcn=Tswc
740  Tamb=Tavd+Tswcn*Tmtp(T)
745  IF T .NE. 3 THEN 765
750  Tend=Tamb
755  Dt=Tend-Taved-Tswc*Tmtp(T)
```

```
760  Tcc=Dt/4
765  IF T .GT. 8 THEN 785
770  IF T .LT. 4 THEN 795
775  Tamb=Tamb+Dt*(1-(T-4)/5)
780  GOTO 795
785  IF T .GT. 21 THEN 795
790  Tamb=Tamb-Tcc
795  Kfaxm=Kfax/(Tamb+460)
800  Hxf=EXP(Ualo*(1/Kfgo-1/Kfaxm))
805  Rhxlh=Kfgo*(1-Hxf)/(Kfgo/Kfaxm-Hxf)
810  Rhxll=.020*Rhxlh
815  Tsky=((Tamb+460)**4-2.14E10)**.25-460
820  Tdp=Tdpad+.25*R4*Tswcn*Tmtp(T)
825  IF Tdp .GT. Tamb THEN Tdp=Tamb
830  IF Sh(T) .LE. 0 THEN Sol=Swnd=0
835  IF Sh(T) .LE. 0 THEN 880
840  Sb=S(T)*Rs
845  Scd=Idnt(T)*(Ccl+Sinb(T)*(Cl-Rs))*Fss
850  Idg=Sh(T)*Rhog*Fsg*Cl
855  Sd=Scd+Idg
860  Swnd=Sb*Trf(T)+Sd*Fd
865  Sol=Sb+Sd
880  Hload=Cloads=Cloadl=Cloadt=Qresd=Qresh=Tcload=Qa5=Qa5o=0
885  IF Load(T)=0 THEN 920
890  IF Load(T) .GT. 0 THEN Hload=INT(Load(T)*100)+FRACT(Load(T))*Hum*100000
895  IF Load(T) .LT. 0 THEN Cloads=-INT(Load(T)*100)
900  IF Load(T) .LT. 0 THEN Cloadl=FRACT(ABS(Load(T)))*100000
904  IF Load(T) .GT. 0 THEN Qclnmt=Qclnmt+Qball+Qbals
905  IF Load(T) .GT. 0 THEN Qball=Qbals=0
906  Tcload=Cloadl+Cloads
914  IF Hload=0 THEN 917
915  Hload=Hload-Losts
916  Hloadm=Hloadm+Losts
917  IF Cloads=0 THEN 919
918  Cloads=Cloads+Losts
919  IF (Hload .GT. 0) OR (Cloads .GT. 0) THEN Losts=0
920  IF Hload .GT. 0 THEN 925
922  Cloadl=Cloadl+Qball
923  Cloads=Cloads+Qbals
924  Qbals=Qball=0
925  Cloadt=Cloads+Cloadl
926  Losx=Qa5o=0
1030 Kfd=Ua5=0
1035 Tds=Ttap(M)
1045 Qdhwl=Use(T)*8.24*G*(Tw-Tds)
1050 Qdhw2=Cdhw*(Tw-Tdhw)
1055 IF Qdhw2 .LT. 0 THEN Qdhw2=0
1060 Qdhw=Qdhwl+Qdhw2
1065 IF Qdhw .GT. 0 THEN Ua5=Ua5o
1070 IF Qdhw .GT. 0 THEN Kfd=Kfdo
1075 Qfrz=Kfwo*(Tw3-Twl+Tstop-33)
1080 Frach=MIN(Hload/(12000*Ton),1)
1085 Fracd=MIN(Qdhw/(12000*Ton),1,1-Frach)
1090 Frac=MIN(Frach+Fracd,1)
1095 Fracc=MIN(Cloadt/(14000*Ton),1)
```

```
1100 IF Tdhw .GT. 150 THEN Fracd=0
1105 Td1=Tdhw
1115 IF (Hload=0) AND (Cloadt=0) THEN 1125
1120 GOTO 1130
1125 IF (Tave(M) .GT. 60) OR (Tsto .GT. 130) THEN 1155
1130 IF Cloadt .GT. 0 THEN 1155
1135 Ua6o=Ua6h
1140 IF Tf4 .LT. 80 THEN Tf4=130
1145 IF Tf5 .GT. 80 THEN Tf5=25
1150 GOTO Heating
1155 IF Tf4 .GT. 80 THEN Tf4=40
1160 IF Tf5 .LT. 80 THEN Tf5=130
1165 GOTO Cooling
1225 Heating: FOR V=1 TO 3
1240 IF UPC$(Sto$)="Y" THEN 1250
1245 GOTO 1255
1250 IF Kfwo .GT. Mcpsto THEN Tw1=Tsto-10
1255 FOR X=1 TO 4
1256 MAT Qgsum=ZER
1260 FOR Y=1 TO 4
1265 Hrejf=0
1270 Kfg=Ua2=Ua7=Qcoll=Qa1=Qa2=Qa7=0
1275 Kfw=Kfwo
1280 Ua1=Ua1o*.020
1285 IF Tamb .LE. Tsto THEN 1295
1290 IF Tamb .GT. Tg4 THEN 1320
1295 IF Sol .GT. 0 THEN 1325
1320 Ua1=Ua1o
1325 Kfg=Kfgo
1330 IF Tg2 .GT. Tw1 THEN 1336
1336 IF Fracd+Frach=0 THEN 1345
1340 Ua2=Ua2o
1345 Kf1=Kfg
1350 IF (Sol=0) AND (Tamb .LT. Tsto) AND (Tamb .LT. Tgnd) THEN 1390
1355 IF Ua1 .LT. Ua1o THEN 1370
1360 Qa1=Rhx1h*(Tamb-Tg4)
1365 GOTO 1375
1370 Qa1=Rhx1l*(Tamb-Tg4)
1375 Tg1=Tg4+Qa1/Kfgo
1380 Hrejf=Hrejf+1
1385 GOTO 1410
1390 Tg2=Tg4+Qpumpo/2/Kfg
1395 IF (Y*X*V=1) AND (Ua3o .GT. 0) THEN Tg2=Tw1-14000*Ton/Kfg+Qpumpo/2/Kfg
1400 IF Ua3o .GT. 0 THEN 1445
1405 GOTO 1470
1410 Tin=Tg1
1415 ON Opt2 GOSUB Solaroll,Miromit
1420 IF Qcoll .LT. 0 THEN Qcoll=0
1425 Tg2=Tg1+Qcoll/Kfg+Qpumpo/2/Kfg
1430 Qcrej=0
1445 IF Tw2 .LT. 34 THEN 1460
1450 GOTO 1480
1455 Qa1=Qcoll=0
1456 Ua2=Qa2=0
1460 Ua2=Qa2=0
```

```
1465 Tg3=Tg2
1470 Tw2=Tw1
1475 GOTO 1525
1480 IF Ua2=0 THEN 1460
1482 Tg2=Tg2
1483 Qa2=-Rhx2*(Tg2-Tw1)
1485 Tg3=Tg2+Qa2/Kfgo
1490 Tw2=Tw1-Qa2/Kfwo
1495 IF Tw2 .LT. 34 THEN 1455
1525 IF (Qa2 .NE. 0) OR (Qcoll .NE. 0) THEN 1530
1526 Kfg=Kfw=Ua7=Qa1=0
1527 IF (Qcoll=0) AND (Qa2=0) THEN 1625
1529 GOTO 1505
1530 Tin=Tg3
1535 IF Frach+Fracd=0 THEN 1505
1540 Tcon=(Tf5*Frach+Tf5x*Fracd)/(Frach+Fracd)
1545 Qa3p=Kfg*((Tin-Tcon)/Expuak+Tcon-Tin)*(Frach+Fracd)
1546 IF V=1 THEN Qa3=Qa3p
1550 Tout=Tin+Qa3/Kfgo
1555 IF (Qa3=0) AND (Qa2=0) THEN 1521
1557 Tg4(Y)=Tout
1560 Qgsum(Y)=Qa1+Qa2+Qa3+Qcoll+Qpumpo/2
1565 IF ABS(Qgsum(Y)) .LT. 100 THEN 1640
1570 IF Y=1 THEN Tg4=Tg4(1)-.3*SGN(Qgsum(Y))
1575 IF Y=1 THEN 1625
1576 Tg4=Tout
1578 IF Y .LT. 3 THEN 1625
1580 Delg=Qgsum(Y)-Qgsum(Y-1)
1585 IF Delg=0 THEN Delg=.001
1590 Slopeg=(Tg4(Y)-Tg4(Y-1))/Delg
1600 Dtg4=Slopeg*Qgsum(Y)
1605 IF Dtg4=0 THEN Dtg4=.00001
1610 ! IF ABS(Dtg4) .LT. 1 THEN Dtg4=1.5*Dtg4/ABS(Dtg4)
1615 Tg4=Tg4(Y)-Dtg4
1625 NEXT Y
1640 Water:FIXED 2
1645 Qsto=0
1646 IF Qa2=0 THEN Kfw=0
1648 IF Kfw=0 THEN 1680
1650 Tw2=Tw1-Qa2/Kfw
1655 Tw3=Tw2
1660 IF Frach+Fracd=0 THEN 1680
1680 Tw4=Tw3
1685 Qa4=0
1725 Ua7=0
1726 IF Kfw=0 THEN 1735
1730 IF Twpipe .GT. Tw4 THEN Ua7=Ua7o
1731 IF (Ua3o .GT. 0) AND (UPC$(Sto$)="N") THEN Ua7=Ua7o
1735 IF UPC$(Gnd$)="Y" THEN GOSUB Ground
1736 IF Kfw=0 THEN 1752
1737 IF UPC$(Sto$)="Y" THEN 1760
1738 Sum=Qa2-Qa7+Qpi-Qpumpo/2
1739 IF ABS(Sum) .LT. 100 THEN 1795
1741 Tws=Tw1
1742 IF X=1 THEN 1748
```

```
1743 Dtwl=-(Two-Tws)/(Sumo-Sum)*Sum
1744 IF ABS(Dtwl) .GT. 10 THEN Dtwl=10*SGN(Dtwl)
1745 Twl=Tws+Dtwl
1746 GOTO 1752
1748 Two=Twl
1750 Twl=Tw5+Qpumpo/Kfw/2
1752 Tstop=Tsto=Twl
1753 Qsto=0
1754 Two=Tws
1755 Sumo=Sum
1757 GOTO 1790
1760 IF (Qa2=0) AND (Qa7=0) THEN 1770
1765 Qsto=-Qa2+Qa4+Qa7+Qpumpo/2-Qpi
1770 Tstop=Tsto+Qsto/Mcpsto
1775 Twl(X)=(Tstop+Tsto)/2
1780 IF ABS(Twl/Twl(X)-1) .LT. .01 THEN 1795
1785 Twl=.5*(Twl(X)+Twl)
1790 NEXT X
1795 IF (Qa2=0) AND (Qa4=0) AND (Qa7=0) THEN Kfw=0
1800 GOSUB Hpump
1805 NEXT V
1810 Qevapp=Frach*Qevap+Fracd*Qevapx
1815 Qcondp=Frach*Qcond+Fracd*Qcondx
1820 Qelecp=Frach*Qelec+Fracd*Qelecx
1825 Frac=Frach+Fracd
1828 Lost=Frach*Loss+Losx
1829 IF Kfw=0 THEN Twl=Tstop=Tsto=Twlp
1830 Deltw=Twl-Tstop
1835 Twl=Twl-Deltw
1840 Tw2=Tw2-Deltw
1845 Tw3=Tw3-Deltw
1850 Tw4=Tw4-Deltw
1855 Tw5=Tw5-Deltw
1860 IF Hrejf .GT. 0 THEN Hrejc=Hrejc+1
1865 Tsto=Tstop
1880 Tdhw=Tdhw+(Qa5+Qresd-Qdhwl)/Cdhw
1881 Qpi=C1*(Twpipep-Twpipe)
1882 Twlp=Twl
1885 Twpipe=Twpipep
1886 Twl=Tsto
1890 Tgn2=Tgn2p
1895 Tgn4=Tgn4p
1900 Tgn6=Tgn6p
1905 Tgn8=Tgn8p
1906 IF (Tcload=0) AND (Hload=0) THEN Losts=Losts+Lost
1910 Tgn10=Tgn10p
1915 Tgn12=Tgn12p
2110 Qballp=0
2115 Qcollrm=Qcollrm+Qcrej
2125 Twl=Tsto
2130 Hloadm=Hloadm+Hload
2135 Cloadtm=Cloadtm+Tcload
2140 Qdhwlm=Qdhwlm+Qdhwl
2145 Qelecm=Qelecm+Qelecp
2150 Qreshm=Qreshm+Qresh
```

