HUD-0003479

ORIGINAL

CONTRACT H-2372

FINAL REPORT OF THE MANAGEMENT SUPPORT CONTRACTOR
FOR THE
RESIDENTIAL SOLAR HEATING DEMONSTRATION

VOLUME III. HIGH TEMPERATURE EXPOSURE OF WOOD STRUCTURES IN SOLAR SYSTEMS

JUNE 1983

by

BE&C Engineers, Inc.

(A Boeing Subsidiary)

for

Office of

Policy Development & Research

Department of Housing and

Urban Development

H-2372

B 5.01.501

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PREFACE

This volume is one of five composing the final report written by BE&C Engineers, a Boeing subsidiary. Under contract to the U.S. Department of Housing & Urban Development (HUD), Boeing provided management support for the Residential Solar Heating Demonstration. The demonstration, part of the National Program for Solar Heating and Cooling, began in 1975. During the next four years, HUD awarded over 900 grants to builders/developers who were to install solar systems on dwellings new or retrofitted; 497 grants actually resulted in construction.

Volume I gives the general history of the demonstration from the contractor's viewpoint. The other volumes cover specific technical issues.

Volume II--Solar Repair Program
Volume III--High Temperature Exposure of Wood Structures in Solar Systems
Volume IV--Corrosion Problems
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SUMMARY

This document provides solar energy system engineers, designers, and manufacturers with actual experience-type data related to high temperature exposure of wood structures in solar systems, and with design recommendations oriented to reducing these temperatures during use.

The need for data and the recommendations included in this document was recognized early in the Residential Solar Heating Demonstration, when a house fire started in a roof-mounted collector. Prolonged periods of stagnation had degraded the collector's foam insulation.

A collector condition survey was conducted to identify collector systems that were susceptible to fire hazards. Thirty-six systems, including solar attics, site-built air and liquid collectors, and manufactured collectors, were identified as potentially hazardous and investigated. Results showed that no apparent fire-related life-safety hazards were present in the 36 systems; however, significant degradation of thermal insulation and adjacent wood structure was observed. The most severe degradation was found in solar attics and site-built collectors.

Three projects, two with solar attics and one with a site-built air system, were selected for further investigation. These projects were instrumented to determine maximum wood temperatures during periods of high solar insolation. Measurements were taken under various conditions including stagnation (system not operating and no ventilation), natural ventilation, forced ventilation, and with wood surfaces shielded by either reflective coatings or thermal insulation. This document contains the analyses of these data and, based on these analyses, provides solar energy system engineers, designers, and manufacturers with recommended methods for reducing temperatures of wood structures in solar systems. Recommendations are made for both solar attics and site-built collectors. In each case the intent is to lower air temperatures, reduce the thermal absorptance of structural wood surfaces, and provide thermal insulation between wood and gypsum board surfaces and the collector absorber materials.

CHAPTER 1. BACKGROUND

The solar demonstration included some solar system configurations where wood and other structural materials and insulation were exposed to elevated temperatures for periods greatly exceeding the program's 30-day stagnation test requirement. Concern over this condition intensified during visits to several solar systems to investigate operating problems. U.S. Department of Housing and Urban Development (HUD) investigators then noted instances of heat-related degradation of materials in collectors. Degradation was seen to occur in wood and in foam insulations--urethane, polyurethane, isocyanurate, polyisocyanurate, and polystyrene—used within collector boxes. It appeared to indicate that potentially hazardous, fire-related conditions could exist in certain site-built and manufactured collectors.

BOULDER COLLECTOR FIRE

This suspicion was further intensified by a fire which occurred in the collector of a solar system at Boulder, Colorado. The fire originated in a roof-mounted collector and was caused by degradation of the collector's foam insulation after it had experienced prolonged periods of stagnation. This exposed the collector's plywood case to high temperatures which, in time, caused the plywood to ignite. The National Bureau of Standards investigated the fire; the results of the investigation have been released in a report, Solar Collector Fire Incident Investigation (Reference 1). Figures 1-1 and 1-2 illustrate the nature of the damage involved.

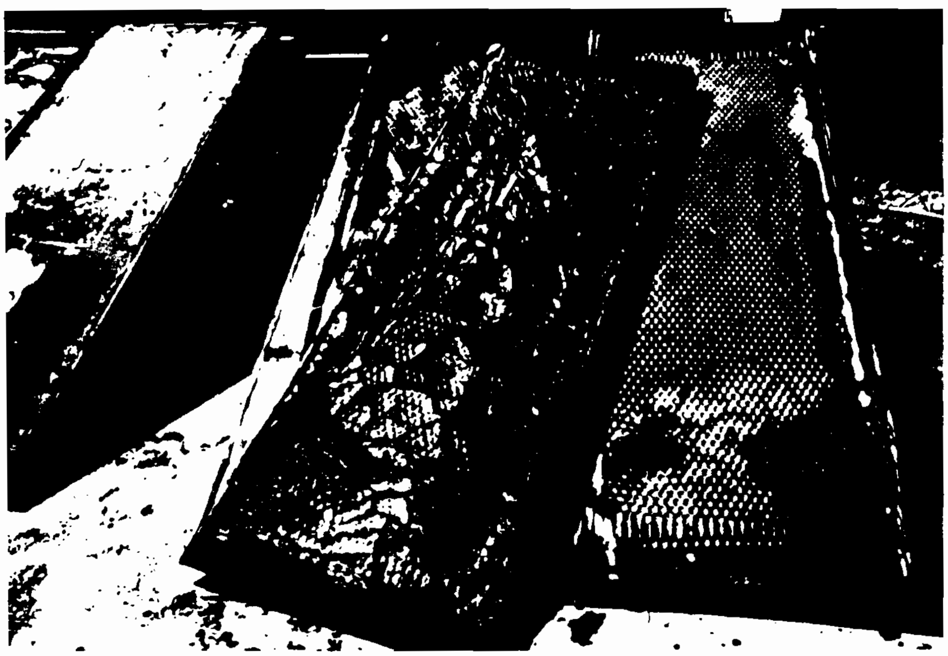

Figure 1-1. Burned Collector, Boulder Fire

*References are listed on p. 43, following Chapter 6 in this volume.

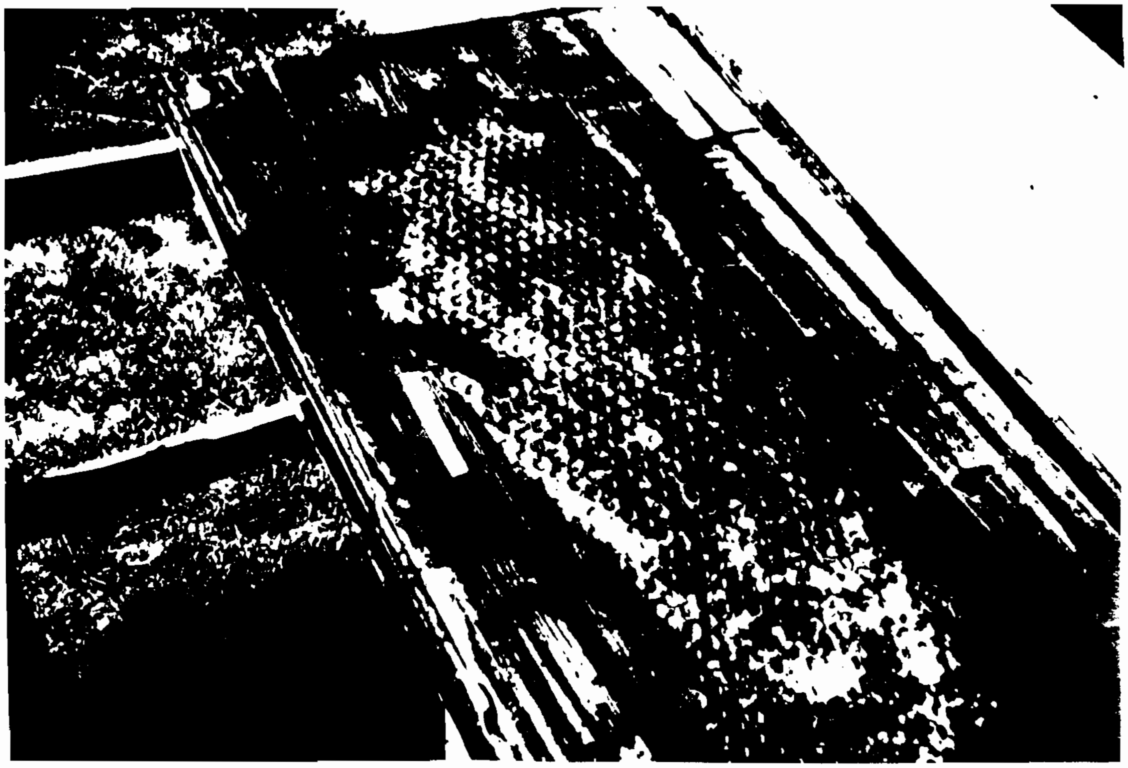

Figure 1-2. Burned Collector, Boulder Fire

COPPER-CLAD PLYWOOD ABSORBERS

Additionally, of 30 collector systems in the HUD program that used manufactured copper-clad plywood absorbers, several were found to have serious heat-related structural degradation of the plywood cores. Most of the cores examined in the investigation of that problem showed charring of the plywood and some were completely disintegrated. Figures 1-3 and 1-4 illustrate the conditions encountered in these absorbers. All roofs of this type were replaced or removed. No further discussion of the copper-clad plywood absorbers or of the Boulder fire appears in this volume. However, both the fire and the copper-clad plywood absorbers are discussed in Volume II of the final report.

COLLECTOR CONDITION SURVEY

After HUD completed its own investigation of the Boulder fire, it decided to investigate all HUD solar grant projects where the solar collection system contained materials that would degrade and possibly create a life-safety hazard if exposed to long-term stagnation conditions. Figure 1-5 is a chronological illustration of the fire incident and the resultant HUD investigations.

During the first half of 1981, based on Boeing/Dubin-Bloome Associates recommendations, HUD authorized a survey of selected collector systems installed under HUD grants to determine the current collector condition and the immediate

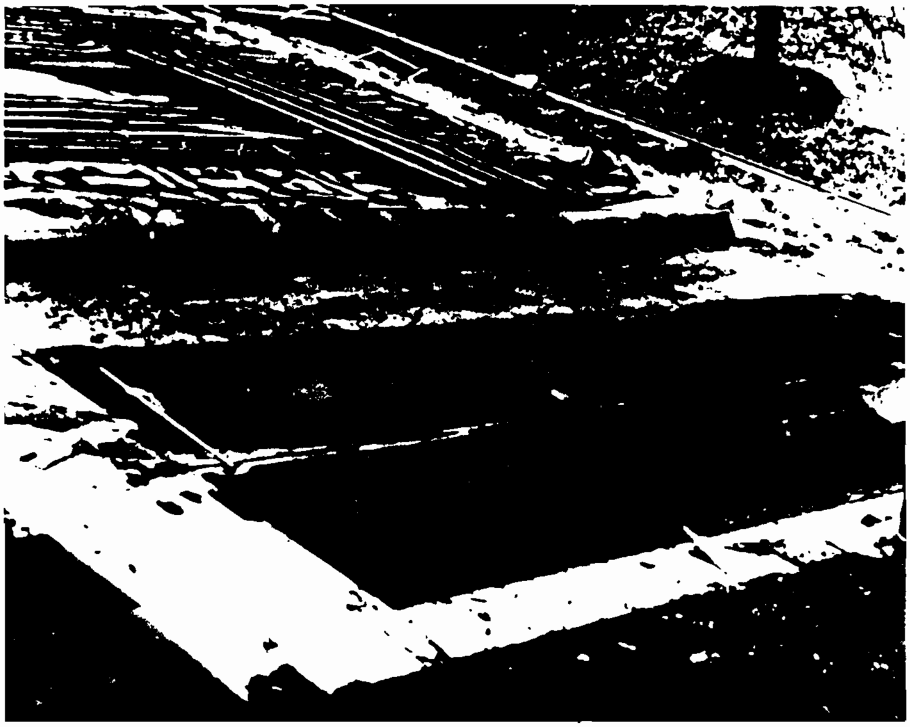

Figure 1-3. Overall View of Damage to Copper-Clad Plywood Absorber

Figure 1-4. Close-Up of Damage to Copper-Clad Plywood Absorber

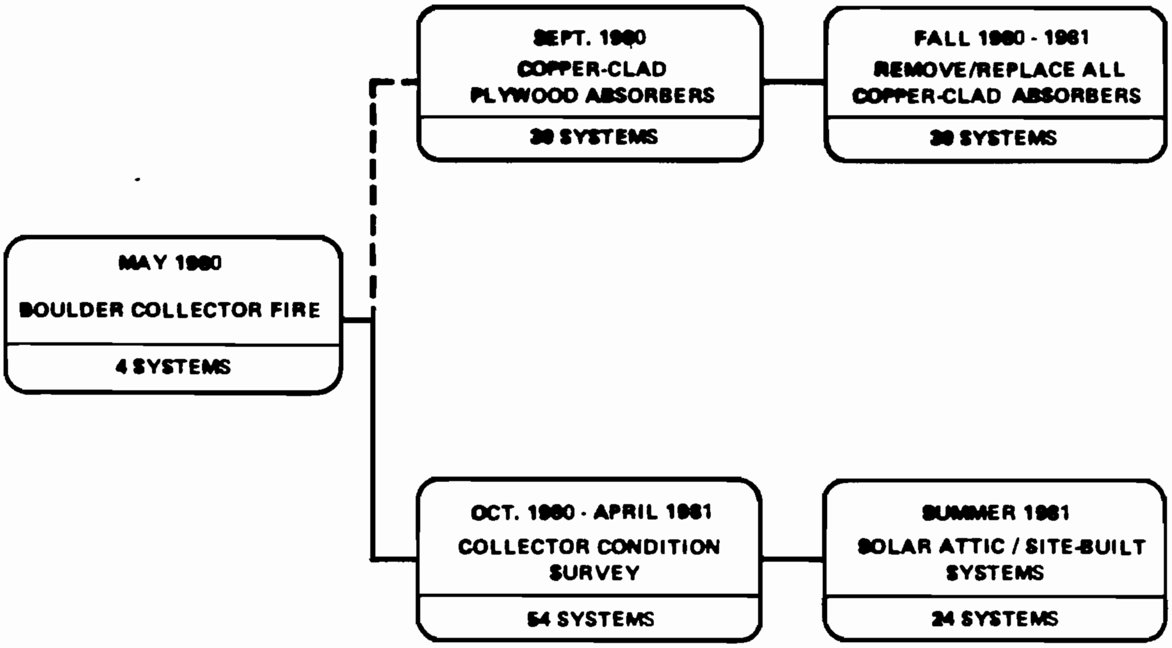

Figure 1-5. Investigation Chronology

potential for collector-caused fires that might present life-safety hazards. Approximately 1,100 active system designs were reviewed to identify those with a high degree of risk--namely those systems involving solar attics; site-built collectors, incorporated into the roof structure; and roof-mounted manufactured collectors containing foam, plywood, or other flammable material in contact with or in close proximity to the absorber plate. The initial review identified 189 potential high-risk systems. The 189 system designs were examined further, resulting in the identification of 54 systems with the highest potential hazard risk. These 54 systems were then subjected to a field survey.

The results revealed no apparent immediate fire-related, life-safety hazards in the systems investigated; however, it was noted that maximum wood surface temperature measurements were found to exceed 150°F* in solar attic configurations. The results of the field survey are the subject of a Dubin-Bloome Associates report entitled "Collector Condition Survey Report" which has been adapted as Chapter 2 of this document.

*These measurements were made in late March and early April and therefore could be expected to increase during the summer months.

SOLAR ATTIC/SITE-BUILT COLLECTOR SURVEY

Results of the solar attic installation survey raised concerns about the long-term effects of high temperatures on the structural strength of wood and other materials used in solar attics and site-built collectors. Another survey and study was conducted during the summer of 1981 to determine, by field investigation, the limits of the temperature environment found in typical installations under different conditions of use. The three sites selected for data gathering were considered to be most representative of other solar attic and site-built collector configurations installed during the demonstration program. Data were also obtained from two non-solar attics to be used for comparison.

Temperatures in the wood were taken under varying conditions to approximate normal use and stagnation. Some wood samples were also obtained and sent to the Forest Products Laboratory in Madison, Wisconsin, for analysis. Documentation of the results of this survey and study appears in Chapters 3 through 6.

CHAPTER 2. COLLECTOR CONDITION SURVEY

The collector fire at Boulder, Colorado, drew attention to fire, health, and safety concerns. This chapter discusses the resulting investigation of projects in the solar demonstration program. It also discusses impaired performance caused by collectors that overheat.

SITE DETERMINATION

Following the Boulder fire, a search was made of manufacturers' literature, involving some 1,100 systems, to determine which collectors employed wood or wood products or one of the foam insulations. Sixteen manufacturers marketed such collectors, which were used by 84 demonstration grantees. An additional 23 grantees used the same materials in site-built or solar attic systems. Therefore, 107 grantees had collectors using potentially hazardous materials in 189 systems.

Further investigations of the problem led to the conclusion that the most serious condition might occur in those systems that either employed wood or had the foam insulation in direct contact with the absorber plate and that were flush mounted or integrated into the roof. This rationale is based on the hazard potential suggested by independent fire investigation in the "Boulder incident," as these conditions were a factor in the Boulder fire. Using this basis for determination, 33 grants comprising 54 individual systems were identified for field investigation. Table 2-1 lists the grants.

INVESTIGATION METHODS

Site inspection involved removing samples by drilling cores from the collector insulation and composite wood/metal absorber plates. The procedure gave physical evidence of deterioration of materials, if existent.

In addition to the coring of the materials present in the collector or energy gathering structure, temperature measurements of the air and surfaces in the collector were taken. The temperature measurements were used in determining the severity of the heat conditions encountered.

Visits were made to all 54 system locations. In most instances, cores were obtained from attic spaces without difficulty. Occasionally glazings had to be removed to obtain insulation samples or probe wood elements of the collector. A 1" to 1¼" coring drill was used to obtain the cores; a digital thermometer was used to obtain the surface temperature data. The observations resulting from this activity are summarized below.

SOLAR ATTICS—AIR

Nineteen solar attic systems with a roof aperture opening to radiate the interior of the attic space were investigated. The entire collection area (plywood, gypsum board, wood) is typically painted flat black. Air is the transfer medium.

