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DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-150601

PRELIMINARY DESIGN REVIEW PACKAGE ON AIR FLAT PLATE COLLECTOR FOR SOLAR HEATING AND COOLING SYSTEM

Prepared by
Life Sciences Engineering
Route 1, Box 746
Morrison, Colorado 80465

Under Contract NAS8-32261 with
National Aeronautics and Space Administration
George C. Marshall Space Flight Center, Alabama 35812

For the U. S. Department of Energy

U.S. Department of Energy

Solar Energy
**Abstract**

This Preliminary Design Review Package as received from Life Sciences Engineering covers development and fabrication of a prototype air flat plate collector subsystem containing 320 square feet (10-4' x 8' panels) of collector area.

The package contains:

- Verification Plan
- Thermal Analysis
- Safety Hazard Analysis
- Drawing List
- Special Handling, Installation and Maintenance Tools
- Structural Analysis
- Selected Drawings

The MSFC review and critique of this Design Review Package are not included.

Some reformatting and renumbering of this package have been done for clarity purposes.
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SECTION A

VERIFICATION PLAN
No. SHC-3071

Air Flat Plate Collector

December 30, 1976

Life Sciences Engineering
Rt. 1, Box 746
Morrison, Colorado 80465
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1. **Introduction**

   This Verification Plan is a process of proving that the hardware meets applicable physical and functional design requirements. The process begins with the Development Phase and is completed at the end of the Verification Phase.

1.1. **Purpose**

   The purpose of the Verification Plan is to verify that the subsystem and components comply with the Subsystems Performance Specification. Where applicable, special handling and maintenance equipment will be evaluated to ensure they meet design requirements.

1.2. **Objectives**

   The tasks specified in the Statement of Work and in Appendix C shall be accomplished to meet the following objectives:

   1.2.1 Meet Interim Performance Criteria
   1.2.2 Meet Subsystem Performance Specifications
   1.2.3 Meet Design Requirements for special handling, installation and maintenance equipment

2. **Development Phase**

   During the Development Phase analyses and tests of various design approaches will ensure that the final selected approach will result in reliable hardware that will function with a high probability of success. The Test Matrix, Figure 2-1 shows the various design tests to be accomplished. The Air Flow/Plenum Depth testing is considered very important to the design concepts and to the Subsystem Performance Specification. This test is designed to determine the optimum plenum spacing and air flow rate for the collector to provide a maximum temperature of 130°F for heated air at the outlet at the register in the house.

3. **Verification Phase**

   The final selected approach determined during the Development Phase will be analyzed and tested to design limits to ensure that it meets the physical and functional requirements. Qualification testing is planned to be completed prior to manufacturing the deliverable prototype units. If an item has not changed to the extent that it would invalidate the Development Test Results, then the development test results may be used as a basis for qual-
ifying the item in lieu of running qualification tests.

4. **Acceptance Phase**

The Acceptance Phase consists of inspecting and testing the subsystem to verify that physical and operational characteristics are within specifications.

5. **Verification Cross Reference Matrix**

The following Verification Cross Reference Matrix briefly summarizes individual performance requirements and the verification method used in each verification phase to assure compliance. Section 6 provides the rationale for the verification method and explains comments in the Remarks column.

6. **Verification Method Rationale**

This section will provide an explanation for the verification method (1. similarity, 2. analysis, 3. inspection and 4. test) selected for the individual performance requirement in the Verification Cross Reference Matrix. In addition, comments briefly mentioned in the Remarks column will be elaborated upon. Items that were designated 'NA' on the October 1, 1976 Verification Cross Reference Matrix will not be elaborated upon.

<table>
<thead>
<tr>
<th>Paragraph</th>
<th>Explanation</th>
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<tbody>
<tr>
<td>1.2.4 Operational Impairment</td>
<td>This item is considered NA as paragraph 1.2 specifies HW System/Subsystem Performance. This is a heating system only.</td>
</tr>
<tr>
<td>1.3 Collector Performance</td>
<td>Collector performance shall be determined by evaluation of the drawings, analytical calculations and testing under operational conditions, as further described in the following paragraph.</td>
</tr>
<tr>
<td>1.3.1 Collector Efficiency</td>
<td>Test Data shall be presented at the Design Reviews. This data includes: input air temperature and flow rate, output air temperature, collector absorber back surface temperatures, solar radiation, outside ambient temperature and time.</td>
</tr>
<tr>
<td>2.1 System Design Conditions</td>
<td>The collector shall be operated and tested at the design temperatures and flow rates and in accordance with the following paragraphs.</td>
</tr>
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</table>
Initial Thomas meter data indicated that it can detect poor blower loading. Thomas meter data recordings will be evaluated into flow rates.

2.1.2 Noise or Erosion
Corrosion

The collector was designed for laminar flow rates and minimizing noise. Inspection of drawings and operational demonstration will show minimum noise conditions. Erosion-corrosion is minimized in the collector as all metal components are of aluminum.

2.1.3 Operating Conditions

Collector drawings, specifications, and historical performance, prior test data and design calculations will show capabilities of components to function at operational conditions without deterioration.

2.1.4 Fluid Flow in Collectors

The test facility manifolds to the collectors have Thomas meters to monitor flow rates. If the meter data indicates flow rates are unequal dampers will be adjusted to equalize flow rates.

2.1.7 Pressure Drops

Inspection of the collector drawings and test facility drawings will show that they were designed to minimize flow resistance.

2.2 Mechanical Stress

Mechanical stress on the Collectors have been minimized by design and will be reviewed in the following paragraphs:

2.2.1 Vibration Stress Levels

The collectors have no moving parts. Inspection of drawings and demonstration of the system in operation will show minimal vibration.

2.2.2 Vibration from Moving Parts

The blower is the only moving component in the system. Inspection of drawings and the blower will show it has been mounted properly to minimize vibrations. An operational demonstration of the blower will demonstrate minimal vibrations or sympathetic vibrations in the collector.

2.2.5 Thermal Changes

A review of the drawings, specifications and calculations will show that the collector design has allowed for thermal movement.

2.2.6 Flexible Joints

This item is considered NA as there are no flexible joints in the collectors or total system.

2.3 Leakage Prevention

The collector has been designed to minimize air leakage, and this design feature will be reviewed in item 3.3.2.
2.3.1 Pressure Test: Nonpotable Fluids
This item is considered NA as it is required for heat transfer fluids other than air.

2.3.2 Pressure Test: Potable Water
This item is considered NA as it is required of systems using potable water.

2.3.3 Air Transport Systems
Inspection of test facility ducting will show it meets NPS specifications. Insulation for the collector plenum or ducting is provided on the outer sides and behind the collector as shown in drawings.

2.4 Collector Adjustment
This item is considered NA as the design specifies a fixed orientation and tilt.

2.4.1 Orientation and Tilt
This item is considered NA for the same reason as item 2.4.

2.4.2 Mutual Shadowing
Mutual shadowing will be shown by photographs taken of the collectors at various times during the day and year.

