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FINAL REPORT

SOLAIR HEATER PROGRAM

SOLAIR APPLICATIONS STUDY

CONTRACT NO. EY-76-C-02-2705

PREPARED FOR

THE

UNITED STATES

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

GENERAL ELECTRIC COMPANY
ADVANCED ENERGY PROGRAMS
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DISCLAIMER

FOREWORD

This research and development program was conducted by General Electric Company at the solar facility of the Space Division at Valley Forge, Pennsylvania. The work was sponsored by the Solar Research and Development Branch of the Solar Energy Division, Department of Energy, Frederick H. Morse, Branch Chief. Program managers for DOE were Lonnie Taylor and Michael Maybaum with technical contract monitoring by Walter Adams, Sandia Laboratories. Their assistance and guidance is gratefully acknowledged.

The results of the Solair Heater Program are contained in three separate final reports corresponding to the three parts of the program. Document COO/2705-1 (GE Document No. 77SDS4260) presents the results of the design and fabrication part or Part I of the program. This report includes the system requirements task, the detailed design task, the fabrication and assembly task, and the test planning task. Document COO/2705-2 (GE Document No. TLSDS4261). This report presents the results of the test program on Part II. It includes the data acquisition on test operations task and the data analysis task. These two parts comprised the research and development program for the Solair. The The third part of the program consisted of the Solair applications study contained in Report C00/2705-3 (GE Document No. 77SDS4262). Continuation of the effort to develop a commercialized version of the Solair is effected via the Medium Temperature Air Heater Program under DOE Contract EG-77-C-04-4127.

ACKNOWLEDGEMENT

"This work has been supported by the Solar Heating and Cooling Research and Development Branch, Office of Conservation and Solar Applications, U.S. Department of Energy."

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SECTION 1

INTRODUCTION

General Electric has designed and tested a low-cost solar system using a vacuum tube solar air heater under ERDA Contract E(11-1)-2705. This contract extension has been provided to evaluate various applications of this solar collector. The evaluation identified attractive applications, evaluated corresponding control procedures, estimated system performance, compared economically insolation and insulation, and evaluated the repackaging of off-the-shelf equipment for improved cost effectiveness.

The results of this study prompted General Electric's marketing group to do a detailed commercialization study of a residential domestic water heating system using the Solair concept which has been selected as the most attractive application.

Other attractive applications are space/domestic water heating and a heat pump assisted solar system/domestic water heating where the heat pump and the solar system function in parallel.

A prime advantage of heated air solar systems over liquid systems is cost and longer life which results in higher BTU's/dollar. Other air system advantages are no liquid leakage problems, no toxicity or freezing problems, and less complicated equipment.

A hybrid solar system has been identified that can improve the market penetration of solar energy. This system would use the existing mass of the house for energy storage thereby reducing solar cost and complexity. Adequate performance can be obtained with house temperature swings comparable to those used in nighttime setback of the thermostat. Details of this system are provided in the report.

SECTION 2

MAJOR CONCLUSIONS

Major conclusions inferred from this investigation are:

a. Air is a very attractive medium for solar systems but requires higher collector operating temperatures than required with liquid working fluids because of its heat transfer characteristics. Solair, with its vacuum tube collectors, is well suited for air operation and consequently provides the potential for low cost, an inherent advantage of air systems.

b. Domestic water heating is a prime application for the Solair concept primarily because of the low initial system cost, year-round operation, ease of integration with the conventional system, and flexibility associated with the installation of smaller solar systems. A more detailed description of performance is provided in Section 5.0.

c. Another attractive application for Solair is space/domestic water heating with backup provided by fossil fuel, resistive heating, or a heat pump. Section 5.0 contains a description and performance estimates for these systems.

d. An attractive hybrid space heating system has been identified that features lower initial cost and a very simple and reliable hardware configuration using an active Solair collector with the passive house structure for energy storage. For smaller solar arrays, the performance of this hybrid system is comparable to that with dedicated rock storage. This approach is described in Section 5.0.

e. When using a solar system for space heating with a heat pump as backup, independent (parallel) operation of these two was found to be the most desirable method of operation.

f. A solar water heating system can be economically competitive with additional insulation for a house that is already insulated.

More detailed conclusions can be found under the specific task sections.

SECTION 3

IDENTIFICATION OF ATTRACTIVE APPLICATIONS (TASK 1)

3.1 OBJECTIVE

The objective of this task was identification of attractive applications and system configurations using the Solair collector as a nucleus. An evaluation of the use of heat pipes to enhance the performance of the various systems identified was also required.

3.2 SUMMARY

Attractive applications of the Solair collector are described. A system dedicated to domestic water heating only is one of the prime configurations because of good performance and low initial cost. Other attractive applications are also detailed.

3.3 ATTRACTIVE APPLICATIONS OF SOLAIR

The criteria used to establish the more attractive applications for Solair is marketability which translates to low initial system cost, widespread applicability, flexibility of installation in various situations and high BTU/$ (payback). Since system cost is largely influenced by the size of the collector array, systems that function satisfactorily with small collector areas fulfill the low initial cost criteria. Flexibility of installation is satisfied by systems with small arrays and lesser sensitivity to tilt angle. The BTU/$ criteria is influenced by yearly duration of energy demand and system efficiency at the required temperature.

3.3.1 CONFIGURATION 1: DOMESTIC WATER HEATING ONLY

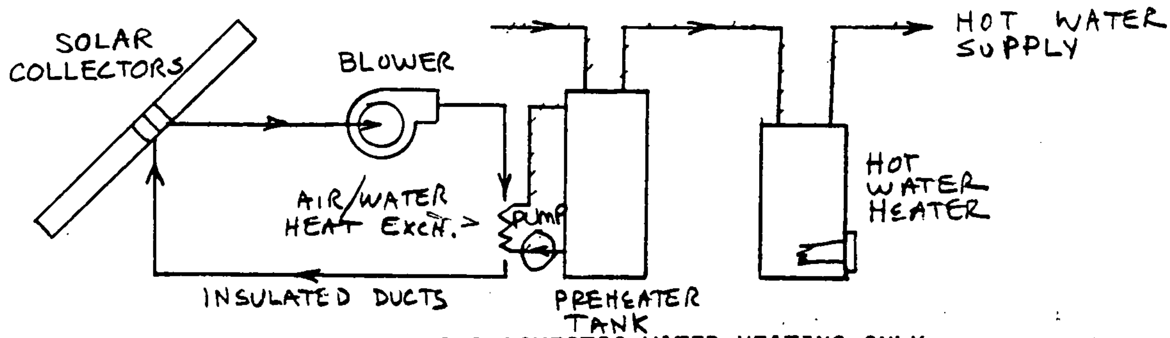


Figure 1-1 DOMESTIC WATER HEATING ONLY

Air is heated by the collectors and is blown across an air to water heat exchanger. Thermosyphon action circulates water between the heat exchanger and the holding tank. In some situations, a circulating pump may be necessary for circulating the water. A heat pipe is well suited to provide this heat exchange.

This type of system is particularly attractive in areas that require freeze protection in the winter. When compared to a water system, this configuration is cheaper because it eliminates the cost of a number of components.

A number of control procedures can be used with this configuration, and are described below. The most attractive approach will be selected as described in Task 2 of the proposal.

Control Option 1A:

solar blower - turned on with solar integrator or solar switch. (to be described at a later date)

Control Option 1B:

solar blower - use temperature sensor in collector to turn on the blower and a differential switch (collector inlet to outlet) to keep blower on.

Control Option 1C:

solar blower - use only temperature sensor in collector to keep blower on (this is good with heat pipe).

Control Option 1D:

solar blower - use only differential temperature switch (collector inlet to outlet) to control variable speed blower. (This is also good with heat pipe.)

Control Option 1E: (if circulating pump required)

solar blower - may use either solar switch or collector temperature to actuate the blower.

pump - use differential thermostat (bottom on preheater tank to air supply).

3.3.2 CONFIGURATION 2: SPACE AND DOMESTIC WATER HEATING (W/O ROCK STORAGE)

This configuration features a low cost system with no dedicated thermal storage, and is particularly effective for systems having low solar contribution. With a minimal investment in a special thermostat (See option 2D), it is possible to use the heat capacity of the house structure to improve system performance. Heat pump systems will be described later.

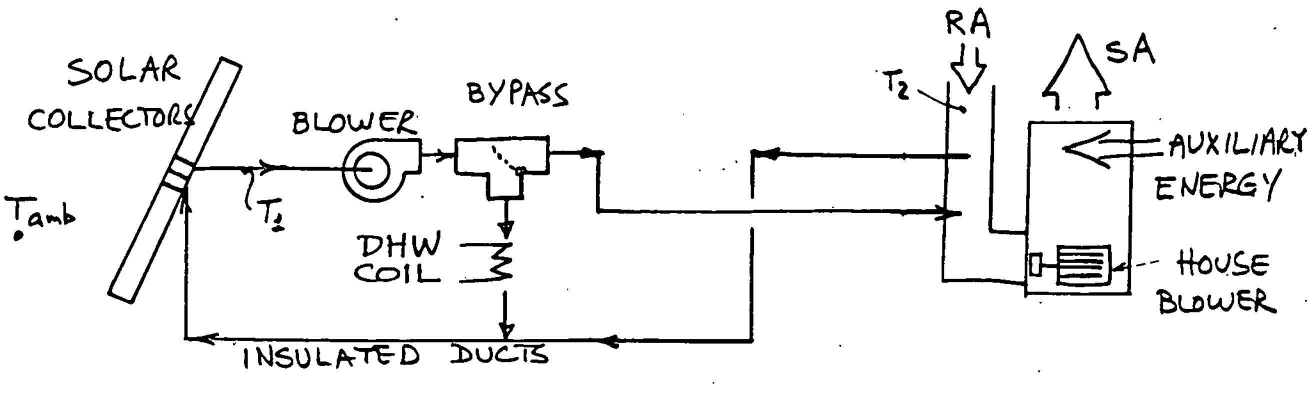


Figure 3-2. SPACE AND DOMESTIC WATER HEATING (W/O ROCK STORAGE)

Control Option 2A:

Auxiliary energy controlled by one stage thermostat, but if $T_1 \geq T_2 + 30°F.$ and $T_{amb} \geq 40°F.$, auxiliary energy is off.

solar blower - use either solar integrator or solar switch for actuation.

house blower - controlled by one stage thermostat and comes on when there is a call for heat.

DHW - heat pipe or thermosyphon type preferred, but if configuration restricted, use pump and actuate by ΔT.

damper - to furnace if there is space heating demand and solar fan on, bypass otherwise.

Control Option 2B:

solar blower - use temperature sensor in collector to turn on blower and a differential switch (collector inlet to outlet) to keep blower on. Other controls are unchanged.

Control Option 2C:

solar blower - use only temperature sensor in collector to keep blower on.

Control Option 2D:

use two stage T/S with auxiliary energy controlled by 2nd stage and solar set to satisfy 1st stage.

1st stage of T/S will control damper so that if solar is available it will be used to heat house to satisfy 1st stage temperature.

3.3.3 CONFIGURATION 3: SPACE AND DOMESTIC WATER HEATING (WITH ROCK STORAGE)

This is similar to Configuration 2, but features thermal energy storage in rocks and a second blower in the solar system. Although it is possible to eliminate the second blower by passing all the return air through the rocks, it is felt that the configuration shown is more desirable in general. Heat pump systems will be described later.

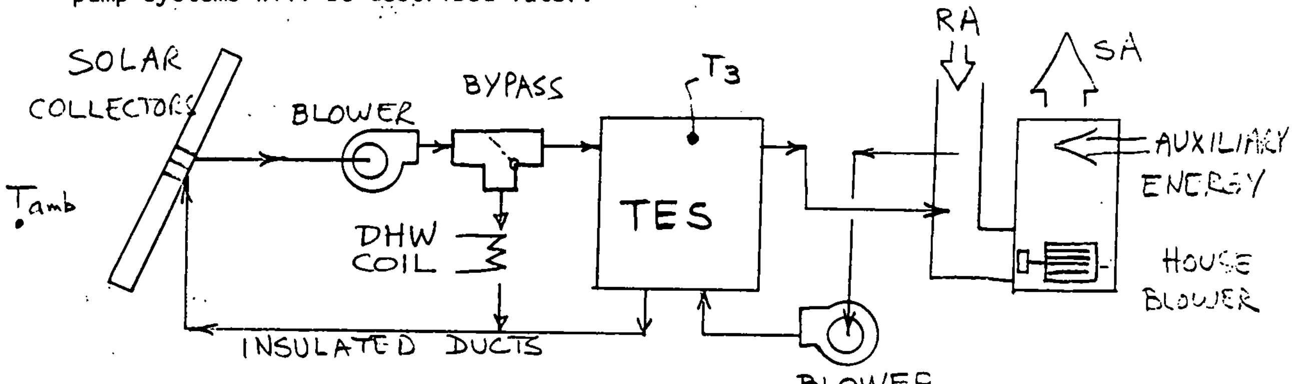


Figure 3-3. SPACE AND DOMESTIC WATER HEATING (WITH ROCK STORAGE)

Control Option 3A:

auxiliary energy - controlled by one stage thermostat, if $T_3 \geq$ 120°F. and $T_{amb} \geq$ 40°F, keep auxiliary off, but if either temperature is lower, use auxiliary.

solar blower - use either solar integrator or solar switch.

house blower - controlled by T/S and comes on when there is a call for heat.

DHW - heat pipe or thermosyphon type preferred, but if pump is necessary, activate it by ΔT measurement.

TES blower - activated by thermostat and if $T_3 \geq$ 90°F. (off in the summer).

Control Option 3B:

solar blower to turn on by temperature or ΔT (same as 2B).

Control Option 3C:

Same as 2C.

3.3.4 CONFIGURATION 4: HEAT PUMP ASSISTED SOLAR (WITHOUT ROCK STORAGE)

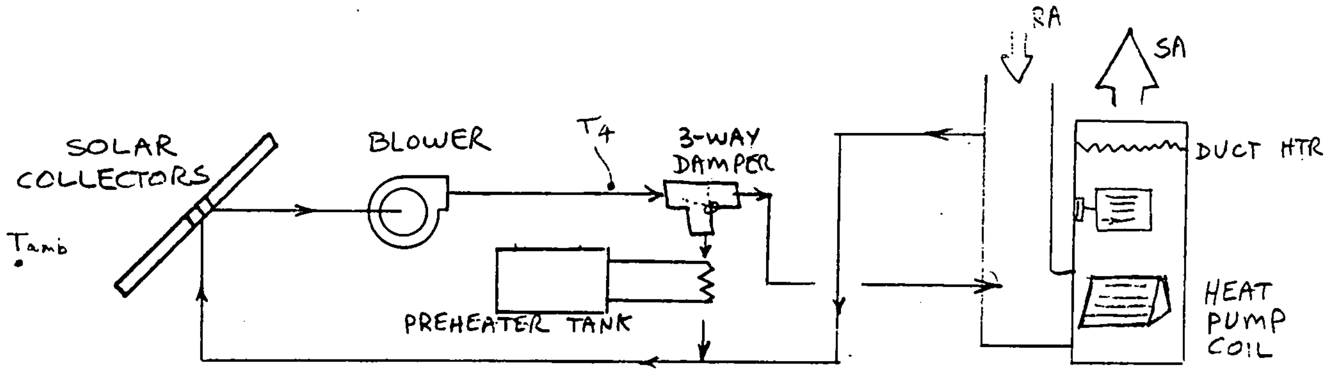


Figure 3-4. HEAT PUMP ASSISTED SOLAR (WITHOUT ROCK STORAGE)

Control Option 4A:

auxiliary energy controlled by two stage thermostat such that:

- if $T_4 \geq 100°F.$ & $T_{amb} \geq 40°F.$, solar is used to satisfy 1st stage and heat pump is used for 2nd stage; duct heater is locked out.
- if $T_4 < 100°F.$ or $T_{amb} < 40°F.$, HP is used to satisfy 1st stage and duct heater is used for 2nd stage.

solar blower - use either solar integrator or solar switch.

house blower - turned on by call for heat.

DHW - heat pipe or thermosyphon type preferred, but pump actuated by T may be used.

damper - to furnace if there is space heating demand and solar blower on, bypass otherwise.

Control Option 4B:

same as 2B.

Control Option 4C:

same as 2C.

3.3.5 CONFIGURATION 5: HEAT PUMP ASSISTED SOLAR (WITH ROCK STORAGE)

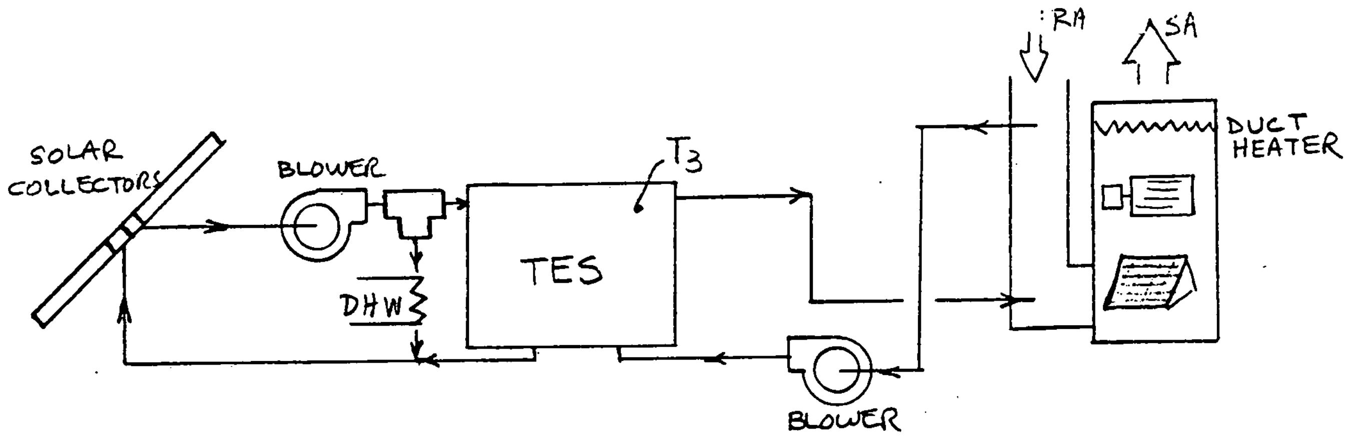


Figure 3-5. HEAT PUMP ASSISTED SOLAR (WITH ROCK STORAGE)

<u>Control Option 5A:</u>

controls same as Configuration 4A, except TES blower - activated by thermostat and T_3.

<u>Control Option 5B:</u>

solar blower to be controlled by temperature sensor and a differential thermostat in parallel as in 2B.

<u>Control Option 5C:</u>

activate solar blower with differential temperature sensor only, as in 2C.

Configuration 6: Solar heating & absorption cooling

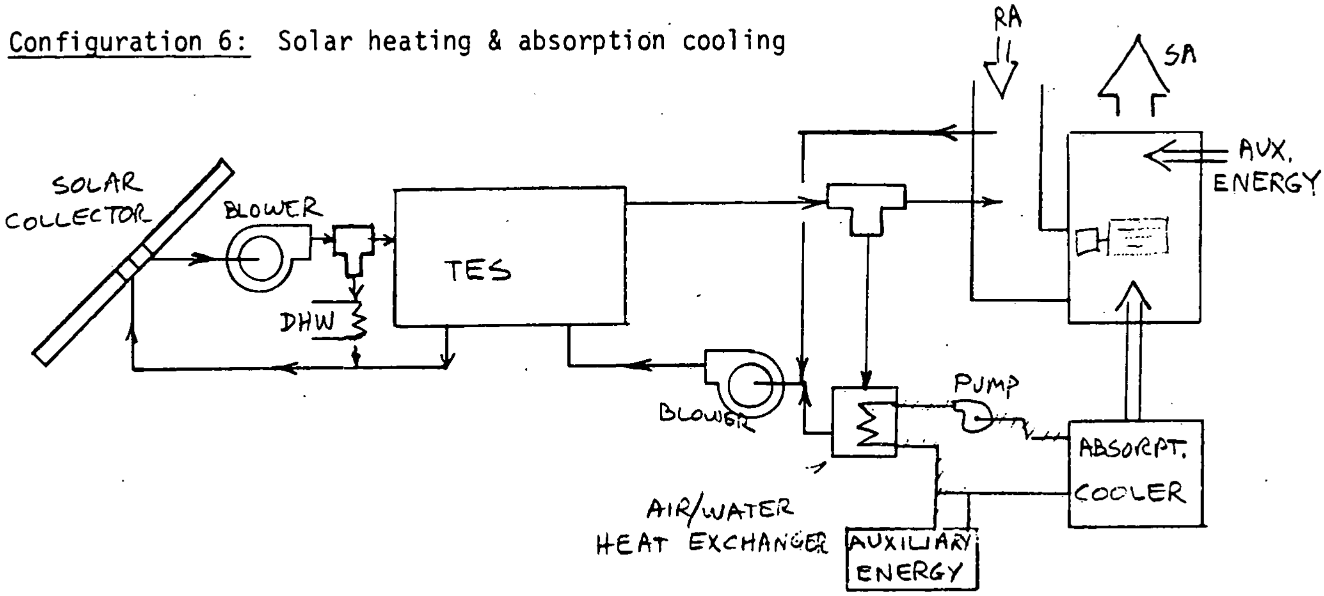


Figure 3-6. SOLAR HEATING AND ABSORPTION COOLING

The configuration shown allows use of solair with available absorption coolers. This is accomplished by maintaining the conventional hot water interface with the absorption unit, and using an air to water heat exchanger.

Configuration 7: Load management with Solair

Load management is particularly important if solar systems are to use electricity as a backup. Although most existing rate structures do not reflect residential useage patterns (load factor), the high cost associated with providing electricity on a backup basis will eventually result in such structures. Public Service Company of Colorado has already instituted such a structure, as have some other utilities in the Southwest.

The solar system shown below has good potential for complimenting residential load management, without compromising occupant comfort. It is based on considering the whole house electrical demand as a load to be managed. The three largest electrical rate users in a typical house are the kitchen circuits, hot water heater and the HVAC equipment. The controls will allow supply either to the kitchen or to the HVAC/DHW. Since kitchen consumption is sporadic, conventional solar energy storage devices are sufficient to flywheel the house load over periods of kitchen consumption.

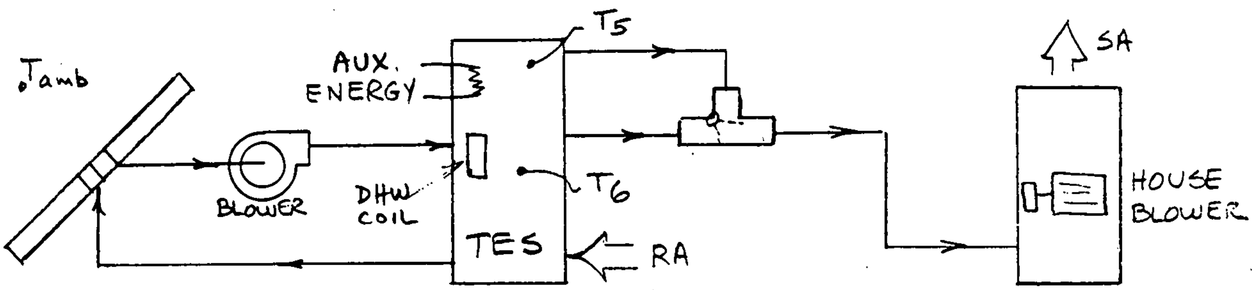


Figure 3-7. LOAD MANAGEMENT WITH SOLAIR

Control Option 7A:

auxiliary energy - controlled by three temperature readings: T_{amb}, T_5, T_6 and a switch related to kitchen usage. Controlled to maintain T_5 at about 180°F. unless T_6 is high or T_{amb} is high. It is locked out if the kitchen circuit is on.

solar blower - Use temperature in collector with differential temperature reading to activate this blower.

house blower - Come on with call for heat from two stage thermostat.

DHW - heat pipe or thermosyphon type preferred, but if pump is necessary, activate by ΔT measurement.

TES blower - Come on with call for heat.

3-way damper - From middle of storage for 1st stage and top of storage for 2nd stage.

Configuration 8: Load management with Solair

The concept here is similar to that previously described (Configuration 7), except that there is no interlock with the kitchen circuit. A conventional European type device is used here to use auxiliary energy, only at off-peak hours.

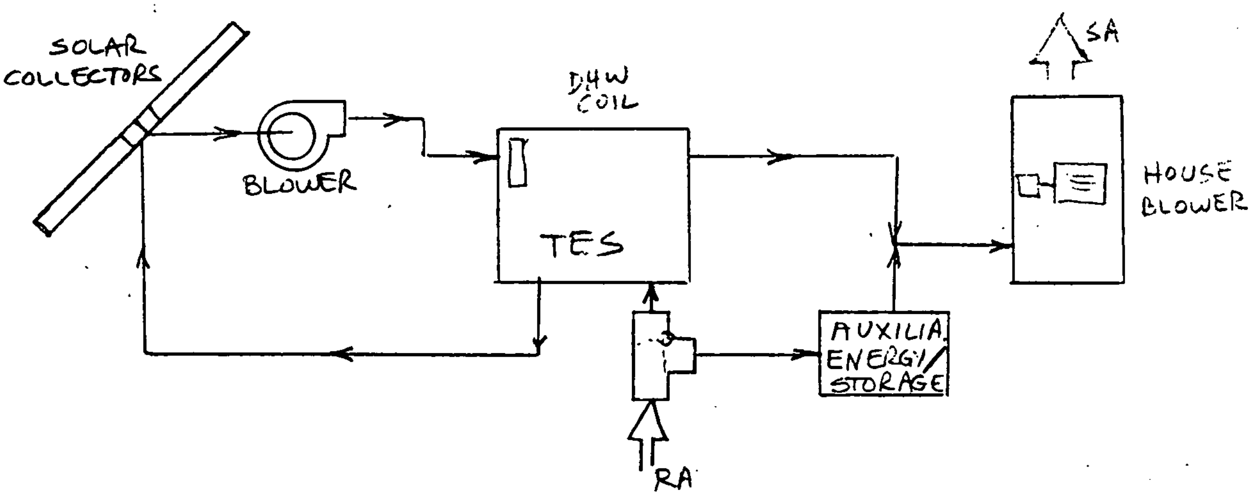


Figure 3-8. LOAD MANAGEMENT WITH SOLAIR

Control Option 8A:

Same as 7A.

3.4 USE OF HEAT PIPES TO ENHANCE SOLAR PERFORMANCE

Various design options utilizing heat pipes were investigated with a number of manufacturers. A cost-effective heat pipe concept has not been identified because conventional heat exchange methods were cheaper, heat exchange to and from the heat pipe was restrictive, and because the physical interface with heat pipes requires custom features which are expensive.

The following manufacturers were contacted with regard to utilization of heat pipes for Solair.

TABLE 3-1. MANUFACTURERS CONTACTED FOR HEAT PIPE UTILIZATION

MANUFACTURER	LOCATION	PERSON CONTACTED
Dynatherm	Marble Court Cockeysville, MD 21030	Mr. Don S. Trimmer (301) 666-9151
Hughes	3100 W. Lomita Blvd. Torrance, CA 90509	Mr. Al Basinlis (213) 534-2121 Extension 2453
Isothermics	P. O. Box 86 Augusta, NJ 07822	Mr. Donald M. Ernst (201) 383-3500
Q-Dot	601 6th Street Los Alamos, NM 87544	Mr. George Grover (505) 662-2595
Thermacore	P.O. Box 135 Leola, PA 17540	G. Yale Eastman (717) 569-6551

A summary of applications considered and design conclusions reached follows:

TABLE 3-2. SUMMARY OF SOLAR DESIGN WITH HEAT PIPES

	HEAT PIPE LOCATION	CONVENTIONAL HX ALTERNATIVE	POTENTIAL ADVANTAGES	CONCLUSIONS REACHED ABOUT USE OF HEAT PIPE
1	In collector between the absorber and the air manifold	Use existing glass tube for air supply with smaller concentric tube for air exhaust; heat transfer via direct contact	Lower pressure drop, simpler manifold	More expensive thermal contact with absorber difficult, finned heat exchanger required on manifold end
2.	Collector hot air to domestic water tank	Air to water heat exchange with pump	Better performance, lower cost	Special water tank penetration required which is expensive, heat transfer to hot water is by convection and is very restrictive
3.	Collector hot air to heat pump evaporator unit	Air ducts with dampers	Simpler and less expensive	This Solar-Boosted (series operation) configuration was not found to be attractive.
4.	Collector hot air to indoor ducting	Air ducts through wall	More desirable wall penetration	Inefficient and difficult for domestic water heating portion of load, lower performance in space heating due to addition of two interfaces; could be cheaper than conventional with many types of walls

SECTION 4

EVALUATION OF CONTROL PROCEDURES

4.1 OBJECTIVE

The objective of this task was development of a preferred control procedure for the management of solar energy in each of the attractive applications.

4.2 SUMMARY

Control of each Solair application is discussed. Control of the collector loop with a vacuum tubular collector differs from flat plate collectors due to its thermal characteristics. Two options are presented for turn-on and turn-off of the collector loop: a solar integrator (developed under ERDA/NASA Huntsville Solar Contract) or a differential thermostat. Control of the other functions is also described.