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TABLE 2-1
COLLECTOR CONDITION SURVEY

GRANT NO.	NAME, LOCATION	NUMBER OF SYSTEMS	TYPE OF SYSTEM L-LIQUID H-HEATING A-AIR W-DHW	TYPE COLLECTOR			FLUSH-MOUNTED	TYPE OF POTENTIAL HAZARD	CONDITIONS OBSERVED
				ATTIC TYPE	SITE-BUILT	MANUFACTURED COLLECTOR			
2423	Innovative Systems Hamburg, NY	1	L HW		X		X	Wood	Charring of sheathing
2428	Cambridge Development Group Columbia, SC	2	A HW	X				Wood	Pyramidal optics system Charring of wood Leaky roof
2450	Helio Thermics Inc. Greenville, SC	1	A HW	X				Wood	No discoloration SFC temp between 130-150 F
2458	Church Community Corp. Newport, RI	1	A HW		X		X	Wood	No discoloration
2602	Mission Viejo Co. Aurora, Colo.	1	L HW			X	X	Insul.	No discoloration
2702	Town of Marion Marion, Mass.	3	L HW			X	X	Insul.	Light discoloration
2715	Pinewood Manor, Inc. Corum, LI, NY	1	A H		X		X	Wood Insul.	No discoloration thru charring. Temp 130-150 F
2744	Helio Thermics, Inc. Greenville, SC	2	A HW	X				Wood	No discoloration SFC temp above 150F
2789	Michael Corbett Davis, Calif.	1	L W			X	X	Wood	No discoloration
2792	Colorado Park Housing Palo Alto, Calif.	1	L W			X	X	Insul.	Heavy discoloration
8032	Joseph Real Estate W. Springfield, Mass.	1	A H		X		X	Masonite	No discoloration
8034	Worcester Polytech Inst. Worcester, Mass.	1	L W			X	Rack	Insul.	Light discoloration
8036	Style Craft Homes Keene, NH	1	A HW		X		X	Aspenite	No discoloration
8037	Forest Park Village North Conway, NH	12	A HW		X		X	Insul. Wood	Light discoloration of insul. No discoloration of wood. Possible structure weakness
8043	M. F. Smith Jamestown, RI	1	L HW		X		X	Wood	No discoloration Possible structural weakness
8074	Page Associates, Inc. Pinehurst, NC	1	A HW	X				Wood	No discoloration SFC temp above 150F Powery drywall cores
8178	Ray L. Hasse Yavapai, Ariz.	1	L HW		X		X	Wood	No discoloration
8203	John DeLapp Design Davis, Calif.	1	L HW			X	X	Wood	No discoloration

TABLE 2-1 (cont.)
COLLECTOR CONDITION SURVEY

GRANT NO.	NAME, LOCATION	NUMBER OF SYSTEMS	TYPE OF SYSTEM L-LIQUID H-HEATING A-AIR W-DHW	TYPE COLLECTOR			FLUSH-MOUNTED	TYPE OF POTENTIAL HAZARD	CONDITIONS OBSERVED
				ATTIC TYPE	SITE-BUILT	MANUFACTURED COLLECTOR			
8207	Mar-Mac Development Monterey, Calif.	2	A HW	X				Wood	No discoloration SFC temp above 150F Possible structural weakening
8310	Jean Cayer, Inc. Shelton, Conn.	1	L HW	X				Wood	Pyramidal optics system No discoloration
8312	Summerwood Associates Old Saybrook, Conn.	1	L HW	X				Wood	Pyramidal optics system No discoloration
8315	National Homes Corp. Lafayette, Ind.	1	A H	X				Wood	No discoloration SFC temp above 150F Powdery drywall cores
8317	Turtle Valley Housing Homestead, Pa.	1	A HW	X				Wood	Light-heavy charring SFC temp between 130-150F Possible structural weakening
8325	Marteq Corp. Murfreesboro, Tenn.	1	A HW	X				Wood	Light-heavy charring SFC temp betwen 130-150F Possible structural weakening
8326	Solar Crafters, Inc. Strawberry Plains, Tenn.	1	A H	X				Wood	No discoloration SFC temp beween 130-150F
8328	Lovins Cont. Co. Somerset, Ky.	2	A HW	X				Wood	Light-heavy charring SFC temp between 130-150F Possible structural weakening
8329	Kentucky Mountain Hsg. Gray Hawk, Ky.	1	A HW	X				Wood	Light-heavy charring SFC temp between 130-150F Possible structural weakening
8330	Nastrom Const. Co. Cambridge, Minn.	1	L HW			X	X	Insul.	No discoloration
8331	Hobmar Homes, Inc. Medina, Minn.	1	A HW	X				Wood	No discoloration SFC temp between 130-150F Powdery drywall cores
8368	Deer Hill Solar Corp. Carmel, NY	2	L HW		X		X	Wood	No discoloration
8428	Lamplighter Const. Idaho Falls, Ida.	1	L HW			X	X	Insul.	No insulation in collector
8669A	Helio Thermics, Inc. Greenville, SC	1	A H	X				Wood	No discoloration
8713	Wonderland Hill Development Boulder, Colo.	4	A H	X				Wood	No discoloration

Plywood surfaces of two systems had cracks in the first ply but otherwise showed no unusual deterioration. These cracks appeared to have resulted from heat. Gypsum board cores in three systems showed excessive dryness of gypsum to the extent that the cores could not be taken whole. The surfaces of the gypsum board did not show any defects.

Temperatures recorded during the visits in late March and early April 1981 reached a maximum of 153°F on the wood surfaces in two systems. Air temperatures in these systems reached the 145°F range. Other attics had air and surface temperatures of 100° to 140°F. The two sites with the highest recorded temperatures were those where gypsum board and plywood showed the most deterioration. Two solar attics were found in such a deteriorated condition during a repair visit that the entire plywood and gypsum board interiors had to be replaced. Figures 2-1 and 2-2 illustrate the conditions in which these systems were found. The foregoing findings led to the investigation described in Chapter 3 of this report, using instrumentation installed to monitor temperature profiles. While the remainder of the systems mentioned above did not show visible signs of degradation, they later received the same protection that was given all solar attics of this type.

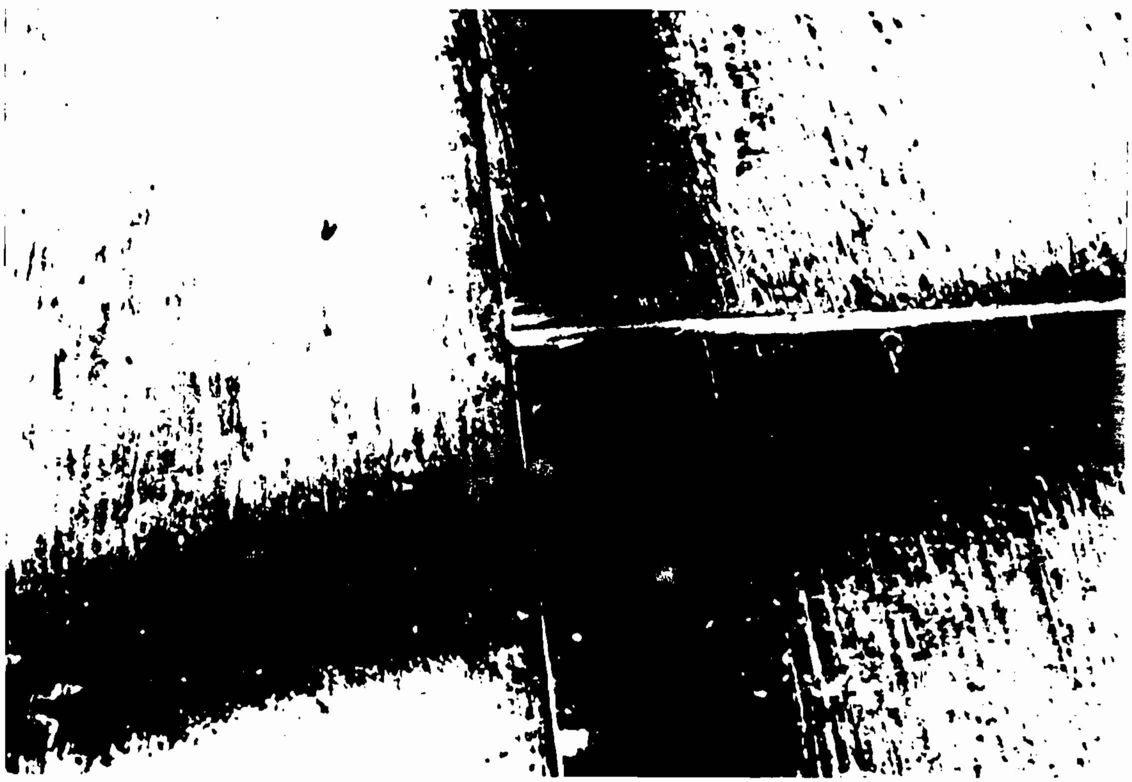

Figure 2-1. Solar Attic Damage

Figure 2-2. Solar Attic Damage

SOLAR ATTICS—PYRAMIDAL OPTICS

Four solar attic type systems employed reflecting panels as opposed to the radiation absorbing panels of the other grants. They are designed to reflect the incoming solar radiation onto centrally located liquid absorber plates. The attics employed wood in contact with the absorber plate, with fiberglass insulation behind the plate. On two systems the fiberglass insulation was not installed and significant charring of the wood occurred. No material degradation or excessive surface or air temperatures were observed on the other two systems where the fiberglass had been installed. Figures 2-3 and 2-4 illustrate the conditions of the systems without fiberglass insulation.

SITE-BUILT AIR

Sixteen site-built systems using air as the transport medium were investigated. Three showed heat-related material degradation. Figure 2-5 is a cutaway illustration of the typical collector construction. In one project with 12 systems, according to design data, foil-faced rigid isocyanurate insulation is in contact with aluminum absorber plates. Core samples of the insulating boards from four of those systems were discolored to a moderate degree, showing that excessive heat was conducted to the boards. Several others showed slight discoloration. Temperatures in these collectors were measured at 75°F at the inlet and 160° to 180°F at the outlets. See Chapter 3 for further investigations of these 12 systems.

One system using wood and polystyrene insulation was investigated during the repair program. No deterioration of either material was noted.

Figure 2-3. Solar Attic Damage

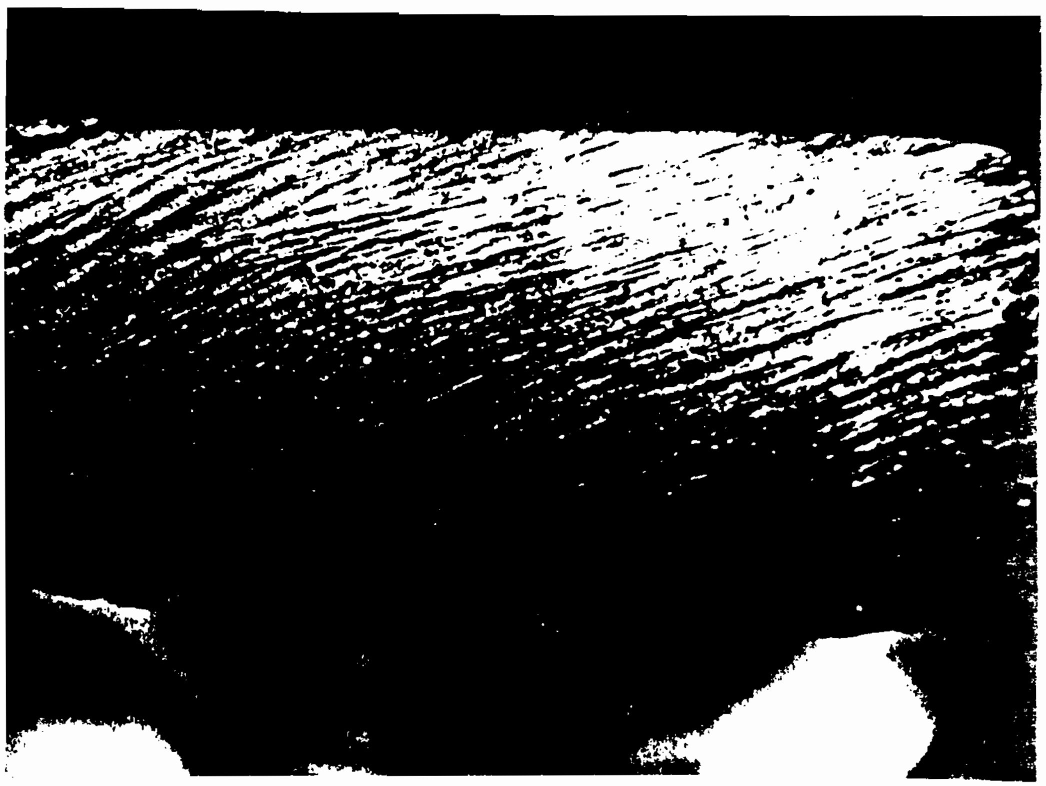

Figure 2-4. Solar Attic Damage

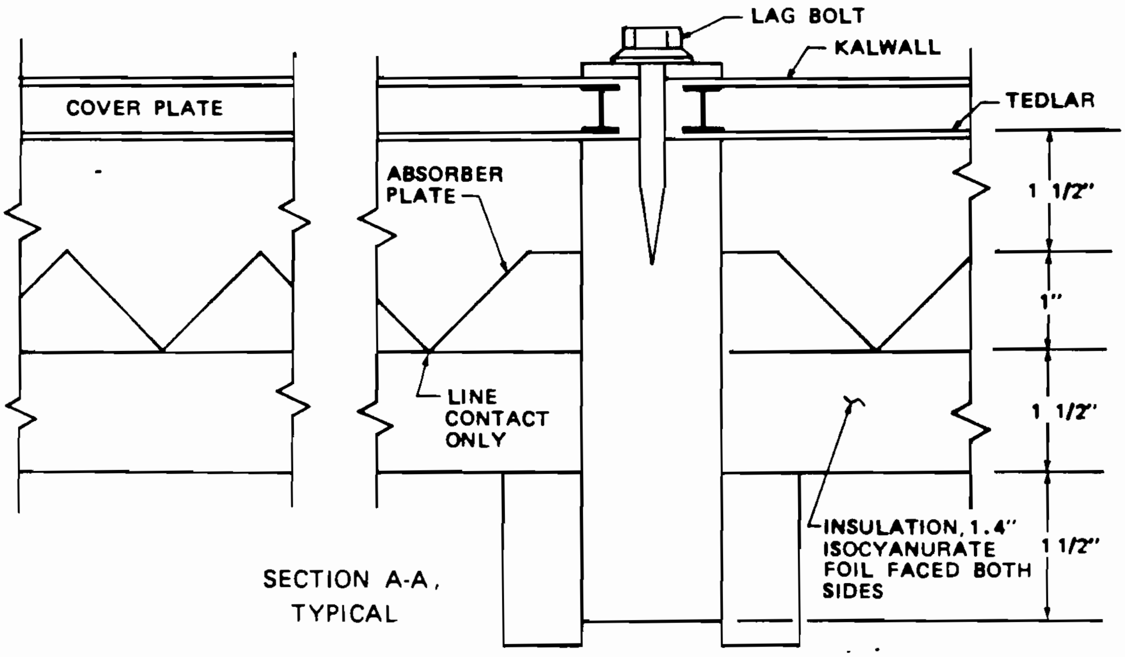

Figure 2-5. Site-Built Collector Cutaway (Air)

SITE -BUILT LIQUID

Four projects with five systems using liquid absorber panels in site-built enclosures were investigated. These included collectors with absorber plates mounted directly on wood products, insulation, or asphalt roofing paper. None of the collector materials showed any sign of degradation. Three systems were reported to have been operating without previous stagnation. A fourth system is drained during the summer months and the collectors allowed to stagnate in a dry condition. The insulation in contact with the absorber plate is fiberglass and is able to withstand the temperatures encountered. The wood spacer between the absorber and glazing did not appear to be affected by the temperatures reached during these stagnation periods. Figure 2-6 is a cutaway illustration of the collector construction.

The fifth system investigated during the repair program showed slight charring of the plywood roof sheathing where the water passageways touched the sheathing. The absorbers were raised and reinstalled on sleepers during the repair process. Foil-faced 3½" fiberglass insulation was placed on the roof in the space between the sleepers, with the foil facing the absorber plates.

MANUFACTURED COLLECTORS

Ten systems with manufactured box collectors were investigated. One site, in which the box collector was mounted on sleepers above the roof, showed heat-induced degradation of the isocyanurate insulation. The collector is made with an aluminum case, a copper absorber with serpentine coil attached to the front of the

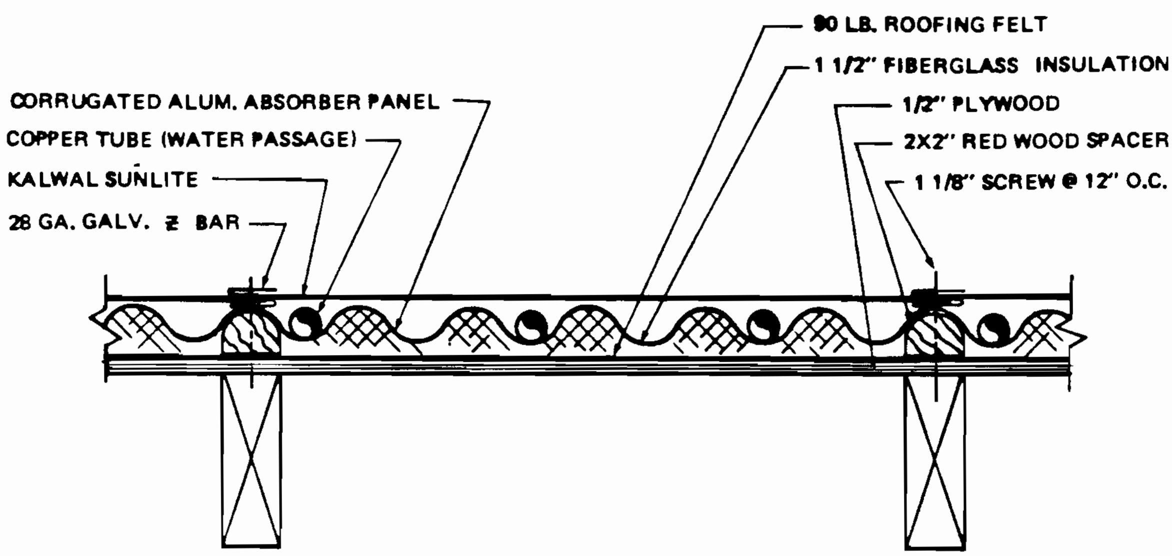

Figure 2-6. Site-Built Collector Cutaway (Liquid)

absorber, and 3/4" isocyanurate insulation attached to 1/8" masonite forming the back. The sides of the collector are also insulated with 3/4" isocyanurate. The surface of the insulation behind and touching the absorber plate had turned dark brown from heat and blended into a tan color toward the back surface. The masonite appeared to be in good condition. The insulation on the sides, which is exposed to ultraviolet rays in addition to the heat, had also turned dark brown and was brittle. Cores were taken from two of the collectors in the array, but all 47 collectors in the array showed evidence of the side insulation deteriorating. It is assumed that the insulation behind the absorber in the others is in a similar condition, based upon the edge insulation appearance.

