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REPORT

DOE/NASA CR-150858

PRELIMINARY DESIGN PACKAGE FOR PROTOTYPE SOLAR  
HEATING SYSTEM

Prepared from documents furnished by

Honeywell, Inc.  
Energy Resources Center  
2600 Ridgway Parkway N. E.  
Minneapolis, MN 44513

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For the U.S. Department of Energy

(NASA-CR-150858) PRELIMINARY DESIGN PACKAGE  
FOR PROTOTYPE SOLAR HEATING SYSTEM

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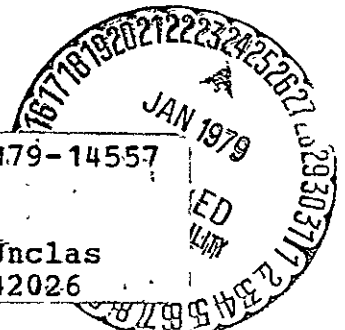
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**U.S. Department of Energy**



**Solar Energy**

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16. ABSTRACT  This report contains a summary of the preliminary analysis and design activity on solar heating systems. The analysis was made without site specific data other than weather; therefore, the results indicate performance expected under these special conditions.  Major items in this report include system candidates, design approaches, trade studies and other special data required to evaluate the preliminary analysis and design.  The program calls for the development and delivery of eight prototype solar heating and cooling systems for installation and operational test. Two heating and six heating and cooling units will be delivered for Single Family Residences (SFR), Multi-Family Residences (MFR) and commercial applications.					
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## HEATING SYSTEMS PRELIMINARY DESIGN REVIEW

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## 1.0 INTRODUCTION

The information presented in this document summarizes the Heating Systems preliminary analysis and design activity. It is provided to NASA/MSFC to prepare for the Heating Systems Preliminary Design Review to be held in Minneapolis, October 6 & 7, 1976.

## **2.0 MARKET ANALYSIS**

A market evaluation to supplement the design optimization studies is being prepared for the preliminary design review. This section is reserved for the market analysis data that will be submitted and presented at the preliminary design review meeting.

### 3.0 System Candidates

#### 3.1 Approach to the Selection of Deliverable Systems

Honeywell's approach to the selection of solar-heating systems is illustrated in Figure 3-1. Primarily, the approach consists of two parallel efforts: identification of all candidate solar-heating subsystem components, and identification of subsystem constraints or evaluation criteria. The next step, preliminary subsystem selection, is designed to narrow the list of candidate subsystem components, using the defined constraints. It becomes evident that the major components for system selection are collector type, storage medium, and auxiliary heating method.

The next step in system selection incorporates subsystem trade-offs and economic trade-offs to further reduce the number of workable and economically desirable systems. The subsystems upon which trade-offs are examined are the following:

- Collector
- Storage
- Auxiliary energy
- Working fluids
- Supplementary elements such as controls, piping, pumps, etc.

The economic analysis is made using methods which incorporate life cycle costing techniques to establish the most economical solar system.

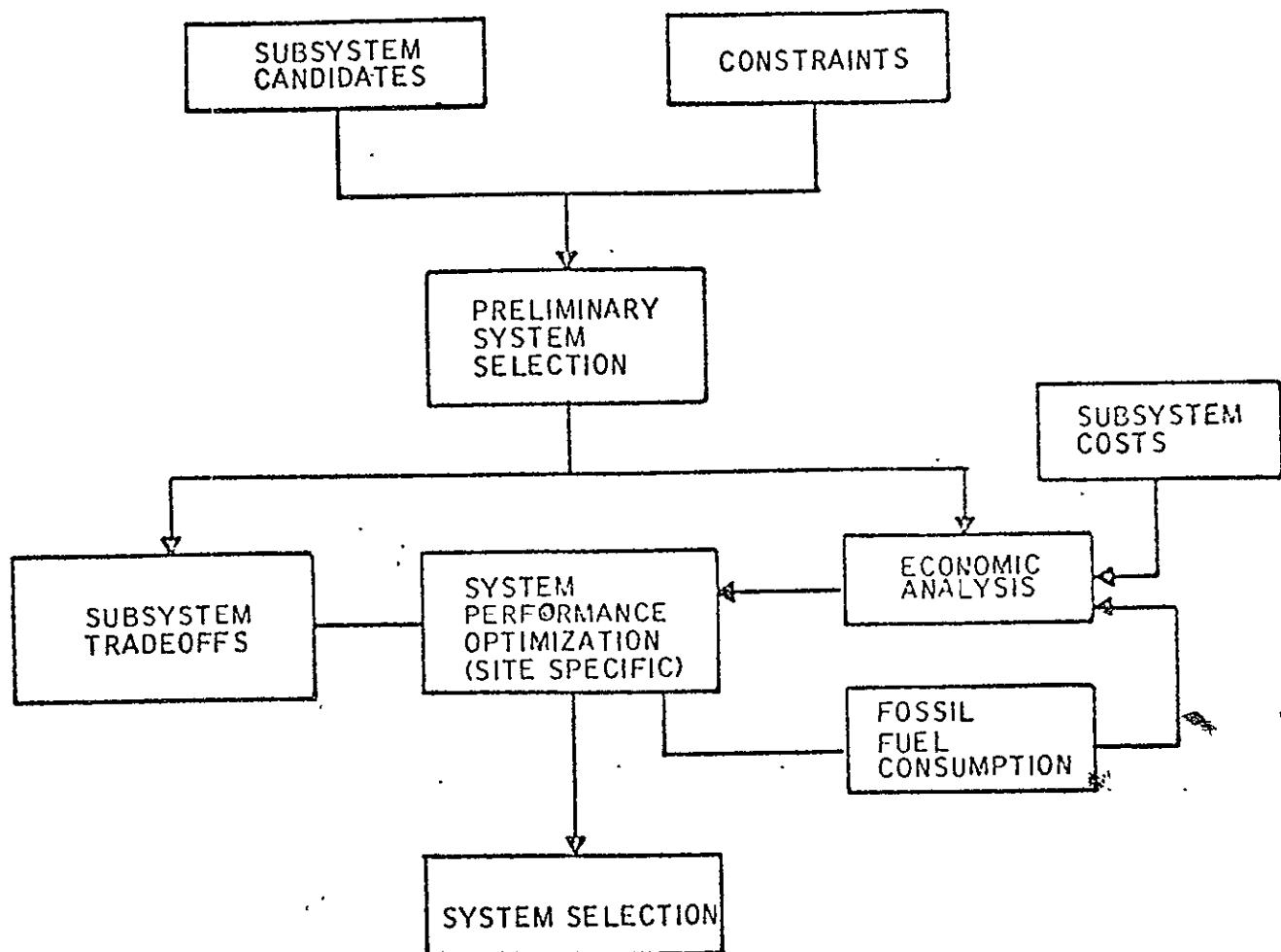


Figure 3-1. System Selection Flow Chart



The solar system performance is determined using Honeywell's Solar Systems Simulation Program. The economic analysis technique is used in conjunction with the simulation program to optimize the selected systems for the designated area and application.

### 3.2 Subsystem Candidates

Subsystem candidates include all those solar heating system components that could be used to design heating systems. Candidate subsystem components identified are listed in Table 3-1. The table includes all those subsystem components that appear to be feasible candidates. Subsystem candidates are categorized by collectors, storage, auxiliary subsystems, working fluid and supplementary elements.

### 3.3 Constraints and Design Criteria

Constraints or evaluation criteria have been identified for purposes of performing preliminary and detailed trade-offs of subsystem components. These include the following:

- Modularity -- subsystems components that are of standard design and size that can be put together to achieve the desired capability. An example that meets this constraint is the flat plate collector panel, a component of standard size that can be combined to create any desired collector area.
- Scalability -- a subsystem component of standard design that can provide a progressive increase in capability by changing some of the components of that subsystem. An example of this type of subsystem component is the standard home furnace, the output capability of which can be increased by scaling burners and blower motor.

Table 3-1

Subsystem Component Candidates

Subsystem	Component
Collectors	<ul style="list-style-type: none"> <li>● Liquid flat plate</li> <li>● Concentrator: <ul style="list-style-type: none"> <li>- Tracking - two planes</li> <li>- Partial tracking - tracking in one plane</li> <li>- Nontracking - fixed</li> </ul> </li> <li>● Air heater</li> </ul>
Thermal Storage Media	<ul style="list-style-type: none"> <li>● Water</li> <li>● Ethylene glycol/water solution</li> <li>● Rock pile</li> <li>● Heat-of-fusion materials</li> </ul>
Auxiliary Subsystems	<ul style="list-style-type: none"> <li>● Fossil fueled forced air furnace</li> <li>● Fossil fueled hydronic boiler</li> <li>● Heating only heat pumps</li> </ul>
Working Fluids	<ul style="list-style-type: none"> <li>● Air</li> <li>● Water/ethylene glycol</li> <li>● Water</li> <li>● Oil</li> <li>● Heat transfer fluids</li> </ul>
Supplementary Elements	<ul style="list-style-type: none"> <li>● Fans</li> <li>● Ducts</li> <li>● Controls</li> <li>● Piping</li> <li>● Pumps</li> </ul>

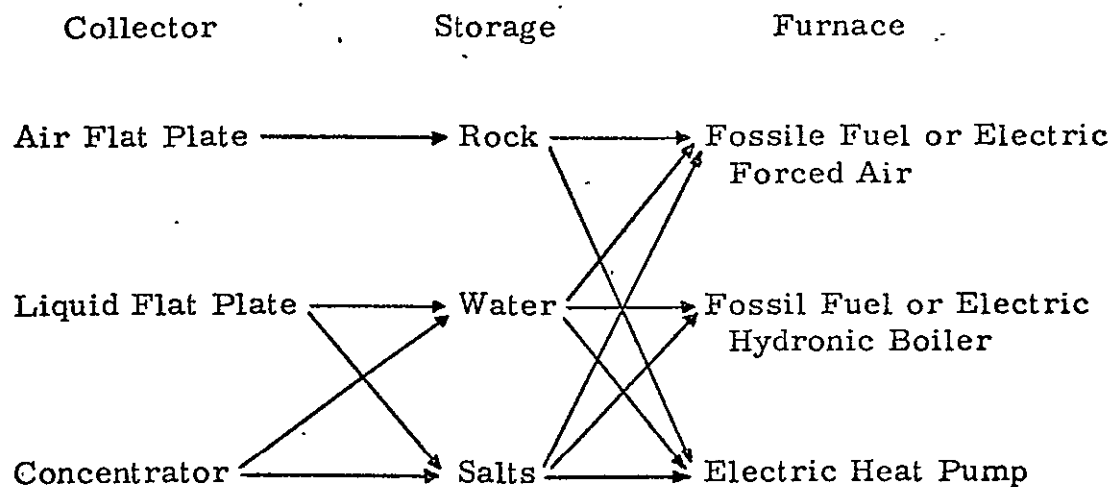
- Architectural Aspects -- includes interface of solar heating systems on a building (especially collectors), impact on construction and aesthetic qualities
- Fuel Type Availability -- assurance that local utilities will provide the type and amounts of fuel required
- Economic Aspects -- costs of procurement, installation, maintenance and operation
- Development Risks -- availability of components within required time frame - subsystem design maturity
- Maintainability -- skill, knowledge and training required to maintain system
- Reliability -- confidence in assuring continued system operation over life cycle
- Safety -- safety of operation and use of system
- Control Philosophy -- control of solar heating system to use needed energy directly from collector or storage. Store excess energy and use auxiliary energy when required.

### 3.4 Preliminary Subsystem Component Selection

The preliminary subsystem selection is designed to narrow the list of subsystem candidates for final consideration. By using the constraints identified, advantages and disadvantages of each subsystem component are examined with respect to these constraints. Relative strengths and weaknesses are identified and components can be ranked with respect to each other.

It becomes evident that collectors, auxiliary heating, and storage subsystems are the three most critical elements of heating system designs. Other subsystems, such as space heat, domestic hot water and controls, are easily defined after the selection of these three primary subsystems. There are three types of collectors which have been considered, liquid cooled flat plate, concentrators and air heaters. The types of auxiliary heating subsystems are a fossil fueled or electric forced air furnace, a fossil fueled or electric hydronic boiler and the third is an electric heat pump. Storage choices are rock, water and salt. The matrix shown in Figure 3-2 defines various system possibilities.

Figure 3-2  
Possible System Combinations



Some system combinations were eliminated because of the general mismatch between subsystems such as air collectors and water storage. Some combinations may be possible but development risks, at present, outweigh advantages (i.e., air collectors with salt storage). Other general trade-offs are listed below for each of the three major subsystem types.

#### Collector type --

- Air and liquid flat plate collectors are generally simpler and offer less development risk than concentrator collectors.
- Liquid flat plates are slightly better than air collectors based on performance and development risk criteria.

#### Storage type --

- Phase change storage systems require a significant development risk.
- Liquid storage is more efficient than rock storage and is readily available from storage tank manufacturers.

#### Auxiliary subsystem type --

- Fossil fuel or electric forced air furnaces are the most common heating source and are easily adapted auxiliary energy subsystems for solar system applications.
- Heat pumps for solar application require development and some initial system cost increases.
- Due to the potential shortage of gas and oil in various regions, heat pumps may be necessary as auxiliary heating units.

The system providing the best match of subsystem components with the smallest development risk for space heating applications is a liquid cooled flat plate collector with sensible heat water storage and a gas fired forced air furnace as the auxiliary heating source. In the event that gas is not available, heat pumps or electric furnaces may be considered in conjunction with the solar heating system.

Numerous other workable systems exist for heating applications. Further studies and trade-offs could yield insights into the use of concentrators or air heaters along with the associated storage and auxiliary energy subsystems mentioned above for space heating applications.

## 4.0 Baseline Systems

### 4.1 Introduction

The proposed solar assisted heating systems are two fluid loop solar collector systems interfacing with conventional fossil fuel fired furnaces. These proposed system designs may be easily sized to fit a wide spectrum of applications. First, the collectors are modular and can be combined in arrays to satisfy site-specific collector configurations. Second, the auxiliary subsystems are selected from a broad product line of fossil fuel-fired warm air furnaces, allowing many choices to fit site-specific requirements. Finally, the storage, hot water, transport and control subsystems are commercially produced items in a broad range of sizes. This subsystem modularity allows variations in system design to accommodate the variable performance requirements that are expected nationwide.

The proposed solar systems are designed to maximize the amount of solar energy collected for use and storage. This is accomplished by:

- A control system that minimizes collector inlet temperatures (maximizes energy into the building)
- Optimum transfer rate heat exchangers
- Direct collector to space heating by by-passing storage.
- Using high-performance flat plate collectors

- Storage which can be operated in parallel and independently from collector loop

System reliability and maintainability is assured through design features which include the following:

- A closed collector loop for over temperature protection via a purge coil
- A control system employing simple logic
- A minimum of components in the system
- Manifolding external to the collector modules

Maintenance of space temperature, hence occupant comfort, is assured through the use of the following components and design techniques:

- A two-stage thermostat with a minimum differential for solar operation
- Conventional furnace control of air temperature to the space

The systems have been designed to minimize contamination of the potable water supply by the use of:

- A two-fluid loop system that isolates the collector heat transfer fluid
- A system in which domestic water pressure is higher than system pressures

#### 4.2 Single Family Residential Heating System Description

The proposed system for a single family residential heating system is a two-fluid-loop, solar assisted, hydronic-to-warm-air system with solar assisted domestic water heating. The system is composed of the following major components:

- Liquid cooled flat plate collectors
- A water storage tank
- A passive solar fired domestic water preheater
- A gas fired hot water heater
- A gas fired warm air furnace with hot water coil unit
- A tube-and-shell heat exchanger, three pumps and associated pipes and valving
- A control system
- An air-cooled heat purge unit

A schematic of the system configuration is shown in Drawing SK140094. The solar collectors supply heat to the furnace through the hot water coil in the furnace return air section and to the storage both through the tube-and-shell heat exchanger in the collector loop. Heat is withdrawn from storage to the hot water coil in the furnace when energy from the collectors is not available. Domestic hot water heating is supplied from storage by the passive heating system in the storage tank. Auxiliary heat is supplied by the gas fired section of the warm air furnace and domestic water heating is tempered by the gas fired hot water heater. The system operates on a priority load basis, providing energy to the space heating load whenever the solar collectors have adequate energy available and the load demands heat. If the space heating load is not demanding energy, the solar collectors can provide energy to the storage tank and hence to the domestic hot water pre heater. The storage tank can supply energy to the space heating load and to the domestic hot water system if the solar



collectors do not have adequate energy available. In the case of high solar availability and no energy demand from space heating, domestic hot water, or storage load, a purge coil has been provided to dissipate the excess energy.

#### 4.3 Multifamily Residential Heating System Description

The proposed system for a multifamily residential dwelling is a two-fluid-loop primary-secondary circulation system for hydronic-to-warm-air heating with solar assisted domestic water heating. The system will provide heat for 12 apartments through individual gas fired furnaces with hot water coils in the return air system, and domestic water to the apartments through a central domestic water heating system. The system has the following major components:

- Liquid cooled flat plate collectors
- A water storage tank for sensible heat storage
- An active solar fired domestic water preheater
- Three gas fired water heaters
- Twelve gas fired warm air furnaces with hot water coil unit
- A tube-and-shell heat exchanger, two main circulating pumps, 12 secondary pumps, 1 hot water pump and associated pipes and valving
- Control system
- An air-cooled heat purge unit

A schematic of the system configuration is shown in Drawing SK140095. The solar collectors supply heat to the apartment units through the hot water coils in each furnace. The gas fired domestic water heaters are connected in parallel to provide the capacity requirements of the RFP.

The system is similar to the single family residence heating system only in that both have pressurized collector loops isolated from the non-pressurized water loop through a tube-and-shell heat exchanger. In addition, the multifamily residence system has a series of secondary pumping loops to each multifamily unit. These secondary loops provide for independent supply of solar heated water without the expenditure of excessive pumping power requirements. The control system is an expanded version of the single family system.

#### 4.4 Commercial Applications Heating System Description

The proposed system for commercial building heating is a two-fluid-loop, primary-secondary circulation system for hydronic-to-warm-air heating with solar assisted domestic water heating. The system will provide space heating through gas fired rooftop heating furnaces, and domestic water heating through a solar heated preheater and gas fired water heater. The system is composed of the following major components:

- Liquid cooled flat plate collectors
- A water storage tank for sensible heat storage
- An active solar fired domestic water preheater
- A gas fired water heater
- Gas fired, rooftop mounted furnaces with hot water coil units
- A tube-and-shell heat exchanger, two main pumps and four secondary pumps and associated pipes and valves
- A control system
- An air cooled heat purge unit

A schematic of the proposed system configuration is shown in Drawing SK140096. The system is similar in operation to the residential and multifamily systems and will provide for four zones of heating with operation of each zone similar to the residential system or to the multifamily heating system.

#### 4.5 System Controls

Each of the proposed systems is controlled to assure maximum utilization of collected energy and excellent control of space temperature. The single family control sensor locations are shown in Drawing SK 140103 while a control ladder diagram and sequence of operation are shown in Drawing SK 140104.

Similar drawings are shown for the multifamily system in Drawing SK 140101 and SK 140102 while the commercial system controls are shown in SK 140106 and SK 140107.

## 5.0 Trade Studies

### 5.1 Methodology

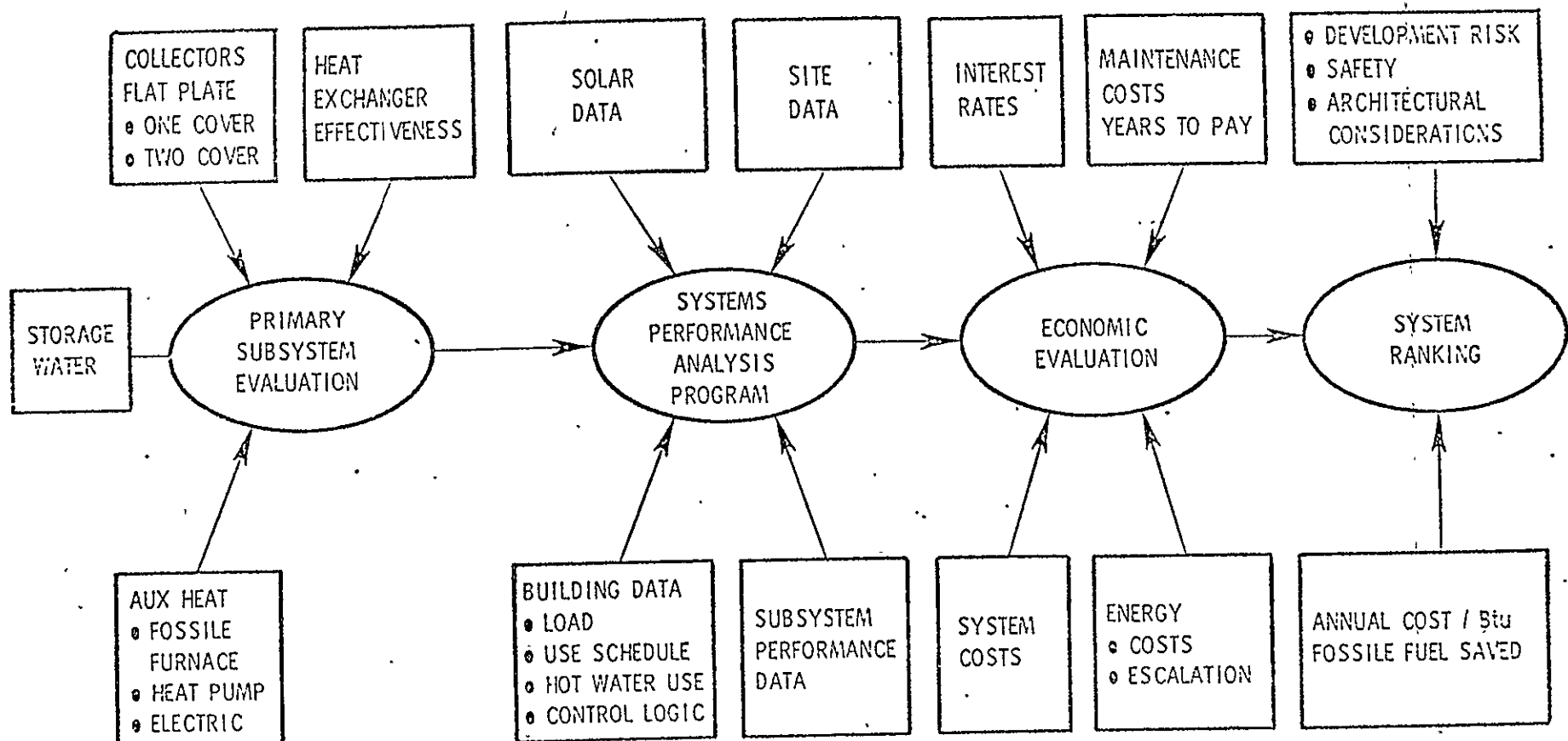
A methodology for a comparison of solar-assisted heating system concepts has been established. The methodology or approach allows a complete examination of the solar system and subsystem candidates. In order to assure that the solar systems development results in products that meet the requirements, the studies included variations in key parameters that influence solar heating systems costs and performance. A systems simulation program was used to study the solar systems cost and/or performance variation as a result of a variation in the key parameters.

The system tradeoff methodology is shown schematically in Figure 5.1-1.

### 5.2 Criteria

The criteria for selection of a solar system configuration will be the following.

- Minimum annual cost per million Btu solar energy provided
- System safety
- Development risk
- Architectural considerations



SYSTEM TRADEOFF FLOW CHART

Figure 5.1-1

Table 5.3.1-1  
Average Monthly Degree Days for Minneapolis

January	1631
February	1380
March	1166
April	621
May	288
June	81
July	22
August	31
September	189
October	505
November	1014
December	1454
Total	8382

### 5.3 Parameters and Assumptions

The prediction of the performance and economics of a solar heating system is based on a simulation analysis using observed weather and solar data generated from cloud cover. The actual system is simulated by a digital computer code on an hour-by-hour basis.

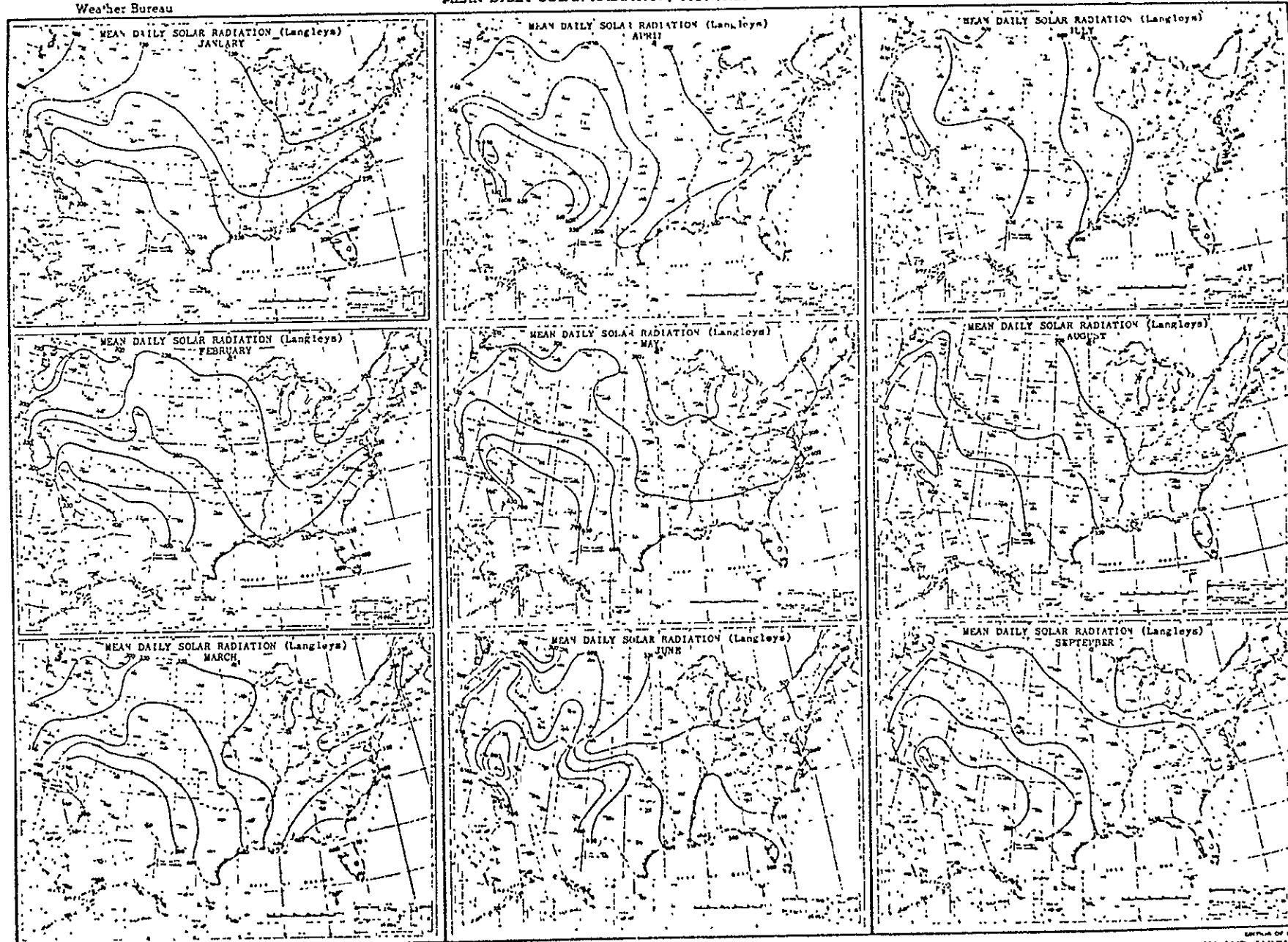
Since specific government selected sites were not available prior to the heating systems preliminary design review, Minneapolis was selected as a site for the systems. A description of the basic parameters and assumptions used in the trade-off studies follows.