4.3 COLLECTOR LOOP CONTROL OPTIONS

The solar collection loop and its control is similar for all the applications being considered. The control system must turn-on the collector blower, which then allows transfer of heat from the collectors. A number of options are available to accomplish this function as described below:

Option A: (Least Desired)

Use temperature sensor in the collector; this is the least expensive option, but it will cause high motor cycling, higher parasitic energy, and efficiency losses under some conditions. This approach is satisfactory for flat plate collectors, but the thermal characteristics of the tubular collector are such that high temperatures are experienced even during nominal solar availability. Thus, it is difficult to determine whether sufficient energy is available from a temperature measurement alone.

Option B: (Preferred)

Use solar integrator or switch; when the solar insolation is above approximately 35 BTUH/Ft^2 on the array, the blower is turned on. This is a desirable approach when this control hardware becomes available. Its disadvantages are that it may require periodic cleaning, and that it does not provide any feedback from the rest of the solar system.

Option C: (Preferred)

Use a temperature sensor in the collector and a differential sensor across the load(s) being supplied. This would work as follows; if the temperature of the stagnant collector goes above about 180°F, the blower is turned on, and it is kept on only if the temperature going in to the collectors is lower than that coming out of the collectors. This differential temperature indicates if the energy being collected is being utilized, such that if the system cannot use the heat being collected, there is no temperature drop, and the blower is deactivated. This provides feedback to the control system. The hardware necessary to implement this scheme is currently available off-the-shelf. An adjustable turn-on temperature is desirable.

4.4 TURN-ON SETTING FOR COLLECTION LOOP

The set point for turning on the blower is important because it affects the bottom line savings provided by the solar system. This results from the following:

- If the set point is too high, the solar blower will not come on soon enough, and potentially recoverable energy will be lost.
- If the set point is too low, the solar blower will come on too early, and will shut down shortly thereafter when there is no usable energy delivered. This results in high parasitic energy consumption, potential for loss of stored heat, and reduced reliability of the motor due to increased cycling.
- The proper set point is such that the value of the heat delivered just exceeds the cost of running the blower, under the most likely conditions.

Selection of the proper set point involves a number of parameters, as described in the equations below:

$$\text{Cost to Run Blower} \;\underline{\sim}\; \text{Value of Heat Collected}$$

$$\text{Cost to Run Blower} = \begin{pmatrix}\text{Blower}\\ \text{Watt Consumption}\end{pmatrix} \times \begin{pmatrix}\text{\$ Per}\\ \text{Watt}\end{pmatrix}$$

$$\text{Value of Heat Collected} = \begin{pmatrix}\text{Cost of Backup}\\ \text{Heat per BTU}\end{pmatrix} \times \begin{pmatrix}\text{Net BTU's}\\ \text{Delivered}\end{pmatrix}$$

$$\text{Net BTU's delivered} = (\text{BTU Collected per Ft}^2) \times (\text{Array Ft}^2) \times (\text{Duct Efficiency}) + (1. - \text{Motor Efficiency}) \times (\text{Blower BTU Consumption})$$

Gathering terms and solving for the minimum acceptable energy collectable per Ft^2 for turning on the blower:

$$\begin{matrix}\text{Collectible}\\ \text{Energy per}\\ \text{Ft}^2\text{ Panel}\\ \text{for Turn-on}\end{matrix} = \begin{matrix}\text{Value of Deliverable}\\ \text{Energy Equals Cost}\\ \text{of Running Blower}\end{matrix} = \left(\frac{\text{Blower Watts per Ft}^2\text{ Panel}}{\text{Duct Efficiency}}\right) \left(\text{Motor Efficiency} - 1 + \left(\frac{\text{Cost of Electricity}}{\text{Cost of Heat}}\right)\right)$$

Figure 4-1 shows the COP versus collectable energy, with COP defined as the value of heat delivered divided by the cost to deliver this heat. As expected, as the cost to run the blower increases, collection should be initiated at a higher level. This same trend in electrical consumption is observed as the blower power per collector area is increased.

Example 1: Space Heating with Solair, oil furnace back up at 48¢/gal., electricity for blower at 5.1¢/KWh.

Typical blower power 1.5 W/Ft^2 collector, motor efficiency = 60%, duct efficiency = 95%

$$\text{Cost Electricity} \div \text{cost heat} = \frac{(5.1¢/\text{kWh})\left(\frac{\text{kWh}}{3413\ \text{BTU}}\right)}{(48¢/\text{Gal})\left(\frac{1\ \text{Gal}}{140\ \text{KBTU}}\right)\left(\frac{1}{6}\right)}$$

$$= 2.62$$

From Figure 1: Blower should not be turned on until collectable energy 12 BTU H/Ft^2

With early morning insolation characteristics, 30% collector efficiency implies a turn on at least 40 BTUH/Ft^2 incident.

Example 2: If the cost of electricity / cost of auxiliary heat = 1.0

From Figure 1: Blower could be turned on with collectable energy of 4 BTUH/Ft^2 or more, corresponding to about 10 BTUH/Ft^2 incident.

The impact of the set points on collectable energy is shown in Figure 4-2, for a typical location. If the collectors are not turned on until 25 BTUH/Ft^2 is incident on the array, 3% of the incident energy will be lost. If the setting is 50 BTUH, 3 + 4 = 7% of the incident energy is lost.

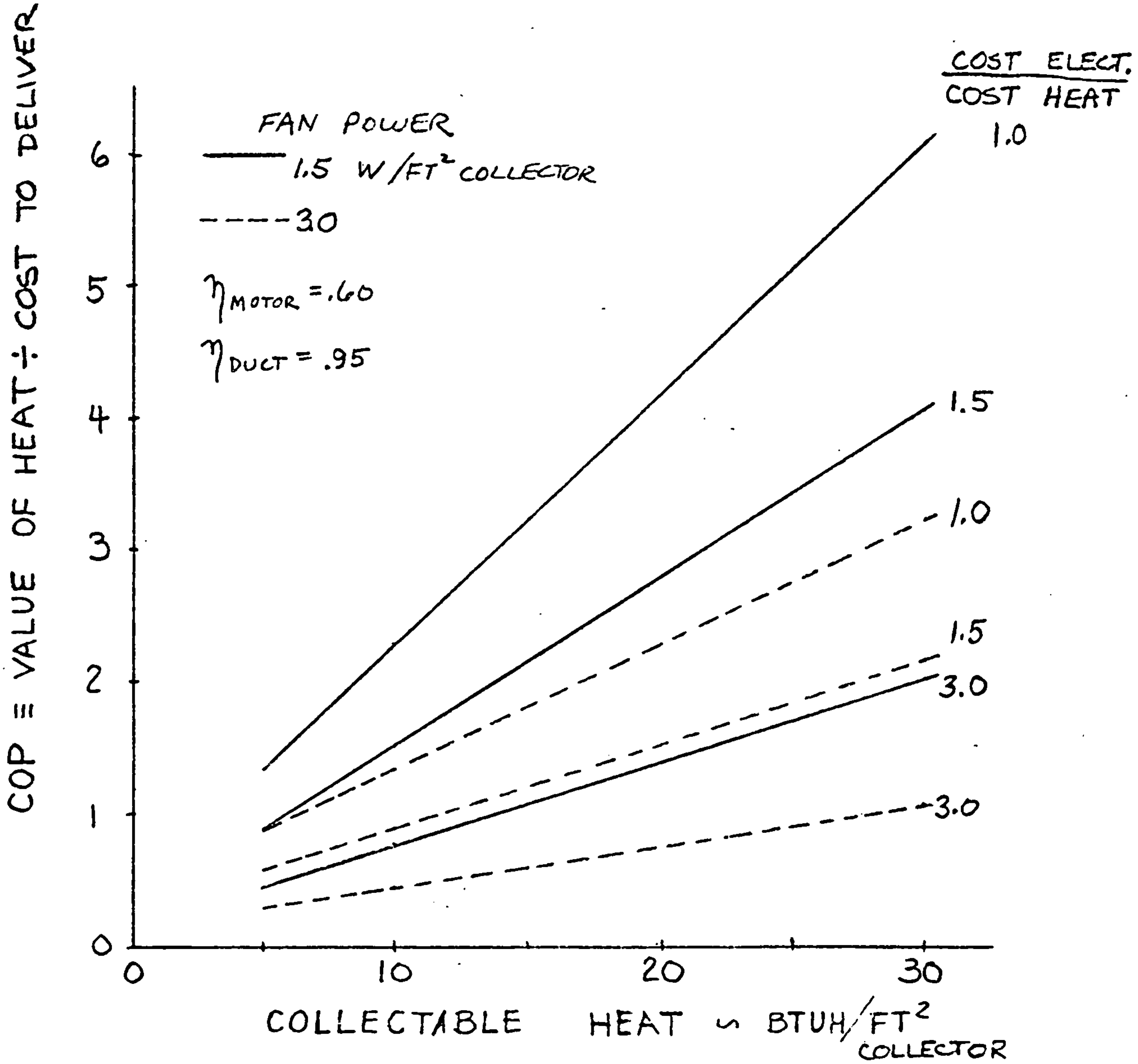


FIGURE 4-1. CRITERIA TO INITIATE SOLAR COLLECTION

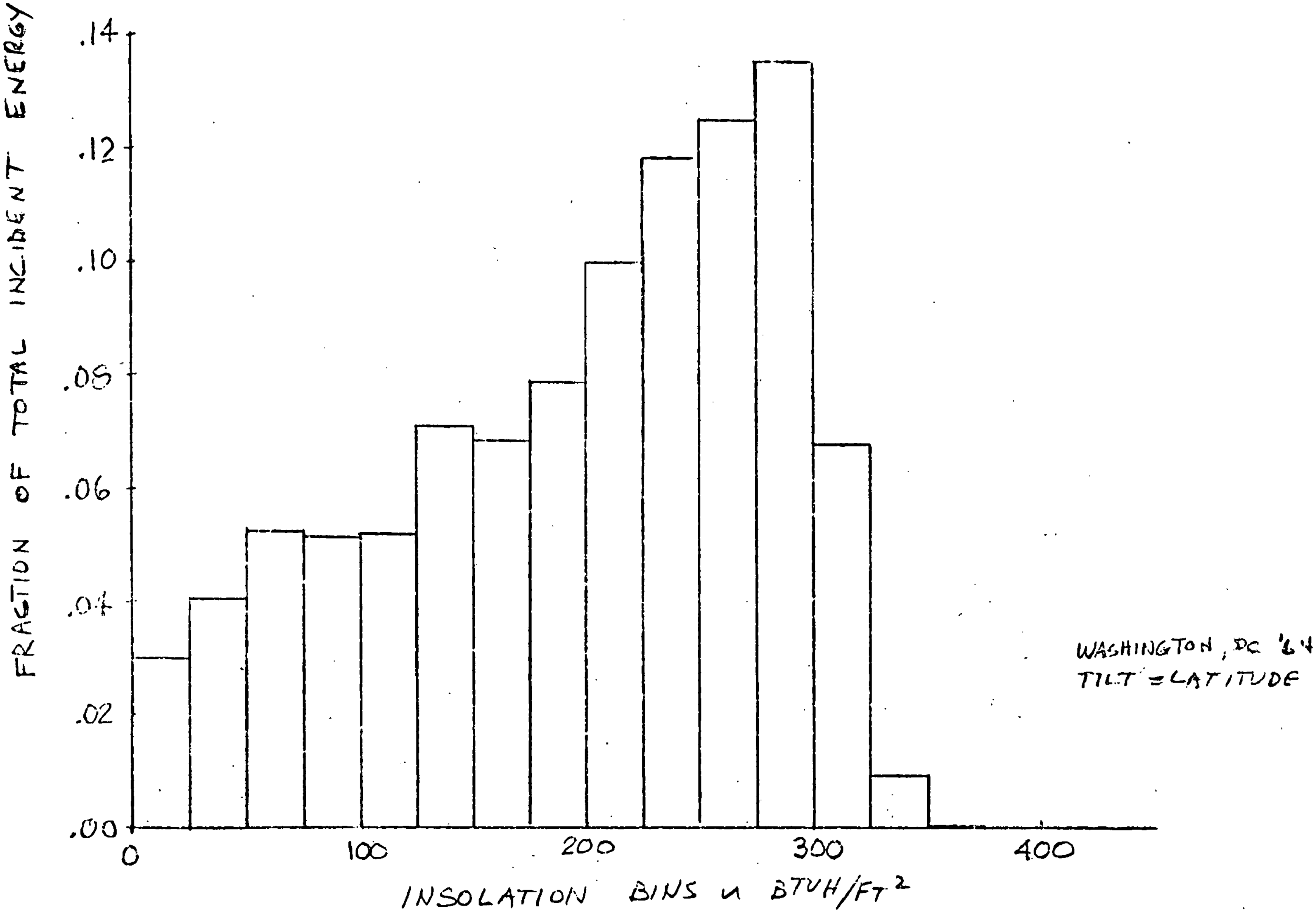


FIGURE 4-2. INSOLATION INTENSITY BINS

4.5 DOMESTIC WATER HEATING (ONLY) CONTROLS

A typical system configuration is shown in Figure 4-3. The solar heat is transferred

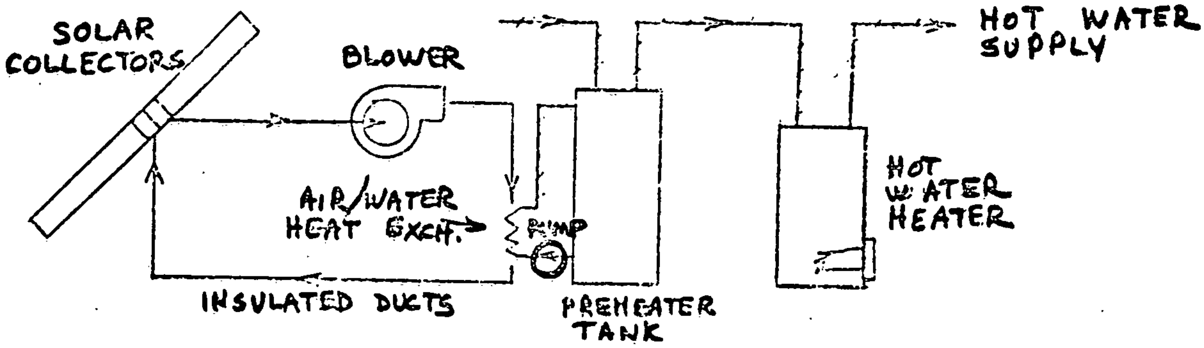


Figure 4-3. System Configuration Domestic Hot Water Only

to the water tank by way of the conventional air-to-water heat exchanger. This type of system has not been popular because the collector must work at hotter temperatures than for a space heating system, which is not efficient with a flat plate collector. However, the evacuated tubular collector is well suited for this application. The advantages of using air for domestic water heating, as compared to liquid collectors, are:

- Less expensive
- Higher BTU's/$
- Simple freeze protection
- No leakage
- Simple over-temperature protection

Three electrically active elements must be activated by the control system; the collector blower, the collection pump and the auxiliary heater. This is accomplished as follows:

Blower: Controlled as previously described, but shut off if tank fully charged.

Pump: Electrically in parallel with blower.

Aux. Energy: If temperature below set point (typically 140-160°F), stay on till set point reached (conventional mode unaffected by solar heating controls).

4.6 SPACE AND DHW HEATING

A typical system configuration is shown in Figure 4-4. Solar heat is used to provide

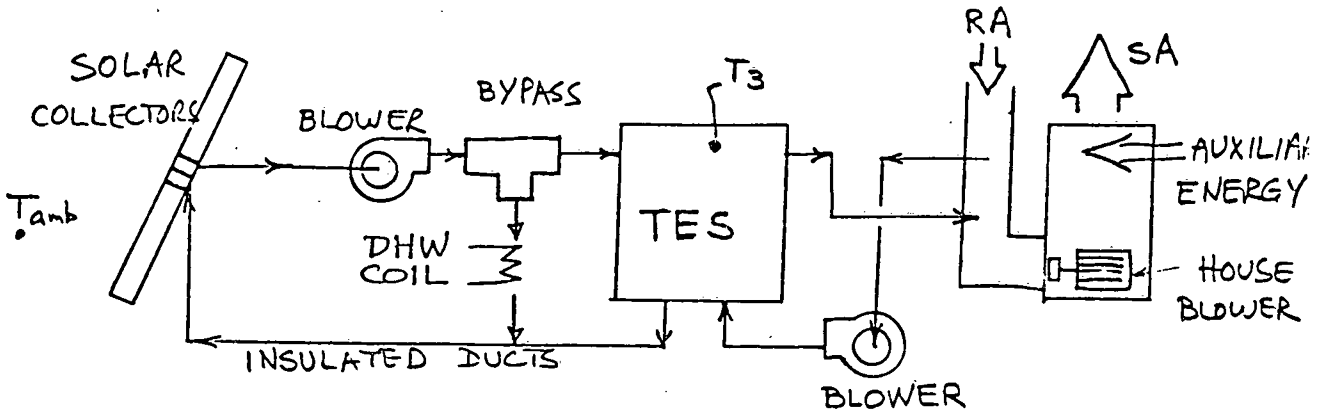


Figure 4-4. Space Heating & DHW Configuration

both space heating and domestic hot water heating. If there is sunshine, solar heat is used to provide space heating. Once space heating is satisfied, the heat is diverted to supply the hot water demand. Rock storage is used to store energy for non-sunny periods. Both demands are not satisfied simultaneously because of the different temperature levels required, with higher temperatures required to satisfy the hot water demand. Air temperature levels coming out of the collectors is inherently controlled by the air inlet temperature. In space heating, the collector inlet temperature is essentially the room air temperature, so that outlet temperature is limited to about 150°F (primarily dependent on solar radiation level and the cfm air flow/unit collector area). In hot water heating, the collector inlet temperature is dependent on the water tank temperature and heat exchanger size. Typically, with water storage at 120°F, the inlet temperature to the collector is 170°F, and outlet temperature is approximately 240°F.

The advantages of Solair over liquid collection systems are:

- Heat used directly, without heat exchange
- Less expensive
- Higher BTU/$
- Simple freeze protection
- No liquid leakage problems
- Simple overtemperature protection

The control system activates the five key components, as follows:

Collector Blower:	Controlled as previously described.
DWH Pump:	If solar blower on and if house demand is satisfied and if water demand temperature is less than 180°F turn pump on.
DHW Auxiliary Energy:	Regulated to satisfy set point temperature.
3-Way Damper:	To furnace if there is space heating demand (1st stage thermostat) and solar fan is on; bypass otherwise, including heat storage mode.
Heating Blower:	Turned on by 1st stage of thermostat only if there is heat in storage or adequate insolation.
Space Heating Auxiliary Energy:	Using conventional two state thermostat, with solar activated by the first stage and auxiliary by the second stage. A timer can be added as an option so that if the 1st stage of the thermostat is not satisfied in a reasonable period, such as 30 minutes, the 2nd stage is activated in addition to the 1st stage.

4.7 SIMPLIFIED SPACE AND DOMESTIC WATER HEATING

One of the objectives of this study is to devise inexpensive solar systems. The following system has potential for reducing cost and physical space requirements of solar utilization. It is based on the fact that the physical mass of the house can provide thermal energy storage, with additional energy storage capacity being provided by the hot water preheater tank. Larger than normal daily indoor temperature variations are required, but variations of approximately 5°F have been shown to yield good performance, and seem to be tolerable.

A typical schematic is shown in Figure 4-5 below.

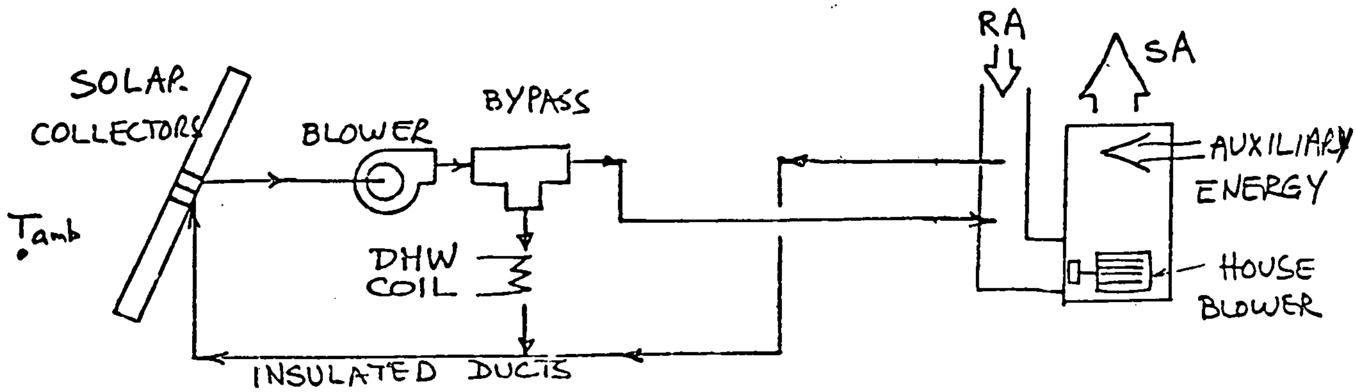


Figure 4-5. SIMPLIFIED SPACED HEATING AND DHW CONFIGURATION

The control functions are identical to those used with conventional rock thermal energy storage, except that there is one less blower to control. In addition, a manually adjustable temperature differential between the two stages of the thermostat is desirable.

Collector Blower:	Controlled as previously described.
DHW Pump:	If solar blower on, and if house demand is satisfied, and if water temperature is less than 180°F, turn pump on.
DHW Auxiliary Energy:	Regulate to satisfy set point temperature.
3-Way Damper:	To furnace if there is a space heating demand (1st stage thermostat) and solar fan is on; bypass otherwise.
Space Heating Auxiliary Energy:	Use two stage thermostat with adjustable differential temperature, with 1st stage controlling solar input and 2nd stage controlling auxiliary energy input to house. Blower to come on with 1st stage call for heat only if the collector blower is on.

SECTION 5

SYSTEM PERFORMANCE ESTIMATES (TASK 3)

5.1 OBJECTIVE

The objective of this task was performance evaluation of the Solair collector in each attractive application identified. Performance sensitivity to key system variables was to be investigated. Different climatic conditions and building codes were to be analyzed.

5.2 SUMMARY

Details of the hour-by-hour computer simulation used in the analysis and the rationale for their selection is discussed. The performance of the attractive Solair applications are discussed in detail with numerous plots to clarify performance details. A comparison is then shown between two space and domestic water heating concepts: one with dedicated rock storage and the other using the mass of the house structure for thermal storage. The latter approach has been identified as having potential to be more cost effective than a configuration with dedicated rock storage. In conclusion, the results of the performance analysis is discussed.

5.3 SYSTEM SIMULATION

Performance analysis of candidate Solair systems has been evaluated using the Solair system simulation program. The performance analysis methodology included:

1. Development of system component models (collector, heat exchanger, blower, ducting, etc.).

2. Development of system control modes.

3. Combination of component/control modes to generate a Solair system model.

4. Integration of the system model into GE's existing Solar System Simulation (SSS) computer program.

5. Parametric analysis to determining system performance sensitivity to key design parameters.

The SSS computer program is a flexible solar system design tool and,as such, is well suited for variations in Solair systems design through seasonal performance simulation. The program as applied to Solair is shown schematically in Figure 5-1. It consists of a multifunctional core program which is used for all simulations and a number of plug in type system models which are specified by the user. The core program provides hourly simulation inputs of weather data and energy demand and generates an energy balance and operating data.

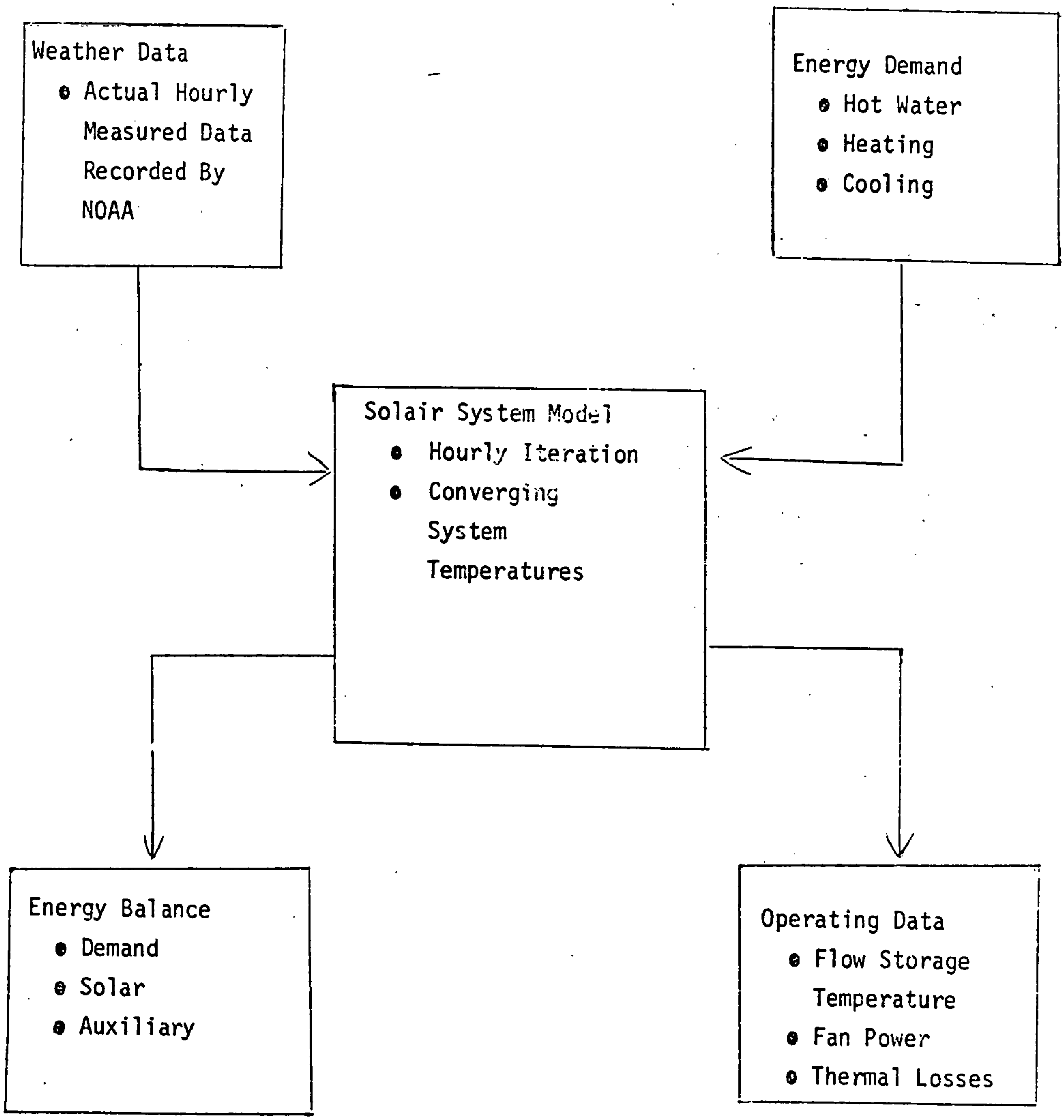


FIGURE 5-1. Solair System Simulation Code

As an example of the program in action, the Solair Domestic Hot Water System model is shown in Figure 5-2. Each component model is based on actual hardware performance and as such provides information relating system performance to hardware specification. The component models are coupled by the system control functions to respond to specific load requirements considering the climatology.

During hourly performance calculations, Newton's Iteration Method is employed in the collector model and in the heat load interface or storage subsystems. This iteration procedure assures convergence of system temperatures and energies.

5.4 CLIMATOLOGY

An evaluation of Solair performance in any location is desirable. The obvious way to accomplish this objective is by simulating the performance with a variety of weather tapes. This is a very costly approach. However, experience indicates that the two most important parameters that characterize local climatology relative to solar system performance are available insolation and winter-time ambient temperatures. These are shown in Figure 5-3A for 12 key regions in the U.S.A. Based on this, Boston and Fort Worth were selected as being representative of these key regions. Using the performance at these representative locations, it is possible to extrapolate solar performance for other regions. A relationship between degree days and population density is shown in Figure 5-3B.

In performing the analysis, weather data as measured by National Oceanic and Atmospheric Administration during a representative year was used. This approach gives performance under fluctuating weather conditions that were actually encountered.

5.5 DOMESTIC WATER HEATING ONLY SYSTEM

The performance of the Solair Domestic Hot Water System Configuration, shown in Figure 5-4, was analyzed in the two representative locations of Boston and Fort Worth. The principal component specifications for a baseline hot water system included:

- 4 TC-100A panels (59 active Ft^2)
- 80 gallon preheat tank
- panels tilted to latitude
- air flow of 30 cfm/panel

Table 5-1 summarizes the baseline system performance for the two locations.