```
2155 Qresdm=Qresdm+Qresd
2158 Lostm=Lostm+Lost
2159 Kfw=1
2160 IF (Qa2 .GT. 0) OR (Qa3 .GT. 0) THEN Kfg=Kfgo
2161 IF Qa2=0 THEN Kfw=0
2163 IF Kfg .GT. 0 THEN Qpumpm=Qpumpm+Qpumpo/2
2165 IF Kfw .GT. 0 THEN Qpumpm=Qpumpm+Qpumpo/2
2170 Qfan1p=Qfan1*INT(Ua1/Ua1o)
2171 Qfan1m=Qfan1m+Qfan1p
2175 Qfanm=Qfanm+(Fracc+Frach)*Qfan6+Qfan1p
2180 IF Qa7 .GT. 0 THEN Qa7cm=Qa7cm+Qa7
2185 IF Qa7 .LT. 0 THEN Qa7rm=Qa7rm+Qa7
2190 Qcollm=Qcollm+Qcoll
2191 Qstom=Qstom+Qsto
2192 Qpim=Qpim+Qpi
2195 Qa1m=Qa1m+Qa1
2200 NEXT T
2201 Qclnmt=Qclnmt+Qball+Qbals
2202 Qball=Qbals=0
2205 NEXT Dm
2206 PRINTER IS 0
2207 FIXED 0
2208 Hloadm=Hloadm/1000
2209 Cloadtm=Cloadtm/1000
2210 Qdhwlm=Qdhwlm/1000
2211 Qelecm=Qelecm/1000
2212 Qreshm=Qreshm/1000
2213 Qresdm=Qresdm/1000
2214 Qpumpm=Qpumpm/1000
2215 Qfanm=Qfanm/1000
2216 Qa7cm=Qa7cm/1000
2217 Qa7rm=Qa7rm/1000
2218 Qcollm=Qcollm/1000
2219 Qcollrm=Qcollrm/1000
2220 Qa1m=Qa1m/1000
2221 Qclnmt=Qclnmt/1000
2222 Lostm=Lostm/1000
2223 Qfan1m=Qfan1m/1000
2224 PRINT LIN(2),Mn$(M)
2225 PRINT "  SPACE HEATING ENERGY REQUIRED  ";Hloadm;"MBTU"
2230 PRINT "  SPACE COOLING ENERGY REQUIRED  ";Cloadtm;"MBTU"
2235 PRINT "  DOMESTIC HOT WATER ENERGY REQUIRED  ";Qdhwlm;"MBTU"
2240 PRINT LIN(1)," NONRENEWABLE ENERGY CONSUMPTION"
2245 PRINT "  ELECTRICITY FOR HEAT PUMP  ";Qelecm/3.413;"KWH    ";Qelecm;"MBTU"
2250 PRINT "  AUXILIARY ELECTRIC FOR SPACE HEATING  ";Qreshm/3.413;"KWH   ";Qres
hm;"MBTU"
2255 PRINT "  AUXILIARY ELECTRIC FOR DOMESTIC HOT WATER  ";Qresdm/3.413;"KWH   "
;Qresdm;"MBTU"
2256 PRINT "  HEAT PUMP ENERGY LOST TO SPACE  ";Lostm
2260 PRINT "  ELECTRICITY FOR PUMPS   ";Qpumpm;"MBTU"
2265 PRINT "  ELECTRICITY FOR FANS   ";Qfanm;"MBTU"
2266 PRINT "  FAN ENERGY LOST TO ATMOSPHERE   ";Qfan1m
2270 PRINT "  ENERGY CONSUMMED BY LIGHTS AND APPLIANCES  ";Qlappl*Dmo(M)/1000;"M
BTU"
2275 PRINT LIN(1)," FREE ENERGY"
```

```
2280 PRINT "  ENERGY COLLECTED FROM GROUND  ";Qa7cm;"MBTU"
2285 PRINT "  ENERGY REJECTED TO GROUND   ";Qa7rm;"MBTU"
2290 PRINT "  ENERGY COLLECTED FROM SOLAR PANELS   ";Qcollm;"MBTU"
2295 PRINT "  ENERGY REJECTED BY SOLAR PANELS   ";Qcollrm;"MBTU"
2300 PRINT "  ENERGY REJECTED TO ATMOSPHERE BY FAN COIL   ";-Qalm;"MBTU"
2301 PRINT LIN(1),"COOLING LOADS NOT MET"
2302 PRINT "  COOLING LOADS NOT MET ";Qclnmt;" MBTU"
2303 PRINT "  HOURS WHEN COOLING LOADS NOT MET ";Lntmt;" HOURS"
2305 FIXED 3
2310 PRINT LIN(1),"COP"
2312 Copepf=(Hloadm+Cloadtm+Qdhwlm)/(Qelecm+Qreshm+Qresdm)
2315 PRINT "  EXCLUDING PUMP AND FAN ENERGIES   ";Copepf
2318 Cop=(Hloadm+Cloadtm+Qdhwlm)/(Qelecm+Qreshm+Qresdm+Qpumpm+Qfanm)
2320 PRINT "  INCLUDING PUMP AND FAN ENERGIES   ";Cop
2321 Lrrr=Lrrr+1
2322 PRINT #3,Lrrr;Hloadm,Cloadtm,Qdhwlm,Qelecm,Qreshm,Qresdm,Lostm,Qpumpm,Qfanm
,Qfanlm,Qa7cm,Qa7rm,Qcollm,Qcollrm,-Qalm,Qclnmt,Lntmt,Copepf,Cop
2325 Hloady=Hloady+Hloadm
2330 Cloady=Cloady+Cloadtm
2335 Qdhwly=Qdhwly+Qdhwlm
2340 Qelecy=Qelecy+Qelecm
2345 Qreshy=Qreshy+Qreshm
2350 Qresdy=Qresdy+Qresdm
2355 Qpumpy=Qpumpy+Qpumpm
2358 Losty=Losty+Lostm
2360 Qfany=Qfany+Qfanm
2361 Qfanly=Qfanly+Qfanlm
2365 Qa7cy=Qa7cy+Qa7cm
2370 Qa7ry=Qa7ry+Qa7rm
2375 Qcolly=Qcolly+Qcollm
2380 Qcollry=Qcollry+Qcollrm
2385 Qaly=Qaly+Qalm
2390 IF Yflag .GT. 0 THEN 4899
2395 NEXT M
2400 Hloadm=Hloady
2405 Cloadtm=Cloady
2410 Qdhwlm=Qdhwly
2415 Qelecm=Qelecy
2420 Qreshm=Qreshy
2425 Qresdm=Qresdy
2426 Lostm=Losty
2430 Qpumpm=Qpumpy
2431 Qfanlm=Qfanly
2435 Qfanm=Qfany
2440 Qa7cm=Qa7cy
2445 Qa7rm=Qa7ry
2450 Qcollm=Qcolly
2455 Qcollrm=Qcollry
2460 Qalm=Qaly
2465 PRINT LIN(2),"YEAR"
2467 PRINT "Ac=";Ac;"Opt2=";Opt2;"Mcpsto=";Mcpsto;"Lgnd=";Lgnd;"Citr=";Citr
2470 Yflag=1
2475 GOTO 2225
2485 Hpump:Qres=Qresh=Qresd=Qcondx=Qevapx=Qelecx=Qa5=Qa5o=0
2490 IF Frach+Fracd=0 THEN 3030
```

```
2495 Qevap=Qevaps=ABS(Qa3)/(Frach+Fracd)
2500 IF Ua3o .GT. 0 THEN 2525
2525 Tin=Tg3
2530 Uaf=Ua3o
2535 Kf=Kfg
2540 IF (Qa3=0)  THEN 3030
2541 IF Hload=0 THEN 2810
2545 FOR W=1 TO 10
2550 N=(Qevap/Ton/14000)**2
2555 Tf5=Tin+Qevap/Kfwo/Exf
2560 X=Tf4+2*N
2565 Z=Tf5-3*N
2570 Qevap=Ao1+Bo1*X+Co1*X**2+Do1*Z+Eo1*X*Z+Fo1*Z*X**2+Go1*Z**2+Ho1*X*Z**2+Io1*
Z**2*X**2
2575 IF ABS(Qevaps-Qevap) .LT. 200 THEN 2595
2580 IF ABS(Qevaps-Qevap) .GT. 20000 THEN Qevap=Qevap-.8*(Qevap-Qevaps)
2585 Qevaps=Qevap
2590 NEXT W
2595 Qelec=Ao2+Bo2*X+Co2*X**2+Do2*Z+Eo2*X*Z+Fo2*Z*X**2+Go2*Z**2+Ho2*X*Z**2+Io2*
Z**2*X**2
2600 Qcond=.95*Qevap+Qelec-.05*Way4*Qevap
2603 Loss=Qevap+Qelec-Qcond
2605 Hf4=11.568+.2381*Tf4+.0003882*Tf4**2
2610 Hf5=104.5+.09884*Tf5-.0001823*Tf5**2
2615 Evapin=Qevap*(1-.05*Way4)
2620 Lbs=Evapin/(Hf5-Hf4)
2625 Hf1=(Qevap+Qelec)*.95/Lbs+Hf4
2630 X=Tf4
2635 Z=Hf1
2640 Tf1=Ao3+Bo3*X+Co3*X**2+Do3*Z+Eo3*X*Z+Fo3*Z*X**2+Go3*Z**2+Ho3*X*Z**2+Io3*Z*
*2*X**2
2645 IF Qdhw=0 THEN 2660
2650 IF Tf1 .LT. Td1 THEN 2660
2655 GOTO 2690
2660 Tf2=Tf1
2665 Hf2=Hf1
2670 Qa5=0
2675 Td2=Td1
2680 Fracd=0
2685 GOTO 2805
2690 IF Tf4 .GT. Td1 THEN 2745
2695 Tf42=Tf4*Tf4
2700 Tf43=Tf42*Tf4
2705 Kff=(.15085+3.2914E-4*Tf4+1.4689E-6*Tf42+1.9926E-8*Tf43)*Lbs
2710 Efua=EXP(Ua5*(1/Kff-1/Kfd))
2715 Uar=Kff*(1-Efua)/(Kff/Kfd-Efua)
2720 Qa5=Qa5o=Uar*(Tf1-Td1)
2725 Flag=1
2730 Tf2=Tf1-Qa5/Kff
2735 Td2=Td1+Qa5/Kff
2740 GOTO 2780
2745 X=Z=Tf4
2750 GOSUB Hf
2755 Hf2=Hfp
2760 CALL Qa5p(Kfd,Ua4o,Td1,Hf1,Hf2,Ua5,Tf1,Tf4,Qa5,Td2,Lbs)
```

```
2765 Tf2=Tf4
2770 Qa5=Kfd*(Td2-Td1)
2775 IF Qa5 .GT. Qcond THEN Qa5=Qcond
2776 Qa5o=Qa5
2780 X=Tf4
2785 Z=Tf2
2790 GOSUB Hf
2795 Hf2=Hfp
2800 Fracd=MIN(Qdhw/Qa5o,1)
2803 IF Qa5o .GT. Qdhw THEN Qa5=Qa5o=Qdhw
2804 IF Hload=0 THEN 2860
2805 Frach=MIN((Hload-Losx+Qa5)/(Qfan6+Loss+Qcond),1)
2860 IF Frach=1 THEN Qresh=Hload-(Qcond-Qa5)-Qfan6-Loss
2865 IF Frach=1 THEN 2880
2870 IF Fracd .LE. Frach THEN 2880
2875 GOTO 2920
2880 Tf2=Tf2*Fracd+(1-Fracd)*Tf1
2885 X=Tf4
2890 Z=Tf2
2895 GOSUB Hf
2900 Hf2=Hfp
2910 IF Fracd .LE. Frach THEN Fracd=0
2915 GOTO 2965
2920 IF Flag .GT. 0 THEN 2955
2925 Fracd=0
2930 Qa4=0
2935 Tw4=Tw3
2940 Qsto=-Qa2+Qa7+Qpumpo/2
2945 IF Qa7=0 THEN Qsto=0
2950 GOTO 2960
2955 CALL Dhwpmp(V)
2958 Losx=(Qevapx+Qelecx-Qcondx)*Fracd
2960 IF Fracd .GT. 1-Frach THEN Fracd=1-Frach
2965 Qa6=(Qcond+Qfan6)*Frach-Qa5o
2970 Qa5=Qa5+Fracd*Qcondx
2975 Flowair=.3062*Cfmi*Pamb
2980 Eadb=65
2985 IF (T .GT. 6) AND (T .LT. 22) THEN Eadb=70
2990 Ladb=Eadb+Qcond/(.24*Flowair)
2995 Ex=EXP(Ua6h*(Ladb-Eadb)/Qcond)
3000 Tf4=(Eadb-Ex*Ladb)/(1-Ex)
3020 IF (Qa3=0)  THEN 3030
3025 GOTO 3045
3030 Qresh=Hload
3035 Qcond=Qelec=Qevap=Frach=Fracd=Qa5=Qa6=Losx=0
3040 Tf2=Tf1
3045 IF Tdhw .GT. 100 THEN 3055
3050 Qresd=10239
3055 Qres=Qresd+Qresh
3056 Qa3=-Frach*Qevap-Fracd*Qevapx
3060 RETURN
3070 Cooling:Qa3d=0
3080 IF Cloadt=0 THEN Tf5=Td1+5
3085 Fracc=MIN(Cloadt/Qcond,1)
3130 FOR V=1 TO 3
```