#### 5.3.1 Site

Minneapolis was selected as the site for the trade-off studies for heating systems. Minneapolis is located at 44.7 degrees north latitude and 93 degrees longitude.

The mean daily total solar radiation for Minneapolis is approximately 345 Langleys. This value varies from about 125 Langleys in December to about 560 Langleys in June. The contoured charts of solar radiation are shown in Figures 5.3.1-1 to 5.3.1-3. These data were taken from the Climatic Atlas of the United States published in 1968 by National Climatic Center, Asheville, North Carolina. The national charts showing mean percentage of sunshine and total hours of sunshine are presented in Figures 5.3.1-4 and 5.3.1-5. An interpolation of these charts shows that Minneapolis has approximately 2550 hours of sunshine annually, or approximately 55 percent of the possible sunshine.

The average annual degree days for Minneapolis is 8382. (Reference ASHRAE Systems Handbook, Chapter 43.4). The average heating season temperature, October to April, is approximately 28 F. The monthly average degree days in shown in Table 5.3.1-1.



Prepared by Office of Meteorological Research  
and Office of Climatology

Scale for the 48 Contiguous States

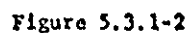
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MEAN DAILY SOLAR RADIATION, MONTHLY AND ANNUAL  
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WEATHER BUREAU

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Figure 5.3.1-1







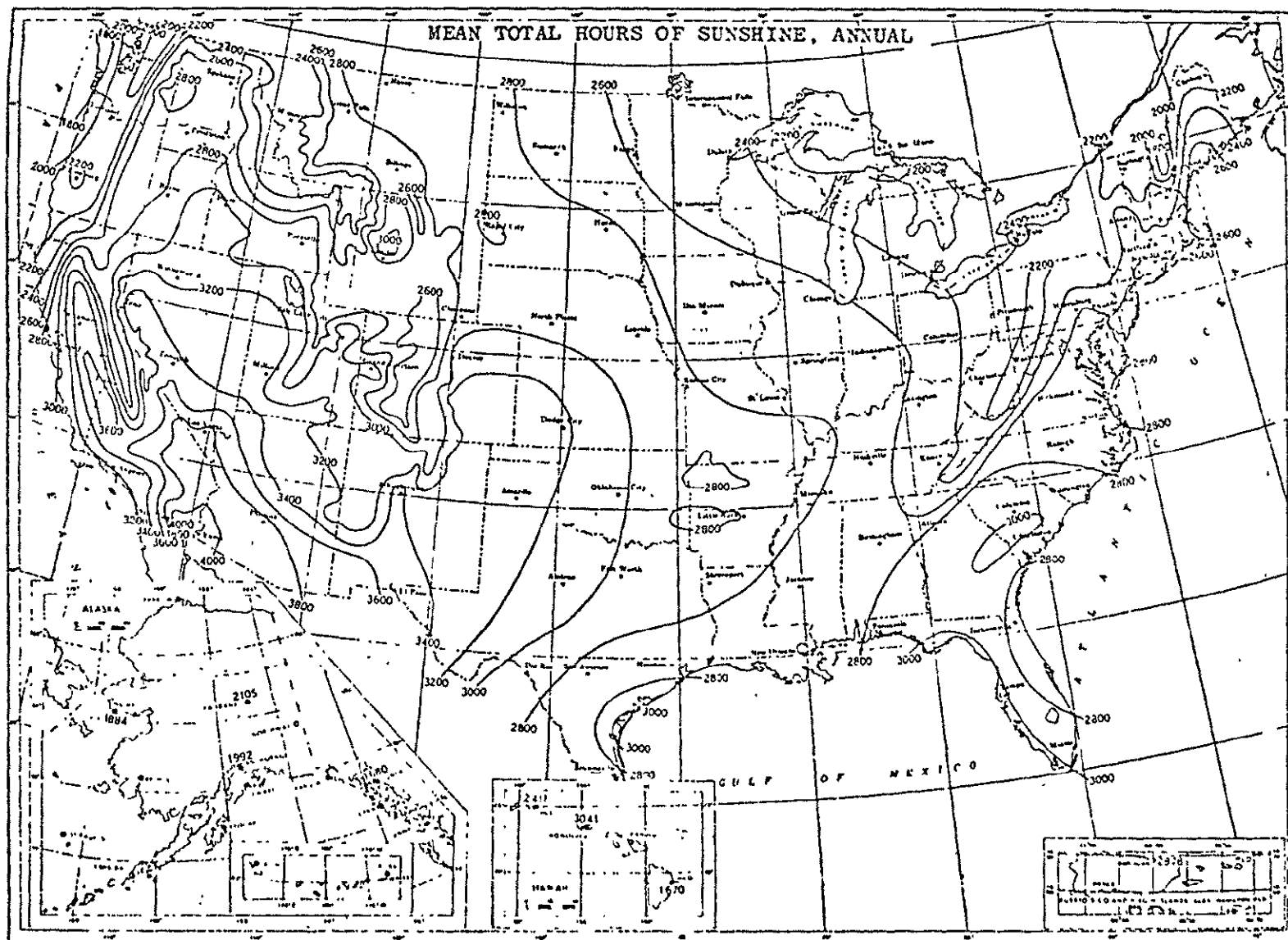
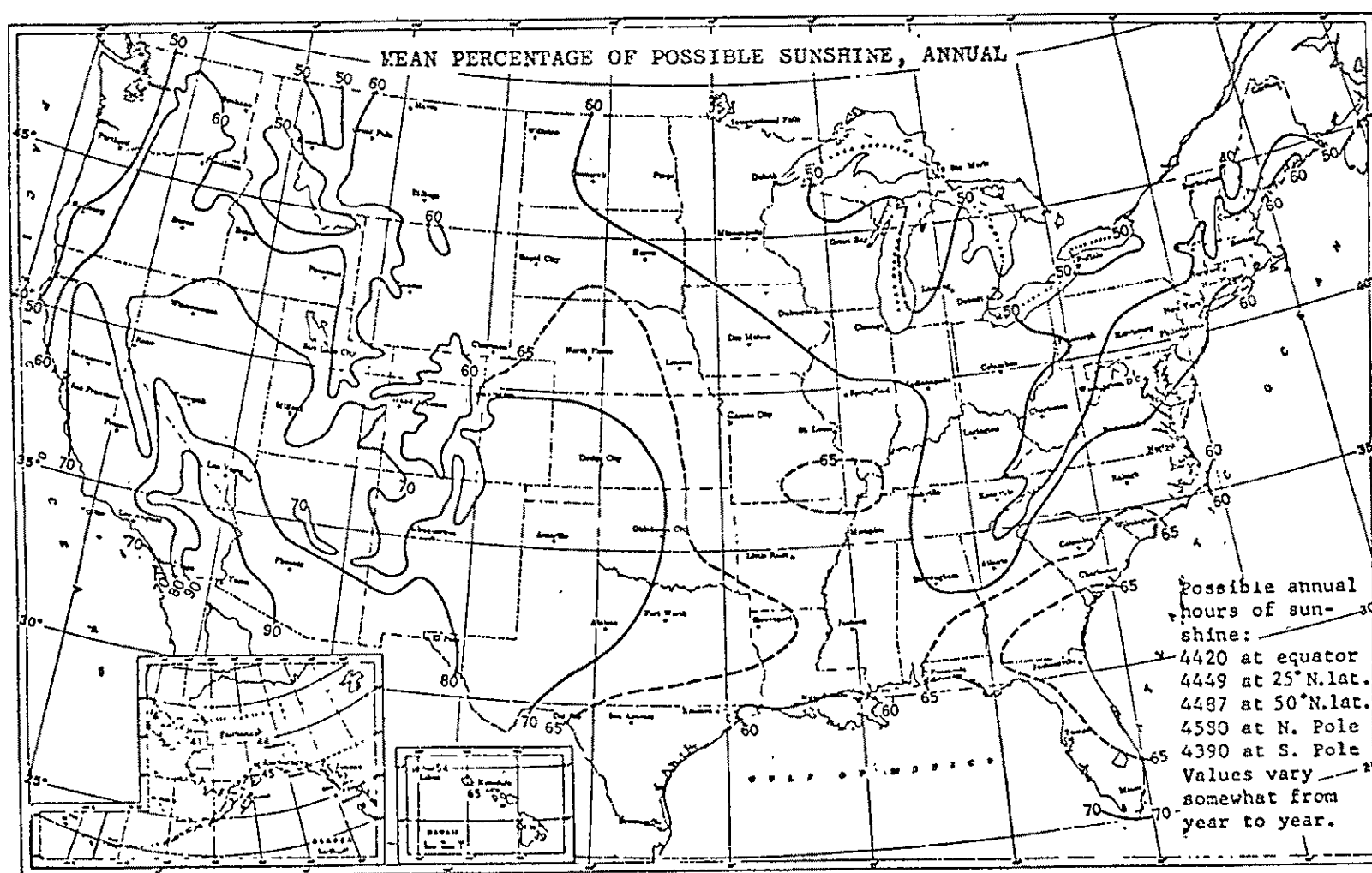


Figure 5.3.1-4 ..Mean Total Hours of Sunshine, Annual



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Figure 5.3.1-5 Mean Percentage of Sunshine, Annual

### 5.3.2 Heating System Design Conditions

The heating system design conditions are based on the requirements outlined in Interim Performance Criteria for Solar Heating and Combined Heating and Cooling systems and Dwellings (IPC).

### 5.3.3 Inside Design Conditions

Winter -- The heating plant capacity will be based on the maximum instantaneous block heat loss at outside winter design when calculated for an inside temperature of 70°F dry bulb, and the selected relative humidity for the project if applicable.

### 5.3.4 Outside Design Conditions

The design will be based on weather data given in the latest issue of the applicable ASHRAE Guide. The heating load will be designed on the basis of the coincident wind velocity and the 97 1/2 percent column. These conditions for Minneapolis are:

Winter: -10 F (97 1/2% column)

For reference,  
the medium of annual extremes for Minneapolis is -19 F.

### 5.3.5 Building Heating Loads

The building heating loads are based on the ASHRAE standard 90-75. Since no specific buildings or sites have been identified, typical sizes have been used for calculating the energy demands for heating a single family and multifamily residence and a small commercial building.

### 5.3.6 Single Family Residence

The single family residence was assumed to be a single story, 1500 ft<sup>2</sup>, rectangular building (25 x 60 ft), facing south. The "U" values for the walls and ceiling were taken from ASHRAE standard 90-75. For Minneapolis with 8382 degree days, Figure 5.3.6-1 shows for a type "A" building, the "U" value is 0.185 Btu/hr. - ft<sup>2</sup> · F. (Reference ASHRAE 90-75 paragraph 4.3.2.2).

The overall thermal transmission conductance is the combination of heat flow through the walls and ceiling.

$$U_{\text{WALL}} = .185$$

$$U_{\text{CEILING}} = .04$$

$$\begin{aligned} UA_{\text{TOT}} &= .185 (170) (8) + 1500 (.04) \\ &= 311.6 \text{ Btu/hr } ^\circ\text{F} \end{aligned}$$

This value includes the transmission through any doors and windows included in the outside walls.

The infiltration through cracks and seams was assumed to be .75 air changes per hour. For a 1500 ft<sup>2</sup> house with an 8 ft. ceiling this is 9000 ft<sup>3</sup>/hr of outside air which has to be heated.

$$\begin{aligned}\text{For infiltration } UA &= \dot{m} C_p = 9000 (.24) (.075) \\ &= 162 \text{ Btu/hr } ^\circ\text{F}\end{aligned}$$

The total "UA" including transmission and infiltration is:

$$UA_{\text{TOTAL}} = 162 + 311 = 473 \text{ Btu/hr } ^\circ\text{F}$$

The design load for the single family residence is:

$$\begin{aligned}Q &= UA (T_{\text{ROOM}} - T_{\text{AMBIENT}}) \\ Q &= 473 (70 - (-10)) = 37840 \text{ Btu/hr}\end{aligned}$$

Our internal load was assumed to account for people and lights.

This load schedule was:

$$\begin{array}{lll}8 \text{ a.m.} - 8 \text{ p.m.} & -- & 2550 \text{ Btu/hr} \\ 8 \text{ p.m.} - 8 \text{ a.m.} & -- & 1350 \text{ Btu/hr}\end{array}$$



## U<sub>o</sub> WALLS—TYPE "A" BUILDINGS

TYPE A BUILDINGS SHALL INCLUDE:

A 1 DETACHED ONE AND TWO FAMILY DWELLINGS

A 2 ALL OTHER RESIDENTIAL BUILDINGS, THREE  
STORIES OR LESS, INCLUDING BUT NOT LIMITED  
TO:

MULTI-FAMILY DWELLINGS  
HOTELS AND MOTELS

ANNUAL CELSIUS HEATING DEGREE DAYS (18 C BASE)  
(IN THOUSANDS)

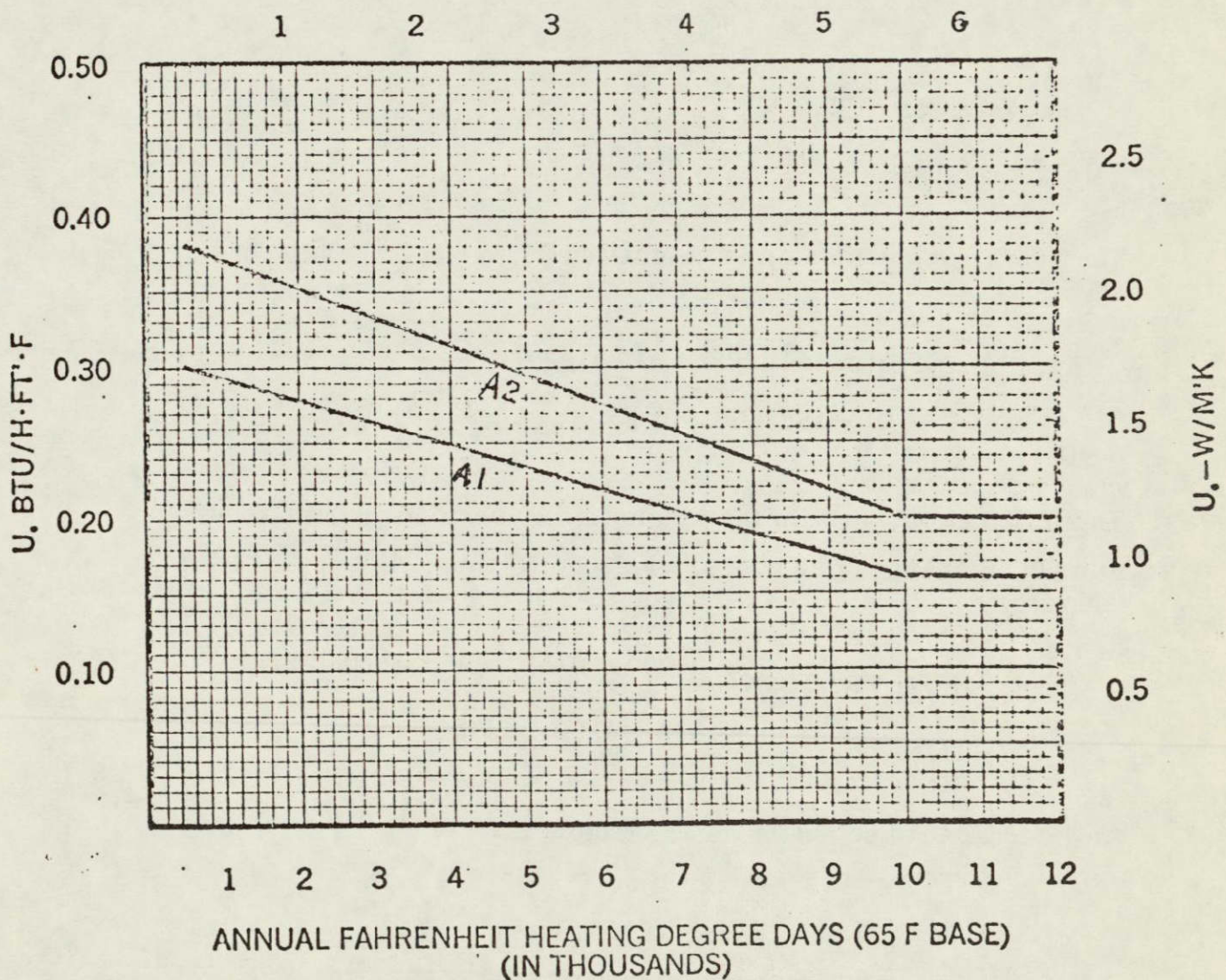


Figure 5.3.6-1



### 5.3.7 Multifamily Residence

The multifamily residence was assumed to be a 12 unit, two story, 15000 ft<sup>2</sup>, rectangular building (70 x 105 ft), facing south. Each unit would contain 1250 ft<sup>2</sup>. The "U" values for the walls and ceiling were taken from Figure 5.3.6-1 and paragraphs 4.3.2.2 of ASHRAE 90-75.

$$U_{\text{WALL}} = .23$$

$$U_{\text{CEILING}} = .04$$

The overall transmission is calculated as:

$$\begin{aligned} UA_{\text{TOTAL}} &= .23 (350) + .04 (7350) \\ &= 1582 \text{ Btu/hr F} \end{aligned}$$

The infiltration, as with the single family residence, was assumed to be 0.75 changes per hours, or 90000 ft<sup>3</sup>/hr.

$$UA_{\text{INFILTRATION}} = 90000 (.075) (.29) = 1620 \text{ Btu/hr F}$$

$$UA_{\text{TOTAL}} = 1620 + 1582 = 3202 \text{ Btu/hr.}$$

An internal load schedule was assumed.

8 a.m. - 8 p.m. -- 25500 Btu/hr

8 p.m. - 8 a.m. -- 13500 Btu/hr

These internal loads are the same as was included in RFP-404.

### 5.3.8 Commercial Building

The commercial building was a  $32500\text{ft}^2$  single story, rectangular ( $100 - 325\text{ft}^2$ ) building. This is identical to the building size specified in RFP-404. The building loads are different than RFP-404 and were calculated from ASHRAE 90-75.

The "U" value for the commercial building was taken from figure 5.3.8-1. For a building under three stories and 8382 degree days in Minneapolis, the "U" value is  $0.23\text{ Btu/Hr. ft}^2\text{ F}$ . The ceiling "U" value is  $0.06\text{ BTU/Hr. ft}^2\text{ F}$  as shown in figure 5.3.8-2 for 8382 degree days. The combined transmission conductance is calculated for a 10 foot high wall as:

$$\begin{aligned} UA_{\text{Transmission}} &= .23 (850)(10) + .06 (32500) \\ &= 3905\text{ Btu/Hr. F} \end{aligned}$$

The infiltration load was assumed to be the same as specified in RFP-404 as 225 cfm or  $UA_{\text{Infiltration}} = 243\text{ Btu/Hr. F}$ . The ventilation schedule was also taken from RFP-404.

$$\begin{array}{ll} 270000\text{ ft}^3/\text{Hr. (UA=4860)} & 8\text{ AM} - 7\text{ PM} \\ 0 & 7\text{ PM} - 8\text{ AM} \end{array}$$

The internal load schedule for people and lights was:

$$\begin{array}{llll} \text{Lights: } 213180\text{ Btu/Hr.} & & 8\text{ AM} - 7\text{ PM} \\ & 106590\text{ " " } & 7\text{ PM} - 8\text{ AM} \\ \text{People: } 60000\text{ " " } & & 8\text{ AM} - 7\text{ PM} \\ & 0\text{ " " } & 7\text{ PM} - 8\text{ AM} \end{array}$$

The total "UA" coefficient is:

$$\begin{aligned} UA_{\text{Total}} &= UA_{\text{Trans}} + UA_{\text{Vent}} + UA_{\text{Infil}} \\ &= 3905 + 243 + 4860 \\ &= 9008\text{ Btu/Hr. F } 8\text{ AM} - 7\text{ PM} \\ &= 4148\text{ Btu/Hr. F } 7\text{ PM} - 8\text{ AM} \end{aligned}$$



# U<sub>o</sub> WALLS—HEATING—TYPE—"B" BUILDING

FOR ALL BUILDINGS NOT COVERED BY PARA. 4.3

ANNUAL CELSIUS HEATING DEGREE DAYS (18 C BASE)  
(IN THOUSANDS)

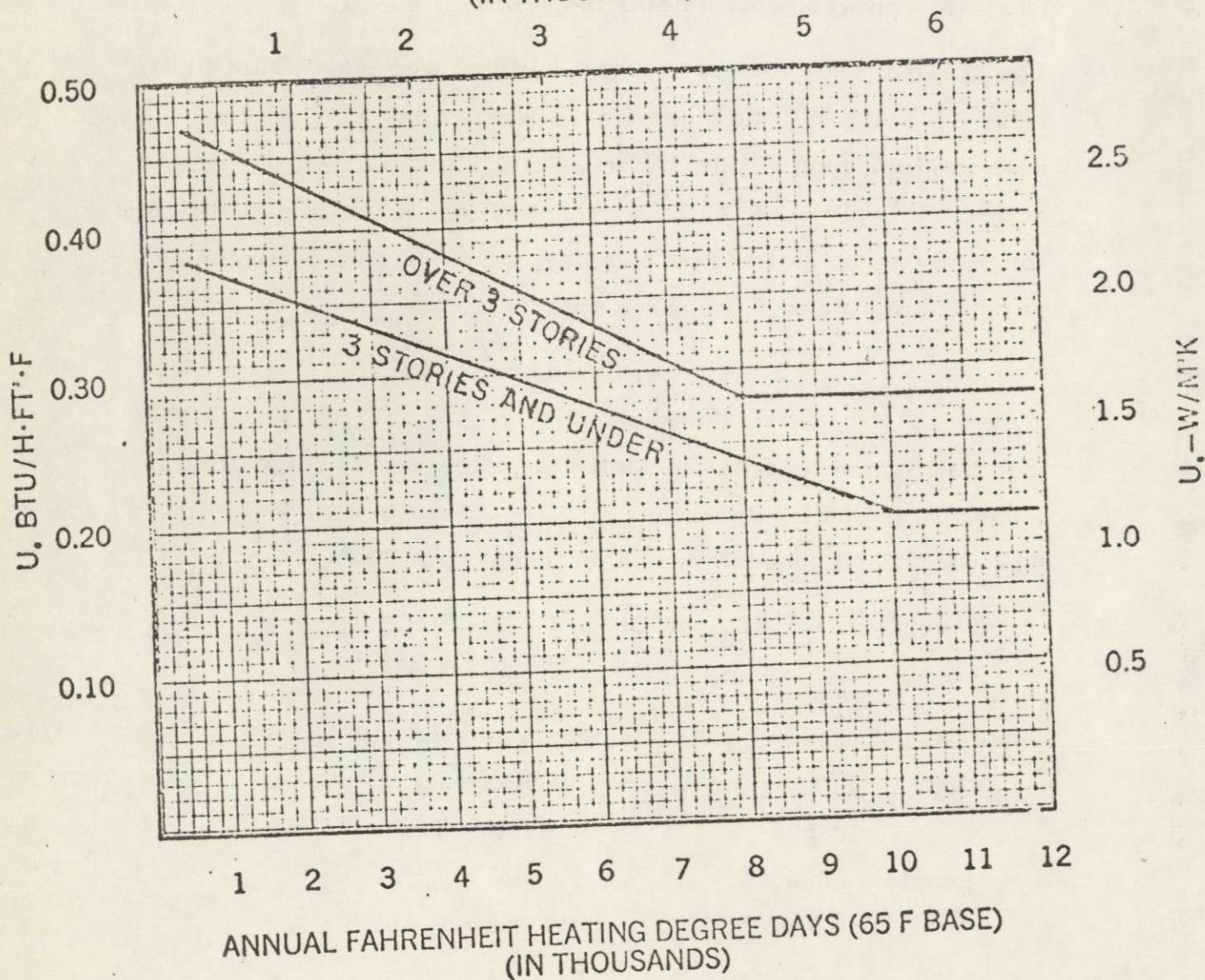


Figure 5.3.8-1

### 5.3.9 Domestic Hot Water

The domestic hot water schedule for the three types of building is shown in Table 5.3.9-1 and graphically in Figure 5.3.9-1 to 5.3.9-3.

Table 5.3.9-1

<u>Time</u>	<u>Gal (SF)</u>	<u>Gal (MF)</u>
7 am	50.4	630
10 am	9.8	122.4
1 pm	9.8	122.4
4 pm	9.8	122.4
10 pm	<u>11.1</u>	<u>138.4</u>
	100.7	1258.

Commercial building: 115 GPH 8 am - 7 pm  
0 GPH 7 pm - 8 am

The energy requirements to heat the domestic hot water were calculated with the following assumptions (reference IPC).

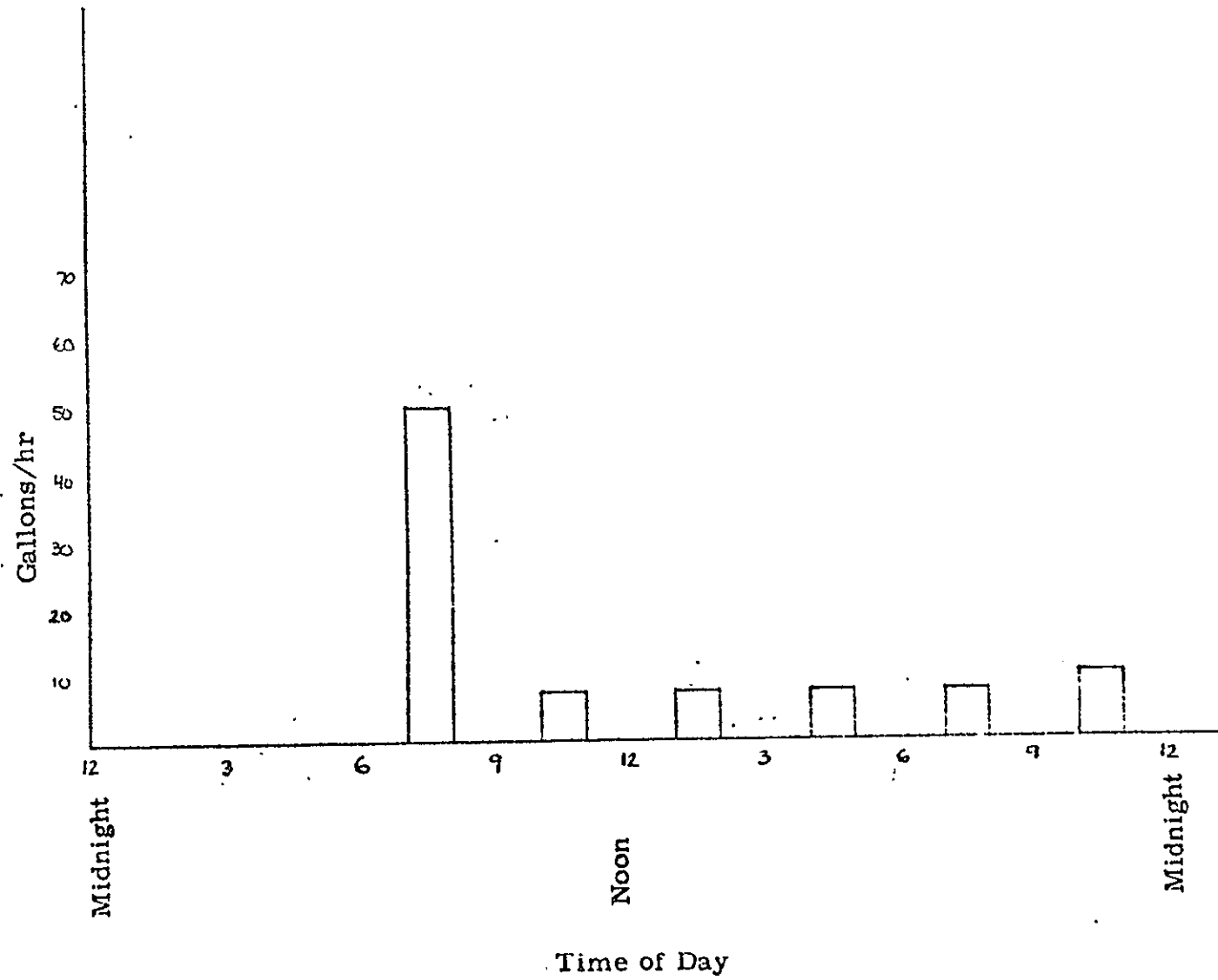
delivery temperature = 140 F

supply temperature = well water temperature

The well water temperature for Minneapolis varies from 39 F to 57 F between summer and winter. (Reference NBSLD Computer Program for Heating and Cooling Loads in Buildings, NBS1R 74-574, T. Kusuda, November, 1974).