Two other sites visited under the repair program use a collector with urethane insulation. Samples from the sites showed discoloration of the insulation. The collectors for one system are roof-mounted on sleepers. In the other system, the collectors are rack-mounted, four rows high with open backs.

The remaining seven systems had light discoloration, no discoloration, or (in one case) no insulation to be discolored or degraded.

CONCLUSIONS

The results of the survey show that no apparent fire-related life-safety hazards were present in the 54 systems investigated. While some collectors showed slight to moderate discoloration of various foam insulations, none were so disintegrated as to pose a threat to combustible materials beneath the insulation.

Based upon this survey, it would be speculative to predetermine the future long-term performance of foam-type insulations in actual use within collector assemblies. It is a fact that foam insulations will degrade significantly under test conditions subjecting them to elevated temperatures for long periods of time. Many knowledgeable individuals insist that this type of degradation will eventually occur when collectors are subjected to prolonged stagnation. While accurate determination of actual prior system stagnation periods (if any) for the systems inspected was not possible, this survey found no cases of significant foam insulation deterioration. However, tests at the Boeing laboratory indicate that urethane experiences an approximate 20% weight loss when exposed to 350°F (177°C) for 72 hours and the material darkened noticeably during the exposure. These results would seem to indicate that the recommended permissible temperature standard of 327°F (164°C) is not a safe maximum permissable temperature for urethane. It is possible that mounting conditions, glazings, stagnation potential, and other variable factors will preclude the existence of any hazard due to degradation of the insulating material. However, there is still the concern of diminished collector efficiency, caused by reduced thermal insulation values, to be considered. Additional details and analysis of this problem can be gained from two reports: Solar Collector Fire Incident Investigation (Reference 1) and Survey and Evaluation of Available Thermal Insulation Materials for Use on Solar Heating and Cooling Systems (Reference 2).

The high temperatures that exist in some solar attics and other collectors containing wood may affect certain characteristics of the wood, making it structurally weaker and lowering its ignition temperature. Various articles listed in the references indicate that temperatures in excess of 150°F will promote these changes. The higher the temperature, the more rapid and severe the change. The high temperatures recorded in the attics and in one site-built air collector were generated by the solar radiation during late March and early April. Intensity of radiation increases as the maximum sun angle is attained on June 21 and remains high throughout the summer months. Temperatures in the attics will increase and, even when the homeowner has activated the summer heat dump method, the temperatures may be above 150°F for extended time periods. Chapter 3 further discusses investigations of solar attics and site-built collectors.

CHAPTER 3. SOLAR ATTIC/SITE-BUILT COLLECTOR INVESTIGATIONS

To determine the long-term effects of high temperatures on wood and other materials used in constructing solar attics and collectors, three typical solar system configurations--two solar attic and one site-built--were selected for evaluation to provide a basis for proposed recommendations. This evaluation included a comparison of measured wood temperatures to allowable wood temperatures as determined from related research.

- o Configuration 1--a solar attic system incorporated in a standard attic structural configuration, represented by a home at Monterey, California
- o Configuration 2--a solar attic system included in a structure attached to a basic roof structure, represented by a home at Greenville, South Carolina
- o Configuration 3--a site-built solar collector system incorporated into the roof rafter structure, represented by a twelve-unit condominium at North Conway, New Hampshire

Configurations are shown schematically in Figures 3-1, 3-2, and 3-3, and are described in Chapter 4.

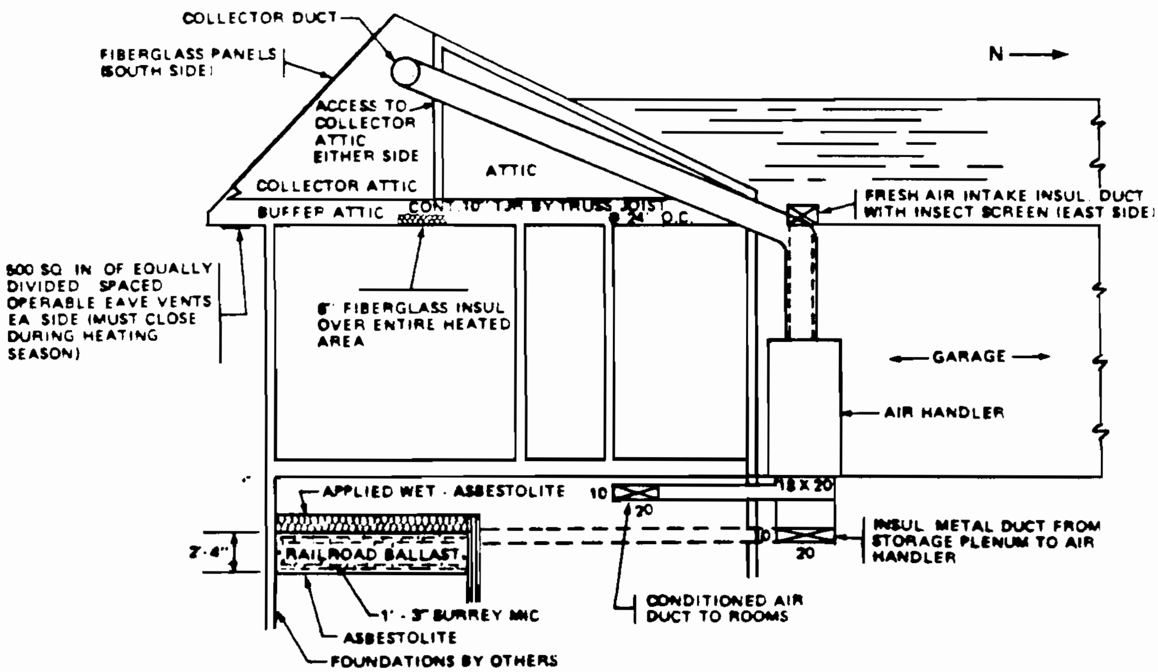

Figure 3-1. Solar System Configuration 1

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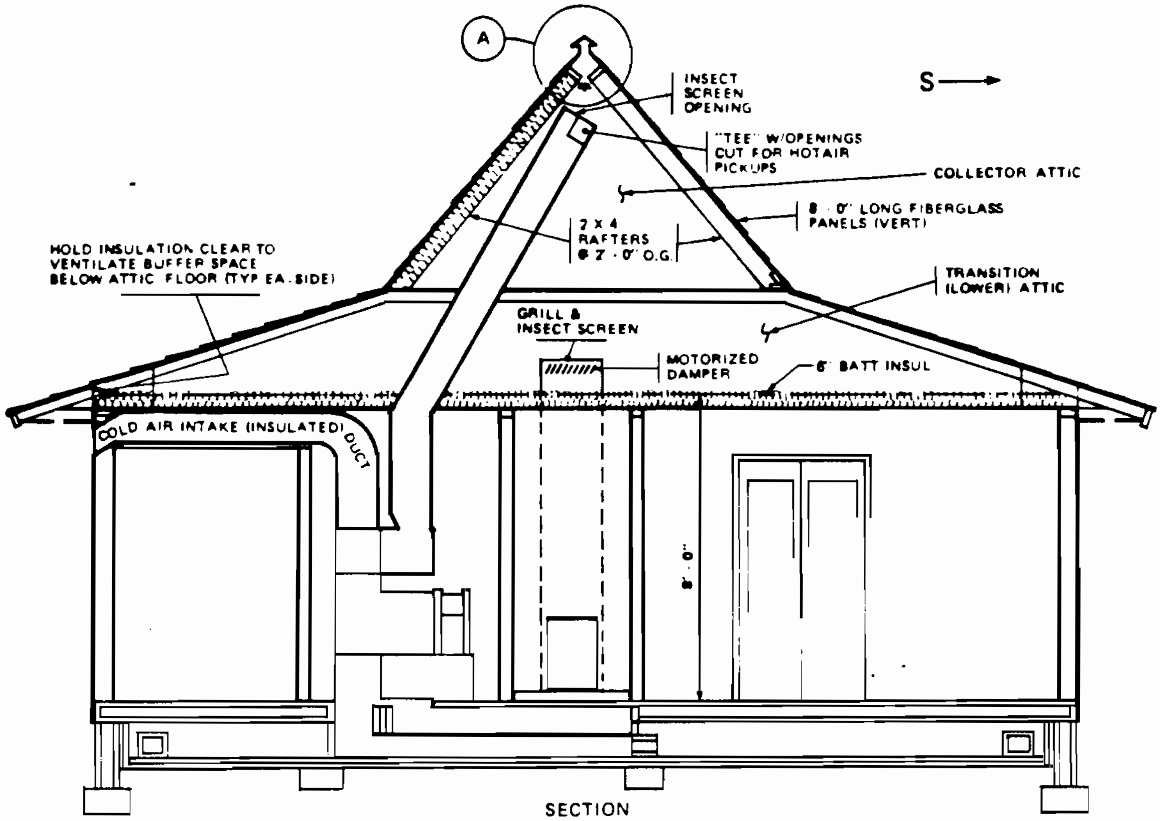
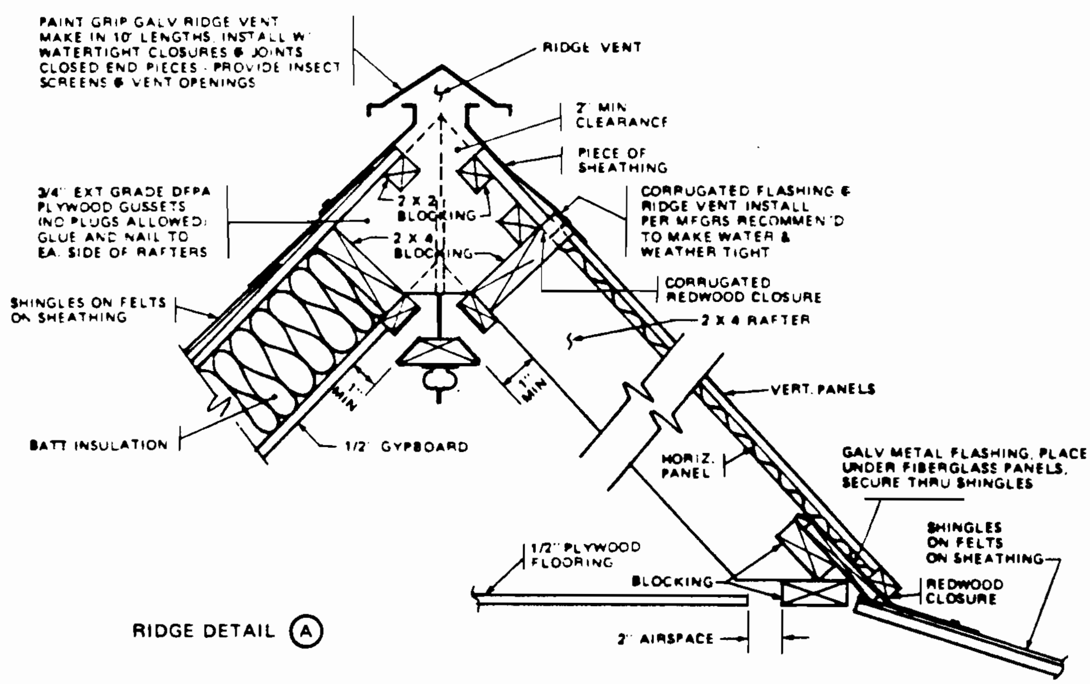
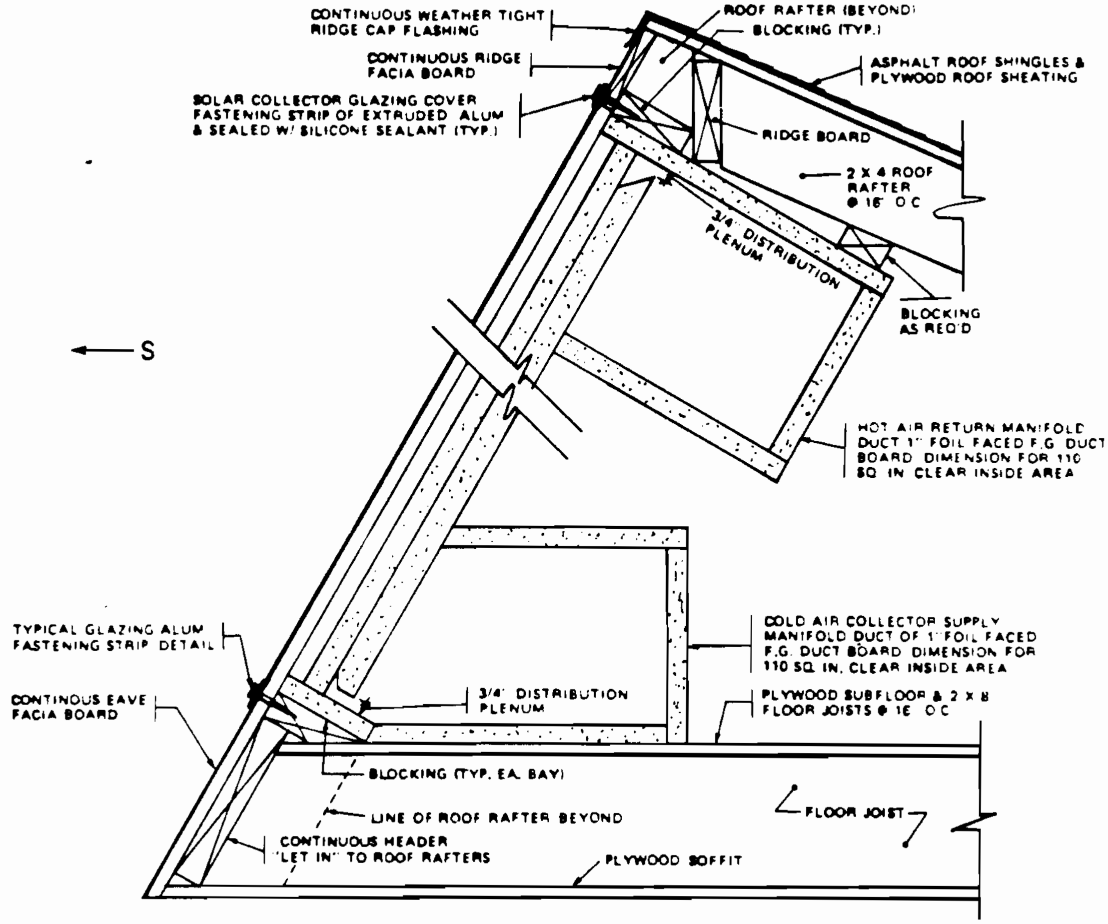


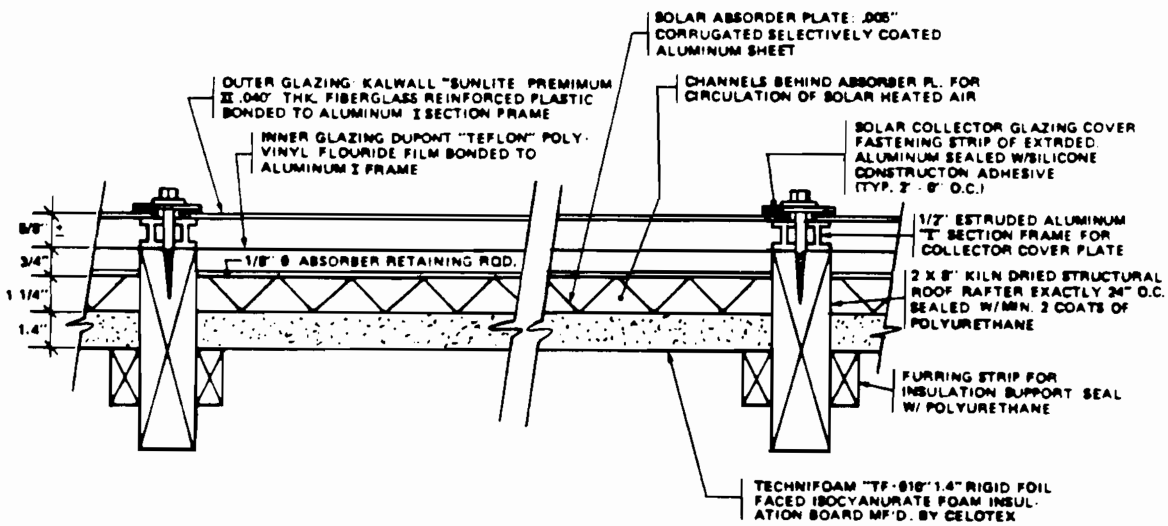


RIDGE DETAIL (A)

Figure 3-2. Solar System Configuration 2



VERTICAL SECTION THRU ROOF INTEGRATED SOLAR COLLECTOR WITH SUPPLY & RETURN



HORIZONTAL SECTION THRU ROOF INTEGRATED SOLAR COLLECTOR

Figure 3-3. Solar System Configuration 3

Each configuration was instrumented to obtain internal wood temperature data during daily periods of insolation approximating seasonal averages. Data from solar attics were compared with data obtained from standard (non-solar) attic configurations, verifying that temperature extremes in solar attics were of sufficient magnitude to warrant a detailed analysis. Chapter 6 includes design recommendations and the rationale that supports recommendations. The rationale compares measured wood temperatures in solar attics and site-built collectors with maximum recommended temperatures obtained from available related research data. In addition, methods of limiting attic temperatures to maximum recommended values are listed.

Chapter 4 summarizes the detailed data obtained from each of the three solar configurations. Temperature measurements were taken during typical periods so that data analysis would allow the prediction of maximum long-term temperatures at critical locations in the wood structure. Temperature measurements for solar attics were taken with the systems not operating and with no ventilation, natural ventilation, and forced ventilation. Temperature measurements for the site-built solar collectors were taken with the system operating, vents closed; and with the system not operating, ventilation dampers open and closed.