```
3145 IF UPC$(Sto$)="N" THEN 3155
3150 IF Kfwo .GT. Mcpsto THEN Twl=Tsto+10
3155 FOR X=1 TO 5
3160 FOR Y=1 TO 5
3165 Crejf=0
3170 Kfg=Kfw=Ua2=Ua7=Qcoll=Qal=Qa2=Qcrej=Qa6=0
3175 Ual=.020*Ualo
3180 IF (Tamb .LT. Tsto) AND (Tamb .LE. Tg4) THEN Ual=Ualo
3185 IF (Tamb .LT. Tsto) AND (Tamb .LE. Tg4) THEN Kfg=Kfgo
3190 IF Fracc+Fracd .GT. 0 THEN Kfg=Kfgo
3195 IF (Tg2 .LT. Tsto) AND (Tg2 .LT. Tgn2) THEN Kfg=Kfgo
3200 IF Kfg .GT. 0 THEN Kfw=Kfwo
3205 IF UPC$(Sto$)="N" THEN Ua7=Ua7o
3210 IF Twl-Tg2 .GT. .5*(Tf5-Tg3) THEN Ua2=0
3215 IF (Ua3o=0) AND (Tamb .GT. Tsto) THEN Ua2=Ua2o
3220 IF Kfg .NE. 0 THEN 3245
3225 Tgl=Tg2=Tg3=Tg4=Tamb
3230 Tw2=Twl
3235 Qcoll=Qcrej=Qal=Qa2=Qa3=0
3240 GOTO Coolwater
3245 IF Ual .LT. Ualo THEN 3270
3255 IF Ual .LT. Ualo THEN 3270
3260 Qal=Rhxlh*(Tamb-Tg4)
3265 GOTO 3275
3270 Qal=Rhxll*(Tamb-Tg4)
3275 Tgl=Tg4+Qal/Kfgo
3276 IF Sol .GT. 0 THEN 3285
3280 GOTO 3300
3285 Qcrej=0
3290 Tg2=Tgl
3295 GOTO 3330
3300 Tin=Tgl
3305 Qcoll=Qcrej=0
3310 IF Tgl .LT. Tamb THEN 3285
3311 ON Opt2 GOSUB Solaroll,Miromit
3315 Crejf=Crejf+1
3320 Qcoll=0
3325 Tg2=Tgl-Qcrej/Kfg
3330 Tg2=Tg2+Qpumpo/2/Kfg
3332 Qa2=-Rhx2*(Tg2-Twl)
3335 Tg3=Tg2+Qa2/Kfgo
3340 Tw2=Twl-Qa2/Kfwo
3341 Ua2=Ua2o
3345 IF Ua3o .GT. 0 THEN 3370
3350 Tout=Tg3
3355 Q=Qa3=0
3360 IF Qcrej+Qa2=0 THEN 3480
3365 GOTO 3410
3370 IF Fracc+Fracd .NE. 0 THEN 3390
3375 Tg4=Tout=Tg3
3380 Qa3=0
3385 GOTO 3410
3390 Tin=Tg3
3391 Tin=Tg3
3395 Tcon=(Tf5*Fracc+Tf5x*Fracd)/(Fracc+Fracd)
```

```
3400 Qa3p=Kfgo*((Tin-Tcon)/Expuak+Tcon-Tin)*(Fracc+Fracd)
3401 IF V=1 THEN Qa3=Qa3p
3405 Tout=Tin+Qa3/Kfgo
3410 Tg4(Y)=Tout
3415 Qgsum(Y)=Qa1+Qa2+Qa3-Qcrej+Qpumpo/2
3420 IF ABS(Qgsum(Y)) .LT. 100 THEN 3496
3425 IF Y=1 THEN Tg4=Tg4(1)+.3*SGN(Qgsum(Y))
3430 IF Y=1 THEN 3480
3435 Tg4=Tout
3440 IF Y .GT. 3 THEN 3480
3445 Delg=Qgsum(Y)-Qgsum(Y-1)
3450 IF Delg=0 THEN Delg=.001
3455 Slopeg=(Tg4(Y)-Tg4(Y-1))/Delg
3460 Dtg4=Slopeg*Qgsum(Y)
3465 IF Dtg4=0 THEN Dtg4=.00001
3475 Tg4=Tg4(Y)-Dtg4
3480 NEXT Y
3496 Coolwater:Tw3=Tw2
3497 Qsto=0
3498 IF Qa2=0 THEN Kfw=0
3499 IF Kfw=0 THEN 3520
3500 IF Fracc+Fracd=0 THEN 3520
3505 IF (Kfg=0) OR (Ua2=0) THEN Tw2=Tw1
3510 Tw3=Tw2
3520 Tw4=Tw3
3525 Qa4=Q=0
3550 IF Twpipe .LT. Tw4 THEN Ua7=Ua7o
3555 IF UPC$(Gnd$)="Y" THEN 3570
3560 Tw5=Tw4
3565 GOTO 3575
3570 GOSUB Ground
3573 Qpi=C1*(Twpipep-Twpipe)
3574 IF Kfw=0 THEN 3620
3575 IF UPC$(Sto$)="Y" THEN 3595
3576 Sum=Qa2-Qa7+Qpi-Qpumpo/2
3577 IF ABS(Sum) .LT. 100 THEN 3625
3578 Tws=Tw1
3579 IF X=1 THEN 3585
3580 IF Sumo-Sum=0 THEN 3585
3581 Dtw1=-(Two-Tws)/(Sumo-Sum)*Sum
3582 IF ABS(Dtw1) .GT. 10 THEN Dtw1=10*SGN(Dtw1)
3583 Tw1=Tws+Dtw1
3584 GOTO 3587
3585 Two=Tw1
3586 Tw1=Tw5+Qpumpo/Kfw/2
3587 Tstop=Tsto=Tw1
3588 Sumo=Sum
3589 Two=Tws
3590 GOTO 3620
3595 Qsto=-Qa2+Qa4+Qa7+Qa4d+Qpumpo/2-Qpi
3600 Tstop=Tsto+Qsto/Mcpsto
3605 Tw1(X)=(Tstop+Tsto)/2
3610 IF ABS(Tw1/Tw1(X)-1) .LT. .01 THEN 3625
3615 Tw1=.5*(Tw1(X)+Tw1)
3620 NEXT X
```

```
3625 IF Fracc+Fracd=0 THEN 3635
3630 GOSUB Cpump
3635 NEXT V
3636 Lost=Fracc*Loss+Losx
3640 IF Qa6 .LE. Cloadt+Lost THEN 3644
3641 Qbals=Cloadt+Lost-Qa6
3642 Lntmt=Lntmt+1
3644 Qevapp=Fracc*Qevap
3645 Qcondp=Fracc*Qcond+Fracd*Qcondx
3650 Qelecp=Fracc*Qelec+Fracd*Qelecx
3655 Frac=Fracc+Fracd
3660 IF Crejf .GT. 0 THEN Crejc=Crejc+1
3665 Deltw=Tw1-Tstop
3670 Tw1=Tw1-Deltw
3675 Tw2=Tw2-Deltw
3680 Tw3=Tw3-Deltw
3685 Tw4=Tw4-Deltw
3690 Tw5=Tw5-Deltw
3695 Tsto=Tstop
3700 Tdhw=Tdhw+(Qa5-Qdhw1)/Cdhw
3705 GOTO 1881
3765 Cpump:Qcondx=Qelecx=Qevapx=Qa5=Qa5o=0
3800 IF Fracc .GT. 0 THEN 3815
3805 Qevap=Qcond=Qelec=Qa5=Qa5o=0
3810 GOTO 4375
3815 Tdb=Eadb=78
3820 Lbswat=.012*Lbsair+Cload1/1075
3825 Wtdp=Lbswat/Lbsair
3830 CALL Pvap(Tdb,Pamb,Pwsdb,Wtsdb)
3835 Pwsdb=Pwsdb*.49118
3840 IF Wtdp .GT. Wtsdb THEN Wtdp=Wtsdb
3845 Pwdb=Wtdp*Pamb/(.62198+Wtdp)
3850 Pwdp=Pwdb
3855 Rhdb=100*Pwdp/Pwsdb
3860 Twb=Tdb*(Rhdb/100)**.3
3865 FOR Iwb=1 TO 5
3870 CALL Pvap(Twb,Pamb,Pwb,Wtwb)
3875 Pwb=Pwb*.49118
3880 Twb1=(1093*(Wtwb-Wtdp)-Tdb*(.24+.444*Wtdp))/(.556*Wtwb-Wtdp-.24)
3885 IF ABS(Twb1-Twb) .LT. .3 THEN 3900
3890 Twb=(Twb1+Twb)/2
3895 NEXT Iwb
3900 Tdp=Twb-.4*(Tdb-Twb)
3905 CALL Pvap(Tdp,Pamb,Pgen,Wgen)
3910 IF ABS(Wgen/Wtdp-1) .LT. .020 THEN 3925
3915 Tdp=Tdp+.5*(Wtdp-Wgen)*Tdp/Wtdp
3920 GOTO 3905
3925 FOR W=1 TO 3
3930 IF (V=1) AND (W=1) THEN 3940
3935 GOTO 3955
3940 Qext=Qext1=Qevap=12000*Ton
3945 Ladb=Tdb-(Qext-Qfan6)/Cfmi
3950 Cfm=Cfmi
3955 FOR Witc=1 TO 5
3960 Ex=Ua6*(Tdb-Ladb)/Qevap
```

```
3965 Tf4=(Tdb-Ladb*EXP(Ex))/(1-EXP(Ex))
3966 IF Tf4 .LT. 600 THEN 3970
3967 Fracc=Fracd=Qa3=Qa4=Qcond=Qelec=Qcondx=Qelecx=Qa6=Qa5=0
3968 RETURN
3970 GOSUB Psycho
3975 Yx=1.5*(Larh/100-.7)
3980 Yy=EXP(Yx+ABS(Yx))-1
3985 Tanh=(EXP(Yy)-EXP(-Yy))/(EXP(Yy)+EXP(-Yy))
3990 Ua6=2*Ton*(280+181*Tanh)
3995 N=(Qevap/Ton/14000)**2
4000 X=Tf5+2*N
4005 Z=Tf4-3*N
4010 Qevap=Ao1+Bo1*X+Co1*X**2+Do1*Z+Eo1*X*Z+Fo1*Z*X**2+Go1*Z**2+Ho1*X*Z**2+Io1*
Z**2*X**2
4020 IF ABS(Qevap/Qext-1) .LT. .020 THEN 4050
4030 Qevap=(Qevap+Qext)/2
4035 Qext1=Qext
4040 Qext=Qevap
4045 NEXT Witc
4050 NEXT W
4055 X=Tf5+2*N
4060 Z=Tf4-3*N
4065 Qelec=Ao2+Bo2*X+Co2*X**2+Do2*Z+Eo2*X*Z+Fo2*Z*X**2+Go2*Z**2+Ho2*X*Z**2+Io2*
Z**2*X**2
4070 Qcond=.95*Qevap+Qelec-.05*Way4*Qevap
4073 Loss=Qevap+Qelec-Qcond
4075 Hf5=11.568+.2381*Tf5+.0003882*Tf5**2
4080 Hf4=104.5+.09884*Tf4-.0001823*Tf4**2
4085 Evapin=Qevap*(1-.05*Way4)
4090 Lbs=Evapin/(Hf4-Hf5)
4095 Kf=Cfmi*.3062*Pamb  !Cfmi*60*.075*Pamb/14.696
4100 Hf1=(Qevap+Qelec)*.95/Lbs+Hf5
4105 X=Tf5
4110 Z=Hf1
4115 Tf1=Ao3+Bo3*X+Co3*X**2+Do3*Z+Eo3*X*Z+Fo3*Z*X**2+Go3*Z**2+Ho3*X*Z**2+Io3*Z*
*2*X**2
4116 Qa5=Qa5o=0
4120 IF (Qdhw=0) OR (Tdhw .GE. Tw+5) THEN 4130
4125 IF Tf1 .GT. Td1 THEN 4180
4130 Tf2=Tf1
4135 Hf2=Hf1
4140 Qa5o=Qa5=0
4145 Fracd=0
4150 Td2=Td1
4155 GOTO 4285
4160 IF Tf5 .GT. Td1 THEN 4210
4165 Tf52=Tf5*Tf5
4170 Tf53=Tf52*Tf5
4175 Kff=(.15085+3.2914E-4*Tf5+1.4689E-6*Tf52+1.9926E-8*Tf53)*Lbs
4180 Efua=EXP(Ua5*(1/Kff-1/Kfd))
4185 Uar=Kff*(1-Efua)/(Kff/Kfd-Efua)
4190 Qa5o=Qa5=Uar*(Tf1-Td1)
4195 Tf2=Tf1-Qa5o/Kff
4200 Td2=Td1+Qa5o/Kff
4205 GOTO 4245
```