Figure 5.3.9-1

ASSUMED USE PROFILE FOR DOMESTIC HOT WATER  
SINGLE FAMILY RESIDENCE



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Figure 5.3.9-2

ASSUMED USE PROFILE FOR DOMESTIC HOT WATER  
MULTIFAMILY RESIDENCE

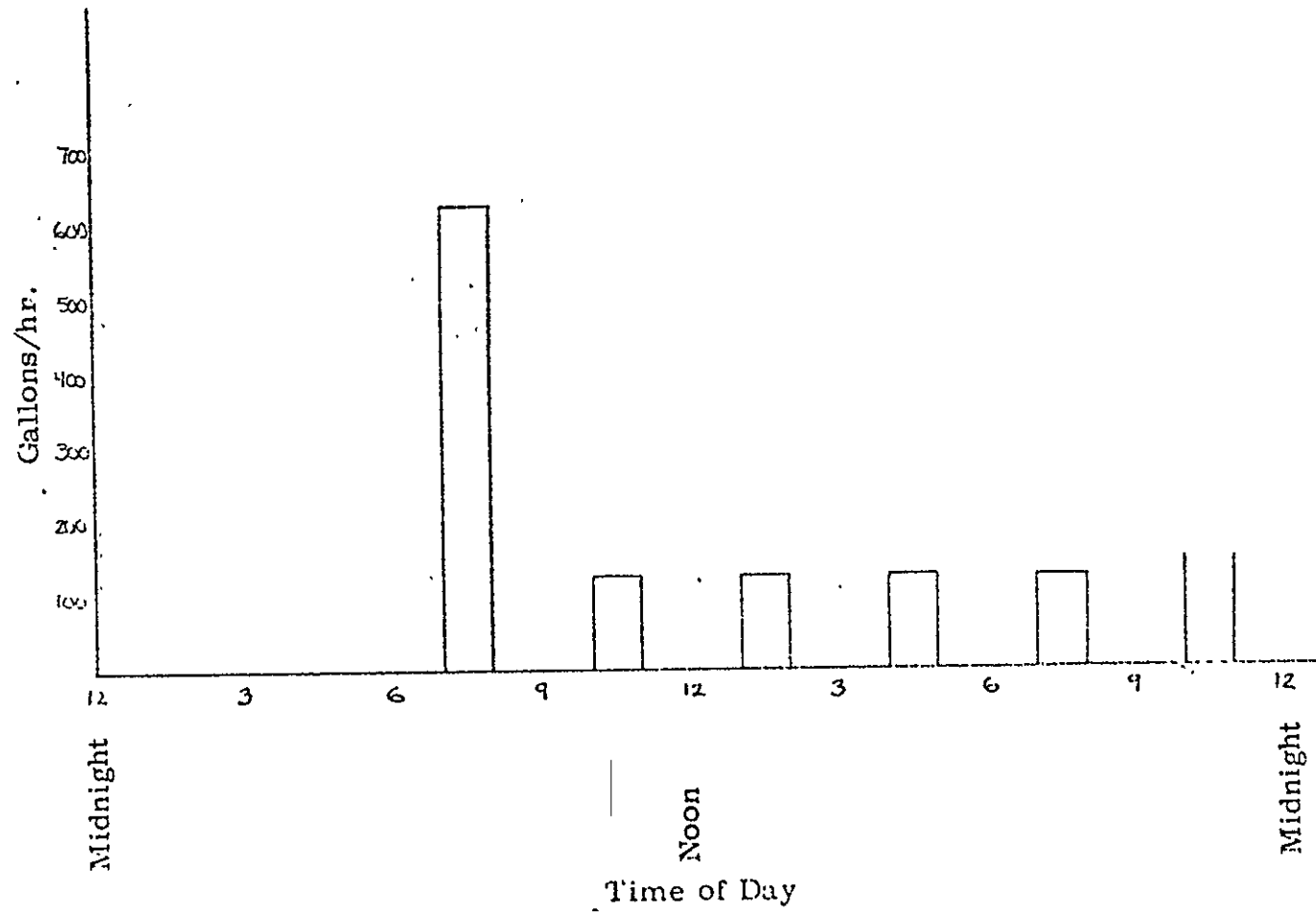
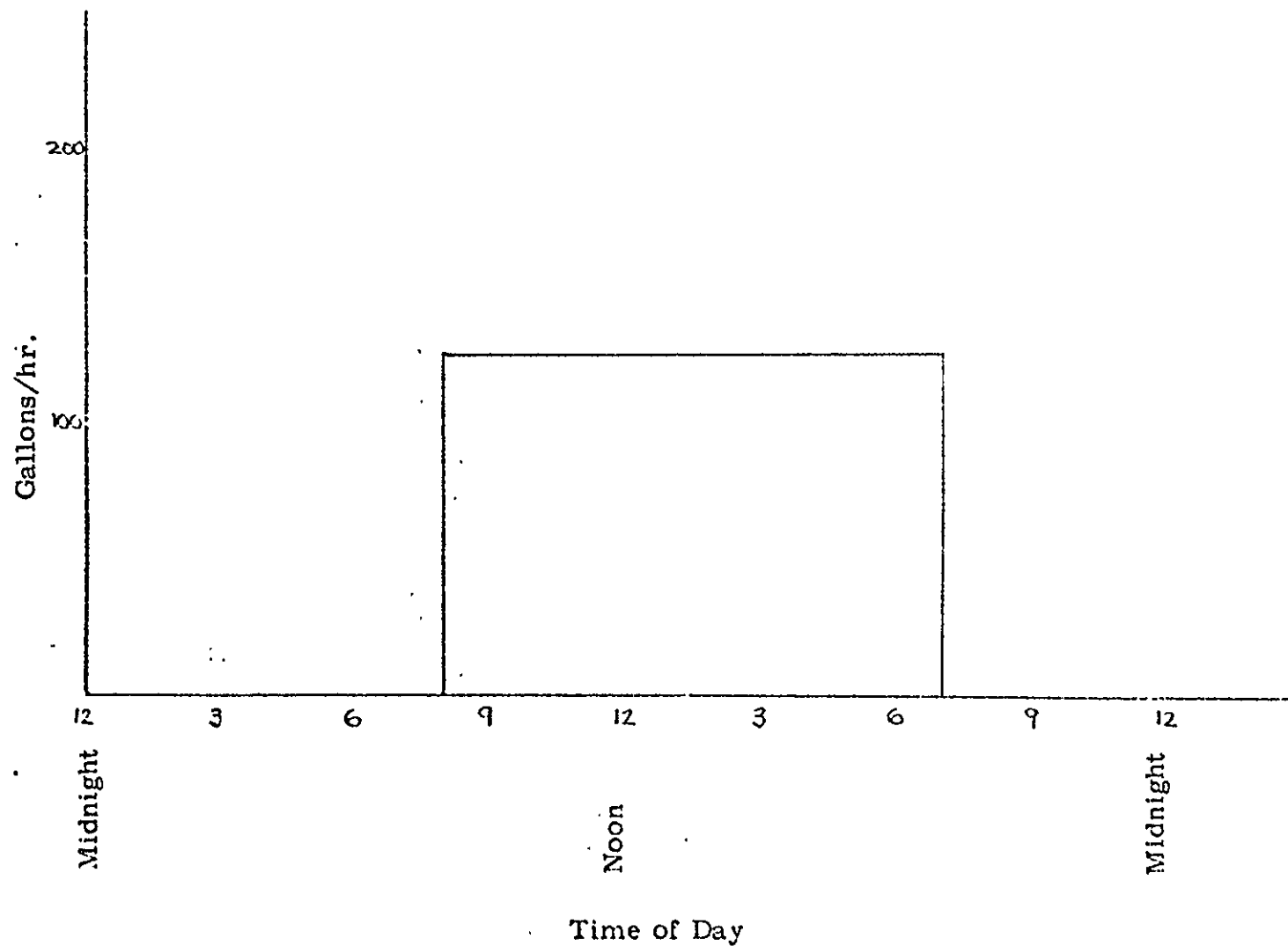


Figure 5.3.9-3  
ASSUMED USE PROFILE FOR DOMESTIC HOT WATER  
COMMERCIAL BUILDING



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#### 5.3.10 Weather Model

The following hourly recorded data is taken from weather tapes provided by the National Climatic Center, Asheville, N. C. (Reference Airways TDF-14, Surface Observations Manual, Director National Climatic Center, Federal Building, Asheville, N. C., 28801).

Dry Bulb Temperature

Dew Point Temperature

Wet Bulb Temperature

Wind Speed

Barometric Pressure

Total Cloud Cover

Type of Cloud

Occurrence of Wet Precipitation

Occurrence of Dry Precipitation

#### 5.3.11 Flat Plate Collector Model

The flat plate model is based on a tilted flat plate facing south. Although the model allows both the tilt and direction to be specified, they are held constant for any one simulation run. The amount of energy collected is expressed by:

$$Q_{out} = K_1 Q_{inc} - K_2 (T_{in} - D_b)$$

where:

$Q_{inc}$  = Amount of solar radiation incident on the collector surface

$T_{in}$  = Temperature of input fluid

$D_b$  = Dry bulb temperature

$K_1, K_2$  = Constants for proposed Lennox collector



For 2 cover collector:

$$K_1 = .74$$

$$K_2 = .6$$

For 1 cover collector

$$K_1 = .8$$

$$K_2 = .68$$

#### 5.3.12 Storage

Energy storage is accomplished through the sensible rise in temperature of a tank filled with water. For the purposes of our analysis, an insulated cylindrical steel tank with specified length and diameter was assumed. Energy supplied to the tank was assumed to be evenly distributed to all segments.

Two types of insulation for reducing heat loss from the tank were considered - fiberglass and urethane. The thermal conductivity of these materials are:

$$k \text{ (fiberglass)} = .26 \text{ Btu-in/HR ft}^2\text{F}$$

$$k \text{ (urethane)} = .13 \text{ Btu-in/HR ft}^2\text{F}$$

### 5.3.13 Economic Studies

A computer subroutine is being used to make economic comparisons between alternate systems and subsystems. The economic evaluations are based on annual cost requirement. The methodology for calculation of the annual cost requirement is based on formulas derived by Grant and Ireson\* and Rosalie T. Ruegg.\*\*

Figure 5.3.13-1 shows a diagram that summarizes the procedure. The output is the annual revenue requirement and is the average dollar amount that would be required each year to cover the cost of operating and paying for the solar system.

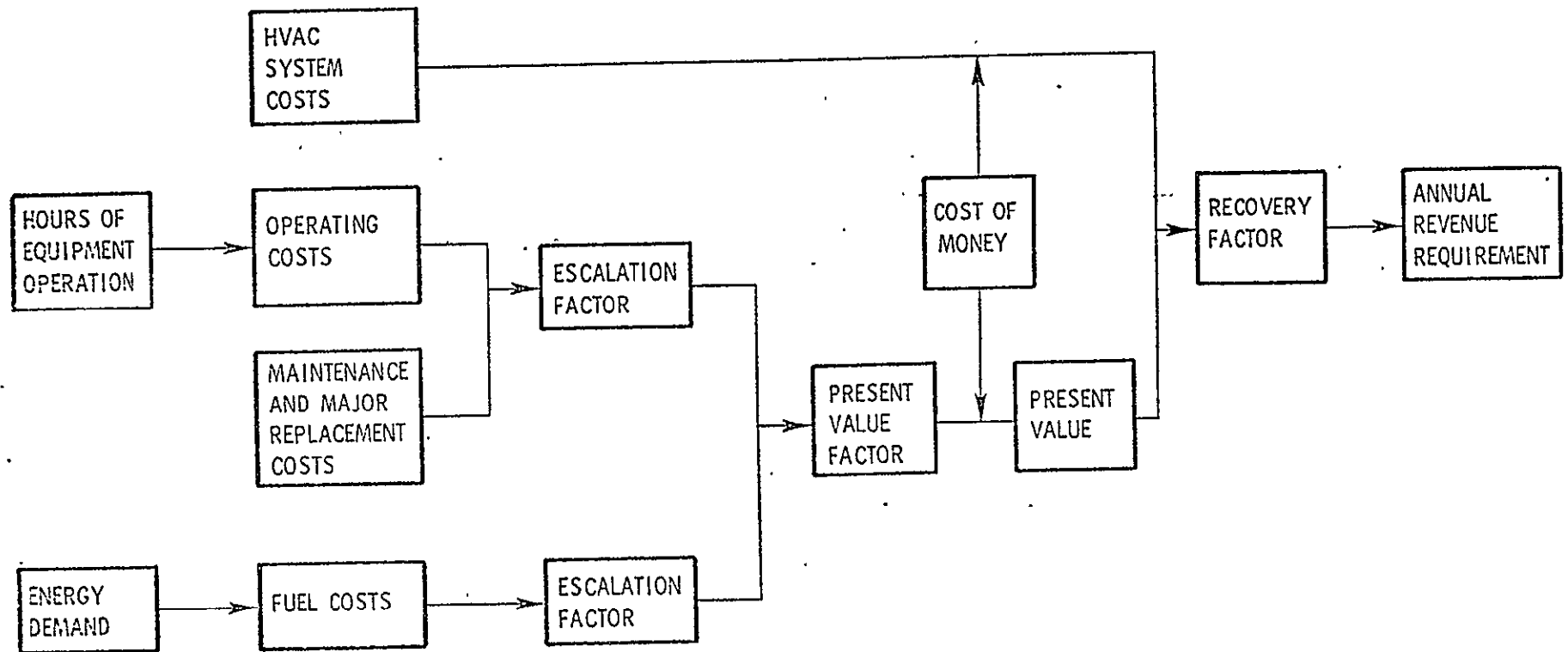
The basic inputs needed for the procedure are as follows:

- System cost
- Annual hours of equipment operation (i. e. pumps and fans)
- Energy demand for the building
- Maintenance and major replacement costs
- Energy costs
- Energy escalation rates
- Cost of money

Fuel costs are shown separately because it is expected that electricity will escalate at a different rate than natural gas or oil. Also maintenance costs are separate since the timing of maintenance may not be demanded at a constant rate whereas the operating costs will be constant.

\* Eugene L. Grant and W. Grant Ireson, Principles of Engineering Economy, Ronald Press Company, New York, 1964.

\*\* R. T. Ruegg, "Solar Heating and Cooling in Buildings: Methods of Economic Evaluation", NBSIR 75-712.



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LEVEL ANNUAL REVENUE REQUIREMENT

Figure 5.3.13-1

The system operating costs, including fuel and equipment operating, is brought to an equivalent basis for comparison purposes by computing the present value. The formula for this is:

$$PV = \frac{1}{(1+i)^n}$$

where  $i$  = interest rate or cost of money and  $n$  = number of interest periods or years. The interest rate selected for the study was 7%. The economic subroutine in the computer simulation allows for inserting various interest rates for study purposes.

The annual cost required by the homeowner to pay for the system as well as the operating and energy costs is predicted by summing the present value of fuel and operating costs over the life of the system, adding the system first cost and then reducing this amount to a uniform payment by the capital recovery factor formula.

$$CRf = \frac{i(1+i)^n}{(1+i)^n - 1}$$

For a 20 year interest period and 7% interest, the capital recovery factor is 0.09439.

The maintenance costs have been neglected. Also not included are allowances for increases in property tax, increases in insurance, or other factors which might increase or decrease payments. Salvage value of equipment at the end of the amortization period was not considered.

#### 5.3.14 Cost of Energy

The cost of natural gas, oil and electricity for Minneapolis for 1976 were based on current rate schedules recently obtained from Northern States Power Company, Minneapolis Gas Company and Mobile Oil Company.

These current rates are as follows:

Natural gas: (1000 Btu/ft<sup>3</sup>)

<u>ft<sup>3</sup></u>	<u>\$</u>
0 - 300	2.4603
300 - 3700	1.9790/1000 ft <sup>3</sup>
3700 - 26000	1.5590/1000 ft <sup>3</sup>
26000 -	1.5090/1000 ft <sup>3</sup>

Oil: (14000 Btu/gal)

No. 2	.393/gal.
-------	-----------

Electricity:

Fixed charge per month -	2.50
First 500 KWH per KWH -	.0353
Next 500 KWH per KWH	.0309
For excess per KWH	.0190

#### 5.3.15 Projected Cost of Energy

There appears to be many scenarios for the escalation of energy in the future. While future availability problems are speculative, the critical nature of energy use in today's society will obviously result in increased fuel costs. Energy costs, unless regulated nationally, will escalate at different rates for each geographical area.

The escalation rates assumed are the rates presented at the NASA contractors meeting of 3 August 1976. (Reference A. D. Little, "Base Prices and Forecast", April, 1974).

Energy	Year		Rate
	1976	2000	
Electricity	1	1.4	$(1.014)^{24} = 1.4$
Gas	1	2.72	$(1.043)^{24} = 2.72$
Oil	1	1.68	$(1.022)^{24} = 1.68$

#### 5.3.16 Example of Economic Procedure

The following example shows the economics procedure for a solar assisted 1500 ft<sup>2</sup> residence in Minneapolis. For present day energy costs (1976) and energy demands based on ASHRAE standard 90-75, the following yearly demands and prices are predicted:

Heating demand	106.6 MBtu
Solar supplied to heating	45.4 MBtu
Electric demand (pumps)	2358 KWH
Hot water demand	3.4 MBtu
Solar supplied to hot water	2.1 MBtu
Fuel cost	\$2.5/MBtu
Electric cost	\$10.43/MBtu

Assuming electricity escalates at 1.4% per year and natural gas at 4.3% per year, the total energy costs over the next 20 years come to \$ 6572.49 which represents a present value of \$ 3462.54 at an interest rate of 7%.

In other words, \$3462.54 invested at 7% interest would generate enough money over the next 20 years to meet all the energy costs as they occur.

The solar system costs are approximately \$11,000 for a 540 ft<sup>2</sup> solar collector/array system. These costs added to the total energy costs of 3462.54 gives \$14,462.54. Assuming a 20 year pay period with interest of 7% would yield an annual homeowner payment for both the system and operating costs of

$$\begin{aligned}
 \text{payment} &= 14462.54 \text{ (CRf)} \\
 &= 14462.54 (.09439) \\
 &= \$1365. \\
 &= \$113.75/\text{mo.}
 \end{aligned}$$

#### 5.4 Simulation Description

Honeywell has developed a general purpose computer program (SUNSIM) for use in closed loop solar system simulation. This computer program has been adapted for use in the design and evaluation of the solar heating and cooling demonstration systems.

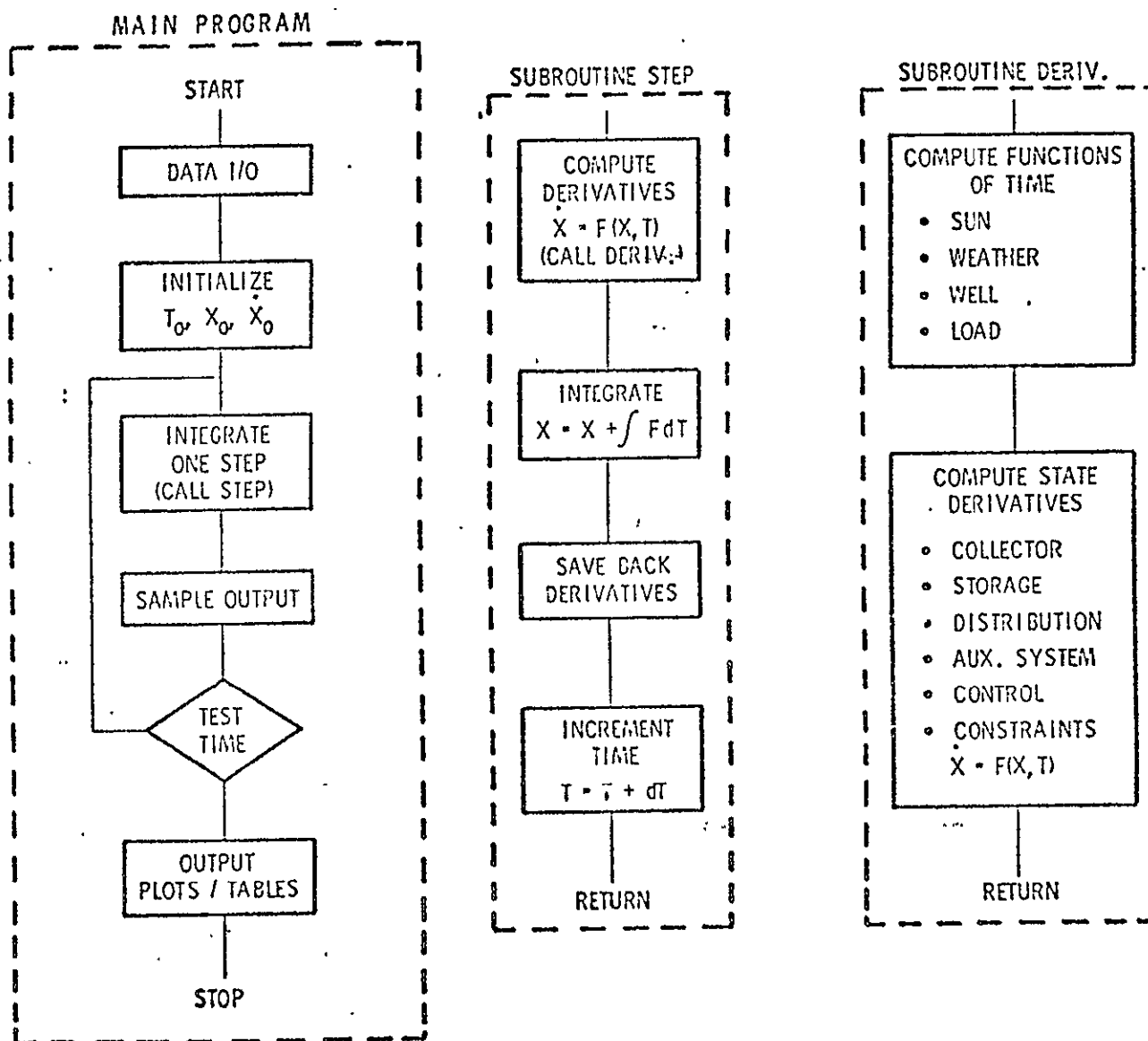
Component relationships and loop constraints are used in the SUNSIM computer program to model multiple loop solar systems as sets of non-linear differential equations. The differential equation may be integrated forward in time to determine fuel savings or linearized numerically for stability analysis using a fully automated modern control software package.

The closed loop simulation structure, illustrated in Figure 5.4-1 consists of three key functional blocks:

- o A MAIN program which inputs data, controls the integration and linearization of the differential equations, samples the output and generates report quality output plots and tables.
- o A first order Adams-Bashforth integration STEP routine which updates state variables based on current and past values of the derivatives.
- o A DERIVative routine which contains the differential equations used to model the system.

A derivative subroutine contains deterministic functions of time such as the diffuse and direct components of solar radiation on cloudy days and hourly weather data available for over 300 weather stations in the United States. Two different models may be used to compute the diffuse and direct components of solar radiation.





Closed Loop Solar System Simulation Structure

Figure 5.4-1

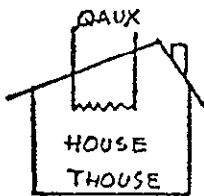
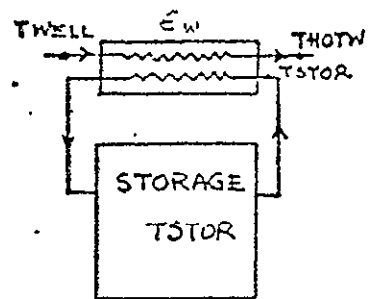
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- An ASHRAE procedure based on weather data provided by the National Climatic Center and a cloud cover radiation model due to Kimura and Stephenson.
- Actual measurements of total radiation on a horizontal surface with an analytical estimate of diffuse and direct components based on a Liu-Jordan correlation. The radiation data is provided on tapes by the University of Wisconsin.

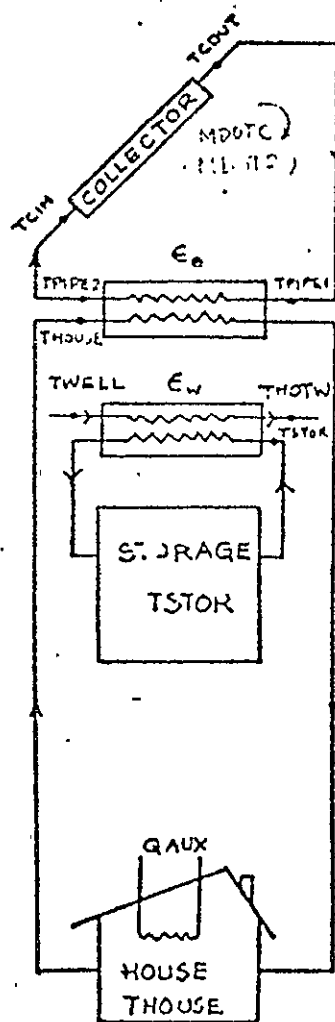
In addition, the DERIVative subroutine contains performance models for solar and conventional system components commonly used in shallow solar ponds, flat plate, Fresnel and trough concentrator systems. The simulation is modular in structure and well documented to minimize modeling time required for the different types of systems.

Figure 5.4-2 illustrates four modes of the solar HVAC system presently being considered for residential space heating and hot water. The four modes of the system modelled are:

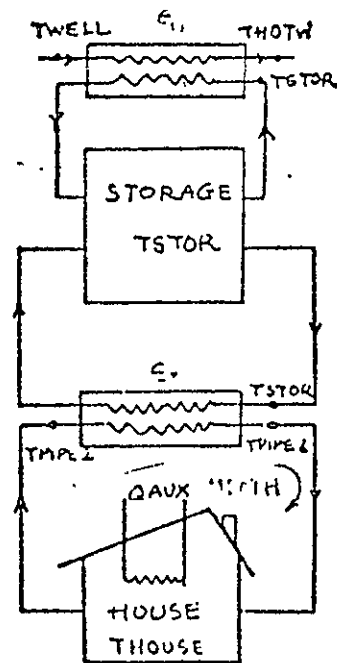
- Mode 1 -- no solar, auxiliary when needed, hot water from storage when available.
- Mode 2 -- space heating in the direct mode and hot water heating.
- Mode 3 -- space heating from storage and hot water heating.
- Mode 4 -- storage charging and heating hot water.