To evaluate methods for limiting wood temperatures in solar attics and site-built collectors, measurements were taken under the following conditions:

- o wood painted flat black
- o wood with no coating, natural surface
- o wood covered with aluminum foil, aluminum-painted, or silver-painted reflective surfaces
- o wood protected by rigid insulation
- o natural and forced ventilation in solar attics

Chapter 5 includes the data analysis that supports the recommendations included in Chapter 6. Attachments A, B, and C to this report include detailed data for each configuration.

CHAPTER 4. DATA SUMMARY

This chapter includes a description of each of the three configurations shown in Chapter 3 and a summary of temperature measurements taken from each configuration.

CONFIGURATION 1, SOLAR ATTIC

This solar attic configuration includes a large, south-facing portion of the roof (500 sq. ft.) which is glazed with two layers of corrugated translucent fiberglass. Sunlight passing through the fiberglass panels is absorbed by black floor and wall surfaces designed to collect solar energy. The fiberglass panels are attached to 2x6 Douglas fir roof rafters which are painted black. The absorber material attached to the floor and walls is DuPont "Typar" (a 3-mil black polypropylene coating treated with an ultaviolet stabilizer) bonded to 1" sheets of rigid isocyanurate insulation (R-factor = 6.7), using a contact-cement with rubber base (Neoprene, Butyl, SBR, etc.) for the bonding agent. Prior to installation of the absorber material, black-painted plywood floors and gypsum board walls had deteriorated in the solar environment. The attic collector is ventilated by an exhaust fan on the west end of the building in conjunction with a power damper on the east end of the building. The controller sensor is located in the peak of the attic in the area of maximum temperature. This ventilation system replaced the previous system which consisted of two weatherproof, airtight, manual open/close air vents installed in the gable walls. One vent was high on the east wall and the other was high on the west wall, vented to the outside. A schematic drawing of the current system was shown in Figure 3-1.

Temperature data were taken in July and August 1981, approximately three years after construction of the solar attic. The data were taken under two conditions:

- o system not operating, manual air vents closed (Typar absorber, original vent configuration)
- o system not operating, powered fan operating (Typar absorber, data taken at two exhaust fan control settings)

Maximum temperature readings were taken during clear weather. Based on Forest Products Laboratory (FPL) data, wood moisture content was estimated to be 4.5 percent. Maximum solar insolation occurred between 1300 and 1330 hours. Maximum temperatures occurred between 1230 and 1500 hours and are tabulated in Table 4-1. Measurements were made in three rafters located at the quarter-points of the solar attic. Sensor locations for a typical rafter and tabulated maximum temperature data are included in Attachment A.

Comparative attic rafter temperatures were measured in a non-solar neighboring home during the same time period when the maximum outside ambient temperature was 72°F and the maximum insolation was 302 BTU/Hr/Ft^2 (Attachment A, page A-6). A rafter temperature of 92°F was recorded at a location comparable to the maximum temperature measurement location for Configuration 1.

A typical rafter was removed from the Configuration 1 solar attic and sent to FPL for analysis. The size and location of the rafter removed from the home and the

TABLE 4-1

CONFIGURATION 1, MAXIMUM TEMPERATURE DATA

Sensor Location	System Not Operating- Manual Vents Closed	System Not Operating - Fan On @180°F Fan Off @150°F	System Not Operating - Fan On @160°F Fan Off @130°F
Solar Insolation, in Plane of Glazing	287 $BTU/Hr/Ft^2$	302 $BTU/Hr/Ft^2$	295 $BTU/Hr/Ft^2$
Collector Rafter, Internal Near Peak	198°F*	194°F	185°F
Collector Rafter, Internal Near Eaves	194°F*	192°F	175°F
Surface of Floor Insulation	209°F	206°F	196°F
Center of Insulation	184°F	186°F	177°F
Center of ½" Plywood	123°F	116°F	110°F
Two Inches into 2x4 Joist	106°F	98°F	95°F
Surface of Back Wall Insulation	188°F	190°F	177°F
Surface of Back Wall	142°F	137°F	131°F
Solar Attic, Ambient	175°F	176°F	162°F
Outside Ambient	81°F	72°F	76°F

*Structural member temperatures exceeded 150°F between 1100 hours and 1830 hours.

FPL analysis report are included in Attachment D. Test specimens removed from this rafter were tested to determine modulus of rupture (MOR) and the work to maximum load (W/V). The MOR is a measure of the load-carrying capacity of a material in bending. The W/V is a measure of displacement versus load per unit volume, i.e. the energy absorbed by the specimen as it is slowly loaded to failure. The results of these tests were compared to average values expected for Douglas fir. Test values were factored to account for the differences in moisture content between test specimens and expected averages. Factoring was necessary because strength typically varies inversely with changes in moisture content. Changes in ductility are variable depending on the species of wood. The data indicated structural degradation of 36% in MOR and 44% in W/V when compared to average FPL data compiled for Douglas fir. These results are considered as indications only because of normal data spread and the small number of specimens tested. In addition, it was noted that the wood quality of the rafters was poor with observed splitting and numerous knots.

CONFIGURATION 2, SOLAR ATTIC

This solar attic configuration is a peaked upper attic attached to and supported by a transition (lower) attic. The south-facing portion of the solar attic has 400 sq. ft. of translucent panels similar to those in Configuration 1. Panels are attached to 2x4 white fir roof rafters painted black. The floor of the solar attic is ½" plywood attached to 2x4 joists. The back wall is faced with gypsum board panels. Both floor and back wall are painted black. The attic collector is cooled in the summer by natural convection through eave vents and a ridge vent. All vents are operated manually. A schematic drawing of this system was shown in Figure 3-2.

Temperature data were taken in September 1981, approximately four years after construction of the solar attic. The data were taken under two conditions:

- o system not operating, vents open
- o system not operating, vents closed

Temperatures were read during clear weather, with a wood moisture content estimated at 7 percent. Maximum solar insolation occurred between 1330 and 1400 hours. Maximum temperatures occurred between 1500 and 1600 hours. Pertinent maximum temperature readings are tabulated in Table 4-2. Maximum temperature readings of rafters with reflective coatings are tabulated in Table 4-3. Data comparable to that provided for Configuration 1 are included in Attachment B.

Comparative lower attic (non-solar) rafter temperatures were measured when the maximum outside ambient temperature was 91^{o}F and the maximum insolation was 275 BTU/Hr/Ft^2 (Attachment B, page B-4). A rafter temperature of 147^{o}F was recorded at a location comparable to the maximum temperature measurement location for Configuration 2.

CONFIGURATION 3, SITE-BUILT COLLECTOR

The solar collectors for each of twelve units consist of eight 2x16 ft. panels installed between the rafters. The net area for each system is approximately 240 square feet. The collector backs are constructed of 1.4" thick double foil-faced

TABLE 4-2

CONFIGURATION 2, MAXIMUM TEMPERATURE DATA

Sensor Location	System Not Operating - Vents Closed	System Not Operating - Vents Open
Solar Insolation, in Plane of Glazing	275 $BTU/Hr/Ft^2$	307 $BTU/Hr/Ft^2$
Collector Rafter, Internal Near Peak	182^oF*	167^oF*
Collector Rafter, Internal Near Eaves	183^oF*	168^oF
Surface of Floor (Plywood)	169^oF	152^oF
Plywood/Joist Interface	156^oF	141^oF
Three-Quarters Inch into Joist	148^oF	132^oF
Two and One-Half Inch into Joist	139^oF	123^oF
West Back Wall, Gypsum Board Surface	151^oF	135^oF
Solar Attic Ambient	161^oF	137^oF
Outside Ambient	91^oF	82^oF

*Structural member temperatures exceeded 150^oF between approximately 1230 hours and 1730 hours.

TABLE 4-3

CONFIGURATION 2, MAXIMUM TEMPERATURES WITH REFLECTIVE SURFACES

Proposed Rafter Condition	System Not Operating - Vents Closed	System Not Operating - Vents Open
Reference Condition, Existing Rafter, Painted Black	182°F	167°F
Existing Black-Painted Rafter, Aluminum Foil Taped to Sides	169°F	155°F
Existing Rafter, Wrapped in Aluminum Foil, Open on Back Side	163°F	147°F
Existing Silver-Painted Rafter, Typar Taped to Sides	174°F	160°F
New Silver-Painted Rafter, Wrapped in Typar, Open on Back Side	163°F	147°F
New Silver-Painted Rafter	170°F	155°F
Existing Natural Rafter	169°F	154°F

isocyanurate rigid insulation board (R-factor = 10.0). These boards are set between 2x6 spruce rafters on 3/4" thick furring strips nailed to the rafters. The rafters and all wood exposed to the inside of the collectors are coated with urethane type varnish. The absorber plates are corrugated, selectively coated, aluminum sheets resting directly on the isocyanurate insulation. The corrugations run vertically.

Air flow is basically at the back of the absorber plate, however no attempt was made to prevent air from flowing on the top of the plates as well. The cover plates are prefabricated double-glazed units with fiberglass on the outside and Tedlar on the inside. The plates are held to the rafters with aluminum batten strips bolted down. Joints are sealed with silicone caulking. Each system is ducted in a direct return configuration from a header at the top and bottom of each array. The headers also contain a heat dump system consisting of a damper on the lower header and a damper and turbine exhauster on the upper header discharging above the roof. A schematic drawing of this system was shown in Figure 3-3.

Temperature data were taken in June 1981, approximately one year after construction of the site-built collector. The data were taken under three conditions:

- o system operating, vents closed
- o system not operating, vents closed
- o system not operating, vents open

Temperature readings represent maximum values at the highest rafter location. This location is subjected to maximum temperatures because it is exposed to both direct solar radiation and the highest temperature air passing between the collector-absorber plates and the rafters. Internal rafter temperature measurements were taken from probes inserted at various depths into selected rafters. Temperatures were read during clear weather. Outside ambient temperature was 87°F. Based on FPL data, wood moisture content was estimated to be 6.3 percent. Maximum solar insolation in the plane of glazing (292 $BTU/Hr/Ft^2$) and maximum wood temperatures both occurred between 1300 and 1400 hours. Pertinent data are tabulated in Table 4-4. Schematic drawings showing temperature measurement locations and additional tabulated temperature measurement data are included in Attachment C. Data represent maximum values obtained from four separate rafter locations.

A typical rafter was removed and sent to FPL for analysis. Analysis procedures were the same as those applied to the Configuration 1 rafter. Data analysis indicated negligible difference in MOR between test samples and average values expected for spruce. The data indicated an increase in W/V for the test samples. These data are considered to be less valid than those taken from the Configuration 1 home (Douglas fir) because the time since fabrication was only one year and because the relatively small data sample included specimens from both direct solar-exposed parts and unexposed parts of the rafters. The FPL report is included in Attachment D.

TABLE 4-4

CONFIGURATION 3, MAXIMUM TEMPERATURE DATA

Sensor Location	System Operating- Vents Closed	System Not Operating - Vents Closed	System Not Operating - Vents Open
Collector Rafter, Internal Near Peak	188°F	208°F	201°F
Collector Rafter, Internal Near Eaves	133°F	153°F	160°F
Collector, Air	172°F	222°F	210°F
Absorber Plates	209°F	256°F	258°F
Isocyanurate Insulation, Top	168°F	197°F	206°F
Isocyanurate Insulation, Bottom	130°F	133°F	137°F
Solar Attic, Ambient	153°F	153°F	153°F

CHAPTER 5. DATA ANALYSIS

The data summarized in Chapter 4 were analyzed to address the following questions:

- o Are wood temperatures in solar systems a potential fire hazard, or of such a magnitude as to cause a reduction in the load-carrying capacity of the wood structure?

- o What practical methods are available to reduce the temperature of wood structure exposed to solar radiation?

POTENTIAL HAZARDS OF HIGH WOOD TEMPERATURES

Analysis of the FPL report Smoldering Initiation of Cellulosics Under Prolonged Low-Level Heating (Reference 3) indicates that concern for smoldering ignition has led to regulations limiting maximum temperatures to about 212°F (100°C) for wood. Available data indicate that one year of heating at 302°F (150°C) or over 10 years at 248°F (120°C) would be required to induce smoldering combustion. Research is continuing to provide more definitive information. Similarly, related FPL data in "Factors Which Influence Serviceability of Wood Structures: Temperature" (Reference 4) indicate that wood strength is reduced as temperatures increase, and above 150°F (66°C) for extended time periods strength becomes increasingly non-recoverable if subsequently evaluated at room temperature. Design allowable stresses for buildings are not reduced for short-term heating if air temperatures are less than 150°F, even though wood temperatures may exceed 150°F. The rationale for this is that wood strength relates inversely to wood moisture content and therefore increases as the wood dries out during temperature increases. The research also indicates that for brief exposures to temperatures up to 212°F (100°C), mechanical properties are fully recoverable.

MEASURED WOOD TEMPERATURES

As shown in Figures 5-1 and 5-4, measured temperatures are less than those considered to be potential fire hazards. Conversely, in all three configurations evaluated, wood temperatures exceeding 150°F were measured, substantiating the concern for degradation of wood structural members in solar systems. It was also verified that wood temperatures in solar systems exceed wood temperatures in conventional attics. Figure 5-1 compares maximum wood temperatures measured in Configuration 1 with those measured in a conventional attic in the same neighborhood during the same time period. Wood temperatures in the conventional attic were less than 100°F. A plot of maximum wood temperatures measured in the conventional lower attic of Configuration 2 shows that they are less than 150°F.

Maximum solar heating system rafter temperatures are caused by a combination of air temperature and direct solar radiation. The magnitudes of both energy sources are shown in Figures 5-2, 5-3, 5-5, and 5-6. The temperature response of each of the test configurations to these energy sources is discussed below.