```
4210 X=Z=Tf5
4215 GOSUB Hf
4220 Hf2=Hfp
4225 CALL Qa5p(Kfd,Ua4o,Td1,Hf1,Hf2,Ua5,Tf1,Tf5,Qa5,Td2,Lbs)
4230 Tf2=Tf5
4235 Qa5o=Qa5=Kfd*(Td2-Td1)
4240 IF Qa5o .GT. Qcond THEN Qa5o=Qcond
4245 X=Tf5
4250 Z=Tf2
4255 GOSUB Hf
4260 Hf2=Hfp
4285 Fracc=MIN((Cloads+Losx+Cloadl)/(Qevap-Qfan6-Loss),1)
4290 IF Qa5o=0 THEN 4300
4295 Fracd=MIN(Qdhw/Qa5o,1)
4300 IF Fracd .LE. Fracc THEN Fracd=0
4330 IF Fracd .GE. Fracc THEN 4340
4335 IF Tf2 .GT. Tf5 THEN Tf2=Tf2*Fracd+(1-Fracd)*Tf1
4340 X=Tf5
4345 Z=Tf2
4346 Qa5=Qa5o*Fracc
4350 Hf2=Ao4+Bo4*X+Co4*X**2+Do4*Z+Eo4*X*Z+Fo4*Z*X**2+Go4*Z**2+Ho4*X*Z**2+Io4*Z*
*2*X**2
4355 IF Fracd=0 THEN 4380
4360 IF Fracc .LT. Fracd THEN 4375
4365 IF (Qdhw-Qa5o*Fracc .GT. 0) AND (Fracc .LT. 1) THEN 4375
4366 Fracd=0
4370 GOTO 4380
4375 CALL Dhwpmp(V)
4378 Losx=(Qevapx+Qelecx-Qcondx)*Fracd
4380 IF Fracd .GT. 1-Fracc THEN Fracd=1-Fracc
4381 Qa3=Fracc*(Qcond-Qa5o)-Fracd*Qevapx
4385 Qa6=(Qevap-Qfan6)*Fracc
4390 Qa5=Qa5o*Fracc+Qcondx*Fracd
4395 IF Tdhw .LT. 110 THEN Qresd=10239
4400 IF Fracd=0 THEN Qa5o=0
4405 Tf5=Tew-(Qcond-Qa5o)/Kfx/Exf
4410 RETURN
4430 Miromit:IF Sol .GT. 0 THEN 4530
4435 Lfts=.25*Tgl+1.388E-9*(Tgl+460)**4+Hc*Tamb+Rgf*(Tamb+460)**4+Rsfcl*(Tsky+
460)**4
4440 Gm=Hc+.25
4445 Ic=1
4450 Tglass2=Tl-.2*(Tgl-Tsky)
4455 Rits2=Tglass2*Gm+Rsfprgf*(Tglass2+460)**4
4456 Tglass2s=Tglass2
4460 IF ABS(Rits2/Lfts-1) .LT. .020 THEN 4520
4475 IF Ic .GT. 1 THEN 4495
4476 Rits1=Rits2
4478 Tglass1=Tglass2
4480 Tglass2=Tglass1+10
4485 Ic=Ic+1
4490 GOTO 4455
4495 Tglass2=Tglass1+(Tglass2-Tglass1)*(Lfts-Rits1)/(Rits2-Rits1)
4496 Rits1=Rits2
4498 Tglass1=Tglass2s
```

```
4500 Ic=Ic+1
4505 IF Ic .LT. 10 THEN 4455
4510 DISP "GREATER THAN 10 ITERATIONS TO FIND GLASS TEMP PAUSE AT 4515"
4515 PAUSE
4520 Qcrej=Ac*(.25*(Tgl-Tglass2)+3.352E-10*((Tgl+460)**4-(Tglass2+460)**4))
4525 RETURN
4530 Qcoll=Ac*(Sol*.73-.866*(Tgl-Tamb))
4535 RETURN
4545 Solaroll:IF Sol .GT. 0 THEN 4565
4550 Tgla=(Tgl+460)**4
4555 Qcrej=Ac*(Hc*(Tgl-Tamb)+Rsf*(Tgla-(Tsky+460)**4)*Cl+Rgf*(Tgla-(Tamb+460)**
4))
4560 RETURN
4565 Qcoll=Ac*(Sol*.49-1.84*(Tgl-Tamb))
4570 RETURN
4575 Hf:X2=X*X
4576 Z2=Z*Z
4577 Hfp=Ao4+Bo4*X+Co4*X2+Do4*Z+Eo4*X*Z+Fo4*Z*X2+Go4*Z2+Ho4*X*Z2+Io4*Z2*X2
4578 RETURN
4585 Ground:FIXED 2
4586 Qa7p=0
4590 IF (Ua7 .GT. 0) AND (Kfw .GT. 0) THEN 4625
4595 Tw5=Tw4
4610 Tgn2p=Tgn2+(G1x*(Twpipe-Tgn2)+G2*(Tgn4-Tgn2))/C2
4615 Twpipep=Twpipe+G1x*(Tgn2-Twpipe)/C1
4616 Qa7=C1*(Twpipep-Twpipe)
4620 GOTO 4670
4625 IF Time1 .LE. 1 THEN 4655
4630 Teff=Twpipe+(Tw4-Twpipe)/2/Time1
4635 GOTO 4660
4655 Teff=Tw4+Time1*(Twpipe-Tw4)/2
4660 Tgn2p=Tgn2+(G1*(Teff-Tgn2)+G2*(Tgn4-Tgn2))/C2
4661 Qa7=G1*(Tgn2-Teff)
4662 Twpipep=Qa7/Cpipe+Teff
4663 Qpi=C1*(Twpipep-Twpipe)
4665 Tw5=Twpipep
4670 Tgn4p=Tgn4+(G3*(Tgn6-Tgn4)+G2*(Tgn2-Tgn4))/C4
4675 Tgn6p=Tgn6+(G4*(Tgn8-Tgn6)+G3*(Tgn4-Tgn6))/C6
4680 Tgn8p=Tgn8+(G5*(Tgn10-Tgn8)+G4*(Tgn6-Tgn8))/C8
4685 Tgn10p=Tgn10+(G6*(Tgn12-Tgn10)+G5*(Tgn8-Tgn10))/C10
4690 Tgn12p=Tgn12+(G7*(Tgn-Tgn12)+G6*(Tgn10-Tgn12))/C12
4700 RETURN
4705 END
4715 Psycho:CALL Pvap(Tdb,Pamb,Pws,Wts)
4720 CALL Pvap(Tdp,Pamb,Pwd,Wtdp)
4725 Relh=100*Pwd/Pws
4730 Twb1=Twb
4735 FOR Iwb=1 TO 5
4740 CALL Pvap(Twb1,Pamb,Pwb,Wtwb)
4745 Twb=(1093*(Wtwb-Wtdp)-Tdb*(.24-.444*Wtdp))/(.556*Wtwb-Wtdp-.24)
4750 IF ABS(Twb-Twb1) .LT. .5 THEN 4765
4755 Twb1=.5*(Twb+Twb1)
4760 NEXT Iwb
4765 Vpsy=.3701*(Tdb+460)*(1+1.6078*Wtdp)/Pamb
4770 Hpsy=.24*Tdb+Wtdp*(1061+.444*Tdb)
```

```
4775 Hdelt=Qext*Vpsy/(Cfm*60)
4780 IF Ladb .LT. Tdp THEN 4800
4785 CALL Pvap(Ladb,Pamb,Pladb,Wtladb)
4790 Larh=100*Pwd/Pladb
4795 IF Larh .LT. 70 THEN 4865
4800 Hea=Hpsy
4805 Hla=Hea-Hdelt
4810 Wteadp=Wtdp
4815 Tladp=Tdp-1
4820 CALL Pvap(Tladp,Pamb,Pladp,Wtladp)
4825 Ladbx=(Hla-Wtladp*1061)/(.24+Wtladp*.444)
4830 CALL Pvap(Ladbx,Pamb,Pladb,Wtladb)
4835 Larhx=100*Pladp/Pladb
4840 Xrh=(Wteadp-Wtladp)*1000
4845 Larh=70+30*(1-1/EXP(Xrh))
4850 IF ABS(Larhx/Larh-1) .LT. .3 THEN 4865
4855 Tladp=Tladp+5*(460/(Ladbx+460))*(Larh-Larhx)/100
4860 GOTO 4820
4865 Ladb=Ladbx
4870 RETURN
5600 SUB Dhwpmp(V)
5605 COM Qevapx,Qcondx,Qelecx,Way4,Ton,Ua3o,Ua4o,Kfwo,Kfgo,Tw3,Tg3,Td1,Frach,Fra
cd,Exf,Expuad,Ao1,Ao2,Ao3,Bo1,Bo2,Bo3,Co1,Co2,Co3,Do1,Do2,Do3,Eo1,Eo2,Eo3
5610 COM Fo1,Fo2,Fo3,Go1,Go2,Go3,Ho1,Ho2,Ho3,Io1,Io2,Io3,Tf5x,Qevapxs,Tf4xs,Kfd,
Qdhw,Qa5,Fracc,W
5620 Qevapm=36000*Ton
5625 Qevapx=Qevapxs
5630 IF V=1 THEN Qevapxs=Qevapx=12000*Ton
5635 Tf4x=150
5640 IF V .GT. 1 THEN Tf4x=Tf4xs
5670 Tinw=Tg3
5675 Uaf=Ua3o
5680 Kff=Kfgo
5685 FOR Wx=1 TO 5
5690 FOR W=1 TO 10
5695 N=(Qevapx/Ton/14000)**2
5700 Tf5x=Tinw+Qevapx/Kff/Exf
5705 X=Tf4x+2*N
5710 Z=Tf5x-3*N
5715 Qevapx=Ao1+Bo1*X+Co1*X**2+Do1*Z+Eo1*X*Z+Fo1*Z*X**2+Go1*Z**2+Ho1*X*Z**2+Io1
*Z**2*X**2
5716 IF ABS(Qevapx) .GT. 1E6 THEN 5885
5720 IF ABS(Qevapxs-Qevapx) .LT. 200 THEN 5760
5725 IF Qevapxs-Qevapx .GT. 20000 THEN Qevapx=Qevapx-.8*(Qevapx-Qevapxs)
730 IF Qevapxs .GT. Qevapm THEN Qevapx=Qevapm
5735 Qevapxs=Qevapx
5740 IF (Wx=5) AND (W=9) THEN 5750
5745 GOTO 5755
5750 BEEP
5755 NEXT W
5760 Qelecx=Ao2+Bo2*X+Co2*X**2+Do2*Z+Eo2*X*Z+Fo2*Z*X**2+Go2*Z**2+Ho2*X*Z**2+Io2
*Z**2*X**2
5765 Qevapxs=Qevapx
5770 Qcondx=.95*Qevapx+Qelecx-.05*Way4*Qevapx
5775 Hf4x=11.568+.2381*Tf4x+.0003882*Tf4x**2
```

```
5780 Hf5x=104.5+.09884*Tf5x-.0001823*Tf5x**2
5785 Evapinx=Qevapx*(1-.05*Way4)
5790 Lbsx=Evapinx/(Hf5x-Hf4x)
5795 Hf1x=(Qevapx+Qelecx)*(.95-.05*Way4)/Lbsx+Hf4x
5800 Hf2x=Hf1x
5805 X=Tf4x
5810 Z=Hf1x
5815 Tf1x=Ao3+Bo3*X+Co3*X**2+Do3*Z+Eo3*X*Z+Fo3*Z*X**2+Go3*Z**2+Ho3*X*Z**2+Io3*Z
**2*X**2
5820 Tf2x=Tf1x
5825 Kf=Kfd
5830 Tin=Td1
5835 Tcon=Tf4x
5840 Ua=Ua5o
5845 Q=Kfd*((Tin-Tcon)/Expuad+Tcon-Tin)
5850 Qhx=ABS(Q)
5855 IF ABS(Qhx/Qcondx-1) .LT. .020 THEN 5895
5860 Tf4x=Tf4x+(Qcondx-Qhx)*(Tf4x-Td1)/Qcondx
5865 IF Tf4x .LT. Tin THEN Tf4x=Tcon-(Tcon-Tin)/2
5870 IF Tf4x .LT. Tin THEN 5885
5875 NEXT Wx
5880 GOTO 5895
5885 Qcondx=Q=Fracd=Qevapx=Qelecx=0
5890 GOTO 5910
5895 Fracd=(Qdhw-Qa5)/Qcondx
5896 IF Fracd .LT. 0 THEN Fracd=0
5900 Tf4xs=Tf4x
5910 SUBEND
5920 SUB Pvap(O,Pamb,Pgen,Wgen)
5925 IF O .LT. 32 THEN Lt32
5930 Pgen=6.75E-50*(O+460)**18
5935 GOTO Humrto
5940 Lt32:Pgen=9.65E-69*(O+460)**25
5945 Humrto:Wgen=.622*Pgen/(Pamb*2.036-Pgen)
5950 SUBEND
5955 SUB Qa5p(Kfd,Ua4,Td1,Hf1,Hf2,Ua5,Tf1,Tf4,Qa5,Td2,Lbs)
5956 I=0
5960 Xx=.8
5965 Td12=Tf4-(Tf4-Td1)/EXP(Ua4*Xx/Kfd)
5966 I=I+1
5967 IF I .GT. 10 THEN 6000
5970 Qa52=Lbs*(Hf1-Hf2)
5975 Td2=Td12+Qa52/Kfd
5980 Xg=1-Qa52/Ua5*LOG((Tf1-Td2)/(Tf4-Td12))/(Tf1-Td2-(Tf4-Td12))
5985 IF ABS((Xx-Xg)/Xx) .LE. .01 THEN 6000
5990 Xx=Xg
5995 GOTO 5965
6000 Qa5=Kfd*(Td2-Td1)
6005 SUBEND
```