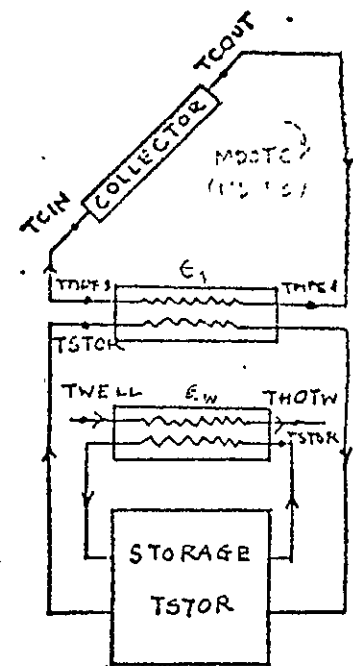
MODE 1



MODE 2



MODE 3



MODE 4

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Figure 5.4-2

A first order model of this system has been constructed for use in computing annual fuel savings in support of system design trades. The effect on annual system performance of all major design variables including finite heat exchangers, pumping power, distribution system sizing and insulation, storage tank volume and insulation, loop flow rates and collector manifold configurations can be readily evaluated with this simulation.

In this simulation, relatively high frequency transients associated with the collector loop thermal capacitance are neglected. As a result, an iterative procedure is required at every integration step to determine the collector loop temperatures in order to satisfy an energy balance constraint on the differential equations.

Simulation of space heating systems and industrial process heat systems have also been conducted using the SUNSIM computer program in which the effects of collector loop thermal capacitance on system dynamics and performance were considered. These simulations required integration steps ranging from 30 seconds to 6 minutes and are primarily used for stability analysis and the investigation of short period effects such as limit cycle frequencies and amplitudes.

## 5.5 Results

Performance and economic simulations of the selected solar assisted heating system was performed for systems for single family residences, multifamily residences and commercial buildings. The trade-off studies began with a "standard" system and various parameters were varied separately to determine their effect on system performance and economics. The effects of these parameter variations have been studied only for Minneapolis and the magnitude of the effects would be different for different localities.

### 5.5.1 Single Family Residence (SFR)

The basic solar system modelled in the digital simulation program is shown schematically in Drawing SK140094 consists of a collector array with piping headers on both sides of the collectors for inlet and outlet of the collector fluid, a collector with 2 glass covers and a single storage tank filled with water for sensible heat storage. The most important variable which greatly effects both performance and economics is the collector area.

The collector area for the SFR was varied from  $180 \text{ ft}^2$  to  $756 \text{ ft}^2$ .

Figure 5.5.1-1 shows the percent of solar energy supplied to a SFR varies from about 21 percent for  $180 \text{ ft}^2$  of collector area to about 45 percent for a  $756 \text{ ft}^2$  system. These predictions were made for a system with a 1000 gallon storage tank. From this curve, it is not obvious what size system to install since the percent of energy increases as the system collector area increases.

An analysis of the economics of the system by the method described in Section 5.3.13 shows that a minimum cost per million Btu's of solar energy provided is realized with a solar system with approximately 540 ft<sup>2</sup> of collector. This is shown in Figure 5.5.1-2. The minimum cost per million Btu's provided is approximately \$34/MBtu.

Collector tilt is important. Figure 5.5.1-3 shows that 55° is optimum which corresponds closely to the rule of thumb of latitude plus 10° for heating systems. The performance is within 1 percent of maximum over the range of 45° to 65°. The economics of the system operation for various collector tilt angles is presented in Figure 5.5.1-4. The optimum tilt angle is 55° as was shown in the performance curve (Figure 5.5.1-3).

The performance of the system with the collector array facing away from south was not simulated. It is well known that the optimum system performance is achieved with collectors facing due south. Previous calculations have shown that variations of 30° east or west reduce performance about 3 percent.

The performance of a 540 ft<sup>2</sup> solar system with different size storage tanks is shown in Figure 5.5.1-5. The percent of solar energy supplied to the load varies from about 23.5 percent for a 125 gallon tank to approximately 42 percent for a 1500 gallon tank. The optimum size storage tank is more obvious from curves shown in Figure 5.5.1-6. An analysis of the figure shows that the cost per million Btu's provided decreases rapidly to about 600 gallons and then decreases more gradual up to 1500 gallons. This is approximately 1.11 to 2.5 gallons per square foot of collector. A 1000 gallon storage tank was selected as the preferred size.

The heat loss from the storage tank was investigated. Figure 5.5.1-7 shows that for a storage tank UA of 9.44 (4 inches of fiberglass), the system would provide about 2 percent less over the year than if no heat was lost from storage. If the storage tank is located inside the building, the heat loss would decrease the building heat load and the net effect would be the same as a perfectly insulated storage tank.

The baseline solar systems described in Section 4.0 have two heat exchangers between the solar collectors and the building air. Figure 5.5.1-8 shows that the performance of the solar system varies approximately 2 percent for a range of heat exchanger heat transfer effectiveness.

A method to cut the cost of solar energy systems is to reduce the piping and solar collector header costs. This can be accomplished by mounting two flat plate collectors in series. The exit flow of one collector enters the second collector directly. Fluid exiting from the second collector then goes into the piping header. The disadvantage of this arrangement is that the performance of the second collector in series is degraded because the fluid inlet temperature is higher. The performance of solar system with the collectors arranged in series is only degraded by a fraction of a percent.

The solar collector can be configured with one cover. This results in the performance equation of the collector having a greater  $\alpha\tau$  but also a larger heat loss,  $U_L$ . The performance effect of one cover collector versus a two cover collector is presented in Figure 5.5.1-9. The figure shows that the one cover collector provides approximately 2 percent more energy over the year. Figure 5.5.1-10 presents the cost per million Btu's versus the number of collector covers. This figure shows that the overall cost is reduced for the one cover collector.

Figure 5.5.1-1

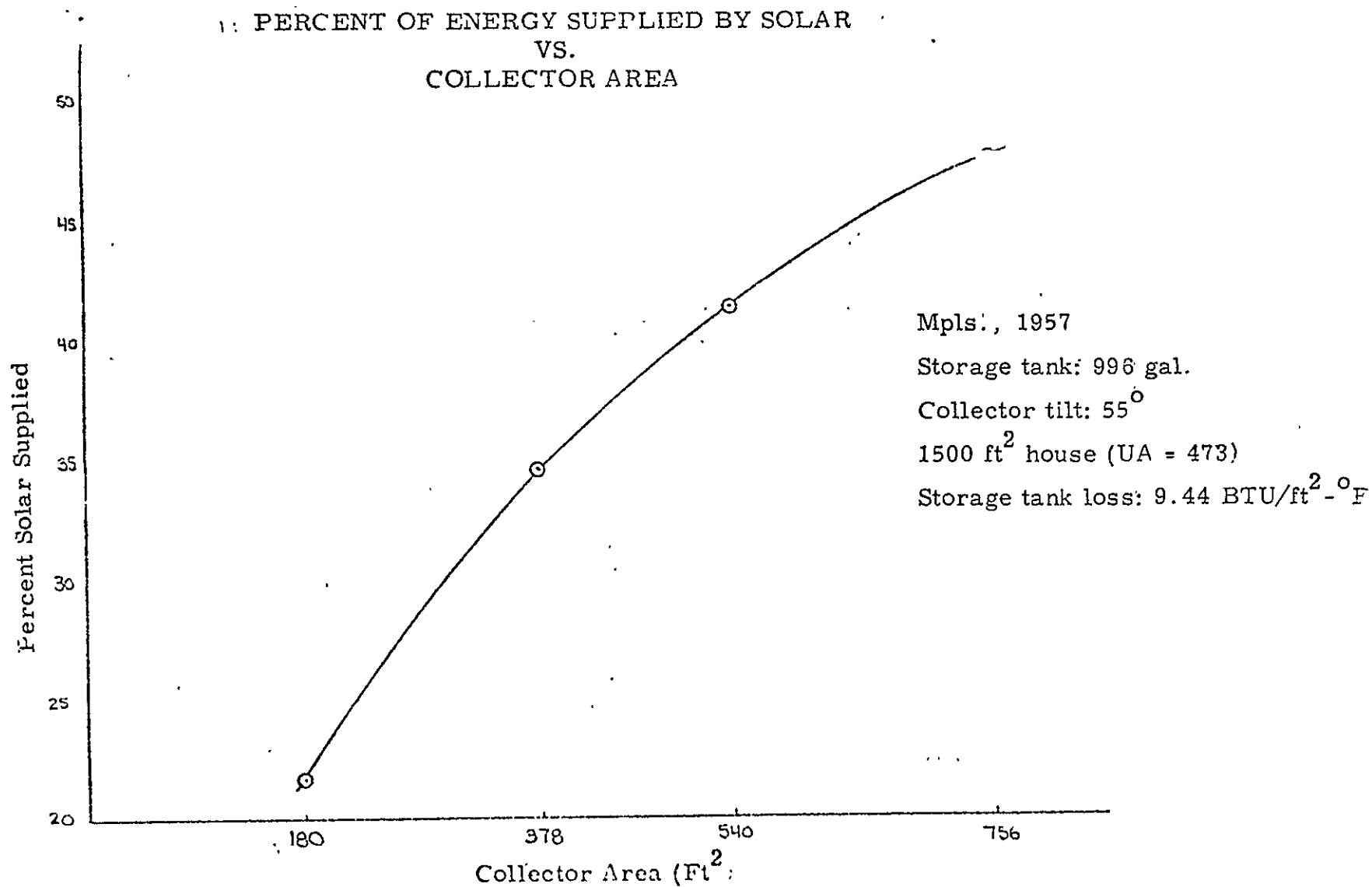




Figure 5.5.1-2  
DOLLARS PER MILLION BTU'S OF SOLAR ENERGY  
VS.  
COLLECTOR AREA  
SINGLE FAMILY RESIDENCE

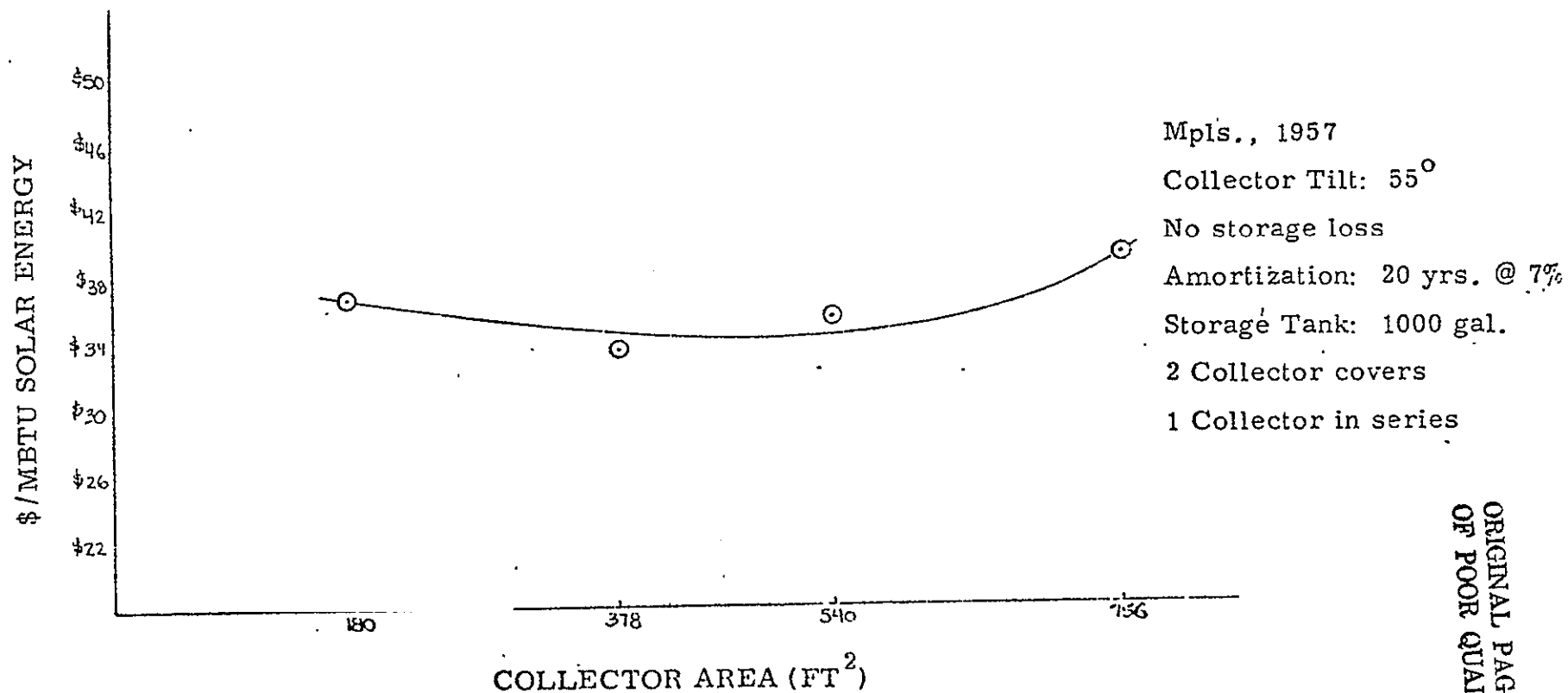


Figure 5.5.1-5  
PERCENT OF ENERGY SUPPLIED BY SOLAR  
VS.  
COLLECTOR TILT

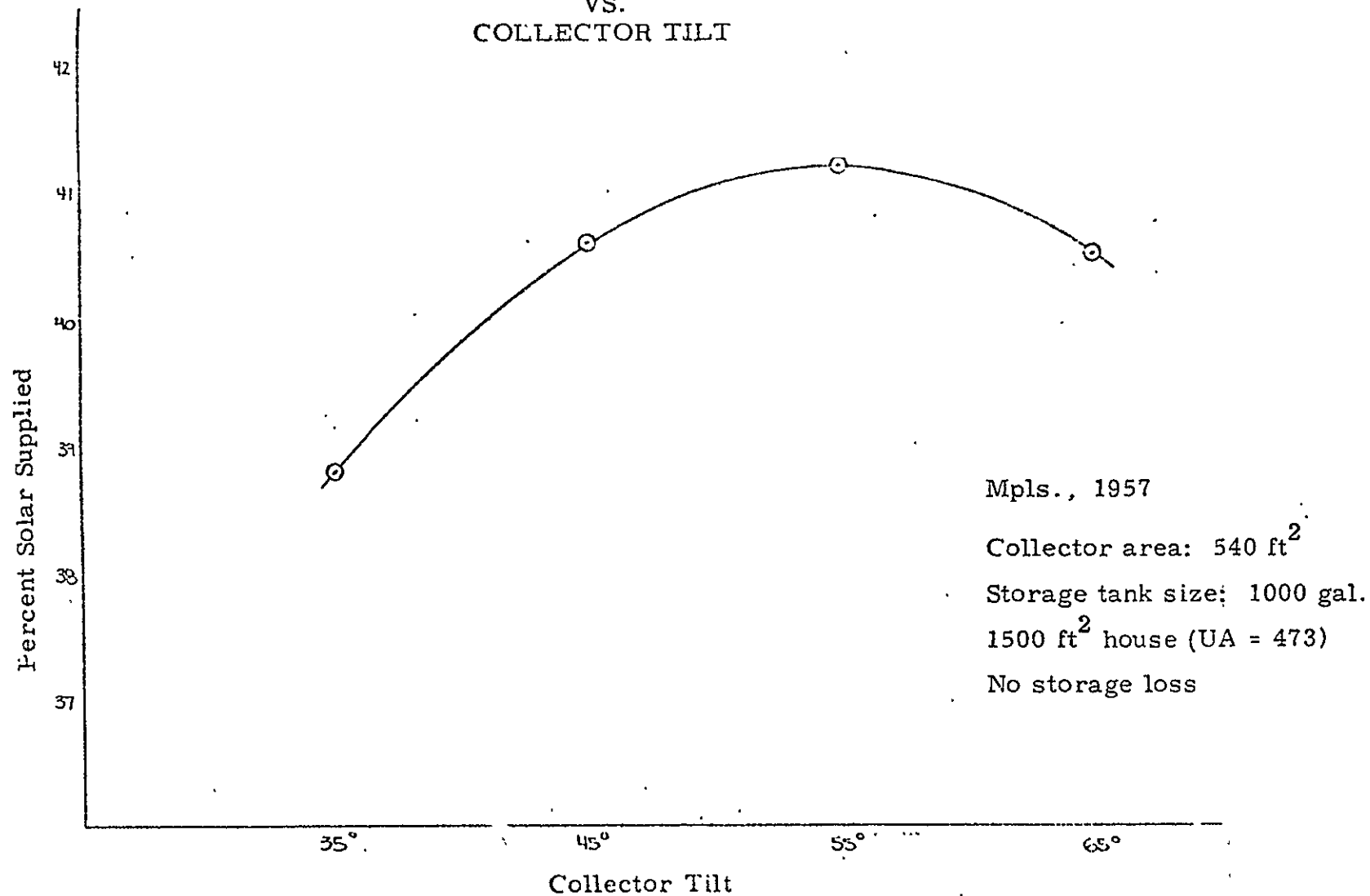
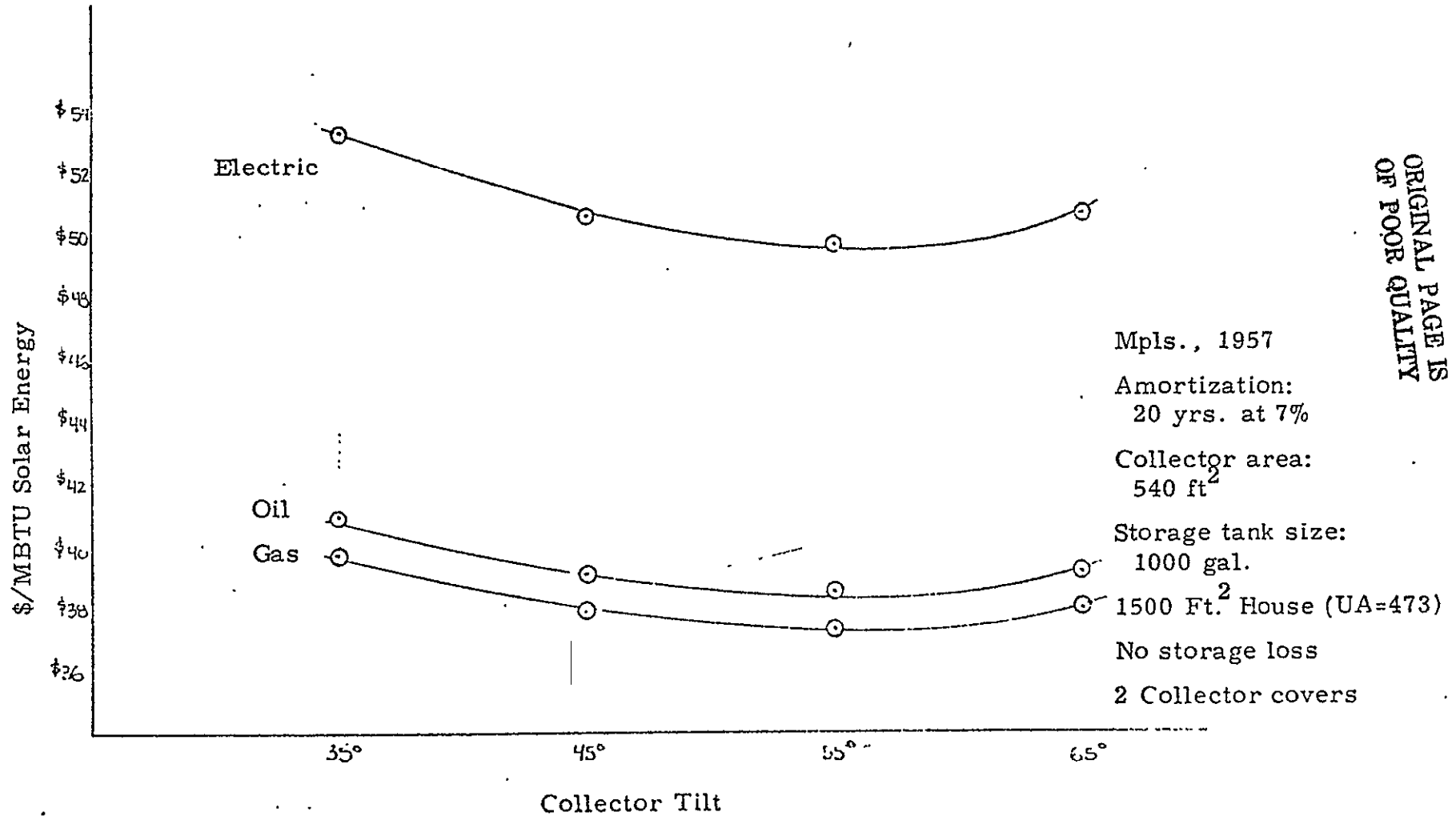
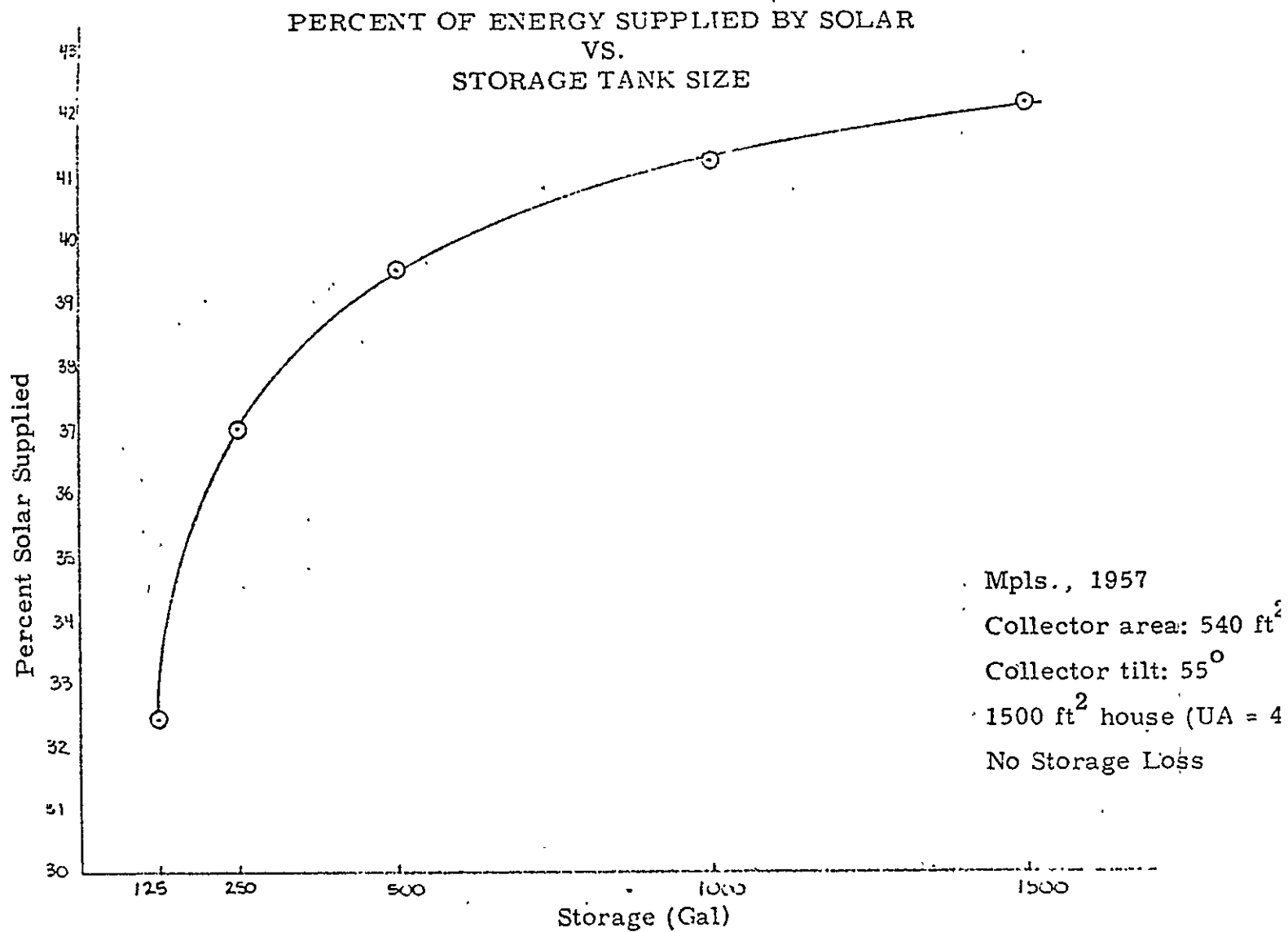


Figure 5.5.1-4

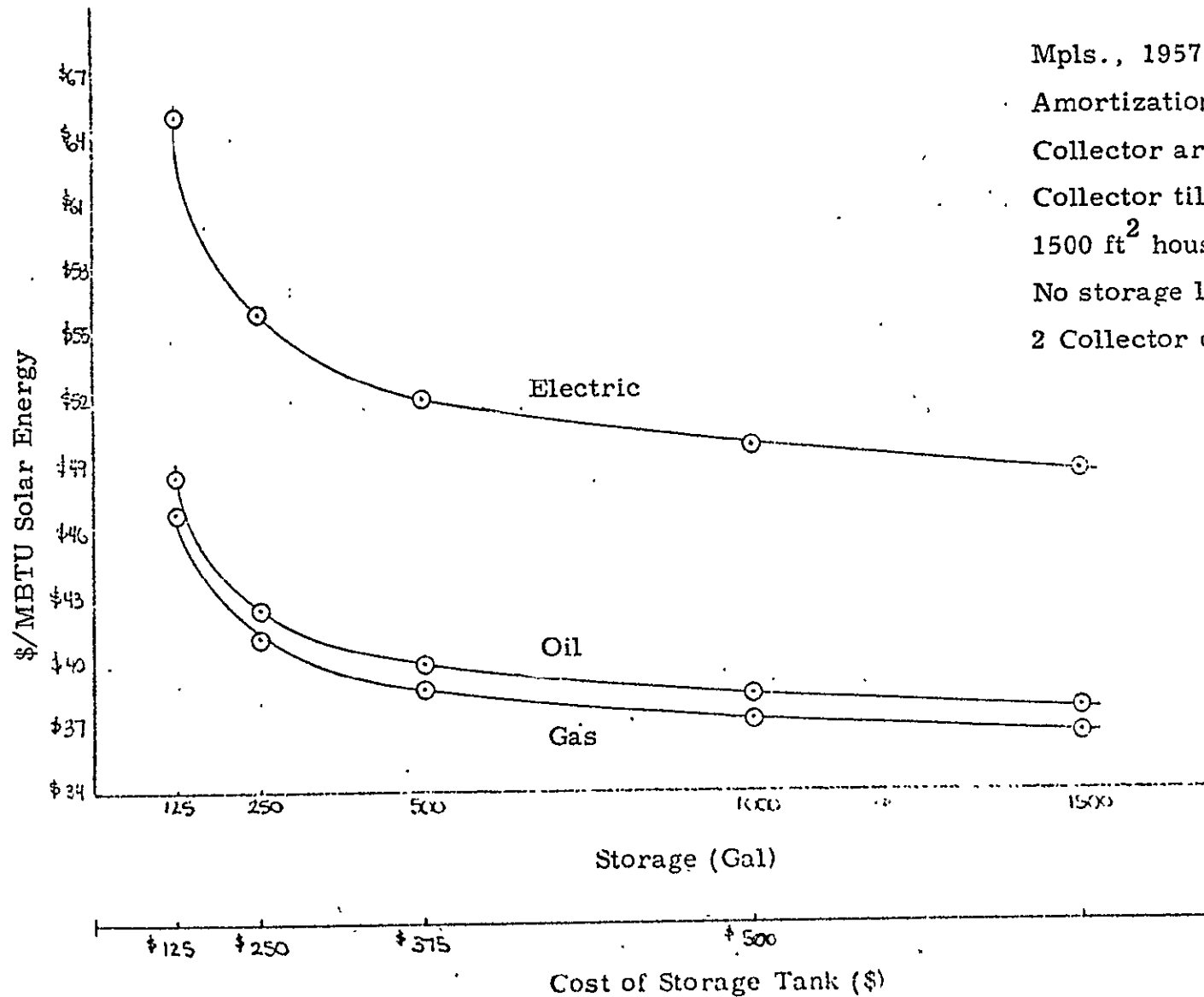
DOLLARS PER MILLION BTUs OF SOLAR ENERGY  
VS.  
COLLECTOR TILT.