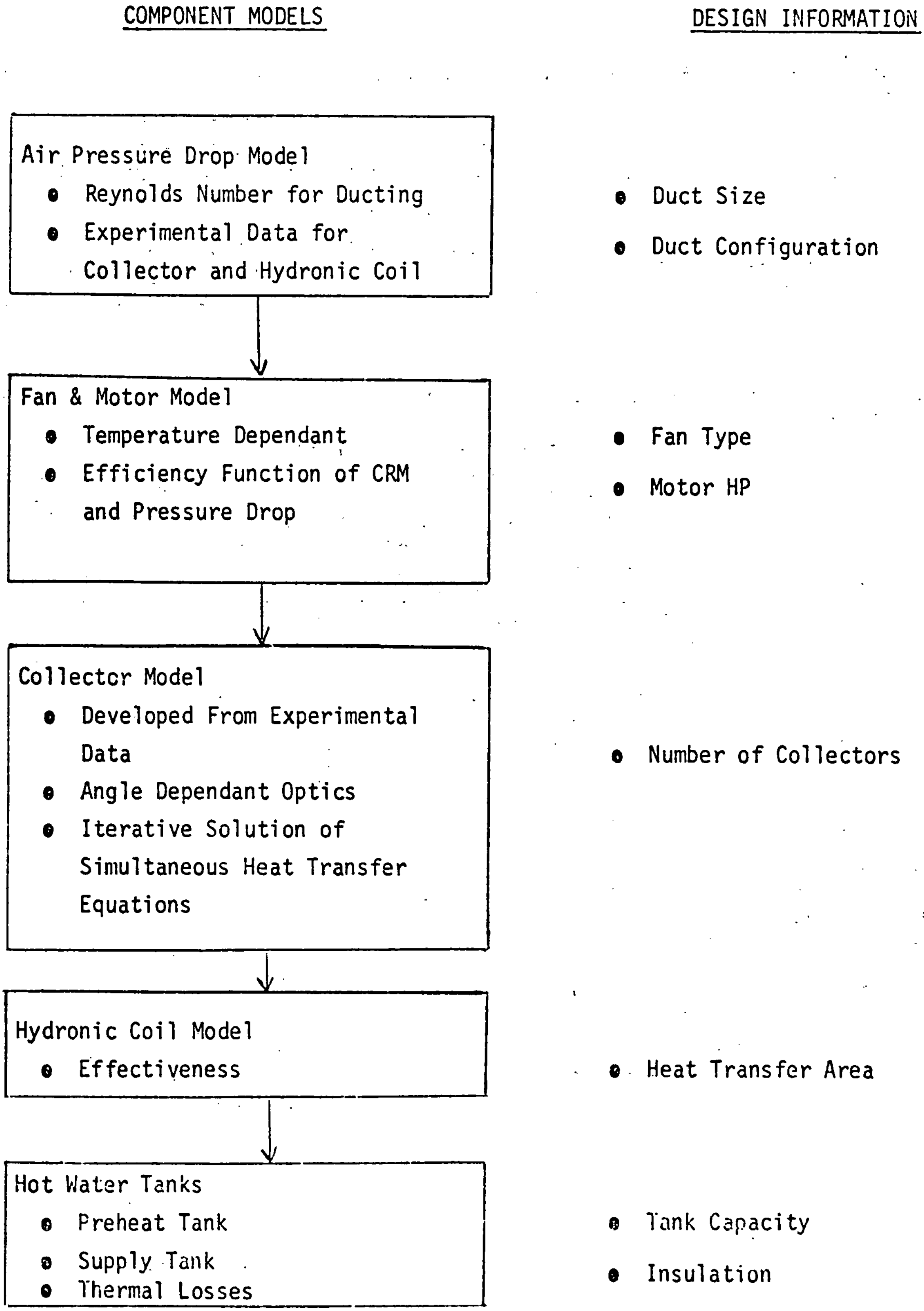


FIGURE 5-2. Solair Domestic Hot Water System Model

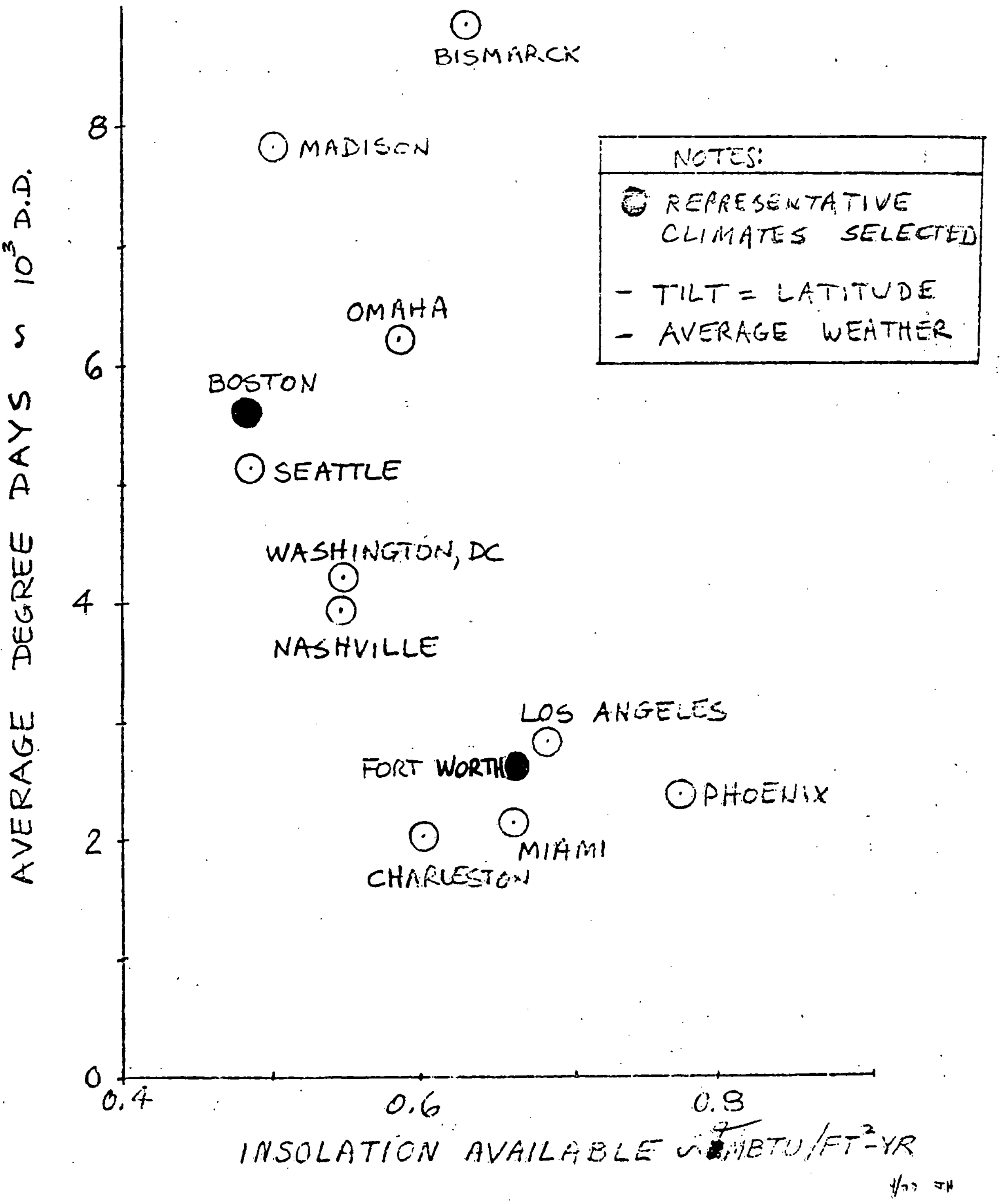


FIGURE 5-3A. Weather Characteristics

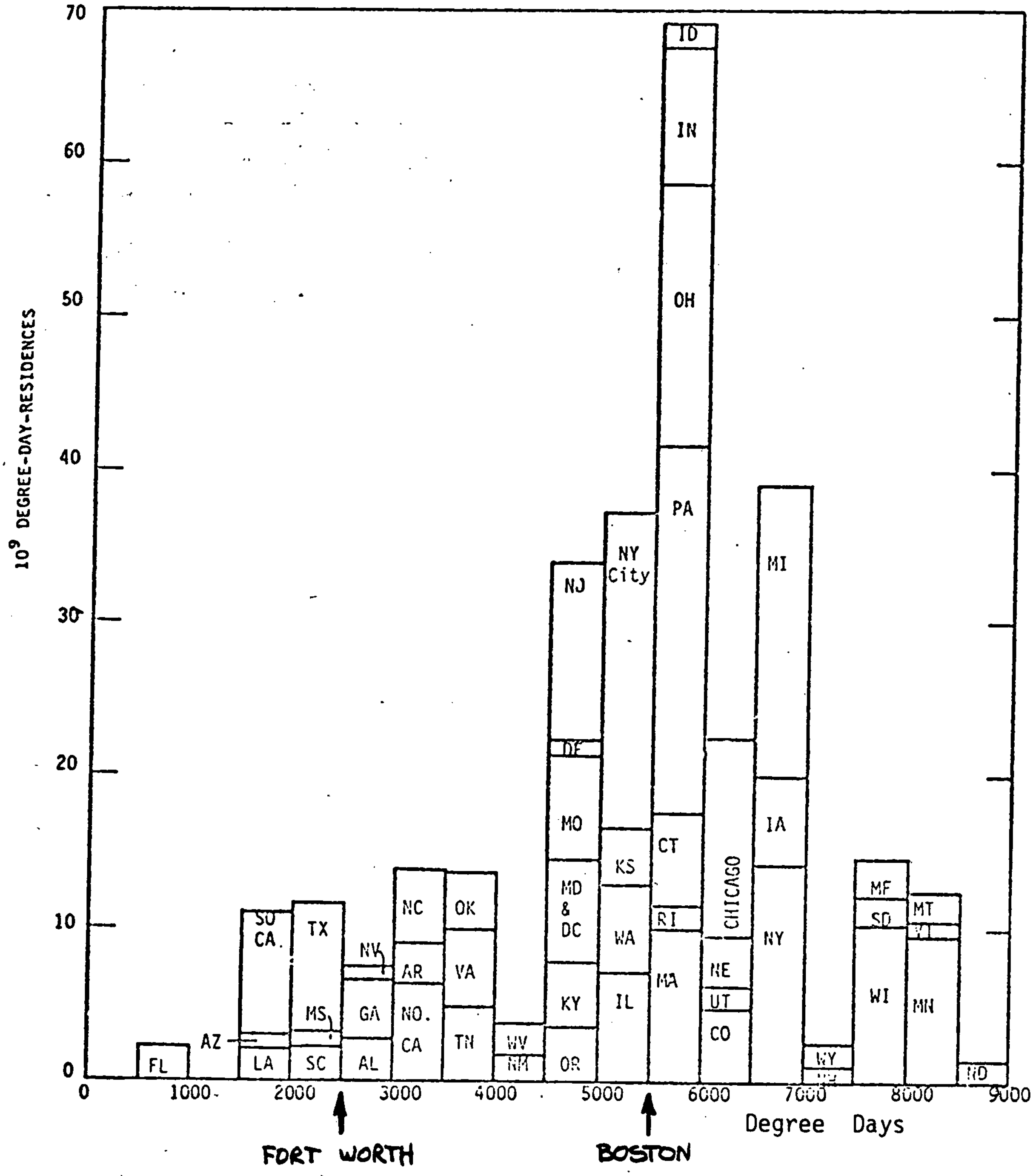


FIGURE 5-3B. The Relation Between the Number of Degree Day Residences and the Number of Degree Days for each of the 48 States. (Adapted from R. Nash and J.W. Williamson, "The Effects of Heat Loss on Solar Heating Systems", Solar Energy, Vol. 18, No. 1, 1976).

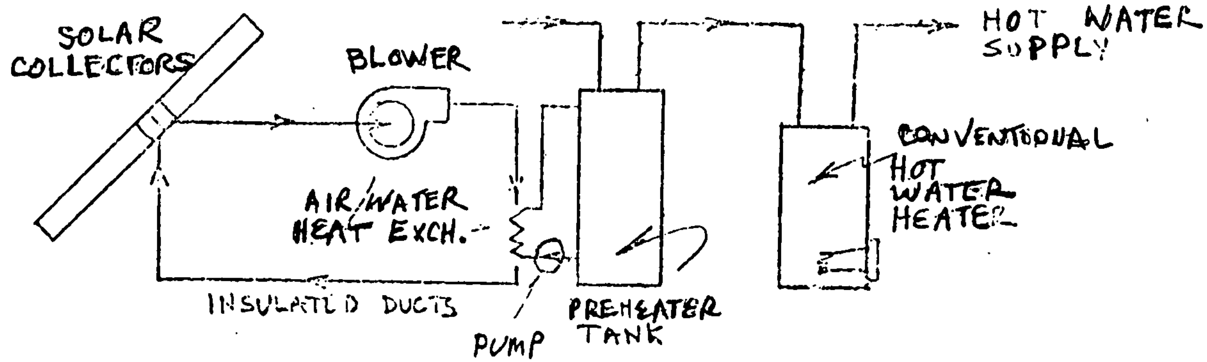


FIGURE 5-4. SOLAIR DOMESTIC WATER HEATING SYSTEM

TABLE 5-1. SOLAIR HOT WATER HEATING PERFORMANCE
59 Ft^2 COLLECT, 80 GAL. PREHEATER TANK

ANNUAL PERFORMANCE DATA	BOSTON	FORT WORTH
Hot Water Load (MBTU/Yr) *	21.4	17.3
Percent of Load Supplied by Solar	53.3	76.6
Effective System Collection Efficiency ***	38.7	37.0
Collection System $KBTU/Ft^2$- yr ***	206	248
Electrical Parasitics Related to Collected Energy	5.5% (189)**	4.4% (198)**

* 76 Gallons/day @ 140°F

** KW-hrs for year

*** After system duct losses, and shutdown when load requirements are satisfied.

The performance breakdown on a monthly basis for the baseline system in Boston is shown in Figure 5-5.

Performance sensitivity to key design parameters was also investigated. Shown in Figure 5-6 is the effect of collector area on solar contribution to the load. As the solar contribution to the load exceeds the 50% level, the system performance on a square foot of collector basis starts to decrease. This is a result of higher operating temperatures and excess solar energy availability during periods of continuous sunny weather.

Figure 5-7 shows the effect of collector tilt angle on performance. The recommended tilt from horizontal is that which equals the latitude; however, a deviation of ± 20° from this value will affect performance by less than 5%.

5.6 SPACE AND DOMESTIC WATER HEATING (WITHOUT ROCK STORAGE)

A new solar system has been identified that may substantially reduce solar system cost. The concept is based upon the inherent thermal capacity of a house that is insulated from ambient tempertures, thus allowing its use for thermal energy storage. By eliminating a dedicated thermal energy storage, this approach reduces system cost, complexity,and physical space requirements. In order to use the house structure for energy storage, the indoor temperature must be allowed to float within a range much like night time setback of the thermostat. The larger the temperature swing permitted, the greater the solar contribution to space heating. A temperature swing of 5°F allows solar system performance comparable to that with dedicated thermal energy storage. A schematic of this system is shown in Figure 5-8.

This novel and potentially inexpensive solar system will save more energy than a hot water only system and will have much better payback than a dedicated large space heating system. Two parameters considered in evaluating the potential of a solar design are the magnitude of energy savings and BTU/$ of an installed system. This criteria is used to compare the new system with conventional solar systems in Figure 5-9. Hot water systems are viable today and the new system may be the next step.

A baseline solar system was specified for the study which included 178 square feet of TC 100A panels and a one hundred and twenty gallon preheat tank. Table 5-2 presents the thermal characteristics of a single family residence. Table 5-3 presents the system performance in the two locales. As solar array size is increased relative to a hot water only system, there is an excess of energy in the summertime. This excess results in reduced performance on the basis of per square foot of collector. For example, in the baseline Boston hot water system 206 KBTU/Ft^2- year was collected, but when the array size was increased to include space heating, the collected energy is reduced to 147 KBTU/Ft^2 - yr. This resulted in the reduced collector efficiency. Appendix A provides the computer printout with accompanying output description for the Boston performance simulation.

