**COST-EFFECTIVE WAYS TO IMPROVE THE
FABRICATION AND INSTALLATION OF SOLAR HEATING AND
COOLING SYSTEMS FOR RESIDENCES**

**FINAL REPORT
FOR PERIOD JUNE 1, 1977 - SEPTEMBER 30, 1978**

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ABSTRACT

The report documents a Colorado State University Solar Energy Applications Laboratory study investigating cost-effective ways of improving fabrication and installation of residential solar energy heating systems. The study entailed on-site observation of twelve installations focusing on the phase of mounting and manifolding of solar collectors. Time lapse photography and work measurement techniques were employed to record these installations. Generic collector types studied included air and liquid panels both internally and externally manifolded. Principal findings of the study synthesized from field observations, analysis of photographic data, time studies, and discussion with installation personnel and manufacturers' representatives are presented in the technical report.

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EXECUTIVE SUMMARY

OBJECTIVES

The objectives of the study were to identify cost-effective ways to improve the installation and fabrication of solar collectors for residences.

SCOPE

Investigations and recommendations for improvements to collector fabrication techniques were limited to changes which would make collector installations more cost-effective and did not include the study of fabrication techniques to reduce the basic collector cost.

METHOD OF APPROACH

The project observed twelve residential solar heating installations in Colorado and recorded those installations by means of time lapse photography and time study techniques. The findings of the project were derived from an analysis of the time study and photographic data and from observations and discussions with installation personnel and manufacturers' representatives.

PRINCIPAL FINDINGS

- The lifting of collectors on to the roof of buildings by means of a light duty cherry picker type boom crane is generally more cost-effective than using either manual lifting or a heavy duty construction crane.
- Installations where collectors were lifted to the roof manually were generally of poorer workmanship, with higher potential for system leaks than installations where collectors were lifted by means of a crane. The lifting of 140 to 160 pound collectors on a pitched roof on a hot day is extremely fatiguing with the result that the installation crew adopts a "devil may care" attitude.
- A few firms in a geographical area will in the future specialize in the installation of collectors because they will possess the specialized experience and equipment necessary to win competitive bids for installation.
- The installation costs of collectors could be reduced and system reliability could be improved if collectors were built in lengths longer than eight feet, since most arrays are taller than eight feet. The present length seems to be dictated by present manual handling methods.
- Manufacturers do not comprehend the abuse their collectors are subject to on the job site before and during installation.

Collectors are walked upon, twisted, allowed to reach high internal temperatures, and exposed to dust storms and precipitation. Pipe fittings are sometimes over-torqued to the point of failure. Warnings and notices should be given special highlighting in the installation manual in order to ensure that they will be read.

- The installation times of internally manifolded air collectors are lower than externally manifolded collectors where individual ducts must be built and connected. The fabrication costs of internally and externally manifolded collectors should be comparable.
- Starter strips used by installers to align the rows of collectors are often badly warped 2 in. by 2 in. or 2 in. by 4 in. lumber. The result is poor alignment of the collectors with gaps beyond the correction capacity of gaskets and pipe unions. System leaks and poor visual appearance are the consequences.
- The cost of installation will be highly dependent upon the crew size because the crews adjust the speed and effort on normal residential installation in such a way that the job takes one full day or multiples thereof.
- Manufacturers' guidelines for mechanical room layouts are sketchy or non-existent with the result that expensive trial and error designs are tried on the job site. It is common, particularly in air systems, to have conflicting uses of space for electrical, domestic plumbing, and solar energy transport. These conflicts usually arise from poor coordination and scheduling of the various trades during construction.
- Poor alignment of collectors with potential complications in cap-stripping and system leaks occur when care is not taken to maintain a precise centerline for the roof trusses.
- Bids for solar installations often contain excessive contingency allowances. (One installation contractor commented that actual costs were less than one-half his bid.)
- Panels delivered to the work site have, on occasion, been loaded in enclosed trailers by forklifts at the warehouse. To remove the panels from the trailer, workers have been forced in some cases to tear apart the packing in place and pull out the panels one by one. The panels may be stored outside without protective packing as a result of destroying the packing during unloading.
- During installation on sunny days exposed panels reach high temperatures. Hot panels can be handled only with gloves which are cumbersome to wear during other steps of the installation. Heat escaping from panels makes working around the array uncomfortable. Glare from exposed glazing also reduces work efficiency.

- Installation subcontractors and general contractors need to be educated to the higher workmanship standards required for solar energy installations. An example of this is solar duct construction for air systems, where the level of workmanship normally applied to conventional heat distribution ductwork is inadequate.

BACKGROUND

In July 1977, the Department of Energy contracted with the Colorado State University Solar Energy Applications Laboratory to conduct a study of cost-effective ways to improve the installation of residential solar heating and cooling systems for residences.

The first phase of the study entailed a review of the literature and initial contact with local installation contractors to establish what installations were scheduled to take place from Fall 1977 through the following summer. Forty-two manufacturers were contacted by mail to obtain information regarding current installation practices, estimates of installation labor requirements, and the location of local distributors.

In the ensuing twelve months, twelve installations were observed and documented via field notes, time study, and time lapse photography. These field studies are documented in Appendix B. Follow-up interviews were arranged with three installation contractors to review the conclusions of the field studies involved.

This report presents findings based on the field observations and contacts with manufacturers and installers. A methodology to analyze time study data and subsequent findings will be contained in the M.S. thesis to be published by Peter Jacobs.

The project staff would like to acknowledge the exceptional cooperation offered by the manufacturers and installation contractors dealt with in the course of this study. Manufacturers were helpful in providing technical information on their equipment and contractors were open to discuss their experience and permit observation of installations in which they were involved.

PROJECT FINDINGS

PRINCIPAL FINDINGS

The following section presents a series of 20 observations derived from field studies and conversations with installers and manufacturers. Documentation of the field studies are contained in Appendix B.

Observation 1

Panels delivered to the work site have, on occasion, been loaded in enclosed trailers by forklifts at the warehouse. To remove the panels from the trailer, workers have been forced in some cases to tear apart the packing in place and pull out the panels one by one.

Conclusion/Inference: Manufacturers should design packaging and method of delivery taking into account conditions encountered on the job site.

Recommendation: If possible panels should be delivered in an open top trailer to allow removal by crane. Space should be provided in the trailer for workers to get in and remove panels. Panels should preferably be packaged one to a carton, if cartons are involved.

Observation 2

Installation procedures issued by collector manufacturers are either non-existent or poorly suited to the needs of installation crews.

Conclusion/Inference: Poor workmanship and/or low productivity may result when an installation crew must decide for themselves how collectors should be installed.

Recommendation: Installation procedures should show sketches and/or pictures of typical installations to guide installation crews while still recognizing that each installation may have its unique features. Long written descriptions will probably not be read. A list of all parts, both supplied with the collector and supplied by the installer, as well as a list of all needed tools and equipment should be included in the installation manual.

Observation 3

Workers must occasionally retrieve needed parts and tools while the installation is in progress. Such interruptions can significantly increase the time required to complete an installation.

Conclusion/Inference: All parts and tools needed for the installation should be close at hand.

Recommendation: An apron containing all parts and fasteners should be worn, as well as a tool belt containing all the needed tools.

Observation 4

Starter strips used by installers to align the rows of collectors are often badly warped 2 in. by 2 in. or 2 in. by 4 in. lumber.

Conclusion/Inference: A poor initial alignment of the first row of collectors becomes visually obvious with a resultant attempt by the installation crew to correct the alignment in the second row. The non-parallel position of collectors is often beyond the sealing capacity of gaskets or pipe unions resulting in system leakage.

Recommendation: Suggest that installation procedures call for either carefully selected lumber or steel or aluminum box for the starter strip. A chalk line reference should be carefully followed during anchoring. Holes for fasteners might be slotted to allow rough initial placement followed by more careful positioning.

Observation 5

Collectors are often lifted to the roof and carried or pushed into position by members of the installation crew. The manual handling of the collectors causes extreme physical fatigue to the installation crew.

Conclusion/Inference: Members of the installation crew, when they become fatigued, adopt a poor work attitude and productivity and workmanship both drop. A large percentage of collector leaks may be attributed to poor workmanship induced by fatigue.

Recommendation: Collectors should be lifted from the shipping container directly to the roof and held in position for securing by a light weight boom crane such as the "cherry picker" type used by tree trimmers and electrical utilities.

Observation 6

Collectors normally have no hooks or other attachment points for crane slings.

Conclusion/Inference: If collectors are to be positioned by a crane (see Observations 5 and 7), it may be cost-effective, depending on the cost of fabrication, to add attachment points for slings during manufacture.

Recommendation: Suggest to manufacturers and installers that the use of a light weight crane is cost-effective and that sling attachment points be considered for inclusion on the collector.

Observation 7

Only two special purpose crane slings were seen which would automatically position the collector at the proper roof slope.

Conclusion/Inference: If cranes are to be used (see Observations 5 and 6), the fabrication of special purpose slings which would position the collector at the proper roof angle would probably be cost-effective.

Recommendation: Recommend that collector manufacturers include plans for the construction of low cost slings to position the collectors at a proper roof angle with their installation manuals.

Observation 8

Air collectors are designed for either internal manifolding between adjacent collectors (collectors are installed side-by-side with compression gaskets forming the seal for connecting air passages) or for external manifolding (collectors may have a space between them and are connected independently to a common duct under the roof).

Conclusion/Inference: Internally manifolded air collectors appear to be faster and easier to install than externally manifolded collectors when time to install the external duct is included. The internally manifolded collectors are probably no more expensive to fabricate than the externally manifolded collectors.

Recommendation: Manufacturers of air collectors should give serious consideration to internally manifolded designs (see Observation 9).

Observation 9

Sloppy installation and/or faulty equipment design may allow significant air leakage in air collector arrays with the following undesirable effects: (1) degradation of system efficiency and (2) introduction of hot air into the house through leaks in the ductwork, rock box, dampers, etc. whenever the collection system is operating, which can cause building overheating.

Conclusion/Inference: Collectors should be designed to reduce leakage to an acceptable level under actual field conditions. This is especially true of internally manifolded air collectors which are highly intolerant to misalignment.

Recommendation: (1) Test collector arrays for leakage during laboratory performance certification; (2) leak test collector array after installation; (3) seal ductwork, rock box, etc. to reduce hot air leakage into the house; (4) design backdraft dampers and motorized dampers to seal effectively and also to tolerate reasonable abuse during shipping and installation; (5) design internally manifolded air collectors to be reasonably leak free while tolerating reasonable misalignments.

Observation 10

Liquid collectors are often manifolded together by means of threaded pipes. Threaded unions are used to connect adjacent collectors and occasionally the connections are over-torqued, causing internal damage to the collector.

Conclusion/Inference: Manufacturers and installers should recognize the potential for damage to pipe fittings from over-torquing.

Recommendation: Manufacturers should specify the tools required for installation and recommend using wrenches of a particular length, since over-torquing tends to occur when long wrenches are used.

Observation 11

Rigid connections between internally manifolded liquid collectors do not allow for much alignment error. Unevenness of the mounting surface (e.g., the roof) may contribute further to the problem.

Conclusion/Inference: System leaks may occur due to misalignment of collectors beyond the capacity to accept misalignment.

Recommendation: Use flexible connections between the rows (columns) of collectors or use a gauge to ensure uniform dimensions of installed pipe fittings. Collector manifolds should be designed to tolerate reasonable misalignments.

Observation 12

Collectors are typically 36 in. (91 cm) wide, making it difficult to install, anchor, and capstrip by reaching across the panel.

Conclusion/Inference: A "narrow" panel may allow the installation of between panel fittings without requiring several ladders and/or walking across the panels. Workers could then systematically install an array while working in one direction with a minimum of workers and movement.

Recommendations: Manufacturers should consider high aspect ratio panel designs.

Observation 13

Most collector arrays are at least 15 ft in height, whereas most collectors are approximately eight ft in height.

Conclusion/Inference: Cost per square foot of collector installed could be reduced if collectors were shipped and installed in modules longer than eight feet. Leakage problems would also be reduced due to the need for fewer connections.

Recommendation: The use of a light weight crane (see Observation 5) would make it possible to build and ship collectors in a more cost-effective size.

Observation 14

During installation on sunny days, exposed panels reach high internal temperatures at the absorber. Hot panels in such cases can be handled only with gloves which are cumbersome to wear during other steps of

the installation. Heat escaping from panels makes working around the array uncomfortable. Glare from exposed glazing also reduces worker efficiency.

Conclusion/Inference: Some manner of temporary glazing covering is highly advised during array installation.

Recommendation: Manufacturers should provide for some manner of glazing cover such as adhesive opaque films, soluble paint, cardboard, etc.

Observation 15

Installations have been observed where the installer was responsible for fabricating mounting brackets for anchoring panels.

Conclusion/Inference: Considerable time and expense is involved in custom design and fabrication of fittings such as mounting brackets.

Recommendation: Manufacturers should be responsible for providing all necessary mounting hardware.

Observation 16

All jobs observed involved customer perimeter flashing arrangements with occasional confusion as to who is responsible for providing and installing the flashing.

Conclusion/Inference: Considerable time and cost is involved in custom flashing.

Recommendation: To the extent possible, manufacturers should provide plans and/or parts for array perimeter flashing and insulation. Capstrip assemblies should be provided to eliminate flashing between collectors.

Observation 17

Glazing replacement in several panel designs is extremely time consuming.

Conclusion/Inference: Allowance for glazing replacement should be given attention in panel design.

Recommendation: Panel should have "modular" replaceable glazing. Capstripping should be reusable.

Observation 18

If it is part of the installation procedure, a substantial amount of time is spent in the attic of the building to attach retaining nuts to collector anchor bolts which protrude through the roof sheathing.

Conclusion/Inference: Time can be saved by eliminating under the roof anchoring procedures.

Recommendation: Design the collector anchors so that the collectors can be anchored from the outside.

Observation 19

Installation crews do not pace themselves to a mental standard of the number of panels that should be installed per hour (only the job estimator has that standard). The installation crew adjusts the speed and effort of installation in such a way that the time required comes out in even multiples of days.

Conclusion/Inference: The cost of installation will be highly dependent upon the crew size and the number of collectors installed.

Recommendation: The crew size should be adjusted to recognize that the installation will generally take even multiples of whole days.

Observation 20

A few HVAC companies are acquiring a reputation as dependable collector installers. These firms are seeing solar installations become an increasing share of their business.

Conclusions/Inference: As solar installations become an increasing share of a firm's business, there are opportunities to improve productivity by purchasing specialized equipment and by utilizing crews that have gained installation experience from previous jobs.

Recommendation: The HVAC industry should recognize that a few firms will specialize in the installation of collectors and that the productivity of those firms will be relatively high due to the use of specialized equipment.

SUPPLEMENTARY FINDINGS

The following observations, although not directly related to the installation of solar collectors, were noted in the course of conducting the installation study. These observations are included because of their importance with respect to the proper and efficient functioning of a residential solar heating system once turned over to the homeowner.

Observation 21

Problems with auxiliary hot air furnaces in solar air systems set up with a series auxiliary have occurred:

(1) Motor burn out. Blower motors in a conventional hot air furnace are not thermally protected since they normally run in the house return air at about 70°F. However, in a solar system, air from collectors or storage can enter the auxiliary furnace at temperatures as high as 170°F, causing premature motor burn out.