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DOLLARS PER MILLION BTUs OF SOLAR ENERGY  
VS.  
STORAGE TANK SIZE



Mpls., 1957

Amortization: 20 yrs. at 7%

Collector area: 540 ft<sup>2</sup>

Collector tilt: 55°

1500 ft<sup>2</sup> house (UA = 473)

No storage loss

2 Collector covers

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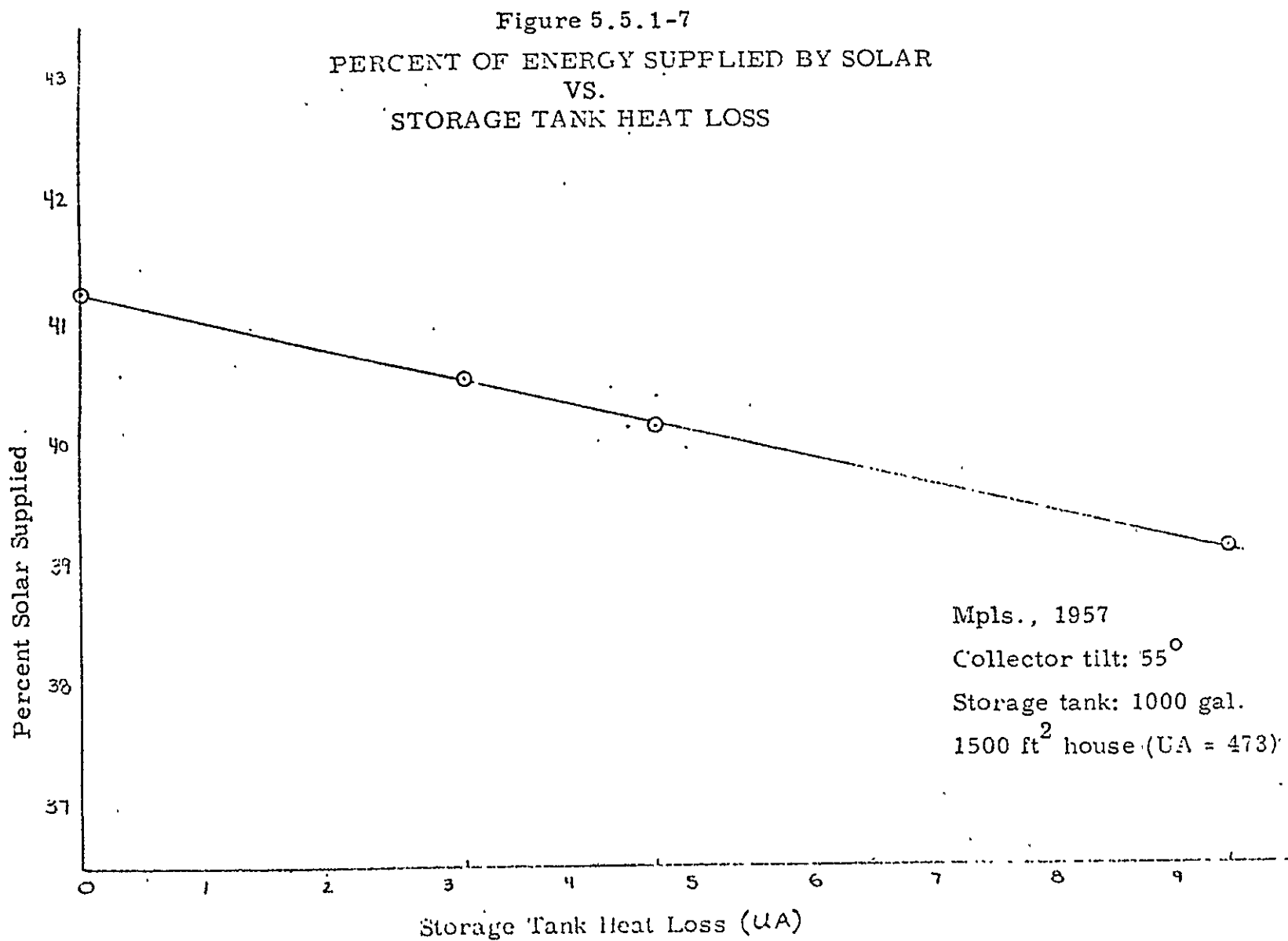


Figure 5.5.1-8

PERCENT OF ENERGY SUPPLIED BY SOLAR  
VS.  
HEAT EXCHANGER HEAT TRANSFER EFFECTIVENESS

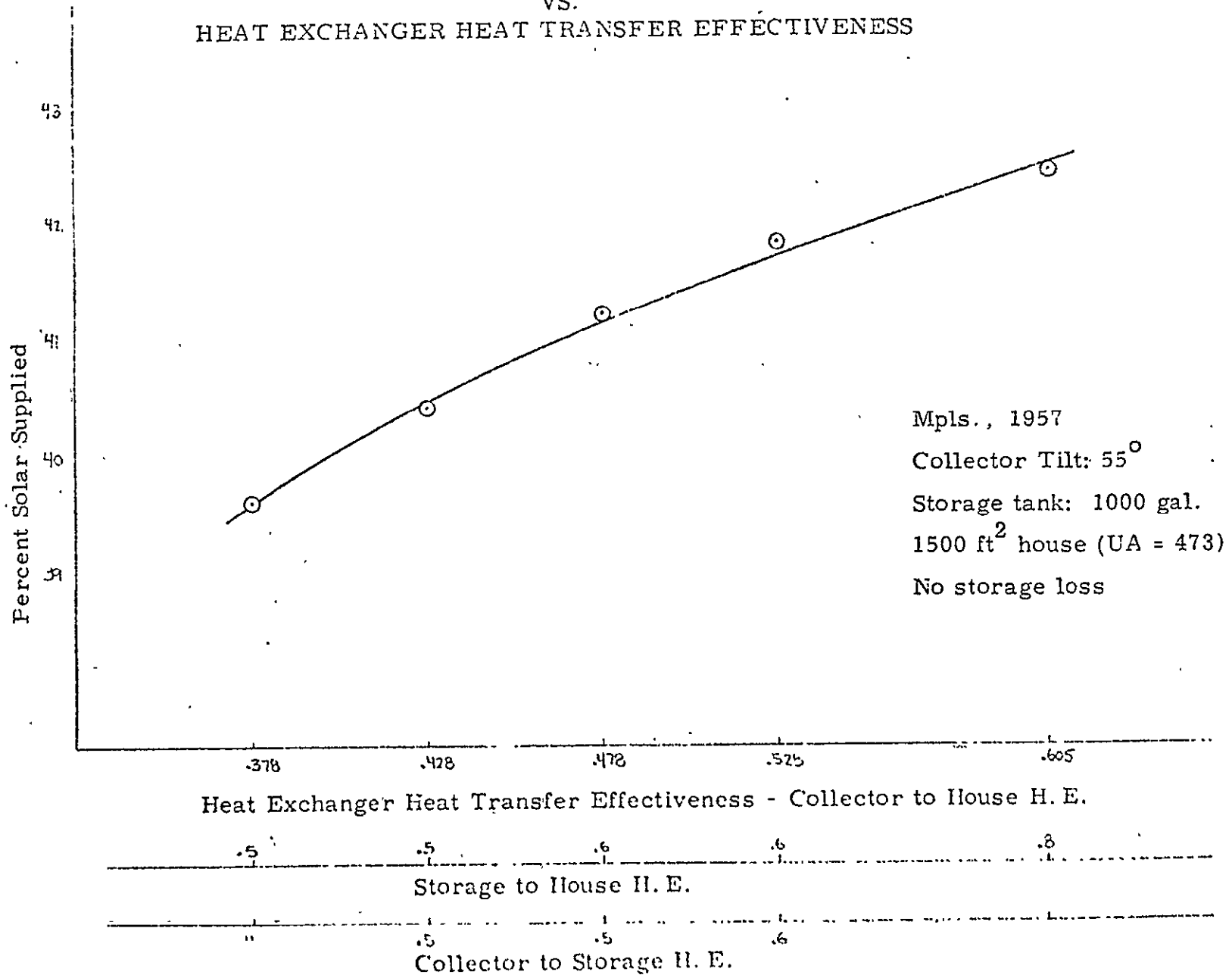
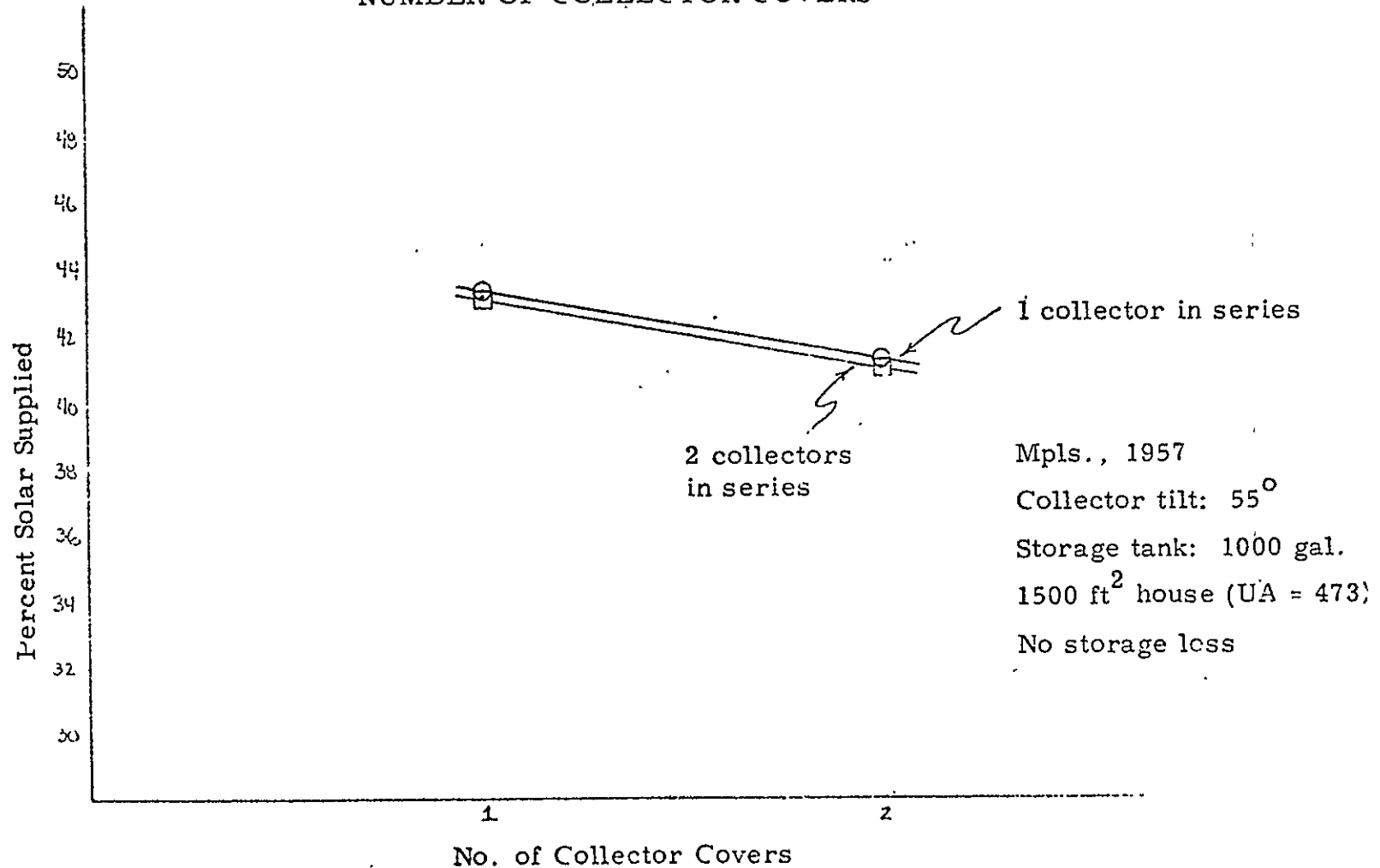
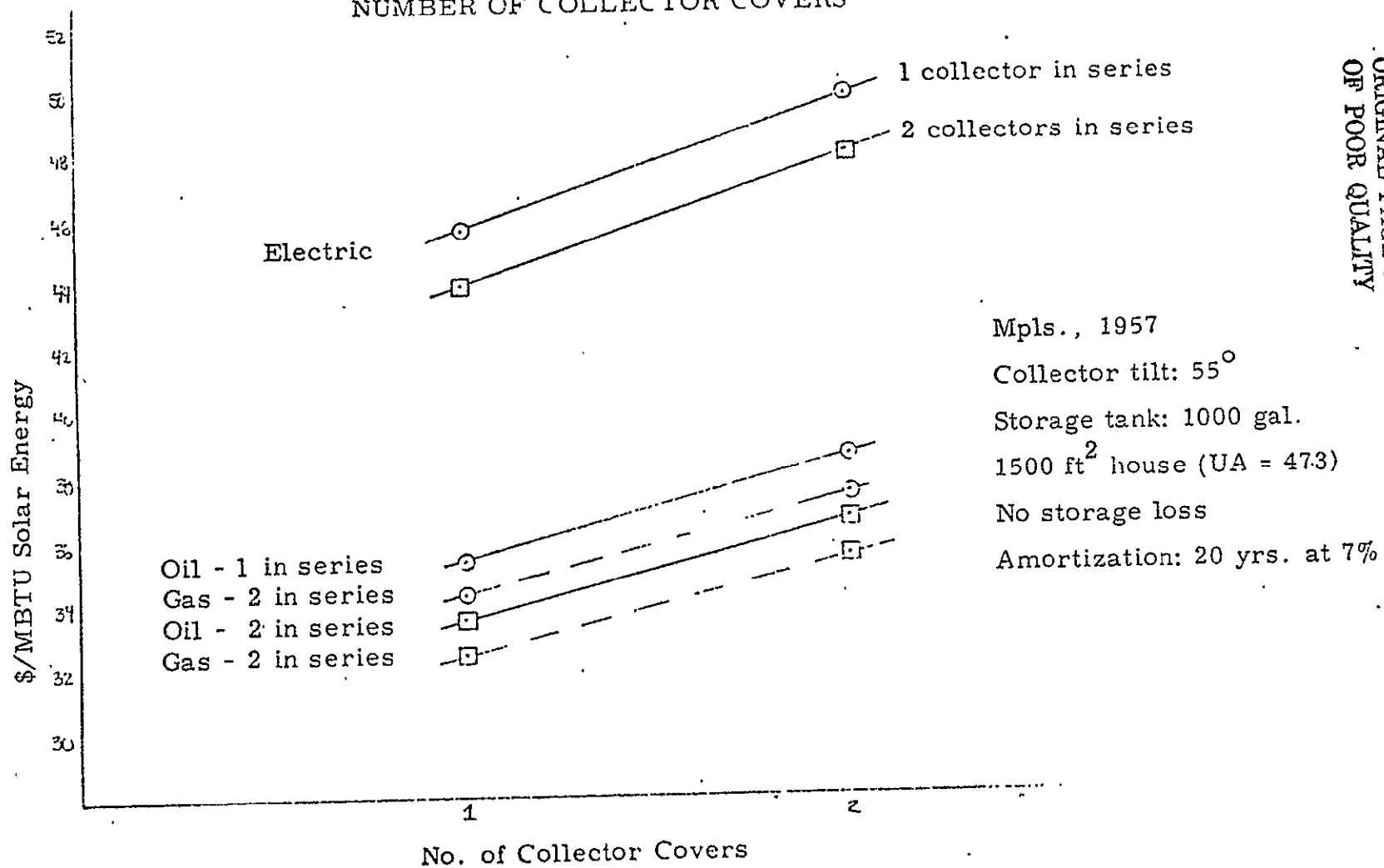


Figure 5.5.1-9  
PERCENT OF ENERGY SUPPLIED BY SOLAR  
VS.  
NUMBER OF COLLECTOR COVERS





DOLLARS PER MILLION BTU'S OF SOLAR ENERGY  
VS.  
NUMBER OF COLLECTOR COVERS



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### 5.5.2 Multifamily Residence (MFR)

The basic solar system modelled in the digital simulation program is shown schematically in Drawing SK 140095. The results of the trade-off for the SFR were used so that not all variables needed to be studied. Since collector area is the most important variable, it was optimized. Figure 5.5.2-1 shows the solar cost as a function of collector area. The minimum cost system consists of 3780 square feet of collector or 210 collector modules.

### 5.5.3 Commercial Building (CB)

The baseline solar system model simulated in the digital computer code is shown in Drawing SK 140096. As in the multifamily system, the collector area was optimized. The performance of the system was predicted for collector areas of 2484 ft<sup>2</sup> to 11250 ft<sup>2</sup>. The percentage of solar energy supplied to the building varies from 36 percent to 74 percent for the cases studied. Figure 5.5.3-1 shows the solar cost as a function of collector area for the commercial building. A minimum cost per million Btu's supplied occurs at a collector area of 5500 ft<sup>2</sup>.

Figure 5.5.2-1  
DOLLARS PER MILLION BTU'S OF SOLAR ENERGY  
VS.

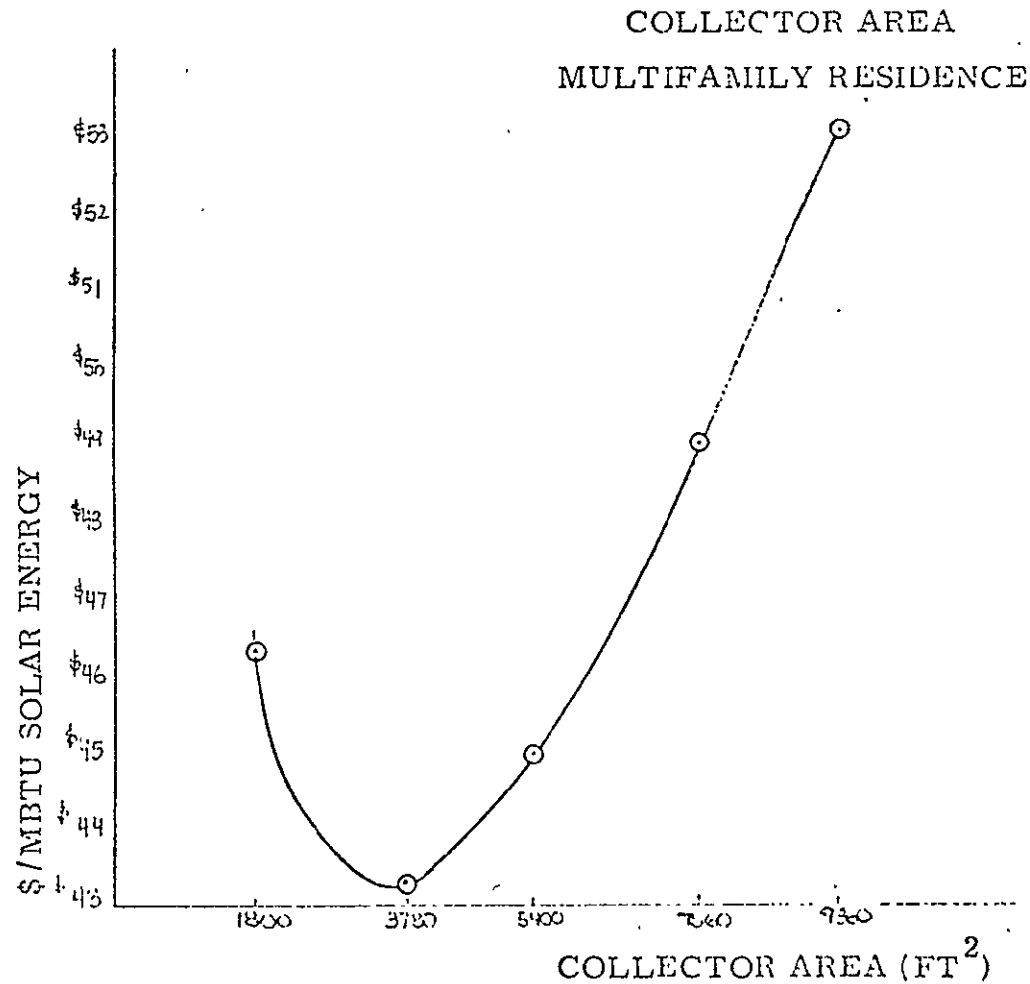


Figure 5.5.2-1

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Mpls., 1957

Collector Tilt: 55°

No storage loss

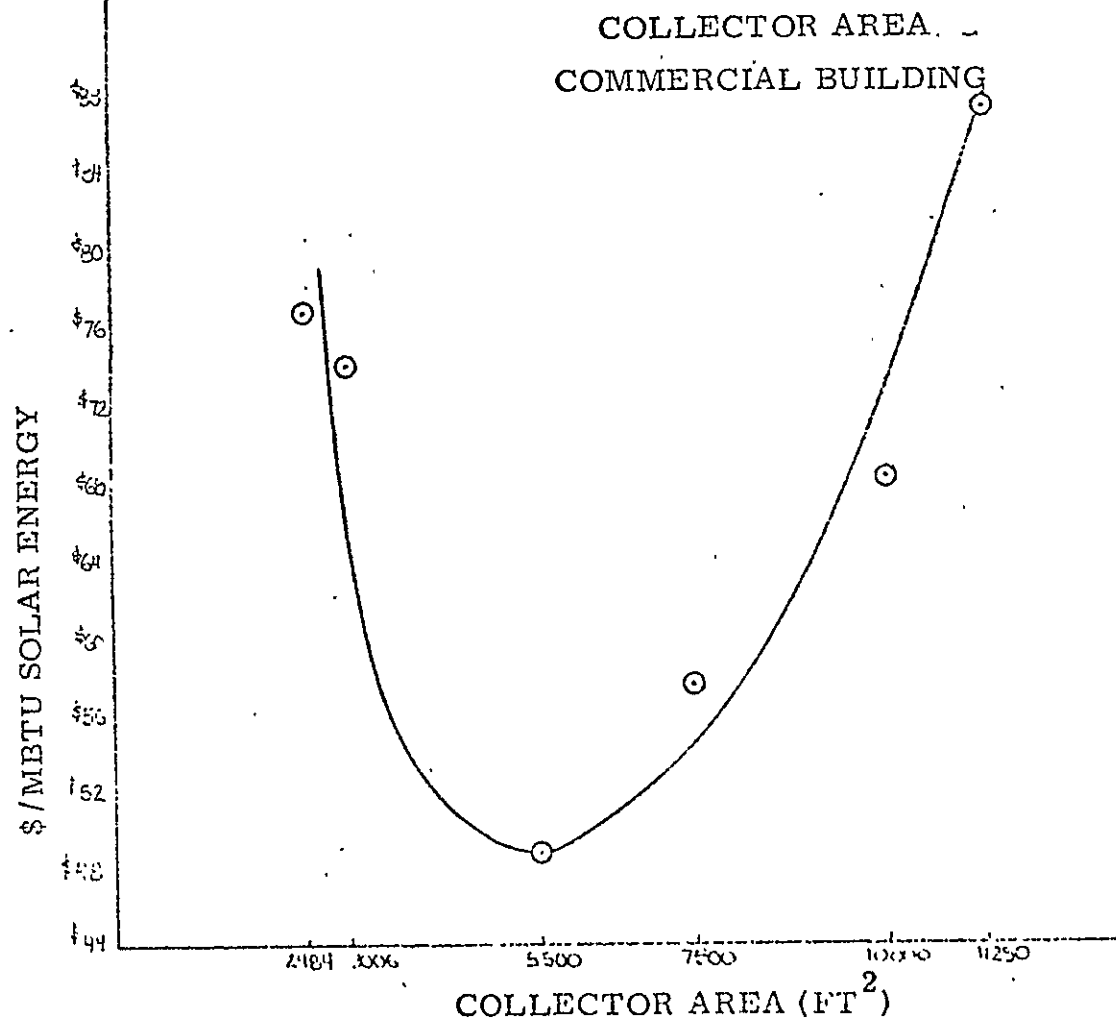
Amortization: 20 yrs @ 7%

Storage Tank: 1.5 gal/ft<sup>2</sup>  
of collector

2 Collector covers

2 Collectors in series

Figure 5.5.3-1  
DOLLARS PER MILLION BTU'S OF SOLAR ENERGY  
VS.



Mpls., 1957

Collector Tilt: 55°

No storage loss

Amortization: 20 yrs @ 7%

Storage Tank: 1.5 gal/ft<sup>2</sup> of Collector

1 Collector cover

2 Collectors in series

Figure 5.5.3-1

## 6.0 Recommended Design

### 6.1 Single Family Residence

The recommended solar assisted heating system for a single family residence is a hydronic-to-warm air system with domestic hot water preheat. The system consists of the following major components:

- 540 square feet flat plate collectors (1 cover)
- Collectors assembled in series-parallel network
- 1000 gallons storage (water)
- Warm air furnace with hot water coil unit

The performance of this system for a Minneapolis 1500 ft<sup>2</sup> house is shown in Figures 6.1-1 and 6.1-2. The space heating load for a typical year is  $106.6 \times 10^6$  Btu of which  $45.4 \times 10^6$  Btu or 42 percent is supplied by solar energy. The yearly service hot water load is  $3.4 \times 10^6$  Btu of which  $2 \times 10^6$  Btu or 60 percent is supplied by solar.

The operation of the pumps and furnace fan for the system consume 2358 KWH electricity. The auxiliary fuel cost for a gas furnace is \$153.

This system is applicable to new construction as well as retrofit buildings.

As an alternate, an oil furnace could be installed as an auxiliary. The cost of its operation, based on 40¢/gallon oil prices would be approximately \$218 per year. If an electric resistance furnace is installed, the auxiliary fuel costs per year would be about \$638 based on \$.0356/KWH.

A heat pump could also be used to supply the auxiliary energy. Assuming the air-to-air heat pump has a seasonal performance factor of 2.5, the auxiliary energy costs for heating would be \$255 per year.