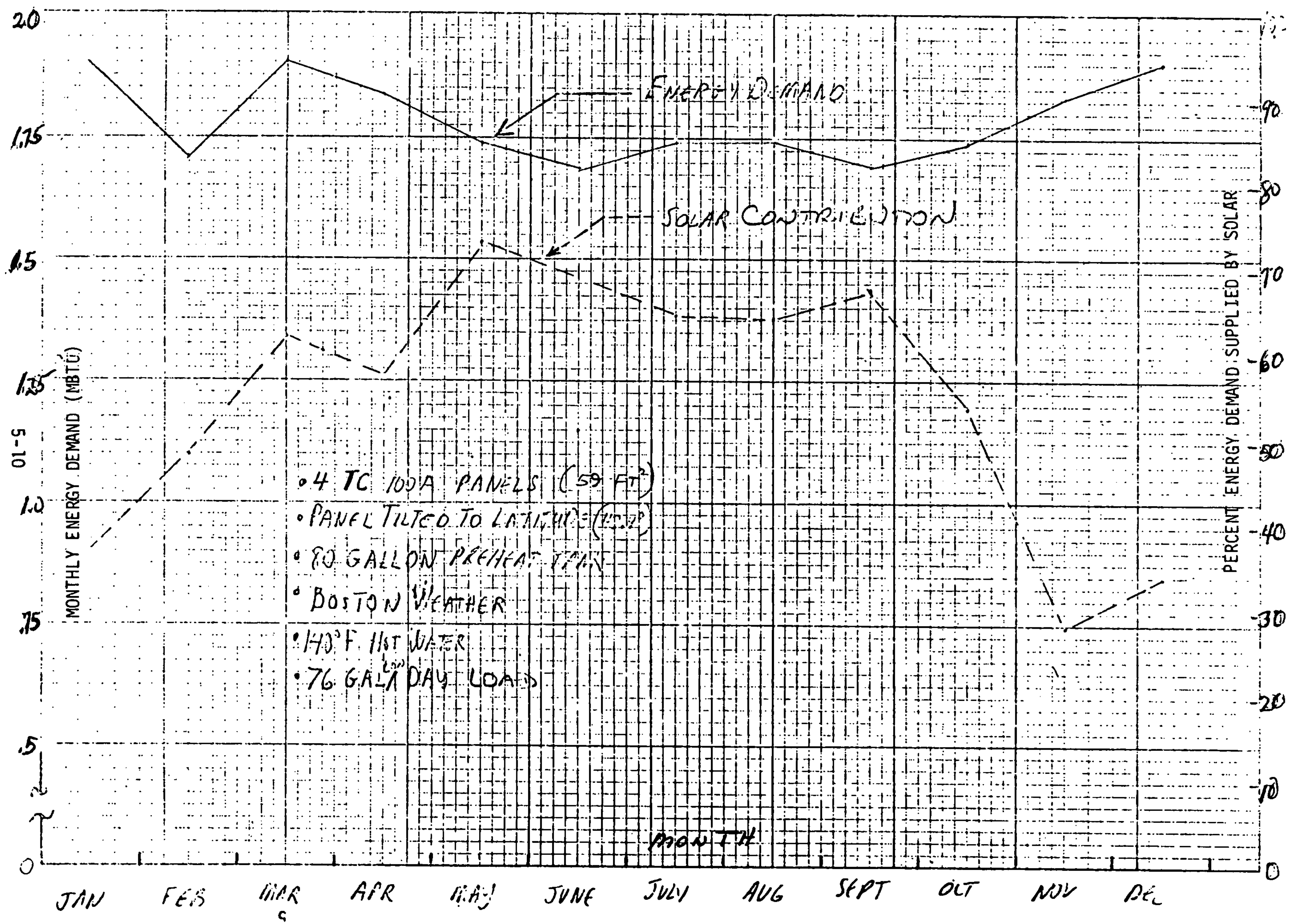


FIGURE 5-5. ANNUAL ENERGY DEMAND AND SOLAR CONTRIBUTION FOR HOT WATER

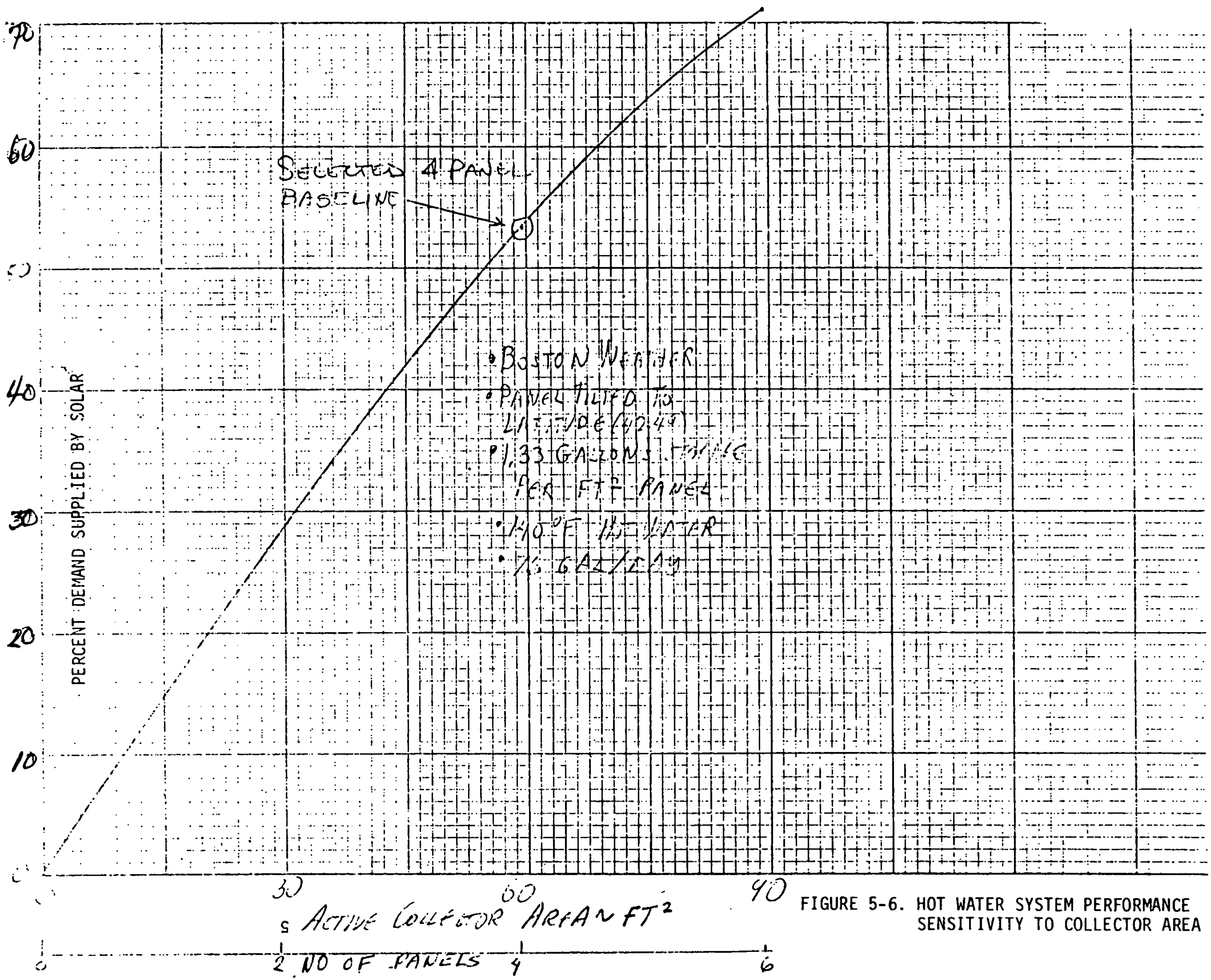


FIGURE 5-6. HOT WATER SYSTEM PERFORMANCE SENSITIVITY TO COLLECTOR AREA

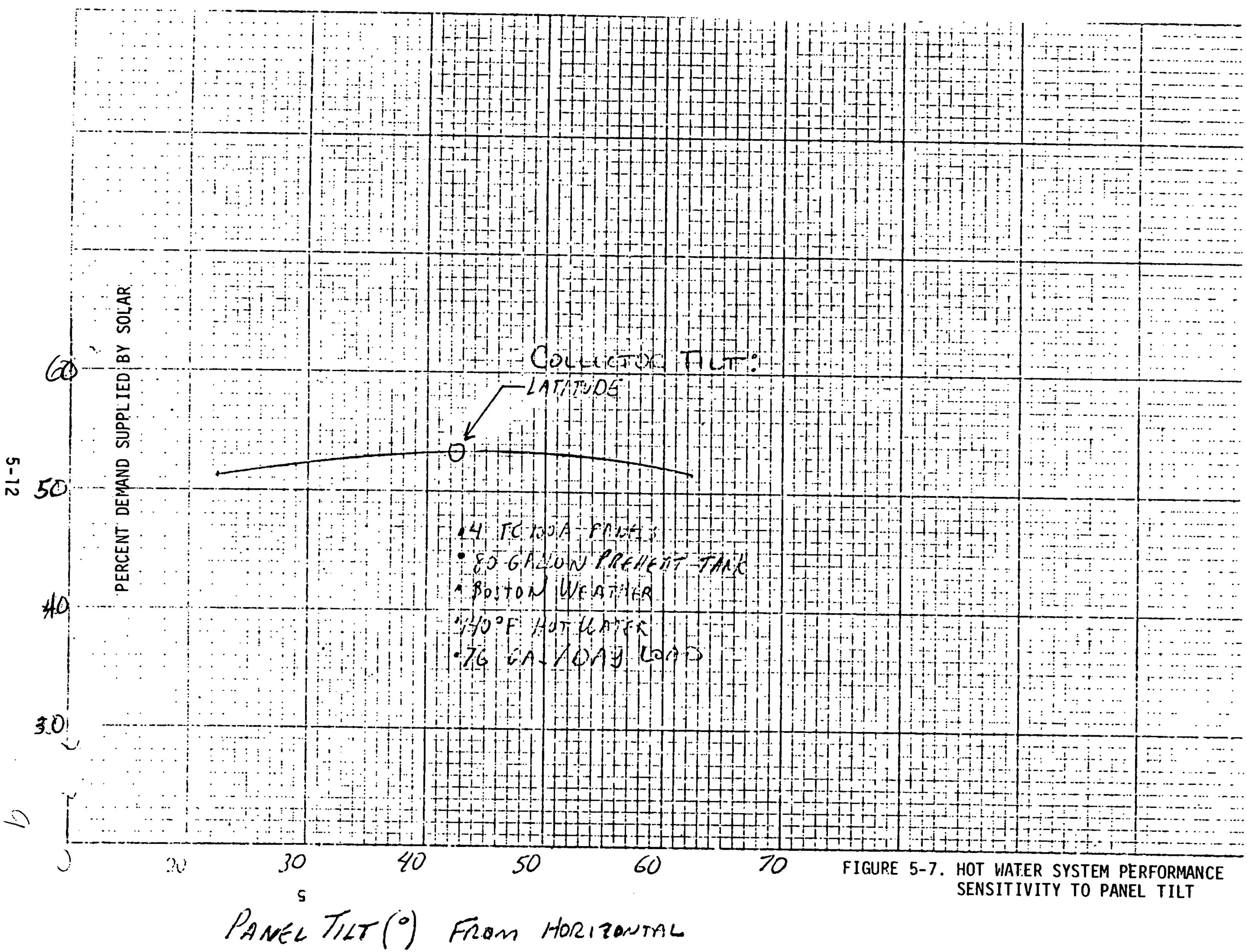


FIGURE 5-7. HOT WATER SYSTEM PERFORMANCE
SENSITIVITY TO PANEL TILT

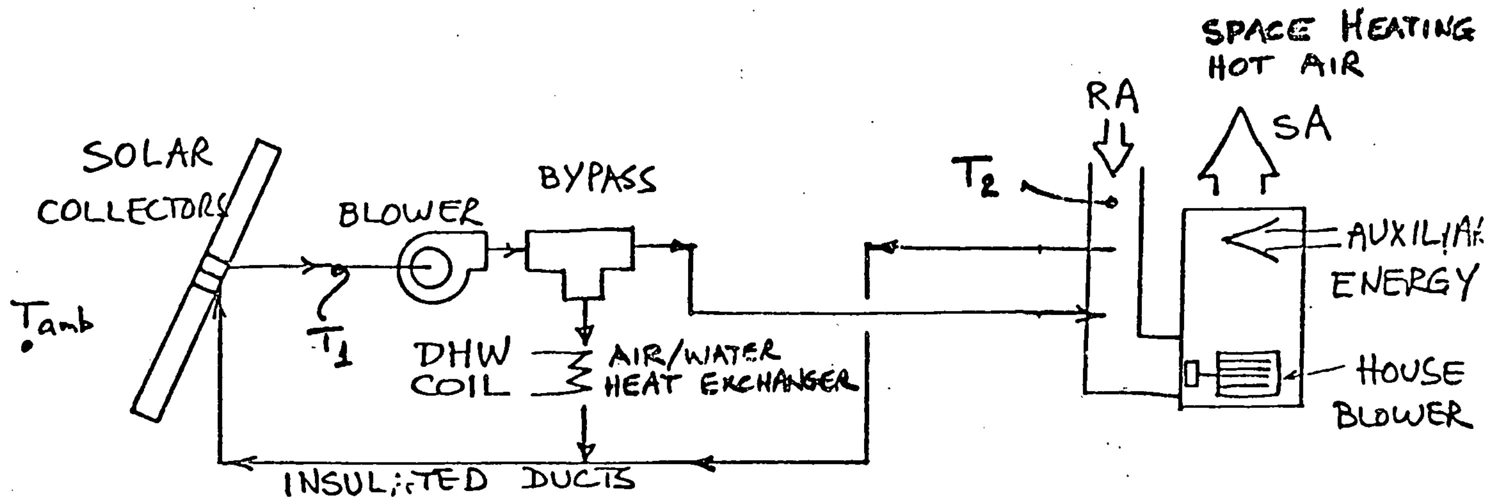


FIGURE 5-8. SOLAIR SPACE HEATING/HOT WATER SYSTEM, HOUSE STORAGE

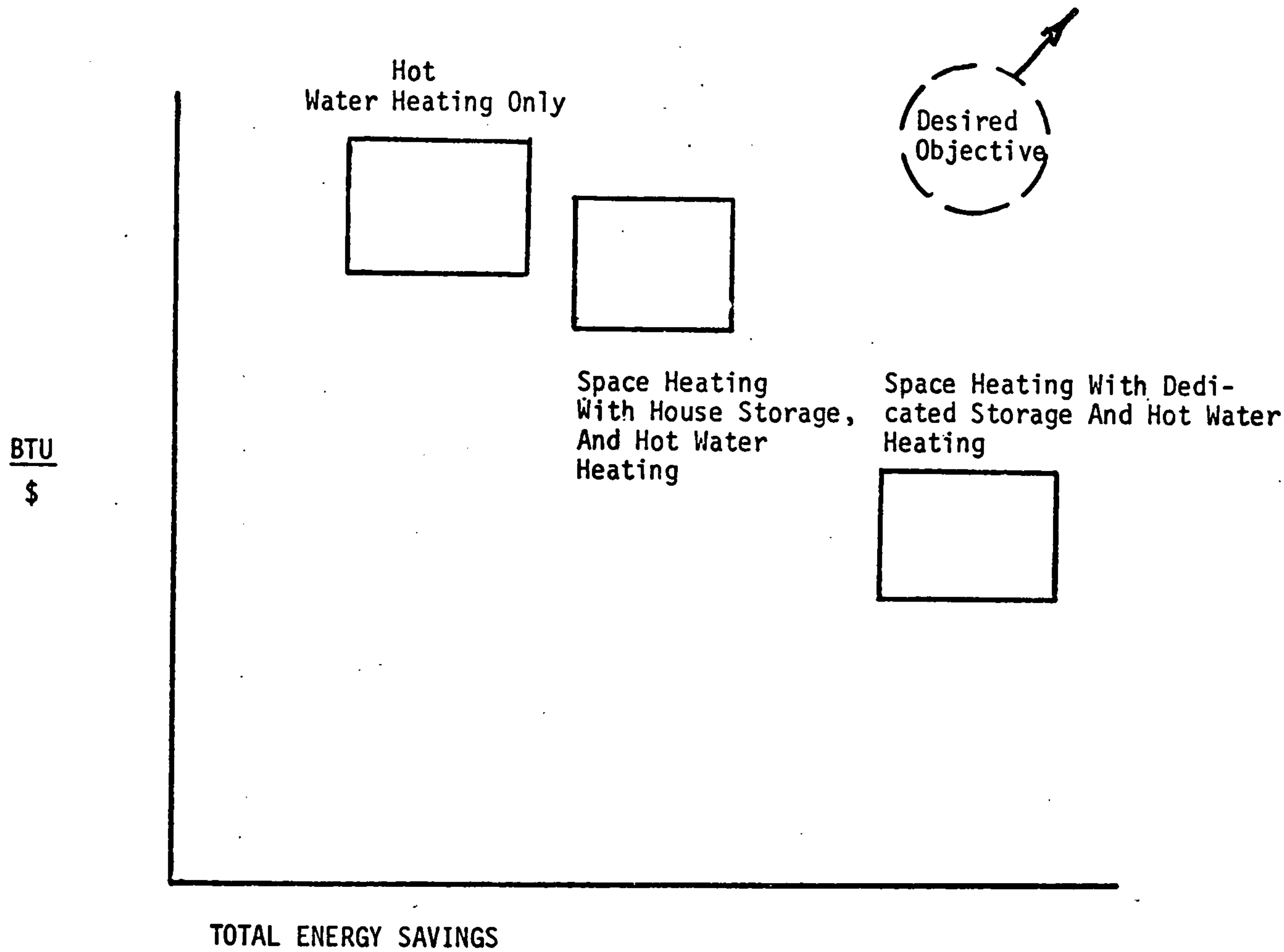


FIGURE 5-9. SOLAR SYSTEM COMPARISON

TABLE 5-2. SINGLE FAMILY RESIDENCE
BUILDING CHARACTERISTICS

CHARACTERISTIC	DESIGN VALVE
• External Surface Overall Loss Coefficient	500 BTU/hr °F
• Structure Thermal Capacitance	7000 BTU/°F
• Internal Volume	16200 Ft^3
• Window Area	330 Ft^2
• Occupancy	2 day; 4 night
• Internal Energy Generation	900 Watts day; 300 Watts night
• Infiltration	107 cfm
• Hot Water Supply Temperature	140°F
• Hot Water Consumption	76 gal/day
• Thermostat Range*	68°F - 73°F

*Auxiliary Energy Setpoint is 68°F-Solar Input Setpoint is 73°F

TABLE 5-3. SOLAIR HEATING/HOT WATER/HOUSE STORAGE PERFORMANCE
178 FT^2 COLLECTOR, 120 GALLON PREHEATER TANK

Annual Performance Data	Boston	Fort Worth
Heating Load (MBTU/Yr)	58.1	29.6
Heating Load Supplied by Solar	23.7%	38.3%
Hot Water Load (MBTU/Yr)	21.8	17.8
Hot Water Load Supplied by Solar	73.2%	91.1%
Effective System Collection Efficiency	29.2%	19.5%
Collection System KBTU/Ft^2-Yr	147.4	124.15
Electrical Parasitics Related to Collected Energy	3.1%	3.0%

* Includes System Duct Losses & Reflects Shutdown When Load Requirements Are Satisfied

The effect on performance of principal system design parameters was investigated. Shown in Figure 5-10 is the sensitivity to collector area. As shown, increased collector area boosts the percent of load supplied. This increase is primarily during the heating months since the system is oversized for summer operation when the hot water demand is the only load. Performance sensitivity to tilt angle (Figure 5-11) shows relatively constant space heating contribution but varying hot water contribution. It is important to note here that the evacuated tube collector with its high efficiency at low insolation yields good performance even when mounted vertically, as in a wall. The effect on heating contribution resulting from varying house capacity is shown in Figure 5-12.

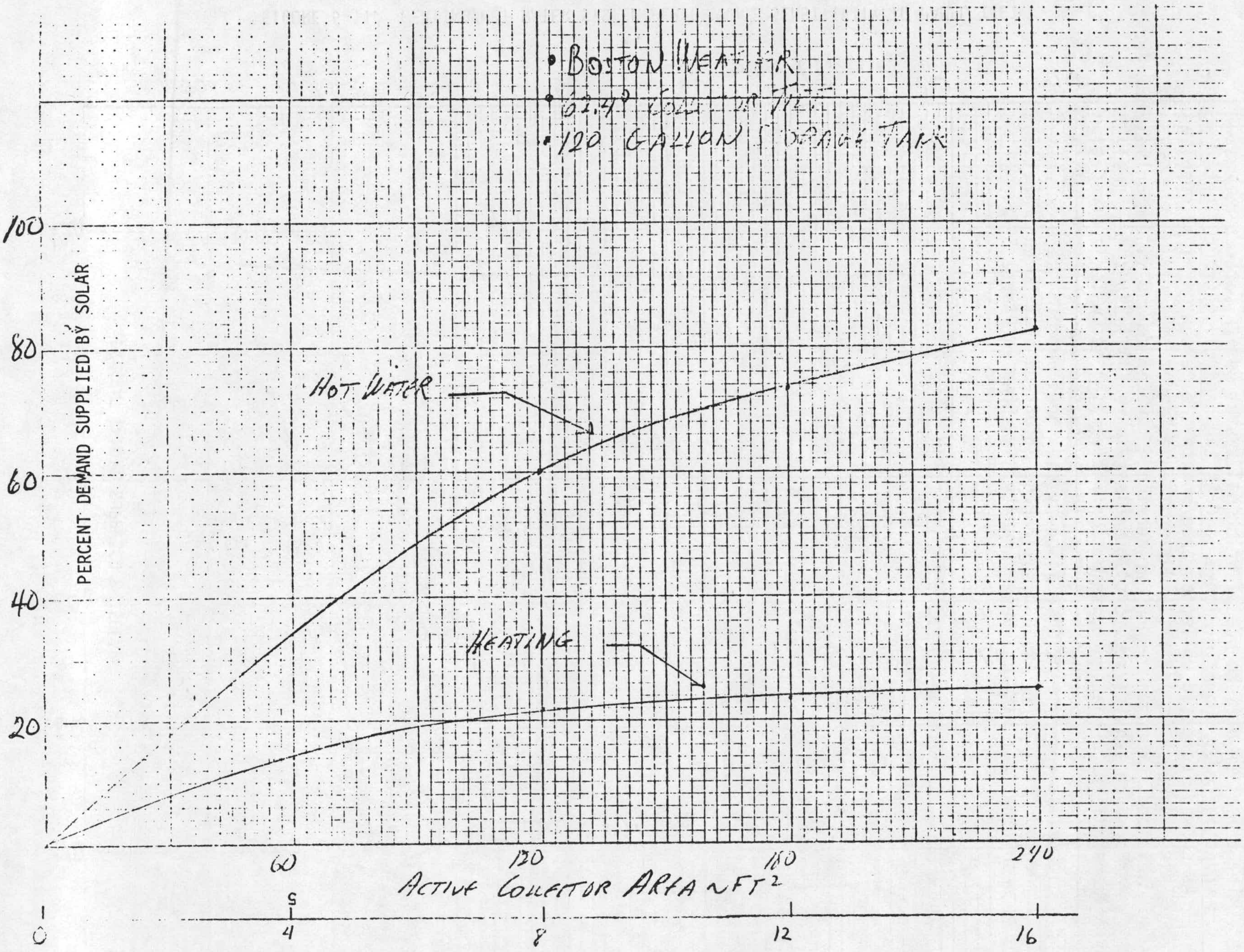


FIGURE 5-10. HEATING/HOT WATER PERFORMANCE SENSITIVITY TO COLLECTOR AREA

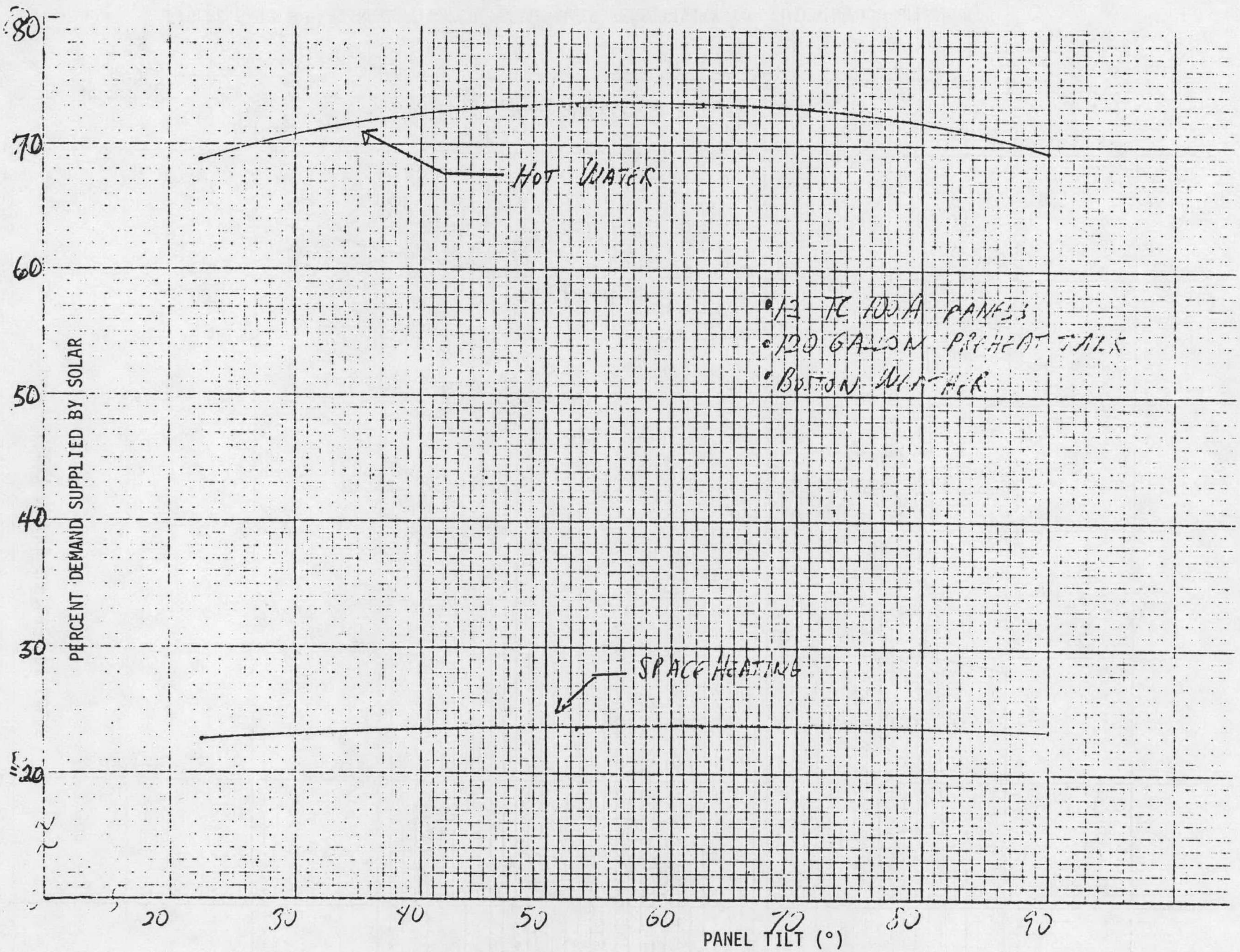


FIGURE 5-11. HEATING/HOT WATER SYSTEM PERFORMANCE SENSITIVITY TO PANEL TILT

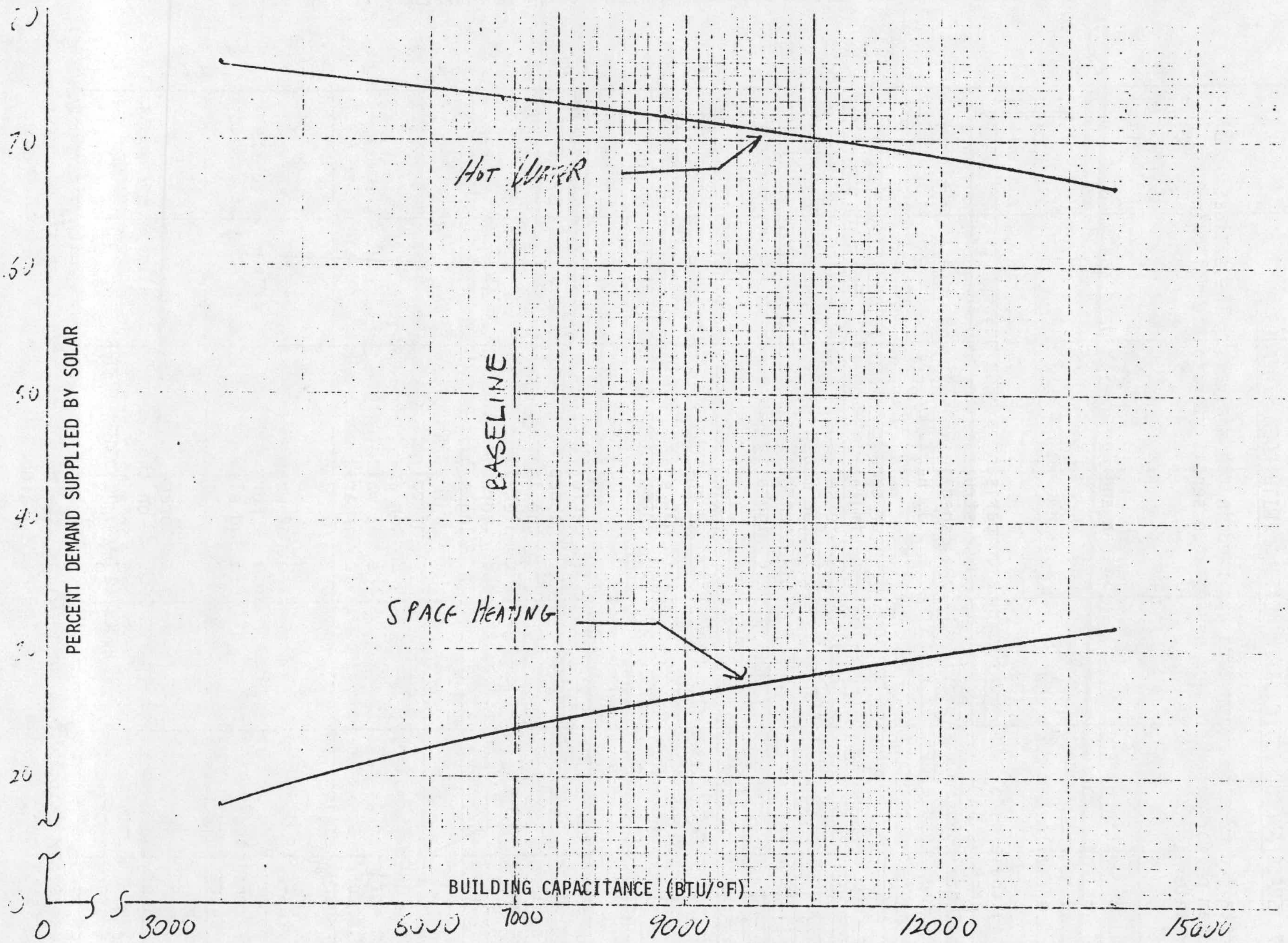


FIGURE 5-12. HEATING/HOT WATER PERFORMANCE SENSITIVITY TO BUILDING CAPACITANCE

5.7 SPACE AND DOMESTIC WATER HEATING (WITH ROCK STORAGE)

A detailed GE simulation code was used in the analysis. The evaluation of system performance includes performance sensitivity to the following parameters:

- collector area
- weather characteristics (Boston and Fort Worth were analyzed)
- rock storage volume
- air duct size
- collector tilt angle

Using these results, a performance comparison is made between systems using rock storage and those using the house structure for storage. Performance of the latter system was previously published in GE PIR -AEP 5974 ("Solair Performance Analysis", R.L. Allred and J. Herz, 6/14/77).

The analysis is based on an hour-by-hour computer simulation using the SSS Air Code (air option of Solar System Simulation Program). For each configuration analyzed, key components were selected from a catalog and were modeled accordingly. The solar collector model utilized has been verified realtive to TC-100 test data and has been adjusted to the air medium. A typical schematic of the hardware configuration is shown in Figure 5-13.

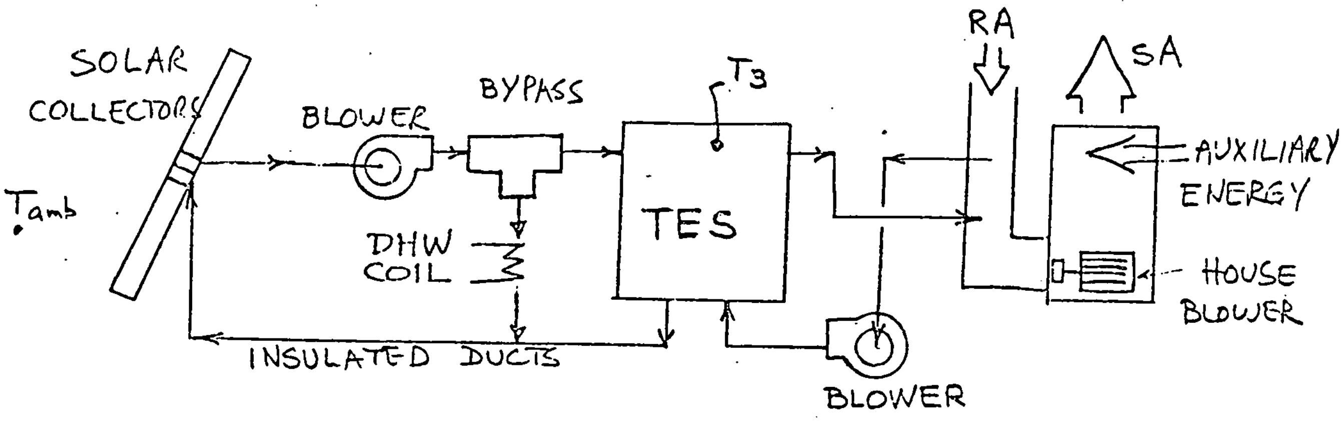
The control scheme is based on the following sequence of priorities: space heating, domestic hot water heating, and thermal energy storage in rocks. Rock storage is not used for domestic hot water heating. Figure 5-14 depicts the control sequence for three possible events: space heating demand, hot water demand and no thermal demand.

Figure 5-15 shows a profile of system performance on a typical day. Starting at midnight with thermal energy storage depleted, the load is satisfied by auxiliary energy. During the day, the load is smaller, and on this sunny day, there is sufficient energy to completely heat the house and also preheat hot water and charge the rock storage. At night, the rock storage is depleted with the energy deficit being supplied by auxiliary energy.

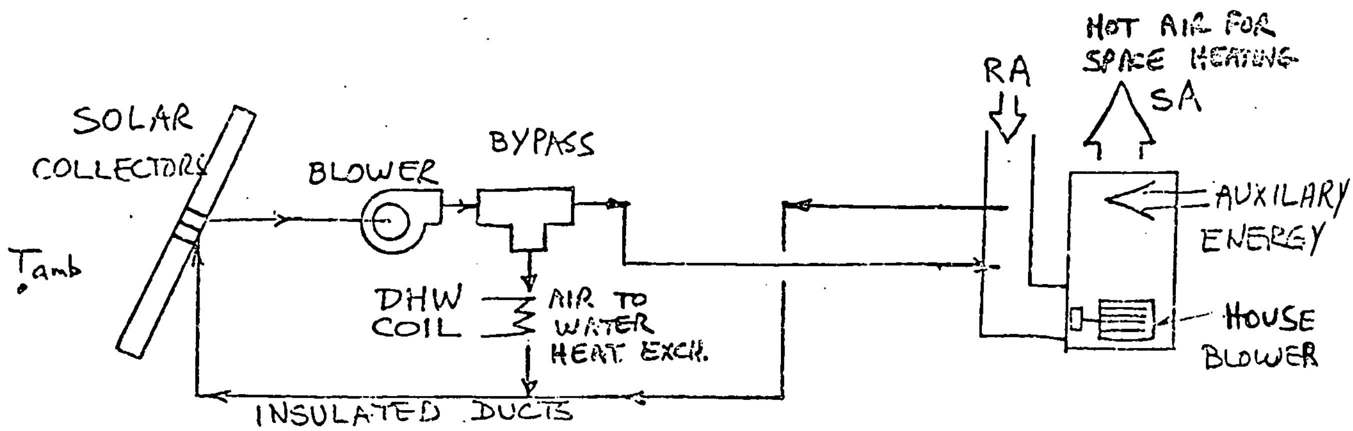
Figures 5-16 and 5-17 show the effect of collector area on solar contribution to the load for a house located in Boston and the same house located in Fort Worth. The contribution to the hot water demand levels out at small collector areas with increased collector area contributing primarily to the space heating demand.

Figures 5-18 and 5-19 show the effect of weather characteristics on solar performance. The better performance at Fort Worth is due primarily to the more consistent insolation available and also to the higher ratio of domestic hot water load to space heating load.

Figure 5-20 shows the effect of rock storage mass on system performance. Proper sizing of the rock storage mass depends on the economic details of the application with minimal benefit obtained for a mass greater than 4000 pounds. This storage capacity corresponds to approximately the equivalent of 1 gallon of water per square foot of collector. For larger solar arrays with a correspondingly larger solar contribution to the load, the optimal storage capacity per unit area is slightly greater than the above value.