(2) High temperature limit switches on oil or gas-fired hot air furnaces will cycle the burner on and off when the furnace is supplied with lukewarm air from storage. This air, which is not hot enough to meet the house load but is warmer than house return air, will quickly reach the high temperature limit when heat is supplied.

Conclusion/Inference: Modify furnaces to remedy these problems or use a parallel auxiliary set-up.

Recommendation: (1) Use a thermally protected motor or mount the motor outside of the furnace; (2) increase the temperature rating of the furnace heat exchanger and increase the high temperature cut off; (3) use a parallel auxiliary set-up.

Observation 22

Some air handling units for air systems are poorly designed. Two of the problems noted were: (1) Class A non-thermally protected motors were subjected to 170°F air temperature which caused premature motor burn out and (2) access doors were poorly constructed and did not fit properly, allowing hot air to leak into the building and cause overheating.

Conclusion/Inference: Redesign air handler.

Recommendation: (1) Mount the blower motor outside of the air handler and (2) tighten quality control on the air handler housing.

Observation 23

Domestic hot water preheat coils mounted at the bottom of the collector supply duct can suffer night time freezing and possible rupture due to cold air from the collectors settling to the bottom of the insulated duct.

Conclusion/Inference: Reconfigure the system.

Recommendation: Either isolate the domestic hot water coil at night by placing a motorized damper in the collector supply duct between the coil and the collector array or locate the coil in the storage loop segment of the system.

Observation 24

Manufacturers' guidelines for mechanical room layouts are sketch or non-existent, resulting in faulty mechanical room designs, large expenditures in time and money for custom designing, and often trial-and-error layout of mechanical rooms.

Conclusion/Inference: Savings could be realized if guidelines for mechanical rooms were furnished.

Recommendation: Manufacturers of collectors and/or air handling equipment should suggest standardized layouts for mechanical rooms, including recommended placement of inlets and outlets in rock storage boxes.

Observation 25

Insufficient space is often allowed for duct chases and/or mechanical rooms.

Conclusion/Inference: Architects and/or consulting engineers do not completely plan for needed space for duct runs and mechanical equipment.

Recommendation: Plans should be carefully checked during the design phase so that space is provided for necessary solar ducts and equipment (see Observation 11).

Observation 26

Hand wrapping of sheet metal ductwork with insulation is a time consuming and often ineffective process.

Conclusion/Inference: A less time consuming, more effective method of ductwork insulation is needed.

Recommendation: Use pre-insulated (lined) sheet duct or fiberglass duct-board. A design study should be undertaken to determine if ductwork insulation R-values greater than those currently available in lined steel duct or fiberglass ductboard are needed.

Observation 27

Bids for solar installations may be unnecessarily high due to lack of knowledge of labor involved in various stages of installation.

Conclusion/Inference: Generally available solar installation guidelines and/or time standards may be valuable to estimators in better pinpointing time necessary for array installation, storage installation, mechanical room completion, etc.

Recommendation: Future effort should be directed toward establishing time guidelines for various types of solar installations.

Observation 28

Workmanship in the collector installation and associated equipment installation such as ductwork, etc. has been poor in some instances due to (1) inexperience, (2) lack of supervision, and (3) "short-cutting" on the part of the installer.

Conclusion/Inference: Installing contractors and general contractors must take more responsibility.

Recommendation: Collector manufacturers should supply complete installation instructions, including a tool list, with their equipment. Installing contractors should be aware of and follow all applicable building codes such as the HUD Minimum Property Standards, SMACNA solar duct construction code, and the IAPMO Uniform Solar Energy Code. General contractors should also be familiar with these codes and inspect the workmanship of the installation.

Observation 29

Poor coordination between the installing contractors and other building contractors have caused problems, delays and, in some cases, faulty installations.

Conclusion/Inference: Better coordination is needed.

Recommendation: The general contractor should take more responsibility for coordinating activities on the job site.

Observation 30

Although manufacturers design their products with some consideration of installation-related factors, by and large the installation of products currently on the market is an extremely labor intensive process.

Conclusion/Inference: Feedback from the market place encouraging installation conscious product design should be enhanced.

Recommendation: An organization such as the National Association of Solar Contractors could compile and publish an index of the "installability" rating of various solar products on the market.

FUTURE ACTIVITIES

DISSEMINATION OF PROJECT RESULTS

The following means of disseminating the findings of this project are planned, subject to clearance by DOE project management and the DOE patent office:

- (1) A summary of the project findings were distributed at the "Third Annual Solar Heating and Cooling Research and Development Contractors' Meeting" held in September 1978.
- (2) A paper reporting the findings was presented at the "Solar Heating and Cooling Systems Operational Results Conference", held in Colorado Springs, Colorado, November 28-December 1, 1978.
- (3) Copies of the summary of project findings distributed at the "Third Annual Solar Heating and Cooling Research and Development Contractors' Meeting" will be mailed to all manufacturers and installers contacted during the study. Several nationwide mailing lists of solar installation contractors are available and these lists could be used to extend the coverage of findings. The direct mailings will include a cover letter which will describe the procedures to obtain copies of the final report from the DOE Technical Information Center.
- (4) The findings will be incorporated into the solar energy installation courses taught by Colorado State University personnel to installation contractors, architects, and engineers.
- (5) Articles and news releases describing the project findings will be prepared for trade publications in the solar energy and the heating, ventilating and air conditioning fields.

The twelve studies completed to date cover a variety of systems and installation circumstances. (Because of project travel constraints, the installation sample was limited entirely to those job sites scheduled local to Colorado during the period fall 1977 through summer 1978.) The opportunity did not present itself to observe the same crew installing the same type of system more than once. It is therefore difficult to infer what degree of variability should reasonably be expected in the work element times derived from limited field data. Although the conclusions suggested by the data accumulated so far indicate areas where improvements in design and practice should be considered, further data gathering is necessary to increase confidence in these conclusions.

In addition to providing a measure of the variability in the field data for a particular crew and system, a more extensive sample would provide information on learning curve effects, novel installation techniques as yet unstudied, and allow the accumulation of a data base from which

guidelines could possibly be developed to aid installers in estimating and bidding. Based on a more extensive sample, quantitative comparison of installation related collector features could be undertaken with more confidence.

The report has suggested improvements in installation practices. Further study could be devoted to verifying such suggestions by specific design studies and controlled in-the-field testing.

Some questions have been raised on certain side effects experienced once a system is running and which are traceable to design and installation practices. Such problems as array and ductwork leakage in air systems deserve further investigation, including in-field testing.

This study has for the project staff indicated the value of field observations in turning up common sense improvements in installation practices and, more important, the value of broad dissemination of such findings to reduce trial and error learning in the solar installation industry. Work measurement techniques appear valuable in backing up in numbers observations made qualitatively in the field and, with a sufficiently large data base, the appropriateness of a proposed design or practice change can be established with relative certainty.

REFERENCES

- [1] Johnson, Ralph J., "Time and Methods Analysis Program (TAMAP)", Building Research, p. 28, March-April (1964)
- [2] Cash, Mitchell, Hardware Problems Encountered in Solar Heating and Cooling Systems, DOE/NASA TM-78172, NASA Scientific and Technical Information Facility
- [3] Orłowski, Henryk, "Solar Steps to Solving Solar System Problems", Solar Engineering, Vol. 3, No. 7, p. 31 (1978)
- [4] Schwolski, R., "Rx for Installers", Solar Age, April 1978 to present.
- [5] InterTechnology Corp., Solar Energy Systems Installation Costs for Selected Commercial Buildings, ITC Report No. 111076, December (1976)
- [6] R.O. Smith Associates, Summary of Performance Problems of 100 Residential Solar Water Heaters Installed by New England Electric Company Subsidiaries in 1976 and 1977, prepared for Brookhaven National Laboratory (1978).
- [7] Jacobs, P.C., "Time Study Analysis of the Installation of Solar Heating Equipment", M.S. thesis, Department of Mechanical Engineering, Colorado State University, Ft. Collins, CO, December (1978)

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APPENDIX A

TIME STUDY METHODOLOGY

Two types of time study methods were used for this project. The first method used was a Continuous Time Study (C.T.S.) technique and later in the project a second method called Group Timing Technique (G.T.T.) was used.

CONTINUOUS TIME STUDY (C.T.S.)

This method simply measures the elapsed time of the various work activities. A stop watch, which runs continuously, is used to time the activities. The start and finish are recorded and subtracted to give the elapsed time of each activity.

GROUP TIMING TECHNIQUE (G.T.T.)

G.T.T. is simply a fixed interval work sampling study. At every specified interval of time, typically .01 hour, the activities of each member of the work crew are recorded by means of a tally. At the conclusion of the study, the tallies are totaled and the percentage of time spent by each worker on each element is determined. From the study total elapsed time, and the percentage of time spent on a particular work element, the elapsed time is determined.

A G.T.T. study, since it is a sampling procedure, is subject to some statistical sampling error. The error inherent in the sampling procedure is represented as a tolerance on the calculated percentage for a particular work element. The formula used to estimate this tolerance, based on the binomial distribution, for a 95 percent confidence interval is shown below:

$$TOL = 1.96 \sqrt{\frac{p(1-p)}{N}}$$

where p is the percent calculated from the work sampling data and N is the total number of samples taken for that particular study. For example, data represented as:

Percent	TOL
32.1	3.2

means that it is 95 percent certain that the true percentage lies between 28.9 and 35.3 percent.

COMPARISON OF C.T.S. AND G.T.T.

C.T.S. worked well to measure the elapsed time of certain work elements, provided the elements preceded themselves in a reasonably orderly fashion. It gave an accurate measure of the amount of time spent, since it was only subject to measurement error and not additionally to statistical sampling error. It did not give as good a measure of idle time

or work crew effectiveness as the G.T.T.; it was very difficult to implement when problems arose during the installation which caused the work elements to be performed out of order.

Although subject to statistical sampling error, a G.T.T. study yielded more valuable information in terms of work crew effectiveness than a C.T.S.. A G.T.T. study could handle many workers doing separate and independent jobs and, because of its flexibility, was used for the majority of the field studies presented.

WORK ELEMENT DESCRIPTIONS

Idle time was broken down into three general categories:

- (1) Idle - normal - non-productive time during the normal course of the installation
- (2) Idle - discussion/confer/discuss - non-productive time spent discussing problems and procedures related to the installation
- (3) Idle - wait - non-productive time spent waiting for some necessary preliminary procedure to be performed

Also a general category called

GET/reposition equipment

-Tools, etc.

-Tools/parts, etc.

-Etc.

was used to represent time spent retrieving tools, small parts, moving ladders, etc.

All other work elements are explained in the text of each field study.

COMPUTER OUTPUT

Included with each field study where G.T.T. was used is a partial listing of the computer output generated. The raw data taken on-site are shown along with summary pages of reduced data. The reduced data span, in some cases, several pages of raw field data.

APPENDIX B
FIELD STUDIES

TABLE I: SUMMARY OF FIELD STUDIES

Field Study No.	Panel *Type	Panel Size m ² (ft ²)	Panel Weight kg (lb)	Crew Size	Crane Used?	Time Study ** Method	Man Hrs [†] Per Panel	Man Hrs [†] Per 10 m ²
1	A	1.8 (19.8)	69 (153)	2-3	No	A	.54	3.0
2	A	1.8 (19.8)	69 (153)	2	No	A	.59 ¹	3.28
3	B	2.8 (30.0)	76 (169)	7	Yes	A	1.17 ^{3,5}	4.18
4	C	2.1 (22.8)	73 (160)	5	Yes	A	.72	3.43
5	A	1.8 (19.8)	69 (153)	3	Yes	B	.82 ^{2,5}	4.55
6	D	2.9 (21.0)	73 (160)	6-8	Yes	B	1.29 ^{2,3}	6.2
7	A	1.8 (19.8)	69 (153)	2	Yes	A/B	.24 ¹	1.33
8	C	9.0 (97.3)	549 (1210)	5	Yes	A	1.27	1.41
9	B	1.7 (18.7)	60 (130)	3	No	B	.36 ^{2,3}	2.12
10	C	1.8 (19.2)	73 (161)	3	No	B	1.33	7.39
11	B	1.9 (20.0)	61 (135)	4	No	B	.48 ^{3,5}	2.53
12	A	1.7 (18.7)	61 (135)	3-5	Yes	B	.76 ^{4,5}	7.0

* Panel Type

- A - Internally Manifolded Air Collector
- B - Externally Manifolded Air Collector
- C - Internally Manifolded Liquid Collector
- D - Externally Manifolded Liquid Collector

** Time Study Method

- A - Continuous
- B - Group Timing Technique

† Panel Installation Only, Crane Operator excluded.

1 Does not include lifting panels to roof.

2 Weighted over both days.

3 Does not include external manifold connections.

4 Second day installation data only.

5 Includes capstripping.

FIELD STUDY SUMMARY SHEET

Study Number 1

COLLECTOR	
1. TYPE	Air - internal manifold - double glazing - non-selective surface
2. DIMENSIONS	.91 m x 1.98 m (36 in x 78 in) 1.8 square meters (19.5 square feet)
3. WEIGHT	69.6 kg (153 lbs)
SITE	
1. BUILDING USE	Single family residence
2. SOLAR APPLICATION	Space heating, DHW preheat
3. ARRAY PITCH	30°
4. ARRAY ACCESS	Ladder from interior to bottom of room 3.05 m (10 ft) from ground
5. ARRAY SIZE	25.4 square meters (273 ft ²) 14 panels
6. GENERAL CONDITIONS	Sunny, windy, cold
7. SAFETY PRECAUTIONS	None
PROCEDURE	
1. CREW SIZE/EXPERIENCE	3 inexperienced, 1 experienced
2. DELIVERY/PACKAGING	Closed semi-trailer Collectors packaged two to a box
3. COLLECTOR POSITIONING	Manual

FIELD STUDY 1

BACKGROUND

At this site an air-heating system was installed on a single family dwelling. Because this was the first installation studied, it was primarily a study to aid in the design of a work measurement procedure. However, some Continuous Time Studies (C.T.S.) were performed on some of the more important steps of the installation.

PRE-INSTALLATION

The pre-installation procedure was as follows:

- (1) Determine from architectural drawings where the bottom edge of the collector array should be and nail down a one inch by one inch starter strip to the roof. Care must be taken to ensure that the strip is aligned square with the roof and is installed as straight as possible as this is the primary reference point for the array.
- (2) Use a large wood triangle to mark off each vertical column of collectors.
- (3) Lay out the line for the top of the array.
- (4) Using the above reference lines and the architectural drawings, cut holes in the roof for the connecting ductwork. A large saber saw was used to make a square hole approximately two inches larger than the diameter of the duct.
- (5) Install some temporary cleats on the roof to hold the upper array during installation. Also install a temporary cleat on the north side of the roof to hold the last collector until it is mounted.
- (6) While steps (1) to (5) were being performed, another crew was uncrating and unloading the collectors and was hauling them to the job site.

The collectors were packaged two to a box and, at this particular site, were stored in a large semi-trailer approximately 250 feet from the job site. Four persons were used to unload and transport the collectors, which were stacked four boxes high in the trailer. The collectors weighed about 160 pounds each, meaning that each box weighed better than 320 pounds. This dictated that the collectors be removed one at a time from the box and unloaded into a pickup truck which was backed up to the trailer. The truck then moved the collectors four at a time to the garage of the house.