```
10   REM ***************** PROGRAM APUMP ************************
20  REM THIS PROGRAM SIMULATES  A CONVENTIONAL AIR TO AIR HEAT PUMP
30   PRINTER IS 0
50   OPTION BASE 1
60   STANDARD
70   COM Qevapx,Qcondx,Qelecx,Way4,Ton,Ualo,Teadp,Tamb,Kff,Pamb,Vcl,Tdl,Frach,Fr
acd,Exf,Expuad,Ao1,Ao2,Ao3,Bo1,Bo2,Bo3,Co1,Co2,Co3,Do1,Do2,Do3,Eo1,Eo2,Eo3
80   COM Fo1,Fo2,Fo3,Go1,Go2,Go3,Ho1,Ho2,Ho3,Io1,Io2,Io3,Tf5x,Qevapxs,Tf4xs,Kfd,
Qdhw,Qa5,Fracc,W,Cfmo,N
90   COM Tout(20),Tout1(20),Qf1(20),R1f(12),R2f(12),R3f(12),R4f(12),R5f(12),Trwf
(16),S(96),Sh(25),Sinb(24),Idnt(24),Trf(24),A(12),B(12),C(12),Dmo(13),Dec(12)
100  COM Mn$(12),Use(24),SHORT Tave(12),Tmax(12),Tdpa(12),Ttap(12),Vm(12),P(12),
Pf(12),Load(24)
110  COM REAL Lo,Lr,Tavyr,Opt1,Ua,Pf1,Dhw$,G,Gdhw,Cdhw,Tw,W1$,Twell,Qevap,Qelec,
Qcond,Cfm,Kfgwd,Ua34,Cfmi,Ua2o,Ua5o,Ua6h,Hum,Fua3,Qfan6,Qfan1
120  COM Kfdo,Rhx2,Hxf,Kfax,Opt2,Tilt,Ac,S,Sto$,Vs,Vst,Mcpsto,Tsto,Gnd$,Ua7o,Ff4
,Mcpgf,Tgnd,Lgnd,Dgnd,Do,Di,Rhognd,Cpgnd,Kpgnd,Depth,Apgnd,Qpumpo
130  COM Vpgnd,Mu,Rfilm,Rpvc,C1,R1,Delr,R2,R3,R4,R5,R6,R7,R8,R9,R10,R11,R12,R13,
Cf,C2,C4,C6,C8,C10,C12,Gf,G1x,G2,G3,G4,G5,G6,Tgn(12),Tgnx,Dz,Dpt,Lag,Col$(20)
140  DEG
150  PRINTER IS 0
160  PRINT LIN(2);TAB(18),"AIR TO AIR HEAT PUMP SIMULATION"
170  PRINT TAB(18),"---------------------------------------------------";LIN(2)
180  BEEP
190  DISP "INSERT 'Weath FILE #1' IN T14"
200  PAUSE
210  Day=0
220  Rhog=.2
230  Fd=.9
240  RESTORE 260
250  MAT READ Trwf
260  DATA .00001,3.0695,-3.671,1.4269,.39411,-.31951
270  RESTORE 290
280  MAT READ A,B,C,Dmo,Dec
290  DATA 390,385,376,360,350,345,344,351,365,378,387,391,.142,.144,.156,.18,.19
6,.205,.207,.201,.177,.16,.149,.142,.058,.06,.071,.097,.121,.134,.136
300  DATA .122,.092,.073,.063,.057,31,28,31,30,31,30,31,31,30,31,30,31,365,-20.0
8,-10.8,0.0,11.6,20.,23.45,20.6,12.3,0.0,-10.5,-19.8,-23.45
310  DATA JAN,FEB,MAR,APRIL,MAY,JUNE,JULY,AUG,SEPT,OCT,NOV,DEC
320  READ Mn$(*)
330  RESTORE 350
340  MAT READ R1f,R2f,R3f,R4f,R5f
350  DATA 1.0224,.9503,.9744,1.0121,1.0004,1.0316,1.1078,.9809,1.0821,.983,.8693
,1.0706
360  DATA 1.093,.976,.8443,1.0078,1.122,1.0674,.9133,1.021,.8638,.9056,.8845,.954
370  DATA .8911,.9626,.8958,.9037,.9787,1.0049,1.0855,1.0548,.9479,.8744,.9647,1
 .1239
380  DATA .9434,1.0983,1.1632,.9472,.9873,1.2305,1.1512,.9837,1.0675,.998,1.1866
,1.0278
390  DATA .8978,.8259,1.0913,1.0204,.9429,.8811,.853,1.1793,.9759,.995,1.0434,.9
938
400  RESTORE 420
410  MAT READ Use
420  DATA 0,0,0,0,0,0,.07,.07,.15,.07,.05,.04,.05,.08,.08,.02,.03,.04,.04,.1,.07
,.04,0,0
```

```
430  ASSIGN "Weath:T14" TO #1
440  INPUT "ENTER ID NUMBER OF DESIRED CITY",Lo
450  Lr=10*Lo
460  READ #1,Lr;Lo$,L
470  READ #1,Lr+2;Tave(*)
480  READ #1,Lr+3;Tmax(*)
490  READ #1,Lr+4;Tdpa(*)
500  READ #1,Lr+5;Ttap(*)
510  READ #1,Lr+7;Vm(*)
520  READ #1,Lr+8;P(*)
530  READ #1,Lr+9;Pf(*)
540  PRINT "WEATHER DATA SOURCE:";Lo$
550  INPUT "ENTER THE LOCAL AMBIENT PRESSURE ,PSI",Pamb
560  PRINT "LOCAL AMBIENT PRESSURE =";Pamb;"psi (for psychrometric calculations)"
570  PRINTER IS 16
580  PRINT PAGE
590  Opt1=2
591  PRINTER IS 0
600  INPUT "DOES SOLAR/HEAT PUMP HEAT DHW - Y/N ?",Dhw$
610  IF UPC$(Dhw$)="N" THEN G=0
620  IF UPC$(Dhw$)="Y" THEN PRINT "HEAT PUMP ASSISTS WITH DHW "
630  IF UPC$(Dhw$)="N" THEN PRINT "HEAT PUMP DOES NOT ASSIST WITH DHW "
640  IF UPC$(Dhw$)="N" THEN 770
650  INPUT "ENTER DHW GALLONS PER DAY ",G
660  PRINT "DHW GALLONS PER DAY =";G;"gal/day"
670  INPUT "ENTER DHW TANK SIZE, GALLONS ",Gdhw
680  PRINT "DHW TANK SIZE =";Gdhw;"gallons"
690  Cdhw=62.4*Gdhw/7.481
700  INPUT "ENTER DESIRED HOT WATER TEMP - Deg F",Tw
710  PRINT "HOT WATER DELIVERY TEMPERATURE =";Tw;"deg-F"
720  INPUT "ENTER 'W' IF WELL WATER ;'M' IF MUNICIPAL",Wl$
730  IF UPC$(Wl$)="M" THEN 770
740  INPUT "WELL WATER TEMP = DEG-F",Twell
750  PRINT "WELL WATER TEMP =";Twell;"deg-F"
760  ! ------------------------------------------------------------------------
770  INPUT "ENTER HEAT PUMP CAPACITY - TONS (2, 2.5,OR 3 TON)",Ton
780  PRINT "HEAT PUMP SIZE =";Ton;"ton unit"
790  Qevap=10000*Ton
800  Qelec=3500*Ton
810  Qcond=13500*Ton
820  IF Ton=2 THEN RESTORE 860
830  IF Ton=2.5 THEN RESTORE 870
840  IF Ton=3 THEN RESTORE 880
850  READ Ao1,Bo1,Co1,Do1,Eo1,Fo1,Go1,Ho1,Io1,Ao2,Bo2,Co2,Do2,Eo2,Fo2,Go2,Ho2,Io
2,Cfm,Kfgwd,Ua1o,Ua34,Qfan6
860  DATA 30467,-281.4,.6949,131.4,3.166,-.01806,12.48,-.1066,.0003061,7014,-41
 .34,.2002,-318.5,5.962,-.02027,3.010,-.05638,.0002264,1200,2966,1400,1866,137
870  DATA 37460,-348.2,.8561,-293.0,11.2,-.05341,18.48,-.1821,.0005914,8261,-47
 .87,.2134,-355.2,7.025,-.02531,3.481,-.0699,.0003073,1500,3708,1750,2172,171
880  DATA 33064,-198.2,.04768,323.6,1.513,-.01232,8.569,.03652,-.0004321,10132,-
57.67,.2333,-410.1,8.62,-.03287,4.188,-.09016,.0004288,1275,4450,1400,2666,206
890  RESTORE 910
900  READ Ao3,Bo3,Co3,Do3,Eo3,Fo3,Go3,Ho3,Io3,Ao4,Bo4,Co4,Do4,Eo4,Fo4,Go4,Ho4,Io
4
910  DATA -749.1,2.049,.01322,8.197,-.02691,-.126E-3,-.009312,.8925E-4,.3156E-6
```

```
920  DATA 95.64,.176,-.002156,.1971,-8.35E-4,9.568E-6,1.149E-7,9.637E-7,-1.18E-8
930  Kfgo=Kfwo=Kfdo=Kfg=Kfw=Kfd=Kfgwd
940  Cfmi=Cfm
941  Cfmo=1.4*Cfmi
950  Flowair=.3062*Cfmi*Pamb
960  Kfar=.24*Flowair
970  Cfmo=Cfmi=Cfm
980  Qfan1=Qfan6
990  Qpumpo=.14810*Kfgwd
1000 Ua1=Ua1o
1010 Ua2=Ua2o=900*Ton
1020 Ua3=Ua4=Ua3o=Ua4o=Ua34
1030 Ua5=Ua5o=Ua1o
1040 Ua6h=Ua1o
1050 Way4=0
1090 Hum=1
1130 ! ---------------------------------------------------------------------
1140 PRINTER IS 0
1150 FIXED 0
1160 PRINT "HEAT EXCHANGER UA FACTORS:"
1168 PRINT "  Ua1 = OUT SIDE AIR TO FREON CONDENSING HX UA FACTOR =";Ua1o;"Btu/h
r-deg-F"
1180 PRINT "  Ua5 = DHW LOOP-TO-FREON DESUPERHEAT HX UA FACTOR =";Ua5o;"Btu/hr-d
eg-F"
1190 PRINT "  Ua6h= HOUSE AIR-TO-FREON CONDENSING HX UA FACTOR =";Ua6h;"Btu/hr-d
eg-F"
1200 PRINT "  Ua6c= HOUSE AIR-TO-FREON EVAPORATING HX UA FACTOR IS COMPUTED WHEN
 APPLICABLE"
1210 ! ---------------------------------------------------------------------
1220 PRINT "THERMAL MASS FLOW RATES:"
1230 PRINT "  Kfd = DHW WATER LOOP Cp*MASS FLOW PRODUCT =";Kfdo;"Btu/hr-deg-F"
1240 PRINT "CFM FOR OUTSIDE AIR (HEAT REJECTION) FAN =";Cfmo;"cfm"
1250 PRINT "CFM FOR INSIDE AIR DUCT FAN =";Cfmi;"cfm"
1251 INPUT "EVAPORATOR LOSS DURING DEFROST MODE",Qevpty
1252 PRINT "EVAPORATOR LOSS DURING DEFROST MODE",Qevpty
1253 INPUT "EXTRA ELECTRICAL ENERGY TO COMPRESSOR DURING DEFROST",Elecpty
1254 PRINT "EXTRA ELECTRICAL ENERGY TO COMPRESSOR DURING DEFROST",Elecpty
1255 INPUT "ELECTRIC AUX DURING DEFROST MODE",Isqr
1256 PRINT "ELECTRIC AUX DURING DEFROST MODE",Isqr
1260 ! ---------------------------------------------------------------------
1270 Kfax=38.95*Cfmo*Pamb  !Cfmo*Pamb*60*.075*.24/14.696*530
1271 Kf=Kfax/.24
1280 DIM Qgsum(5),Tg4(5),Qwsum(5),Tw1(5),Tmtp(24)
1300 FOR T=1 TO 24
1310 Tmtp(T)=COS(15*(T-15))
1320 NEXT T
1330 INPUT "TOTAL DAILY ENERGY FOR LIGHTS AND APPLIANCES IN BTU",Qlappl
1340 PRINT "TOTAL DAILY ENERGY FOR LIGHTS AND APPLIANCES IN BTU= ";Qlappl
1350 PRINTER IS 0
1360 Tapeload:BEEP
1370 DISP "REMOVE PROGRAM CASSETT FROM T15. INSERT LOAD FILE IN T15"
1380 PAUSE
1381 DISP " REMOVE WEATHER TAPE FROM T14 AND INSERT RESULTS TAPE"
1382 PAUSE
1390 ASSIGN "LOADS:T15" TO #2
```