SOLAIR HARDWARE CONFIGURATION WITH ROCK STORAGE



SOLAIR HARDWARE CONFIGURATION WITH HOUSE STORAGE

FIGURE 5-13. SOLAIR HARDWARE CONFIGURATIONS

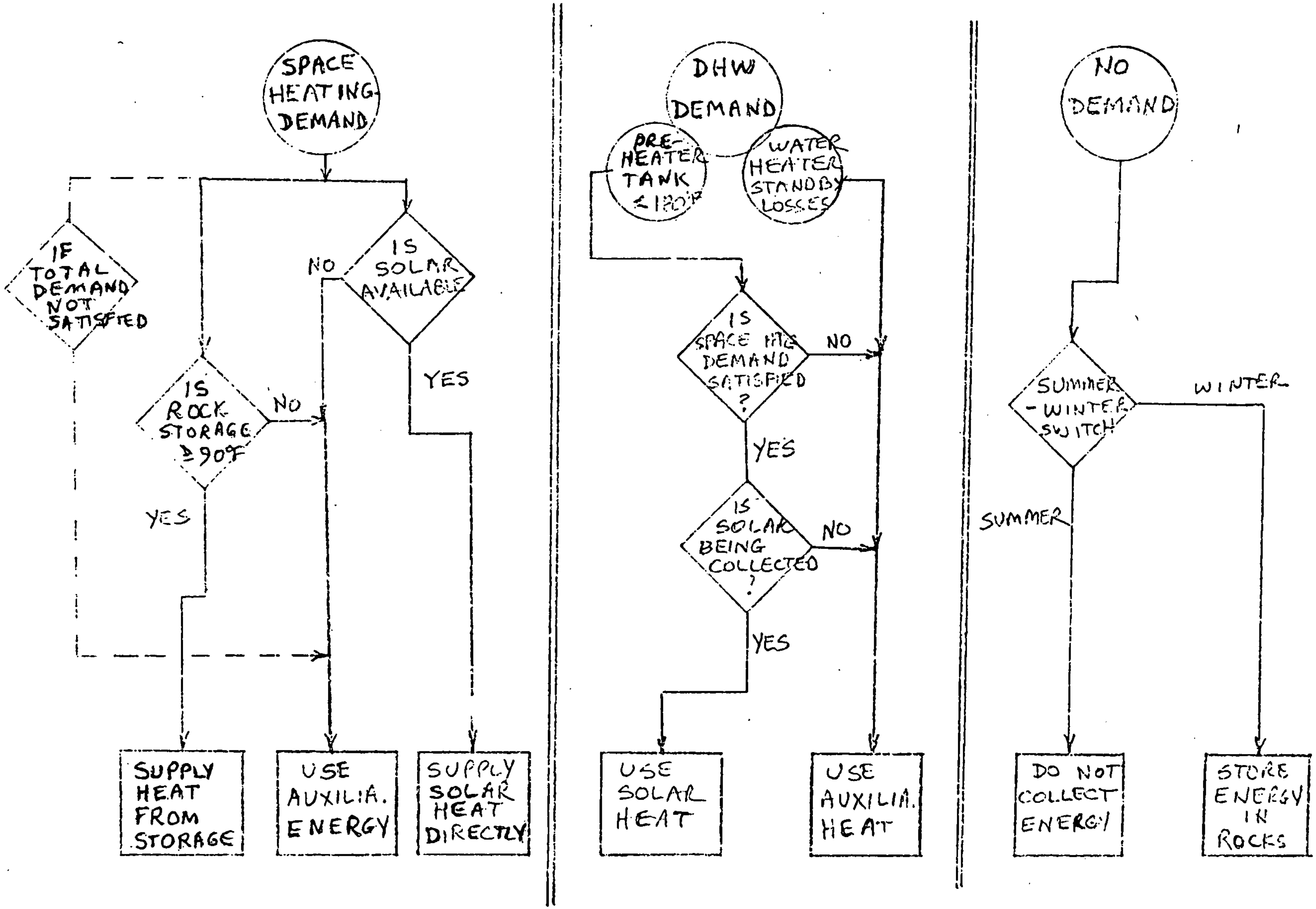


FIGURE 5-14. SOLAIR CONTROL SEQUENCE WITH ROCK STORAGE

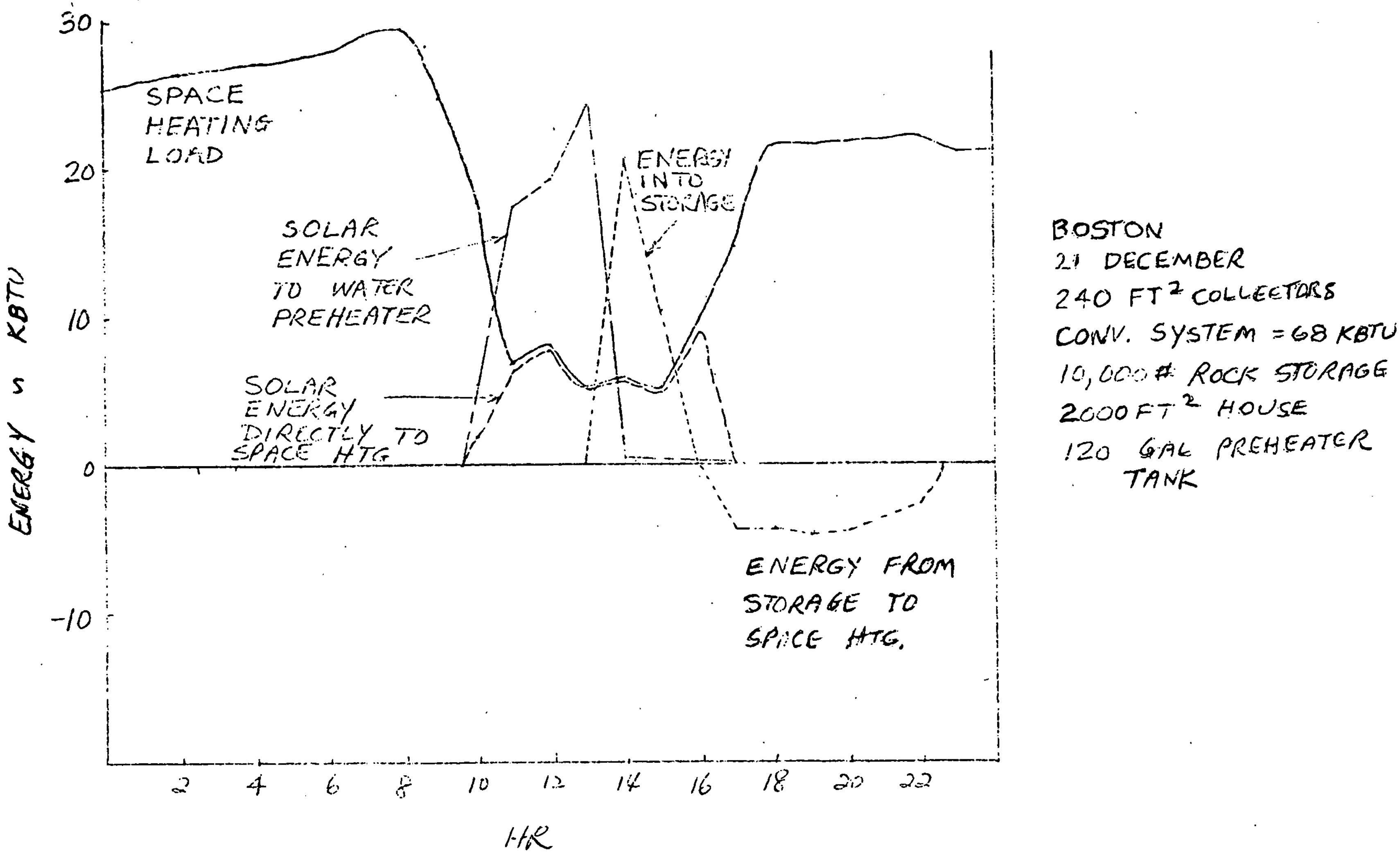


FIGURE 5-15. TYPICAL ENERGY MANAGEMENT

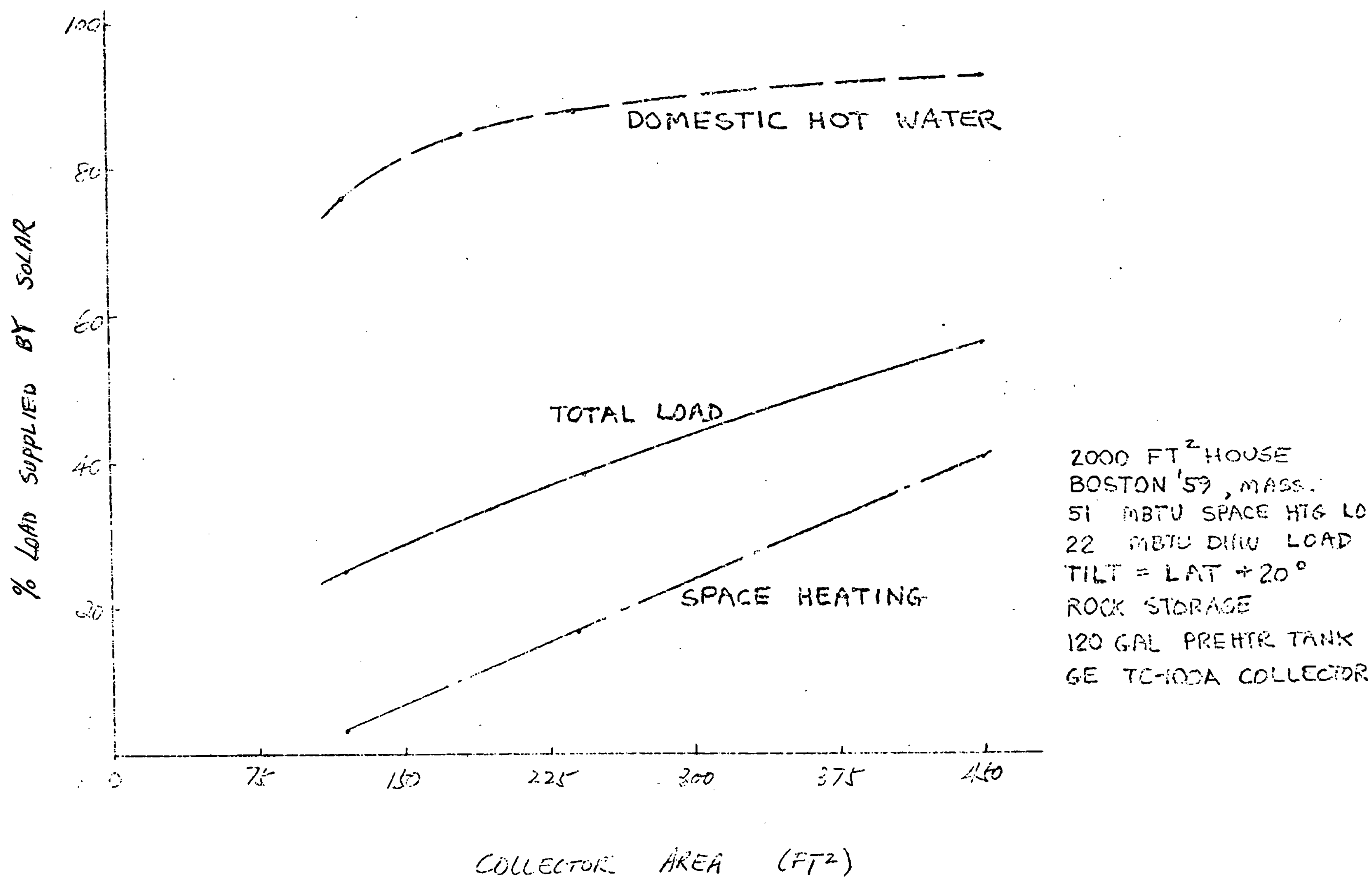


FIGURE 5-16. SOLAR CONTRIBUTION TO BOSTON HOUSE

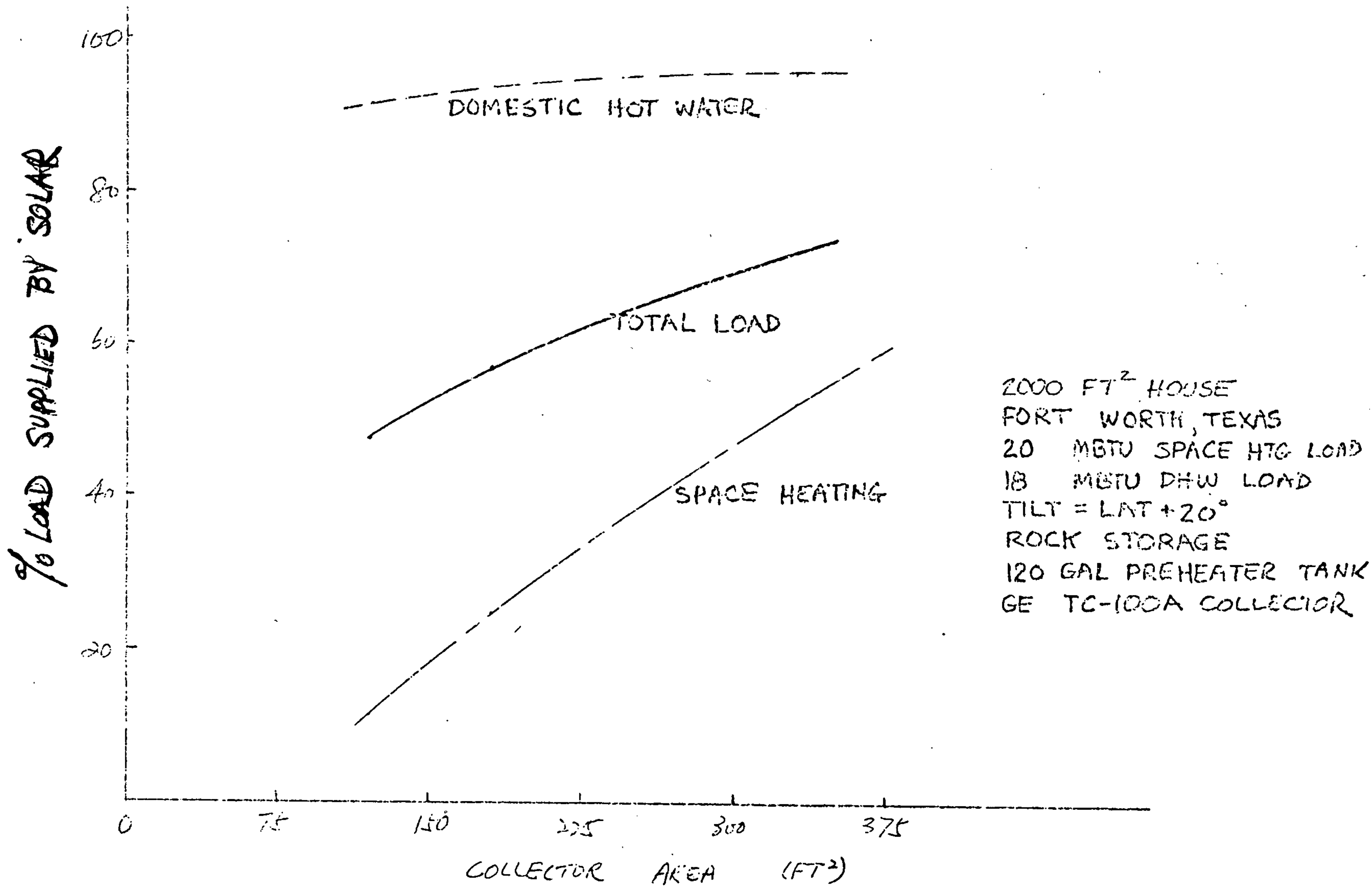


FIGURE 5-17. SOLAR CONTRIBUTION FOR FORT WORTH HOUSE

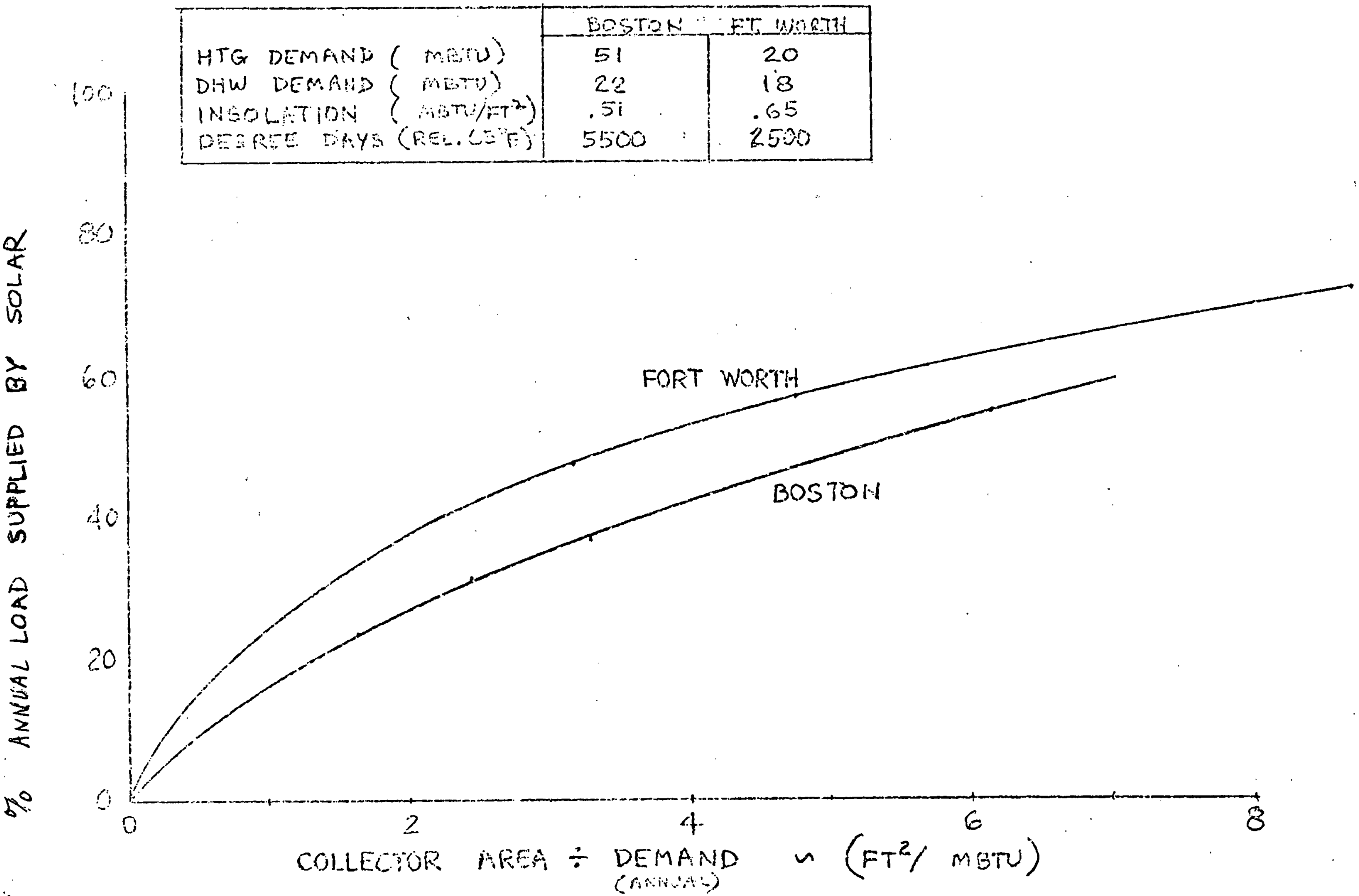


FIGURE 5-18. NORMALIZED SOLAR PERFORMANCE

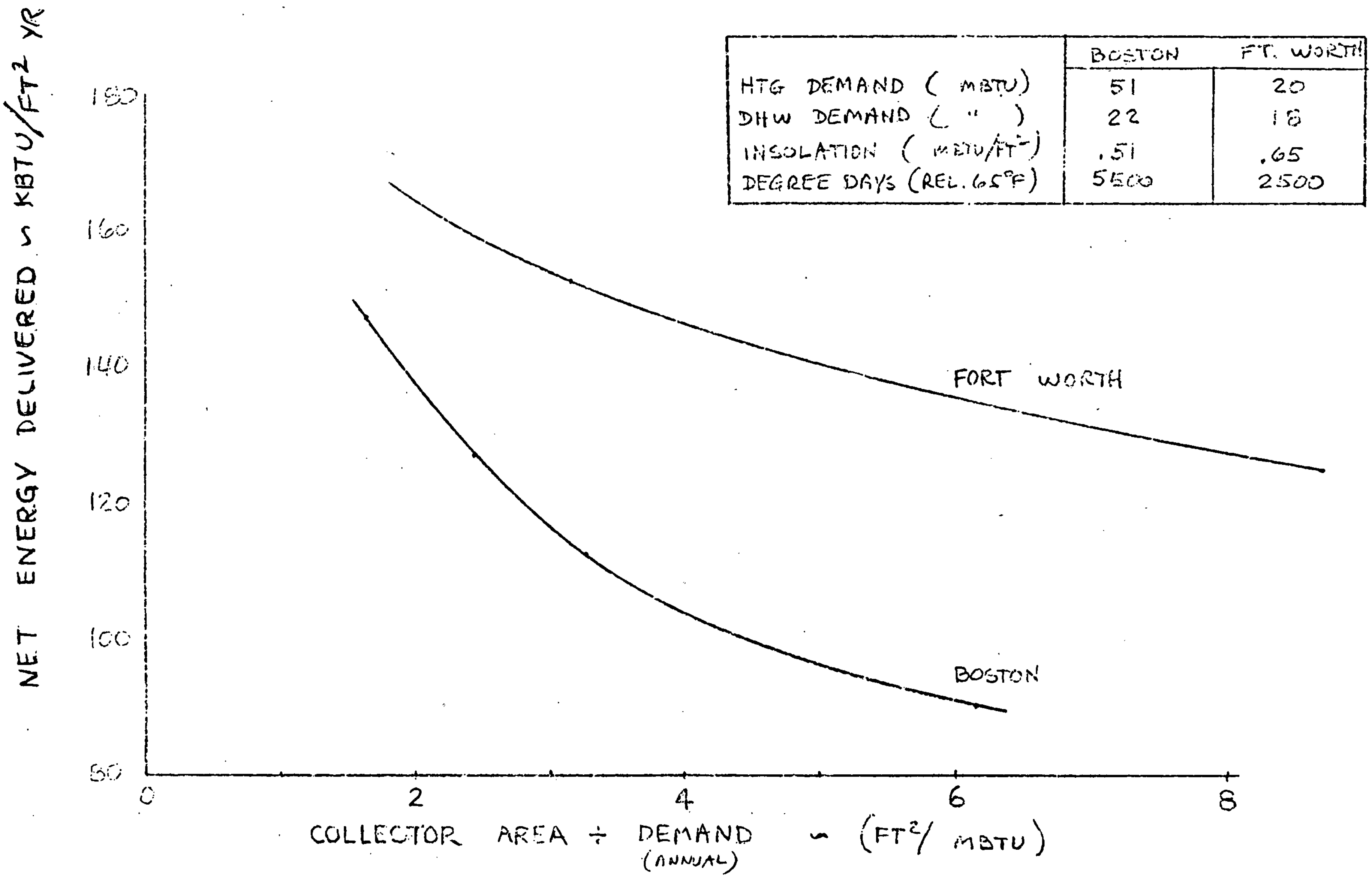


FIGURE 5-19. NORMALIZED SOLAR PERFORMANCE

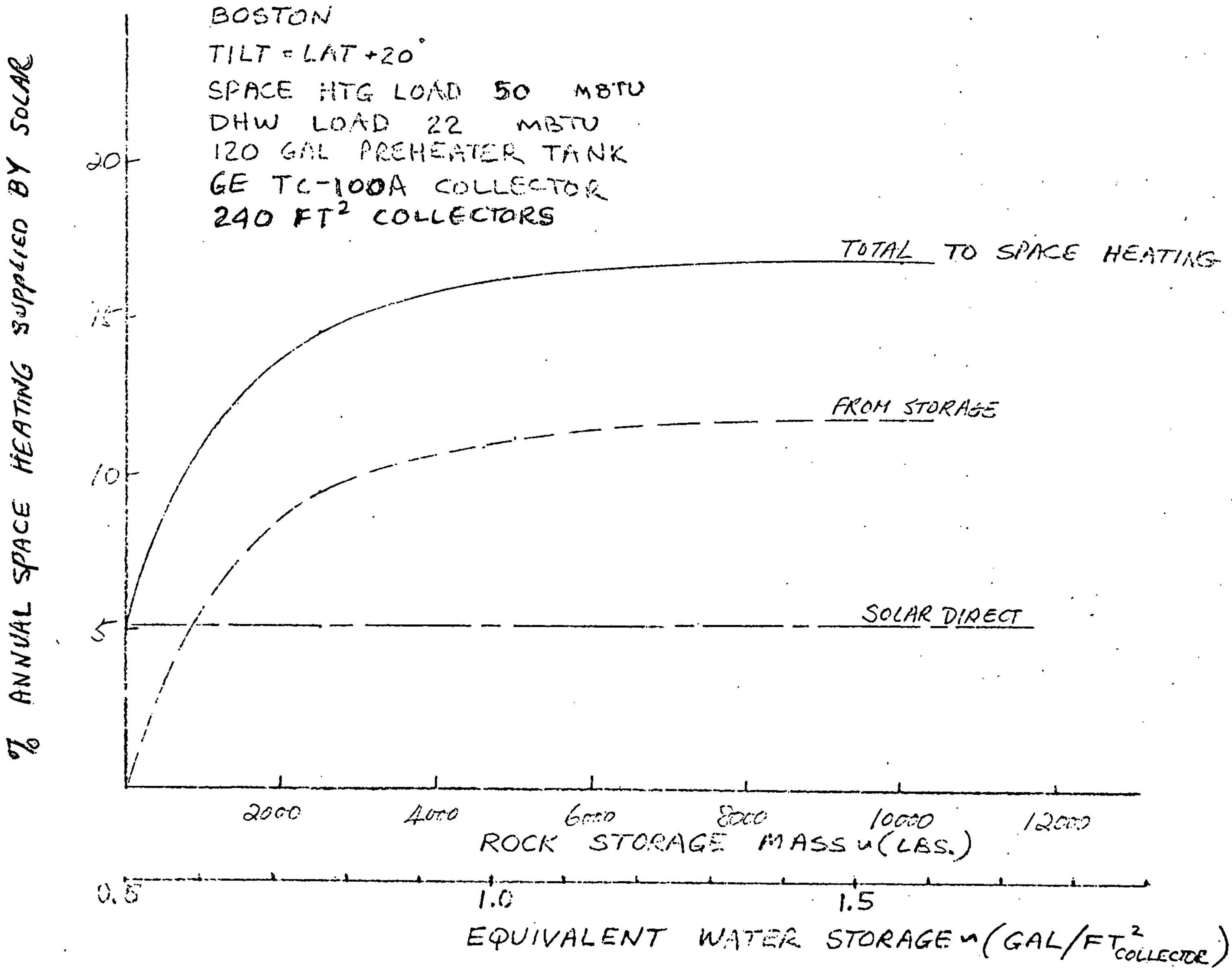


FIGURE 5-20. EFFECT OF ROCK STORAGE ON PERFORMANCE

Figure 5-21 shows the effects of duct size on system performance. Increasing duct size increases the duct losses but decreases the solar system electrical energy consumption. For a particular application, duct sizing depends on an economic evaluation. However, if we assume that electrical energy costs twice as much as heat added to the house, then the best duct diameter in this example is approximately 9 inches (ΔP = .31 inch/100 feet, velocity = 1100 fpm), as shown in Figure 5-21.

Figure 5-22 shows the sensitivity of solar performance to collector tilt angle for a house in Boston. Domestic hot water heating is not sensitive to tilt angle, but space heating is noticeably affected. The net result is a loss of less than 10% in a tilt range of latitude - 20° (L-20) to a vertical installation (L=48). This is characteristic of the evacuated tube collector resulting from its high efficiency at low insolation rates. Sensitivity to tilt angle is reduced in Forth Worth as the domestic hot water load is much larger in relation to the space heating load.

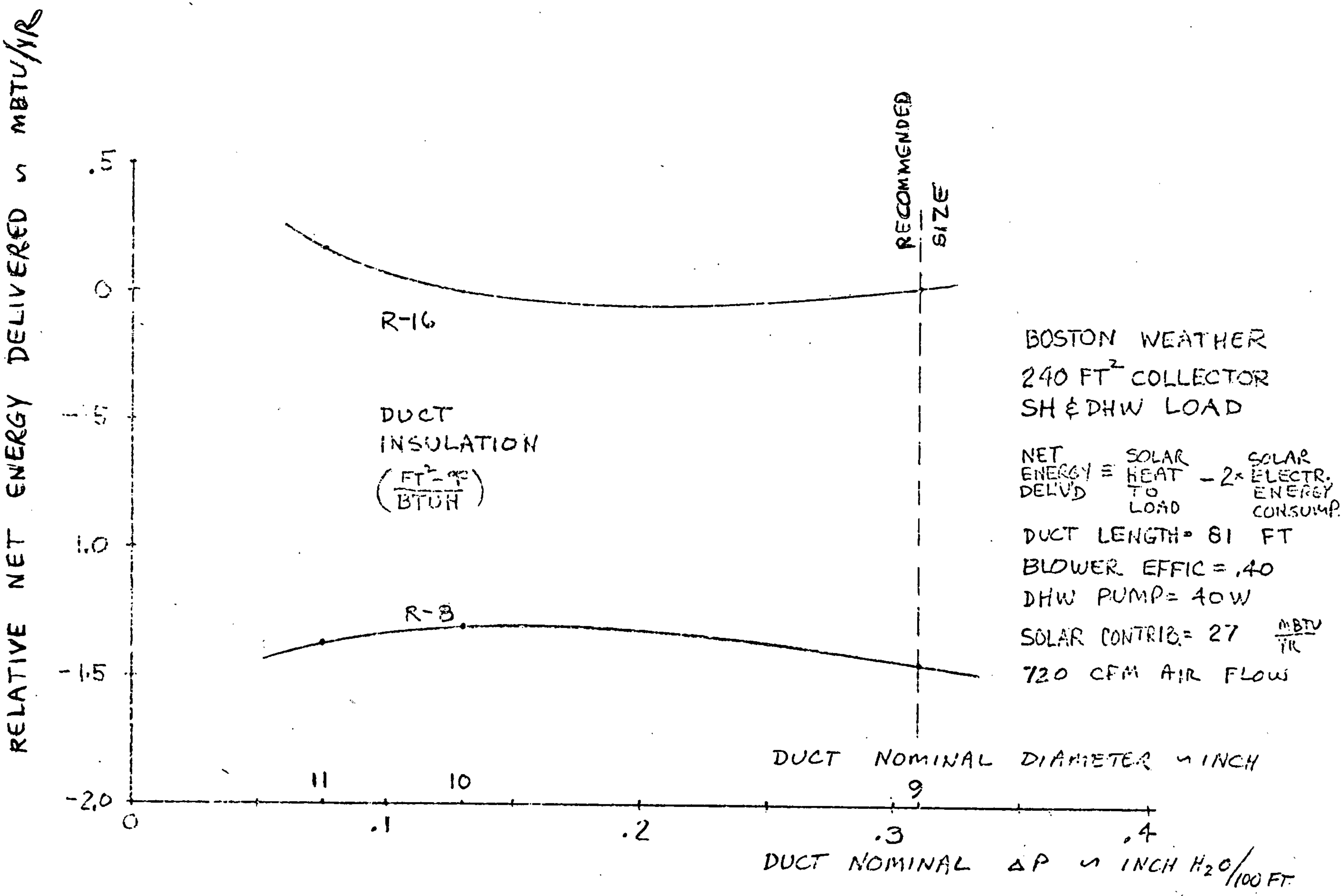


FIGURE 5-21. DUCT SIZE TRADEOFF

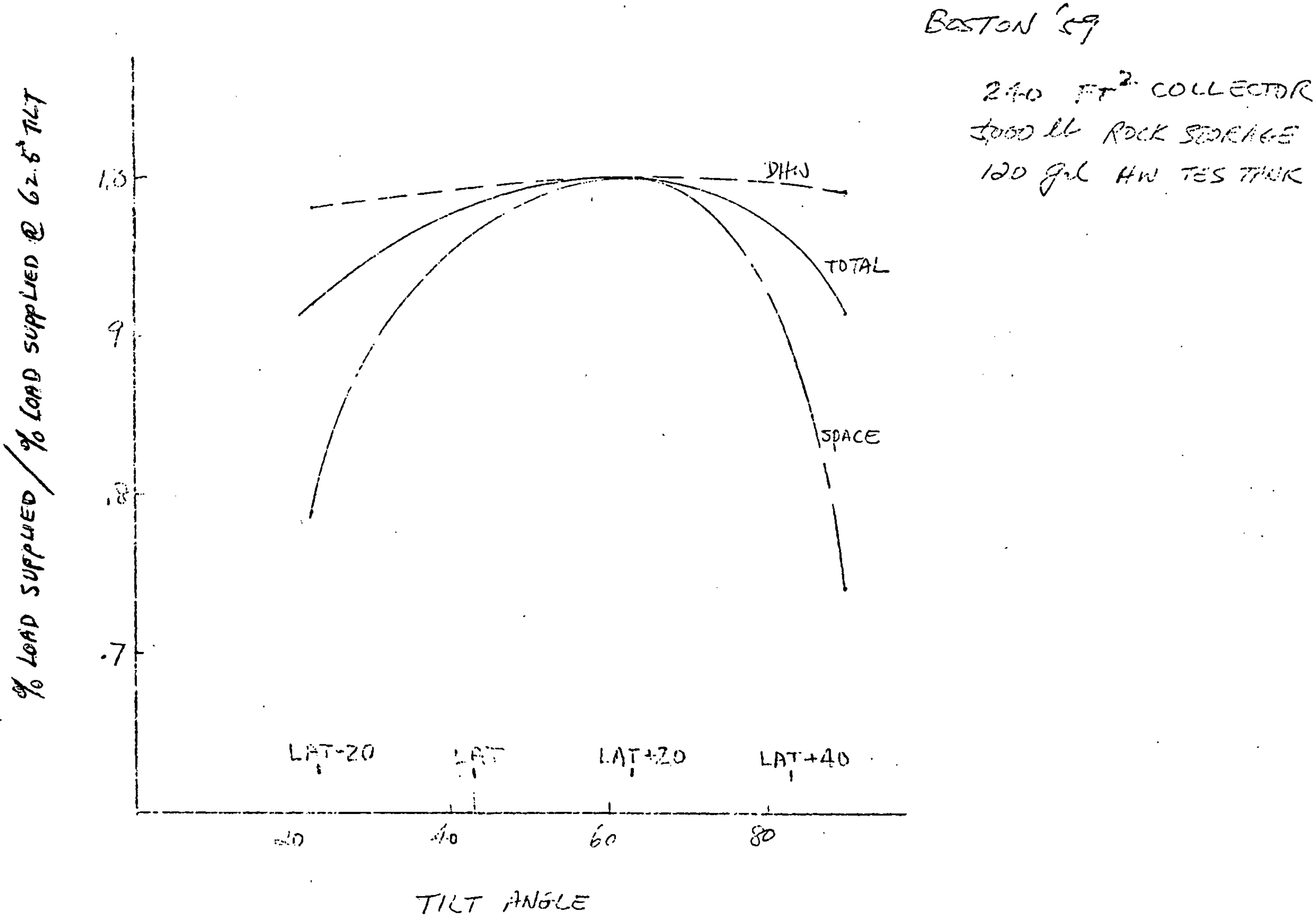


FIGURE 5-22. EFFECT OF COLLECTOR TILT

5.8 HEAT PUMP ASSISTED SOLAR SYSTEM (WITH ROCK STORAGE)

Performance estimates of a vacuum tube solar collector system using air as a heat transfer fluid with rock thermal energy storage and a heat pump for backup have been completed. Of the various means of using a solar system with a heat pump, independent (parallel) operation of the two systems has been found to be most desirable. Solar system efficiency of this system is comparable to that with resistive or fossil fuel backup.