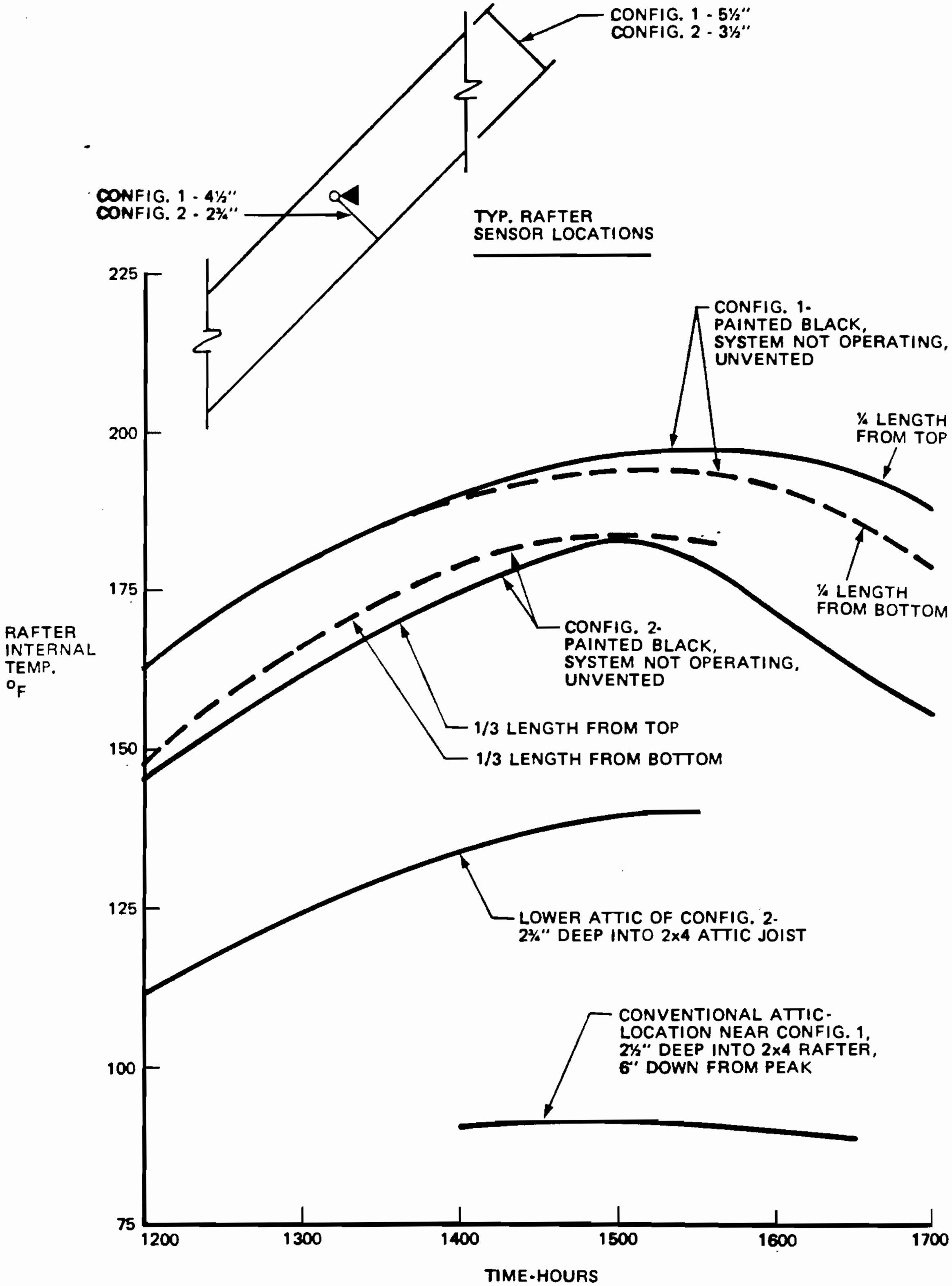


Figure 5-1. Maximum Rafter Temperatures, Solar Attics

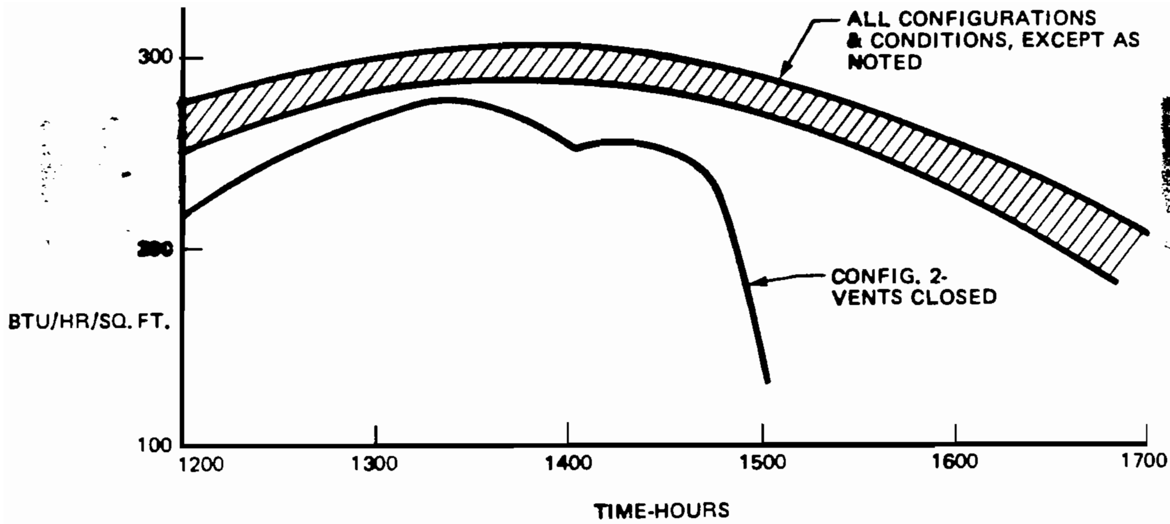


Figure 5-2. Solar Insolation, Solar Attics

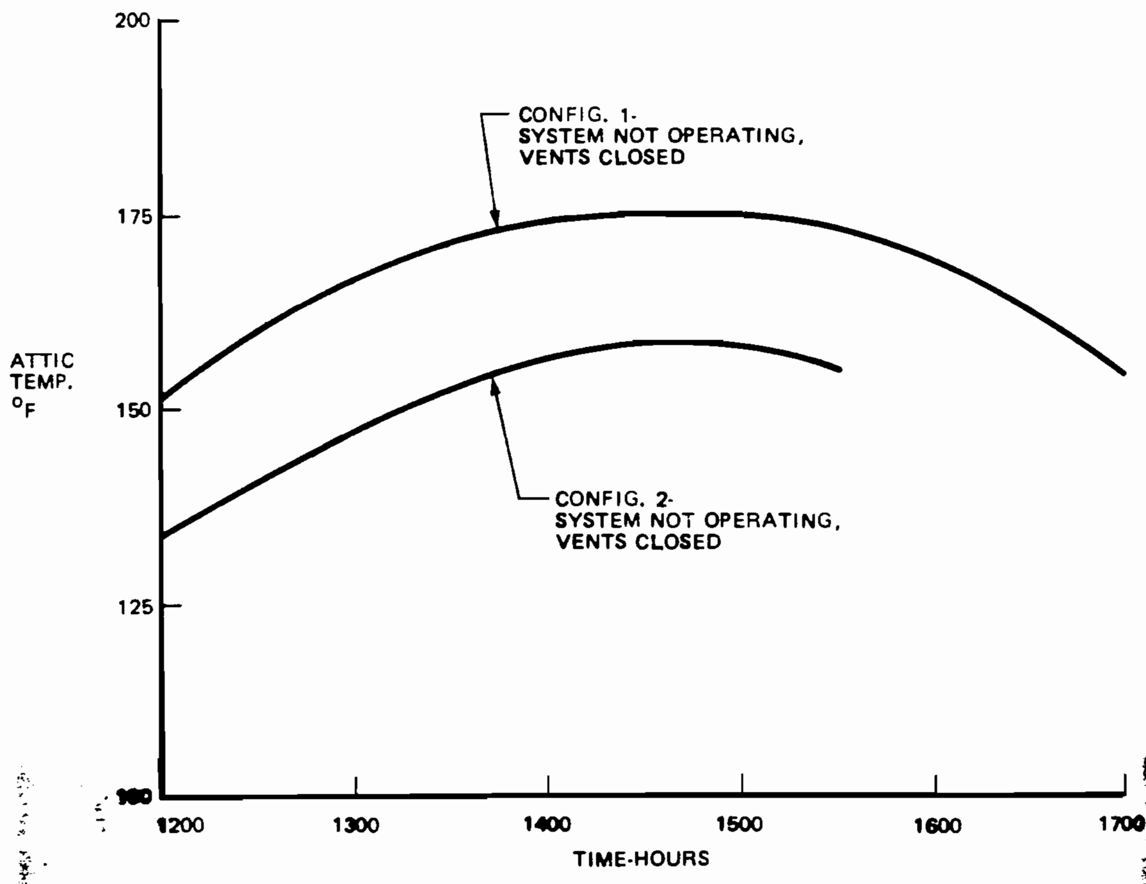


Figure 5-3. Maximum Attic Ambient Temperatures, Vents Closed

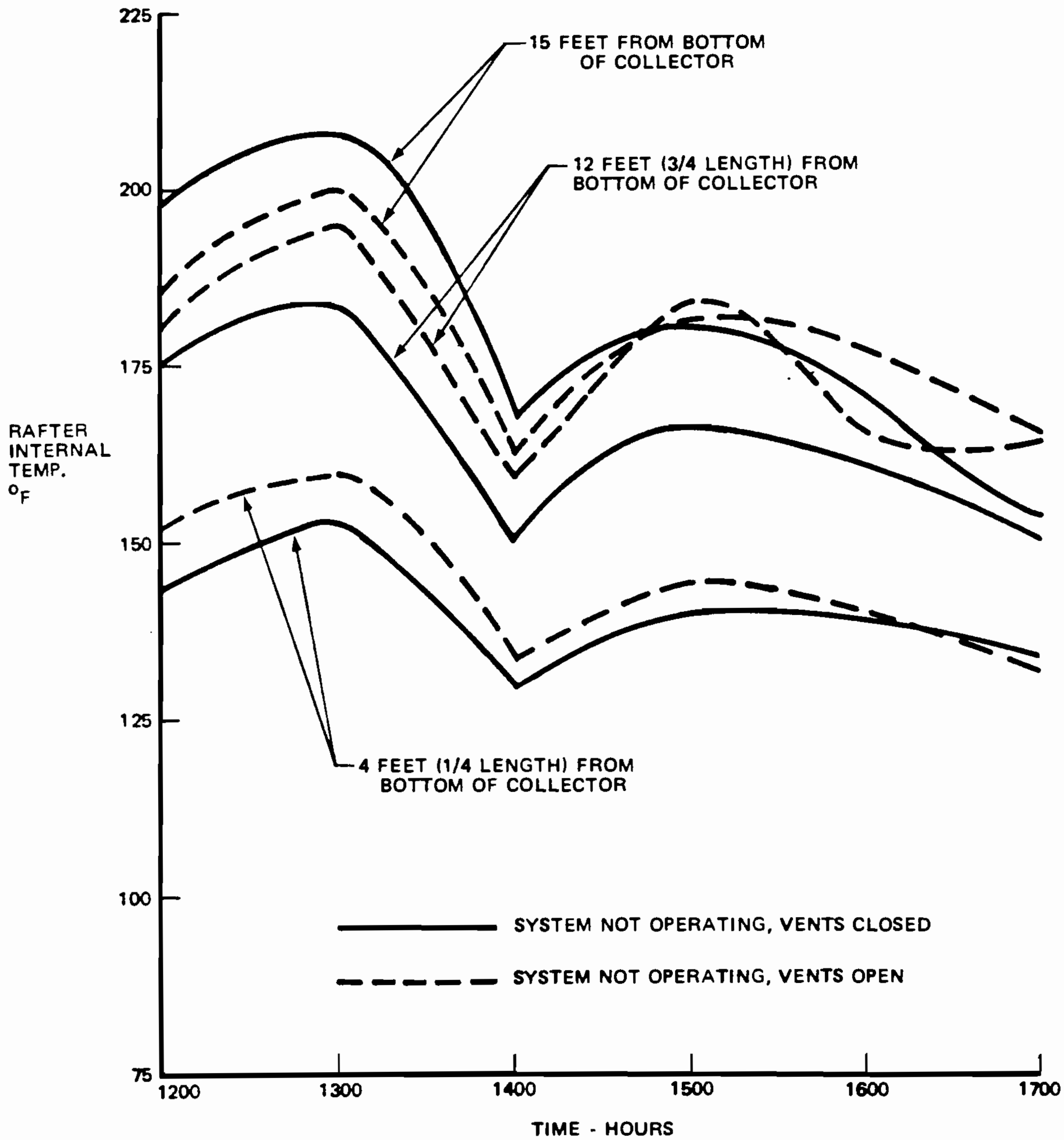


Figure 5-4. Maximum Rafter Temperatures, Site-Built Air Collector, Configuration 3

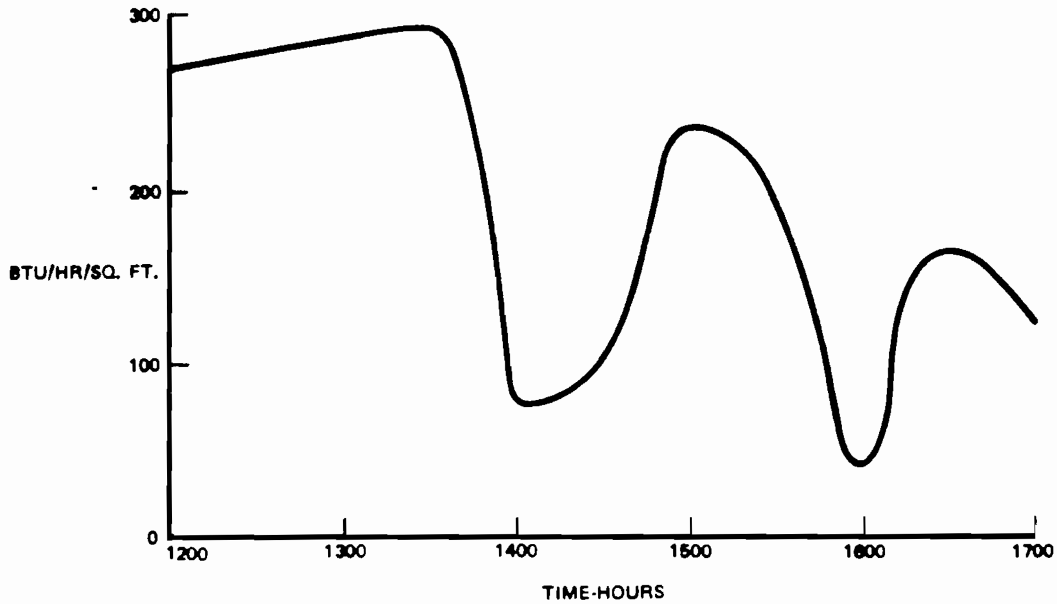


Figure 5-5. Solar Insolation, Site-Built Collector, Configuration 3

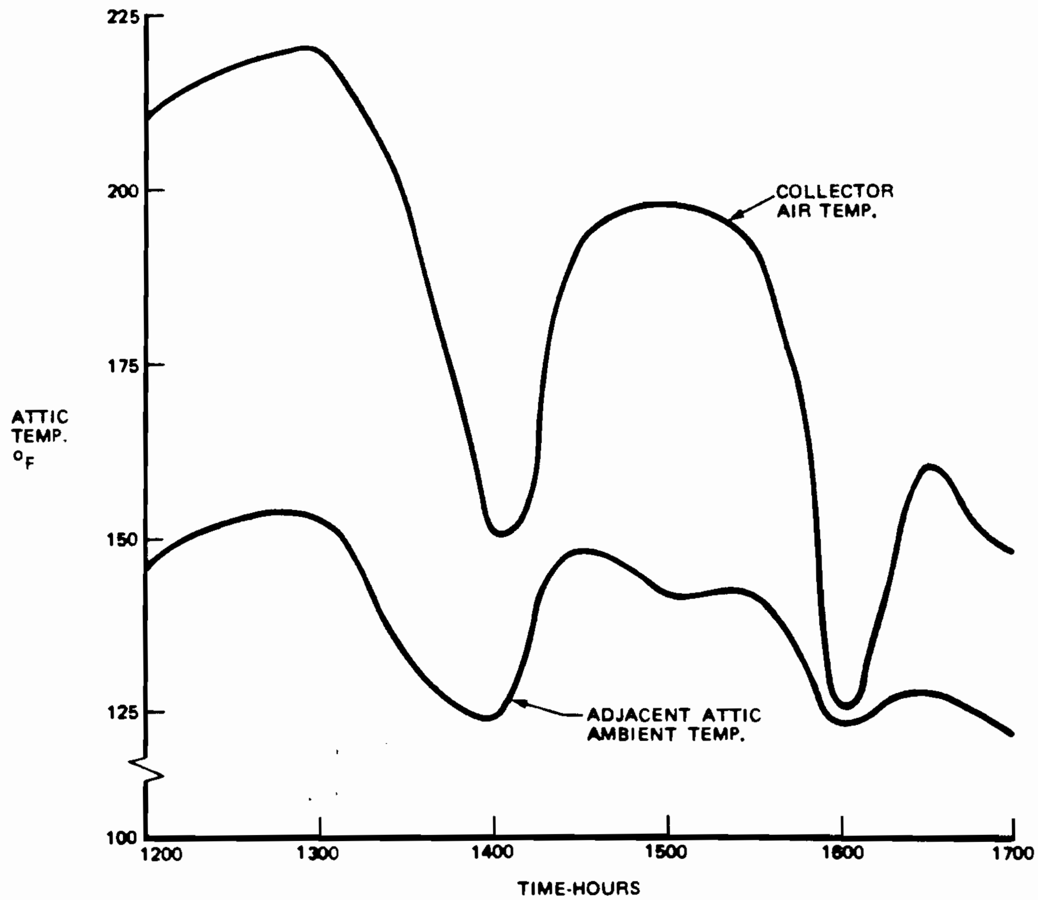


Figure 5-6. Maximum Air Temperatures, Site-Built Collector, Configuration 3

Configuration 1
A maximum solar attic rafter temperature of 198°F was measured near the top. As shown in Figure 5-1, temperature variation between the top and bottom of the rafter is small. Figures 5-1 and 5-3 indicate that maximum solar attic temperatures (175°F) occur approximately one hour before maximum rafter temperatures.

Configuration 2
A maximum solar attic rafter temperature of 183°F (Figure 5-1) was measured near the eaves. Again, Figure 5-1 indicates little temperature difference between the top and bottom of the rafter. A maximum solar attic temperature of 161°F (Figure 5-3) was recorded. As shown in Figure 5-2, solar insolation for this test condition was somewhat less than when temperature measurements were taken for other test conditions.

Configuration 3
A maximum site-built collector rafter temperature of 208°F (Figure 5-4) was measured one foot from the top. Figure 5-4 shows rafter temperatures during a non-operating period when the vents were closed. Temperature profiles are plotted for rafter locations 4 feet, 12 feet, and 15 feet from the bottom of the 16-foot collector. Figure 5-5 shows solar insolation for the day data were obtained. Figure 5-6 includes plots of collector air temperature and the ambient air temperature in the attic. It is interesting to note that a period of low solar insolation occurred during the day that reported site-built collector data were recorded. This day was selected because periods of very high solar insolation also occurred. Figures 5-4, 5-5, and 5-6 show that for site-built collectors, changes in the temperature of the rafter, collector air, and attic ambient air followed very closely the changes in solar insolation.

METHODS FOR REDUCING HIGH WOOD TEMPERATURES

Potential methods for reducing temperatures include forced and natural ventilation, reflective coating on wood surfaces, and thermal insulating materials covering wood surfaces.

Effects of Forced Ventilation, Solar Attics
The effects of forced ventilation were evaluated in Configuration 1. Figure 5-7 compares the effect on maximum rafter temperature of ventilation fans actuated at 160°F and 180°F. Comparing the attic ambient temperature when the fan is initially actuated at 160°F (Figure 5-8) with the effect on maximum rafter temperature (Figure 5-7), the following was observed: Attic ambient temperature dropped to below 150°F and could be maintained at that level with the fan on; maximum rafter temperature initially dropped and then remained approximately constant when the fan was on. The reduction in maximum rafter temperature can also be observed in the plot for fan-on at 180°F (Figure 5-7).

Effects of Natural Ventilation, Solar Attics
The effects of natural ventilation using eave and ridge vents were evaluated in Configuration 2. Figure 5-7 compares maximum rafter temperatures for two conditions, attic vents open and attic vents closed. As shown in Figure 5-8, ambient attic temperature was less than 150°F when attic vents were open. It should be noted that the air vents previously installed and replaced in gabled

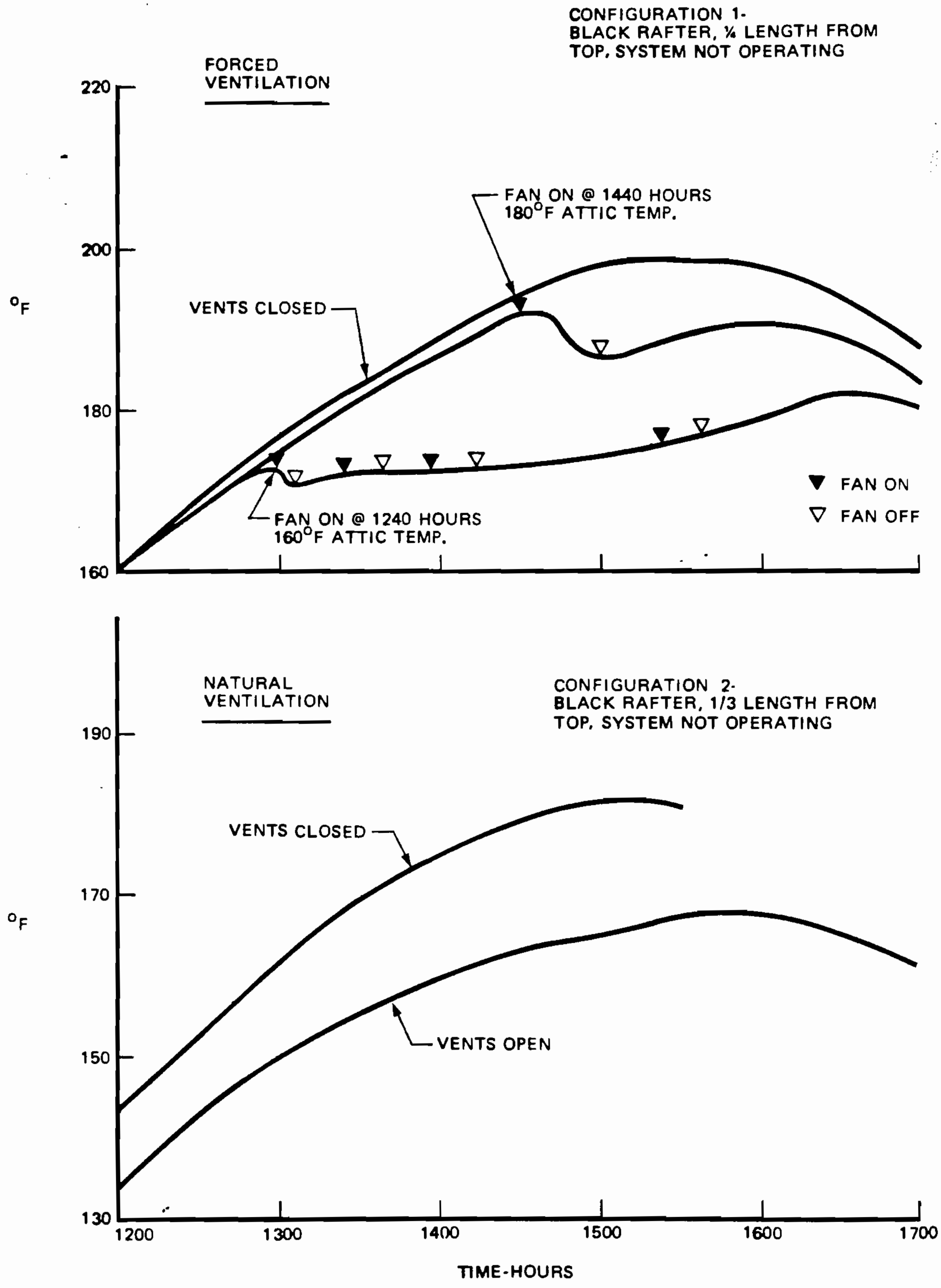


Figure 5-7. Rafter Internal Temperatures, Solar Attics, Forced and Natural Ventilation