```
1400 INPUT "ENTER CITY POSITION ON LOAD TAPE",Cit
1401 ASSIGN "RESLTS:T14" TO #3
1402 INPUT "ENTER POSITION ON RESULTS TAPE",Citr
1410 Hloady=Cloady=Qdhwly=Qelecy=Qreshy=Qresdy=Qpumpy=Qfanly=Qa7cy=Qa7ry=Qcolly=
Qcollry=Qaly=Yflag=Cploosy=Dfrsty=Isqry=Qevapy=Qfan6y=0
1430 IF Ua5o .GT. 0 THEN Expuad=EXP(Ua5o/Kfdo)
1440 Tf1=170   ! INITIAL HEAT PUMP INPUT
1450 Tf2=140
1460 Tf3=135
1470 Tf4=Tf4x=140
1480 Tf5=Tf5x=25
1490 Tf6=25
1500 Qevap=Qcond=Qevapx=Qcondx=14000*Ton
1510 Ua6=800*Ton
1520 Tdhw=Td1=Tw
1530 ! ---------------------------------------------------------------
1540 Lr=(Cit-1)*370+1
1550 READ #2,Lr;Lo$,L1
1560 PRINT "LOAD DATA FOR HOME IN ";Lo$
1561 Lrrr=(Citr-1)*14+1
1562  PRINT #3,Lrrr;Lo$,","
1570 Rndweath:Cos1=COS(L1)
1580 Sin1=SIN(L1)
1590 Tan1=TAN(L1)*-1
1600 Crejc=Hrejc=0
1601 Vc1=53.5/Pamb/144
1610 Lbsair=25000*.075*Pamb/14.696
1620 Day=0
1630 FOR M=1 TO 12
1640 Cloadtm=Hloadm=Qdhwlm=Qelecm=Qreshm=Qresdm=Qpumpm=Qa7cm=Qa7rm=Qcollm=Qcollr
m=Qalm=Qfanlm=Qclnmt=Lntmt=Cploosm=Dfrstm=Isqrm=Qevapm=Qfan6m=0
1650 Tgn=Tgn(M)
1660 RANDOMIZE 2*PI/180/M
1670 FOR Dm=1 TO Dmo(M)
1680 Lr=Lr+1
1690 R1=RND*R1f(M)
1700 R2=RND*R2f(M)
1710 R3=RND*R3f(M)
1720 R4=RND*R4f(M)
1730 R5=RND*R5f(M)
1790 End:Tavedp=Taved
1800 Tswcp=Tswc
1810 R2=.5+ABS(R2-.5)*.25*SGN(R2-.5)
1820 Taved=2*Tave(M)-Tmax(M)+2*R2*(Tmax(M)-Tave(M))
1830 Tdpad=Tdpa(M)+.5*R3*(Taved-Tave(M))
1840 Vmd=Vm(M)*(8.306*R5**3-9.95*R5**2+4.158*R5-.0763)
1850 Tswc=R1*(Tmax(M)-Tave(M))*2
1860 Day=Day+1
1870 IF Day .GT. 1 THEN 1910
1880 Tavedp=Taved
1890 Tswcp=Tswc
1900 FIXED 3
1910 DISP "Rs=";Rs;"Taved=";Taved;"Tswc=";Tswc;"C1=";C1
1920 READ #2,Lr;Load(*)
1930 FOR T=1 TO 24
```

```
1940 Twl=Tsto
1950 Tf5x=Tf5
1961  IF (Qevap .LT. 10000) OR (Qevap .GT. 55000) THEN Qevap=42000
1962  IF (Qcond .LT. 10000) OR (Qcond .GT. 55000) THEN Qcond=42000
1963  IF (Qevapx .LT. 10000) OR (Qevapx .GT. 55000) THEN Qevapx=42000
1964  IF (Qcondx .LT. 10000) OR (Qcondx .GT. 55000) THEN Qcondx=42000
1970 Qa5=Qsto=B40=Dfrst=Qal=0
1980 Vmph=Vmd*(1.5-RND)  ! WIND VELOCITY
1990 IF Vmph .LT. 0 THEN Vmph=0
2000 IF T .GT. 3 THEN 2040
2010 Tavd=Tavedp
2020 Tswcn=Tswcp
2030 GOTO 2060
2040 Tavd=Taved
2050 Tswcn=Tswc
2060 Tamb=Tavd+Tswcn*Tmtp(T)
2070 IF T .NE. 3 THEN 2110
2080 Tend=Tamb
2090 Dt=Tend-Taved-Tswc*Tmtp(T)
2100 Tcc=Dt/4
2110 IF T .GT. 8 THEN 2150
2120 IF T .LT. 4 THEN 2170
2130 Tamb=Tamb+Dt*(1-(T-4)/5)
2140 GOTO 2170
2150 IF T .GT. 21 THEN 2170
2160 Tamb=Tamb-Tcc
2170 Kff=Kfa=Kfax/(Tamb+460)
2180 Exf=1/EXP(Ualo/Kff)-1
2210 Tsky=((Tamb+460)**4-2.14E10)**.25-460
2220 Tdp=Tdpad+.25*R4*Tswcn*Tmtp(T)!   DEW POINT TEMP
2225 IF Tamb .LT. 40 THEN B40=1
2230 IF Tdp .GT. Tamb THEN Tdp=Tamb
2231 Teadp=Tdp
2240 Hload=Cloads=Cloadl=Cloadt=Qresd=Qresh=Tcload=Sf=0
2250 IF Load(T)=0 THEN 2360
2260 IF Load(T) .GT. 0 THEN Hload=INT(Load(T)*100)+FRACT(Load(T))*Hum*100000
2270 IF Load(T) .LT. 0 THEN Cloads=-INT(Load(T)*100)
2280 IF Load(T) .LT. 0 THEN Cloadl=FRACT(ABS(Load(T)))*100000
2290 IF Load(T) .GT. 0 THEN Qclnmt=Qclnmt+Qball+Qbals
2300 IF Load(T) .GT. 0 THEN Qball=Qbals=0
2310 Tcload=Cloadl+Cloads
2320 Cloadl=Cloadl+Qball
2330 Cloads=Cloads+Qbals
2340 Qbals=Qball=0
2350 Cloadt=Cloads+Cloadl
2360 Kfd=Ua5=0
2370 Tds=Ttap(M)
2380 IF UPC$(W1$)="W" THEN Tds=Twell
2390 Qdhwl=Use(T)*8.24*G*(Tw-Tds)
2400 Qdhw2=Cdhw*(Tw-Tdhw)
2410 IF Qdhw2 .LT. 0 THEN Qdhw2=0
2420 Qdhw=Qdhwl+Qdhw2
2430 IF Qdhw .GT. 0 THEN Ua5=Ua5o
2440 IF Qdhw .GT. 0 THEN Kfd=Kfdo
2450 Frach=MIN(Hload/(12000*Ton),1)
```

```
2460 Fracd=MIN(Qdhw/(12000*Ton),1,1-Frach)
2470 Frac=MIN(Frach+Fracd,1)
2480 Fracc=MIN(Cloadt/(14000*Ton),1)
2490 IF Tdhw .GT. 150 THEN Fracd=0
2500 Td1=Tdhw
2520 IF (Hload=0) AND (Cloadt=0) THEN 2540
2530 GOTO 2550
2540 IF (Tave(M) .GT. 60) OR (Tsto .GT. 130) THEN 2600
2550 IF Cloadt .GT. 0 THEN 2600
2560 Ua6o=Ua6h
2570 IF Tf4 .LT. 80 THEN Tf4=130
2580 IF Tf5 .GT. 80 THEN Tf5=25
2590 GOTO Heating
2600 IF Tf4 .GT. 80 THEN Tf4=40
2610 IF Tf5 .LT. 80 THEN Tf5=130
2620 GOTO Cooling
2630 Heating: Qal=0
2631 Sf=1
2640 Qres=Qresh=Qresd=Qcondx=Qevapx=Qelecx=Qa5=Qa5o=Qa6=0
2650 IF Frach+Fracd=0 THEN 3660
2670 IF (Qevap .LT. 10000) OR (Qevap .GT. 40000) THEN Qext=Qevap=12000*Ton
2680 CALL Pvap(Tdp,Pamb,Peadp,Weadp)
2690 Vspea=Vcl*(Tamb+460)*(1.6078*Weadp)
2700 Hea=.24*Tamb+Weadp*(1061+.444*Tamb)
2702 FOR V=1 TO 4
2705 IF Frach=0 THEN 3500
2710 FOR W=1 TO 10
2720 Tladb=Tamb-Qevap*Vspea/Cfmo/14.146
2730 IF Tladb .GT. Teadp THEN 2770
2740 CALL Pvap(Tladb,Pamb,Pladb,Wladb)
2750 Larh=Peadp/Pladb
2751 IF Larh .GT. 1 THEN Larh=1
2760 IF Larh .LT. .7 THEN 2810
2770 Hdlt=Qevap*Vspea/Cfmo/60
2780 Hla=Hea-Hdlt
2790 Tladp=Teadp-1
2800 CALL Lvdb(Hla,Teadp,Weadp,Pamb,Tladp,Tladb,Larh)
2810 Yx=1.5*(Larh-.7)
2820 Yy=EXP(Yx+ABS(Yx))-1
2830 Tanh=(EXP(Yy)-EXP(-Yy))/(EXP(Yy)+EXP(-Yy))
2840 Ual=1.3*Ton*(280+181*Tanh)
2850 Ex=Ual*(Tamb-Tladb)/Qevap
2860 Tf5=(Tamb-Tladb*EXP(Ex))/(1-EXP(Ex))
2870 N=(Qevap/Ton/14000)**2
2880 X=Tf4+2*N
2890 Z=Tf5-3*N
2900 Qevap=Ao1+Bo1*X+Co1*X**2+Do1*Z+Eo1*X*Z+Fo1*Z*X**2+Go1*Z**2+Ho1*X*Z**2+Io1*
Z**2*X**2
2910 IF ABS(Qevap/Qext-1) .LT. .020 THEN 2960
2920 Qevap=(Qevap+Qext)/2
2930 Qext1=Qext
2940 Qext=Qevap
2941 FIXED 4
2950 NEXT W
2960 Qelec=Ao2+Bo2*X+Co2*X**2+Do2*Z+Eo2*X*Z+Fo2*Z*X**2+Go2*Z**2+Ho2*X*Z**2+Io2*
```

```
Z**2*X**2
2970 Qcond=.95*Qevap+Qelec-.05*Way4*Qevap
2980 Hf4=11.568+.2381*Tf4+.0003882*Tf4**2
2990 Hf5=104.5+.09884*Tf5-.0001823*Tf5**2
3000 Evapin=Qevap*(1-.05*Way4)
3010 Lbs=Evapin/(Hf5-Hf4)
3020 Hf1=(Qevap+Qelec)*.95/Lbs+Hf4
3030 X=Tf4
3040 Z=Hf1
3050 Tf1=Ao3+Bo3*X+Co3*X**2+Do3*Z+Eo3*X*Z+Fo3*Z*X**2+Go3*Z**2+Ho3*X*Z**2+Io3*Z*
*2*X**2
3060 IF Qdhw=0 THEN 3090
3070 IF Tf1 .LT. Td1 THEN 3090
3075 IF Tdhw .GT. 135 THEN 3090
3080 GOTO 3150
3090 Tf2=Tf1
3100 Hf2=Hf1
3110 Qa5=0
3120 Td2=Td1
3130 Fracd=0
3140 GOTO 3371
3150 IF Tf4 .GT. Td1 THEN 3250
3160 Tf42=Tf4*Tf4
3170 Tf43=Tf42*Tf4
3180 Kff=(.15085+3.2914E-4*Tf4+1.4689E-6*Tf42+1.9926E-8*Tf43)*Lbs
3190 Efua=EXP(Ua5*(1/Kff-1/Kfd))
3200 Uar=Kff*(1-Efua)/(Kff/Kfd-Efua)
3210 Qa5=Uar*(Tf1-Td1)
3215 IF Qa5 .GT. Qcond THEN Qa5=Qcond
3220 Tf2=Tf1-Qa5/Kff
3230 Td2=Td1+Qa5/Kfd
3240 GOTO 3320
3250 X=Z=Tf4
3260 GOSUB Hf
3270 Hf2=Hfp
3280 CALL Qa5p(Kfd,Ua4o,Td1,Hf1,Hf2,Ua5,Tf1,Tf4,Qa5,Td2,Lbs)
3290 Tf2=Tf4
3300 Qa5=Kfd*(Td2-Td1)
3310 IF Qa5 .GT. Qcond THEN Qa5=Qcond
3320 X=Tf4
3330 Z=Tf2
3331 Qa5o=Qa5
3340 GOSUB Hf
3350 Hf2=Hfp
3360 Fracd=MIN(Qdhw/Qa5,1)
3370 IF Qa5o .GT. Qdhw THEN Qa5=Qdhw
3371 IF B40=0 THEN 3380
3372 Frach=MIN((Hload+Qa5)/(Qcond+Isqr/.9-Qevpty/.9),.9)
3374 IF Frach+Fracd .GT. .9 THEN Fracd=.9-Frach
3375 Qresh=MAX(0,Hload+Qa5+Frach*((Qevpty-Isqr)/.9-Qcond-Qfan6))
3376 GOTO 3410
3380 Frach=MIN((Hload+Qa5)/(Qcond+Qfan6),1)
3390 IF Frach=1 THEN Qresh=Hload-Qcond+Qa5-Qfan6
3400 IF Frach=1 THEN 3430
3410 IF Fracd .LE. Frach THEN 3430
```