The following options were considered in order to determine an operating mode for using a solar system in conjunction with a heat pump:

1. Air-to-air heat pump with solar functioning independently of the heat pump (Heat Pump Assisted Solar System - Parallel Operation). In this mode, a demand for space heating is satisfied by solar first, but if solar is depleted, the electrically-driven heat pump provides the heat. The ultimate backup is an electrical duct heater (resistive).

2. Air-to-air heat pump with solar heat boosting the performance of the heat pump (Solar-Boosted Heat Pump - Series Operation). In this mode, solar-heated air is used to augment the effective outdoor temperature as seen by the outdoor evaporator.

3. Air-to-air heat pump with solar either boosting or functioning independently of the heat pump (Parallel/Series Operation). This is a combination of the two previous modes of operation such that when solar system temperatures drop, and it cannot directly satisfy the load, solar heat is redirected to the heat pump evaporator and thereby boosts heat pump performance by acting as a heat energy source.

4. Solar with a heat pump other than air-to-air (water-to-water and air-to-water heat pumps are an alternative to the air-to-air heat pump).

In making a comparison between these options, the following system assumptions were made:

- GE TC-100A vacuum tube solar collector.

- Domestic water heating demand substantial relative to space heating demand.

- Solar system with largest market potential is desirable.

With these assumptions, the first option, the parallel system composed of an air-to-air heat pump with solar functioning independently, is most suitable for the following reasons:

- The GE TC-100 is relatively insensitive to operating temperature and functions almost as effectively at the relatively higher temperature suitable for direct space heating as at the lower operating temperatures suitable for boosting heat pump performance.

- The higher temperature capability of a collector designed for heating space directly is compatible with the requirements of domestic water heating.

- An air-to-air heat pump is the most prevalent form of residential heat pumps, and thus a solar system working side by side with such a system is readily suited for retrofit of many homes.

- The performance of a solar system working side by side with a heat pump is better than a boosted mode because free heat is derived from both air and solar. Another benefit is the larger contribution to domestic water heating.

- The existing reliability of heat pumps is not affected with a solar system working in parallel with the heat pump.

The performance of a conventional air-to-air heat pump is shown in Figure 5-23. As the outdoor temperature goes down, both the heating capacity and the coefficient of performance decreases. Although the data shown is for a particular GE Weathertron Heat Pump, it is representative of other heat pumps currently available.

The contribution of a solar system to a house in Boston and the same house in Fort Worth, Texas, is shown in Figures 5-24 and 5-25. The non-linear contribution to space heating results from the control strategy established for operation of a solar system with a heat pump. This strategy is based on the advantage of supplying solar heat to domestic water heating first becuase of the COP advantage (i.e.,a BTU supplied to water heating saves an equivalent amount of electricity; whereas, a BTU supplied to space heating saves a lesser quantity of electricity as determine by the heat pump COP). The percent electricity displaced by a heat pump-assisted solar system is greater than a system with electrical resistive backup. This is not due to a change in solar performance but rather to a decrease in electrical consumption of the reference conventional (non-solar) system.

A generalized system performance estimate can be obtained from Figures 5-26 and 5-27. The abscissa of these figures is the collector area normalized by theannual thermal demand which allows performance estimates for various collector array sizes and various loads. Interpolation between the two curves may be used for performance estimates at other locations depending on the insolation availability. When comparing solar system performance with a heat pump to solar with resistive (or fossil fuel) backup, Figure 5-26 shows a larger percentage of electricity displaced due to the smaller electrical demand with a heat pump system. Figure 5-27 shows solar performance as electrical energy displaced per square foot of collector. This is a more meaningful comparison, because it shows the bottom line savings to the consumer. The values here with a heat pump are lower than with resistive (or fossil fuel) backup because of the COP of the heat pump (i.e., 1.0 BTU supplied to space heating bysolar displaces 1.0 ÷ COP BTU's equivalent of electricity). Thus, the larger the solar contribution, the greater the divergence of electricity displaced when comparing backup by heat pump to electrical resistance.

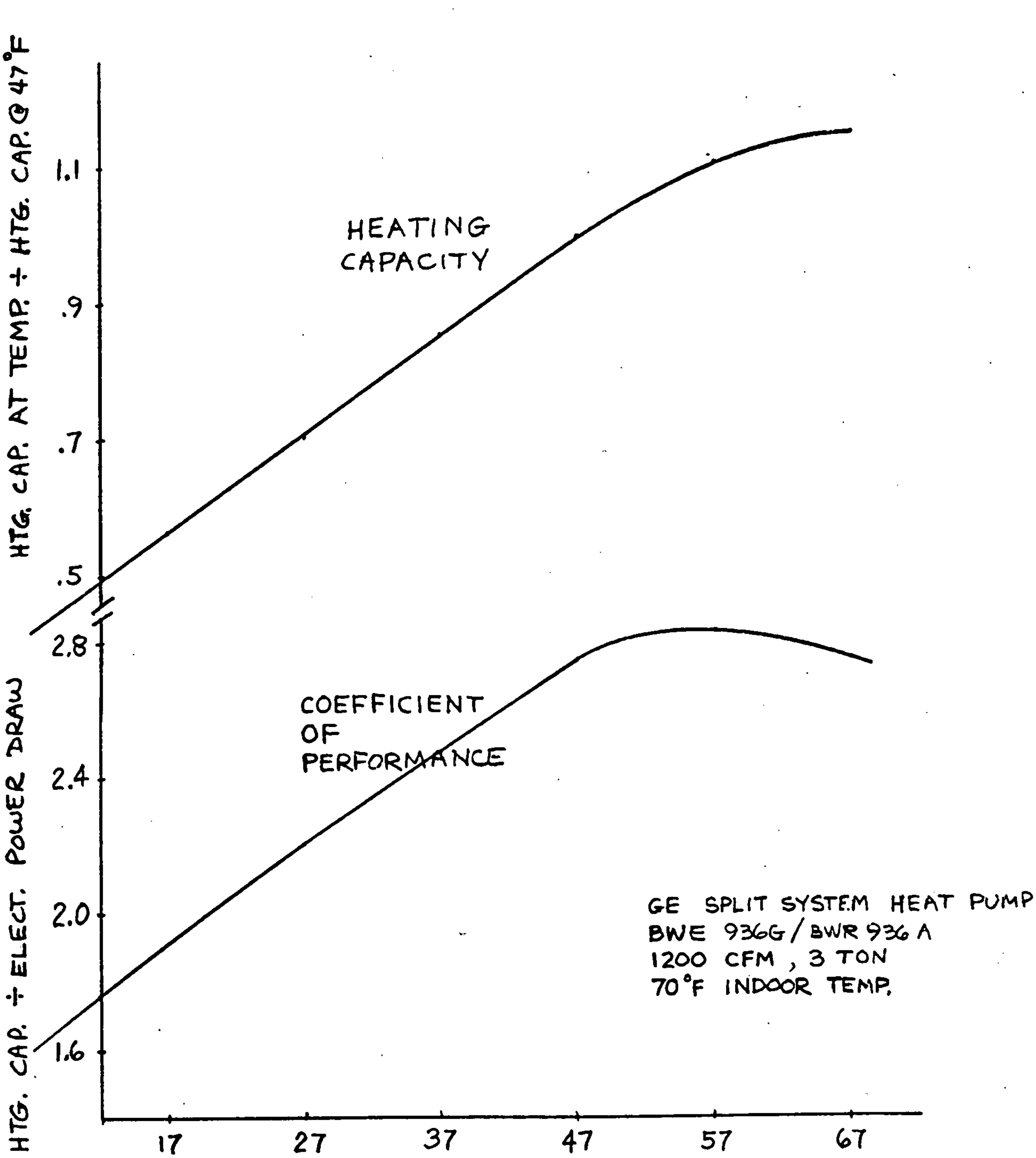


FIGURE 5-23. AIR-TO-AIR HEAT PUMP PERFORMANCE

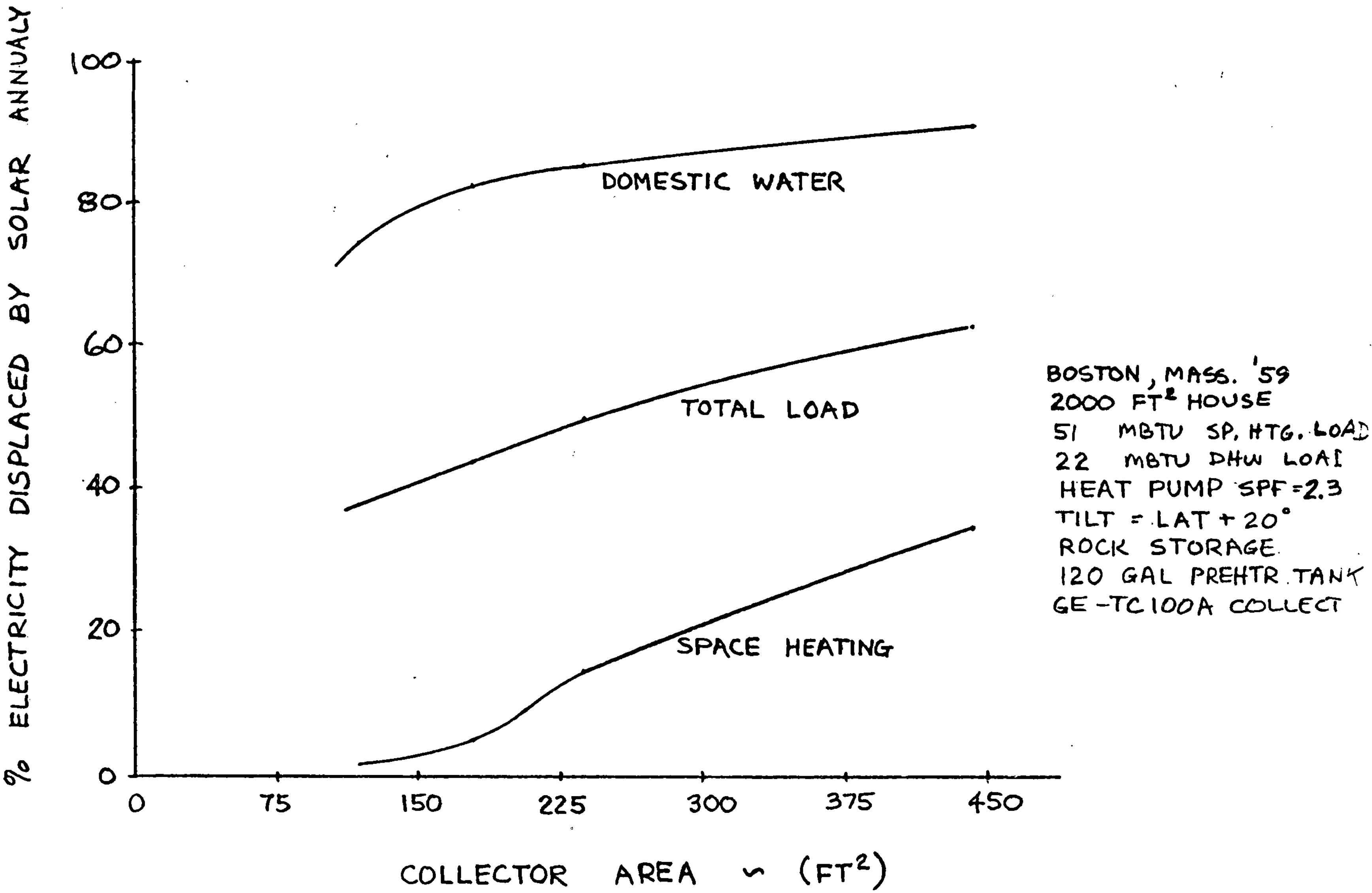


FIGURE 5-24. SOLAR CONTRIBUTION TO BOSTON HOUSE

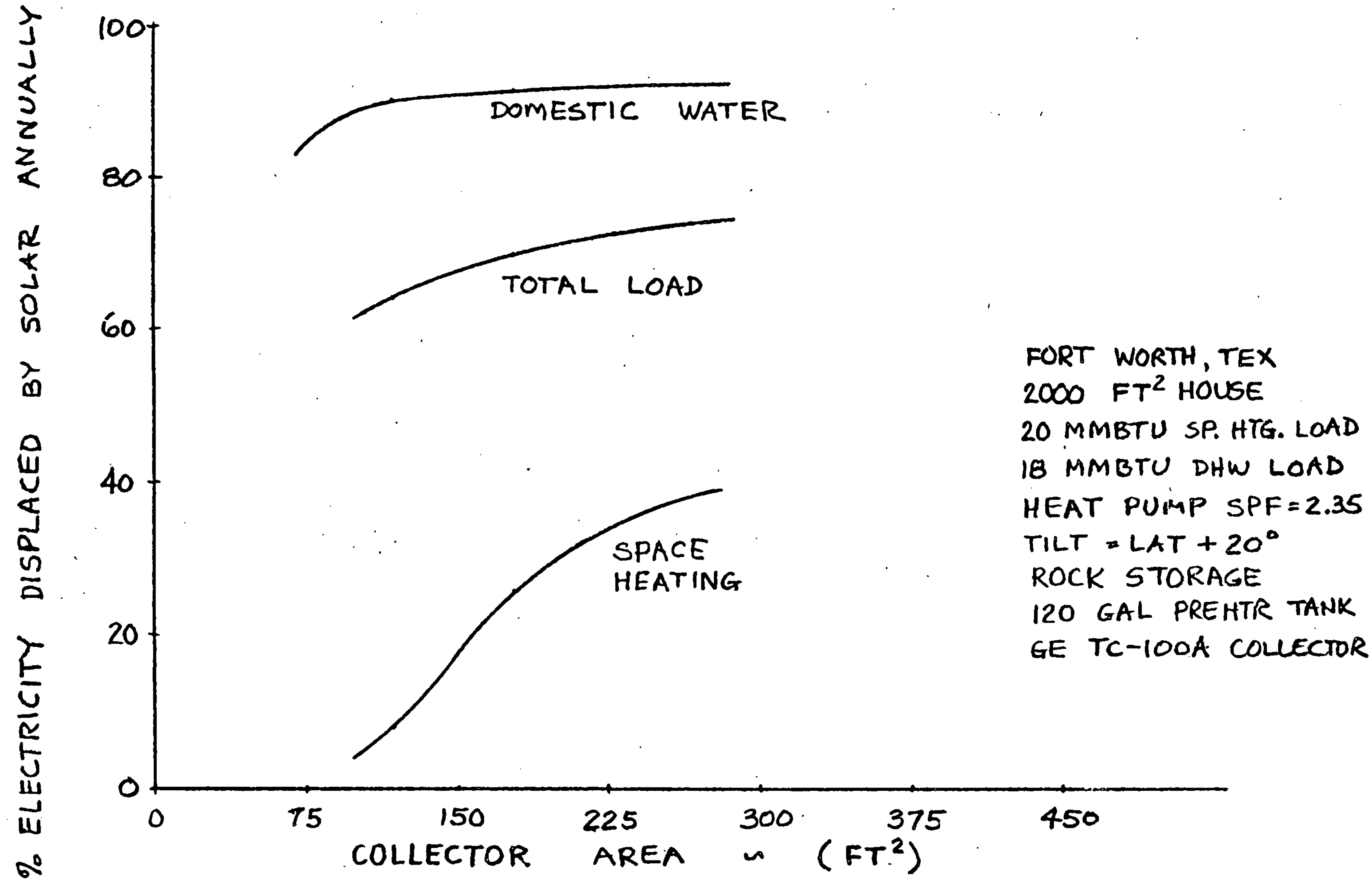


FIGURE 5-25. SOLAR CONTRIBUTION TO FORT WORTH HOUSE

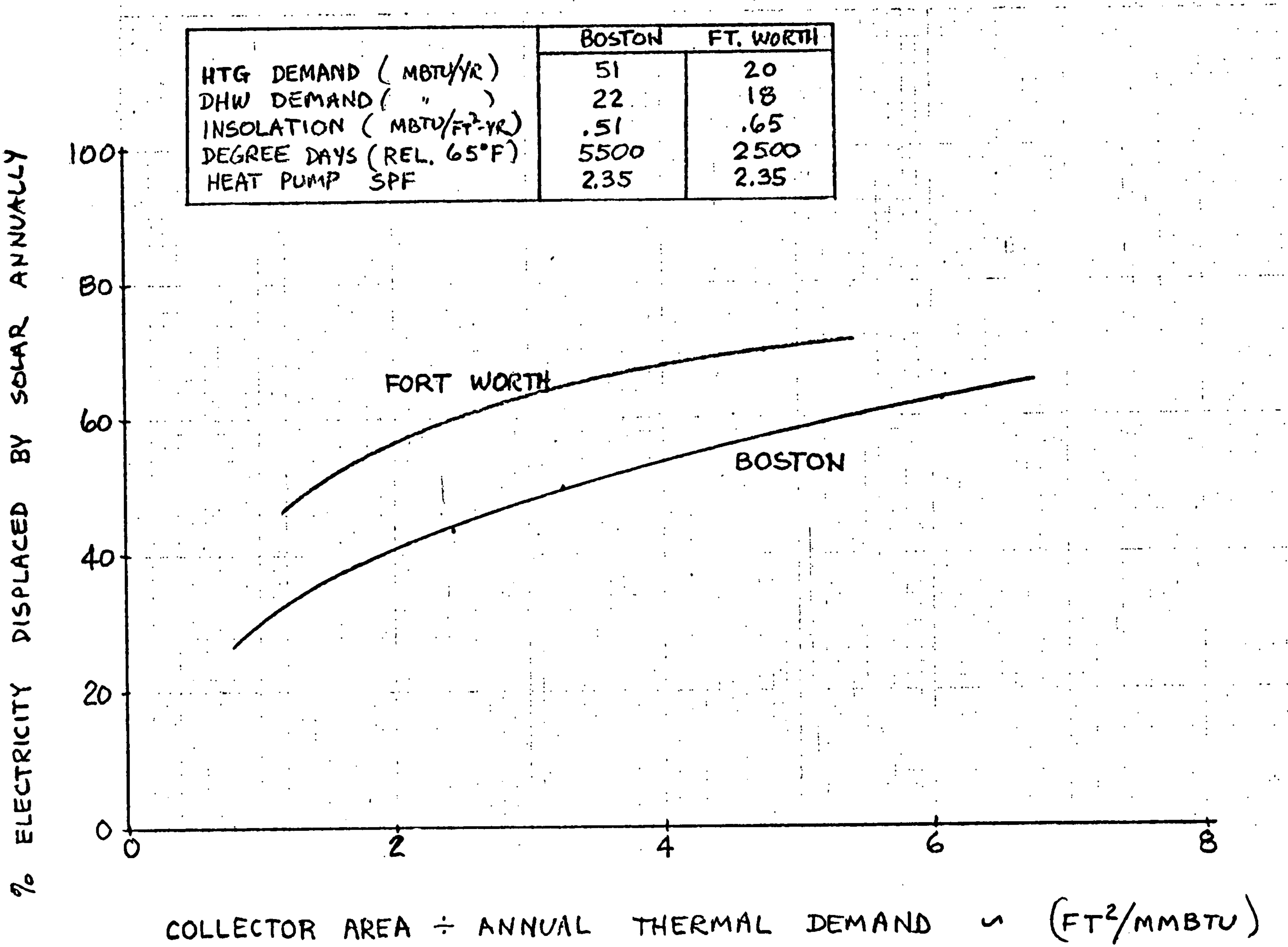


FIGURE 5-26. GENERALIZED SOLAR PERFORMANCE WITH HEAT PUMP

	BOSTON	FT. WORTH
HTG DEMAND (MBTU/YR)	51	20
DHW DEMAND (")	22	18
INSOLATION (MBTU/FT²-YR)	.51	.65
DEGREE DAYS (REL 65°F)	5500	2500
HEAT PUMP SPF	2.35	2.35

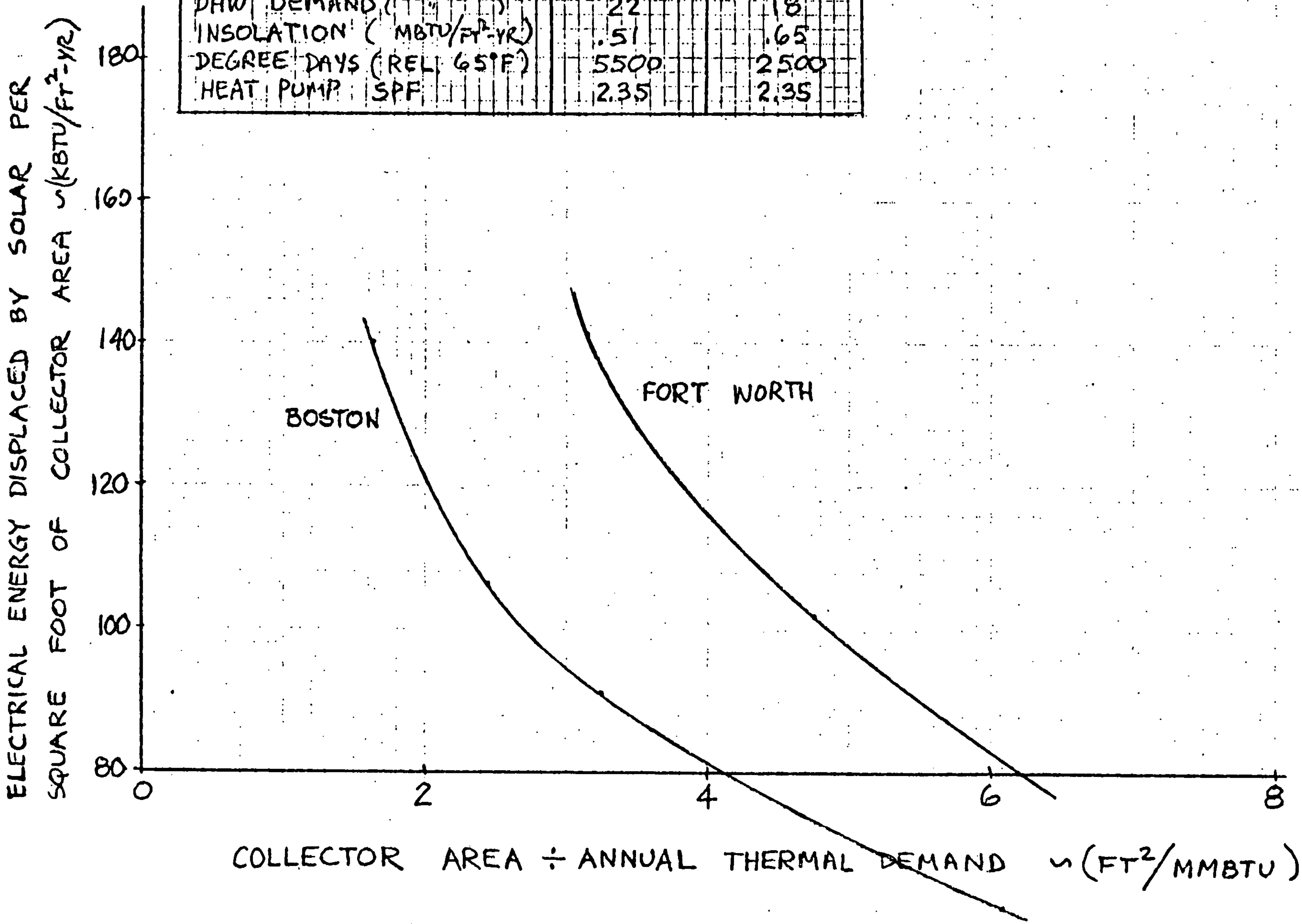


FIGURE 5-27. GENERALIZED SOLAR PERFORMANCE WITH HEAT PUMP

The difference in performance previously noted does not, in itself, imply that solar is not as effective with a heat pump as with other back-up systems since the cost of the backup fuel is required for a comparison. If the cost of electircity is the same in operation a heat pump or resistive heating, then solar performance is better with resistive backup.

5.9 PERFORMANCE COMPARISON: ROCK STORAGE VS. NO DEDICATED STORAGE

Effective utilization of solar energy for space and domestic hot water heating requires energy storage to act as a buffer between the fluctuating availability of sunshine and the fluctuating energy demand. Various mediums may be used to provide this storage capacity, such as a container filled with small rocks, the mass of the house structure including furnishings, water, etc. Depending on the application, one or more of these mediums will be best suited. A performance comparison of a solar system with dedicated rock storage versus one using the house structure are investigated here. The concept of the house structure storage system is low cost so that a less-expensive and less-complicated control system was assumed. Although system cost is a more important criteria than the performance comparison, it will not be investigated here. It is clear, however, that a system using the house structure for storage will have a cost advantage.

The concept of using the structure of the house for storage is based on the inherent thermal capacity available, which is insulated from outside temperatures and provides heat passively to the living space. A typical hardware configuration is shown in Figure 5-13. In order to use this mass for energy storage, the indoor temperature must be allowed to float within a range much like night time set back of the thermostat. The larger the temperature swing permitted, the greater the solar contribution to space heating. A temperature swing of 5°F was assumed in the analysis.

The two modes of thermal storage affect a number of performance factors, most important of which is the auxiliary energy consumption. This is related to yearly heating cost and includes the energy consumed by solar components. Figure 5-28 shows the fraction of the load supplied by solar for the two different systems.

$$\text{\% Solar Supplied} = 100. \left(1 - \frac{\text{Total Auxiliary Energy Consumed}}{\text{Auxiliary Energy W/O Solar}} \right)$$

The abscissa in the plot is collector area normalized by yearly thermal demand.