2.6 Heat Transfer Quality
The heat transfer fluid quality shall be maintained in accordance with the following applicable paragraphs:

2.6.2 Air Quality
A review of the drawings, specifications and the collector will show provisions for minimizing deposits of dust and dirt. The test facility blower will be checked for dust and cleaned if needed.

2.8 Excessive Pressure and Temperature Protection
This item is considered NA as this item is considered a system function.

3.1 Structural Design Basis
The collector structural design basis has been developed in accordance with the following paragraphs:

3.1.1 Applicable Standards
The HUD Minimum Property Standards for One and Two Family Dwellings shall be used in the evaluation of connections and supporting elements based on loads anticipated during the service life of the collectors. The MPS will be used in the review of drawings, specifications and structural calculations.

3.1.2 Service Loads
The following loads shall be used in evaluating the structural design of the collectors:
Dead Loads shall be calculated using the actual weight of the collector. Calculations shall be based on generally accepted engineering practices.

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Live Loads shall be evaluated in accordance with NPS 601-3, to consider the weight of all moving or variable loads on the collectors. For the collectors designed for a tilt angle between 50° and 70°, the live load shall be 15 psf, on the horizontal projection of the collector area.

Snow Loads on the collectors shall be evaluated in accordance with ANSI A58.1.

Wind Loads effects on the collector structure shall be evaluated in accordance with NPS standards for roofs. The analysis for collectors designed for 50° to 70° tilt angle shall show capability to withstand pressures acting inward normal to the surface, equal to the design wind pressure.

Earthquake Loads analysis for the collectors shall be based on the latest available Uniform Building Code.

Constraint Loads caused by the environment shall be shown in the 1 year history of the prototype collector that has been in daily stagnation testing. Samples of Tedlar are available from indoor storage, the outer glazing and the inner glazing. The inner Tedlar glazing had the more severe constraint load, high stagnation temperatures.

Constraint Loads induced by differential foundation settlement effects on the collector are considered NA as IPC 3.8.1 considers conventional elements as meeting this criterion. All components are considered conventional elements.

Ice Loads shall be analyzed in accordance with IPC load combinations:
(1) $1.4D \times 1.7L$
(4) $1.1D \times 1.3L \times 1.7W$

The mean annual number of days with glaze varies from 4 to 8. The live load calculation for ice will be a 3/4 inch thickness.

Hail Loads analysis shall be developed in accordance with IPC which indicated 4 to 6 days of hail per year which estimates the hail size at 1.5". NASA test data on Tedlar is requested to support this analysis.

Vehicular Loads are considered NA as the collectors will be on structures away from roads.

3.2 Failure Loads and Load Capacity

3.2.1 Ultimate Load Combinations

This item is considered NA as all components are conventional elements.
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
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<tbody>
<tr>
<td>3.2.2</td>
<td>Ice Loads</td>
</tr>
<tr>
<td></td>
<td>This item is considered NA as the IPC intent of this criterion is to account for the effect of ice loads primarily on wires, pipes and similar components which are exposed to the natural environment. The collectors have no exposed wires or pipes etc.</td>
</tr>
<tr>
<td>3.2.3</td>
<td>Vehicular Loads</td>
</tr>
<tr>
<td></td>
<td>This item is considered NA as the collectors are installed above grade in all cases.</td>
</tr>
<tr>
<td>3.2.4</td>
<td>Load Capacity</td>
</tr>
<tr>
<td></td>
<td>This item is considered NA as all components are conventional items.</td>
</tr>
<tr>
<td>3.3</td>
<td>Damage Control</td>
</tr>
<tr>
<td></td>
<td>The structural elements and connections of the collectors shall withstand service loads without damage as described in the following paragraphs:</td>
</tr>
<tr>
<td>3.3.1</td>
<td>Resistance to Damage</td>
</tr>
<tr>
<td></td>
<td>This item is considered NA as all components are conventional items.</td>
</tr>
<tr>
<td>3.3.2</td>
<td>Glazing Design</td>
</tr>
<tr>
<td></td>
<td>The collector outer glazing shall be tested for air leakage and water infiltration in accordance with ASTM E283 and ASTM E331 respectively. Physical Load tests shall be conducted in accordance with ASTM E330. Glazing shall comply with the manufacturers directions for installing Tedlar, and the experience of the NASA test program on Tedlar. The inner glazing of glass shall have a minimum clearance on all 4 sides equal to the thickness of the glass. Sealer space between the face of the glass and fixed or applied stops shall be sufficient to prevent glass-to-stop contact.</td>
</tr>
<tr>
<td>3.4</td>
<td>Cyclic Loads</td>
</tr>
<tr>
<td></td>
<td>This item and sub-item 3.4.1 are considered NA as all components are conventional elements.</td>
</tr>
<tr>
<td>3.7</td>
<td>Hail Resistance</td>
</tr>
<tr>
<td></td>
<td>The collectors shall be capable of resisting impact of hail without unacceptable damage as described in the following paragraphs:</td>
</tr>
<tr>
<td>3.7.1</td>
<td>Hail Size and Loading</td>
</tr>
<tr>
<td></td>
<td>Evaluation of the Tedlar glazing to withstand hail impact will be based on results of the NASA Tedlar test program.</td>
</tr>
<tr>
<td>3.8</td>
<td>Constraint Loads</td>
</tr>
<tr>
<td></td>
<td>This criterion is considered NA as all components are conventional elements. NA also applies to 3.8.1 for the same reason.</td>
</tr>
<tr>
<td>3.9</td>
<td>Ponding Conditions</td>
</tr>
<tr>
<td></td>
<td>Collector horizontal surfaces have been designed to assure stability in service under ponding conditions as follows:</td>
</tr>
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</table>

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3.9.1 Design Provisions

The only surface of the collector in a horizontal plane is the 1/8" groove in the aluminum H-bar. However, this groove contains Tedlar and a 1/8" plastic spline. Hence inspections will show there is little room for ponding. There is expected to be minimal collection of water on the taut Tedlar at angles between 50° and 70°.

4.1 Plumbing and Electrical Installation

This criterion and 4.1.1 and 4.1.2 are considered NA as there is no plumbing or electrical installation on the collector.

4.2 Fail-Safe Controls

This criterion, 4.2.1 and 4.2.2 are considered NA as fail-safe controls are considered a system function.

4.3 Fire Safety

The design and installation of the collectors shall provide a minimum level of fire safety as follows:

4.3.1 Applicable Fire Standards

The collector drawings and specifications reviews will show conformance with applicable fire standards. Test data will be available for such parameters as potential heat, rate of heat release and ease of ignition. The last item will be obtained from handbooks.

4.4 Toxic

This criterion is considered NA as toxic and flammable fluids are not used.

4.5.2 Identification and Location of Controls

This criterion is considered NA as the collectors do not contain controls.