INSTALLATION

Because a crane was not available for collector installation, it was decided that the collectors would be disassembled into two parts, (1) the metal absorber and box assembly and (2) the double glass-weatherstrip assembly. This was a relatively simple procedure which required the removal of eight pieces of tape and lifting the glass out of the box. The parts weighed approximately 90 pounds for the steel box and 70 pounds for the glass. The parts were carried from the garage to the "greenhouse" part of the house (see Fig. 1-1), where they could be lifted up to the roof. Two men would disassemble the collectors, carry them to the greenhouse, and lift them to the roof. Another two men would then carry the parts up to the roof to the correct location.

The collector and/or glass assemblies were not all passed onto the roof with the correct orientation, causing a need to reorient the assemblies on the roof. The times for this stage are presented in Table 1-1.

The top row of collectors was brought up first, putting the first collector on a temporary cleat on the north side of the roof and the remaining six collector modules for the upper row were mounted on temporary cleats about two feet higher than the final positions. The bottom row was set along the starter strip. The times are presented in Table 1-2.

The final part of the installation which was studied involved installation of internal manifold gaskets, end caps, and collector anchoring.

Gaskets and end caps were installed on the manifold ports on the collectors which were at the ends of the array. This was accomplished before the collectors were brought onto the roof. The gasket was set into the manifold port by hand and the end cap was installed with sheet-metal screws which were installed by an electric drill. It was noted that the sheetmetal screws could "strip out" the holes in the collector quite easily, causing a poor fit of the end cap which may result in leakage.

The collectors were tied down in a stair step fashion, starting at the lower left corner of the array. The gaskets were installed by hand into the manifold ports. Using the starter strip and the chalk lines as a reference, two collectors were mated. Extreme care was necessary to ensure that the collectors met each other square so that the internal manifold connections did not leak. The internal and external hold down brackets are used in conjunction with lag bolts to anchor the collector. An electric drill with a socket and extension was used to drive the lag bolts.

COMMENTS

- (1) The collector packaging scheme made it very difficult to unload the collectors from the trailer. Collectors packaged one to a box are desirable, as forklifts are generally unavailable on a construction site.
- (2) Moving panels to the roof by hand, rather than using a crane, was acceptable in this case because the roof pitch was only 30

degrees and the distance from the floor of the greenhouse to the roof surface was only about eight feet.

- (3) The roof surface was extremely uneven, causing problems with the alignment of the panels, increasing the leakage potential. See Fig. 1-2.
- (4) The factory-supplied gaskets for interpanel connections did not fit the collectors properly, causing a number of them to be rejected after repeated attempts to make them fit. Gaskets which fit only marginally were used due to a limited supply. This also increased the leakage potential.
- (5) The lag bolts which anchored the collectors used an additional Tinnerman fastener nut under the roof surface. This fastener was difficult to install because of its position under the roof surface and the large number of nuts required (10 per collector).

WORK ELEMENT DESCRIPTION

- (1) Haul collector, set into approximate place -- two men lift collector through greenhouse and carry to temporary placement on cleat or starter strip.
- (2) Haul glazing, set into collector -- two men lift glazing assembly through greenhouse and carry to collector and set into place.
- (3) Idle, wait -- non-production time to rest, wait for the men on the first floor to send up the pieces.
- (4) Hand up collector and glazing, idle -- the time spent by the two men on the first floor, lifting collectors to the crew on the roof.
- (5) Install gaskets -- select and fit the required number of gaskets to each collector for manifold connections.
- (6) Align collectors -- move panels from temporary position to final position.
- (7) Interior hold downs -- install the required number of interior hold downs.
- (8) Exterior hold downs -- install the required number of exterior hold downs.

Fig. 1-1. Collector Array
Note greenhouse area in lower left corner of roof

Fig. 1-2. Roof Pitch Variation
Note variation in roof pitch where upper edge of collector meets perimeter strip

Table 1-1. Move Collectors to Roof

Study 1	Element	Man-hrs/ Panel	Percent	Fixed (man-hrs)	Source
Roof	Haul collect, set in approx. place	.031	19.5		CTS
Roof	Haul glazing, set into collector	.043	27.0		CTS
Roof	Idle, wait	.085	53.5		CTS
Total		.159			
Ground	Hand up collect. & glazing, idle	.080			est
Total		.239			

Table 1-2. Collector Tie Down

Study 1	Element	Man-hrs/ Panel	Percent	Fixed (man-hrs)	Source
	Install gaskets	.126	42.3		CTS
	Align collectors	.057	19.2		CTS
	Interior hold-downs	.048	16.1		CTS
	Exterior hold-downs	.067	22.5		CTS
Total		.298			

FIELD STUDY SUMMARY SHEET

Study Number 2

COLLECTOR	
1. TYPE	Air - internal manifold - double glazing - non-selective surface
2. DIMENSIONS	.914 m x 1.981 m (36 in x 78 in) 1.8 square meters (19.5 square feet)
3. WEIGHT	69.5 kg (153 lbs)
SITE	
1. BUILDING USE	Five unit condominium
2. SOLAR APPLICATION	Space heating and DHW preheat
3. ARRAY PITCH	23°
4. ARRAY ACCESS	Ladder, 3.05 m (10 ft) from roof to ground
5. ARRAY SIZE	28.98 m ² (312 ft ²) 16 panels
6. GENERAL CONDITIONS	Clear and cool
7. SAFETY PRECAUTIONS	Rope and homemade safety belt
PROCEDURE	
1. CREW SIZE/EXPERIENCE	2/Good
2. DELIVERY/PACKAGING	Boxes unloaded and stacked on-site, two collectors per box
3. COLLECTOR POSITIONING	Bucket loader to roof level, manual to final position

FIELD STUDY 2

BACKGROUND

The installation of five panels out of a twelve panel array was observed. This array was approximately the thirtieth out of thirty-four units with air solar systems installed in a townhouse development. Each building has five living units, each of which has an independent solar heating system. The installing crew consisted of two sheetmetal workers employed by the subcontracting sheetmetal shop.

PRE-INSTALLATION

Since thirty-four systems were installed at this development, the solar collectors were delivered in large lots and stacked until required in a fenced equipment area approximately 200 meters (600 ft) from the installation sites. Panels were transferred to the site via bucket loader. The starter strip which located the lower row of the array was nailed down over the roof felt by the roof carpenters based on instructions from the installation crew.

INSTALLATION

The positioning and anchoring of the solar panels involved the following sequence of steps:

- (1) Rough positioning -- it was possible at this site to hoist the collectors to the roof by bucket loader. Two workers removed the panels from the bucket and either placed the panels roughly in their final position or, when space no longer allowed, placed the remaining panels on the adjoining north roof.
- (2) Port gaskets -- before setting each panel into final position, rubber gaskets were installed in the previously anchored adjoining panels. Workers laid a bead of silicone caulk around the edge of the manifold port primarily to hold the gasket in place.
- (3) Final alignment -- two workers set the panel into position (either sliding the panel a few inches or carrying the panel from the north roof). Panels were drawn up together, generally by brute force, and the final space was checked by using the anchor bolt head as a gauge.
- (4) Anchors -- Three to five external hold down anchors (clip and lag bolt assembly) were installed immediately. When all panels adjoining a given panel were in place, several additional internal hold down anchors common to several panels were installed such that each panel was finally held down at eight points.

POST-INSTALLATION

On this job the subcontracting sheetmetal shop crew was responsible for completing capstripping, perimeter flashing, and water leak checking the array. Although these tasks were not directly observed in this study, the estimated labor time was 8 to 16 man-hours.

COMMENTS

- (1) Members of the installation crew estimated that each complete installation required approximately two man-weeks (80 man-hours). This entailed ductwork and equipment installation in the mechanical room, array installation and completion of collector feed and return ducting. It was estimated of the two man-weeks total, a minimum of 16 man-hours were involved in array installation. Because of the custom nature, ductwork in the mechanical room required 8 to 16 man-hours shop fabrication time and 8 to 16 man-hours on-site installation time.
- (2) The crew often found it necessary to tear out framing (requiring return of the framing crew) where insufficient space was allowed for duct chases.
- (3) Phases of the installation were delayed pending completion of framing and roofing. In general, the crew had to schedule their activities around other work crews on the site.

Fig. 2-1. Solar Heated Condominium
Far left unit was one observed

Table 2-1. Collector Installation

Study 2	Element	Man-hrs/ Panel	Percent	Fixed (man-hrs)	Source
	Position panel	0.02			CTS
	Install gaskets	0.07			CTS
	Align	0.09			CTS
	Anchor	0.23			CTS
	Miscellaneous	0.152		0.76	CTS
	Get tools/ equipment	0.029		0.12	CTS
	Break			0.17	

FIELD STUDY SUMMARY SHEET

Study Number 3

COLLECTOR	
1. TYPE	Air - external manifold - single glazing - selective surface
2. DIMENSIONS	.61 m x 4.57 m (2 ft x 15 ft) 2.79 square meters (30 square feet)
3. WEIGHT	73.2 kg (168 lbs)
SITE	
1. BUILDING USE	Custom single family house
2. SOLAR APPLICATION	Space heating and DHW preheat
3. ARRAY PITCH	55°
4. ARRAY ACCESS	Ladder from ground, north roof. 4.57 m (15 ft) roof to ground level
5. ARRAY SIZE	41.8 m ² (450 ft ²) 15 panels
6. GENERAL CONDITIONS	Warm, sunny day
7. SAFETY PRECAUTIONS	Chicken ladder, rope and safety belt
PROCEDURE	
1. CREW SIZE/EXPERIENCE	5/none 2/extensive
2. DELIVERY/PACKAGING	Delivered in factory truck morning of installation/none
3. COLLECTOR POSITIONING	Crane from truck to final position

FIELD STUDY 3

BACKGROUND

This study involved an externally manifolded air collector installed on a custom one-family home. The collectors were manufactured locally, so the general contractor for the project was able to arrange factory supervision of the installation as well as collector delivery on the morning of the installation.

The work crew consisted of the general contractor and three carpenters on the roof, one carpenter and one laborer from the factory on the ground, and the factory representative. Except for the factory personnel, the crew was inexperienced in solar collector installation.

The collectors were delivered in a flat bed truck on factory racks. A crane was used to lift the collectors directly to the roof from the back of the truck (see Fig. 3-1).

PRE-INSTALLATION

Two square holes per collector were cut into the roof for the inlet and outlet air ducts. Also, two 2 by 4's nailed together form the starter strip. A chalk line was made perpendicular to the starter strip at the correct dimension from the roof edge to fix the position of the first collector and hence the position of the entire array (Fig. 3-2).

INSTALLATION

Two men on the ground unhooked a collector from a rack on the truck. Four mounting brackets were installed on the first collector and two on each collector thereafter. The brackets were simple 90 degree bent sheet metal tabs which were attached to the collector on-site by two sheetmetal screws.

These two men then attached the sling to the collectors and one man helped to guide the collectors from the ground with a long rope attached to the sling.

Four men were positioned on the roof, one man below the collector stood on a temporary roof cleat, two more were on the ladder, and one was on the north roof. The collector was guided into place as it was brought up by the crane. Once in place, it was tipped up slightly so that the ropes could be removed from under it. The sling was then sent away (Fig. 3-3). The two men on the ladder anchored the collector to the roof by driving lag bolts through the mounting tabs into the plywood roof sheathing with an electric drill and socket bit. Four mounts were made on the first collector installed and two on each subsequent collector. The next collector module was brought into position by the same method. It was positioned about one-quarter inch away from the adjacent collector. The collectors are designed so that a common channel is formed for the connecting strips. One of two connecting strips was fed from the bottom by

Fig. 3-1. Crane and Delivery Truck

Fig. 3-2. Preinstallation

Fig. 3-3. Positioning Collector

Fig. 3-4. Cap Strip Anchoring

the bottom man and pulled to the top by the top man using a long piece of wire attached to the strip. The second connecting strip was fed from the bottom by the bottom man and the excess was trimmed off using tin snips. The feed wire was also cut off by the top man. Next, the capstrip was installed. Two lengths of precut and predrilled capstrip were set between the collectors by the men on the ladders. The men on the ladders then drove sheetmetal screws through the capstrip into the connecting strip using an electric drill with a socket head bit. A total of nine sheetmetal screws were required for both capstrips (see Fig. 3-4). The top man moved the ladder over in position for the next collector and the sequence was repeated.

POST INSTALLATION

The array perimeter insulation and flashing, as well as the collector inlet and outlet manifolds and panel to manifold connections, were subcontracted to a sheetmetal firm. The estimates for installation times are not available.

COMMENTS

A collector which is as long as the total height of the array is desirable to maximize the number of square feet of collector installed during each cycle. This also decreases the number of connections needed, thus decreasing the potential for array leakage.

A narrow (two foot) collector is desirable and seems to be a practical limit to the span over which an installer can stretch to perform the necessary hook-up procedures without suspending himself over the array. A collector which has no on-roof interpanel air flow connections will tolerate a greater amount of roof unevenness and collector misalignment, thus reducing installation time. The sheetmetal screws which attach the capstrips to the collectors are very difficult to start and require a great amount of downward pressure. This presents a dangerous, time consuming and tiring situation for the installer. This great pressure could cause the installer to lose his balance and fall or cause the drill to slip, breaking the glass or otherwise damaging the collector and injuring the installer. An improvement to this procedure would be:

- (1) Use sheetmetal screws with a sharper, tougher point to facilitate self-starting.
- (2) Use a connecting strip with cage nuts already installed which could be aligned with the capstrip easily with a drift pin, allowing the capstrip to be installed with regular machine screws. This would also result in a tighter fit with less chance of stripping the screw. This would also allow for easy removal and replacement of the cap strip for cover glass maintenance.

The upper external manifold for the array was difficult to install because the room below the collectors had a cathedral ceiling. Ladders had

to be extended from the ground floor two stories up into the peak of the roof. This problem could have been alleviated if the carpenters had constructed a simple walkway for the sheetmetal crew to use while installing the upper manifold and while making the panel to manifold connections.

Table 3-1. Roof Crew

Study 3	Element	Man-hrs/ Panel	Percent	Fixed (man-hrs)	Source
	Remove sling	.016	2.4		CTS
	Align	.017	2.5		CTS
	Anchor	.074	11.0		CTS
	Feed connecting strip	.051	7.6		CTS
	Install cap strip	.103	15.4		CTS
	Move ladder	.010	1.5		CTS
	Idle, normal	.268	40.0		CTS
	Idle, wait for collector	.083	12.4		CTS
	Foreign elements	.048	7.2		CTS
Totals		.670			

Table 3-2. Ground Crew

Study 3	Element	Man-hrs/ Panel	Percent	Fixed (man-hrs)	Source
	Remove panel from truck				est
	Attach sling				est
	Guide to roof				est
	Idle				est
Total		.503			

FIELD STUDY SUMMARY SHEET

Study Number 4

COLLECTOR	
1. TYPE	Liquid - internal manifold
2. DIMENSIONS	1.12 m x 1.85 m (45 in x 73 in) 2.11 square meters (22.8 square feet)
3. WEIGHT	72.7 kg (160 lbs)
SITE	
1. BUILDING USE	Commercial
2. SOLAR APPLICATION	Solar assisted heat pump for space heating and DHW preheat
3. ARRAY PITCH	45°
4. ARRAY ACCESS	Ladder, 30° pitch below array
5. ARRAY SIZE	122.4 m ² (1322.4 ft ²) 58 panels
6. GENERAL CONDITIONS	Cool, cloudy
7. SAFETY PRECAUTIONS	None
PROCEDURE	
1. CREW SIZE/EXPERIENCE	5/good
2. DELIVERY/PACKAGING	Boxes stacked on-site, one collector per box
3. COLLECTOR POSITIONING	Crane from ground to final position

FIELD STUDY 4

BACKGROUND

Although this installation involved a relatively large array (122 square meters) on a commercial type building, the study is of interest because of the somewhat atypical mounting technique employed. The crew consisted of the three project staff members and two general laborers employed by the mechanical subcontractor.