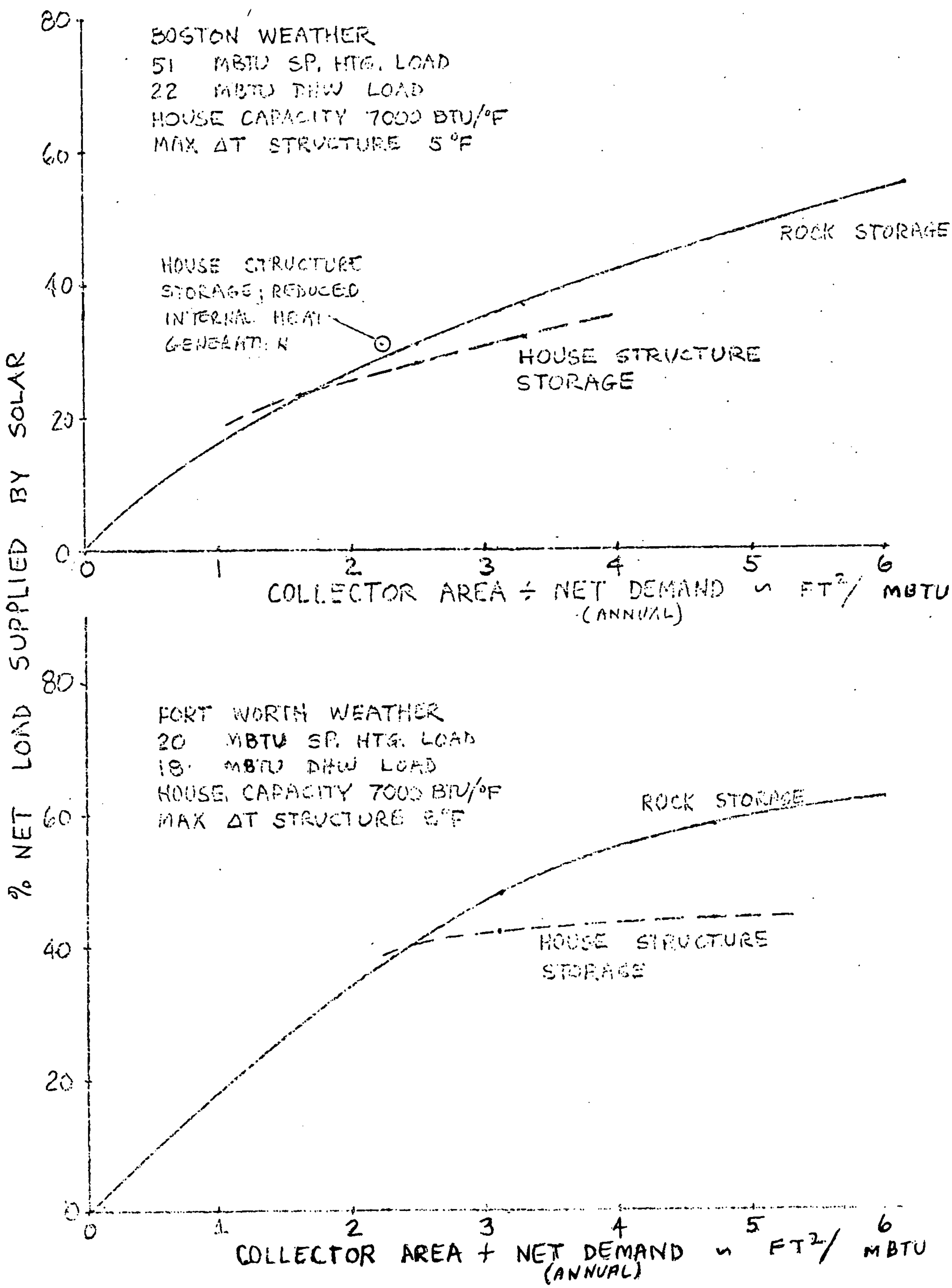


FIGURE 5-28. SOLAR PERFORMANCE WITH/WITHOUT ROCK STORAGE

The system using the house structure for storage performs as well as a system using dedicated rock storage, except for systems with larger collector areas. Considering the difference in cost between the two systems, the performance differential is not very substantial. The following conditions will enhance the performnace of the system using the house structure for storage beyond the values indicated.

- Allowable indoor temperature swing greater than 5°F
- Lower winter heat gain from ambient conditions and sunshine
- Night time thermostat setback
- Higher hot water load
- Lower speed blower for house air distribution when using solar heat

A higher load is induced on the system using house structure for storage because indoor temperatures can be higher by as much as 5°F, the latter being the temperature swing allowed. This difference in load is treated as an inefficiency of the system and is factored in accordingly in all the comparisons. The difference in the load is shown in Figure 5-29. The added load induced by building up the house temperature is not as substantial as one would expect. The thermal loss model of the house assumes substantial heat addition to the house from sunshine and from internal heat generation. This effect tends to reduce the efficiency of the solar system using the house structure for thermal energy storage. When internal heat generation was reduced in the house loss model, the performance of of the system without dedicated storage improved from 98 to 139 $KBTU/Ft^2$ solar contribution.

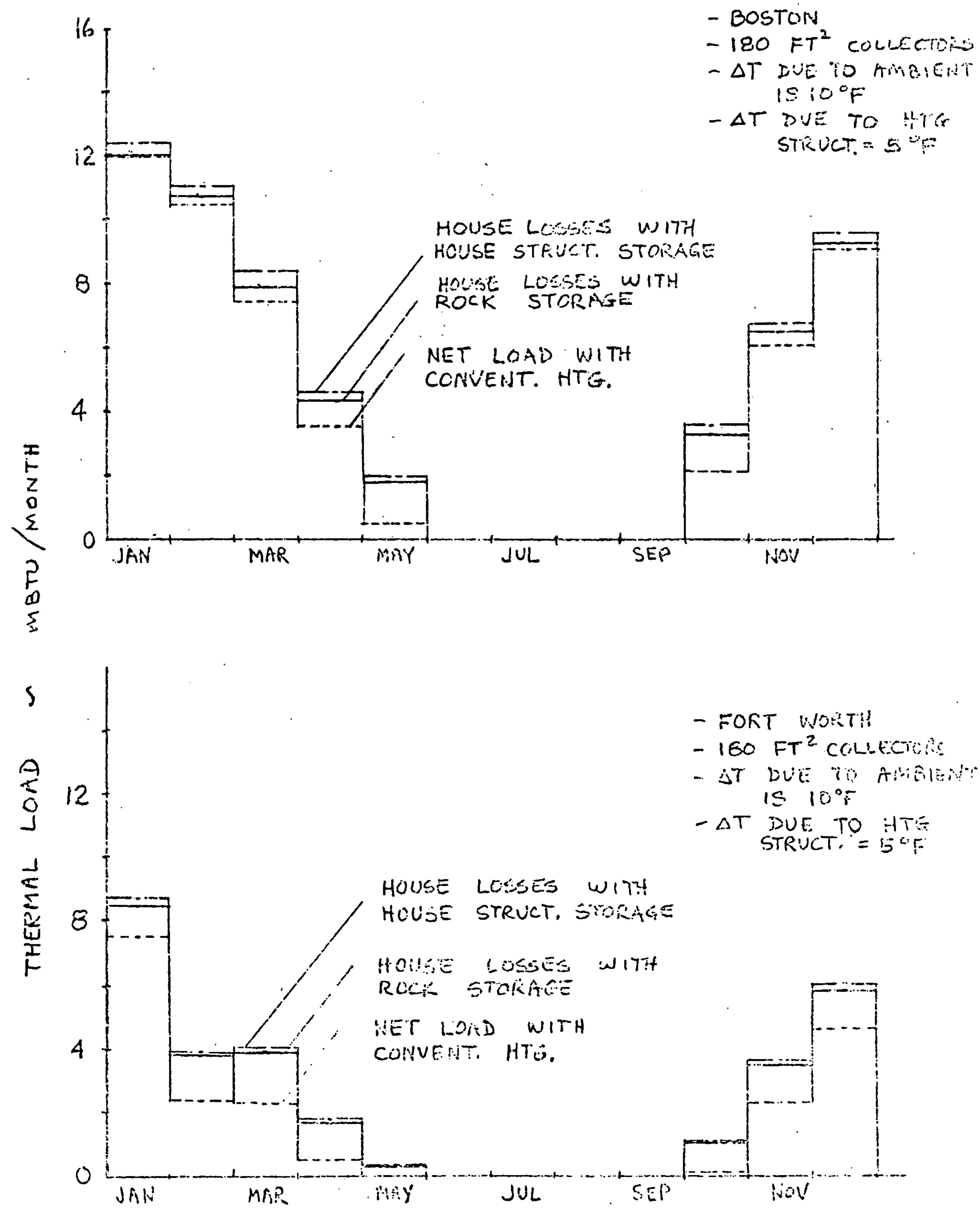


FIGURE 5-29. HOUSE HEAT LOSSES WITH/WITHOUT ROCK STORAGE

5.10 RESULTS

Results of the analysis of various Solair applications are summarized below:

- Solair performance is comparable to liquid collector performance in the applications analyzed.
- The Solair concept has numerous advantages over liquid solar collectors, especially in smaller applications.
- Solair is well suited for domestic water heating, particularly in climates requiring freeze protection.
- A hybrid space heating system has been identified that can substantially improve solar system cost effectiveness.
- Electrical energy consumption of Solair solar components is comparable to liquid collector systems because the thermal characteristics of the vacuum tube collector yields good performance at low air flow rates.
- The performance results for the two locations selected can be extended to other geographical locations.
- Rock storage capacity for Solair equivalent to approximately 1 gallon per square foot of collector is recommended for space heating applications.
- Air ducts should be sized with criteria currently used for sizing ducts in forced air residential systems.
- Collector tilt angle is not a very important parameter when using the vacuum tube collector.

5.11 APPENDIX A. COMPUTER OUTPUT DISCUSSION

Solair Heating/House Storage/Hot Water System

Overall Energy Balance

1. Energy In = Energy Out + Energy Accumulation

   Energy In

   QU + FANF + GAIN + AUX + AUXHW

   Energy Out

   -QL + HWLOAD + QLOSS

   Energy Accumulation

   ΔHOUSECAP + ΔHWEX + ΔQSTORO

Heating Energy Balance

2. -QL = QDIR + (QHOUSE - FFANTCAP) + AUX + FANF) + AUX + FANF

Solar Energy Balance

3. QU + QDIR + (QHOUSE - GAIN - FFANTCAP)

   + QLOSS + (HWLOAD - AUXHW) + ΔHOUSECAP

   + ΔHWEX + ΔQSTORO

Output Description (Monthly or Final Seasonal)

M	=	Month (999 means end of year)
EFFH	=	Solar Heating System Efficiency defined as (QL - AUX)/QL
EFFHW	=	Solar Hot Water System Efficiency defined as (HWLOAD-AUXHW)/HWLOAD
QL	=	Heating Load for House (printed as negative)
QDIR	=	Solar Energy Supplied Directly to House to Supply Heating Load
QHOUSE	=	Energy Supplied from House Storage Capacity to Meet Heating Load
AUX	=	Auxiliary (furnace) Energy Supplied to Heating Load
FNAF	=	Furnace Fan Energy (Total)
THOUSE	=	House Capacitance Temperature
HOUSECAP	=	Energy Stored in House Above Heating Setpoint Temperature which is 68°F at time of printout
GAIN	=	Energy Added to House during Heating Season due to Insolation through Windows, Larger Internal Generation, etc. (limited by cooling temperature).
QCOND	=	Conduction Losses from House
QL68	=	House Load if Capacitance Temperature was always 68°F
QU	=	Solar Energy Delivered to Distribution Subsystems
SOL	=	Incident Solar on Panels (active area)
HBAR	=	Incident on Horizontal (per Ft^2)
COLFF	=	QU/SOL; Collector Active Area Efficiency
FANC	=	Collector Array Fan Power
DUCTIS	=	Collector Array Ductl Losses (already subtracted from QU)
HWLOAD	=	Hot Water Load (includes standby losses)
AUXHW	=	Auxiliary Heat Added to Hot Water Tank
QLOSHW	=	Standby Losses from Hot Water Tank
THW	=	Hot Water Tank Temperature
HWEX	=	Energy Stored in Hot Water Tank above Supply Temperature
TTES	=	Hot Water Preheat Tank Temperature
QSTORO	=	Hot Water Preheat Tank Stored Energy
QLOSS	=	Hot Water Preheat Tank Losses
PUMPOW	=	Hot Water Preheat Tank Pump Power
QOVR	=	Hot Water Preheat Tank Overtemperature Energy which is lost due to fully charged storage
FFANGAP	=	Furnace Fa n Energy used to Store Solar in House

SYSTEM PRESSURE DROP= 0.54766 IN H2O AT 70
DUCT PRESSURE DROP= 0.16536 IN H2O AT 70

MONTHLY DATA:KBTU

M	EFFH	EFFHW	QL	QDIR	QHOUSE	AUX	FANF	THOUSE	HOUSECAP	GAIN	QCOND
	QLOS	QU	SOL	HBAR	COLEFF	FANC	DUCTLS	HWLOAD	AUXHW	QLOSHW	THW
	HWEX	TTES	QSTORO	QLOSS	PUMPPOW	QOVR	FFANTCAP				
10	45.0	76.7	-3494.7	53.7	1494.9	1926.5	48.2	68.0	0.	1003.8	6405.8
	-2904.4	2144.5	7674.0	26.7	27.9	40.9	203.3	1901.8	442.9	113.5	140.0
	0.	100.6	51.7	151.8	15.3	1970.9	62.6				

MONTHLY DATA:KBTU

M	EFFH	EFFHW	QL	QDIR	QHOUSE	AUX	FANF	THOUSE	HOUSECAP	GAIN	QCOND
	QLOS	QU	SOL	HBAR	COLEFF	FANC	DUCTLS	HWLOAD	AUXHW	QLOSHW	THW
	HWEX	TTES	QSTORO	QLOSS	PUMPPOW	QOVR	FFANTCAP				
11	18.7	47.5	-6836.2	169.8	1002.7	5438.9	147.9	66.0	0.	359.4	9056.7
	-6375.2	1652.2	4641.0	14.8	35.6	41.7	139.9	1637.5	958.7	106.9	140.0
	0.	60.9	11.9	73.2	5.9	543.4	73.1				

MONTHLY DATA:KBTU

M	EFFH	EFFHW	QL	QDIR	QHOUSE	AUX	FANF	THOUSE	HOUSECAP	GAIN	QCOND
	QLOS	QU	SOL	HBAR	COLEFF	FANC	DUCTLS	HWLOAD	AUXHW	QLOSHW	THW
	HWEX	TTES	QSTORO	QLOSS	PUMPPOW	QOVR	FFANTCAP				
12	16.7	44.5	-9557.1	303.1	1183.9	7957.3	208.2	66.0	0.	157.2	12154.5
	-9296.7	2133.4	5436.4	15.1	39.2	51.6	162.6	1898.2	1056.4	109.9	140.0
	0.	49.7	0.7	66.4	4.1	92.2	95.5				

MONTHLY DATA:KBTU

M	EFFH	EFFHW	QL	QDIR	QHOUSE	AUX	FANF	THOUSE	HOUSECAP	GAIN	QCOND
	QLOS	QU	SOL	HBAR	COLEFF	FANC	DUCTLS	HWLOAD	AUXHW	QLOSHW	THW
	HWEX	TTES	QSTORO	QLOSS	PUMPPOW	QOVR	FFANTCAP				
1	15.5	36.8	-12378.2	482.2	1352.0	10408.2	225.4	68.0	0.	89.4	15024.6
	-12062.9	2451.1	6031.4	17.4	41.1	50.3	164.0	1397.5	1200.1	109.2	140.4
	0.2	133.1	64.2	45.0	6.6	0.	89.7				

MONTHLY DATA:KBTU

M	EFFH	EFFHW	QL	QDIR	QHOUSE	AUX	FANF	THOUSE	HOUSECAP	GAIN	QCOND
	QLOS	QU	SOL	HBAR	COLEFF	FANC	DUCTLS	HWLOAD	AUXHW	QLOSHW	THW
	HWEX	TTES	QSTORO	QLOSS	PUMPPOW	QOVR	FFANTCAP				
2	19.4	57.7	-11060.6	642.1	1238.1	6916.5	247.3	58.0	0.	160.7	14054.5
	-10779.0	2751.9	6919.3	24.4	39.8	60.5	207.9	1715.1	725.0	99.6	140.0
	0.	100.0	51.1	76.8	6.5	160.9	63.2				

MONTHLY DATA:KBTU

M	EFFH	EFFHW	QL	QDIR	QHOUSE	AUX	FANF	THOUSE	HOUSECAP	GAIN	QCOND
	QLOS	QU	SOL	HBAR	COLEFF	FANC	DUCTLS	HWLOAD	AUXHW	QLOSHW	THW
	HWEX	TTES	QSTORO	QLOSS	PUMPPOW	QOVR	FFANTCAP				
3	25.3	72.9	-8375.5	316.6	1714.2	6253.4	209.8	66.0	0.	305.6	12506.0
	-7934.4	3177.7	9589.4	42.5	33.1	57.9	247.0	1900.9	517.1	112.7	145.3
	3.1	145.7	99.5	133.4	11.7	1279.3	118.5				

MONTHLY DATA:KBTU

M	EFFH	EFFHW	QL	QDIR	QHOUSE	AUX	FANF	THOUSE	HOUSECAP	GAIN	QCOND
	QLOS	QU	SOL	HBAR	COLEFF	FANC	DUCTLS	HWLOAD	AUXHW	QLOSHW	THW
	HWEX	TTES	QSTORO	QLOSS	PUMPPOW	QOVR	FFANTCAP				
4	34.2	80.0	-4639.6	97.1	1445.2	3051.6	139.6	68.0	0.	641.8	8211.1
	-4172.9	2349.4	8262.1	45.0	28.4	49.6	215.7	1840.3	366.6	119.7	140.0
	0.	72.3	23.3	150.0	14.1	1057.3	93.9				

MONTHLY DATA:KBTU

M	EFFH	EFFHW	QL	QDIR	QHOUSE	AUX	FANF	THOUSE	HOUSECAP	GAIN	QCOND
	QLOS	QU	SOL	HBAR	COLEFF	FANC	DUCTLS	HWLOAD	AUXHW	QLOSHW	THW
	HWEX	TTES	QSTORO	QLOSS	PUMPPOW	QOVR	FFANTCAP				
5	77.1	95.7	-1710.9	1.6	1469.7	436.7	44.6	73.0	35.0	1197.0	4926.5
	-1229.3	2377.9	10411.5	65.9	22.8	49.3	292.7	1903.7	94.6	120.4	153.6
	6.8	156.3	107.4	205.6	26.6	1633.2	41.6				

MONTHLY DATA:KBTU

```
M      EFFH      EFFHW     QL        QDIR      QHOUSE    AUX       FANF      THOUSE    HOUSECAP  GAIN      QCOND
       QLOS      QU        SOL       HBAR      COLEFF    FANC      DUCTLS    HWLOAD    AUXHW     QLOSHW    THW
       HWEX      TTES      QSTORD    QLOSS     PUMPPOW   QOVR      FFANTCAP
5      77.1      83.7      0.        0.        0.        0.        0.        73.0      35.0      0.        0.
       0.        15669.6   7138.6    46.2      22.1      43.1      244.3     1694.3    276.2     115.8     154.9
       7.5       155.1     109.2     166.0     29.7      235.7     0.
MONTHLY DATA:KBTU
M      EFFH      EFFHW     QL        QDIR      QHOUSE    AUX       FANF      THOUSE    HOUSECAP  GAIN      QCOND
       QLOS      QU        SOL       HBAR      COLEFF    FANC      DUCTLS    HWLOAD    AUXHW     QLOSHW    THW
       HWEX      TTES      QSTORD    QLOSS     PUMPPOW   QOVR      FFANTCAP
7      77.1      95.1      0.        0.        0.        0.        0.        73.0      35.0      0.        0.
       0.        1590.6    9050.5    57.1      20.9      50.3      265.5     1756.0    60.6      125.0     151.5
       5.3       154.7     105.8     203.5     32.6      1402.9    0.
MONTHLY DATA:KBTU
M      EFFH      EFFHW     QL        QDIR      QHOUSE    AUX       FANF      THOUSE    HOUSECAP  GAIN      QCOND
       QLOS      QU        SOL       HBAR      COLEFF    FANC      DUCTLS    HWLOAD    AUXHW     QLOSHW    THW
       HWEX      TTES      QSTORD    GLOSS     PUMPPOW   QOVR      FFANTCAP
8      77.1      94.2      0.        0.        0.        0.        0.        73.0      35.0      0.        0.
       0.        1349.9    5537.3    51.3      20.9      41.3      249.3     1753.6    101.6     122.5     147.3
       5.6       152.5     103.5     202.5     27.1      1637.3    0.
MONTHLY DATA:KBTU
M      EFFH      EFFHW     QL        QDIR      QHOUSE    AUX       FANF      THOUSE    HOUSECAP  GAIN      QCOND
       QLOS      QU        SOL       HBAR      COLEFF    FANC      DUCTLS    HWLOAD    AUXHW     QLOSHW    THW
       HWEX      TTES      QSTORD    GLOSS     PUMPPOW   QOVR      FFANTCAP
9      77.1      95.7      0.        0.        0.        0.        0.        73.0      35.0      0.        0.
       0.        1351.9    9167.7    43.7      20.2      37.3      252.7     1697.3    56.8      118.8     150.6
       5.3       156.5     107.7     205.6     24.9      2611.6    0.
****PEAK HEATING LOAD= 33421.BTU     ****PEAK COOLING LOAD=     0.BTU
**********************************************************************
FINAL SEASONAL DATA:KBTU   QU/AC= 147.49
M      EFFH      EFFHW     QL        QDIR      QHOUSE    AUX       FANF      THOUSE    HOUSECAP  GAIN      QCOND
       QLOS      QU        SOL       HBAR      COLEFF    FANC      DUCTLS    HWLOAD    AUXHW     QLOSHW    THW
       HWEX      TTES      QSTORD    GLOSS     PUMPPOW   QOVR      FFANTCAP
13.    23.5      73.1      -55107.0  2066.3    11000.7   44387.1   1311.2    73.0      35.0      3937.9    32372.0
       -55744.2  23247.0   43232.2   452.0     23.2      573.3     2665.0    21801.2   5854.7    1364.4    150.6
       5.7       155.5     107.7     7691.6    214.0     13234.6   656.3
**********************************************************************
```


```
M      EFFH      EFFHW     QL        QDIR      QHOUSE    AUX       FANF      THOUSE    HOUSECAP  GAIN      QCOND
       QLOS      QU        SOL       HBAR      COLEFF    FANC      DUCTLS    HWLOAD    AUXHW     QLOSHW    THW
       HWEX      TTES      QSTORD    QLOSS     PUMPPOW   QOVR      FFANTCAP
5      77.1      83.7      0.        0.        0.        0.        0.        73.0      35.0      0.        0.
       0.        15669.6   7138.6    46.2      22.1      43.1      244.3     1694.3    276.2     115.8     154.9
       7.5       155.1     109.2     166.0     29.7      235.7     0.
MONTHLY DATA:KBTU
M      EFFH      EFFHW     QL        QDIR      QHOUSE    AUX       FANF      THOUSE    HOUSECAP  GAIN      QCOND
       QLOS      QU        SOL       HBAR      COLEFF    FANC      DUCTLS    HWLOAD    AUXHW     QLOSHW    THW
       HWEX      TTES      QSTORD    QLOSS     PUMPPOW   QOVR      FFANTCAP
7      77.1      95.1      0.        0.        0.        0.        0.        73.0      35.0      0.        0.
       0.        1590.6    9050.5    57.1      20.9      50.3      265.5     1756.0    60.6      125.0     151.5
       5.3       154.7     105.8     203.5     32.6      1402.9    0.
MONTHLY DATA:KBTU
M      EFFH      EFFHW     QL        QDIR      QHOUSE    AUX       FANF      THOUSE    HOUSECAP  GAIN      QCOND
       QLOS      QU        SOL       HBAR      COLEFF    FANC      DUCTLS    HWLOAD    AUXHW     QLOSHW    THW
       HWEX      TTES      QSTORD    GLOSS     PUMPPOW   QOVR      FFANTCAP
8      77.1      94.2      0.        0.        0.        0.        0.        73.0      35.0      0.        0.
       0.        1349.9    5537.3    51.3      20.9      41.3      249.3     1753.6    101.6     122.5     147.3
       5.6       152.5     103.5     202.5     27.1      1637.3    0.
MONTHLY DATA:KBTU
M      EFFH      EFFHW     QL        QDIR      QHOUSE    AUX       FANF      THOUSE    HOUSECAP  GAIN      QCOND
       QLOS      QU        SOL       HBAR      COLEFF    FANC      DUCTLS    HWLOAD    AUXHW     QLOSHW    THW
       HWEX      TTES      QSTORD    GLOSS     PUMPPOW   QOVR      FFANTCAP
9      77.1      95.7      0.        0.        0.        0.        0.        73.0      35.0      0.        0.
       0.        1351.9    9167.7    43.7      20.2      37.3      252.7     1697.3    56.8      118.8     150.6
       5.3       156.5     107.7     205.6     24.9      2611.6    0.
****PEAK HEATING LOAD= 33421.BTU     ****PEAK COOLING LOAD=     0.BTU
**********************************************************************
FINAL SEASONAL DATA:KBTU   QU/AC= 147.49
M      EFFH      EFFHW     QL        QDIR      QHOUSE    AUX       FANF      THOUSE    HOUSECAP  GAIN      QCOND
       QLOS      QU        SOL       HBAR      COLEFF    FANC      DUCTLS    HWLOAD    AUXHW     QLOSHW    THW
       HWEX      TTES      QSTORD    GLOSS     PUMPPOW   QOVR      FFANTCAP
13.    23.5      73.1      -55107.0  2066.3    11000.7   44387.1   1311.2    73.0      35.0      3937.9    32372.0
       -55744.2  23247.0   43232.2   452.0     23.2      573.3     2665.0    21801.2   5854.7    1364.4    150.6
       5.7       155.5     107.7     7691.6    214.0     13234.6   656.3
**********************************************************************
```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<*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*>
ERROR 134. TRACE OF CALLS IN REVERSE ORDER
CALLING     IS      ABSOLUTE    ARGUMENT        ARGUMENT        ARGUMENT        ARGUMENT        ARGUMENT
ROUTINE     #       LOCATION    #1              #2              #3              #4              #5
......      67      023202      00000000000042
......      757     022347
......      1270    023727      00000000000005  452144012020
END OF FILE READING   FILE CODE 03
CHECK AS RETURN NOT REQUESTED
<*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*>
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SECTION 6

COMPARISON OF SOLAIR WITH ENERGY CONSERVING DESIGNS

6.1 OBJECTIVE

The objective of this task was to compare an investment in Solair to an investment in various house insulation options.

6.2 SUMMARY

Energy savings and cost of various home insulation options are described, and a cost effectiveness ranking of options is determined. A relationship of investment required to the corresponding energy savings is derived and sensitivity to geographical location and types of construction (new or retrofit) is investigated.

In order to compare insulation to insolation, both are plotted on a graph of total investment required versus the corresponding annual energy savings. This comparison approach features a minimal number of assumptions.

6.3 ANALYSIS

Potential savings from energy conservation devices were analyzed for homes located in Boston, Massachusetts, and Fort Worth, Texas. Storm windows and doors were considered as well as insulation in the ceiling, walls and floor. Principal assumptions are presented in Table 6-1.

Heating load computations were based on the methdology of Peterson (Reference 1). Cooling loads were not considered in the analysis. Both locations showed identical cost effectiveness rankings for the conservation measures considered, namely:

1. 6" attic insulation.
2. 6" floor insulation.
3. 4" wall insulation.
4. storm windows
5. storm doors
6. 6" wall insulation (6" studs on 24" centers)
7. 8" attic insulation
8. 10" attic insulation
9. 12" attic insulation.

Details of this computation are shown in Table 6-2.

The annual heating load savings were computed for successive additions of the above items. Figure 6-1 and Table 6-3 present annual load savings for new construction versus total cost of conservation devices - insulation and storm windows and doors. Savings in purchased fuel requirements can be obtained by dividing heating load savings by an appropriate average value of heating equipment efficiency.

TABLE 6-1. PRINCIPAL ASSUMPTIONS (NEW CONSTRUCTION)

Residence	-	2 Story, with unheated basement 40 ft. x 25 ft. floor area, 2 doors 15 windows: 6 3' x 5' 4 3' x 3' 4 3' x 2' 1 6' x 8' No insulation
Locations	-	Boston 6000 degree-days t_o = 42.5°F Ft. Worth 2500 degree-days t_o = 50°F
Prices	-	Storm Doors $75 each Storm Windows $25 + $.5/inch for over 100 united inches Insulation $.05/in/Ft^2 (R = 3.1/in) + $.05/Ft installation*

* Assumes new construction. Retrofit would be higher, particularly walls.