4.6 Protection of Potable Water and Circulating Air

The collector design and development carefully checked that no material, form of construction, appurtenance or item of equipment shall be employed that will support the growth of microorganisms or introduce substances, impurities, bacteria or chemicals into circulating air systems, in quantities sufficient to cause disease or harmful physiological effects. Furthermore, the following applicable items will continue to be monitored:

4.6.1 Contamination by Materials

This criterion is considered NA as it concerns potable water.

4.6.2 Separation of Circulation Loops

This criterion is considered NA as the collector heat transfer fluid is air.

4.6.3 Backflow Prevention

This criterion is considered NA as it concerns nonpotable heat transfer fluids.
4.6.4 Growth of Fungi
Growth of fungi will be checked by inspection and by the certification company. If fungi growth is found tests will be made and corrective actions taken.

4.7 Excessive Surface Temperatures
Temperatures of exterior surfaces of the collectors shall not create a hazard and shall be checked as follows:

4.7.1 Protection from Heated Components
Only the lower horizontal edge of the collector may be accessible to public traffic. It is not normally expected to reach temperatures of 140°F or more. However an electric power failure or blower motor failure may cause the temperature to reach between 140°F and 160°F. The temperature of this component will be monitored during stagnation tests. If temperatures reach these limits, insulation will be provided where the collectors will be installed near public traffic.

5.1 Effects of External Environment
The collectors shall not be affected by external environment factors to an extent that will significantly impair their function during their design life as described in the following paragraphs:

5.1.1 Solar Degradation
Collector components and materials have been exposed to UV radiation for 1 year under Colorado weather conditions. The Tedlar inner glazing of our experimental SC4X10 model has undergone extreme stagnation heat testing with temperatures reaching a minimum of 180°F every sunny day. Samples of this inner glazing will be analyzed.

5.1.2 Soil Corrosion
This criterion is considered NA as collectors will not be buried in the ground.

5.1.3 Airborne Pollutants
Airborne Pollutants will be checked by inspection and by the certification company. No data is currently available as the test facility environment is relatively airborne pollutant free. If airborne pollution contamination is found, analysis of samples will determine the corrective action to be taken.

5.1.4 Dirt Retention on Cover Plate Surface
Dirt retention shall be monitored by photographing a small target behind the outer glazing and recording weather conditions. During long periods without precipitation, dirt may be washed off by hosing after photographic data has been taken.
5.1.5 Abrasive Wear

Engineering analysis and data on the Tedlar glazing that has been in environmental testing for the past year and surface hardness specifications will be reviewed.

5.1.6 Flutter by Wind

Outer glazing flutter by wind will be minimized by controlled shrinkage during fabrication. Wind flutter will be checked using small fibres temporarily attached to the Tedlar and photographed. Wind and temperature data will be taken by our instrumentation.

5.2 Temperature and Pressure Resistance

Collector components have been designed to perform their intended function of their design life when exposed to maximum temperatures that could be developed in the system, as follows:

5.2.1 Thermal Degradation

Data will be supplied on Tedlar and absorber paint degradation. Effects of thermal degradation will be monitored after stagnation tests and recorded in the test report.

5.2.2 Deterioration of Heat Transfer Fluids

This criterion is considered NA as air is the heat transfer fluid.

5.2.3 Thermal Cycling Stresses

Thermal cycling is considered an important test as it may stress the inner glazing if the blower starts while the collector is at sub-zero temperatures. Test data will be recorded and the inner glazings inspected after the test.

5.2.4 Leakage

This criterion is considered NA as it refers to heat transfer fluids other than air.

5.2.5 Deterioration of Gaskets and Sealants

Gaskets and sealants in direct contact with heat transfer fluid and the exterior environment will be monitored by inspection to assure these materials will continue to function over their design life. Manufacturers data will be supplied.

5.2.6 Transmission Losses Due to Outgassing

Outgassing is expected to be minimized by oven heating of the absorber coating after painting. Subsequent outgassing during operation would be noticed during inspections as a fine coating on the interior surface of the inner glazing. Photographing resolution targets will assist in this evaluation.

5.3 Chemical Compatibility of Components

In the design of the collectors careful consideration was given to the selection of materials to prevent corrosion and deterioration. This will be further checked as follows:
### 5.3.1 Materials/Transfer Fluid Compatibility
This category is considered NA as the heat transfer fluid is air.

### 5.3.2 Corrosion of Dissimilar Metals
Inspection of the drawings and prototype collectors will show all metals are either of aluminum or in the same electro-conductive category. Two prototype collectors have been in environment test for one year without protection, and have shown no corrosion or deterioration problems.

### 5.3.3 Leaching of Dissimilar Materials
This criterion is considered NA as it is an air system and insulation is separated from the air plenum by the back plate.

### 5.3.4 Effects of Decomposition Products
This will be monitored by inspections. Two prototypes have not shown any decomposition. Absorber paint may decompose after 10 years but is retained within an enclosure and cannot affect other materials.

### 5.4 Components Involving Moving Parts
This criterion and 5.4.1 are considered NA as the collector has no moving parts.

### 6.1 Accessibility for Maintenance
Accessibility for maintenance will be demonstrated by review of drawings, and specifications and prototype collectors.

#### 6.1.1 Access for System Maintenance
Access may be required to remove and replace the inner glazing, or repaint the absorber coating after 10 years. Inspection of drawings will show that the outer glazing may be removed for access to the inner glazing or absorber coating without removing adjacent units.

#### 6.1.2 Access for System Monitoring
Access for system monitoring has been included in the test facility design and construction. Thomas flow meters and supporting instrumentation are used to measure flow rates. Temperatures will be monitored on the absorber plate back, with resistance thermometers, input and output air temperatures. Backup thermometer probes will be used at special ports to check regular instrumentation.

### 6.2 Installation, Operation and Maintenance Manual
This manual shall be prepared in accordance with similar manuals. Drawings, diagrams and photographs will support written instructions prepared at the appropriate reading level.

#### 6.2.1 Installation Instructions
Installation instructions shall include physical, functional and procedural instructions. Particular attention will be given to safety functions, especially the output temperature from.
6.2.2 Maintenance and Operation Instructions

Maintenance instructions will describe the relationship of the major components to the collector operation. Collector maintenance is expected to consist of repairing the inner and outer glazings due to wilful damage, primarily (or accidents.) Routine maintenance will include occasional washing with a hose and inspection of the outer glazing/caulking and leakage.

6.2.3 Maintenance Plan

The maintenance plan will provide a schedule and procedures for outer glazing washing and inspections, and minor repair work.

6.2.4 Replacement Parts

Lists of parts, components, special tools and test equipment for service, repair or replacement will be provided along with sources for supplies.

6.3 Repair and Service Personnel

A review of the Installation, Operation and Maintenance Manual will demonstrate that the instructions, diagrams and procedures and the collectors design can easily be used by qualified service personnel.

6.3.1 Maintenance of Heating Systems

Review of drawings, specifications, maintenance manual and test equipment will show maintenance can be accomplished with a minimum amount of special equipment.