A shallow pitched section of roof below the slope roof section on which the array was located proved to be an advantage in providing additional work space, reducing exposure with respect to safety, and providing generally easy access to the array.

PRE INSTALLATION

The general contractor installed rails and "V" stanchions to which the solar collectors were to be mounted (see Figs. 4-1, 4-2). It was necessary to go back and shim the rails to get a level run the length of the array. The panels involved threaded, rigid unions between each panel, therefore the mounting rails needed to run as straight as possible. The solar panels were delivered prior to the day of installation and stacked on-site. One day prior to the scheduled installation the installation crew installed a single panel to determine required tools and establish a procedure.

INSTALLATION

Collectors were set off a crane positioned as indicated in Fig. 4-3. The sequence of installation steps was as follows:

- (1) Panel preparation -- two workers stationed on the ground removed the panels from the packing carton, bolted four mounting brackets to the four corners of the collector, and attached two nylon webbing slings to the panel and crane hook.
- (2) Receive collector -- three workers stationed on the roof grasped and steadied the panel, removed protective caps on the threaded unions, and guided the panel into place so that the connection could be completed.
- (3) Complete union connection -- with one worker above and below the panel poised with pipe wrench, and a third worker forcing the panel into final alignment, the two unions were tightened down and the two left unistrut brackets were attached.
- (4) Complete mounting -- with two brackets holding the left edge, the right edge of the panel was raised 3 to 4 cm to remove both slings. The final two brackets were assembled and tightened down. Pipe joint cement was applied to the two right manifold connections and, if a new column of panels was to be started, tools were repositioned to the right.

Fig. 4-1

Fig. 4-2

Fig. 4-3

Fig. 4-4

Generally the ground crew was able to prepare the panels faster than the roof crew was able to mount them, leaving the ground crew idle during each work cycle.

POST INSTALLATION

The array as designed stood roughly 15 cm off the roof with no capstripping between panels. Completing the array entailed completion of the feed and return plumbing and installation of hardware such as isolation and pressure relief valves.

COMMENTS

Interpanel spacing was greater than anticipated due perhaps to variability in tightening the threaded unions between each panel.

Fig. 4-5

Fig. 4-6

Table 4-1. Installation Roof Crew

Study 4	Element	Man-hrs/ Panel	Percent	Fixed (man-hrs)	Source
	Receive position	0.059	13.7		CTS
	Align/unions	0.065	15.1		CTS
	Brackets 1 and 2	0.073	16.9		CTS
	Brackets 3 and 4/ sling	0.065	15.1		CTS
	Idle (wait)	0.075	17.4		CTS
	Idle (normal)	0.094	21.8		CTS
Total		0.431			

FIELD STUDY SUMMARY SHEET

Study Number 5

COLLECTOR	
1. TYPE	Air - internal manifold - double glazing - non-selective surface
2. DIMENSIONS	.91 m x 1.49 m (36 in x 78 in) 1.81 square meters (19.5 square feet)
3. WEIGHT	69.5 kg (153 lbs)
SITE	
1. BUILDING USE	Commercial
2. SOLAR APPLICATION	Solar assisted heat pump for space heating and DHW preheat
3. ARRAY PITCH	55°
4. ARRAY ACCESS	Ladder, 1.2 m (3.9 ft) from roof to ground
5. ARRAY SIZE	76.02 m ² (819 ft ²) 42 panels
6. GENERAL CONDITIONS	Hot, clear
7. SAFETY PRECAUTIONS	Chicken ladder
PROCEDURE	
1. CREW SIZE/EXPERIENCE	3/second solar installation
2. DELIVERY/PACKAGING	Closed truck/two collectors per box
3. COLLECTOR POSITIONING	Crane to roof, manual final positioning

FIELD STUDY 5

BACKGROUND

In this installation the framed structure on which the solar collectors were set also served as the roof of the mechanical room. The roof surface, pitched at 55 degrees, extends down to within 1.2 meters of the ground, allowing ready access by ladder to the collector array (see Fig. 5-1). The installation was performed by a crew of three pipefitters employed by the solar contractor. This installation was the first air collector system that the crew had been involved in and the second solar system in which the solar contractor had been involved.

PRE INSTALLATION

The contractor rented a closed truck into which the collectors were loaded at the dealer's warehouse. The truck was parked on-site and panels were unloaded as the installation progressed (see Fig. 5-2).

A square steel channel (5 cm on a side) was predrilled and bolted down as a starter strip by the installation crew. This task took approximately 2 to 3 man-hours. Some adjustment, hammering, etc. was necessary to finally install this piece straight and level.

Six panels were set by hand the first day of the study to determine required tools and procedures (see Tables 5-1, 5-2).

INSTALLATION

On the second day of the installation a crane, which was rented on an hourly basis, was on-site. Due to the hourly rental fee, the crew set all the remaining panels on the roof. The first row rested on the starter strip and the second and third rows of panels rested on temporary cleats (see Tables 5-3 and 5-4). The sequence of steps was as follows:

- (1) Remove packing -- two workers on the ground removed the panels from the closed truck and set the panels down temporarily near by. Generally this involved removing the packaging from the collectors in the truck and then carrying the collector panels out one at a time.
- (2) Attach sling and guide to roof -- the two workers on the ground attached a nylon strap around the perimeter of the panel such that, with tension, it remained in a slot running around the collector pan. The panel when lifted was suspended vertically and swung over the roof. One of the ground crew members occasionally walked the suspended collector over to the array to steady the panel.
- (3) Receive and position -- a single worker positioned on the roof received the panel and guided it into rough position. This worker also removed the sling and installed temporary cleats, where necessary, to receive the next collector.

After all panels had been temporarily positioned, the crew returned to the leftmost panels to begin anchoring and capstripping (see Tables 5-5 to 5-6).

- (4) Install gaskets -- one or two workers distributed and installed internal manifold gaskets.
- (5) Anchor -- generally two workers would push the collector into final position (removing temporary cleats if necessary) with the third worker driving in six to eight screws on the back side.
- (6) Prepare and install capstrip -- one worker inserted capstrip bolts into prepunched holes in a piece of capstrip and attached a threaded clip. This worker alternated between preparing capstripping and anchoring panels. Once assembled, the piece was handed to two workers on a ladder and installed. This procedure proceeded in a stair-step fashion toward the right across the array.

Miscellaneous tasks included installing end caps on unused manifold ports around the exterior of the array and installing cross pieces to complete capstripping at the intersection of four panels.

POST INSTALLATION

Array perimeter flashing and duct connections were subcontracted.

COMMENTS

In this installation it was appropriate to temporarily position all panels with the crane and manually move the panels into final position since the crane was rented on an hourly basis. When the crane is available on a daily basis only, it may be more cost-effective to anchor each panel "as you go".

Fig. 5-1

Fig. 5-2

Table 5-1. Field Study 5 (Air collector/internal manifold)

PAGE 1

ELEMENT	WORKERS/NO. UNITS				
	1	2	3	4	
REMOVE PKG.	0.00	0.00	0.00	0.00	0.00
UNLOAD COLLECTOR	1.00	1.00	0.00	0.00	1.00
MOVE TO ROOF	6.00	5.00	4.00	3.00	3.00
INSTALL GASKETS	7.00	0.00	11.00	15.00	8.00
ALIGN	4.00	4.00	11.00	20.00	3.00
ANCHOR	0.00	17.00	0.00	0.00	3.00
GET/REPOSITION EQMT.	16.00	12.00	1.00	7.00	3.00
OFFSITE	0.00	17.00	1.00	2.00	3.00
IDLE1 (NORMAL)	33.00	33.00	57.00	33.00	3.00
IDLE2 (DISCUSSION)	20.00	4.00	6.00	1.00	3.00
FOREIGN ELEMENT	6.00	1.00	0.00	12.00	3.00
TSTART=0.000 TFINAL=1.000 TINT= .010 UNITS= 3.00 WKRS= 4.00					
THE TOTAL TALLIES FOR WORKER 1 ARE 92.00 OUT OF 100.00 POSSIBLE					
THE TOTAL TALLIES FOR WORKER 2 ARE 94.00 OUT OF 100.00 POSSIBLE					
THE TOTAL TALLIES FOR WORKER 3 ARE 91.00 OUT OF 100.00 POSSIBLE					
THE TOTAL TALLIES FOR WORKER 4 ARE 93.00 OUT OF 100.00 POSSIBLE					

Table 5-2. Field Study 5 (Air collector/internal manifold) Summary
Manual lifting of first three collectors into position

FLAPSCD TIME	MOS	MANN-HRS			
1.000	4.000				
ELEMENT	NO. COMPLETED	PERCENT TIME (TOL)	MANHRS	MANHRS PER COLLECTOR	COMMENTS
UNLOAD COLLECTOR	1.00	4.4 2.75	.0216	.0216	
MOVE TO RIG	2.00	4.95 2.30	.1941	.0970	
INSTALL GASKETS	4.00	8.90 2.00	.3558	.1116	0)
ALIGN	3.00	10.51 3.17	.4205	.1402	
ANCHOR	3.00	4.80 2.17	.1832	.0611	
GET/REPOSITION EMT.	2.00	9.70 3.01	.3881	.1294	
OFFSITE	2.00	4.70 2.30	.2154	-	
IDLE1 (NORMAL)	2.00	42.04 5.07	1.6910	.5606	
IDLE2 (DISCUSSION)	3.00	8.16 2.82	.3342	.1114	
FOREIGN ELEMENT	2.00	5.17 2.74	.2040	-	
FOR CREW MEMBER 1				1.10	

ELEMENT	PERCENT TIME (TOL)
UNLOAD COLLECTOR	1.00 2.75
MOVE TO RIG	4.95 2.30
INSTALL GASKETS	7.90 2.00
ALIGN	4.80 2.17
GET/REPOSITION EMT.	17.72 3.01
IDLE1 (NORMAL)	35.43 5.07
IDLE2 (DISCUSSION)	21.51 2.82
FOREIGN ELEMENT	4.45 2.74

COMMENTS

0) 0 gaskets per 3 panels

ELEMENT	PERCENT TIME (TOL)
UNLOAD COLLECTOR	1.00 2.75
MOVE TO RIG	5.32 2.30
ALIGN	4.21 2.00
ANCHOR	14.30 2.17
GET/REPOSITION EMT.	12.77 3.01
OFFSITE	14.30 2.30
IDLE1 (NORMAL)	35.21 5.07
IDLE2 (DISCUSSION)	4.76 2.82
FOREIGN ELEMENT	1.00 2.74

ELEMENT	PERCENT TIME (TOL)
UNLOAD COLLECTOR	1.00 2.75
MOVE TO RIG	4.80 2.30
INSTALL GASKETS	12.00 2.00
ALIGN	12.00 2.17
GET/REPOSITION EMT.	1.10 3.01
OFFSITE	1.10 2.30
IDLE1 (NORMAL)	62.54 5.07
IDLE2 (DISCUSSION)	4.53 2.82

ELEMENT	PERCENT TIME (TOL)
MOVE TO RIG	3.23 2.30
INSTALL GASKETS	14.13 2.00
ALIGN	21.51 2.17
GET/REPOSITION EMT.	7.43 3.01
OFFSITE	2.15 2.30
IDLE1 (NORMAL)	39.48 5.07
IDLE2 (DISCUSSION)	1.00 2.82
FOREIGN ELEMENT	12.30 2.74

Table 5-3. Field Study 5 (Air collector/internal manifold)

PAGE 1

ELEMENT	WORKERS/MIN. UNITS				
	1	2	3	4	5
UNLOAD/REMOVE PVC.	0.00	0.00	2.00	9.00	4.00
ATTACH SLING	0.00	0.00	7.00	7.00	4.00
LEFT PANEL TO BOOM	4.00	0.00	0.00	0.00	4.00
SLING OFF/POSITION	0.00	4.00	0.00	0.00	4.00
RETURN BOOM	4.00	0.00	0.00	0.00	4.00
INSTALL GASNETS	0.00	0.00	0.00	0.00	0.00
ALIGN	0.00	0.00	0.00	0.00	0.00
ANCHOR	0.00	0.00	0.00	0.00	0.00
PREPARE CAPSTRIPS	0.00	0.00	0.00	0.00	0.00
INSTALL END CAPSTRIPS	0.00	0.00	0.00	0.00	0.00
INSTALL LONG CAPSTRIP	0.00	0.00	0.00	0.00	0.00
TIE-OFF	0.00	0.00	0.00	0.00	0.00
IDLE1 (NOFFAL)	8.00	0.00	4.00	6.00	4.00
IDLE2 (DISCUSSION)	0.00	1.00	0.00	0.00	4.00
OFFSITE	0.00	0.00	0.00	0.00	4.00
GET/REPOSITION PONT.	0.00	0.00	0.00	0.00	4.00
CLEANUP	0.00	0.00	0.00	0.00	0.00
POSITION/MISF.	0.00	0.00	0.00	0.00	4.00
TOTAL=0.000 TOTAL= .250 TIME= .010 UNITS= 4.00 WORKS= 4.00					

THE TOTAL TAILIES FOR WORKER 1 ARE 22.00 OUT OF 25.00 POSSIBLE
 THE TOTAL TAILIES FOR WORKER 2 ARE 22.00 OUT OF 25.00 POSSIBLE
 THE TOTAL TAILIES FOR WORKER 3 ARE 22.00 OUT OF 25.00 POSSIBLE
 THE TOTAL TAILIES FOR WORKER 4 ARE 22.00 OUT OF 25.00 POSSIBLE

PAGE 2

ELEMENT	WORKERS/MIN. UNITS				
	1	2	3	4	5
UNLOAD/REMOVE PVC.	0.00	1.00	21.00	24.00	9.00
ATTACH SLING	0.00	0.00	12.00	12.00	9.00
LEFT PANEL TO BOOM	21.00	0.00	4.00	10.00	9.00
SLING OFF/POSITION	0.00	0.00	4.00	1.00	9.00
RETURN BOOM	12.00	0.00	0.00	0.00	9.00
INSTALL GASNETS	0.00	0.00	0.00	0.00	0.00
ALIGN	0.00	0.00	0.00	0.00	0.00
ANCHOR	0.00	0.00	0.00	0.00	0.00
PREPARE CAPSTRIPS	0.00	0.00	0.00	0.00	0.00
INSTALL END CAPSTRIPS	0.00	0.00	0.00	0.00	0.00
INSTALL LONG CAPSTRIP	0.00	0.00	0.00	0.00	0.00
TIE-OFF	0.00	0.00	0.00	0.00	0.00
IDLE1 (NOFFAL)	24.00	19.00	2.00	2.00	9.00
IDLE2 (DISCUSSION)	0.00	0.00	0.00	0.00	9.00
OFFSITE	0.00	1.00	0.00	0.00	9.00
GET/REPOSITION PONT.	0.00	0.00	0.00	0.00	9.00
CLEANUP	0.00	0.00	0.00	0.00	0.00
POSITION/MISF.	1.00	21.00	1.00	0.00	0.00
TOTAL=0.000 TOTAL= .510 TIME= .010 UNITS= 0.00 WORKS= 4.00					