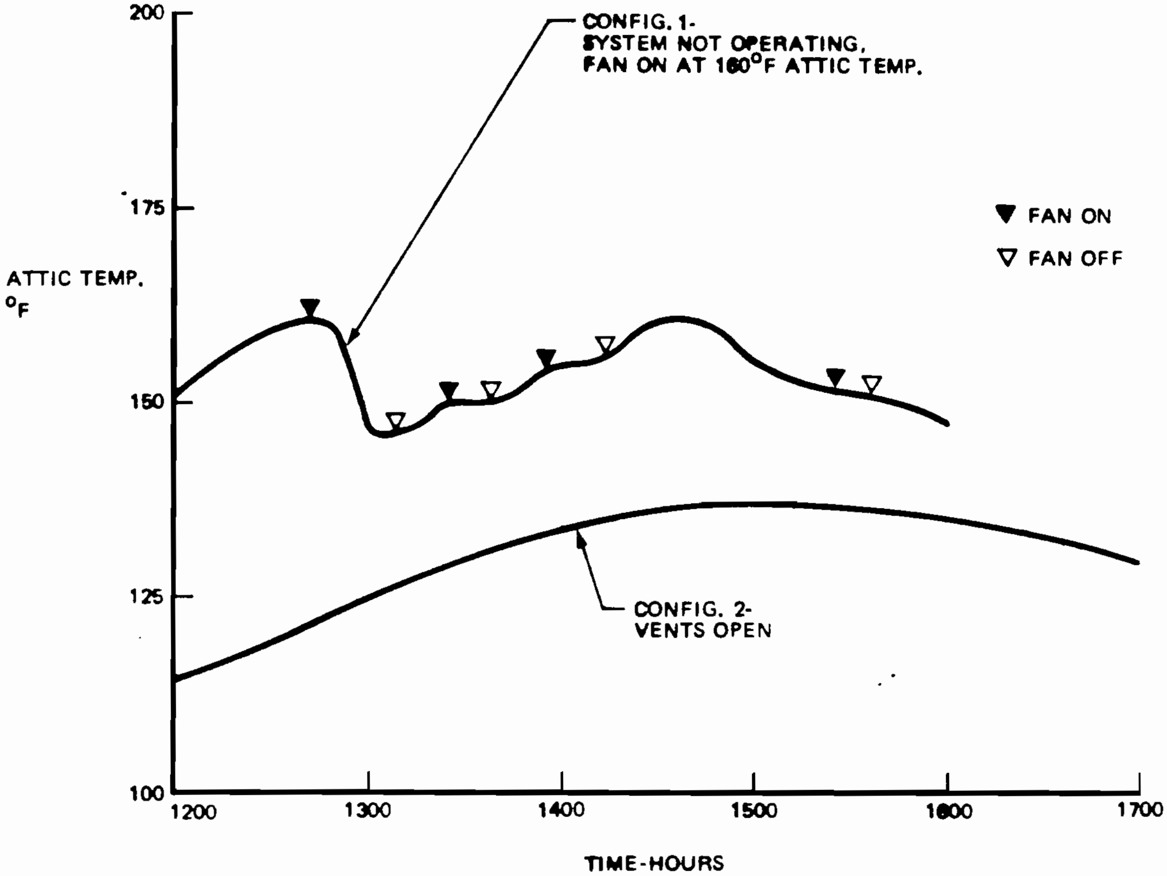


Figure 5-8. Maximum Solar Attic Ambient Temperatures, Forced and Natural Ventilation

walls had minimal effect in reducing attic air temperatures (as shown, ridge vents were more effective).

Effects of Natural Ventilation, Site-Built Collectors

The effects of natural ventilation on rafter temperatures with site-built collectors were shown in Figure 5-4. Maximum rafter temperatures, when the system was not operating, were compared for the vents-open and vents-closed conditions. Maximum temperatures occur at the top end of the rafter when vents are closed; however, from the three-quarter point down, rafter temperatures are higher when the vents are open.

Effects of Reflective Coatings, Solar Attics and Site-Built Collectors

The effects of reflective coating on maximum rafter temperatures for both solar attics and site-built collectors were evaluated using Configuration 2. Figure 5-9 compares various coatings during both vents-open and vents-closed conditions. The reduction in maximum rafter temperature by type of reflective surface appears to have the order shown in Table 5-1. Minimal difference was observed between the vents-open and vents-closed conditions.

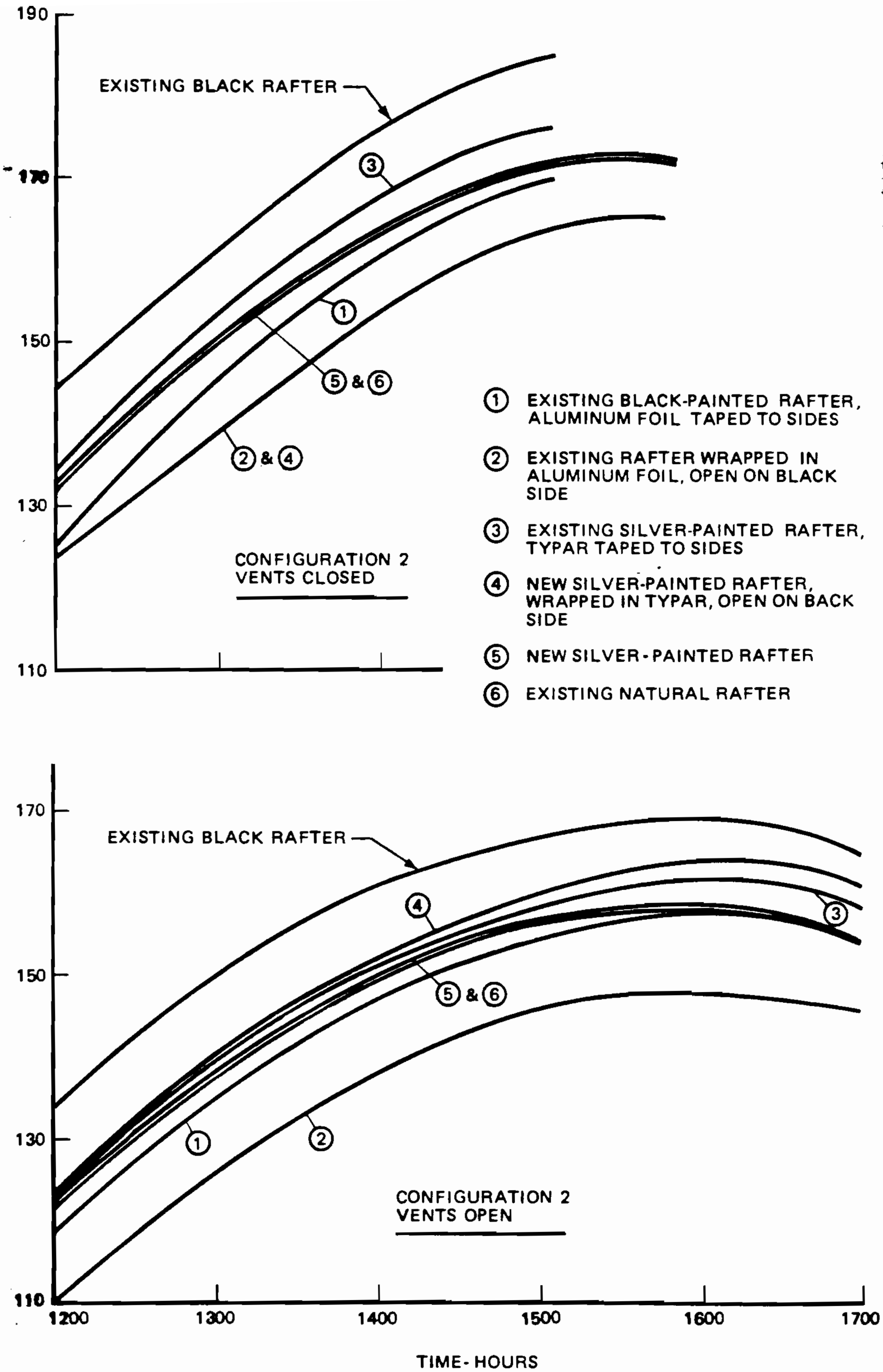


Figure 5-9. Effect of Reflective Surfaces on Rafter Internal Temperatures

TABLE 5-1

HOW REFLECTIVE COATINGS AFFECT RAFTER TEMPERATURES

	Approximate Reduction in Rafter Temperature
Rafter wrapped in Typar or aluminum foil, open on back side	20°F
Rafter with Typar or aluminum foil taped to sides	16°F
Natural rafter	14°F
Silver-painted rafter	12°F

Effects of Thermal Insulation, Solar Attics and Site-Built Collectors

The reduction of wood temperatures by applying rigid insulation between the wood surface and the energy source was evaluated for solar attics and site-built collectors using Configuration 1 (see Attachment A, p. A-4, data for July 9, 1981). Maximum temperature at the center of plywood floor sheathing was 123°F while maximum temperature on the Typar surface was 209°F. Similarly, maximum surface temperature on the back wall covering was 142°F while maximum temperature on the Typar surface was 188°F.

DESIGN CONSIDERATIONS

Evaluation of data suggests that to maintain wood or gypsum board temperatures at a satisfactory level, the following design requirements should be considered for solar attics:

- When the system is not operating, natural or forced ventilation shall be provided so that the maximum attic ambient temperature does not exceed 150°F.
- Wood or gypsum board surfaces exposed to direct solar radiation shall be left natural or covered with a reflective coating. This condition coupled with a maximum attic temperature of 150°F will likely maintain maximum rafter temperatures at less than 150°F, based on the previous analysis indicating

that rafter temperatures remained constant when ventilation maintained attic temperature at 150°F. As seen in Figures 5-1 and 5-3, Configuration 1, an attic temperature of 150°F at 1200 hours relates to a maximum rafter temperature of 163°F. Figure 5-9 indicated that further reductions of 14 to 20°F can be expected with appropriate rafter surfaces.

- Wood surfaces adjacent to solar collector absorber material shall be isolated by thermal insulation with a minimum R-value of 7 and the capability to withstand surface temperatures in excess of 250°F. The insulation must also be ultraviolet (UV)-stabilized.

The same requirements are recommended for site-built collectors with the exception that when the system is not operating, the site-built collector should be vented; and thermal insulation adjacent to absorber materials shall have a minimum R-value of 10 to attenuate the higher expected collector air temperatures.

These proposed design requirements are consistent with previous HUD requirements based on the same or similar supporting data (Attachment E).

CHAPTER 6. RECOMMENDATIONS

Recommendations are made for both solar attics and site-built collectors. In each case the intent is to lower air temperatures, reduce the thermal absorptance of structural wood surfaces, and provide thermal insulation between wood or gypsum board surfaces and the collector absorber materials.

SOLAR ATTICS

- Solar attics should incorporate ventilation systems designed to ensure that attic air temperatures do not exceed 150°F.
- Structural wood material surfaces exposed to direct solar radiation should be left natural or protected by a reflective material.
- Wood and gypsum board surfaces adjacent to solar collector absorber material should be isolated by thermal insulation with a minimum R-value of 7. Insulation should be capable of withstanding surface temperatures in excess of 250°F and should be UV-stabilized.

SITE-BUILT COLLECTORS

- Site-built air collectors should be vented when not operating.
- Wood material surfaces exposed to direct solar radiation should be left natural or protected by a reflective material.
- Wood surfaces that form the collector box of site-built air collectors should be isolated from solar collector absorber material by thermal insulation with a minimum R-value of 10. Insulation shall be capable of withstanding surface temperatures in excess of 250°F and shall be UV-stabilized.

RATIONALE FOR RECOMMENDATIONS

The basis for the stated recommendations is a concern that high wood temperatures maintained for extended periods of time may result in fires or cause a reduction in the structural strength of critical wood members.

The possibility of fire was evaluated by comparing maximum measured wood temperatures to data obtained from related wood fire research. Temperature measurements from the solar attic configurations evaluated indicate that wood structures used as an absorber (i.e. black surface) reach temperatures exceeding 200°F during periods of maximum solar insolation. Measured wood temperatures exceeded 150°F for approximately 6½ hours during clear summer days. Similar temperatures were measured in rafters exposed to the inside of collectors built into the roof rafter structure. Maximum long-term wood temperatures measured in solar collectors were compared to data included in the FPL report (Reference 3) in order to evaluate potential fire hazards in the various collector configurations.

The FPL report states that fire is a concern under prolonged, low-level heating at temperatures over 212°F. Although temperatures measured in the three typical solar collectors evaluated did not exceed 212°F, they were high enough (for this limited sample) to verify the need for maximum temperature controls. Solar collector-related fires are a possibility in the absence of such controls.

Possible reductions in strength of wood members in solar collectors were evaluated by comparing predicted wood temperatures to FPL serviceability data (Reference 4). Based on these wood research studies, wood member temperatures in solar attics or solar collectors should be minimized. FPL has determined that strength may be reduced as wood temperatures increase above 150°F. Observance of the stated recommendations will maintain maximum temperatures well below the maximum allowable temperature (212°F) when considering fire hazards and reasonably close to the maximum allowable temperature (150°F) when considering structural strength.

Additional structural data were obtained from tests of samples taken from Configuration 1 and 3 rafters with known solar exposure histories. FPL performed these tests, which compared results with average values expected for the wood species tested. Although results were not conclusive, because of the limited number of test samples, significant strength reductions (approximately 40%) were observed in the Douglas fir test samples taken from Configuration 1. Data are included in the FPL report, Attachment D.

Data summarized and analyzed in Chapters 4 and 5 include methods for reducing internal wood temperatures. Field data taken from Configurations 1 and 2 (ventilated and unventilated) indicated that when black-painted rafters are exposed to direct solar radiation, internal wood temperatures exceed ambient by an average of 24°F. To evaluate the possibility of reducing the internal temperature of wood members, reflective coating experiments were performed during evaluation of Configuration 2. Results indicate that application of a reflective coating can reduce internal wood temperatures of black-painted rafters by approximately 12 to 22°F. In selecting the coating or determining the extent of coverage, consideration must be given to permitting normal moisture migration in wood, since strength is related to moisture content. Temperatures on a natural surface (uncoated) were approximately the same as those measured on surfaces of some reflective coatings.

Other methods evaluated that resulted in reduced temperatures in solar systems included: 1) natural ventilation in the ridge and eaves of solar attics, 2) forced ventilation of solar attics through gabled end walls, and 3) thermal insulating material between wood materials and solar absorbers in solar attics and site-built collectors.

REFERENCES

1. William D. Walton. Solar Collector Fire Incident Investigation (NBSIR 81-2326). Washington, D.C.: National Bureau of Standards, Center for Fire Research, 1981.

2. Versar Inc. & Burt Hill Kosar Rittleman Associates. Survey and Evaluation of Available Thermal Insulation Materials for Use on Solar Heating and Cooling Systems (DOE/CS/35363-T1). Albuquerque, N.M.: U.S. Department of Energy, Albuquerque Operations Office, 1980.

3. E. L. Schaffer. Smoldering Initiation of Cellulosics Under Prolonged Low-Level Heating. Madison, Wisc.: U.S. Forest Service, Forest Products Laboratory, 1979.

4. ________. "Factors Which Influence Serviceability of Wood Structures: Temperature" (prepared for the Journal of the Structural Division, American Society of Civil Engineers). Madison, Wisc.: U.S. Forest Service, Forest Products Laboratory, 1981.