6.3.2 Maintenance of DHW Systems

This criterion is considered NA as it concerns hot water heating.

11.2.1 Chemical Corrosion

Chemical corrosion as mentioned in 5.3.2 and 5.3.4 has not been found in two prototype collectors or the adjacent site elements for 1 year. Chemical corrosion will continue to be monitored for during inspections.

11.2.2 Heat and Moisture

Review of installation plans, specifications, drawings and calculations will demonstrate that the roofing structure is protected by insulation from excessive build-up and from moisture by design and caulking.

11.3.1 Material Compatibility

As described in 5.3.2, and 11.2.1, materials requirements have been included in the design of the collectors. Connections between the collectors and the dwelling will be reviewed by drawings, specifications and by inspection.
7. **Test Plan**
The Collector Subsystem Test Program consists of 3 phases, Development Testing, Qualification Testing, and Acceptance Testing. The Test Program Plan defines the milestones for testing this subsystem (Figure 7.1.)

7.1 **Development Testing**
Development testing is designed to verify that the preliminary design specifications are feasible and performance requirements are realistic. Three major inter-related tests are planned for this phase: Air Flow, Plenum Spacing and Air Temperature Output. Changes to air flow and/or plenum spacing will result in changes in air temperature output. The objective of this phase is to optimize air flow and plenum spacing for the optimum temperature output and obtain data on basic collector efficiency.

This test data for combined air flow and plenum spacing for optimum temperature output will be presented at the Preliminary Design Review. It will also be used for planning additional testing during the next phase.

7.2 **Qualification Testing**
Qualification testing is designed to optimize subsystem components and also to analyze and test the subsystem to design limits. This will ensure that the subsystem meets physical and functional requirements. Component testing includes absorber coatings tests and glazings tests, followed by a combined absorber-glazings test. Systems qualification tests include stagnation, and other environmental tests and structural analysis or testing.

7.3 **Acceptance Testing**
Acceptance testing is designed to inspect and test each prototype collector to verify that each prototype collector's physical and operational characteristics are within specifications. These tests will be performed for 3 units prior to First Article Configuration Inspection FACI and for the remaining 7 units Acceptance Testing will be performed prior to delivery.
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<td>Development</td>
<td>Qualification</td>
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<td>1.2.4 Operational Impairment</td>
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<td>NA</td>
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<td>NA</td>
</tr>
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<td>NA</td>
<td>NA</td>
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<td>2.3.3 Air Transport Systems</td>
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FIGURE 7.1 TEST PROGRAM PLAN
SECTION B

THERMAL ANALYSIS

Air Flat Plate Collector

December 30, 1976

Life Sciences Engineering
Rt. 1, Box 746
Morrison, Colorado 80465

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THERMAL ANALYSIS

1. Introduction

Several designs are being investigated during the course of this contract. For the purposes of this analysis a baseline design is examined. For this design the covers will be assumed to be constructed using ASG Industries, "Sunadex" glass, 5/32 inch in thickness, having a transmittance of 0.91. This glass is manufactured with a non-specular textured surface which reduces reflection losses. It has been used widely in large solar projects. Combinations of glass and plastic films have also been examined. These will be reported upon later.

The absorber plate as well as the duct interior will be assumed to be coated with black paint which has a spectral reflectance of 5 percent throughout the visible and infrared wavelength region.

The heat transfer coefficient, $U_L$, for heat loss out of the top of the collector is shown in Figure 1 as a function of average plate temperature. This data is adapted from Reference 1. The coefficient is relatively linear with ambient temperature over the range shown.

2. Methods of Analysis

Several investigators (2-8) found that the performance of flat-plate collectors operating under steady-state conditions can be adequately described by the following relationship:

$$\frac{q_u}{A} = I (\tau \alpha) e - U_L (t_p - t_a)$$

(1)

where

- $q_u$ = rate of useful energy extraction from the solar collector, in Btu/h
- $A$ = cross-sectional area, ft$^2$
- $I$ = total solar energy incident upon the plate of the solar collector per unit time per unit area, Btu/ft$^2$
Figure 1.1, Top Loss Coefficient for Slope of 60°
\( (\tau \alpha)_e \) = effective transmission-absorptance product for the solar collector

\( U_L \) = heat transfer loss coefficient for the solar collector, Btuh/ft²°F

\( \bar{t}_p \) = average temperature of the absorber surface of the solar collector, °F

\( t_a \) = ambient air temperature, °F

Two parameters \( F' \) and \( F_R \) have been developed to assist in obtaining detailed information about the performance of various kinds of solar collectors:

\[
F' = \frac{\text{actual useful energy collected}}{\text{useful energy collected if the entire collector surface were at the average fluid temperature}}
\]

and

\[
F_R = \frac{\text{actual useful energy collected}}{\text{useful energy collected if the entire collector surface were at the temperature of the fluid entering the collector}}
\]

Introducing these factors into equation (1) results in new performance equations, respectively:

\[
\frac{q_u}{A} = F' \left[ I (\tau \alpha)_e - U_L \left( \frac{t_{f,i} + t_{f,e}}{2} - t_a \right) \right]
\]

and

\[
\frac{q_u}{A} = F_R \left[ I (\tau \alpha)_e - U_L (t_{f,i} - t_a) \right]
\]

where

\( t_o \) = temperature of the fluid leaving the collector, °F

\( t_i \) = temperature of the fluid entering the collector, °F

If the solar collector efficiency can be defined as:
\[ \eta = \frac{q_u}{A} \]  

or in equation form

\[ \eta = \frac{u}{A} \]  

then the efficiency of the flat plate collector is given by:

\[ \eta = (\tau \alpha) - U_L \left( \frac{t_p - t_a}{I} \right) \]  

or

\[ \eta = \frac{F^* (\tau \alpha) - F^* U_L \left( \frac{t_1 + t_0}{2} - t_a \right)}{I} \]  

or

\[ \eta = \frac{F_R (\tau \alpha) - F_R U_L \left( t_1 - t_a \right)}{I} \]  

Equations 5, 6, and 7 indicate that if the efficiency is plotted against some appropriate \( \frac{\Delta t}{I} \), a straight line will result where the slope is some function of \( U_L \) and the y intercept is some function of \( \tau \alpha \). In reality \( U_L \) is not a constant but rather a function of the operating temperature of the collector and of the ambient weather conditions. In addition, the product \( \tau \alpha \) varies with incident angle to the collector.

The line drawn in Specification Sheet SHC-3058 is representative of the plot that results from equation (7). The y-axis is the thermal efficiency (\( \eta \)) and the x-axis, the temperature difference between the collector fluid inlet and the ambient air divided by the incident solar radiation \( \left( \frac{t_1 - t_a}{I} \right) \). The slope of a linear curve fit for the efficiency curve represents the product \( F_R U_L \). The y-axis intercept is equal to \( F_R \left( \tau \alpha \right) \).