TABLE 6-2. COMPARISON OF CONSERVATION OPTIONS (NEW CONSTRUCTION)

	BOSTON			FORT WORTH		
OPTION	10^6 BTU/YR SAVINGS	10^6 BTU/$	RANK	10^6 BTU/YR SAVINGS	10^6 BTU/$	RANK
Storm Wind.	18.487	.0452	4	7.556	.0185	4
Storm Doors	3.676	.0245	5	1.460	.0097	5
Attic 6	45.575	.1302	1	21.231	.0607	1
8	1.630	.0163	7	.759	.0076	7
10	1.056	.0106	8	.483	.0048	8
12	.714	.0071	9	.341	.0034	9
Walls 4	26.443	.0581	3	11.018	.0242	3
6	3.953	.0217	6	1.647	.0090	6
Floor 6	27.963	.0799	2	9.937	2	

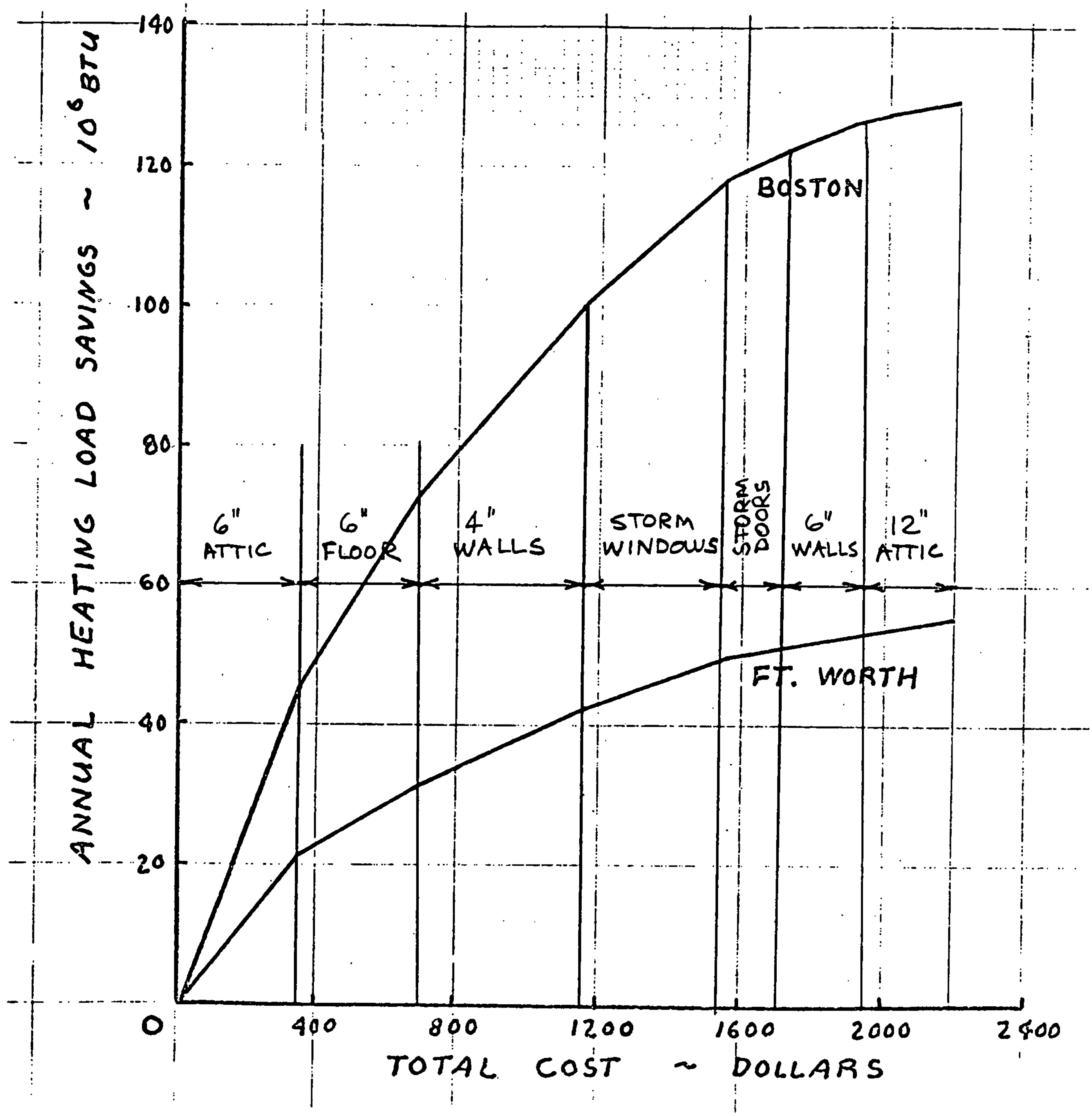

FIGURE 6-1. INVESTMENT AND BENEFIT OF INSULATION
(NEW CONSTRUCTION)

TABLE 6-3. INVESTMENT/BENEFIT ANALYSIS OF INSULATION (NEW CONSTRUCTION)

ITEM	INCREMENTAL COST	TOTAL COST	CUM. SAVINGS 10^6 BTU	
			BOSTON	FT. WORTH
6" Attic	$ 350	$ 350	45.575	21.231
6" Floor	350	700	73.538	31.168
4" Walls	455	1155	99.981	42.186
Storm Windows	409	1564	118.468	49.742
Storm Doors	150	1714	122.144	51.202
6" Walls	182	1896	126.097	52.849
8" Attic	100	1996	127.727	53.608
10" Attic	100	2096	128.783	54.367
12" Attic	100	2196	129.497	54.708

Retrofit installations are as important to consider as new construction, and a modified analysis is required. Using the same approach as before, the various options are ranked with details shown in Table 6-4. Both locations showed identical cost effectiveness rankings for the conservation measures considered, namely:

1. Triple glass windows
2. Add 2" to attic
3. Add 2" more to attic
4. Add 2" more to attic
5. Add 4" to floor
6. Add 2" more to floor

The relationship between investment required and corresponding energy savings is shown in Figure 6-2.

In order to compare insulation to insolation, both are evaluated in terms of total initial cost and corresponding annual energy savings. This approach eliminates many assumptions required for other comparisons that utilize life cycle costs. In new construction the value of insulation far outweighs any solar system benefits and is not plotted. In the retrofit of a reasonably well-insulated house, a solar domestic water heating system can be economically competitive, as shown in Figure 6-3. A water heating Solair system was selected, because it is the most cost effective. There is no established price for such a system, so it is plotted as a horizontal line representing a fixed energy saving with variable cost. Figure 6-3 shows that a Solair system is more cost effective than adding insulation to a reasonably well insulated house in Fort Worth. In a colder region like Boston, a Solair water heating system would have to sell for $900 installed to be competitive with additional insulation.

TABLE 6-4. INVESTMENT/BENEFIT ANALYSIS OF CONSERVATION (RETROFIT)

BOSTON				
ITEM	COST ($)	SAVING (10^6 BTU)	CUMUL.COST ($)	CUMUL.SAVING (10^6 BTU)
Triple Glass	409	7.35	409	7.35
Attic +2"	150	1.63	559	8.98
+4"	250	1.06	659	10.04
+6"	350	0.71	759	10.75
Floor +2"	200	1.24	959	11.99
+4"	300	0.81	1059	12.80
+6"	400	0.57	11.59	13.37

FT. WORTH				
ITEM	COST ($)	SAVING (10^6 BTU)	CUMUL.COST ($)	CUMUL.SAVING (10^6 BTU)
Triple Glass	409	3.03	409	3.03
Attic +2"	150	0.76	559	3.79
+4"	250	0.48	659	4.27
+6"	350	0.34	759	4.61
Floor +2"	206	0.43	959	5.04
+4"	300	0.28	1059	5.32
+6"	400	0.20	1159	5.52

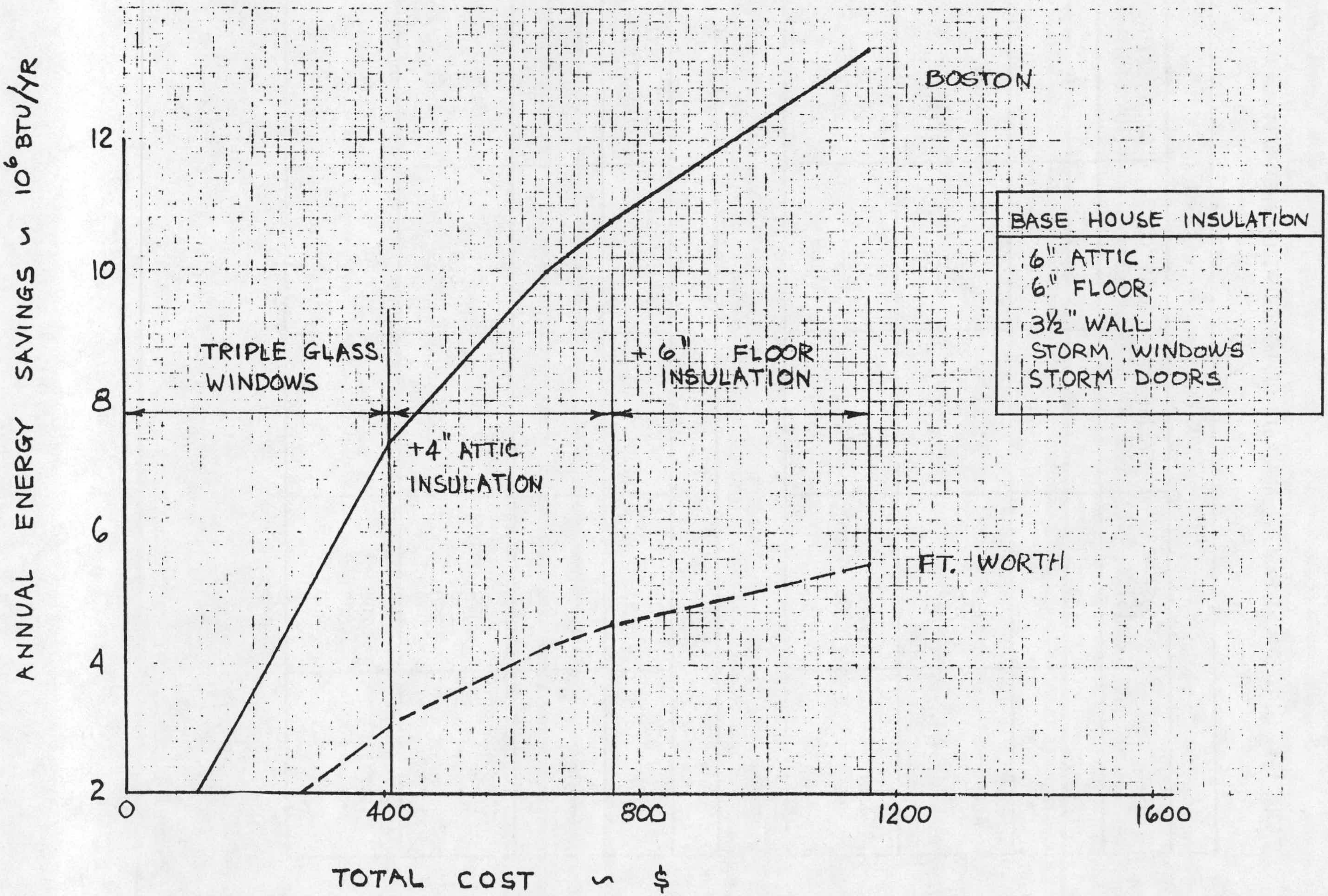

FIGURE 6-2: INVESTMENT & BENEFIT OF INSULATION (HOUSE RETROFIT)

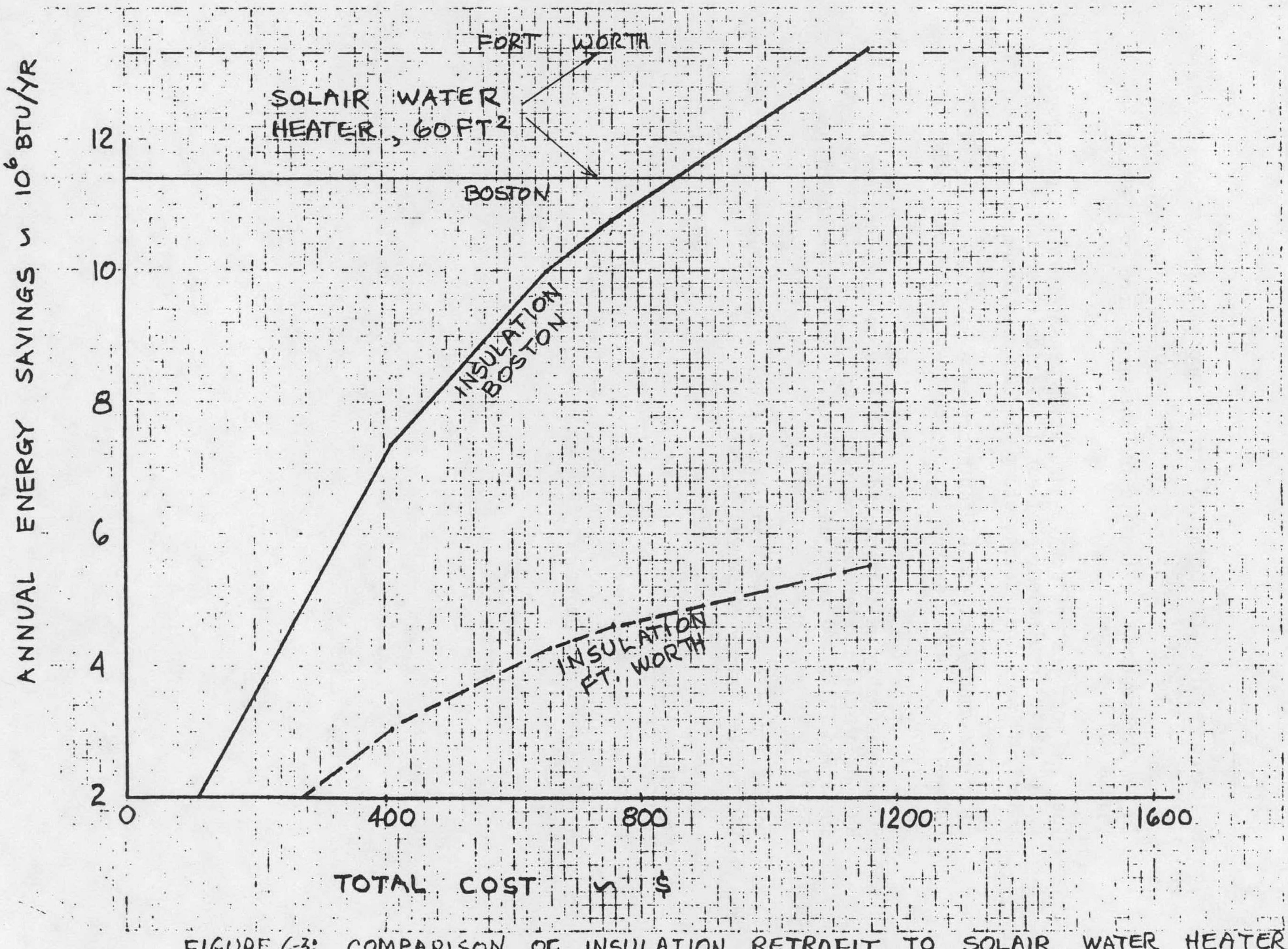

FIGURE 6-3: COMPARISON OF INSULATION RETROFIT TO SOLAIR WATER HEATER

6.4 RESULTS

The following results were obtained from an economic evaluation of Solair and house insulation options:

- In new construction, extensive insulation is more cost effective than a solar system.
- The five most cost effective insulation measures in new construction are 6" attic insulation, 6" floor insulation (over unheated crawl space), 4" wall insulation, storm windows, and storm doors.
- For a reasonably well-insulated house in a warm region such as Fort Worth, a Solair system is more cost effective than added insulation.
- For a reasonably well-insulated house in a cold region such as Boston, a Solair water heating system would have to sell for $900 installed ($15/Ft^2) to be as economically attractive as further insulation.
- Once a house is very well insulated a Solair system becomes attractive for further energy conservation.

SECTION 6 REFERENCES

1. Peterson, S.R., "Retrofitting Existing Housing for Energy Conservation: An Economic Analysis", National Bureau of Standards, Washington, D.C., December, 1974.

SECTION 7

EVALUATE REPACKAGING OF "OFF-THE-SHELF" EQUIPMENT (TASK 5)

7.1 OBJECTIVE

The objective of this task was to investigate minor modifications to commercially available equipment such that the associated energy savings would warrant the additional cost of the hardware.

7.2 SUMMARY

Two packaging concepts have been identified: solar collectors should be modularized, and the active solar components should be prepackaged for ease of field installation. This conclusion has been reached as a result of Task 1, identification of the more attractive Solair applications. These attractive applications have been determined to be domestic hot water heating and space heating with the solar system acting independently of the conventional space heating system. Applications whereby the solar system interacts with the heating systems, such as in using solar heat to boost the performance of a heat pump, have not been found to be primary applications for Solair.

7.3 DISCUSSION

At the time of the proposal, it appeared that using existing components with the Solair vacuum tube collectors may compromise performance and, as a result, customizing certain equipment could be economically warranted. The concepts considered are tabulated below as well as comments regarding individual conclusions. Repackaging of the vacuum tube collector into smaller modules than the current 96 square feet is common modification recommended for all the applications.

Table 7-1. Customizing Equipment Concept

APPLICATION	REPACKAGING CONSIDERED	COMMENTS
Domestic water heating only	Special preheater tank with integral heat exchanger.	Incentive for approach was a simpler and more reliable system with potential cost savings. This approach is not recommended, because it is more expensive and less flexible than a conventional pump/heat exchanger approach.
	One storage tank approach.	High cost of custom tank in small quantities and reduced performance eliminated this approach.
	Energy Management Module (package containing all active solar components)	This is a very desirable approach and is recommended for other configurations.
Space and domestic water heating (with or without rock storage); solar system independent of conventional heating system	Domestic water heating options	See discussion under water heating application.
	Energy Management Module for all active solar components.	This approach is recommended.
	Two-speed house blower.	Use of a slower blower speed for heating with solar is desirable but not essential.
Solar heating and absorption cooling	Domestic water heating options.	See discussion under water application.
	Direct heat exchange air to absorption working fluid.	Not a prime configuration (more details follow).
Solar boosted heat pump (solar heat to outdoor unit option)	Special ducting to outdoor unit for heat exchange air-to-freon.	Not a prime configuration (more details follow).

Solar heating and absorption cooling using air in the collectors is not considered to be a prime application for Solair. One of the major reasons for this is that a liquid collector is better suited for this application largely because of the high operating temperature required. Initial cost of a system has been found to be one of the most influential factors on the marketability of a system, and all existing cooling systems are relatively more expensive and consequently less popular.

A solar-boosted heat pump whereby solar heat is supplied to the outdoor unit is not considered to be a primary application for Solair. The rationale for this conclusion is as follows:

- Solar heating independent of heat pump heating is more desirable because:
  - better system performance
  - better suited for retrofit market
  - reliability of heat pump unaffected.
- Low temperature collection requirement for boosting performance of heat pump is not well suited for Solair because:
  - Solair performance is not noticeably improved at lower temperature.
  - Higher temperature capability is very beneficial to water heating which is a large part of the demand.

7.4 RESULTS

Modularization of the collector into sections smaller than the existing 96 Ft^2 module is an important feature of a flexible solar system. Ground and roof installations are expected to be equally popular so that a common design is desirable for both. A ground-mounted concept is shown in Figure 7-1. A roof-mounted concept is shown in Figure 7-2. Although the smaller plenum surface area associated with the roof-mounted concept is more efficient, a low profile approach is more desirable for on-the-ground installations. The key to these approaches is the plenum design, and with the configuration shown in Figure 7-3, the same elements are used for both configurations.

Integration of all the active solar components into an Energy Transfer Module has also been identified to be desirable. An example of this is shown in Figure 7-2 for a hot water heating system. This approach makes an attractive package and features substantial savings of field labor.

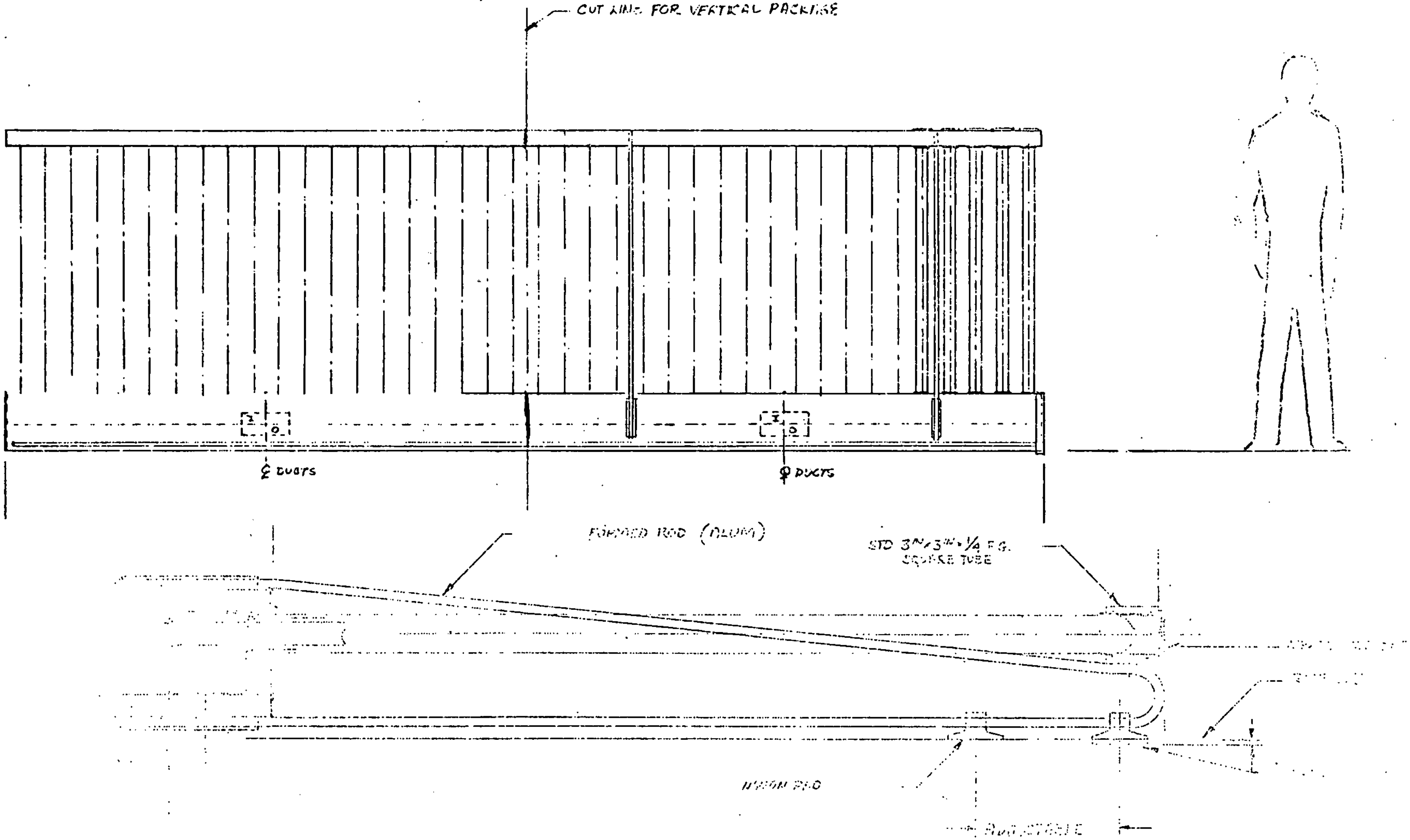

FIGURE 7-1. ON THE GROUND TYPE COLLECTOR ARRAY

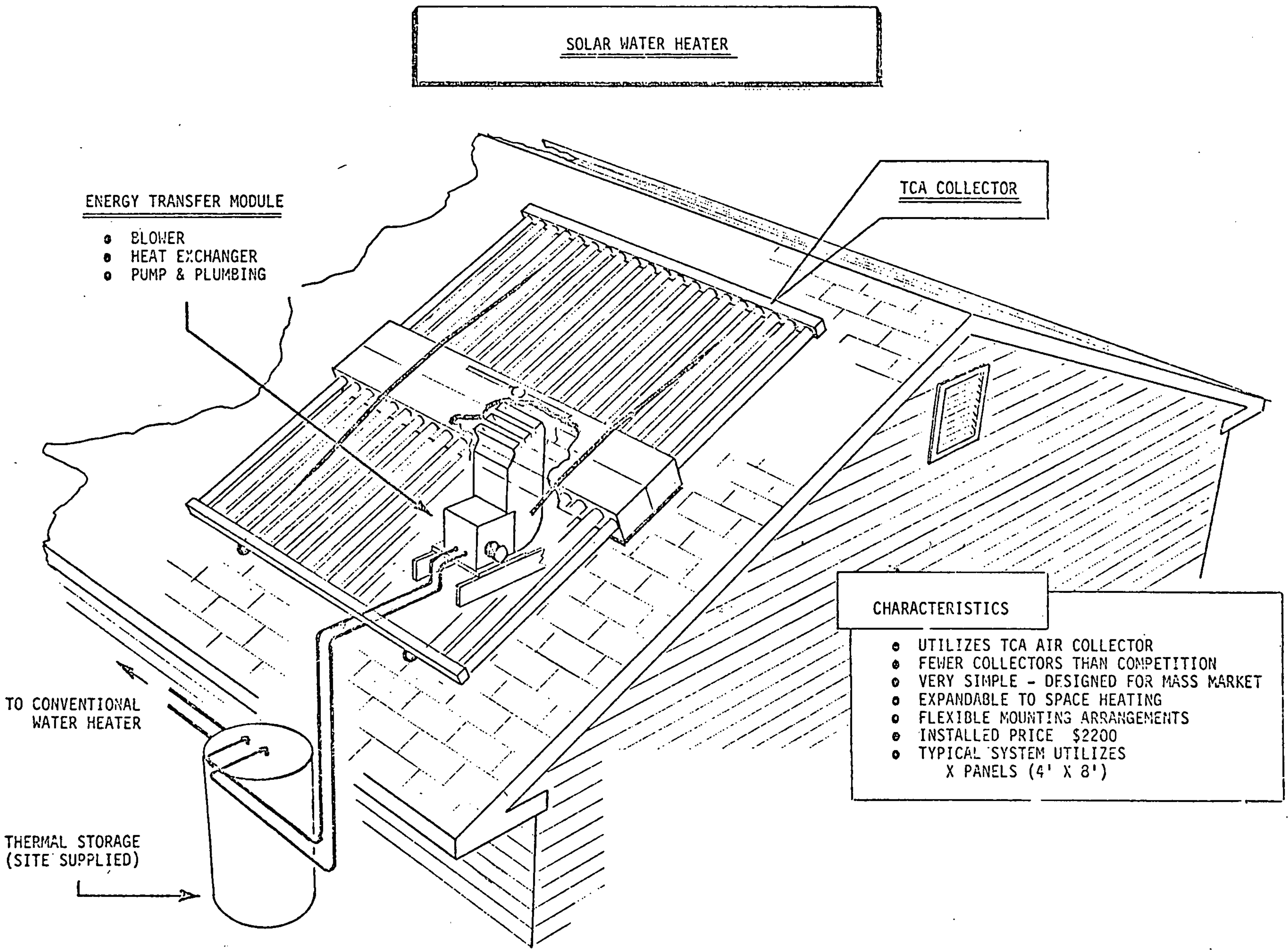

FIGURE 7-2. ROOF MOUNTED COLLECTOR ARRAY

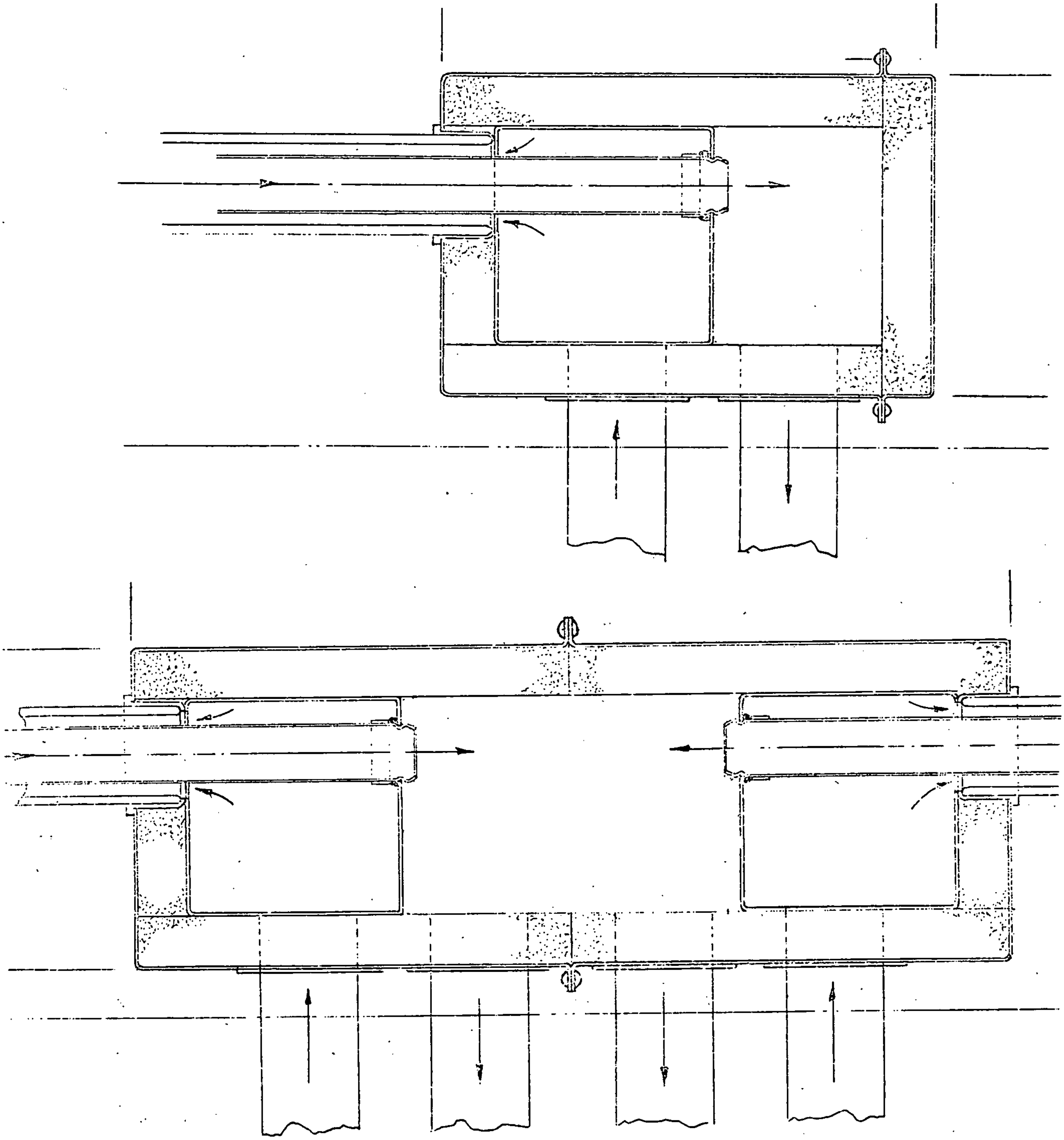

FIGURE 7-3. PLENUM DESIGN

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