# SELECTED SOLAR SYSTEM BTU's PER DAY AVERAGED OVER 30 DAYS

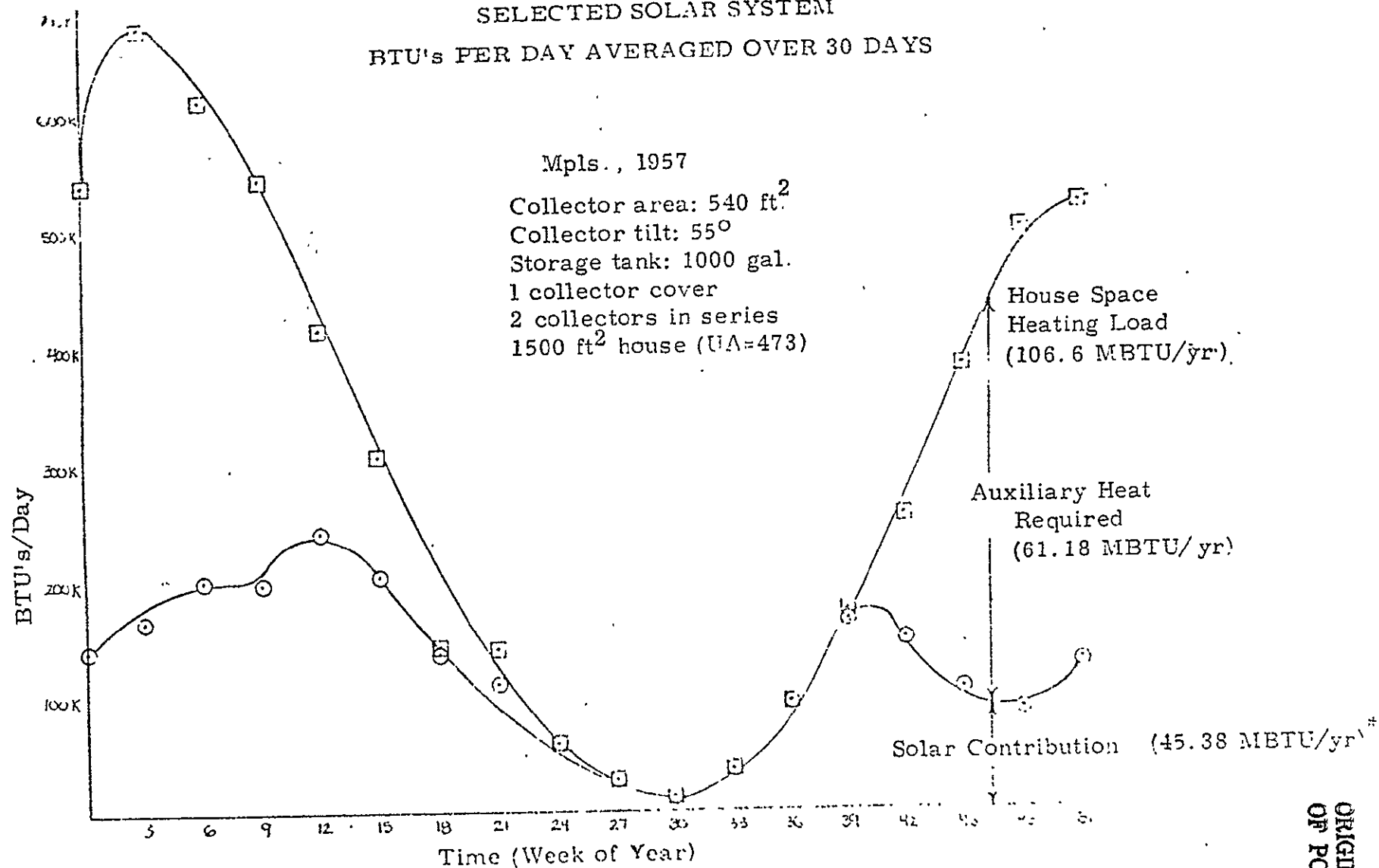


Figure 6.1-1

# SELECTED SOLAR SYSTEM BTU's PER DAY AVERAGED OVER 30 DAYS

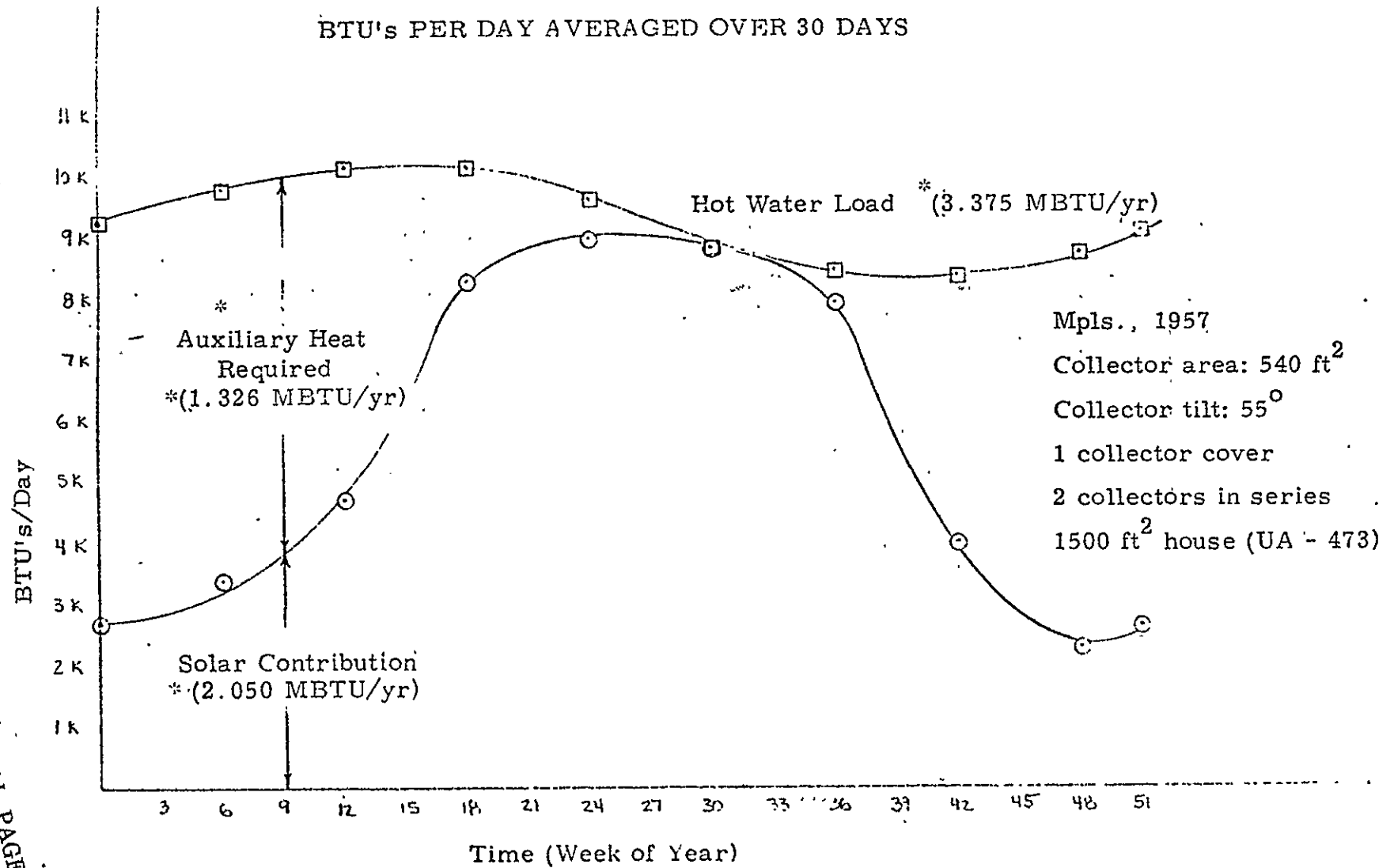


Figure 6.1-2



## 6.2 Multifamily Residence

The recommended solar assisted heating system for a multifamily residence is a hydronic-to-warm air system with domestic hot water preheat. The system consists of the following major components:

- o 3780 square feet flat plate collectors (1 cover)
- o Collectors assembled in series parallel network
- o Water storage ( $1.5 \text{ gallons/ft}^2$ )
- o Warm air furnace with hot water coil unit

The performance of this system for a Minneapolis multifamily residence is shown in Figures 6.2-1 and 6.2-2. The space heating load for a typical year is  $721.0 \times 10^6$  Btu of which  $339. \times 10^6$  Btu or 47 percent is supplied by solar energy. The yearly service hot water load is  $38. \times 10^6$  Btu of which  $23. \times 10^6$  Btu or 60 percent is supplied by solar.

The operation of the pumps and furnace fan for the system consume 29362 KWH electricity. The auxiliary fuel cost for a gas furnace is \$955 per year.

The system is applicable to new construction as well as retrofit buildings.

As an alternate, an oil furnace could be installed as an auxiliary. The cost of its operation, based on 40¢/gallon oil prices, would be approximately \$1364 per year. If an electric resistance furnace is installed, the auxiliary fuel costs per year would be about \$3989, based on \$.0356/KWH.

A heat pump could also be used to supply the auxiliary energy. Assuming the air-to-air heat pump has a seasonal performance factor of 2.5, the auxiliary energy costs for heating would be \$1595. per year.

### 6.3 Commercial Building

The recommended solar assisted heating system for a commercial building is a hydronic-to-warm air system with domestic hot water preheat. The system consists of the following major components:

- o 5500 square feet flat plate collectors (1 cover)
- o Collectors assembled in series parallel network
- o Water storage ( $1.5 \text{ gal/ft}^2_c$ )
- o Warm air furnace with hot water coil unit

The performance of this system for a commercial building in Minneapolis is shown in Figures 6.3-1 and 6.3-2. The space heating load for a typical year is  $438.0 \times 10^6$  Btu of which  $352. \times 10^6$  Btu or 80 percent is supplied by solar energy. The yearly service hot water load is  $46.3 \times 10^6$  Btu of which  $41.9 \times 10^6$  Btu or 90 percent is supplied by solar.

The operation of the pumps and furnace fan for the system consume 22007 KWH electricity. The auxiliary fuel cost for a gas boiler is \$215.

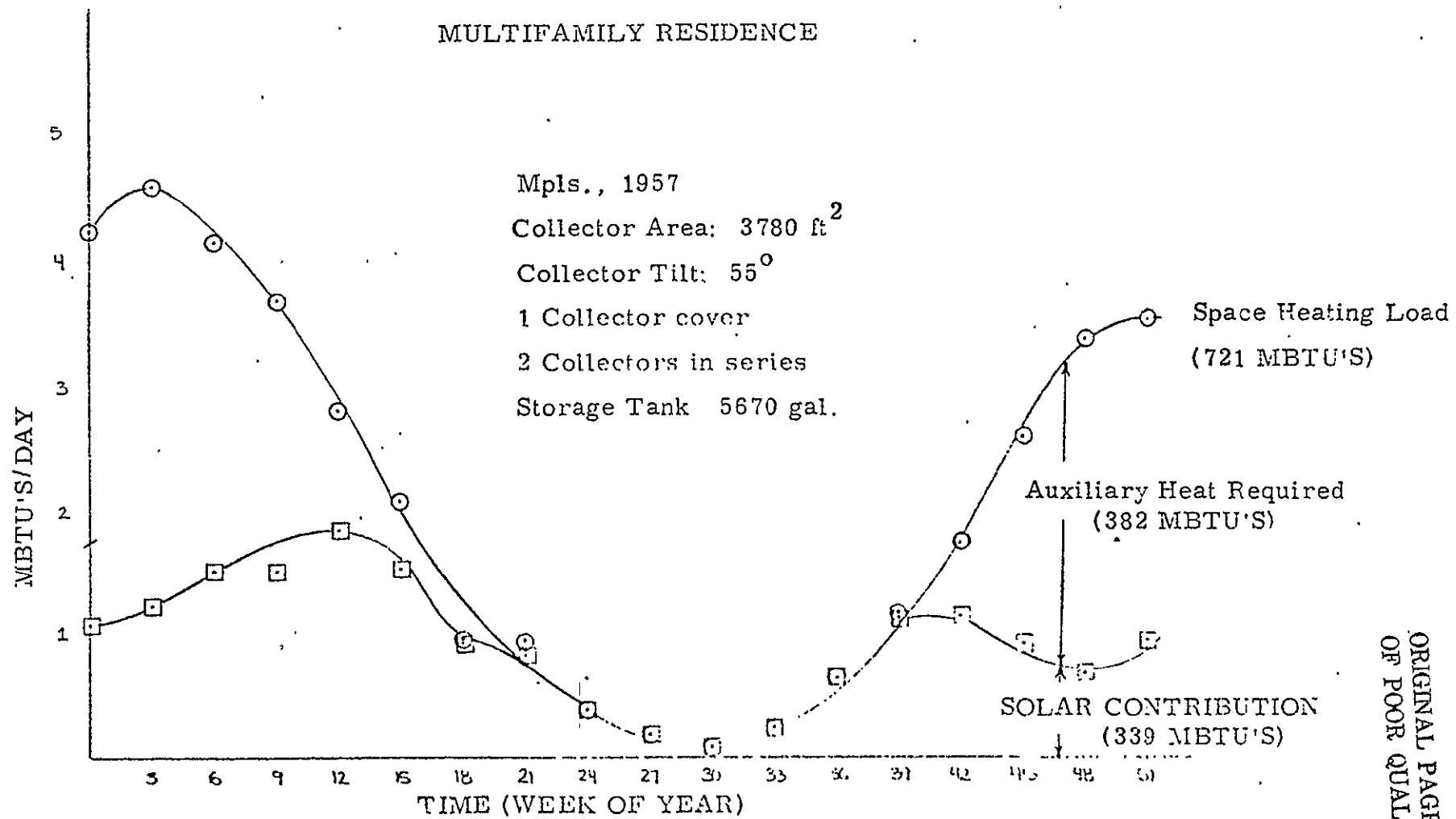
This system is applicable to new construction as well as retrofit buildings.

As an alternate, an oil furnace could be installed as an auxiliary. The cost of its operation, based on 40¢/gallon oil prices, would be approximately \$307 per year. If an electric resistance furnace is installed, the auxiliary fuel costs per year would be about \$899 based on \$.0356/KWH.

A heat pump could also be used to supply the auxiliary energy. Assuming the air-to-air heat pump has a seasonal performance factor of 2.5, the auxiliary energy costs for heating would be \$360 per year.

L-7

Figure 6.2-1  
SELECTED SOLAR SYSTEM  
BTU'S PER DAY AVERAGED OVER 30 DAYS  
MULTIFAMILY RESIDENCE



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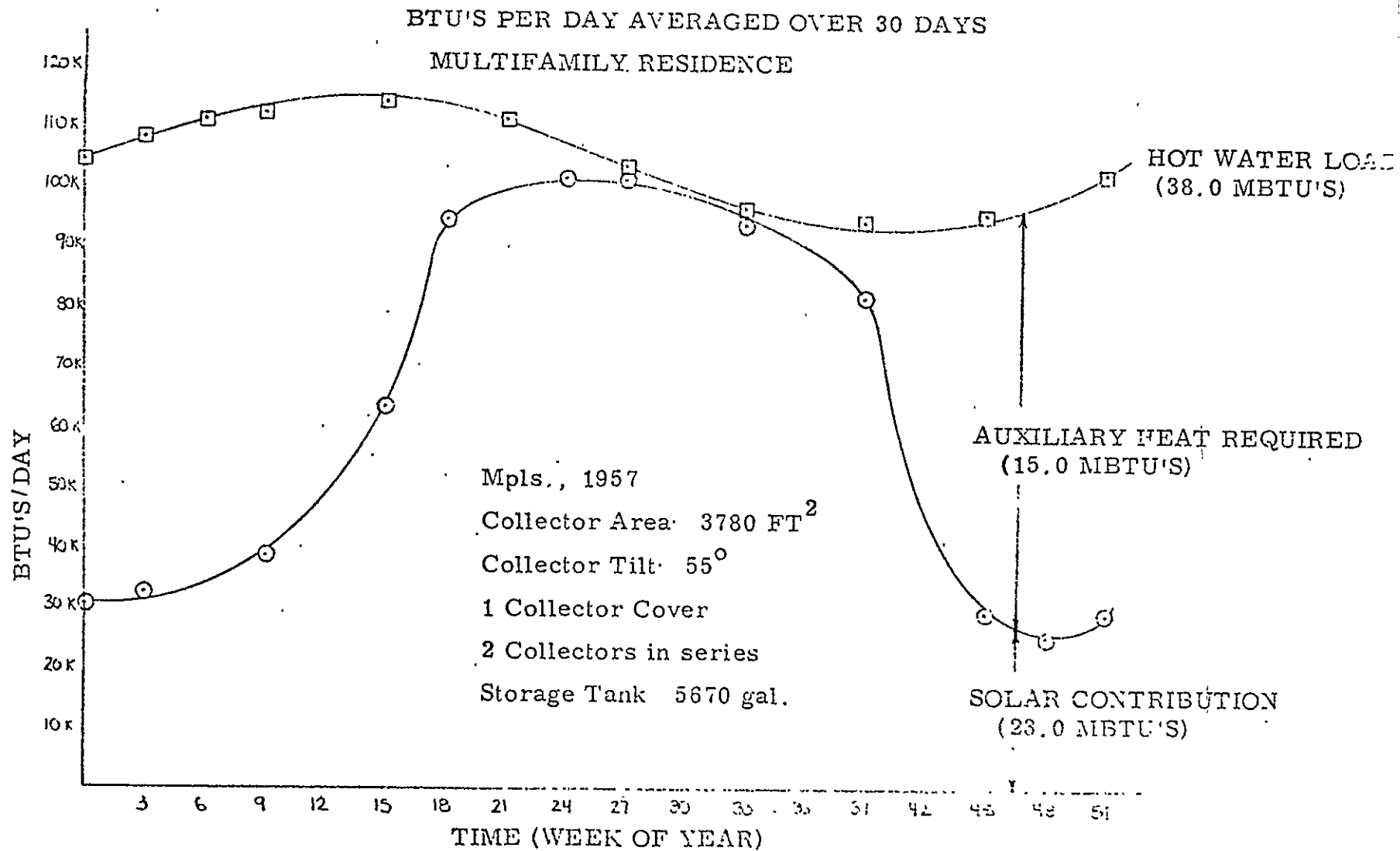
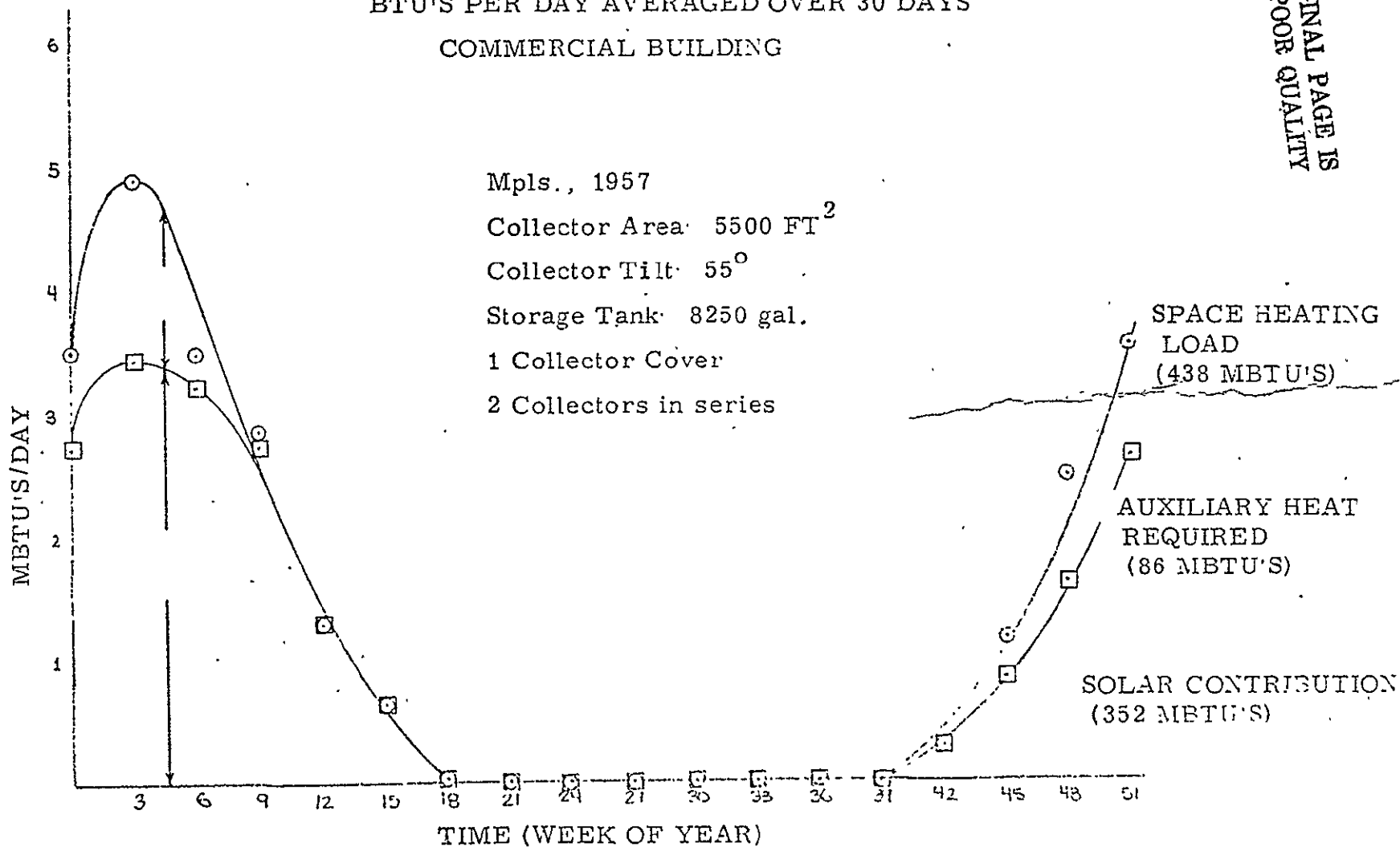
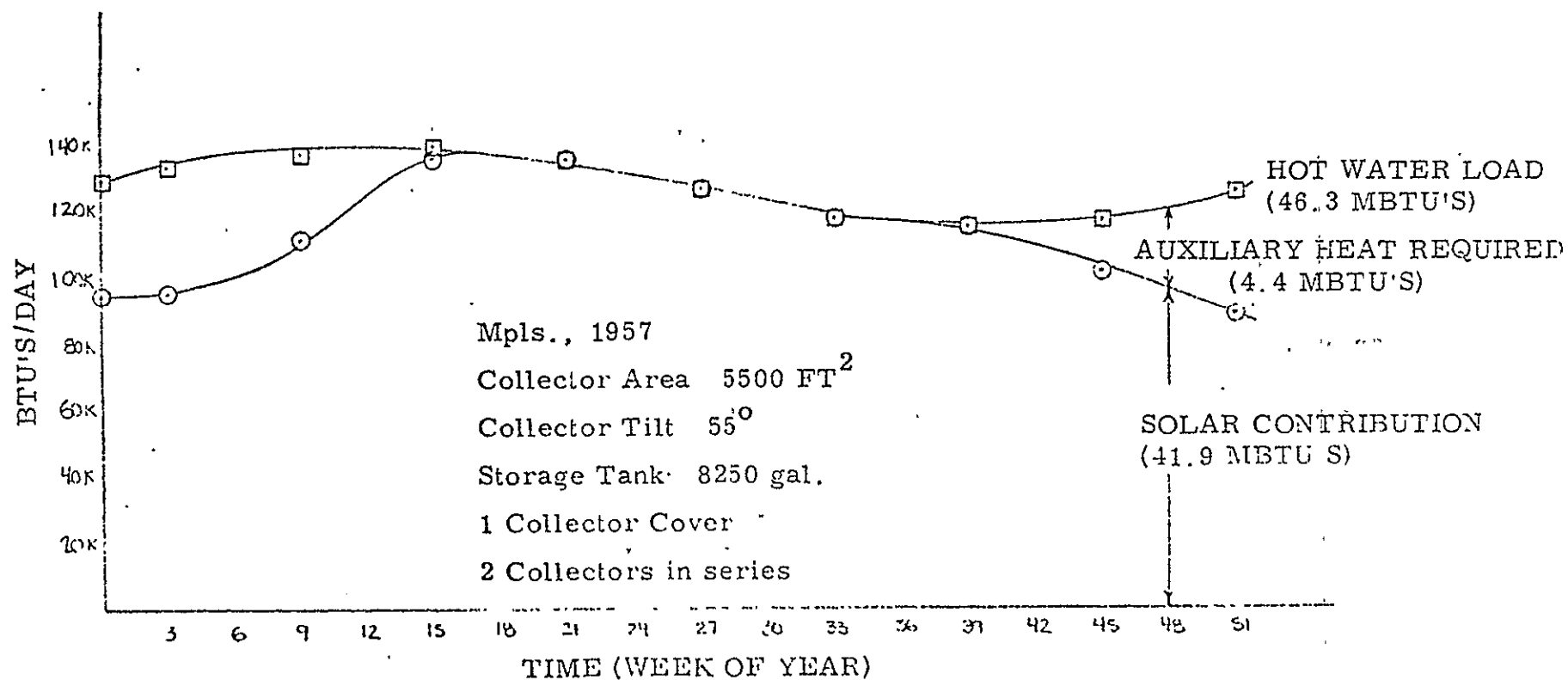


Figure 6.3-1  
 SELECTED SOLAR SYSTEM  
 BTU'S PER DAY AVERAGED OVER 30 DAYS  
 COMMERCIAL BUILDING



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SELECTED SOLAR SYSTEM  
BTU'S PER DAY AVERAGED OVER 30 DAYS  
COMMERCIAL BUILDING



## 7.0 Design and Development Approaches

### 7.1 Introduction

Honeywell's approach is to effectively sequence and combine technical efforts to provide the most cost effective prototype system within the schedule guidelines of the statement of work. We have incorporated, as much as possible, subsystems that are "standard" or already have been proven in similar system applications. This will expedite design maturity and keep system development costs low.

With the similarity of subsystems and the varied degrees of performance maturity, Honeywell has laid out a program that maximizes the effective combination of manufacturing development, qualification, and acceptance efforts. This combining and coordination of efforts is reflected in the overall program schedule which includes as parallel effort, the development of residential, multifamily and commercial systems.

The Development Plan (DR 500 Item 1) summarizes the approach, detailed plans for developing the subsystems and a plan for system installation and evaluation.

### 7.2 Detail Design Procedure

Following the selection of specific sites, the subsystem designs will be completed for each system. These detailed designs begin with a systematic study of the Interim Performance Criteria and codes and standards for application to the particular subsystem being designed. Next, the particular design tasks which assure compliance with the criteria are completed. Consideration during design is given to modularity, retrofit versus new construction, utilization of off-the-shelf components and designing for a

wide variety of subsystem sizes. Upon completion of the subsystem designs and the subsystem integration tasks, the heating systems will be complete to the extent that the drawings and specifications will form a completed design package.

### 7.3 Interim Performance Criteria and Standards

The Interim Performance Criteria for solar heating and combined heating/cooling were developed to provide a baseline design criteria for the large number of solar applications being developed at the present time. These criteria will be used to:

- Assure minimum levels of health and safety consistent with similar standards for conventional systems.
- Ensure consistent performance over time.
- Verify that design performance levels will be met.
- Ascertain that systems will be durable, reliable, maintainable and conform to good engineering practice.

The IPC will not be used to take the place of existing standards of good engineering practice or to supplant local or national codes or test and material specifications. The IPC will be used as a framework for applying these codes and standards to solar system design.

Honeywell has used the framework provided by the IPC to consolidate the design standards shown in Table 7-1 to be used in developing solar systems.