The value of this approach is that later data taken from performance tests can be plotted from which slopes and y intercepts can be used.
together to determine the values of \( F_R, F', U_L \) and \( (\varphi \alpha)_e \). The efficiency expression shown in Specification Sheet SHC-3058 is used with test data on flow and temperature difference between inlet and outlet air to compute efficiency. As discussed in Reference 1, solar collector performance for specific operation conditions can be predicted with reasonable accuracy once the values of \( F_R, U_L \) and \( (\varphi \alpha)_e \) have been determined.

3. **Collector Efficiency**

The collector efficiency factor is essentially a constant for any collector design and fluid flow rate. For the collector video study

\[
F' = \left[ 1 + \frac{U_L}{h + \left( \frac{1}{h} + \frac{1}{h_R} \right)^{-1}} \right]^{-1}
\]

where

- \( h \) = heat transfer coefficient between air and duct walls.
- \( h_R \) = radiation coefficient between the two air duct surfaces.

For analysis purposes it is convenient to define a quantity that relates the actual useful energy gain of a collector to the useful gain if the whole collector surface were at the fluid inlet temperature. This quantity, termed the Collector Heat Removal Factor, \( F_R \), can be expressed by:

\[
F_R = \left( 1 - \frac{U_L F'}{G C_p} \right)
\]

where

- \( G \) = flow rate per unit of collector area, lb/hr-ft
- \( C_p \) = specific heat of fluid, 0.24 for air

4. **Effective Transmissivity-Absorptivity Product**

All of the solar radiation that is absorbed by a cover system is not lost, since this absorbed energy tends to increase the cover temperature and consequently reduce the losses from the plate. This partial usefulness of the radiation absorbed in the cover plates is most conveniently
thought of as an artificial increase in transmittance and gives rise to the concept of "effective transmissivity-absorptivity product", \((\tau \alpha)_e\).

It is necessary to evaluate the transmittance-absorptance product \((\tau \alpha)\). Of the radiation passing through the cover system and striking the plate, some is reflected back to the cover system. All of the radiation is not lost however, since some is reflected back to the plate. The energy ultimately absorbed is:

\[
(\tau \alpha) = \frac{\tau \alpha}{1 - (1 - \alpha) \rho_d}
\]

where
\[
\tau = \text{transmittance} \\
\alpha = \text{absorptance} \\
\rho_d = \text{diffuse reflectance} = 0.24 \quad \text{(for two glass cover system, Ref. 1)}
\]

\[
(\tau \alpha) = \frac{(0.91)^2 \times 0.95}{1 - (1 - 0.95) 0.24}
\]

\[
(\tau \alpha) = 0.797
\]

The effective transmissivity absorptivity product can be expressed by

\[
(\tau \alpha)_e = (\tau \alpha) + (1 - \tau_{a,1}) a_1 + (1 - \tau_{a,2}) a_2 \tau_1
\]

where
\[
\tau_{a} = \text{transmittance considering only absorption} \\
\tau_{a} = e^{-KL}
\]

where
\[
K = \text{extinction coefficient} \\
L = \text{length of path through the glass}
\]

For \(K = 0.2 / \text{inch}\)
\[
L = 5/32 \text{ inch}
\]

\[
\tau_{a} = e^{-0.2 \times 0.16} = 1.032
\]

\[
(\tau \alpha)_e = 0.797 + (1 - 1.032) 0.15 + (1 - 1.032) 0.62 \times 0.91
\]

\[
(\tau \alpha)_e = 0.82
\]

Constants \(a_1 = 0.15\) and \(a_2 = 0.62\) ave from Ref. 1.
Examinations were made for the effect of variations in the parameters of air flow and duct spacings. Air flow was varied from 60 to 360 CFM (0.06 lb/ft³ Denver altitude). Duct spacings were varied from 3/8 to 1 inch. Efficiency was computed using equation (3). This requires making an estimate of the collector plate temperature, \( T_p \), for the purpose of determining the heat loss coefficient, \( U_L \). \( T_p \) is a function of specific air flow through the collector. Estimates of plate temperatures at various air flows are shown in Figure 5.1, together with resulting values for \( U_L \) and \( h_r \). These are used in computing the useful heat, \( q_u \), collected per unit area, the resulting efficiency, and the air temperature, \( t_o \), as it leaves the collector. The calculations are based on the conditions that the collector is tilted at an angle of 60° above the horizontal and that at noon the insolation per unit area of exposed glass is 300 Btuh/ft². In the computations the values of \( U_L \) are increased by 15 percent to allow for back and edge losses. This estimate is in accordance with information from Reference (7). With urethane insulation the percentage may be less. The resultant is \( U_L \), the overall loss coefficient.

5.a Heat Transfer Coefficients

The radiation coefficient between the two air duct surfaces is calculated by using mean plate temperatures taken from and using the expression

\[
h_r = \frac{4\sigma T^3}{\frac{1}{E_1} + \frac{1}{E_2} - 1}
\]

where the Stefan-Boltzmann constant \( \sigma = 0.1714 \times 10^{-8} \) Btu/hr ft² °R⁴

\( T = 0_R \)

and \( E = \) surface emittance

The heat transfer coefficients between the air and the duct wall will be assumed to be equal. The characteristic length is the hydraulic diameter, which for flat plates is twice the plate spacing.
Figure 5.1, Relationship of Plate Temperatures, Air Flow and Radiation Coefficient
For air, the following correlation for turbulent flow between flat plates with one side heated has been derived. (Ref. 1)

\[ \text{Nu} = 0.0158 \text{Re}^{0.8} \]

where

\( \text{Nu} = \text{Nusselt number} \) \((h D/K)\)

\( \text{Re} = \text{Reynolds number} \) \(\left(\frac{\text{M}}{\text{Ac}}\right)\)

and

\( h = \text{Convective film coefficient} \)

\( D = \text{Hydraulic diameter} \)

\( K = \text{Fluid thermal conductivity} \)

\( M = \text{Mass flow rate, lbs/hr} \)

\( \text{Ac} = \text{Free flow area, ft}^2 \)

\( \nu = \text{Viscosity, lb/hr ft} \)

The advantages of the dimensional analysis that utilizes the Nusselt number are well known in correlating large amounts of data. An arithmetic operation is used to obtain \( h \) from the Nusselt number once the Reynolds number has been obtained.