ATTACHMENT A

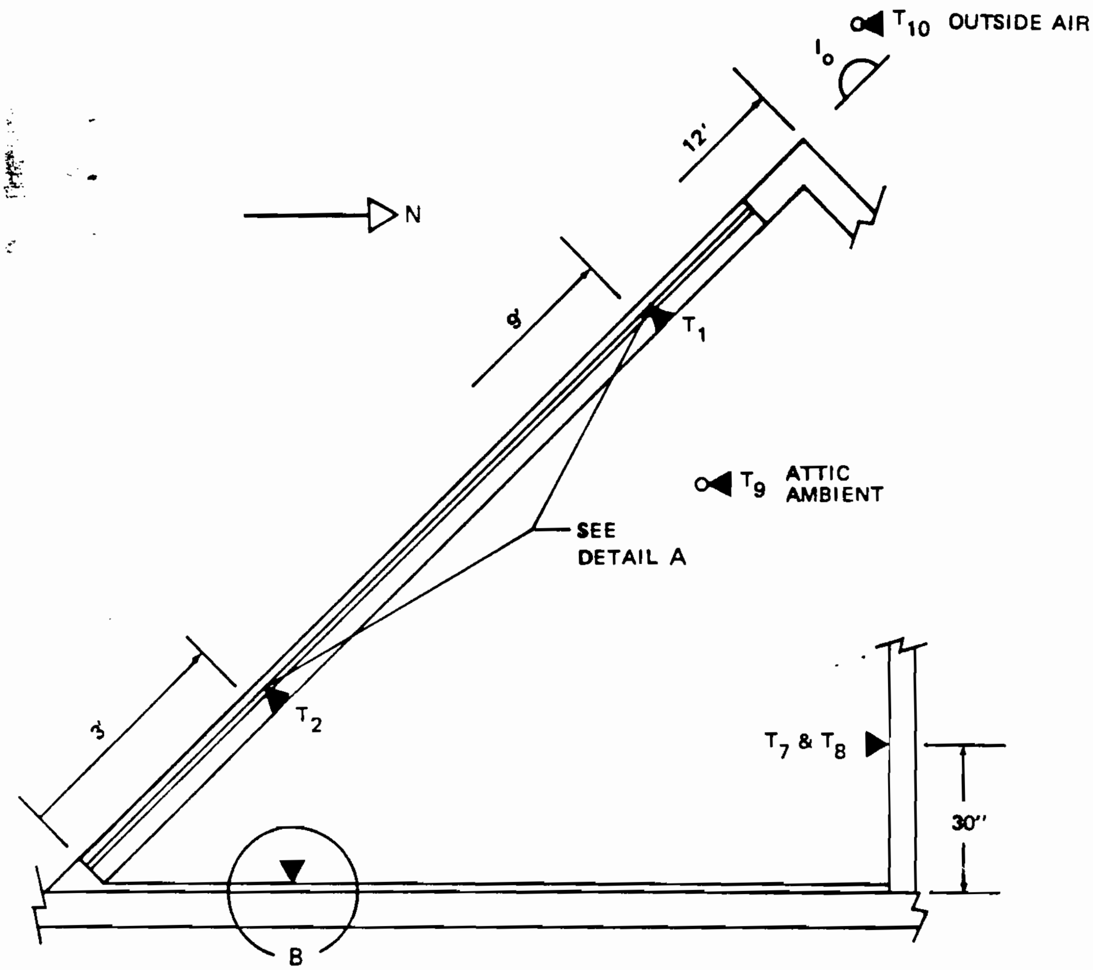
TEMPERATURE SENSOR LOCATIONS AND RECORDED DATA

CONFIGURATION 1

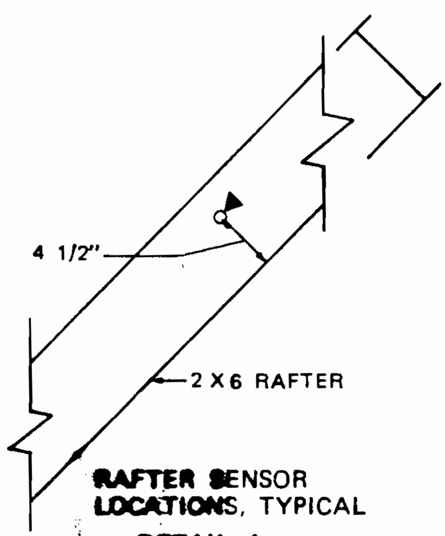
Monterey, California

SUMMARY

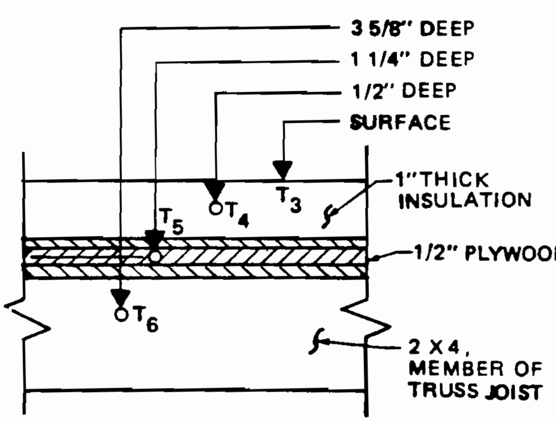
This attachment includes a sketch showing the location of temperature sensors referred to in Chapter 4 of this report. In addition, temperature readings for each condition evaluated were taken at one-half hour increments and are listed for days when maximum solar insolation was recorded. These data are an expansion of data included in Chapter 4 which lists only maximum temperature readings recorded.



TYPICAL ATTIC SECTION, AND SENSOR LOCATIONS



RAFTER SENSOR LOCATIONS, TYPICAL
DETAIL A



FLOOR SENSOR LOCATIONS, TYPICAL
DETAIL B

SENSOR LOCATION	Solar Insolation, in Plane of Glazing	Collector Rafter, Internal--Near Peak	Collector Rafter, Internal--Near Eave	Surface of Floor Insulation	Center of Insulation	Center of ½" Plywood	2" into 2x4 Joist	Surface of Back Wall Insulation	Surface of Back Wall	Solar Attic, Ambient	Outside Ambient
SENSOR IDENTIFICATION	I_o Btu/Hr/Ft^2	T_1 °F	T_2 °F	T_3 °F	T_4 °F	T_5 °F	T_6 °F	T_7 °F	T_8 °F	T_9 °F	T_{10} °F
7-9-81 TIME											
1000	135	105	107	119	106	72	64	108	73	102	68
1030	192	122	124	142	125	80	68	124	81	116	71
1100	220	137	139	156	136	86	73	138	89	130	75
1130	245	149	153	171	148	93	78	150	97	142	76
1200	262	160	164	185	161	100	83	162	106	152	80
1230	275	169	174	195	171	107	88	171	114	160	81
1300	284	177	181	200	176	112	92	179	121	167	75
1330	287	183	186	202	178	116	96	185	128	172	74
1400	285	189	190	207	182	119	99	187	133	174	74
1430	282	194	193	209	184	122	102	188	137	175	73
1500	270	197	194	204	182	123	104	187	140	175	76
1530	250	198	194	194	175	123	106	184	142	173	77
1600	226	198	192	185	167	122	106	178	142	169	74
1630	203	195	186	172	157	119	106	166	141	162	72
1700	170	188	178	159	147	116	105	157	139	153	72
1730	134	178	168	145	136	112	103	145	135	145	71
1800	110	162	154	123	120	108	101	128	130	130	68
1830	108	137	131	104	104	102	98	109	124	115	66
1900	107	117	112	96	96	97	95	101	118	104	63

CONFIGURATION 1
TEMPERATURE MEASUREMENT DATA
System Not Operating -- Manual Vents Closed

SENSOR LOCATION	Solar Insolation, in Plane of Glazing	Collector Rafter, Internal--Near Peak	Collector Rafter, Internal--Near Eave	Surface of Floor Insulation	Center of Insulation	Center of ½" Plywood	2" into 2x4 Joist	Surface of Back Wall Insulation	Surface of Back Wall	Solar Attic, Ambient	Outside Ambient
SENSOR IDENTIFICATION	I_o Btu/Hr/Ft^2	T_1 °F	T_2 °F	T_3 °F	T_4 °F	T_5 °F	T_6 °F	T_7 °F	T_8 °F	T_9 °F	T_{10} °F
8-20-81 TIME											
1000	165	105	107	119	107	68	59	108	70	101	66
1030	200	123	124	139	125	76	63	123	77	116	69
1100	230	138	138	152	136	83	68	139	86	129	72
1130	245	151	150	170	152	90	72	152	95	141	73
1200	265	163	159	184	165	97	77	163	103	151	72
1230	283	172	167	194	173	103	82	172	111	159	70
1300	295	173	166	156	148	103	86	141	113	146	69
1330	295	174	166	153	147	105	88	149	119	151	73
1400	295	175	166	166	157	108	90	154	123	156	76
1430	292	176	165	196	177	110	91	177	126	162	71
1500	275	177	166	189	110	109	93	172	126	156	73
1530	257	184	174	148	146	110	94	148	129	152	70
1600	233	182	171	172	157	109	94	169	130	156	70
1630	200	185	175	170	155	110	95	165	131	154	69
1700	171	182	163	154	145	108	95	152	129	147	67
1730	--	170	140	120	117	103	95	127	124	128	67
1800	--	137	122	103	102	97	93	108	117	108	66

CONFIGURATION 1
TEMPERATURE MEASUREMENT DATA
System Not Operating -- Fan On @ 160°F, Fan Off @ 130°F

SENSOR LOCATION	Solar Insolation, in Plane of Glazing	Collector Rafter, Internal--Near Peak	Collector Rafter, Internal--Near Eave	Surface of Floor Insulation	Center of Insulation	Center of ½" Plywood	2" into 2x4 Joist	Surface of Back Wall Insulation	Surface of Back Wall	Solar Attic, Ambient	Outside Ambient	Non-Solar Home, 2"x4" Rafter, Internal (2½")--Near Peak
SENSOR IDENTIFICATION	I_o Btu/Hr/Ft^2	T_1 ^oF	T_2 ^oF	T_3 ^oF	T_4 ^oF	T_5 ^oF	T_6 ^oF	T_7 ^oF	T_8 ^oF	T_9 ^oF	T_{10} ^oF	$T_1{}^1$ ^oF
TIME												
1000	167	106	107	122	112	74	65	111	77	104	62	
1030	200	123	125	139	125	79	68	123	82	115	65	
1100	230	138	140	151	136	85	71	138	90	129	65	
1130	250	151	153	168	151	91	75	151	97	141	65	
1200	265	162	164	183	164	98	79	162	105	150	68	
1230	285	170	173	193	173	103	82	171	112	158	68	
1300	298	177	180	198	178	107	86	179	119	165	70	
1330	302	183	185	198	178	110	89	185	125	170	69	
1400	298	189	189	204	183	113	92	189	131	174	70	90
1430	290	194	192	206	186	116	95	190	135	176	71	92
1500	280	187	177	192	172	113	96	176	132	158	72	91
1530	264	191	182	188	173	115	96	181	136	168	68	-
1600	235	193	185	178	163	114	97	176	137	165	67	91
1630	202	192	183	173	158	113	98	168	136	160	70	-
1700	170	186	176	156	147	111	98	154	134	149	65	89
1730	--	172	160	122	119	105	97	129	128	128	65	
1800	—	138	132	104	103	99	94	108	120	109	64	
1830	—	116	112	95	95	93	91	99	114	100	64	

CONFIGURATION 1
TEMPERATURE MEASUREMENT DATA
System Not Operating -- Fan On @ 180^{o}F, Fan Off @ 150^{o}F

ATTACHMENT B

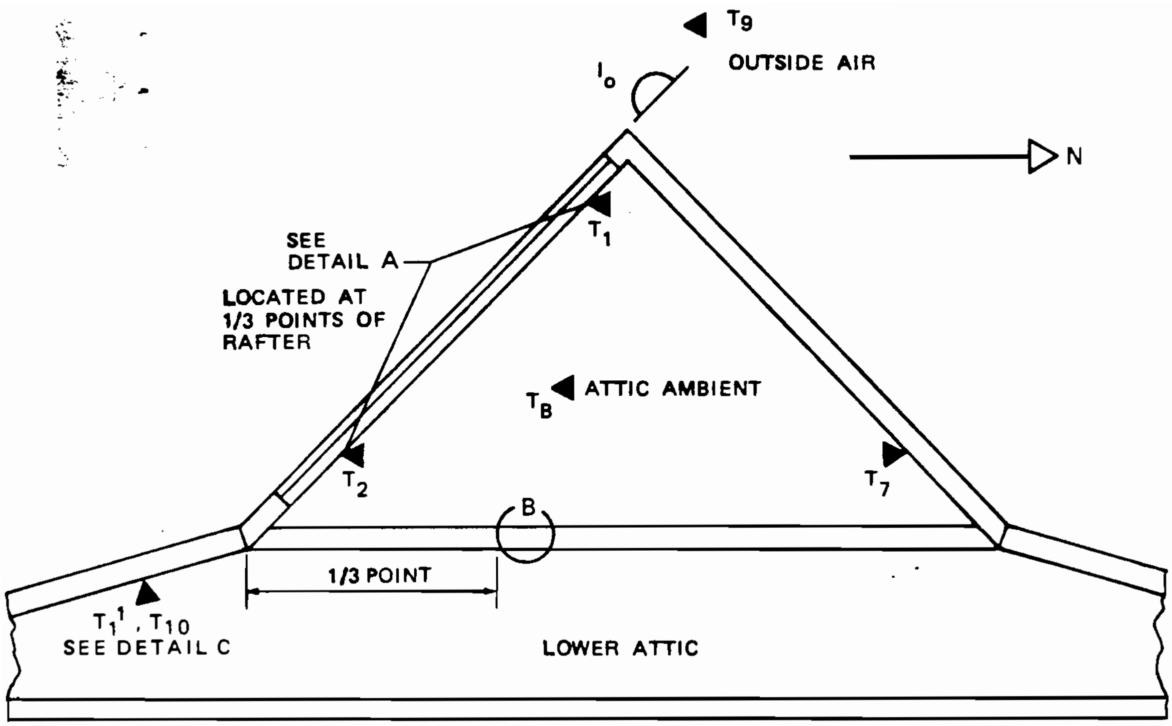
TEMPERATURE SENSOR LOCATIONS AND RECORDED DATA

CONFIGURATION 2

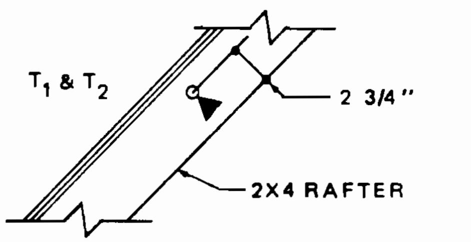
Greenville, South Carolina

SUMMARY

This attachment includes a sketch showing the location of temperature sensors referred to in Chapter 4 of this report. In addition, temperature readings for each condition evaluated were taken at one-half hour increments and are listed for days when maximum solar insolation was recorded. These data are an expansion of data included in Chapter 4 which lists only maximum temperature readings recorded.

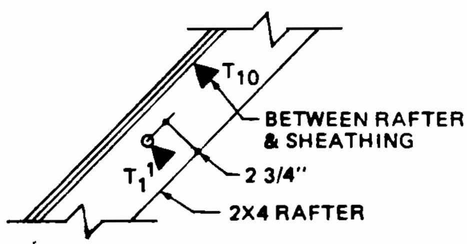


TYPICAL ATTIC SECTION AND SENSOR LOCATIONS



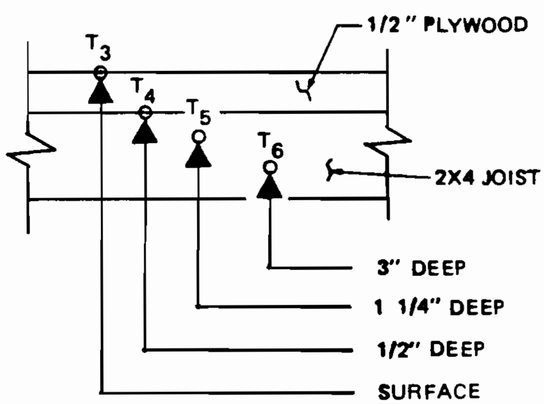
RAFTER SENSOR LOCATIONS, TYPICAL

DETAIL A



LOWER ATTIC

DETAIL C



FLOOR SENSOR LOCATIONS, TYPICAL

DETAIL B

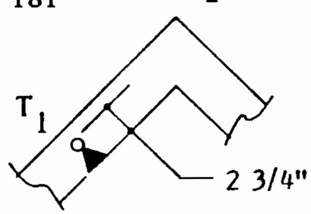
SENSOR LOCATION	Solar Insolation, in Plane of Glazing	Collector Rafter, Internal--Near Peak	Collector Rafter, Internal--Near Eave		Surface of Floor (plywood)	Plywood/Joist Interface	3/4" into Joist	2½" into Joist		West Back Wall, Sheetrock Surface		Solar Attic, Ambient	Outside Ambient		Lower Attic: Rafter, Internal	Lower Attic: Between Rafter & Sheathing
SENSOR IDENTIFICATION	I_o Btu/Hr/Ft^2	T_1 °F	T_2 °F		T_3 °F	T_4 °F	T_5 °F	T_6 °F		T_7 °F		T_8 °F	T_9 °F		$T_1{}^1$ °F	T_{10} °F
TIME																
1030	137	106	108		101	94	87	83		91		102	83		86	95
1100	170	119	122		114	105	96	90		100		113	89		95	105
1130	200	132	136		125	115	105	98		110		123	90		103	114
1200	225	143	147		135	124	114	106		118		133	87		112	122
1230	245	153	157		144	132	121	113		126		140	89		118	128
1300	265	162	166		153	140	128	119		134		147	89		124	134
1330	275	170	174		161	147	135	125		141		154	88		130	140
1400	255	175	178		165	152	140	130		146		157	91		134	143
1430	258	179	181		168	156	144	134		150		161	90		138	145
1500	145	182	183		163	156	147	131		151		158	88		139	147
1530	085	181	181		156	155	148	139		150		155	--		140	145

CONFIGURATION 2
TEMPERATURE MEASUREMENT DATA
System Not Operating -- Vents Closed

SENSOR LOCATION	Solar Insolation, in Plane of Glazing	Collector Rafter, Internal--Near Peak	Collector Rafter, Internal--Near Eave	Surface of Floor (plywood)	Plywood/Joist Interface	3/4" into Joist	2½" into Joist	West Back Wall, Sheetrock Surface	Solar Attic, Ambient	Outside Ambient
SENSOR IDENTIFICATION	I_o Btu/Hr/Ft^2	T_1 °F	T_2 °F	T_3 °F	T_4 °F	T_5 °F	T_6 °F	T_7 °F	T_8 °F	T_9 °F
TIME										
1000	--	86	89	84	78	72	69	75	82	71
1030	159	99	103	94	86	80	75	83	92	78
1100	193	112	116	105	96	88	82	90	99	80
1130	220	124	129	115	104	96	89	98	107	80
1200	245	134	140	124	113	103	96	105	114	80
1230	267	143	148	131	120	110	102	112	120	85
1300	285	150	155	138	126	115	107	118	125	81
1330	300	155	160	144	131	120	111	123	131	82
1400	307	160	164	149	136	125	115	128	134	82
1430	291	163	165	151	139	128	119	131	136	81
1500	285	165	167	152	141	130	121	134	137	83
1530	275	167	168	151	141	132	122	135	136	82
1600	255	167	168	150	141	132	123	135	136	82
1630	230	165	165	145	138	131	123	134	133	82
1700	202	161	160	140	135	129	121	132	130	81
1730	163	156	154	135	131	126	119	128	126	82
1800	113	147	144	127	125	122	116	123	119	81
1830	038	137	132	119	119	117	113	118	113	79
1900	018	125	120	111	112	112	109	112	107	77