Good engineering practice will be guided by the extensive ASHRAE Handbooks. The Handbook of Fundamentals will be used for guidance in material data, psychrometrics, weather data and methodology of heat load calculations. The Systems Handbook can be utilized for design information



Table 7-1

## APPLICABLE DESIGN STANDARDS AND SYMBOLOGY

Reference	Application
ASHRAE Handbook, Fundamentals, 1972	System Performance
ASHRAE Handbook, Systems, 1973	(H, HC)
ASHRAE Handbook, Applications, 1974	
ASIRAE Equipment Guide and Data Book, 1972	System Performance (DIW)
National Plumbing Code, ASA, A40.8	Plumbing
HUD Minimum Property Standards	Residential System Installation and Structural
4900.1 Single Family	
4910.1 Multi Family	
4930.1 Acceptable Practices	
ANSI A58.1 1972 Building Code Requirements for Minimum Design Loads in Buildings and other Structures	Commercial Structural
Uniform Building Code, International Conference of Building Officials, 1973	Structural
NBS, Building Science Series 23, 1969	Hail Resistance
NFPA, National Electric Code	Electrical Installation
NFPA No. 89 M	
NFPA No. 90 B	Installation
NFPA No. 211	Fire Standards
NFPA No. 54	
NFPA No. 101	
Public Health Service Drinking Water Standards, HEW, 1962	HW Subsystem

on ducting systems, hydronic system principles, water heaters, heat pumps and systems testing while Applications Handbook can provide solar system guidelines.

The mandatory codes which will be studied and utilized fall into three categories. First the structural codes which dictate structural form and integrity. An example is the HUD Minimum Property Standards which is applicable to Residential and Multifamily installations and deals with structural and aesthetic values. It is primarily applicable to roof mounted collectors. The Uniform Building Code is more detailed in mechanical installations and is applicable to both Residential and Commercial structures. The second category of codes covers the installation of mechanical systems. Two examples are the National Electric Code and the National Plumbing Code. The NFPA National Electric Code has gained national acceptance at this time. In 1975, it became an ANSI standard, ANSI C1 - 1975 and it will be used in all installation designs. The National Plumbing Code, on the other hand, has not gained universal acceptance. The closest thing to a national code is the American Standards Association ASA A40.8 Code sponsored by ASME. Accordingly, ASA A40.8 will be used as a guide but local codes peculiar to the site selected will also be checked for compliance.

A third category of codes are the health and safety codes. The National Fire Protection Association has a number of codes influencing the design of hot water heaters, auxiliary heating, high temperature solar equipment, electric motors and controls. In addition, the integrity of potable water will be protected. The guidelines for potable water standards will be taken from HEW Department of Public Health.

As opposed to mandatory controls, there will be the need to draw on standards that affect material selection for the purposes of efficient selection. It is expected that extensive use will be made of material specifications developed by the American Society of Testing of Materials. These same sources will be used whenever appropriate to design tests of materials and components for the sake of standardization. Where appropriate standard tests do not exist, test procedures will be developed.

#### 7.4 Design Procedures - Collector Subsystem

The collector subsystem is an example of the design procedures to be used on subsystem design and/or development. This product is presently being manufactured by Lennox Industries and is considered developed to the prototype level. However, collector qualification was not complete. A study of applicable IPC was made of those tasks already accomplished to determine what parameters of the solar collector had been sufficiently investigated already. In the case of the collector, the development activity fell into two main areas: function and mechanical configuration.

During collector development, much effort was expended to design a highly efficient collector. Selective coatings and glass transmittance were investigated thoroughly. Therefore, it was determined that the efficiency of collection was a fixed design characteristic at the beginning of qualification and that efficiency of a newly produced collector was not a relevant qualification criteria. At the same time, however, it was apparent that the affect on efficiency of environmental exposure over time had not been sufficiently investigated so efficiency degradation was determined to be a qualification criteria.

The mechanical configuration of the collector was investigated during development yielding a design that permitted easy integration with the structure and a long service life. One element of the mechanical configuration which was not verified during development was exposure to mechanical loads inherent in a structural application.

The result of reviewing the work done during development was a determination that the following tests needed to be conducted to complete qualifications of the collector:

Degradation due to:

Solar Exposure

Pollutants

Thermal Exposure

Outgassing

Mechanical loads due to:

Internal Pressure

Roof Loads

Hail

After determination of the parameters to be tested, an investigation was made to find or develop suitable test techniques. Wherever feasible, the approach was to make use of existing standard test techniques. Toward this end, the Interim Performance Criteria was used as a baseline to standardize the tests. Referenced test standards were used whenever practical. This approach resulted in a series of tests set out in the following paragraphs.

Efficiency tests which will establish a baseline for determining the extent of any degradation due to environmental exposure were designed around a solar simulator. This was done to permit control and consistency of solar flux which is the most important variable in the test. There is not a standard acceptable test for testing with a solar simulator. The standard test sponsored by the National Bureau of Standards is based on natural sunlight for flux. Because of this, a new procedure was developed using the methodology of the NBS, but substituting the solar simulator for a flux source.

The effects of internal pressure is accomplished by a simple hydrostatic test of the collector pressurized to 150 percent of its rated pressure.

The effect of normal roof loads will be done by determining a uniform load criteria based on standards contained in the HUD Minimum Property Standards. This criteria will be demonstrated by uniformly placing sandbags on the normally supported collector.

The effect of hail on roofing materials is determined by an NBS specification involving propelling a spherical ice ball into the material using a compressed air gun. This procedure will be used without deviation. Collector glass will be considered a roofing material.

The effect of solar flux over an extended time period will be tested in accordance with one of the options in the IPC. Namely, a six month exposure in an area near Phoenix, Arizona where the mean daily solar flux exceeds 500 Langleys. The efficiency of the collector will be measured before and after this exposure to determine if any degradation has occurred.

The effect of airborne pollutants will be determined by exposing coupon specimens of collector parts to ozone, salt, sulfurous acid, hydrochloric acid, and nitric acid. The exposure will be in accordance with IPC standards and any degradation will be determined by using ASTM materials examination techniques.

The effect of the thermal environment will similarly be done using coupon specimens exposed to temperature extremes in environmental chambers. Examination of the coupons will be in accordance with ASTM procedures.

Outgassing of collector insulation will cause a degradation of transmittance of the collector glass. This will be tested by measuring transmittance by ASTM methods both before and after exposure to solar flux.

Upon completion of these qualification tests, the collector should meet all applicable IPC and standards. Details of the application IPC and the qualification tests procedures are contained in the Verification Plan (DR 500 Item 2) and the Qualification Tests for Collector Subsystem (DR 500 Item 13).

In addition, it was recognized that the collectors are modular, suitable for retrofit or new construction and can be combined to provide any subsystem size. It was also recognized that a study of possible flow configurations for various collector arrays should be studied. Of concern is the possibility of non-uniform flow in the collector arrays which can lead to serious degradation of performance. A simulation program was developed from which guidelines will be established for the number and methods of collector arrangements on the supply and return headers in an array. The results of this study will be presented at the Preliminary Design Review.

## 8.0 Special Data for Heating Systems Preliminary Design Review

This section contains the information requested by Appendix B para 4.1.3 d, e, g and h that is to be included with the data submitted two weeks prior to the Preliminary Design Review.

It includes:

- 8.1 Hazard Analysis
- 8.2 Drawing List
- 8.3 Type I and II Documents
- 8.4 Prototype Design Review Data Recommendations
- 8.5 Site Data Acquisition System Schedule
- 8.6 Symbols

## 8.1 Hazard Analysis

This section consists of a copy of the Hazard Analysis submitted 9 September 1976. This preliminary analysis will be updated at the Prototype Design Review.



Document F3437-P-103

9 September, 1976

HEATING SYSTEMS  
HAZARD ANALYSIS

DR500 Item 18  
Contract NAS8-32093

Honeywell Inc.  
Energy Resources Center  
2600 Ridgway Parkway N. E.  
Minneapolis, Minnesota 44513

Document F3437-P-103

9 September, 1976

HEATING SYSTEMS  
HAZARD ANALYSIS

DR500 Item 18

Signatures		Date
Prepared by	<i>Allen P. Baldwin</i>	<i>Aug 25, 1976</i>
Approved by	<i>W. H. Merrill</i>	<i>Aug 25, 1976</i>
	<i>W. H. D. Koppert</i>	<i>Aug 26, 1976</i>
Reviewed by	<i>John C. Kimball</i>	<i>Aug 27, 1976</i>

Revisions			
Test	Description	Date	Approval

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## CONTENTS

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2.0	DICTIONARY	8-6
3.0	IDENTIFICATION AND CONTROL OF HAZARDS	8-8
4.0	RATIONALE FOR CORRECTIVE ACTION	8-8

## 1.0 INTRODUCTION

This document has a twofold purpose:

- To identify and categorize actual or potential hazards or hazardous conditions in single-family, multiple-family, and commercial solar heating systems.
- To identify, rationalize, and document measures to eliminate or mitigate these hazards.

These precautionary activities will continue through system development, and this document will be revised as necessary to ensure its completeness prior to the heating systems Prototype Design Review. All revisions will be approved by the program manager and will be recorded in the revision log.

## 2.0 DICTIONARY

Hazard - A hazard is any actual or potential condition that could cause injury or death to persons, or damage to or loss of equipment or property.

Hazard Level - A qualitative categorization of hazards in terms of potential consequences.

The following hazard levels which pertain in this program result from conditions such that user error, environment, design characteristics, procedural deficiencies, or component or subsystem failure could cause these types of damage:

Category I - Negligible - Will not result in injury to persons or damage to the system.

Category II - Marginal - Can, if not controlled, result in minor injury to persons or damage to equipment or structures.

Category III - Critical - Can if not controlled, result in serious injury to persons or major damage to equipment or structures.

Category IV - Catastrophic - Can, if not controlled cause death to persons or destruction of equipment or structures.

Hazard Control - Actions that eliminate or mitigate hazards. The hazard control techniques below are in descending order of preference. The highest level of practical action will be taken in a given case, with the goal in all cases being to reduce the hazard to the Category I level, or below, i.e., minimize it even further.

- (1) Design for Minimum Hazard - The major effort during the design phases will be directed toward selecting appropriate design safety features, e.g., failsafe, redundancy.
- (2) Safety Devices - Known hazards that cannot be eliminated from the design will be reduced to an acceptable level through use of appropriate safety devices.
- (3) Warning Devices - When it is not practical to preclude the existence or occurrence of an identified hazard, a device that will detect it and provide timely warning will be used.
- (4) Special Procedures - When none of the above is feasible, special operating procedures will be developed to reduce the hazards.

### 3.0 IDENTIFICATION AND CONTROL OF HAZARDS

This process will, as stated, be continuous during system development, with the goal being to reduce all hazards to the Category I level or below.

Table 1 is a list of identified hazards, the levels to which they are hazards, elements exposed to them [persons (p), equipment (e), and structures (s)], and corrective actions to eliminate or minimize them.

### 4.0 RATIONALE FOR CORRECTIVE ACTION

Class (2), (3) and (4) corrective actions leave residual hazard potential associated with failure of a safety device, failure of or failure to heed a warning device, or failure to follow procedures properly. The rationale for accepting this residual hazard rather than striving for a fail-safe design in all of its aspects is set forth below.

(Will be provided in a future revision).

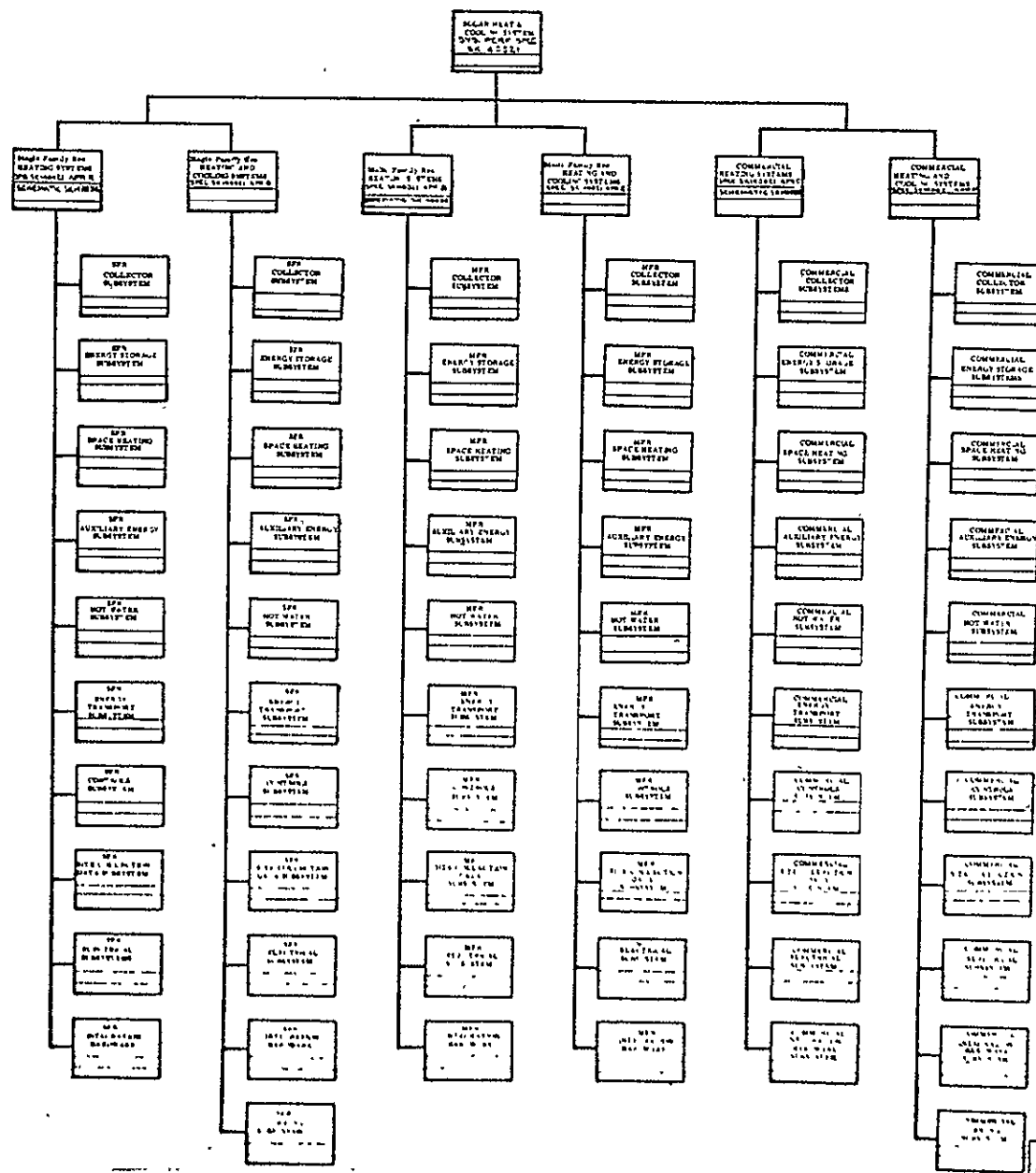
Table 1. Hazards and Corrective Action

Source of Hazard	Level	Exposure	Corrective Action	
			Type	Description
Plumbing defects	III	p, e, s	(1)	Design to Code
Electrical defects	IV	p, e, s	(1)	Design to Code
<u>Controls</u>				
Excessive temperatures	II	e, s	(Will be provided in a future revision)	
Excessive pressures	II	p, e		
<u>Line</u>				
Increased fire hazard due to solar systems	IV	p, e, s		
Reduced building fire resistance due to installation	IV	p, e, s		
<u>Toxic and Flammable Fluids</u>				
Drainage of overflow	IV	p		
	II	s		
Undetected leaks	IV	p		
	II	s		
<u>Emergency Conditions</u>				
Blocked emergency exits	IV	p		
Blocked emergency access	IV	e, s		
Inconspicuous/in-accessible controls	III	e, s		
<u>Protection of Water and Air</u>				
Contamination of potable water	IV	p		
<u>Excessive Surface Temperatures</u>				
Personnel burns	II	p		
<u>Facility and Site</u>				
Falling snow and ice	III	p		

## 8.2 Drawing List

The attached chart outlines the drawings required to define each of heating and heating/cooling systems. To date, only top level schematics and a reference to the appropriate appendix of the System Specification SK 140021 are shown as being completed. As the site specific design is accomplished - an installation drawing will be created and identified for each system and assembly drawings prepared for each subsystem.





### 8.3 Type I and II Documents

The following Type I or Type II documents have been submitted and are expected to be approved at the Preliminary Design Review.

1. Heating Systems Development Plan -- F3437-P-101
2. Heating Systems Verification Plan -- F3437-P-102
3. Qualification Tests for Collector Subsystem -- F3437-T-101
4. Safety and Health Plan --
5. New Technology Reporting Plan -- F3437-P-104
6. Work Breakdown Structure and Dictionary -- F3437-A-101

Several copies of the above were submitted and so no additional copies are now submitted. If MSFC desires additional copies, Honeywell will forward them.

The following Type II documents will be available at the Preliminary Design Review.

1. Quality Assurance Plan -- F3437-Q-101

#### 8.4 Prototype Design Review Data

The data Honeywell recommends to be used to accomplish the Prototype Design Review is as follows:

- System Specifications for SF, MF, and Commercial
- Installation drawings for each site
- System top assembly drawing or bill of material with site specific callouts
- Subsystem assembly drawing or bill of material with site specific callouts
- Procurement Specifications
- Verification data and status summary
- Final Hazard Analysis
- List of special handling, installation and maintenance tools
- Review of support philosophy and spare parts requirements
- Proposed format and outlines for installation, operation and maintenance manuals
- Other Type I, II and III documentation
- Results of analysis and trade-off studies

## 8.5 Site Data Acquisition Subsystem Schedule

The sensors furnished by MSFC as part of the Site Data Acquisition Subsystem will be required for the Heating Subsystems as listed below. These dates are based on the key assumption that the site ready date and the contractual delivery date of 11/15/77 are approximately coincident. Any significant change in this relationship will alter these dates. HI assumes the balance of the data Acquisition Subsystem to be available (on-site) at site ready date.

<u>Subsystem</u>	<u>Sensor Need Date</u>
Single Family Residential	19 May 1977
Multi Family Residential	19 May 1977
Commercial Applications	24 May 1977

## Section 8.6            Symbology -

Honeywell is planning to utilize the ASHRAE abbreviations and symbols as the basis for the HI standard for abbreviations and symbols. A copy of the ASHRAE standards is included herein for completeness, i. e., Chapter 28 of Handbook of Fundamentals

## CHAPTER 28

# ABBREVIATIONS AND SYMBOLS

*Standard Abbreviations, Letter Symbols, Graphical Symbols for Piping, Ductwork, Heating and Ventilating, Refrigerating, Identification of Piping by Color*

**T**HIS chapter contains information regarding abbreviations and symbols which are of particular interest to the engineer engaged in heating, ventilating, refrigerating, and air conditioning.

### ABBREVIATIONS FOR TEXT AND DRAWINGS

Abbreviations are shortened forms of names and expressions employed in texts and tabulations, and should not generally be used as symbols in equations. Most of the following abbreviations have been compiled from a list of approved standards.<sup>1,2,3</sup> In general, the period has been omitted in all abbreviations, except where the omission results in the formation of an English word.

Term	Text	Drawings
absolute.....	abs	ABS
accumulator.....	...	ACCUM
adapter.....	...	ADPT
agitator.....	...	AGTR
air circuit breaker.....	...	ACB
air condition (-ing, -ed, -er).....	...	AIR COND
air horsepower.....	ahp	AHP
alarm.....	...	ALM
alteration.....	...	ALTN
alternating current.....	ac	AC
altitude.....	alt	ALT
ambient.....	amb	AMB
American Standard.....	Amer Std	AMER STD
American wire gage.....	AWG	AWG
ampere.....	amp	AMP
ampere-hour.....	amp-hr	AMP-HR
anhydrous.....	...	ANHYD
Angstrom unit.....	A	A
apparatus dew point.....	adp	ADP
apartment.....	...	APT
approved.....	...	APPD
approximate.....	approx	APPROX
arc weld.....	...	ARC/W
atmosphere.....	atm	ATM
automatic.....	...	AUTO
automatic check valve.....	...	ACV
average.....	avg	AVG
avoidupois.....	avdp	AVDP
barometer.....	baro	BARO
barrel.....	bbl	BBL
basement.....	...	BSMT
Baume.....	Be	BE
bill of material.....	...	B/M

The general responsibility for this chapter is assigned to TC 1.10, Definitions and Nomenclature.

Term	Text	Drawings
boiler.....	...	BLR
boiling point.....	bp	BP
brake horsepower.....	bhp	BHP
brake horsepower-hour.....	bhp-hr	BHP-HR
British thermal unit(s).....	Btu	BTU
British thermal unit <sup>1</sup> per hour.....	Btuh	BTUH
British thermal unit <sup>2</sup> per hour (thousands).....	MBh	MBH
Brown & Sharpe wire gage.....	B&S	B&S
bushel.....	bu	...
B-X cable.....	...	BX
calorie.....	cal	CAL
center-to-center.....	c to c	C to C
centigrade heat unit.....	chu	...
centigram.....	cg	CG
centimeter.....	cm	CM
centimeter-gram-second (system)...	cgs	CGS
check valve.....	...	CV
clockwise.....	...	CW
condenser.....	...	COND
corporation.....	...	CORP
counterclockwise.....	...	CCW
cubic.....	cu	CU
cubic centimeter.....	cc	CC
cubic feet per minute.....	cfm	CFM
cubic feet per second.....	cfs	CFS
cubic foot.....	cu ft	CU FT
cubic inch.....	cu in.	CU IN.
cylinder.....	cyl	CYL
decibel.....	db	DB
degree <sup>4</sup> .....	deg or °	DEG or °
degree Centigrade.....	C	C
degree Fahrenheit.....	F	F
degree Kelvin.....	K	K
degree Rankine.....	R	R
dew point temperature.....	dpt	DPT
diameter.....	dia	D.A
direct connected.....	...	D R-CONN
direct current.....	dc	DC
discharge.....	...	DISCH
dry-bulb temperature.....	dbt	DBT

<sup>1</sup> Abbreviations for Scientific and Engineering Terms, Z10.1-1941 (American National Standards Institute).

<sup>2</sup> Abbreviations for Use on Drawings, Z32.13-1950 (American National Standards Institute).

<sup>3</sup> Refrigeration Nomenclature for Text and Drawings, (Proposed American Standard B33, Part B) (Published in *Refrigerating Engineering*, August 1949, p. 770).

<sup>4</sup> It is recommended that the abbreviation for the temperature scale, F. C. K. R., be included in expressions for numerical temperatures but, whenever feasible, the abbreviation for degree be omitted e.g., 68 F.

Term	Text	Drawings
economizer.....	...	ECON
effective horsepower.....	...	EHP
efficiency.....	eff	EFF
electromotive force.....	emf	EMF
equivalent direct radiation.....	edr	EDR
evaporat(e) (-ing, -ed, -or).....	...	EVAP
expansion valve.....	...	EXP VLV
face-to-face.....	f to f	F to F
factor of safety.....	...	F/S
feet per minute.....	fpn	FPM
feet per second.....	fps	FPS
foot.....	ft	FT
foot-pound.....	ft lb	FT LB
foot-pound-second (system).....	fps	FPS
freezing point.....	fp	FP
gage or gauge.....	ga	GA
gallon.....	gal	GAL
gallons per hour.....	gph	GPH
gallons per minute.....	gpm	GPM
gallons per second.....	gps	GPS
grain.....	spell out	...
gram-calorie.....	gcal	GCAL
higher heating value.....	HHV	...
horsepower.....	hp	HP
horsepower-hour.....	hp hr	HPHR
hour.....	hr	HR
inch.....	in.	IN.
inch-pound.....	in.-lb	IN.-LB
indicated horsepower.....	ihp	IHP
indicated horsepower-hour.....	ihph	IHPH
inside diameter.....	ID	ID
iron-pipe size.....	ips	IPS
kilocalorie.....	kcal	...
kilogram.....	kg	KG
kilowatt.....	kw	KW
kilowatt hour.....	kwh	KWH
linear feet.....	lin ft	...
liquid.....	liq	LIQ
logarithm (natural).....	log <sub>e</sub>	...
logarithm (to base 10).....	log <sub>10</sub>	...
lower heating value.....	LHV	...
maintenance.....	...	MAINT
male and female.....	...	M&F
mass.....	mass	MASS
maximum.....	max	MAX
mean effective.....	mep	MEP
melting point.....	mp	MP
meter.....	m	M
meters per second.....	mps	MPS
micron.....	...	U(MU)
miles per hour.....	mph	MPH
milinches.....	mi	MI
millimeter.....	mm	MM
minute.....	min	MIN
minimum.....	min	MIN
molecular weight.....	mol wt	MOL WT
mol.....	mol	MOL
National Electrical Code.....	...	NEC
number.....	no.	NO.
ounce.....	oz	OZ
outside diameter.....	OD	OD
parts per million.....	ppm	PPM
pound.....	lb	LB
pounds per square foot.....	psf	PSF
pounds per square foot absolute.....	psfa	PSFA
pounds per square foot gage.....	psfg	PSFG
pounds per square inch.....	pai	PSI

Term	Text	Drawings
pounds per square inch absolute.....	psia	PSIA
pounds per square inch gage.....	psig	PSIG
pneumatic.....	...	PNEU
pressure.....	press.	PRESS.
pressure reducing valve.....	...	PRV
quart.....	qt	QT
receiver.....	...	REC
recirculate(d).....	...	RECIRC
relative humidity.....	rh	RH
required.....	...	REQD
revolution.....	...	REV
revolutions per minute.....	rpm	RPM
revolutions per second.....	rps	RPS
Saybolt seconds Furlö (oil viscosity).....	SSF	SSF
Saybolt seconds Universal (oil viscosity).....	SSU	SSU
second.....	sec	SEC
shaft horsepower.....	shp	SHP
specification.....	...	SPEC
specific gravity.....	sp gr	SP GR
specific heat.....	sp ht	SP HT
square.....	sq	SQ
square foot.....	sq ft	...
square inch.....	sq in.	...
standard.....	std	STD
suction.....	...	SUCT
temperature.....	temp	TEMP
thermostat.....	...	THERMO
thousand.....	M	M
ton.....	spell out	...
thousand cubic feet.....	Mcf	MCF
ton of refrigeration.....	tr	TR
United States Gage.....	USG	USG
United States Standard.....	USS	USS
vacuum.....	...	VAC
valve.....	...	V
vapor proof.....	...	VAP PRF
velocity.....	vel	VEL
viscosity.....	visc	VISC
volume.....	...	VOL
watt.....	w	W
watthour.....	whr	WHR
wet-bulb temperature.....	wbt	WBT
year.....	yr	YR

LETTER SYMBOLS<sup>1,2</sup>

1. *Letter Symbol.* A letter symbol is a single character, such as *t* for temperature, with subscript or superscript if required, such as *t'* for temperature of saturated liquid, used to designate a physical magnitude in mathematical equations and expressions. Two or more symbols together always represent a product.

Letter symbols are to be distinguished from abbreviations, mathematical signs and operators, graphical symbols and chemical symbols.

2. *The Same Symbols* should be used for the same physical magnitude regardless of the units employed and regardless of special values occurring for different states, points, parts, times, etc. Units or special values may be distinguished when necessary by subscripts, superscripts, or by upper- and lower-

<sup>1</sup> Letter Symbols for Quantities used in Mechanics of Solid Bodies, Y10.3-1968, and Letter Symbols for Heat and Thermodynamics, Y10.4-1957 (American National Standards Institute).

<sup>2</sup> Refrigeration Nomenclature for Text Drawings (Proposed American Standard B53, Part C) (Published in *Refrigerating Engineering*, September 1951, p. 876).

case letters when both are specifically included as symbols in a standard list. The units used should be indicated when necessary. Sometimes different symbols are used for the components of a vector.

3. *Subscript.* A subscript preferably should be a single character. It is commonly employed to indicate constancy of a particular physical magnitude, such as pressure or temperature, when there are other variables. A multiple subscript, sometimes divided by a comma, refers to more than one state, point, part, time, etc. A subscript should not be attached to a subscript.