Calculations for the convective film coefficient \( h \) are tabulated below:

<table>
<thead>
<tr>
<th>Plate Spacing</th>
<th>M</th>
<th>M/\text{Ac}</th>
<th>\text{Re}</th>
<th>\text{Nu}</th>
<th>h</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.375 in.</td>
<td>216</td>
<td>1800</td>
<td>2483</td>
<td>8.216</td>
<td>2.054</td>
</tr>
<tr>
<td>&quot;</td>
<td>432</td>
<td>3600</td>
<td>4967</td>
<td>14.306</td>
<td>3.577</td>
</tr>
<tr>
<td>&quot;</td>
<td>864</td>
<td>7200</td>
<td>9934</td>
<td>24.909</td>
<td>6.227</td>
</tr>
<tr>
<td>&quot;</td>
<td>1296</td>
<td>10800</td>
<td>14900</td>
<td>34.451</td>
<td>8.613</td>
</tr>
<tr>
<td>0.500 in.</td>
<td>216</td>
<td>1350</td>
<td>2483</td>
<td>8.216</td>
<td>1.538</td>
</tr>
<tr>
<td>&quot;</td>
<td>432</td>
<td>2700</td>
<td>4967</td>
<td>14.306</td>
<td>2.678</td>
</tr>
<tr>
<td>&quot;</td>
<td>864</td>
<td>5400</td>
<td>9934</td>
<td>24.909</td>
<td>4.663</td>
</tr>
<tr>
<td>&quot;</td>
<td>1296</td>
<td>8100</td>
<td>14900</td>
<td>34.451</td>
<td>6.449</td>
</tr>
<tr>
<td>1.000 in.</td>
<td>216</td>
<td>675</td>
<td>2483</td>
<td>8.216</td>
<td>0.769</td>
</tr>
<tr>
<td>&quot;</td>
<td>432</td>
<td>1350</td>
<td>4967</td>
<td>14.306</td>
<td>1.339</td>
</tr>
<tr>
<td>&quot;</td>
<td>864</td>
<td>2700</td>
<td>9934</td>
<td>24.909</td>
<td>2.331</td>
</tr>
<tr>
<td>&quot;</td>
<td>1296</td>
<td>4050</td>
<td>14900</td>
<td>34.451</td>
<td>3.225</td>
</tr>
</tbody>
</table>

Summaries of experiment and analysis for gas flow in rectangular tubes are reported in Reference 9, Kays and Loudon Compact Heat Exchangers, as a function of the Stanton number. Comparisons of results of the above calculations and their data show good agreement for \( h \).
Calculations for the collector efficiencies for different air flows and plate spacings defining the air duct behind the absorber plate are tabulated in Table 2. Also shown are the outlet air temperatures, $t_o$, for the collector. These may be used in selecting the air flow to achieve a given temperature rise across the collector.
### Table 2. Collector Efficiency Calculations

<table>
<thead>
<tr>
<th>CFM</th>
<th>W</th>
<th>G</th>
<th>hr</th>
<th>h</th>
<th>U_L</th>
<th>F'</th>
<th>GCp U_L</th>
<th>F_R</th>
<th>qu/A</th>
<th>t_f,e</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>216</td>
<td>7.06</td>
<td>1.59</td>
<td>2.05</td>
<td>0.79</td>
<td>0.79</td>
<td>2.14</td>
<td>0.66</td>
<td>147</td>
<td>0.49</td>
</tr>
<tr>
<td>120</td>
<td>432</td>
<td>14.11</td>
<td>1.31</td>
<td>3.58</td>
<td>0.72</td>
<td>0.84</td>
<td>4.70</td>
<td>0.77</td>
<td>174</td>
<td>0.58</td>
</tr>
<tr>
<td>240</td>
<td>864</td>
<td>28.16</td>
<td>1.18</td>
<td>6.23</td>
<td>0.69</td>
<td>0.91</td>
<td>9.79</td>
<td>0.87</td>
<td>196</td>
<td>0.65</td>
</tr>
<tr>
<td>360</td>
<td>1296</td>
<td>42.34</td>
<td>1.12</td>
<td>8.61</td>
<td>0.67</td>
<td>0.93</td>
<td>15.17</td>
<td>0.90</td>
<td>204</td>
<td>0.68</td>
</tr>
</tbody>
</table>

#### 0.375 Inch Plate Spacing

<table>
<thead>
<tr>
<th>CFM</th>
<th>W</th>
<th>G</th>
<th>hr</th>
<th>h</th>
<th>U_L</th>
<th>F'</th>
<th>GCp U_L</th>
<th>F_R</th>
<th>qu/A</th>
<th>t_f,e</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>216</td>
<td>7.06</td>
<td>1.59</td>
<td>1.54</td>
<td>0.79</td>
<td>0.75</td>
<td>2.14</td>
<td>0.63</td>
<td>140</td>
<td>0.47</td>
</tr>
<tr>
<td>120</td>
<td>432</td>
<td>14.11</td>
<td>1.31</td>
<td>2.68</td>
<td>0.72</td>
<td>0.83</td>
<td>4.70</td>
<td>0.76</td>
<td>170</td>
<td>0.57</td>
</tr>
<tr>
<td>240</td>
<td>864</td>
<td>28.16</td>
<td>1.18</td>
<td>4.66</td>
<td>0.69</td>
<td>0.89</td>
<td>9.79</td>
<td>0.85</td>
<td>191</td>
<td>0.64</td>
</tr>
<tr>
<td>360</td>
<td>1296</td>
<td>42.34</td>
<td>1.12</td>
<td>6.45</td>
<td>0.67</td>
<td>0.92</td>
<td>15.17</td>
<td>0.89</td>
<td>202</td>
<td>0.67</td>
</tr>
</tbody>
</table>

#### 0.5 Inch Plate Spacing

<table>
<thead>
<tr>
<th>CFM</th>
<th>W</th>
<th>G</th>
<th>hr</th>
<th>h</th>
<th>U_L</th>
<th>F'</th>
<th>GCp U_L</th>
<th>F_R</th>
<th>qu/A</th>
<th>t_f,e</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>216</td>
<td>7.06</td>
<td>1.59</td>
<td>0.77</td>
<td>0.79</td>
<td>0.62</td>
<td>2.14</td>
<td>0.54</td>
<td>120</td>
<td>0.40</td>
</tr>
<tr>
<td>120</td>
<td>432</td>
<td>14.11</td>
<td>1.31</td>
<td>1.34</td>
<td>0.72</td>
<td>0.74</td>
<td>4.70</td>
<td>0.68</td>
<td>153</td>
<td>0.51</td>
</tr>
<tr>
<td>240</td>
<td>864</td>
<td>28.16</td>
<td>1.18</td>
<td>2.33</td>
<td>0.69</td>
<td>0.82</td>
<td>9.79</td>
<td>0.79</td>
<td>177</td>
<td>0.59</td>
</tr>
<tr>
<td>360</td>
<td>1296</td>
<td>42.34</td>
<td>1.12</td>
<td>3.22</td>
<td>0.67</td>
<td>0.86</td>
<td>15.17</td>
<td>0.84</td>
<td>189</td>
<td>0.63</td>
</tr>
</tbody>
</table>
REFERENCES


SECTION C

SAFETY HAZARD ANALYSIS
FOR

AIR FLAT PLATE COLLECTOR

January 3, 1977

Life Sciences Engineering
Rt. 1, Box 746
Morrison, Colorado 80465
SAFETY HAZARD ANALYSIS

1. Scope
1.1 Purpose
The purpose of this report is to identify and evaluate significant hazards to the installation crew, resident occupants and visitors.