CONFIGURATION 2
TEMPERATURE MEASUREMENT DATA
System Not Operating -- Vents Open

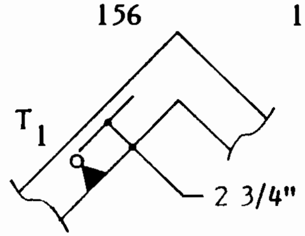
RAFTER SURFACE CONDITION	Reference Condition, Painted Black	Existing Black-Painted Rafter, Aluminum Foil Taped to Sides	Existing Rafter Wrapped in Aluminum Foil, Open on Back Side	Existing Silver-Painted Rafter, Typar Taped on Sides	New Silver-Painted Rafter, Wrapped in Typar, Open on Back	New Silver-Painted Rafter	Existing Natural Rafter
SENSOR IDENTIFICATION	T_1 °F	T_1 °F	T_1 °F	T_1 °F	T_1 °F	T_1 °F	T_1 °F
TIME							
1030	106	94	90	100	90	98	98
1100	119	104	101	111	101	110	109
1130	132	115	111	123	112	121	120
1200	143	126	122	134	123	132	131
1230	153	136	131	144	133	142	140
1300	162	146	140	153	141	150	148
1330	170	154	148	161	149	158	156
1400	175	161	154	167	155	164	161
1430	179	165	159	171	159	168	166
1500	182	169	163	174	163	171	169
1530	181	-	163	-	163	171	168



Rafter Sensor Location, Typical

CONFIGURATION 2
TEMPERATURES RESULTING FROM RAFTER REFLECTIVE SURFACES
System Not Operating -- Vents Closed

RAFTER SURFACE CONDITION	Reference Condition, Painted Black	Existing Black-Painted Rafter, Aluminum Foil Taped to Sides	Existing Rafter Wrapped in Aluminum Foil, Open on Back Side	Existing Silver-Painted Rafter, Typar Taped to Sides	New Silver-Painted Rafter, Wrapped in Typar, Open on Black	New Silver-Painted Rafter	Existing Natural Rafter
SENSOR IDENTIFICATION	T_1 °F	T_1 °F	T_1 °F	T_1 °F	T_1 °F	T_1 °F	T_1 °F
TIME							
1030	99	86	81	92	88	89	90
1100	112	96	91	103	100	100	101
1130	124	107	100	113	112	111	111
1200	134	117	109	123	123	121	121
1230	143	126	118	132	133	129	129
1300	150	134	125	139	141	136	136
1330	155	141	132	145	148	142	142
1400	160	147	138	151	153	147	147
1430	163	150	141	154	157	151	150
1500	165	153	145	157	161	153	153
1530	167	155	146	159	163	155	154
1600	167	155	147	160	164	155	154
1630	165	154	147	159	163	154	153
1700	161	151	144	155	161	151	149
1730	156	147	141	151	157	147	145



Rafter Sensor Location, Typical

CONFIGURATION 2
TEMPERATURES RESULTING FROM RAFTER REFLECTIVE SURFACES
System Not Operating -- Vents Open

ATTACHMENT C

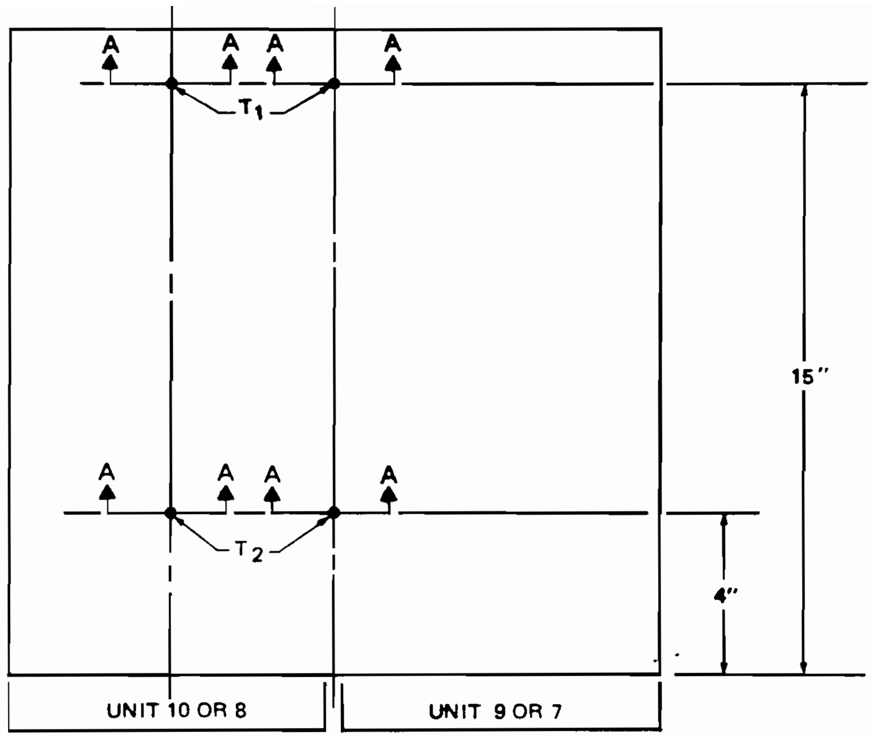
TEMPERATURE SENSOR LOCATIONS AND RECORDED DATA

CONFIGURATION 3

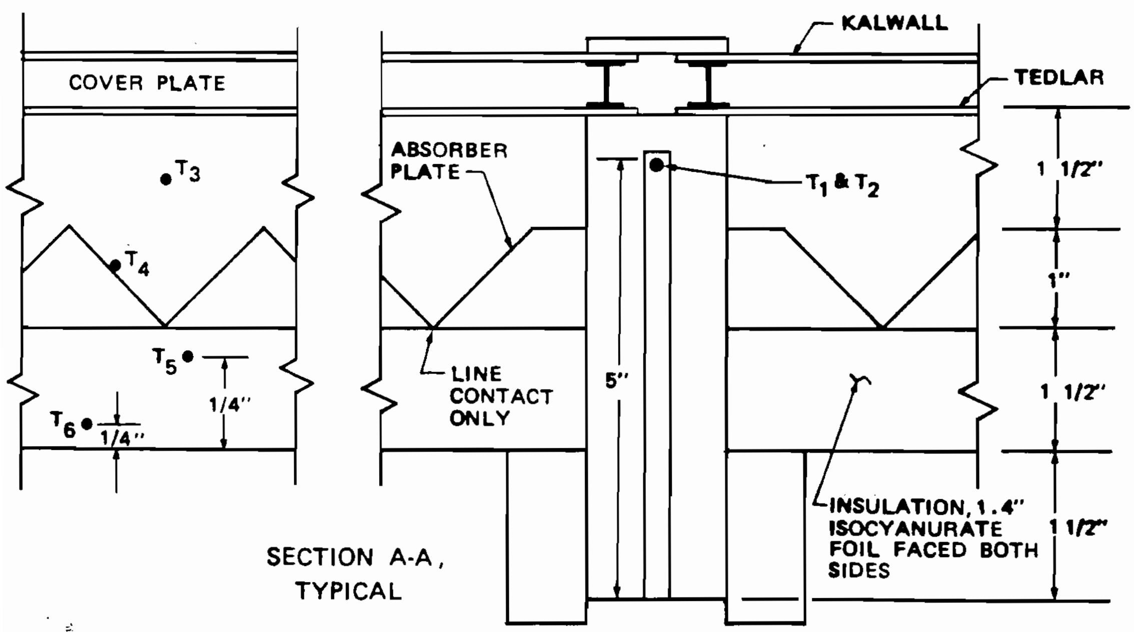
North Conway, New Hampshire

SUMMARY

This attachment includes a sketch showing the location of temperature sensors referred to in Chapter 4 of this report. In addition, temperature readings for each condition evaluated were taken at one-half hour increments and are listed for days when maximum solar insolation was recorded. These data are an expansion of data included in Chapter 4 which lists only maximum temperature readings recorded.



PLAN VIEW -- TYPICAL UNITS



SECTION A-A, TYPICAL

SENSOR LOCATION	Solar Insolation, in Plane of Glazing		Collector Rafter, Internal--Near Peak	Collector Rafter, Internal--Near Eave		Collector, Air		Absorber Plates		Isocyanurate Insulation, Top	Isocyanurate Insulation, Bottom		Heat Dump, Ambient
SENSOR IDENTIFICATION	I_o Btu/Hr/Ft^2		T_1 ^oF	T_2 ^oF		T_3 ^oF		T_4 ^oF		T_5 ^oF	T_6 ^oF		T_7 ^oF
6-28-81													
TIME													
1000	160		143	111		154		172		137	101		110
1030	185		160	122		173		194		153	108		120
1100	215		176	131		190		214		167	115		130
1130	240		189	139		200		229		179	121		139
1200	270		199	144		211		241		189	126		146
1230	275		207	151		220		251		197	131		151
1300	287		208	153		222		256		197	133		153
1330	292		169	132		199		229		151	116		133
1400	77		168	131		151		167		160	121		124
1430	100		192	147		193		218		195	132		148
1500	237		183	142		198		228		181	127		142
1530	200		187	150		192		221		180	129		142
1600	40		169	141		126		135		139	121		123
1630	164		160	135		161		181		155	121		128
1700	123		155	137		148		162		146	119		122
1730	90		145	130		131		142		133	115		116
1800	60		132	120		114		123		120	110		110

CONFIGURATION 3
TEMPERATURE MEASUREMENT DATA
System Not Operating -- Vents Closed

SENSOR LOCATION	Solar Insolation, in Plane of Glazing		Collector Rafter, Internal--Near Peak	Collector Rafter, Internal--Near Eave		Collector, Air		Absorber Plates		Isocyanurate Insulation, Top	Isocyanurate Insulation, Bottom		Heat Dump, Ambient
SENSOR IDENTIFICATION	I_o Btu/Hr/Ft^2		T_1 ^oF	T_2 ^oF		T_3 ^oF		T_4 ^oF		T_5 ^oF	T_6 ^oF		T_7 ^oF
6-28-81 TIME													
1000	160		133	120		147		173		141	103		110
1030	185		149	131		164		194		158	111		120
1100	215		165	141		180		215		174	119		130
1130	240		179	149		190		230		186	125		139
1200	270		187	153		199		243		197	131		146
1230	275		198	159		207		252		205	136		151
1300	287		201	160		210		258		206	137		153
1330	292		167	136		182		228		154	117		133
1400	77		163	134		147		168		163	124		124
1430	100		187	149		189		222		203	136		148
1500	237		182	144		189		228		188	130		142
1530	200		191	149		185		221		185	133		142
1600	40		178	141		122		136		138	122		123
1630	164		166	133		153		180		158	123		128
1700	123		163	133		141		160		147	120		122
1730	90		153	127		126		140		133	115		116
1800	60		137	118		110		121		119	110		110

CONFIGURATION 3
TEMPERATURE MEASUREMENT DATA
System Not Operating -- Vents Open

SENSOR LOCATION	Solar Insolation, in Plane of Glazing	Collector Rafter, Internal--Near Peak	Collector Rafter, Internal--Near Eave	Collector, Air	Absorber Plates	Isocyanurate Insulation, Top	Isocyanurate Insulation, Bottom	Heat Dump, Ambient
SENSOR IDENTIFICATION	I_o Btu/Hr/Ft^2	T_1 ^oF	T_2 ^oF	T_3 ^oF	T_4 ^oF	T_5 ^oF	T_6 ^oF	T_7 ^oF
6-28-81 TIME								
1000	160	134	107	117	135	116	99	110
1030	185	145	112	131	152	128	106	120
1100	215	158	118	145	169	141	114	130
1130	240	171	125	155	184	152	120	139
1200	270	180	129	162	195	161	125	146
1230	275	188	133	170	204	168	130	151
1300	287	187	133	172	209	168	130	153
1330	292	152	114	154	187	135	112	133
1400	77	147	114	116	133	134	119	124
1430	100	167	126	155	183	168	131	146
1500	237	160	122	156	186	156	125	142
1530	200	162	125	153	180	154	127	142
1600	40	152	121	102	114	117	116	123
1630	164	137	115	129	148	134	118	128
1700	123	134	115	120	134	126	116	122
1730	90	127	112	110	121	117	112	116
1800	60	118	107	100	110	109	108	110

CONFIGURATION 3
TEMPERATURE MEASUREMENT DATA
System Operating -- Vents Closed

ATTACHMENT D

FOREST PRODUCTS LABORATORY REPORT

RAFTER ANALYSIS, CONFIGURATIONS 1 AND 3

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
Forest Products Laboratory
Box 5130
Madison, WI 53705

4700-1
October 15, 1981

Mr. H. R. Sparkes, District Manager
Dubin - Bloome Associates, P.C.
312 Park Road
West Hartford, CT 06107

Dear Bob:

You had forwarded two rafters from attic type solar collectors in Miramec, Calif. and North Conway, N.H. along with relevant temperature histories at each location.

The rafter section from North Conway was identified as being Spruce and that from Miramec Douglas-fir. From each rafter clear specimens 1- by 1.5- by 22-inches long were extracted. These were subjected to standard center point bending tests with each specimen oriented so that the outside edges of the rafter were at the top and bottom of the bending test specimens. Determined for each specimen were:

Modulus of rupture (MOR)
Modulus of elasticity (MOE)
Work to maximum load (W/V)

A summary of the results of the tests is included as Table 1 and 2.

If these results are compared with species averages (at equivalent moisture contents and specific gravities), the following is seen:

	MOR		W/V	
	Spruce	Douglas-fir	Spruce	Douglas-fir
Observed	10,180	7,985	11.05	5.12
Species population	10,200	12,400	8.4	9.1

FDO-11 (1/68)

The Douglas-fir appears to be significantly lower in bending strength and is also lower in work absorption capacity. The spruce is close to that obtained for the spruce population.

We can only conclude from this very limited data and analysis, that it is possible that the Douglas-fir rafter from Miramec, Calif. is lower in strength than the Douglas-fir population. This may be due to a number of factors of which one is thermal degradation in the solar collector in California. Testing of a much larger number of specimens would be required to prove whether the effect observed in one rafter is real or just the occurrence of chance.

Sincerely,

Erwin L. Schaffer

E. L. SCHAFFER, Project Leader
Fire Design Engineering

Preceding page

TABLE 1

MECHANICAL PROPERTIES OF BENDING TEST SPECIMENS
FROM SOLAR COLLECTOR RAFTER IN NORTH CONWAY, N.H. (SPRUCE)

Specimen No.	MOR (psi)	Work per Unit Volume (in.-lb/in^3)	MOE (Ksi)	Moisture Content (%)	Dry Spec. Gravity
AB-1	11,730	11.93	1,698	8.22	.418
AB-2	12,620	12.42	1,740	7.51	.412
AB-3	13,210	12.75	1,649	4.66	.419
AB-4	12,210	11.26	1,594	6.43	.414
AT-1	13,260	12.03	1,736	7.13	.415
AT-2	12,780	14.05	1,684	6.92	.403
AT-3	11,730	6.18	1,704	4.82	.401
AT-4	13,820	13.13	1,901	4.83	.418
Mean	12,670	11.72	1,713	6.32	.412
S.D.	752	2.39	89	1.38	.007
COV	5.89%	20.4%	5.22%	21.8%	1.7%

TABLE 2

MECHANICAL PROPERTIES OF BENDING TEST SPECIMENS
FROM SOLAR COLLECTOR RAFTER IN MONTEREY, CALIF. (DOUGLAS FIR)

Specimen No.	MOR (psi)	Work per Unit Volume (in.-lb/in^3)	MOE (Ksi)	Moisture Content (%)	Dry Spec. Gravity
B-1	11,430	4.96	1,815	5.28	.472
B-2	9,400	3.11	1,787	4.50	.467
B-3	8,080	2.07	1,753	5.89	.496
B-4	9,870	3.55	1,810	4.96	.496
T-1	13,450	9.35	1,945	4.63	.477
T-2	12,740	7.65	1,968	4.02	.474
T-3	12,690	4.89	2,354	3.91	.517
T-4	12,080	5.30	1,743	5.00	.443
T-5	11,070	6.81	1,890	4.38	.471
T-6	12,470	7.67	1,898	3.70	.450
T-7	7,010	1.55	1,798	3.96	.440
T-8	8,600	2.54	1,692	4.10	.464
Mean	10,740	4.95	1,871	4.53	.472
S.D.	2,102	2.50	173	0.65	.023
COV	19.58%	50.5%	9.3%	14.4%	4.8%

ATTACHMENT E

HUD SOLAR ATTIC COLLECTOR SYSTEM SAFETY CONDITIONS

Memorandum

U.S. DEPARTMENT OF
HOUSING AND URBAN DEVELOPMENT

TO: Thomas Sherman, Director
Office of Public Housing, HGP

DATE: SEP 28 1981

IN REPLY REFER TO:

FROM: Joseph Sherman, Division of Energy, Building
Technology and Standards Research, TRB

SUBJECT: Solar Attic Collector Systems

Reference is made to your memorandum of September 15, 1981, on the same subject. We became concerned about possible problems with solar attic collector systems when we found significant deterioration of some wood products which had been exposed to temperatures over 200°F. When exposed to such temperatures for extended periods, wood can change its properties; in particular, both the structural strength and ignition temperatures can be significantly reduced.

After collecting and evaluating information on the performance of several of these systems, we believe that the solar attic collector concept is safe, provided certain conditions are met. We have advised Dominic Eng, of the Technical Support Division, that any project approval recommended by your office should incorporate the following six safety conditions:

1. All structural members (rafters, truss members, etc.) exposed to direct solar radiation must be painted white. In order to permit normal moisture migration in the wood, however, we suggest that the lower edge of the rafter, not exposed to sunlight, be left without paint.

2. No plywood or gypsum board panels are to be used as absorbers by being painted black and exposed to direct solar radiation. We have found these materials to be severely deteriorated in this use. Other materials, capable of withstanding the high temperatures from direct radiation, should be used.

3. The material chosen for the absorbing surface must be isolated from any supporting plywood, gypsum board, or other wood framing members. The insulation must withstand the high temperatures of the absorber material.

4. The peak of the solar collector area is not to be a structural part of the roof system. This area is subjected to the highest ambient temperatures.

5. The maximum ambient air temperature in the attic is not to exceed 150°F. This can be achieved either by using a fan system or by providing a gravity ventilation system with temperature-controlled dampers. I don't think HUD should specify the type of system, but your field offices should review the approach taken by the builder.

6. No wiring is to be run through the heated attic area. High attic temperatures can degrade wire insulation.

With these provisions, I believe that solar attic collector systems can safely be used in HUD housing programs.

Director

CREDITS

The Technical Services group of BE&C Engineers (a Boeing subsidiary) produced this management support contractor's report. Government Technical Representatives Robert C. Jones, Jr. and William Freeborne furnished general guidance. As the Boeing program manager, David R. Beers was responsible for overall direction. James D. Akins, Robert J. Cole, Randolph Kirk, and John C. Stevens prepared the text for Volume III, with a Dubin-Bloome Associates contribution from H. Robert Sparkes. E. K. Muller was book manager, aided by Kathryn M. Talbott, secretary, and George Gulacsik, artist.