4. *Superscript.* A symbol with a superscript, such as a prime (') or a second (''), should be enclosed in parentheses, braces, or brackets before affixing an exponent—e.g.—(D')<sup>2</sup>. A complicated exponent (or any other expression frequently repeated) may be replaced by a single symbol selected to represent it. Reference marks should not be attached to symbols.

5. *Unlisted Magnitudes.* To symbolize a special value of a listed magnitude, see Item 4. The symbol chosen by an author for a physical magnitude not appearing in any standard list should be one that does not already have a different meaning in the field of the text.

6. When standard symbols in related fields are needed, reference to ANSI standards is recommended:

Letter Symbols for Heat and Thermodynamics, ANSI Y10-1957

Letter Symbols for Hydraulics, ANSI Y10.2-1958

Letter Symbols for Chemical Engineering, ANSI Y10.12-1955

Letter Symbols for Quantities used in Mechanics of Solid Bodies, ANSI Z10.3-1918

Letter Symbols for Physics, ANSI Z10.6-1948

Additional symbols and variations in the standard symbols found necessary in the individual chapters will be found in lists at the end of Chapters 1, 2, 3, 4, 5, and 22.

## LETTER SYMBOLS

Symbol	Description of item	Typical units
<i>A</i>	area	sq ft
<i>b</i>	breadth or width	ft
<i>B</i>	barometric pressure	psia or in. Hg
<i>c</i>	concentration	lb per cu ft, mole per cu ft
<i>c<sub>p</sub></i>	specific heat	Btu per (lb) (F)
<i>c<sub>p</sub></i>	specific heat at constant pressure	Btu per (lb) (F)
<i>c<sub>v</sub></i>	specific heat at constant volume	Btu per (lb) (F)
<i>C</i>	coefficient	—
<i>C</i>	thermal conductance	Btu per (hr) (sq ft) (F), or Btu per (hr) (F)
<i>C</i>	fluid capacity rate	Btu per (hr) (F)
<i>C<sub>L</sub></i>	loss coefficient	—
<i>C<sub>p</sub></i>	coefficient of performance	—
<i>d</i>	prefix meaning differential	—
<i>D</i> or <i>d</i>	diameter	ft.
<i>D<sub>e</sub></i>	equivalent or hydraulic diameter	ft
<i>D<sub>v</sub></i>	mass diffusivity	sq ft per hr
<i>e</i>	base of natural logarithms	—
<i>E</i>	energy	Btu
<i>E</i>	electrical potential	volts
<i>f</i>	film conductance (alternate for <i>h</i> )	Btu per (hr) (sq ft) (F)
<i>f<sub>D</sub></i>	friction factor, D'Arcy-Weisbach formulation	—
<i>f<sub>r</sub></i>	friction factor, Fanning formulation	—
<i>F</i>	force	lb
<i>F<sub>ij</sub></i>	angle factor (radiation)	—
<i>g</i>	gravitational acceleration	ft per (sec) (sec)
<i>Q</i>	mass velocity	lb per (hr) (sq ft)
<i>h</i>	heat-transfer coefficient	Btu per (hr) (sq ft) (F)

Symbol	Description of item	Typical units
<i>A</i>	hydraulic head	ft
<i>A<sub>D</sub></i>	mass-transfer coefficient	lb per (hr) (sq ft) (lb per cu ft)
<i>h</i>	specific enthalpy	Btu per lb
<i>h<sub>a</sub></i>	enthalpy of dry air	Btu per lb
<i>h<sub>s</sub></i>	enthalpy of moist air at saturation	Btu per lb dry air
<i>H</i>	total enthalpy	Btu
<i>I</i>	electric current	amperes
<i>J</i>	mechanical equivalent of heat	ft-lb per Btu
<i>j<sub>H</sub></i>	heat transfer factor = $N_{Gr} V \rho \mu / k$	—
<i>j<sub>M</sub></i>	mass transfer factor = $\frac{h D}{V} N_{Gr}^{1/3}$	—
<i>k</i>	thermal conductivity	Btu per (hr) (sq ft) (F per ft) or (F per in.)
<i>k</i> (or $\gamma$ )	ratio of specific heats, $c_p/c_v$	—
<i>K</i>	proportionality constant	—
<i>l</i> or <i>L</i>	length	ft
<i>m</i> or <i>M</i>	mass	lb
<i>M</i>	Mach number	—
<i>M</i>	molecular weight	lb per mol
<i>N</i>	rate of rotation	rpm
<i>N</i> or <i>n</i>	number in general	—
<i>N<sub>Fr</sub></i>	Fourier number = $\alpha t / L^2$	—
<i>N<sub>Gr</sub></i>	Graetz number = $W \rho \mu / k L$	—
<i>N<sub>Le</sub></i>	Lewis number = $\alpha / D_v$	—
<i>N<sub>Nu</sub></i>	Nusselt number = $h D / k$	—
<i>N<sub>Pe</sub></i>	Peclet number = $G D \rho / k$	—
<i>N<sub>Pr</sub></i>	Prandtl number = $c_p \mu / k$	—
<i>N<sub>Re</sub></i>	Reynolds number = $\rho V D / \mu$	—
<i>N<sub>Sc</sub></i>	Schmidt number = $\mu / \rho D_v$	—
<i>N<sub>Sh</sub></i>	Sherwood number = $h D / D_v$	—
<i>N<sub>St</sub></i>	Stanton number = $h / G c_p$	—
<i>p</i> or <i>P</i>	pressure	psi or psf
<i>p<sub>a</sub></i>	partial pressure of dry air	psi
<i>p<sub>w</sub></i>	partial pressure of water vapor in moist air	psi
<i>p<sub>s</sub></i>	vapor pressure of water in saturated moist air	psi
<i>P</i>	power	hp, watts
<i>q</i>	time rate of heat transfer	Btu per hr
<i>Q</i>	volumetric flow rate	cfm
<i>Q</i>	total heat transfer	Btu
<i>r</i>	radius	ft
<i>r</i> or <i>R</i>	thermal resistance	(hr) (sq ft) (F) per Btu, or (hr) (F) per Btu
<i>R</i>	gas constant	ft-lb per (lb) (R)
<i>s</i>	specific entropy	Btu per (lb) (R)
<i>S</i>	total entropy	Btu per R
<i>t</i>	temperature	F
<i>T</i>	absolute temperature	R
$\Delta t_m$ or $\Delta T_m$	mean temperature difference	F
<i>u</i>	specific internal energy	Btu per lb
<i>U</i>	total internal energy	Btu
<i>U</i>	overall heat-transfer coefficient	Btu per (hr) (sq ft) (F)
<i>v</i>	specific volume	cu ft per lb
<i>V</i>	total volume	cu ft
<i>V</i>	linear velocity	ft per sec
<i>w</i>	mass rate of flow	lb per hr
<i>W</i>	weight	lb
<i>W</i>	work	ft-lb
<i>W</i>	humidity ratio of moist air	lb water per lb dry air
<i>W<sub>s</sub></i>	humidity ratio of moist air at saturation	lb water per lb dry air
<i>x</i>	mol fraction	—
<i>x</i>	quality, mass fraction of vapor	—
<i>x, y, z</i>	lengths along principal coordinate axes	ft
<i>Z</i>	figure of merit	—
$\alpha$	absolute Seebeck coefficient	volt per C
$\alpha$	absorptivity, absorptance (radiation)	—
$\alpha$	linear coefficient of thermal expansion	per F
$\alpha$	thermal diffusivity	sq ft per hr
$\beta$	volume coefficient of thermal expansion	per F
$\gamma$ (or $k$ )	ratio of specific heats, $c_p/c_v$	—
$\gamma$	specific weight	lb per cu ft
$\Delta$	difference between values	—
$\epsilon$	emissivity, emittance (radiation)	—
$\eta$	efficiency or effectiveness	—



Symbol	Description of item	Typical units
$\lambda$	wave length	cm
$\mu$	degree of saturation	—
$\mu$	dynamic viscosity	lb per (ft) (hr)
$\nu$	kinematic viscosity	sq ft per hr
$\rho$	density	lb per cu ft
$\rho$	volume resistivity	ohm-cm
$\rho$	reflectivity, reflectance (radiation)	—
$\sigma$	Stefan-Boltzmann constant	Btu per (hr) (sq ft) (R) <sup>4</sup>
$\sigma$	surface tension	lb per ft
$\tau$	stress	lb per sq ft
$t$	time	sec
$\tau$	transmissivity, transmittance (radiation)	—
$\phi$	relative humidity	—

### SUBSCRIPTS

These are to be affixed to the appropriate symbols. Several subscripts may be used together to denote combinations of various states, points, or paths. Often the subscript indicates that a particular property is to be kept constant in a process.

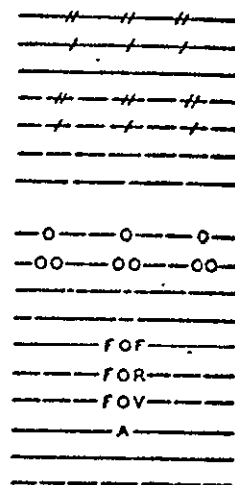
- $a, b, \dots$  referring to different phases, states or physical conditions of a substance, or to different substances
- $a$  air
- $a$  ambient
- $b$  barometric (pressure)
- $c$  referring to critical state or critical value
- $c$  convection
- $db$  dry bulb
- $dp$  dew point
- $e$  base of natural logarithms
- $f$  referring to saturated liquid
- $f$  film
- $fg$  referring to evaporation or condensation
- $P$  friction
- $g$  referring to saturated vapor
- $h$  referring to a process having no change in enthalpy
- $H$  water vapor
- $i$  referring to saturated solid
- $i$  internal
- $if$  referring to change of phase in melting
- $ig$  referring to change of phase in sublimation
- $k$  kinetic
- $L$  latent
- $m$  mean value
- $M$  molar basis
- $o$  referring to initial or standard states or conditions
- $p$  referring to constant pressure conditions or processes
- $p$  potential
- $r$  refrigerant
- $r$  radiant or radiation
- $s$  referring to moist air at saturation
- $s$  sensible
- $s$  referring to isentropic conditions or processes
- $s$  static (pressure)
- $s$  surface
- $t$  total (pressure)
- $T$  referring to isothermal conditions or processes
- $v$  referring to constant volume conditions or processes
- $v$  vapor
- $v$  velocity (pressure)
- $w$  wall
- $w$  water
- $wb$  wet bulb
- $1, 2, \dots$  different points in a process, or different instants of time

## GRAPHICAL SYMBOLS FOR DRAWINGS<sup>1</sup>

### Piping

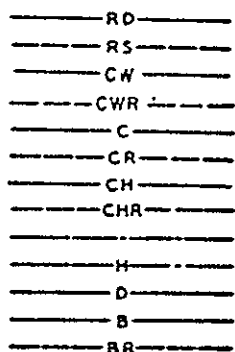
#### Heating

- High-Pressure Steam
- Medium-Pressure Steam
- Low-Pressure Steam
- High-Pressure Return
- Medium-Pressure Return
- Low-Pressure Return
- Boiler Blow Off
- Condensate or Vacuum
- Pump Discharge
- Feedwater Pump Discharge
- Make-Up Water
- Air Relief Line
- Fuel Oil Flow
- Fuel Oil Return
- Fuel Oil Tank Vent
- Compressed Air
- Hot Water Heating Supply
- Hot Water Heating Return



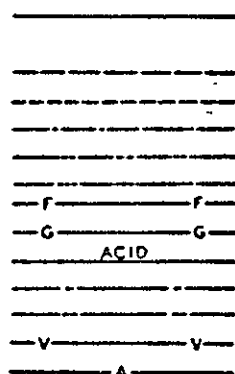
#### Air Conditioning

- Refrigerant Discharge
- Refrigerant Suction
- Circulating Water Flow
- Circulating Water Return
- Condenser Water Flow
- Condenser Water Return
- Chilled Water Flow
- Chilled Water Return
- Make-Up Water
- Humidification Line
- Drain
- Brine Supply
- Brine Return



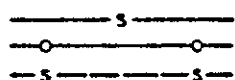
#### Plumbing

- Soil, Waste, or Leader (Above Grade)
- Soil, Waste, or Leader (Below Grade)
- Vent
- Cold Water
- Hot Water
- Hot Water Return
- Fire Line
- Gas
- Acid Waste
- Drinking Water Flow
- Drinking Water Return
- Vacuum Cleaning
- Compressed Air



#### Sprinklers

- Main Supplies
- Branch and Head
- Drain



#### Valves

- Check Valve



<sup>1</sup> Extracted from: American National Standard Graphical Symbols for Pipe Fittings, Valves, and Piping (ANS Z32.2.3-1949) and American National Standard Graphical Symbols for Heating, Ventilating, and Air Conditioning (ANS Z32.2.4-1949) with the permission of the publisher, The American Society of Mechanical Engineers.

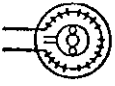
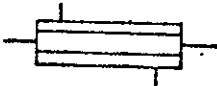




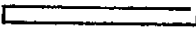
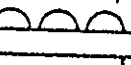
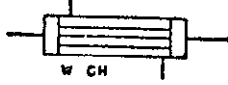
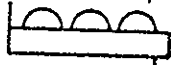

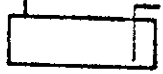
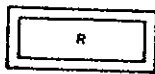

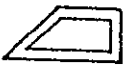
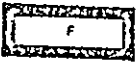
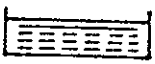

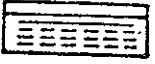





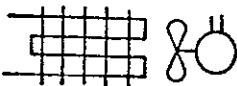


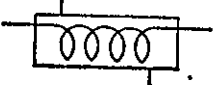

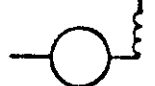






Angle Check Valve	
Stop Cock	
Valve, Diaphragm	
Valve, Float Operated	
Gate Valve, Elevation	
Gate Valve, Plan	
Gate Valve, Motor Operated	
Angle Gate Valve, Elevation	
Angle Gate Valve, Plan	
Globe Valve, Elevation	
Globe Valve, Plan	
Globe Valve, Motor Operated	
Angle Globe Valve, Elevation	
Angle Globe Valve, Plan	
Valve, Lock and Shield	
Valve, Air Line	
Water Regulating Valve, Pressure Operated	
Valve, Quick Opening	
Safety Valve	

Fittings:	Flange	Screw	Weld
Bushing			
Cross			
Elbow, 90°			

Fittings (Continued)	Flange	Screw	Weld
Elbow, 45°			
Elbow, turned up			
Elbow, turned down			
Elbow, reducing			
Elbow, base			
Elbow, long radius			
Elbow, double branch			
Elbow, side outlet, outlet up			
Elbow, side outlet, outlet down			
Flange, expansion joint			
Flange, reducing			
Joint			
Reducer, concentric			
Reducer, eccentric			
Sleeve			
Tee			
Tee, outlet up			
Tee, outlet down			
Tee, side outlet, outlet up			
Tee, side outlet, outlet down			
Tee, single sweep			

Fittings (Continued)	Flange	Screw	Weld
Tee, double sweep			
Union			
Lateral			
Heating			
Air Eliminator			
Anchor			
Expansion Joint			
Hanger or Support			
Heat Exchanger			
Heat Transfer Surface, Plan (Indicate Type Such as Convector)			
Pump (Indicate Type Such as Vacuum)			
Strainer			
Tank (Designate Type)			
Trops			
Boiler Return			
Blast Thermostatic			
Float			
Float and Thermostatic			
Thermostatic			
Unit Heater (Centrifugal Fan), Plan			
Unit Heater (Propeller), Plan			
Unit Ventilator, Plan			
Pumps			
Pump, Service			
Pump, Air			
Pump, Circulating Water			
Pump, Boiler Feed			
Pump, Condensate			
Pump, Reciprocating			
Dynamic Pump, Air Ejector			
Air Circulating Equipment			
Fans and Ventilators			
Fan and Motor with Belt Guard			
Unit Ventilator, Plan			
Fan Motor			
Ductwork			
Direction of Flow			
Duct, Width X Depth			
Supply Duct, Section			
Exhaust Duct, Section			
Fresh Air Duct, Section			
Recirculation Duct, Section			
Other Ducts, Section			
Inclined Rise, in Respect to Air			
Inclined Drop, in Respect to Air			
Canvas Connection			
Adjustable Blank-off			
Volume Damper			

Automatic Damper		Compressor, Open Crankcase, Reciprocating, Belted	
Deflecting-Damper		Compressor, Open Crankcase, Reciprocating, Direct Drive	
Deflecting Damper Up		Motor Compressor Units (pump and motor only)	
Deflecting Damper, Down		Motor-compressor, Enclosed Crankcase, Reciprocating, Direct Drive	
Vane		Motor-compressor, Enclosed Crankcase, Reciprocating, Belted Drive	
Grilles, Registers, Diffusers, Etc.		Motor-compressor, Enclosed Crankcase, Rotary, Direct Drive	
Louver Opening		Motor-compressor, Sealed Crankcase, Reciprocating	
Intake Louvers and Screen		Motor-compressor, Sealed Crankcase, rotary	
Adjustable Plaque		Condensing Units (pump, motor, and condenser)	
Register		Condensing Unit, Air-Cooled	
Grille		Condensing Unit, Water-Cooled	
Top Register or Grille		Low Sides and Refrigerated Fixtures	
Center Register or Grille		Low Sides	
Bottom Register or Grille		Pipe Coil	
Top and Bottom Register or Grille		Evaporator, Plate Coil	
Ceiling Register or Grille		Evaporator, Finned Type, Natural Convection	
Supply outlet		Evaporator, Manifolded, Bare-Tube, Gravity Air	
Exhaust inlet		Evaporator, Manifolded, Finned, Gravity Air	
Compressors		Evaporator, Plate Coils, Headed or Manifolded	
Compressors (pump only)		Evaporator, Forced Convection	
Compressor		Evaporator, Manifolded, Finned Forced Convection	
Compressor, Enclosed Crankcase, Rotary, Belted			

Evaporator, Circular, Ceiling Type, Finned		Condenser, Water-Cooled, Concentric Tube in Tube	
Evaporator, Domestic or Ice Making Unit		Condenser, Evaporative	
Immersion Cooling Unit		Cooling Towers	
Heat Transfer Surface, Plan		Cooling Tower	
Water Chiller, Shell and Tube		Spray Pond	
Brine Chiller, Shell and Tube		Receivers	
Refrigerated Fixtures		Receiver, Horizontal	
Refrigerator, Above 32 F		Receiver, Vertical	
Display Counter		Miscellaneous	
Freezer, Room		Open Tank	
Ice Cream Cabinet		Closed Tank	
Beverage Cooler			
Drinking Fountain, Pedestal			
Drinking Fountain, Trough Type			
Drinking Fountain, Wall Type			
Condensers, Cooling Towers, Etc.			
Condensers			
Condenser, Air Cooled, Finned, Static		motors and Other Power Sources	
Condenser, Air-Cooled, Finned, Forced Air		DC Motors	
Condenser, Water-Cooled Shell and Tube		DC Motor	
Condenser, Water-Cooled Shell and Coil		DC Compound Motor or 2-wire Generator or Stabilized Shunt Motor	
		DC Series Motor or 2-wire Generator	
		DC Shunt Motor or 2-wire Generator	
		AC Motors	
		Repulsion motor	
		1-Phase Shaded Pole Motor	
		1-Phase Repulsion Start Induction Motor	
		2-Phase 4-wire, or Single phase Split Phase Induction Motor or Generator or Rotary Phase Converter	
		3-phase or 2-phase, 3-wire Squirrel Cage Induction Motor or Generator	

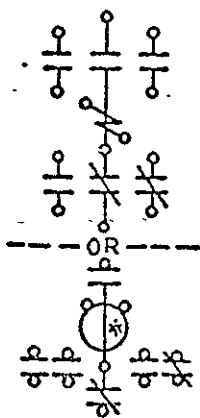
3-phase Synchronous Motor or Generator or Condenser	
3-phase Wound Rotor Induction Motor, Synchronous Induction Motor, or Induction Generator	
<b>Turbines</b>	
Steam Turbine	
Condensing Turbine	
<b>Controls</b>	
<b>Refrigerant Controls</b>	
Capillary Tube	
Expansion Valve, Hand	
Expansion Valve, Automatic	
Expansion Valve, Thermostatic	
Float Valve, High Side	
Float Valve, Low Side	
Thermal Bulb	
Solenoid Valve	
Constant Pressure Valve, Suction	
Evaporator Pressure Regulating Valve, Thermostatic, Throttling Type	
Evaporator Pressure Regulating Valve, Thermostatic, Snap Action	
Evaporator Pressure Regulating Valve, Throttling-Type, Evaporator Side	
Compressor Suction Valve, Pressure Limiting, Throttling Type, Compressor Side	
Thermo-Suction Valve	
Snap Action Valve	
Check Valve, Liquid or Suction	

<b>Temperature or Temperature-Actuated Electrical or Flow Controls</b>	
Thermostat, Self-contained	
Thermostat, Remote Bulb	
<b>Pressure or Pressure-Actuated Electrical or Flow Controls</b>	
Pressure Switch	
Pressurestat	
Pressure Switch with High-Pressure Cutout	
Automatic Reducing Valve	
Automatic Valve Operated by Governor	
Automatic Bypass Valve	
Valve; Reducing-pressure	
<b>Auxiliary Equipment</b>	
<b>Refrigerant</b>	
Filter	
Strainer	
Filter and Strainer	
Scale Trap	
Drier	
Vibration Absorber	
Heat Exchanger	
Oil Separator	
Sight Glass	
Fusible Plug	
Rupture Disc	

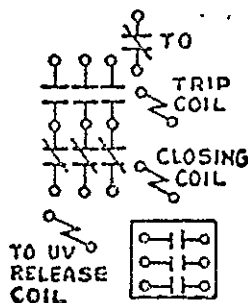
## Electrical

Power Switches		Resistor	
Power Switches, with Auxiliary Contacts, Normally Open		Relay, air core with normally open switch	
Disconnect Switch		Relay, magnet core with normally closed switch	
Fuse		Relay, overcurrent or overvoltage relay, 1 normally open contact	
Fuse, Current Responsive		Relay, overload, having 2 current coils and 1 normally closed contact with time opening	
Indicating Lights, Letters to Indicate Color:		Relay, thermal overload, having 2 series heating elements and 1 normally closed contact	
A—amber    G—green    R—red		Thermal overload with normally closed switch	
B—blue    O—orange    W—white		Contactor, 3-pole, manually operated, without blowout coils	
C—clear    P—Purple    Y—yellow		Contactor, 3-pole, electrically operated, with blowout coils, 2 normally open and 1 normally closed auxiliary contacts	
FL—fluorescent    OP—opalcent		Contactor, 3-pole, electrically operated, with blowout coils, 2 normally open and 1 normally open auxiliary contact with time closing	
Contact, Normally Closed			
Contact, Normally Open			
Contacts, Transfer, SPDT			
Contact, normally open, with Time Closing			
Contact, Normally Closed, with Time Opening			
Battery, general			
Battery, polarity given			
Battery, one cell			
Capacitor			
Circuit breaker, 3-pole single-throw, without and with terminals			
Circuit breaker, 3-pole double-throw, without and with terminals			
Coils, air core			
Coils, magnet core			

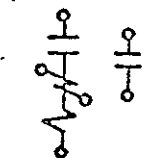
Contactor, double-throw, electrically operated, 1 normally open and 1 normally closed main contacts with common connection; 3 normally open and 1 normally closed auxiliary contacts, spring or gravity return



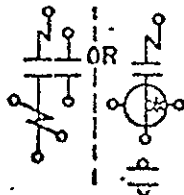
Contactor, 3-pole, electrically operated with oil-immersed contacts and time delay undervoltage release, instantaneous trip from trip coil, time delay opening auxiliary contact and 3 normally open and 3 normally closed auxiliary contacts with common points



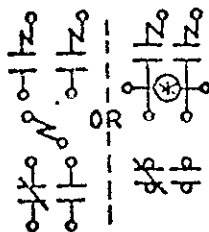
Contactor, single-pole, electrically operated, without blowout coil, with operating coil and series holding coil, 1 normally closed auxiliary contact



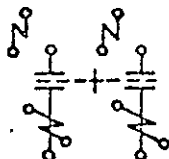
Contactor, single-pole, electrically operated, with blowout coil and 1 normally open auxiliary contact



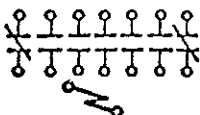
Contactor, 2-pole, electrically operated, with blowout coils, 1 normally open and 1 normally closed auxiliary contacts



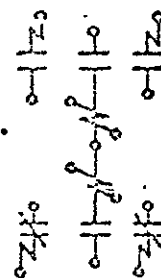
Contactor, 2 single-pole, electrically operated with operating coils and separately excited blowout coils, shown mechanically interlocked



Contactor, multipole, electrically operated, with 5 normally open and 2 normally closed contacts.



Contactor, double-throw, electrically operated, with 2 normally open and 2 normally closed main contacts with blowout coils and 2 normally open auxiliary contacts with a common connection.



Alarm, annunciator



Alarm, bell



Alarm, buzzer



Alarm, horn



Measurement

Indications of Measure

Square inches



Square feet



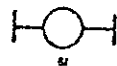
Cubic feet



Pounds



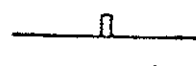
Measuring Devices  
Meter



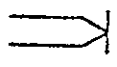
Gage



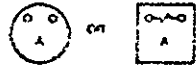
Thermometer



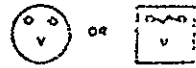
Thermocouple



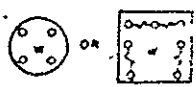
Ammeter



Voltmeter



Watt-hour Meter



DC Watt-hour Meter





## IDENTIFICATION OF PIPING SYSTEMS BY COLOR

The color scheme for identification of piping systems, based on material carried, as listed in the following table and shown in Fig. 1, is reprinted from Part V, Fifth Edition (1950), of the Engineering Standards of the Mechanical Contractors Association of America.

CLASS	COLOR
F—Fire-protection	Red
D—Dangerous materials	Yellow or Orange
S—Safe materials	Green (or the achromatic colors, white, black, gray or aluminum)

and, when required

P—Protective materials	Bright blue
V—Extra valuable materials	Deep purple

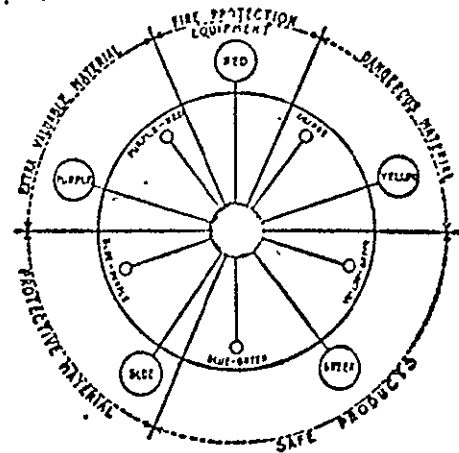


Fig. 1.... Main Classification by Color

## THE GREEK ALPHABET

A α	Alpha	H η	Eta	N ν	Nu	T τ	Tau
B β	Beta	Θ θ	Theta	Ξ ξ	Xi	Υ υ	Upsilon
Γ γ	Gamma	Ι ι	Iota	Ο ο	Omicron	Φ φ	Phi
Δ δ	Delta	Κ κ	Kappa	Π π	Pi	Χ χ	Chi
Ε ε	Epsilon	Λ λ	Lambda	Ρ ρ	Rho	Ψ ψ	Psi
Ζ ζ	Zeta	Μ μ	Mu	Σ σ	Sigma	Ω ω	Omega

ORIGINAL PAGE IS  
OF POOR QUALITY