1.2 Scope
This report presents an assessment of hazards peculiar to this equipment. The hazards have been identified and categorized. The possible causes and effects have been listed, together with the methods or safeguards required to control or limit the hazard. This analysis does not consider facility or manufacturing features that are required to be made safe under the local codes and regulations.

1.3 Summary
The Hazards Analysis identified no potentially catastrophic hazards and one critical hazard. A catastrophic hazard (Category 1) is one in which death or severe injury to personnel or system loss can occur. A critical hazard (Category 2) is one which could result in personnel injury or cause major damage.
<table>
<thead>
<tr>
<th>ITEM NO.</th>
<th>NOMENCLATURE OF HARDWARE/ACTIVITY</th>
<th>POTENTIAL/INHERENT HAZARD CAUSES AND EFFECTS</th>
<th>HAZARD CATEGORY</th>
<th>PROPOSED METHOD OF HAZARD CONTROL OR ELIMINATION</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Solar Panel Assembly</td>
<td>1. Large areas of dielectric (Tedlar) surface exposed to sky could build up sufficient static charge to act as flat plate capacitance attractor for lightning. Large amounts of metal in frames could also attract lightning.</td>
<td>marginal</td>
<td>Installation will require electrical busing of panel assemblies together and to ground per standards and codes for locality.</td>
<td>Lightning rods may be required by code in areas of high strike potential (i.e. Colorado Springs).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Aluminum frame of panels will conduct stagnation temperatures to surrounding structure if forced convection air flow is inhibited. High stagnation temp. (500°F) could cause local charring or combustion.</td>
<td>marginal</td>
<td>Installation will provide for adequate insulation between panel assembly frame and surrounding structure.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Toxic outgassing of materials could have debilitating effect on residents</td>
<td>marginal</td>
<td>Materials used in solar panel assembly shall not produce toxic or noxious products when exposed to expected temperature.</td>
<td></td>
</tr>
<tr>
<td>ITEM NO.</td>
<td>NOMENCLATURE OF HARDWARE/ACTIVITY</td>
<td>POTENTIAL/INHERENT HAZARD CAUSES AND EFFECTS</td>
<td>HAZARD CATEGORY</td>
<td>PROPOSED METHOD OF HAZARD CONTROL OR ELIMINATION</td>
<td>REMARKS</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------------------</td>
<td>---------------------------------------------</td>
<td>----------------</td>
<td>-----------------------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>2</td>
<td>Installation of Solar Panel Assembly to Supporting Structure</td>
<td>Installation personnel could be burned by hot frame or panel when handling.</td>
<td>negligible</td>
<td>Personnel should wear gloves whenever working around exposed panel frames. Panel storage prior to installation should be in a shady area. Panels should be transported with collector face away from direct sunlight.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Large panel assemblies (4 x 8 ft.) will be heavy (100 lbs.) and act as sails in wind. Above ground installations present potential for severe injury to personnel by being blown off or by dropping panel on self or another.</td>
<td>critical</td>
<td>Installation should be designed to maximize use of lifting apparatus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Improper sealing of panel/supporting structure could result in water leaks.</td>
<td>negligible</td>
<td>Installation manual will recommend proper installation techniques/requirements.</td>
<td>Local codes may take precedent.</td>
<td></td>
</tr>
</tbody>
</table>
SECTION D

DRAWINGS LIST, STANDARDS AND SYMBOLS
FOR

AIR FLAT PLATE COLLECTOR

January 1, 1977

Life Sciences Engineering
Rt. 1, Box 746
Morrison, Colorado 80465

D-i

ORIGINAL PAGE IS OF POOR QUALITY.
SC4X8100-9 Top Drawing SC4X8 Solar Collector
SC4X8200-9 Assembly
Consisting of:
SC4X8200-19 Absorber Panel and Frame Installation
Drilling Holes Detail
Installation Thermal Resistors Detail
RTV 560 Detail
SC4X8200-29 Back Panel Installation
SC4X8200-29-1 Back Panel Detail and Hole Drilling
SC4X8200-29-3 Back Panel Support
SC4X8300-9 Main Frame Assembly
Consisting of:
SC4X8300-9-1 Side Detail
SC4X8300-9-3 End Detail
SC4X8300-9-5 Corner Detail
SC4X8400-9 Absorber Panel and Frame
Consisting of:
SC4X8400-9-1 'U' Channel Side Detail
SC4X8400-9-3 Angle Aluminum Detail
Drilling Holes Detail
Paint Detail
SC4X8500-9 Glazing
Consisting of:
SC4X8500-19 Inner Glazing Installation
SC4X8500-19-1 Inner Glazing Detail
SC4X8500-19-3 Pressure Tape Detail
SC4X8500-29 Outer Glazing Installation
SC4X8500-29-1 H-Bar Side Detail
SC4X8500-29-3 H-Bar End Detail
Outer Glazing Bonding Detail
Outer Glazing Spline Detail
STANDARDS

ASTM E283 for Air Leakage Testing, American Society for Testing and Materials
ASTM E330 for Water Infiltration Testing, American Society for Testing and Materials
ASTM E331 for Load Test Conductance, American Society for Testing and Materials


Heat Producing Appliance Clearances, 1971, National Fire Protection Association, NFPA No. 89M


Installation of Air Conditioning and Ventilating Systems, 1976, National Fire Protection Association, NFPA No. 90 A

Marking for Shipment, Life Sciences Engineering 1977

MS 33586 Metals, Definition of Dissimilar

National Electric Code, 1975

Warm Air Heating and Air Conditioning Systems, 1973, National Fire Protection Association, No. 90 B
SYMBOLS