THE TOTAL TAILIES FOR WORKER 1 ARE 51.00 OUT OF 51.00 POSSIBLE
 THE TOTAL TAILIES FOR WORKER 2 ARE 51.00 OUT OF 51.00 POSSIBLE
 THE TOTAL TAILIES FOR WORKER 3 ARE 51.00 OUT OF 51.00 POSSIBLE
 THE TOTAL TAILIES FOR WORKER 4 ARE 51.00 OUT OF 51.00 POSSIBLE

Table 5-3 (con't)

ELEMENT	1	2	3	4	5
UNLOAD/REMOVE PNC.	0.00	0.00	0.00	0.00	0.00
ATTACH SLING	0.00	0.00	0.00	0.00	0.00
LIFT PANEL TO ROOF	0.00	0.00	0.00	0.00	0.00
SLING DISPOSITION	0.00	0.00	0.00	0.00	0.00
RETURN ROOF	0.00	0.00	0.00	0.00	0.00
INSTALL GASKETS	0.00	17.00	2.00	4.00	11.00
ALIGN	0.00	0.00	2.00	2.00	1.00
ANCHOR	0.00	0.00	1.00	0.00	0.00
PREPARE FASTENERS	0.00	0.00	0.00	0.00	0.00
INSTALL END FASTENERS	0.00	0.00	0.00	0.00	0.00
INSTALL END FASTENERS	0.00	0.00	0.00	0.00	0.00
TIE-OFF	0.00	0.00	0.00	0.00	0.00
IDLE1 (NORMAL)	0.00	3.00	2.00	2.00	1.00
IDLE2 (DISCUSSION)	0.00	4.00	7.00	2.00	1.00
OFFSITE	0.00	16.00	1.00	0.00	1.00
GET/REPOSITION PONT.	0.00	2.00	10.00	0.00	1.00
CLEANUP	0.00	0.00	0.00	0.00	0.00
FOREIGN/MSC.	0.00	25.00	61.00	24.00	1.00
TSTART=0.000 TFINAL= 2.00 TINT= .010 UNITS= 0.10 MINS= 3.00					

THE TOTAL TALLIES FOR WORKER 1 ARE 0.00 OUT OF 80.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 2 ARE 25.00 OUT OF 80.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 3 ARE 60.00 OUT OF 80.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 4 ARE 69.00 OUT OF 80.00 POSSIBLE

PAGE 4

ELEMENT	1	2	3	4	5
UNLOAD/REMOVE PNC.	0.00	0.00	0.00	0.00	0.00
ATTACH SLING	0.00	0.00	0.00	0.00	0.00
LIFT PANEL TO ROOF	0.00	0.00	0.00	0.00	0.00
SLING DISPOSITION	0.00	0.00	0.00	0.00	0.00
RETURN ROOF	0.00	0.00	0.00	0.00	0.00
INSTALL GASKETS	0.00	4.00	6.00	6.00	4.00
ALIGN	0.00	2.00	22.00	23.00	4.00
ANCHOR	0.00	25.00	0.00	0.00	4.00
PREPARE FASTENERS	0.00	4.00	0.00	4.00	4.00
INSTALL END FASTENERS	0.00	5.00	1.00	0.00	2.00
INSTALL END FASTENERS	0.00	1.00	10.00	2.00	2.00
TIE-OFF	0.00	0.00	0.00	0.00	0.00
IDLE1 (NORMAL)	0.00	0.00	14.00	13.00	4.00
IDLE2 (DISCUSSION)	0.00	1.00	6.00	0.00	4.00
OFFSITE	0.00	0.00	3.00	4.00	4.00
GET/REPOSITION PONT.	0.00	5.00	2.00	4.00	4.00
CLEANUP	0.00	0.00	0.00	0.00	0.00
FOREIGN/MSC.	0.00	0.00	1.00	0.00	4.00
TSTART=0.000 TFINAL= 2.00 TINT= .010 UNITS= 4.00 MINS= 3.00					

THE TOTAL TALLIES FOR WORKER 1 ARE 0.00 OUT OF 80.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 2 ARE 25.00 OUT OF 80.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 3 ARE 23.00 OUT OF 80.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 4 ARE 23.00 OUT OF 80.00 POSSIBLE

Table 5-3 (con't)

PAGE 5

ELEMENT	WORKER/NO. MINUTE				
	1	2	3	4	
UNLOAD/REMOVE PKG.	0.00	0.00	0.00	0.00	0.00
ATTACH SLING	0.00	0.00	0.00	0.00	0.00
LIFT PANEL TO POS	0.00	0.00	0.00	0.00	0.00
SLING REPOSITION	0.00	0.00	0.00	0.00	0.00
POSITION PANEL	0.00	0.00	0.00	0.00	0.00
INSTALL CASSETTE	0.00	0.00	0.00	0.00	0.00
ALIGN	0.00	0.00	0.00	0.00	0.00
ANCHOR	0.00	0.00	0.00	0.00	0.00
PREPARE C-STRIPS	0.00	0.00	0.00	0.00	0.00
INSTALL C-STRIPS	0.00	0.00	0.00	0.00	0.00
INSTALL LONG C-STRIP	0.00	0.00	0.00	0.00	0.00
TIE-OFF	0.00	0.00	0.00	0.00	0.00
TOLE1 (NORMAL)	0.00	0.00	0.00	0.00	0.00
TOLE2 (DISCUSSION)	0.00	0.00	0.00	0.00	0.00
REFSITE	0.00	0.00	0.00	0.00	0.00
GET/REPOSITION FORT.	0.00	0.00	0.00	0.00	0.00
CLEANUP	0.00	0.00	0.00	0.00	0.00
FORFEIGN/MISC.	0.00	0.00	0.00	0.00	0.00
TSTART=0.000 TFINAL=.930 TINT=.010 UNITS= 1.00 WORKS= 3.00					

THE TOTAL TALLIES FOR WORKER 1 ARE 0.00 OUT OF 93.00 POSSIBLE

THE TOTAL TALLIES FOR WORKER 2 ARE 76.00 OUT OF 93.00 POSSIBLE

THE TOTAL TALLIES FOR WORKER 3 ARE 78.00 OUT OF 93.00 POSSIBLE

THE TOTAL TALLIES FOR WORKER 4 ARE 77.00 OUT OF 93.00 POSSIBLE

Table 5-4. Field Study 5 (Air collector/internal manifold) Summary
Lift collectors to approximate position on roof by crane

ELAPSED TIME	HRS .750	MANHRS 3.040				
ELEMENT	NO. COMPLETED	PERCENT TIME (TOL)	MANHRS	MANHRS PER COLLECTOR		
UNLOAD/REMOVE PKG.	13.00	22.19 4.76	.6744	.0519		
ATTACH SLING	13.00	12.97 3.85	.3943	.0303		
LIFT PANEL TO ROOF	13.00	16.04 4.20	.4576	-	(1)	
SLING OFF/POSITION	13.00	7.51 3.02	.2283	.0116		
RETURN BOOM	13.00	6.49 2.92	.1971	-	(1)	
IDLE1 (NORMAL)	13.00	23.55 4.86	.7159	.0357	(1)	
IDLE2 (DISCUSSION)	13.00	.34 .67	.0104	-		
OFFSITE	13.00	.34 .67	.0104	-		
FOREIGN/MISC.	13.00	10.59 3.52	.3216	.0241		
FOR CREW MEMBER 1		FOR CREW MEMBER 3		.136		
ELEMENT	PERCENT TIME (TOL)		ELEMENT	PERCENT TIME (TOL)		
LIFT PANEL TO ROOF	39.73	11.73	UNLOAD/REMOVE PKG.	40.54	11.19	
RETURN BOOM	26.03	10.03	ATTACH SLING	25.68	9.09	
IDLE1 (NORMAL)	32.84	10.74	LIFT PANEL TO ROOF	10.91	7.07	
FOREIGN/MISC.	1.37	2.67	SLING OFF/POSITION	10.81	7.67	
FOR CREW MEMBER 2		FOR CREW MEMBER 4		(1) CRANE OPERATOR EXCLUDED		
ELEMENT	PERCENT TIME (TOL)		ELEMENT	PERCENT TIME (TOL)		
UNLOAD/REMOVE PKG.	1.37	2.67	UNLOAD/REMOVE PKG.	46.58	11.44	
SLING OFF/POSITION	17.41	8.79	ATTACH SLING	26.03	10.07	
IDLE1 (NORMAL)	38.34	11.15	LIFT PANEL TO ROOF	13.70	7.86	
IDLE2 (DISCUSSION)	1.37	2.67	SLING OFF/POSITION	1.37	2.67	
OFFSITE	1.37	2.67	IDLE1 (NORMAL)	12.33	7.54	
FOREIGN/MISC.	39.73	11.73				

Table 5-5. Field Study 5 (Air collector/internal manifold)

ELAPSED TIME		HRS	MANHRS			
2.410			7.230			
ELEMENT	NO. COMPLETED	PERCENT TIME (TOL)		MANHRS	MANHRS PER COLLECTOR	COMMENTS
INSTALL GASKETS	23.00	7.14	1.97	.5164	.0599	(1)
ALIGN	6.00	13.07	2.50	.9450	.1575	
ANCHOR	9.00	5.62	1.74	.4066	.0913	
PREPARE CAPSTRIPS	8.00	2.40	1.74	.2048	.0496	(2)
INSTALL END C-STRIPS	4.00	1.04	1.06	.1428	.0238	(3)
INSTALL LONG C-STRIP	4.00	5.17	1.49	.3736	.0959	
TIE-OFF	3.00	.15	.30	.0110	-	
IDLE1 (NORMAL)	6.00	10.94	2.40	.7911	.1319	
IDLE2 (DISCUSSION)	4.00	12.14	2.50	.4790	.1465	
OFFSITE	6.00	3.56	1.40	.2527	-	
GET/REPOSITIONING EOMT.	6.00	4.38	1.87	.4615	.0769	
CLEANUP	36.00	14.57	2.44	1.1977	-	
FOREIGN/MISC.	6.00	14.44	2.49	1.0438	-	
					<u>.8408</u>	
FOR CREW MEMBER 1						

FOR CREW MEMBER 3		FOR CREW MEMBER 4	
ELEMENT	PERCENT TIME (TOL)	ELEMENT	PERCENT TIME (TOL)
INSTALL GASKETS	12.09 4.36	INSTALL GASKETS	5.94 3.13
ALIGN	.43 1.74	ALIGN	17.41 5.07
ANCHOR	17.73 5.05	PREPARE CAPSTRIPS	4.11 2.43
PREPARE CAPSTRIPS	4.65 2.41	INSTALL LONG C-STRIP	6.39 3.76
INSTALL END C-STRIPS	2.29 2.20	TIE-OFF	.46 .80
INSTALL LONG C-STRIP	1.46 1.81	IDLE1 (NORMAL)	13.24 4.49
IDLE1 (NORMAL)	7.44 3.41	IDLE2 (DISCUSSION)	14.61 4.49
IDLE2 (DISCUSSION)	6.30 3.89	OFFSITE	1.83 1.77
OFFSITE	7.44 3.51	GET/REPOSITIONING EOMT.	7.31 3.45
GET/REPOSITIONING EOMT.	4.65 2.41	CLEANUP	15.07 4.74
CLEANUP	20.00 5.35	FOREIGN/MISC.	13.24 4.40
FOREIGN/MISC.	12.43 4.74		

COMMENTS

- (1) 8 GASKETS/3 PANELS
 (2) 5 PC. CAPSTRIP/3 PANELS
 (3) 2 PC. /3 PANELS

Table 5-6. Field Study 5 (Air collector/internal manifold)

PAGE 1

ELEMENT	WORKERS/NO. UNITS			
	1	2	3	
REPOSITION PANEL	0.00	4.00	3.00	4.00
SCROUNGE GASKETS	0.00	0.00	0.00	0.00
INSTALL GASKETS	0.00	4.00	2.00	2.00
REPOSITION GASKETS	0.00	0.00	1.00	1.00
ALIGN PANEL	0.00	14.00	23.00	3.00
ANCHOR PANEL	17.00	0.00	0.00	4.00
PREPARE CAPSTRIP	4.00	0.00	0.00	2.00
INSTALL CAPSTRIP	3.00	11.00	11.00	2.00
INSTALL CROSSERS	0.00	0.00	0.00	0.00
INSTALL PORT ENDCAP	0.00	0.00	0.00	0.00
ADJUST STARTER STRIP	0.00	0.00	0.00	0.00
GET/REPOSITION FRONT	1.00	9.00	4.00	4.00
DUCT TAPE	0.00	0.00	1.00	1.00
OFFSITE	0.00	0.00	0.00	0.00
IDLE (NORMAL)	35.00	27.00	14.00	4.00
IDLE (DISCUSSION)	4.00	2.00	4.00	4.00
TSTART=0.000 TFINAL= .800 TINT= .010 UNITS= 3.00 WKRS= 2.00				

THE TOTAL TALLIES FOR WORKER 1 ARE 44.00 OUT OF 80.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 2 ARE 44.00 OUT OF 80.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 3 ARE 45.00 OUT OF 80.00 POSSIBLE

PAGE 2

ELEMENT	WORKERS/NO. UNITS			
	1	2	3	
REPOSITION PANEL	0.00	3.00	2.00	4.00
SCROUNGE GASKETS	0.00	0.00	0.00	0.00
INSTALL GASKETS	0.00	3.00	4.00	4.00
REPOSITION GASKETS	0.00	0.00	0.00	0.00
ALIGN PANEL	3.00	24.00	33.00	4.00
ANCHOR PANEL	17.00	0.00	0.00	4.00
PREPARE CAPSTRIP	25.00	0.00	0.00	4.00
INSTALL CAPSTRIP	0.00	8.00	11.00	3.00
INSTALL CROSSERS	0.00	0.00	0.00	0.00
INSTALL PORT ENDCAP	0.00	0.00	0.00	0.00
ADJUST STARTER STRIP	0.00	4.00	0.00	4.00
GET/REPOSITION FRONT	7.00	13.00	4.00	4.00
DUCT TAPE	0.00	0.00	4.00	4.00
OFFSITE	4.00	0.00	0.00	4.00
IDLE (NORMAL)	36.00	29.00	17.00	4.00
IDLE (DISCUSSION)	0.00	1.00	6.00	4.00
TSTART=0.000 TFINAL= .950 TINT= .010 UNITS= 4.00 WKRS= 3.00				

THE TOTAL TALLIES FOR WORKER 1 ARE 87.00 OUT OF 95.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 2 ARE 87.00 OUT OF 95.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 3 ARE 84.00 OUT OF 94.00 POSSIBLE

Table 5-6 (con't)