```
3420 GOTO 3500
3430 Tf2=Tf2*Fracd+(1-Fracd)*Tf1
3440 X=Tf4
3450 Z=Tf2
3460 GOSUB Hf
3470 Hf2=Hfp
3471 Qa5=Qdhw
3480 IF Fracd .LE. Frach THEN Fracd=0
3490 GOTO 3520
3500 CALL Dhwpmp(V)
3510 IF Fracd .GT. 1-Frach THEN Fracd=1-Frach
3520 Qa6=(Qcond+Qfan6-B40*Qevpty/.9)*Frach-Qa5
3521 IF Qa6 .LT. 0 THEN Qa6=0
3530 Qa5=Qa5+Fracd*Qcondx
3540 Eadb=65
3550 IF (T .GT. 6) AND (T .LT. 22) THEN Eadb=70   ! CHANGE PER HTLD PGM
3560 Ex=EXP(Ua6h/Kfar)
3561 Tf4b=Tf4
3570 Tf4=Eadb-Qcond*Ex/Kfar/(1-Ex)
3580 GOTO 3646
3590 Qresh=Hload
3600 Qcond=Qelec=Qevap=Frach=Fracd=Qa5=Qa6=0
3610 Tf2=Tf1
3646 IF ABS(Tf4-Tf4b) .LT. .05 THEN 3660
3650 NEXT V
3660 GOTO 6000
3670 Cooling:FIXED 2 !________________________________START COOLING OPTION
3671 Sf=-1
3680 Qa3d=Supht=0
3690 IF Cloadt=0 THEN Tf5=Td1+5
3700 Fracc=MIN(Cloadt/Qcond,1)
3710 FOR V=1 TO 3
3720 IF Fracc+Fracd=0 THEN 3740
3730 GOSUB Cpump
3740 NEXT V
3750 IF Qa6 .NE. 0 THEN 3771
3760 Qbals=Cloads+Cloadl
3771 IF Fracc+Fracd=0 THEN 3780
3772 IF Fracc=1 THEN 3780
3773 IF Fracd=1 THEN 3780
3774 Dfrst=Elecpty
3780 Qevapp=Fracc*Qevap
3790 Qcondp=Fracc*Qcond+Fracd*Qcondx
3800 Qelecp=Fracc*Qelec+Fracd*Qelecx+Dfrst
3810 Frac=Fracc+Fracd
3820 Qalm=Qalm+Qal
3910 GOTO 6040
3920 Cpump:Qcondx=Qelecx=Qevapx=0  !------------START HEAT PUMP COOLING
3921 Qa5o=Qa5=Qres=Qresd=Qresh=0
3925 IF Fracc=0 THEN 5175
4020 Tdb=Eadb=78
4030 Lbswat=.012*Lbsair+Cloadl/1075      ! .012 IS DESIRED HUM RATIO ?
4040 Wtdp=Lbswat/Lbsair
4050 CALL Pvap(Tdb,Pamb,Pwsdb,Wtsdb)
4060 Pwsdb=Pwsdb*.49118    ! PSI
```

```
4070 IF Wtdp .GT. Wtsdb THEN Wtdp=Wtsdb  ! LBS WATER/LB AIR
4080 Pwdb=Wtdp*Pamb/(.62198+Wtdp)
4090 Pwdp=Pwdb
4100 Rhdb=100*Pwdp/Pwsdb
4110 Twb=Tdb*(Rhdb/100)**.3    ! FIRST APPROX
4120 FOR Iwb=1 TO 3
4130 CALL Pvap(Twb,Pamb,Pwb,Wtwb)
4140 Pwb=Pwb*.49118
4150 Twb1=(1093*(Wtwb-Wtdp)-Tdb*(.24+.444*Wtdp))/(.556*Wtwb-Wtdp-.24)
4160 IF ABS(Twb1-Twb) .LT. .3 THEN 4190
4170 Twb=(Twb1+Twb)/2
4180 NEXT Iwb
4190 Tdp=Twb-.4*(Tdb-Twb)    ! FIRST APPROX
4191 FOR Iwb=1 TO 3
4200 CALL Pvap(Tdp,Pamb,Pgen,Wgen)
4210 IF ABS(Wgen/Wtdp-1) .LT. .020 THEN 4240
4220 Tdp=Tdp+.5*(Wtdp-Wgen)*Tdp/Wtdp
4230 NEXT Iwb
4240 FOR W=1 TO 5
4310 Ex=Ua6*(Tdb-Ladb)/Qevap
4320 Tf4=(Tdb-Ladb*EXP(Ex))/(1-EXP(Ex))
4330 IF Tf4 .LT. 600 THEN 4360
4340 Fracc=Fracd=Qa3=Qa4=Qcond=Qelec=Qcondx=Qelecx=Qa6=Qa5=Qa1=0
4350 RETURN
4360 GOSUB Psycho
4370 Yx=1.5*(Larh/100-.7)
4380 Yy=EXP(Yx+ABS(Yx))-1
4390 Tanh=(EXP(Yy)-EXP(-Yy))/(EXP(Yy)+EXP(-Yy))
4400 Ua6=1.3*Ton*(280+181*Tanh)
4410 N=(Qevap/Ton/14000)**2
4420 X=Tf5+2*N
4430 Z=Tf4-3*N
4440 Qevap=Ao1+Bo1*X+Co1*X**2+Do1*Z+Eo1*X*Z+Fo1*Z*X**2+Go1*Z**2+Ho1*X*Z**2+Io1*
Z**2*X**2
4450 IF ABS(Qevap/Qext-1) .LT. .020 THEN 4510
4460 Qevap=(Qevap+Qext)/2
4470 Qext1=Qext
4480 Qext=Qevap
4500 NEXT W
4510 X=Tf5+2*N
4520 Z=Tf4-3*N
4530 Qelec=Ao2+Bo2*X+Co2*X**2+Do2*Z+Eo2*X*Z+Fo2*Z*X**2+Go2*Z**2+Ho2*X*Z**2+Io2*
Z**2*X**2
4540 Qcond=.95*Qevap+Qelec-.05*Way4*Qevap
4550 Hf5=11.568+.2381*Tf5+.0003882*Tf5**2
4560 Hf4=104.5+.09884*Tf4-.0001823*Tf4**2
4570 Evapin=Qevap*(1-.05*Way4)
4580 Lbs=Evapin/(Hf4-Hf5)
4600 Hf1=(Qevap+Qelec)*.95/Lbs+Hf5
4610 X=Tf5
4620 Z=Hf1
4630 Tf1=Ao3+Bo3*X+Co3*X**2+Do3*Z+Eo3*X*Z+Fo3*Z*X**2+Go3*Z**2+Ho3*X*Z**2+Io3*Z*
*2*X**2
4640 IF Qdhw=0 THEN 4660
4650 IF Tf1 .GT. Td1 THEN 4720
```

```
4660 Tf2=Tf1
4670 Hf2=Hf1
4680 Qa5=0
4690 Fracd=0
4700 Td2=Td1
4710 GOTO 4930
4720 IF Tf5 .GT. Td1 THEN 4820
4730 Tf52=Tf5*Tf5
4740 Tf53=Tf52*Tf5
4750 Kff=(.15085+3.2914E-4*Tf5+1.4689E-6*Tf52+1.9926E-8*Tf53)*Lbs
4760 Efua=EXP(Ua5*(1/Kff-1/Kfd))
4770 Uar=Kff*(1-Efua)/(Kff/Kfd-Efua)
4780 Qa5=Qa5o=Uar*(Tf1-Td1)
4781 IF Qa5 .GT. Qcond THEN Qa5=Qa5o=Qcond
4790 Tf2=Tf1-Qa5/Kff
4800 Td2=Td1+Qa5/Kfd
4810 GOTO 4890
4820 X=Z=Tf5
4830 GOSUB Hf
4840 Hf2=Hfp
4850 CALL Qa5p(Kfd,Ua4o,Td1,Hf1,Hf2,Ua5,Tf1,Tf5,Qa5,Td2,Lbs)
4860 Tf2=Tf5
4870 Qa5=Qa5o=Kfd*(Td2-Td1)
4880 IF Qa5 .GT. Qcond THEN Qa5=Qa5o=Qcond
4890 X=Tf5
4900 Z=Tf2
4910 GOSUB Hf
4920 Hf2=Hfp
4930 Qlat1=Flowair*1061*(Wtdp-Wtladp)
4940 IF Qlat1 .GE. Qevap THEN Fracc=1
4950 IF Qlat1 .GE. Qevap THEN 4980
4960 IF Qlat1*Fracc .GT. Cloadl THEN Qlat1=Cloadl/Fracc
4970 Fracc=MIN(Cloads/(Qevap-Qlat1-Qfan6),1)
4980 IF Qa5=0 THEN 5010
4990 Fracd=MIN(Qdhw/Qa5,1)
4991 Qa5=Qa5o=MIN(Qdhw,Fracc*Qa5o)
5000 IF Tdhw .GT. 150 THEN Fracd=0
5010 IF Fracc .LE. 1 THEN 5050
5020 Qbals=Cloads+Cloadl-Qevap+Qfan6
5030 Lntmt=Lntmt+1
5040 Fracc=1
5050 Qlat=Fracc*Qlat1
5060 Qball=Qballp=Cloadl-Qlat
5070 IF Qball .LT. 0 THEN Qball=0
5080 IF Fracd .GE. Fracc THEN 5100
5081 Fracd=0
5090 IF Tf2 .GT. Tf5 THEN Tf2=Tf2*Fracd+(1-Fracd)*Tf1
5100 X=Tf5
5110 Z=Tf2
5120 Hf2=Ao4+Bo4*X+Co4*X**2+Do4*Z+Eo4*X*Z+Fo4*Z*X**2+Go4*Z**2+Ho4*X*Z**2+Io4*Z*
*2*X**2
5130 IF Fracd=0 THEN 5180
5140 IF Fracc .LT. Fracd THEN 5170
5160 GOTO 5180
5170 IF Fracd=0 THEN 5180
```

```
5175 CALL Dhwpmp(V)
5180 IF Fracd .GT. 1-Fracc THEN Fracd=1-Fracc
5181 Qa1=Qcond*Fracc-Qa5-Qevapx*Fracd
5182 IF Fracc=0 THEN 5200
5185 Tf5=Tamb-(Qcond-Qa5/Fracc)/Kfa/Exf
5190 Qa6=(Qevap-Qfan6)*Fracc
5200 Qa5=Qa5o+Fracd*Qcondx
5240 RETURN ! ---------------------END HEAT PUMP COOLING
5250 Hf:X2=X*X
5260 Z2=Z*Z
5270 Hfp=Ao4+Bo4*X+Co4*X2+Do4*Z+Eo4*X*Z+Fo4*Z*X2+Go4*Z2+Ho4*X*Z2+Io4*Z2*X2
5280 RETURN
5290 Psycho:CALL Pvap(Tdb,Pamb,Pws,Wts)
5300 CALL Pvap(Tdp,Pamb,Pwd,Wtdp)
5310 Relh=100*Pwd/Pws
5320 Twb1=Twb                          ! ESTIMATE T WET BULB
5330 FOR Iwb=1 TO 3
5340 CALL Pvap(Twb1,Pamb,Pwb,Wtwb)
5350 Twb=(1093*(Wtwb-Wtdp)-Tdb*(.24-.444*Wtdp))/(.556*Wtwb-Wtdp-.24)
5360 IF ABS(Twb-Twb1) .LT. .5 THEN 5390
5370 Twb1=.5*(Twb+Twb1)
5380 NEXT Iwb
5390 Vpsy=.3701*(Tdb+460)*(1+1.6078*Wtdp)/Pamb
5400 Hpsy=.24*Tdb+Wtdp*(1061+.444*Tdb)
5410 Hdelt=Qext*Vpsy/(Cfm*60)
5420 IF Ladb .LT. Tdp THEN 5460      ! DEHUMIDIFICATION OCCURS
5430 CALL Pvap(Ladb,Pamb,Pladb,Wtladb)
5440 Larh=100*Pwd/Pladb
5450 IF Larh .LT. 70 THEN 5590
5460 Hea=Hpsy
5470 Hla=Hea-Hdelt
5480 Wteadp=Wtdp
5490 Tladp=Tdp-1  ! ESTIMATE Lv AIR DEW PT - DEHUMID
5491 FOR Iwb=1 TO 3
5500 CALL Pvap(Tladp,Pamb,Pladp,Wtladp)
5510 Ladbx=(Hla-Wtladp*1061)/(.24+Wtladp*.444)
5520 CALL Pvap(Ladbx,Pamb,Pladb,Wtladb)
5530 Larhx=100*Pladp/Pladb
5540 Xrh=(Wteadp-Wtladp)*1000
5550 Larh=70+30*(1-1/EXP(Xrh))
5560 IF ABS(Larhx/Larh-1) .LT. .3 THEN 5590
5570 Tladp=Tladp+5*(460/(Ladbx+460))*(Larh-Larhx)/100
5580 NEXT Iwb
5590 Ladb=Ladbx
5600 RETURN
6000 Qevapp=Frach*Qevap+Fracd*Qevapx
6001 Dfrst=Elecpty*Frach*B40/.9
6002 Qevapm=Qevapm+Qevapp
6003 IF B40=1 THEN 6010
6004 IF Frach+Fracd=0 THEN 6010
6005 IF Frach=1 THEN 6010
6006 IF Fracd=1 THEN 6010
6007 Dfrst=Elecpty
6010 Qcondp=Frach*Qcond+Fracd*Qcondx
6015 Qelecp=Frach*Qelec+Fracd*Qelecx+Dfrst
```