A = Cross-sectional area of a plenum in ft^2
A_c = Free flow area of collector in ft^2
\alpha = Absorptance
CFM = Cubic feet per minute
C_P = Specific heat of transport fluid in BTU/lb\cdot°F
\text{(for air 0.24)}
D = Hydraulic diameter
E = Surface emittance
F_t = Collector efficiency factor:
\quad F_t = \frac{\text{(actual useful energy collected)}}{\text{(useful energy collected if the entire collector surface were at the average fluid temperature.)}}
F_R = Collector heat removal factor:
\quad F_R = \frac{\text{(actual useful energy collected)}}{\text{(useful energy collected if the entire collector surface were at the temperature of the fluid entering the collector.)}}
G = Flow rate per unit of collector area in lb/hr/ft^2, or
\quad \text{Flow stream mass velocity: } G = \frac{W}{A_C}
\h = Heat transfer coefficient between air and duct walls, or
\quad \text{Convective film coefficient}
\h_I = Radiation coefficient between 2 air duct surfaces
I = Total solar insolation on the plane of the solar collector per unit time per unit area in BTU/hr ft^2
K = Fluid thermal conductivity
k = Extinction coefficient
L = Length of path through glass
\eta = Efficiency of the flat plate collector:
\quad \eta = (\omega) e - U_L \frac{(t_p - t_a)}{I} \quad \text{or} \quad \eta = \frac{M C_P (t_o - t_i)}{AC I}
\text{Nu} = \text{Nusselt number}
\quad \text{Nu} = \frac{h D}{K}
P_d = Diffuse reflectance
\[ Q_{u'} = \text{Heat transfer loss coefficient in BTU/hr/ft}^2{^\circ}\text{F} \]
\[ \text{Re} = \text{Reynolds number} \]
\[ \text{Re} = \frac{G \cdot D}{\mu} \]
\[ \sigma = \text{Stefan-Boltzmann constant} \]
\[ \tau = \text{Transmittance} \]
\[ \overline{\tau} = {^\circ}\text{R} \]
\[ (\text{\(\tau\alpha\)}) = \text{Effective transmission-absorptance product for the solar collector} \]
\[ t_a = \text{Ambient air temperature} \]
\[ t_{f,e} = \text{Temperature of the fluid leaving the collector in} {^\circ}\text{F} \]
\[ t_{f,i} = \text{Temperature of the fluid entering the collector in} {^\circ}\text{F} \]
\[ \overline{t_p} = \text{Average temperature of the absorber surface of the solar collector in} {^\circ}\text{F} \]
\[ t_p = \text{Collector plate temperature} \]
\[ \nu = \text{Viscosity} \]
\[ U_L = \text{Heat transfer loss coefficient in BTU/hr/ft}^2{^\circ}\text{F} \]
\[ U_t = \text{Glass thermal losses (top losses)} \]
\[ W = \text{Mass flow rate in lbs/hr} \]
SECTION E

LIST OF DATA RECOMMENDED FOR PROTOTYPE DESIGN REVIEW

AND

DESCRIPTION AND RATIONALE FOR PROPOSED

SPECIAL HANDLING, INSTALLATION AND MAINTENANCE TOOLS

LIFE SCIENCES ENGINEERING
Rt. 1, Box 746
Morrison, Colorado 80465
LIST OF DATA RECOMMENDED FOR PROTOTYPE DESIGN REVIEW

Recommended data for the Prototype Design Review will be additional performance evaluation data resulting from the test program which will reflect differences in performance due to:

- Plenum Spacing (flow passage) Tests
- Coatings Tests
- Glazings Tests
- Stagnation Tests

DESCRIPTION AND RATIONALE FOR PROPOSED SPECIAL HANDLING, INSTALLATION AND MAINTENANCE TOOLS

The only special test equipment projected at this time to be used follows installation of the collectors during total system checkout. This special test equipment is:

Micro Tector Electronic Hook Gage Model 1430

The purpose of this Hook Gage is to accurately measure the velocity pressure associated with the very low flow rates in the collectors and provide for balancing flow rates through parallel collectors.
SECTION F

STRUCTURAL ANALYSIS

AND

SELECTED DRAWINGS

AIR FLAT PLATE COLLECTOR

to

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

January 3, 1977

Life Sciences Engineering
Route 1, Box 746
Morrison, Colorado 80465
STRUCTURAL ANALYSIS

This preliminary Collector Subsystem structural design analysis is based on the following references:

Verification Plan No. SHG-3071, Sections 3.1 to 3.9.1

Interim Performance Criteria, Sections 3.1 to 3.9.1

HUD Minimum Property Standards, 4900.1, Section 601 and applicable standards

**Aluminum** - The preliminary analysis showed a maximum projected stress assuming yield on secondary load carrying members (i.e. Tedlar) is ≥ 6900psi. Since 6063 T-6 allows at least 25ksi in tension, the Safety Factor for the frame is at least 3. Thermal stresses will be analyzed later this month. The absorber panel sag may be excessive and if so, it will require stiffening support. Testing and further analysis will be performed to determine if stiffening is required. The deflections in the glass supporting structure are well within the allowable limits specified in the Minimum Property Standards.

**Glass** - The maximum projected stress for 5/32" glass is 4300psi, assuming Tedlar carries 25% of the wind load. If the Tedlar should rupture, thereby dumping all the load on the glass, the result will be approximately 5800psi stress in the glass. Tests shown in ASTM 251 on testing window assemblies showed that large plate sheets break at ≥ 3000psi stress. Tempering of glass increases the breaking stress by a factor of 2 1/2 to 3 1/2 (ref. Glass Engineering Handbook - Shand) resulting in a design limit of 7500psi which is a Safety Factor of 1.3. Also the Minimum Property Standards in Fig. 5-8.1 permits a 3/16" glass sheet for use up to 50 square feet in size for the design of 15psf.
windloads. Short duration loads on glass such as in a wind
gust were shown in ASTM 251 to have a stress increase to break-
age of a factor of about 2.

**Summary** - The deflections of the Tedlar, glass, and absorber panel are expected to act as air trapping membranes such that the Tedlar will not contact the glass and the glass will not contact the absorber panel when rapid loading occurs. The deflection of the glass at 4300psi is approximately 1.2" at the center. Test results from ASTM 251 indicated that actual stress and deflections could be as low as 2/3 the calculated values.

The shear stresses in the rivet connections appear minimal from preliminary calculations and the maximum allowable spacing will be allowed. When thermal stresses are analyzed, the rivet loads will be reevaluated.

Tedlar stress with maximum wind loading is \( \approx 1000 \text{psi} \) for a deflection of 1.5". Yield is approximately 6000psi for a safety factor of 6.
1" x 1" x 1/3" ANGLE ALUMINUM

SEE CORNER DETAIL

1" x 2" x 1/8" ANGLE ALUMINUM

47 1/2"

SOLAR II COLLECTOR MAIN FRAME SKSC4X8300-9

DRAWN BY: [Signature]

CHECKED BY: [Signature]
**STEP 1 - ASSEMBLE**
1. Assemble frame L & U - solvent clean surface &
2. Apply SolarSorb paint for use in dry
   thickness using 10% solution of 85%
   phosphoric acid in isopropyl alcohol.
   Ratio 80% acid/alcohol mix to 2% dry paint.

**STEP 2**
Absorber flange to frame

**STEP 3**
End L to ABS flange

**STEP 4**
Flange to end L

**STEP 5**
Paint absorber. 
1. Mask frame L & U - solvent clean surface &
2. Apply SolarSorb paint for use in dry
   thickness using 10% solution of 85%
   phosphoric acid in isopropyl alcohol.
   Ratio 80% acid/alcohol mix to 2% dry paint.

**STEP 6**
Backplate strap to frame assembly

**STEP 7**
Glass & trimco to ABS frame assembly

**STEP 8**
H-bar to frame

**STEP 9**
Press spline into glue inserted H-bar

**LEGEND**
SHT - Sheet stock
R - Plate or bar stock
H - H-bar stock
L - Angle stock
U - Channel stock
D - Direction of assembly
All stock 6061 aluminum

**ORIGINAL PAGE IS OF POOR QUALITY**

**SOLAR LP COLLECTOR FINAL ASSEMBLY STEPS SKSC4X8160**