PAGE 3

ELEMENT	WORKERS/MO. UNITS			
	1	2	3	4
REPOSITION PANEL	0.00	2.00	2.00	4.00
SCUMING GASKETS	0.00	0.00	0.00	0.00
INSTALL GASKETS	0.00	0.00	0.00	0.00
REPOSITION GASKETS	0.00	0.00	0.00	0.00
ALIGN PANEL	1.00	10.00	10.00	4.00
ANCHOR PANEL	12.00	0.00	0.00	4.00
PREPARE CAPSTRIP	0.00	0.00	0.00	0.00
INSTALL CAPSTRIP	0.00	0.00	0.00	0.00
INSTALL COSSSES	0.00	0.00	0.00	0.00
INSTALL PORT ENOCAP	0.00	0.00	0.00	0.00
ADJUST STARTER STRIP	0.00	0.00	0.00	0.00
GET/REPOSITION EQMT.	2.00	4.00	5.00	4.00
DUCT TAPE	0.00	2.00	1.00	4.00
OFFSITE	2.00	4.00	0.00	4.00
IDLE (NORMAL)	34.00	15.00	10.00	4.00
IDLE (DISCUSSION)	1.00	3.00	4.00	4.00
TSTART=0.000 TFINAL= .720 TIME= .010 UNITS= 4.00 WKS= 3.00				

THE TOTAL TALLIES FOR WORKER 1 ARE 57.00 OUT OF 77.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 2 ARE 55.00 OUT OF 77.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 3 ARE 53.00 OUT OF 77.00 POSSIBLE

PAGE 4

ELEMENT	WORKERS/MO. UNITS			
	1	2	3	4
REPOSITION PANEL	0.00	2.00	2.00	4.00
SCUMING GASKETS	2.00	2.00	4.00	12.00
INSTALL GASKETS	0.00	4.00	0.00	12.00
REPOSITION GASKETS	0.00	0.00	2.00	12.00
ALIGN PANEL	0.00	21.00	27.00	4.00
ANCHOR PANEL	17.00	0.00	0.00	4.00
PREPARE CAPSTRIP	12.00	0.00	0.00	10.00
INSTALL CAPSTRIP	1.00	15.00	15.00	10.00
INSTALL EXOSSES	2.00	0.00	0.00	0.00
INSTALL PORT ENOCAP	2.00	0.00	0.00	4.00
ADJUST STARTER STRIP	0.00	0.00	0.00	0.00
GET/REPOSITION EQMT.	13.00	14.00	4.00	4.00
DUCT TAPE	0.00	4.00	10.00	4.00
OFFSITE	1.00	2.00	0.00	4.00
IDLE (NORMAL)	4.00	4.00	7.00	4.00
IDLE (DISCUSSION)	44.00	28.00	9.00	6.00
TSTART=0.000 TFINAL=1.170 TIME= .010 UNITS= 6.00 WKS= 3.00				

THE TOTAL TALLIES FOR WORKER 1 ARE 100.00 OUT OF 117.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 2 ARE 100.00 OUT OF 117.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 3 ARE 100.00 OUT OF 117.00 POSSIBLE

Table 5-7. Field Study 5 (Air collector/internal manifold)

ELAPSED TIME	MRS	MANHRS				
1.440	10.00					
ELEMENT	NO. COMPLETED	PERCENT TIME (TOL)		MANHRS	MANHRS PER COLLECTOR	COMMENTS
REPOSITION PANEL	18.00	2.39	.99	.2611	.0145	
SCROUNGE GASKETS	12.00	.99	.44	.1068	-	
INSTALL GASKETS	31.00	4.24	1.30	.4629	.0398	(1)
REPOSITION GASKETS	13.00	.22	.30	.0237	-	
ALIGN PANEL	12.00	20.33	2.60	2.2196	.1306	
ANCHOR PANEL	18.00	4.30	1.57	.5884	.0382	
PREPARE CAPSTRIP	22.00	4.44	1.35	.4867	.0369	(2)
INSTALL CAPSTRIP	27.00	10.31	1.05	1.1030	.0681	(2)
INSTALL CROSSES	6.00	.22	.30	.0237	-	
INSTALL PORT ENDCAP	6.00	.22	.30	.0237	-	
ADJUST STARTER STRIP	4.00	.43	.43	.0475	-	
GET/REPOSITION EMT.	19.99	9.46	1.89	1.0327	.0574	
DUCT TAPE	15.00	2.81	1.03	.2849	-	
OFFSITE	16.30	1.41	.74	.1543	-	
IDLE (NORMAL)	18.00	24.79	2.70	2.7063	.1504	
IDLE (DISCUSSION)	12.00	11.85	2.09	1.2936	.0719	
FOR CREW MEMBER 1					.608	
ELEMENT	PERCENT TIME (TOL)					
SCROUNGE GASKETS	.97	1.10				
ALIGN PANEL	1.30	1.36				
ANCHOR PANEL	12.83	4.37				
PREPARE CAPSTRIP	13.31	3.79				
INSTALL CAPSTRIP	1.30	1.26				
INSTALL CROSSES	.45	.00				
INSTALL PORT ENDCAP	.45	.00				
GET/REPOSITION EMT.	9.00	3.21				
OFFSITE	2.27	1.66				
IDLE (NORMAL)	25.39	5.36				
IDLE (DISCUSSION)	16.23	4.12				

COMMENTS:

(1) 6 GASKETS PER 3 PANELS

(2) 5 AC. PER 3 PANELS

Table 5-7 (con't)

FOR CREW MEMBER 2

ELEMENT	PERCENT TIME	TOTAL
REPOSITION PANEL	2.47	2.19
SCRUNGE GASKETS	.65	.89
INSTALL GASKETS	5.48	2.53
ALIGN PANEL	24.10	4.77
INSTALL CAPSTRIP	13.97	3.65
ADJUST STAPLER STRIP	1.24	1.24
GET/REPOSITION EQMT.	32.40	9.79
DUCT TAPE	1.96	1.53
OFFSITE	1.94	1.54
IDLE (NORMAL)	22.90	4.69
IDLE (DISCUSSION)	10.97	3.44

FOR CREW MEMBER 3

ELEMENT	PERCENT TIME	TOTAL
REPOSITION PANEL	2.31	2.07
SCRUNGE GASKETS	1.32	1.79
INSTALL GASKETS	7.20	2.93
REPOSITION GASKETS	.54	.91
ALIGN PANEL	35.76	5.41
INSTALL CAPSTRIP	15.23	4.05
GET/REPOSITION EQMT.	6.29	2.76
DUCT TAPE	5.96	2.47
IDLE (NORMAL)	15.00	4.17
IDLE (DISCUSSION)	4.28	3.11

FIELD STUDY SUMMARY SHEET

Study Number 6

COLLECTOR	
1. TYPE	Liquid - external manifold - selective surface - single glazing
2. DIMENSIONS	.92 m x 2.14 m (36-1/4 in x 84-1/4 in) 1.97 square meters (21.2 square feet)
3. WEIGHT	72.7 kg (160 lbs)
SITE	
1. BUILDING USE	Experimental solar house (single family residential design)
2. SOLAR APPLICATION	Space heating, DHW preheat, absorption cooling
3. ARRAY PITCH	45°
4. ARRAY ACCESS	Scaffold, 61 m (20 ft) from ground
5. ARRAY SIZE	58.5 m ² (630 ft ²) 30 collectors
6. GENERAL CONDITIONS	Hot, sunny
7. SAFETY PRECAUTIONS	Scaffold
PROCEDURE	
1. CREW SIZE/EXPERIENCE	Variable (6 to 8)/good
2. DELIVERY/PACKAGING	Truck - stacked in front of building/ stacked and banded 5 panels per pallet.
3. COLLECTOR POSITIONING	Small crane, ground to final position

FIELD STUDY 6

BACKGROUND

This study involved installation of a new collector array on an experimental solar house. The panels were of an externally manifolded, liquid design. They were delivered to the job site on a flat bed truck and stacked on pallets. Each pallet contained five collectors, banded together with cardboard attached to the collector on the front side to protect the glazing. The pallets were unloaded with a fork lift and the collectors were stored outside for a few days before installation.

A variable work crew of up to eight people was used for the installation. This work crew consisted primarily of laboratory technicians and graduate students and was not representative of an actual commercial installation.

PRE INSTALLATION

A few installation steps were required on the ground before the collectors could be moved to the roof. The collectors were removed from the pallets and brought over to the front of the building (Fig. 6-1). The seams on the rear of the panels were sealed with silicone sealer at the recommendation of the manufacturer. Since the collectors were not supplied with mounting hardware, installer-designed brackets were mounted on the collectors, as well as the necessary pipe fittings.

A movable scaffold and a forklift-mounted scaffold were available as working platforms. The first step in the collector mounting procedure was to measure the roof and lay out the array dimensions. Next, at the manufacturer's suggestion, 2 by 6 inch wood stringers were nailed vertically to the roof surfaces to lift the collectors off the sheathing. These stringers also provided a solid surface into which lag bolts were driven to anchor the collector. Next, horizontal chalk lines were snapped to fix the position of the bottom and top row of panels.

INSTALLATION

A small "cherry picker" crane was used to lift the panels from the ground to the roof. A crew of 2 to 3 people was used to move the panels to the ground staging area and attach a sling to the collector. The crane lifted the collector to the roof, where a crew of 3 to 4 people guided it into place, removed the sling, and anchored it with lag bolts into the 2 by 6 stringers (Fig. 6-2).

The mounting brackets were designed so that one bracket was used for mounting the corners of two adjacent collectors (Fig. 6-2). A large amount of effort was expended to align the holes in the mounting bracket with the holes in the body of the collector because the holes in the brackets were drilled to a close tolerance.

Fig. 6-1

Fig. 6-2

Fig. 6-3

POST INSTALLATION

After the collector array was in place, connections were made between the upper and lower array by use of flexible hoses. The inlet manifold was lifted into place using the forklift and connections were made to the lower row of panels using flexible hoses. The outlet manifold was brought up from the north roof and worked into place at the top of the array. The connections to the panels were then made again using flexible hoses.

COMMENTS

- (1) The packing system for the collectors was inadequate, as some of the collectors arrived at the job site in damaged condition.
- (2) The collector body was poorly designed. The seams on the collector needed to be caulked, internal cage nuts into which the mounting bracket bolts were attached twisted out when tightened, internal pipe threads for fluid connections broke when pipe fittings were tightened into them.
- (3) Collector mounting hardware should be supplied by the manufacturer. The collector mounting brackets were expensive to fabricate in the shop facilities and were poorly designed due to installer inexperience.
- (4) Two collectors sharing one mounting bracket was not a good idea in this application. Panel-to-panel alignment is not critical because of the external manifolding and flexible connections. Panels mounted independently with a chalk line reference is sufficient.

WORK ELEMENT DESCRIPTION

- (1) Roof preparation -- measure roof, determine position of 2 by 6 inch stringers, nail stringers down, determine horizontal position of the two rows of panels, snap a chalk line indicating that position.
- (2) Discussion -- discussion of installation procedure with collector manufacturer representative.
- (3) Bracket preparation -- painting the steel brackets with primer.
- (4) Remove packaging, caulk, stack -- unband the pallets of collectors, caulk the seams on the rear of the collector, stack near the building.
- (5) Attach brackets, elbows, stack -- attach two brackets to each panel, attach a pipe nipple and steel elbow for the hose connections, stack near the house.
- (6) Deliver panel -- guide panel to roof
- (7) Prepare/attach sling -- move panels from stack to crane staging area, perform last minute adjustments to panel, attach sling

- (8) Receive/remove sling -- roof crew receives collector from the crane, guides it into approximate position on the roof.
- (9) Align -- move collector into final position
- (10) Anchor -- install mounting bolts into collector body, install lag bolts into roof.
- (11) Move scaffold -- move the forklift-mounted scaffold to follow the action of the crew.
- (12) Install stringer -- nail down a 2 by 6 stringer (most of which was installed during preinstallation).

Table 6-1. Field Study 6 (Liquid Collector/external manifold)

PAGE 1

ELEMENT	WORKERS/NO. UNITS					
	1	2	3	4	5	6
DELIVER PANEL	9.00	1.00	3.00	0.00	0.00	6.00
ALIGN	1.00	0.00	0.00	0.00	0.00	6.00
ANCHOR	4.00	0.00	0.00	0.00	0.00	6.00
PREPARE/ATTACH SLING	5.00	20.00	18.00	5.00	0.00	6.00
OPERATE CRANE	0.00	0.00	0.00	0.00	48.00	6.00
GET TOOLS	2.00	0.00	2.00	8.00	0.00	6.00
MISC TASKS	0.00	1.00	10.00	24.00	0.00	6.00
IDLE1 (WAIT)	11.00	30.00	20.00	14.00	24.00	6.00
IDLE2 (INSTRUCTIONS)	12.00	3.00	3.00	1.00	0.00	6.00
IDLE3 (NORMAL)	27.00	15.00	14.00	14.00	0.00	6.00
OFFSITE	0.00	0.00	0.00	5.00	0.00	6.00
TSTART=0.000 TFINAL=.670 TINT=1.000 UNITS=16.00 WKPS=3.00						
THE TOTAL TALLIES FOR WORKER 1 ARE	74.00	OUT OF	83.75	POSSIBLE		
THE TOTAL TALLIES FOR WORKER 2 ARE	70.00	OUT OF	83.75	POSSIBLE		
THE TOTAL TALLIES FOR WORKER 3 ARE	72.00	OUT OF	83.75	POSSIBLE		
THE TOTAL TALLIES FOR WORKER 4 ARE	72.00	OUT OF	83.75	POSSIBLE		
THE TOTAL TALLIES FOR WORKER 5 ARE	72.00	OUT OF	83.75	POSSIBLE		

PAGE 2

ELEMENT	WORKERS/NO. UNITS					
	1	2	3	4	5	6
DELIVER PANEL	0.00	3.00	7.00	1.00	0.00	5.00
ALIGN	0.00	0.00	4.00	0.00	0.00	5.00
ANCHOR	0.00	0.00	7.00	0.00	0.00	5.00
PREPARE/ATTACH SLING	0.00	34.00	3.00	0.00	0.00	5.00
OPERATE CRANE	0.00	0.00	0.00	0.00	50.00	5.00
GET TOOLS	0.00	0.00	3.00	14.00	0.00	5.00
MISC TASKS	0.00	14.00	17.00	4.00	0.00	5.00
IDLE1 (WAIT)	0.00	25.00	24.00	22.00	15.00	5.00
IDLE2 (INSTRUCTIONS)	0.00	7.00	4.00	4.00	0.00	5.00
IDLE3 (NORMAL)	0.00	10.00	20.00	40.00	0.00	5.00
OFFSITE	0.00	1.00	0.00	0.00	0.00	5.00
TSTART=0.000 TFINAL=.750 TINT=1.000 UNITS=3.00 WKPS=4.00						
THE TOTAL TALLIES FOR WORKER 1 ARE	0.00	OUT OF	83.75	POSSIBLE		
THE TOTAL TALLIES FOR WORKER 2 ARE	40.00	OUT OF	83.75	POSSIBLE		
THE TOTAL TALLIES FOR WORKER 3 ARE	44.00	OUT OF	83.75	POSSIBLE		
THE TOTAL TALLIES FOR WORKER 4 ARE	69.00	OUT OF	83.75	POSSIBLE		
THE TOTAL TALLIES FOR WORKER 5 ARE	63.00	OUT OF	83.75	POSSIBLE		

Table 6-1. Field Study 6 (Liquid collector/external manifold)