```
6022 Qelecp=Qelecp
6023 Supht=B40*Isqr*Frach/.9
6030 Frac=Frach+Fracd
6040 Tdhw=Tdhw+(Qa5-Qdhwl)/Cdhw
6041 IF Tdhw .GT. 110 THEN 6047
6042 Qresd=10239
6043 Tdhw=Tdhw+10239/Cdhw
6047 Qres=Qresh+Supht+Qresd
6048 IF Sf=1 THEN Cploos=Qevapp+Qelecp+Qres+Qfan6*Frach-Hload-Qa5
6049 IF Sf=-1 THEN Cploos=Qelecp+Qevapp-Qa1-Qa5+Qres
6360 Qballp=0
6370 Hloadm=Hloadm+Hload
6371 Isqrm=Isqrm+Supht
6380 Cloadtm=Cloadtm+Tcload
6390 Qdhwlm=Qdhwlm+Qdhwl
6400 Qelecm=Qelecm+Qelecp
6410 Qreshm=Qreshm+Qresh
6420 Qresdm=Qresdm+Qresd
6425 Fnfrc=Frach*(B40*.11111+1)
6430 Qfanlp=Qfanl*(Fracc+Fracd+Fnfrc)
6431 Qfanlm=Qfanlm+Qfanlp
6440 Qfan6m=Qfan6m+(Fracc+Fnfrc)*Qfan6
6441 Cploosm=Cploosm+Cploos
6442 Dfrstm=Dfrstm+Dfrst
6450 NEXT T
6460 Qclnmt=Qclnmt+Qball+Qbals
6470 Qball=Qbals=0
6480 NEXT Dm
6481 PRINTER IS 0
6482 Hloadm=Hloadm/1000
6483 Cloadtm=Cloadtm/1000
6484 Qdhwlm=Qdhwlm/1000
6485 Qelecm=Qelecm/1000
6486 Qreshm=Qreshm/1000
6487 Qresdm=Qresdm/1000
6488 Qfan6m=Qfan6m/1000
6489 Qfanlm=Qfanlm/1000
6490 Qevapm=Qevapm/1000
6491 Qalm=Qalm/1000
6492 Cploosm=Cploosm/1000
6493 Dfrstm=Dfrstm/1000
6494 Isqrm=Isqrm/1000
6495 Qclnmt=Qclnmt/1000
6499 PRINTER IS 0
6500 FIXED 0
6510 PRINT LIN(2),Mn$(M)
6520 PRINT "  SPACE HEATING ENERGY REQUIRED  ";Hloadm;"MBTU"
6530 PRINT "  SPACE COOLING ENERGY REQUIRED  ";Cloadtm;"MBTU"
6540 PRINT "  DOMESTIC HOT WATER ENERGY REQUIRED  ";Qdhwlm;"MBTU"
6550 PRINT LIN(1)," NONRENEWABLE ENERGY CONSUMPTION"
6560 PRINT "  ELECTRICITY FOR HEAT PUMP  ";Qelecm/3.413;"KWH    ";Qelecm;"MBTU"
6570 PRINT "  AUXILIARY ELECTRIC FOR SPACE HEATING  ";Qreshm/3.413;"KWH   ";Qres
hm;"MBTU"
6580 PRINT "  AUXILIARY ELECTRIC FOR DOMESTIC HOT WATER  ";Qresdm/3.413;"KWH   "
;Qresdm;"MBTU"
```

```
6590 PRINT "  ELECTRICITY FOR INSIDE FAN   ";Qfan6m;"MBTU"
6600 PRINT "  ELECTRICITY FOR OUTSIDE FAN   ";Qfanlm;"MBTU"
6610 PRINT "  ENERGY CONSUMMED BY LIGHTS AND APPLIANCES  ";Qlappl*Dmo(M);"MBTU"
6620 PRINT LIN(1)," FREE ENERGY"
6625 PRINT "  ENERGY COLLECTED FROM OUTSIDE IN WINTER  ";Qevapm;"MBTU"
6626 PRINT "  ENERGY REJECTED TO OUTSIDE IN SUMMER  ";Qalm;"MBTU"
6631 PRINT LIN(1),"COMPRESSOR LOSSES AND PENIALTIES"
6632 PRINT "  COMPRESSOR LOSSES  ";Cploosm
6633 PRINT "  DEFROST PENIALTY  ";Dfrstm
6634 PRINT "  AUX HEAT DURING DEFROST CYCLE  ";Isqrm
6640 PRINT LIN(1),"COOLING LOADS NOT MET"
6650 PRINT "  COOLING LOADS NOT MET ";Qclnmt;" MBTU"
6660 PRINT "  HOURS WHEN COOLING LOADS NOT MET ";Lntmt;" HOURS"
6670 FIXED 3
6680 PRINT LIN(1),"COP"
6685 Copepf=(Hloadm+Cloadtm+Qdhwlm)/(Qelecm+Qreshm+Qresdm)
6690 PRINT "  EXCLUDING FAN ENERGIES   ";Copepf
6695 Cop=(Hloadm+Cloadtm+Qdhwlm)/(Qelecm+Qreshm+Qresdm+Qfanlm+Qfan6m)
6700 PRINT "  INCLUDING FAN ENERGIES   ";Cop
6701 Lrrr=Lrrr+1
6702 PRINT #3,Lrrr;Hloadm,Cloadtm,Qdhwlm,Qelecm,Qreshm,Qresdm,Qfan6m,Qfanlm,Qeva
pm,Qalm,Cploosm,Dfrstm,Isqrm,Qclnmt,Lntmt,Copepf,Cop
6710 Hloady=Hloady+Hloadm
6715 Qevapy=Qevapy+Qevapm
6720 Cloady=Cloady+Cloadtm
6730 Qdhwly=Qdhwly+Qdhwlm
6740 Qelecy=Qelecy+Qelecm
6750 Qreshy=Qreshy+Qreshm
6760 Qresdy=Qresdy+Qresdm
6770 Qpumpy=Qpumpy+Qpumpm
6780 Qfanly=Qfanly+Qfanlm
6785 Qfan6y=Qfan6y+Qfan6m
6790 Qaly=Qaly+Qalm
6791 Cploosy=Cploosy+Cploosm
6792 Dfrsty=Dfrsty+Dfrstm
6793 Isqry=Isqry+Isqrm
6800 IF Yflag .GT. 0 THEN 5610
6810 NEXT M
6820 Hloadm=Hloady
6830 Cloadtm=Cloady
6840 Qdhwlm=Qdhwly
6850 Qelecm=Qelecy
6860 Qreshm=Qreshy
6861 Qevapm=Qevapy
6870 Qresdm=Qresdy
6880 Qpumpm=Qpumpy
6890 Qfanlm=Qfanly
6891 Qfan6m=Qfan6y
6900 Qalm=Qaly
6901 Isqrm=Isqry
6902 Cploosm=Cploosy
6903 Dfrstm=Dfrsty
6910 PRINT LIN(2),"YEAR"
6920 Yflag=1
6930 GOTO 6520
```

```
6940 SUB Dhwpmp(V)
6950 COM Qevapx,Qcondx,Qelecx,Way4,Ton,Ualo,Teadp,Tamb,Kff,Pamb,Vcl,Tdl,Frach,Fr
acd,Exf,Expuad,Ao1,Ao2,Ao3,Bo1,Bo2,Bo3,Co1,Co2,Co3,Do1,Do2,Do3,Eo1,Eo2,Eo3
6960 COM Fo1,Fo2,Fo3,Go1,Go2,Go3,Ho1,Ho2,Ho3,Io1,Io2,Io3,Tf5x,Qevapxs,Tf4xs,Kfd,
Qdhw,Qa5,Fracc,W,Cfmo,N
6970 Qevapm=36000*Ton
6980 Qevapx=Qevapxs
6990 IF V=1 THEN Qevapxs=Qevapx=12000*Ton
7000 Tf4x=150
7010 IF V .GT. 1 THEN Tf4x=Tf4xs
7111 IF (Qevapx .LT. 10000) OR (Qevapx .GT. 40000) THEN Qevapxs=Qevapx=12000*Ton
7112 CALL Pvap(Teadp,Pamb,Peadp,Weadp)
7113 Vspea=Vcl*(Tamb+460)*(1.6078*Weadp)
7114 Hea=.24*Tamb+Weadp*(1061+.444*Tamb)
7115 FOR Wx=1 TO 4
7116 FOR W=1 TO 10
7117 Tladb=Tamb-Qevapx*Vspea/Cfmo/14.146
7118 IF Tladb .GT. Teadp THEN 7123
7119 CALL Pvap(Tladb,Pamb,Pladb,Wladb)
7120 Larh=Peadp/Pladb
7121 IF Larh .LT. .7 THEN 7127
7123 Hdlt=Qevapx*Vspea/Cfmo/60
7124 Hla=Hea-Hdlt
7125 Tladp=Teadp-1
7126 CALL Lvdb(Hla,Teadp,Weadp,Pamb,Tladp,Tladb,Larh)
7127 Yx=1.5*(Larh-.7)
7128 Yy=EXP(Yx+ABS(Yx))-1
7129 Tanh=(EXP(Yy)-EXP(-Yy))/(EXP(Yy)+EXP(-Yy))
7130 Ual=2*Ton*(280+181*Tanh)
7131 Ex=Ual*(Tamb-Tladb)/Qevapx
7132 Tf5x=(Tamb-Tladb*EXP(Ex))/(1-EXP(Ex))
7134 X=Tf4x+2*N
7135 Z=Tf5x-3*N
7136 Qevapx=Ao1+Bo1*X+Co1*X**2+Do1*Z+Eo1*X*Z+Fo1*Z*X**2+Go1*Z**2+Ho1*X*Z**2+Io1
*Z**2*X**2
7137 IF ABS(Qevapx/Qevapxs-1) .LT. .020 THEN 7260
7138 Qevapx=(Qevapx+Qevapxs)/2
7140 Qevapxs=Qevapx
7250 NEXT W
7260 Qelecx=Ao2+Bo2*X+Co2*X**2+Do2*Z+Eo2*X*Z+Fo2*Z*X**2+Go2*Z**2+Ho2*X*Z**2+Io2
*Z**2*X**2
7270 Qevapxs=Qevapx
7280 Qcondx=.95*Qevapx+Qelecx-.05*Way4*Qevapx
7290 Hf4x=11.568+.2381*Tf4x+.0003882*Tf4x**2
7300 Hf5x=104.5+.09884*Tf5x-.0001823*Tf5x**2
7310 Evapinx=Qevapx*(1-.05*Way4)
7320 Lbsx=Evapinx/(Hf5x-Hf4x)    ! EVAP LBS
7330 Hf1x=(Qevapx+Qelecx)*(.95-.05*Way4)/Lbsx+Hf4x
7340 Hf2x=Hf1x
7350 X=Tf4x
7360 Z=Hf1x
7370 Tf1x=Ao3+Bo3*X+Co3*X**2+Do3*Z+Eo3*X*Z+Fo3*Z*X**2+Go3*Z**2+Ho3*X*Z**2+Io3*Z
**2*X**2
7380 Tf2x=Tf1x
7390 Kf=Kfd
```

```
7400 Tin=Td1
7410 Tcon=Tf4x
7420 Ua=Ua5o
7430 Q=Kfd*((Tin-Tcon)/Expuad+Tcon-Tin)
7440 Qhx=ABS(Q)
7450 IF ABS(Qhx/Qcondx-1) .LT. .020 THEN 7530
7460 Tf4x=Tf4x+(Qcondx-Qhx)*(Tf4x-Td1)/Qcondx
7470 IF Tf4x .LT. Tin THEN Tf4x=Tcon-(Tcon-Tin)/2
7480 IF Tf4x .LT. Tin THEN 7510
7490 NEXT Wx
7500 GOTO 7530
7510 Qcondx=Q=Fracd=Qevapx=Qelecx=0
7520 GOTO 7550
7530 Fracd=(Qdhw-Qa5)/Qcondx
7540 Tf4xs=Tf4x
7550 SUBEND
7560 SUB Pvap(O,Pamb,Pgen,Wgen)
7570 IF O .LT. 32 THEN Lt32
7580 Pgen=6.75E-50*(O+460)**18
7590 GOTO Humrto
7600 Lt32:Pgen=9.65E-69*(O+460)**25
7610 Humrto:Wgen=.622*Pgen/(Pamb*2.036-Pgen)
7620 SUBEND
7630 SUB Qa5p(Kfd,Ua4,Td1,Hf1,Hf2,Ua5,Tf1,Tf4,Qa5,Td2,Lbs)
7640 I=0
7650 Xx=.8
7660 Td12=Tf4-(Tf4-Td1)/EXP(Ua4*Xx/Kfd)
7670 I=I+1
7680 IF I .GT. 10 THEN 7750
7690 Qa52=Lbs*(Hf1-Hf2)
7700 Td2=Td12+Qa52/Kfd
7710 Xg=1-Qa52/Ua5*LOG((Tf1-Td2)/(Tf4-Td12))/(Tf1-Td2-(Tf4-Td12))
7720 IF ABS((Xx-Xg)/Xx) .LE. .01 THEN 7750
7730 Xx=Xg
7740 GOTO 7660
7750 Qa5=Kfd*(Td2-Td1)
7760 SUBEND
7770 SUB Lvdb(Hla,Teadp,Weadp,Pamb,Tladp,Tladb,Larh)
7772 FIXED 5
7780 Itc=0
7790 CALL Pvap(Tladp,Pamb,Pladp,Wladp)
7800 Rhla=.7+.3*(1-1/EXP(1000*(Weadp-Wladp)))
7810 Tladb=(Hla-Wladp*1061)/(.24+Wladp*.444)
7820 Itc=Itc+1
7830 CALL Pvap(Tladb,Pamb,Pladb,Wladb)
7840 Larh=Pladp/Pladb
7841 IF Larh .GT. 1 THEN Larh=1
7850 IF ABS(Rhla-Larh) .LT. .05 THEN Done
7870 Rhla=(Rhla+Larh)/2
7871 IF Rhla .GT. .98 THEN Rhla=.98
7880 Wladp=Weadp-.001*LOG(1/(1-(Rhla-.7)/.3))
7881 IF Wladp .LT. 0 THEN Wladp=0
7890 Pladp=Wladp*Pamb/(.622+Wladp)
7900 GOTO 7810
7930 Done:IF Pladp .GT. .1926 THEN Gt32
```

```
7940 Tladp=(Pladp/9.5E-70)**.04
7950 GOTO 7970
7960 Gt32:Tladp=(Pladp/6.75E-75)**.055555
7970 SUBEND
```


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