PAGE 1

ELEMENT	WORKERS/NO. UNITS				
	1	2	3	4	5
RECEIVE/SLING OFF	10.00	0.00	0.00	0.00	0.00
ALIGN	0.00	0.00	13.00	0.00	0.00
ANCHOR	11.00	20.00	37.00	14.00	0.00
GET TOOL	12.00	0.00	0.00	0.00	0.00
OFFSITE	0.00	0.00	0.00	0.00	0.00
IDLE(WAIT FOR PANEL)	2.00	10.00	1.00	0.00	0.00
IDLE(DISCUSSION)	0.00	0.00	1.00	0.00	0.00
IDLE(NORMAL)	14.00	0.00	0.00	10.00	0.00
MOVE SCAFFOLD	0.00	0.00	0.00	0.00	0.00
MEASURE	0.00	1.00	0.00	0.00	0.00
INSTALL STRINGER	0.00	0.00	0.00	0.00	0.00
TSTART=0.000 TFINAL= .670 TINT= .010 UNITS= 0.00 WORKS= 4.00					
THE TOTAL TALLIES FOR WORKER 1 ARE 60.00 OUT OF 67.00 POSSIBLE					
THE TOTAL TALLIES FOR WORKER 2 ARE 60.00 OUT OF 67.00 POSSIBLE					
THE TOTAL TALLIES FOR WORKER 3 ARE 40.00 OUT OF 67.00 POSSIBLE					
THE TOTAL TALLIES FOR WORKER 4 ARE 54.00 OUT OF 67.00 POSSIBLE					

PAGE 2

ELEMENT	WORKERS/NO. UNITS				
	1	2	3	4	5
RECEIVE/SLING OFF	0.00	0.00	0.00	12.00	0.00
ALIGN	0.00	0.00	0.00	0.00	0.00
ANCHOR	12.00	21.00	17.00	0.00	0.00
GET TOOL	12.00	0.00	0.00	0.00	0.00
OFFSITE	0.00	0.00	0.00	0.00	0.00
IDLE(WAIT FOR PANEL)	0.00	10.00	10.00	10.00	0.00
IDLE(DISCUSSION)	0.00	0.00	1.00	0.00	0.00
IDLE(NORMAL)	0.00	0.00	0.00	10.00	0.00
MOVE SCAFFOLD	0.00	0.00	0.00	0.00	0.00
MEASURE	0.00	0.00	0.00	0.00	0.00
INSTALL STRINGER	12.00	0.00	0.00	0.00	0.00
TSTART=0.000 TFINAL= .540 TINT= .010 UNITS= 4.00 WORKS= 4.00					
THE TOTAL TALLIES FOR WORKER 1 ARE 54.00 OUT OF 66.00 POSSIBLE					
THE TOTAL TALLIES FOR WORKER 2 ARE 50.00 OUT OF 66.00 POSSIBLE					
THE TOTAL TALLIES FOR WORKER 3 ARE 50.00 OUT OF 66.00 POSSIBLE					
THE TOTAL TALLIES FOR WORKER 4 ARE 52.00 OUT OF 66.00 POSSIBLE					

Table 6-3. Field Study 6 (Liquid collector/external manifold)

FLASPED TIME		MPS	MANHRS		
1.420		6.350			
ELEMENT	NO. COMPLETED	PERCENT TIME (TOL)	MANHRS	MANHRS PER COLLECTOR	COMMENTS
DELIVER PANEL	11.00	3.00 1.77	.1985	.0179	
ALIGN	11.00	.70 .43	.0447	.0041	
ANCHOR	12.00	1.83 .98	.2181	.0106	
PREPARE/ATTACH SLING	11.00	12.74 7.43	.7770	.0706	
OPERATE CRANE	11.00	13.78 7.44	.8722	—	(1)
GET TOOLS	11.00	4.50 1.52	.2856	.0260	
MISC TASKS	11.00	9.70 2.12	.6182	.0560	(1)
IDLE1 (WAIT)	11.00	24.83 2.32	1.8300	.1179	(1)
IDLE2 (INSTRUCTIONS)	11.00	4.35 1.50	.2760	.0152	
IDLE3 (NORMAL)	11.00	20.11 2.04	1.2771	.1161	
OFFSITE	11.00	.84 .47	.0536	—	
FOR CREW MEMBER 1			FOR CREW MEMBER 3	.444	(2)
ELEMENT	PERCENT TIME (TOL)	ELEMENT	PERCENT TIME (TOL)		
DELIVER PANEL	17.12 7.45	DELIVER PANEL	4.75 3.75		
ALIGN	1.35 2.42	ALIGN	2.50 2.42		
ANCHOR	8.13 4.77	ANCHOR	4.35 3.17		
PREPARE/ATTACH SLING	4.76 5.77	PREPARE/ATTACH SLING	13.13 5.22		
GET TOOLS	4.05 4.69	GET TOOLS	4.34 3.17		
IDLE1 (WAIT)	14.84 5.11	MISC TASKS	13.75 5.34		
IDLE2 (INSTRUCTIONS)	14.27 4.40	IDLE1 (WAIT)	27.50 4.97		
IDLE3 (NORMAL)	26.40 10.97	IDLE2 (INSTRUCTIONS)	5.43 3.97		
		IDLE3 (NORMAL)	22.40 2.82		
FOR CREW MEMBER 2			FOR CREW MEMBER 4		
ELEMENT	PERCENT TIME (TOL)	ELEMENT	PERCENT TIME (TOL)		
DELIVER PANEL	1.25 1.77	DELIVER PANEL	.62 1.21		
PREPARE/ATTACH SLING	35.22 7.42	PREPARE/ATTACH SLING	3.11 2.44		
MISC TASKS	8.44 4.84	GET TOOLS	13.24 5.31		
IDLE1 (WAIT)	34.59 7.30	MISC TASKS	19.88 6.14		
IDLE2 (INSTRUCTIONS)	3.14 2.71	IDLE1 (WAIT)	22.36 6.44		
IDLE3 (NORMAL)	15.77 5.66	IDLE2 (INSTRUCTIONS)	3.11 2.44		
OFFSITE	.53 1.77	IDLE3 (NORMAL)	34.14 7.32		
		OFFSITE	1.11 2.44		
			FOR CREW MEMBER 5		
ELEMENT	PERCENT TIME (TOL)	ELEMENT	PERCENT TIME (TOL)		
DELIVER PANEL	1.25 1.77	DELIVER PANEL	1.25 1.77		
PREPARE/ATTACH SLING	35.22 7.42	PREPARE/ATTACH SLING	35.22 7.42		
MISC TASKS	8.44 4.84	MISC TASKS	8.44 4.84		
IDLE1 (WAIT)	34.59 7.30	IDLE1 (WAIT)	34.59 7.30		
IDLE2 (INSTRUCTIONS)	3.14 2.71	IDLE2 (INSTRUCTIONS)	3.14 2.71		
IDLE3 (NORMAL)	15.77 5.66	IDLE3 (NORMAL)	15.77 5.66		
OFFSITE	.53 1.77	OFFSITE	.53 1.77		

COMMENTS

(1) CRANE OPERATOR EXCLUDED

(2) PARTIAL CREW (SEE TABLE 6-4)

Table 6-4. Field Study 6 (Liquid collector/external manifold)

ELAPSED TIME	HRS	MAN-HRS			
	1.310	5.320			
ELEMENT	NO. COMPLETED	PERCENT TIME (TOL)	MANHRS	MANHRS PER COLLECTOR	COMMENTS
RECEIVE/SLING OFF	10.00	6.88 2.74	.5236	.0524	
ALIGN	10.00	6.75 2.54	.4656	.0466	
ANCHOR	10.00	30.85 4.23	1.6414	.1642	
GET TOOL	10.00	7.84 2.47	.4191	.0419	
OFFSITE	6.00	.64 .41	.0233	-	
IDLE(WAIT FOR PANEL)	10.00	14.66 3.74	.7800	.0780	
IDLE(DISCUSSION)	10.00	2.04 1.70	.2595	.0270	
IDLE(NORMAL)	10.00	14.63 3.41	.6847	.0885	
MOVE SCAFFOLD	10.00	2.43 1.43	.1281	-	
MEASURE	6.00	.22 .43	.0116	-	
INSTALL STRINGER	6.00	4.34 1.90	.2328	-	

FOR CREW MEMBER 1

.493

(1)

ELEMENT	PERCENT TIME (TOL)
RECEIVE/SLING OFF	13.79 6.24
ALIGN	6.77 4.61
ANCHOR	18.97 7.13
GET TOOL	22.62 7.37
OFFSITE	.64 1.68
IDLE(WAIT FOR PANEL)	5.17 4.09
IDLE(DISCUSSION)	4.90 4.61
IDLE(NORMAL)	16.74 6.73
INSTALL STRINGER	10.34 5.84

FOR CREW MEMBER 2

ELEMENT	PERCENT TIME (TOL)
RECEIVE/SLING OFF	1.74 2.30
ALIGN	6.00 4.59
ANCHOR	47.61 9.04
GET TOOL	6.35 3.73
IDLE(WAIT FOR PANEL)	25.79 7.06
IDLE(DISCUSSION)	4.35 3.74
IDLE(NORMAL)	14.74 6.49
MEASURE	.97 1.90

FOR CREW MEMBER 3

ELEMENT	PERCENT TIME (TOL)
RECEIVE/SLING OFF	13.04 6.74
ALIGN	13.91 6.43
ANCHOR	42.81 9.04
IDLE(WAIT FOR PANEL)	6.52 5.20
IDLE(DISCUSSION)	1.74 2.30
IDLE(NORMAL)	12.17 5.00
INSTALL STRINGER	6.94 4.72

FOR CREW MEMBER 4

ELEMENT	PERCENT TIME (TOL)
RECEIVE/SLING OFF	10.81 5.78
ALIGN	8.11 5.08
ANCHOR	18.92 7.20
GET TOOL	6.31 4.92
OFFSITE	.20 1.76
IDLE(WAIT FOR PANEL)	18.92 7.20
IDLE(DISCUSSION)	2.70 3.07
IDLE(NORMAL)	23.42 7.88
MOVE SCAFFOLD	9.91 5.84

COMMENTS

(1) PARTIAL CREW:

TOTAL INSTALLATION TIME

.444 (TABLE 6-3)

.493 (TABLE 6-4)

.937

Table 6-6. Field Study 6 (Liquid collector/external manifold)

PAGE 1

WORKERS/NO. UNITS								
ELEMENT	1	2	3	4	5	6	7	
DELIVER PANEL	2.00	4.00	3.00	0.00	0.00	0.00	0.00	2.00
PREPARE/ATTACH SLING	10.00	0.00	3.00	0.00	0.00	0.00	0.00	2.00
ALIGN	3.00	13.00	0.00	0.00	0.00	0.00	0.00	2.00
ANCHOR	0.00	16.00	0.00	0.00	0.00	0.00	0.00	2.00
OPERATE CRANE	0.00	0.00	0.00	14.00	0.00	0.00	0.00	2.00
GET TOOLS	0.00	7.00	7.00	0.00	0.00	0.00	0.00	2.00
IDLE1 (WAITING)	34.00	13.00	48.00	27.00	0.00	0.00	0.00	2.00
IDLE2 (INSTRUCTIONS)	0.00	10.00	2.00	0.00	0.00	0.00	0.00	2.00
IDLE3 (NORMAL)	0.00	4.00	7.00	10.00	0.00	0.00	0.00	2.00
MISC. TASKS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TSTART=0.000 TFINAL=1.200 TIME= .000 UNITS= 2.00 WORKS= 4.00								

THE TOTAL TALLIES FOR WORKER 1 ARE	44.00	OUT OF	65.00	POSSIBLE
THE TOTAL TALLIES FOR WORKER 2 ARE	45.00	OUT OF	65.00	POSSIBLE
THE TOTAL TALLIES FOR WORKER 3 ARE	44.00	OUT OF	65.00	POSSIBLE
THE TOTAL TALLIES FOR WORKER 4 ARE	44.00	OUT OF	65.00	POSSIBLE
THE TOTAL TALLIES FOR WORKER 5 ARE	0.00	OUT OF	65.00	POSSIBLE
THE TOTAL TALLIES FOR WORKER 6 ARE	0.00	OUT OF	65.00	POSSIBLE
THE TOTAL TALLIES FOR WORKER 7 ARE	0.00	OUT OF	65.00	POSSIBLE

PAGE 2

WORKERS/NO. UNITS								
ELEMENT	1	2	3	4	5	6	7	
DELIVER PANEL	17.00	0.00	0.00	0.00	0.00	0.00	0.00	7.00
PREPARE/ATTACH SLING	20.00	0.00	0.00	0.00	0.00	0.00	0.00	7.00
ALIGN	0.00	0.00	14.00	0.00	0.00	0.00	0.00	7.00
ANCHOR	0.00	0.00	21.00	0.00	0.00	0.00	0.00	7.00
OPERATE CRANE	0.00	0.00	0.00	47.00	0.00	0.00	0.00	7.00
GET TOOLS	0.00	0.00	21.00	0.00	0.00	0.00	0.00	7.00
IDLE1 (WAITING)	76.00	0.00	17.00	74.00	0.00	0.00	0.00	7.00
IDLE2 (INSTRUCTIONS)	7.00	0.00	4.00	0.00	0.00	0.00	0.00	7.00
IDLE3 (NORMAL)	0.00	0.00	10.00	0.00	0.00	0.00	0.00	7.00
MISC. TASKS	0.00	0.00	7.00	0.00	0.00	0.00	0.00	7.00
TSTART=0.000 TFINAL=1.070 TIME= .000 UNITS= 7.00 WORKS= 3.00								

THE TOTAL TALLIES FOR WORKER 1 ARE	117.00	OUT OF	137.75	POSSIBLE
THE TOTAL TALLIES FOR WORKER 2 ARE	0.00	OUT OF	137.75	POSSIBLE
THE TOTAL TALLIES FOR WORKER 3 ARE	117.00	OUT OF	137.75	POSSIBLE
THE TOTAL TALLIES FOR WORKER 4 ARE	117.00	OUT OF	137.75	POSSIBLE
THE TOTAL TALLIES FOR WORKER 5 ARE	0.00	OUT OF	137.75	POSSIBLE
THE TOTAL TALLIES FOR WORKER 6 ARE	0.00	OUT OF	137.75	POSSIBLE
THE TOTAL TALLIES FOR WORKER 7 ARE	0.00	OUT OF	137.75	POSSIBLE

PAGE 3

WORKERS/NO. UNITS								
ELEMENT	1	2	3	4	5	6	7	
DELIVER PANEL	2.00	0.00	0.00	0.00	2.00	3.00	0.00	3.00
PREPARE/ATTACH SLING	1.00	0.00	0.00	0.00	1.00	1.00	0.00	3.00
ALIGN	4.00	0.00	0.00	0.00	10.00	11.00	0.00	3.00
ANCHOR	13.00	0.00	0.00	0.00	6.00	5.00	0.00	3.00
OPERATE CRANE	0.00	0.00	0.00	17.00	0.00	0.00	0.00	3.00
GET TOOLS	1.00	0.00	0.00	0.00	0.00	0.00	1.00	3.00
IDLE1 (WAITING)	7.00	0.00	0.00	14.00	7.00	4.00	11.00	3.00
IDLE2 (INSTRUCTIONS)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IDLE3 (NORMAL)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MISC. TASKS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TSTART=0.000 TFINAL=1.420 TIME= .000 UNITS= 7.00 WORKS= 4.00								

THE TOTAL TALLIES FOR WORKER 1 ARE	30.00	OUT OF	52.50	POSSIBLE
THE TOTAL TALLIES FOR WORKER 2 ARE	0.00	OUT OF	52.50	POSSIBLE
THE TOTAL TALLIES FOR WORKER 3 ARE	0.00	OUT OF	52.50	POSSIBLE
THE TOTAL TALLIES FOR WORKER 4 ARE	24.00	OUT OF	52.50	POSSIBLE
THE TOTAL TALLIES FOR WORKER 5 ARE	24.00	OUT OF	52.50	POSSIBLE
THE TOTAL TALLIES FOR WORKER 6 ARE	23.00	OUT OF	52.50	POSSIBLE
THE TOTAL TALLIES FOR WORKER 7 ARE	27.00	OUT OF	52.50	POSSIBLE

Table 6-6. Field Study 6 (Liquid collector/external manifold)

PAGE 1

ELEMENT	WORKERS/NO. UNITS				
	1	2	3	4	
RECEIVE/SLING OFF	4.00	0.00	1.00	1.00	3.00
ALIGN	4.00	4.00	6.00	2.00	1.00
ANCHOR	11.00	16.00	15.00	3.00	3.00
GET TOOL/REPOSITION	4.00	4.00	4.00	3.00	3.00
TOLE3(NORMAL)	15.00	30.00	37.00	15.00	3.00
TOLE2(INSTRUCTIONS)	4.00	4.00	5.00	16.00	2.00
TOLE1(WAIT)	10.00	14.00	15.00	4.00	3.00
REPOSITION COLLECTOR	5.00	0.00	4.00	1.00	2.00
INSTALL HOSE FITTING	0.00	2.00	0.00	0.00	1.00
OFFSITE	1.00	0.00	0.00	50.00	1.00
MEASURE	4.00	0.00	1.00	3.00	1.00
MOVE SCAFFOLD	11.00	0.00	0.00	0.00	1.00
MOVE CLEAT	0.00	0.00	0.00	0.00	0.00
TSTART=0.000 TFINAL=1.000 TINT=.010 UNITS= 3.00 WORKS= 4.00					

THE TOTAL TALLIES FOR WORKER 1 ARE 79.00 OUT OF 100.00 POSSIBLE

THE TOTAL TALLIES FOR WORKER 2 ARE 74.00 OUT OF 100.00 POSSIBLE

THE TOTAL TALLIES FOR WORKER 3 ARE 88.00 OUT OF 100.00 POSSIBLE

THE TOTAL TALLIES FOR WORKER 4 ARE 141.00 OUT OF 100.00 POSSIBLE

PAGE 2

ELEMENT	WORKERS/NO. UNITS				
	1	2	3	4	
RECEIVE/SLING OFF	11.00	3.00	6.00	4.00	4.00
ALIGN	14.00	20.00	35.00	11.00	4.00
ANCHOR	11.00	23.00	12.00	43.00	4.00
GET TOOL/REPOSITION	4.00	1.00	0.00	1.00	4.00
TOLE3(NORMAL)	43.00	34.00	13.00	20.00	4.00
TOLE2(INSTRUCTIONS)	1.00	0.00	0.00	1.00	4.00
TOLE1(WAIT)	1.00	1.00	1.00	1.00	4.00
REPOSITION COLLECTOR	0.00	0.00	0.00	0.00	0.00
INSTALL HOSE FITTING	0.00	0.00	0.00	0.00	0.00
OFFSITE	0.00	0.00	0.00	0.00	0.00
MEASURE	1.00	0.00	0.00	1.00	4.00
MOVE SCAFFOLD	0.00	0.00	0.00	0.00	0.00
MOVE CLEAT	3.00	0.00	0.00	0.00	4.00
TSTART=0.000 TFINAL=1.070 TINT=.010 UNITS= 5.00 WORKS= 4.00					

THE TOTAL TALLIES FOR WORKER 1 ARE 91.00 OUT OF 107.00 POSSIBLE

THE TOTAL TALLIES FOR WORKER 2 ARE 93.00 OUT OF 107.00 POSSIBLE

THE TOTAL TALLIES FOR WORKER 3 ARE 87.00 OUT OF 107.00 POSSIBLE

THE TOTAL TALLIES FOR WORKER 4 ARE 81.00 OUT OF 107.00 POSSIBLE

Table 6-8. Field Study 6 (Liquid collector/external manifold)

ELAPSED TIME	M45 2.019	M45-405 2.300				
ELEMENT	NO. COMPLETED	PERCENT TIME (TDL)	MANHRS		MANHRS PER COLLECTOR	COMMENTS
DELIVER PANEL	12.00	5.78 1.37	.2792		.0233	
PREPARE/ATTACH SLING	12.10	5.13 1.54	.3790		.0316	
ALIGN	12.00	8.10 1.96	.5984		.0499	
ANCHOR	12.00	9.91 2.07	.6587		.0549	
OPERATE CRANE	12.00	11.94 2.33	.8776		—	
GET TOOLS	12.00	4.00 1.57	.3690		.0308	
IDLE1 (WAITING)	12.00	46.95 3.50	3.4706		.2403	CRANE OPERATOR EXCL
IDLE2 (INSTRUCTIONS)	5.00	2.44 1.35	.2593		.0229	
IDLE3 (NORMAL)	4.00	4.34 1.75	.4587		.0414	CRANE OPERATOR EXCL
MISC. TASKS	2.00	2.27 1.27	.0199		—	
FOR CREW MEMBER 1					.995	PARTIAL CREW (SEE TABLE 6-8)
ELEMENT	PERCENT TIME (TDL)					
DELIVER PANEL	9.02	3.44				
PREPARE/ATTACH SLING	15.77	6.22				
ALIGN	1.45	1.83				
ANCHOR	4.33	3.77				
GET TOOLS	.67	.09				
IDLE1 (WAITING)	44.62	6.44				
IDLE2 (INSTRUCTIONS)	2.30	2.43				
FOR CREW MEMBER 2						
ELEMENT	PERCENT TIME (TDL)					
DELIVER PANEL	4.15	5.06				
ALIGN	14.92	0.12				
ANCHOR	24.42	10.67				
GET TOOLS	10.77	7.54				
IDLE1 (WAITING)	20.00	0.72				
IDLE2 (INSTRUCTIONS)	15.30	4.79				
IDLE3 (NORMAL)	4.15	5.44				

Table 6-7 (con't)

FOR CREW MEMBER 3		
ELEMENT	PERCENT TIME	(TOL)
REMOVE PANEL	1.64	1.64
PREPARE/ATTACH SLING	1.44	1.44
ALIGN	9.84	4.71
ANCHOR	11.44	4.42
GET TOOLS	14.30	5.77
IDLE1 (WAITING)	35.57	4.09
IDLE2 (INSTRUCTIONS)	5.46	3.29
IDLE3 (NORMAL)	18.03	5.47
MISC. TASKS	1.09	1.61
FOR CREW MEMBER 4		
ELEMENT	PERCENT TIME	(TOL)
OPERATE CRANE	42.11	6.40
IDLE1 (WAITING)	43.11	5.77
IDLE3 (NORMAL)	4.74	2.40
FOR CREW MEMBER 5		
ELEMENT	PERCENT TIME	(TOL)
REMOVE PANEL	7.60	10.24
PREPARE/ATTACH SLING	3.64	7.29
ALIGN	38.45	18.70
ANCHOR	21.08	16.20
IDLE1 (WAITING)	26.92	17.04
FOR CREW MEMBER 6		
ELEMENT	PERCENT TIME	(TOL)
REMOVE PANEL	9.70	11.52
PREPARE/ATTACH SLING	4.35	4.39
ALIGN	47.43	20.42
ANCHOR	21.74	16.86
IDLE1 (WAITING)	17.30	15.49
FOR CREW MEMBER 7		
ELEMENT	PERCENT TIME	(TOL)
ALIGN	26.09	17.04
ANCHOR	21.74	16.86
GET TOOLS	4.35	4.39
IDLE1 (WAITING)	47.43	20.42

Table 6-8. Field Study 6 (Liquid collector/external manifold)

HRS		MANHRS			
ELAPSED TIME	2.070	4.240			
ELEMENT	NO. COMPLETED	PERCENT TIME (TOL)	MANHRS	MANHRS PER COLLECTOR	COMMENTS
RECEIVE/SLING OFF	7.00	4.41 1.00	.3792	.0523	
ALIGN	7.00	15.15 2.44	1.2212	.1816	
ANCHOR	7.00	71.55 1.07	1.7443	.2549	
GET TOOL/REPOSITION	7.00	9.47 1.74	.2913	.0416	
IDLE (NORMAL)	7.50	30.70 1.36	2.5423	.3632	
TOLEZ (INSTRUCTIONS)	7.00	4.37 1.00	.3815	.0516	
TOLEZ (WAIT)	7.50	7.04 1.48	.3851	.0513	
REPOSITION COLLECTOR	7.00	1.41 .07	.1164	-	
INSTALL HOSE FITTING	3.00	.78 .30	.0239	-	
OFFSITE	7.00	7.43 1.00	.6311	-	
WEASURE	7.00	1.41 .07	.1164	.0167	
MOVE SCAFFOLD	3.00	1.43 .01	.1283	-	
MOVE CLEAR	4.00	.43 .28	.0360	-	
FOR CREW HOURS				1.05	(1)
ELEMENT	PERCENT TIME (TOL)				
RECEIVE/SLING OFF	10.00 6.51				
ALIGN	11.74 6.84				
ANCHOR	17.34 9.04				
GET TOOL/REPOSITION	7.00 3.85				
IDLE (NORMAL)	34.12 7.13				
TOLEZ (INSTRUCTIONS)	2.94 2.44				
TOLEZ (WAIT)	4.47 3.70				
REPOSITION COLLECTOR	2.94 2.44				
OFFSITE	.89 1.18				
WEASURE	2.94 2.44				
MOVE SCAFFOLD	4.47 3.70				
MOVE CLEAR	1.74 1.00				
COMMENTS					
(1) PARTIAL CREW					
TOTAL INSTALLATION TIME:					
ELEMENT	PERCENT TIME (TOL)				
RECEIVE/SLING OFF	1.75 1.07				
ALIGN	20.47 6.00				
ANCHOR	22.51 6.79				
GET TOOL/REPOSITION	2.62 2.44				
IDLE (NORMAL)	30.40 7.10				
TOLEZ (INSTRUCTIONS)	2.34 2.27				
TOLEZ (WAIT)	8.94 4.48				
INSTALL HOSE FITTING	1.17 1.61				
		.495	(TABLE 6-7)		
		1.05	(TABLE 6-8)		
		1.55			

Table 6-8 (con't)

FOR CREW MEMBER 1

ELEMENT	PERCENT TIME	TIME
RECEIVE/SIGNALING OFF	4.00	2.00
ALIGN	23.43	4.69
ANCHOR	24.81	4.97
GET TOOL/REPOSITION	2.20	2.21
IDLE1(NORMAL)	28.57	5.69
IDLE2(INSTRUCTIONS)	2.96	2.67
IDLE3(WAIT)	9.14	4.27
REPOSITION COLLECTOR	2.20	2.21
MEASURE	.57	1.17

FOR CREW MEMBER 4

ELEMENT	PERCENT TIME	TIME
RECEIVE/SIGNALING OFF	2.59	2.23
ALIGN	6.70	3.52
ANCHOR	23.20	5.04
GET TOOL/REPOSITION	2.06	2.00
IDLE1(NORMAL)	22.44	5.00
IDLE2(INSTRUCTIONS)	8.76	3.98
IDLE3(WAIT)	3.09	2.44
REPOSITION COLLECTOR	.52	1.01
OFFSITE	20.19	6.34
MEASURE	2.06	2.00

Table 6-9. Pre-Installation

Study 6	Element	Man-hrs/ Panel	Percent	Fixed (man-hrs)	Source
	Roof preparation	0.40 ± 0.1		12 ± 3	NW
	Discussion	0.40 ± 0.1		12 ± 3	NW
	Bracket prep	0.30 ± 0.07		4 ± 1	NW
	Remove packaging, caulk and stack	0.27 ± 0.07		8 ± 2	NW
	Attach brackets, elbows, stack	0.30 ± 0.07		9 ± 2	NW
Total		1.67 ± 0.19			

Table 6-10. Post-Installation

Study 6	Element	Man-hrs/ Panel	Percent	Fixed (man-hrs)	Source
	Install top manifold, connec- ting hoses, insu- late conn. hoses			14.0	est
	Bottom manifold as above			14.0	est
	Connect center hoses & insulation			8.0	est
	Insulate manifolds			3.0	est
Total				39.0	

FIELD STUDY SUMMARY SHEET

Study Number 7

COLLECTOR	
1. TYPE	Air - internal manifold
2. DIMENSIONS	0.9 m x 2.0 x (36 in x 78 in) 1.8 square meters (19.5 square feet)
3. WEIGHT	70 kg (153 lbs)
SITE	
1. BUILDING USE	Single family residence
2. SOLAR APPLICATION	Space heating, DHW preheat
3. ARRAY PITCH	35°
4. ARRAY ACCESS	Ladder to on-roof array, 15 ft above ground
5. ARRAY SIZE	44 m ² (468 ft ²)
6. GENERAL CONDITIONS	T _{amb} approx. 60°; grounds - unlevel, upper story window served as tool ledge
7. SAFETY PRECAUTIONS	Cleats nailed to roof sheathing
PROCEDURE	
1. CREW SIZE/EXPERIENCE	2/good
2. DELIVERY/PACKAGING	Two panels per carton
3. COLLECTOR POSITIONING	Set by crane, manual final positioning

FIELD STUDY 7

BACKGROUND

The installation of this system involved an internally manifolded air collector and proceeded much as in previously described installations (see Field Studies 1, 2 and 5). No roof penetrations were made during the setting and anchoring phase of the installation. Workspace around the array perimeter was minimal. Two workers started and completed the installation.

PRE INSTALLATION

The two workers, employed by the subcontracting solar installer, positioned and installed the starter strip for the array. Roof felt was to have been in place for the array installation but was not down on the day the panels were to be set. Due to the arrival of both crane and collectors, the decision was made to set the panels directly on the roof sheathing.

INSTALLATION

The panels were set by crane in rough position on the south roof with the last eight out of 24 panels set temporarily on the north roof. The middle row of panels rested on temporary cleats.

The workers started the second day anchoring first the bottom row, and proceeding right to left, followed by the second row. The top row was set by dragging the eight collectors over the roof peak. The panels were anchored again from right to left. Some difficulty was encountered in anchoring the final panel as the left edge of this panel was within 10 cm of the roof edge, which prevented the workers from installing left edge holddowns. Work on the final row was interrupted by roofers laying down plywood sheathing on the north roof near the peak.

POST INSTALLATION

The crew estimated four man-days (32 man-hours) to complete capstripping and perimeter flashing. (This estimate included no rigorous accounting for idle time, breaks, and/or foreign work elements, and as such the range of uncertainty in this estimate is ± 4 to 8 man-hours.)

COMMENTS

The elimination of roof felt under the collectors and the interruption of work by the roofing crew were mentioned above. The obvious impact of such job coordination problems is to reduce the quality of solar installations and increase costs.

Table 7-1. Field Study 7 (Air collector/internal manifold)

PAGE 1

ELEMENT	WORKERS/NO. UNITS		
	1	2	3
INSTALL GASKET	0.00	0.00	1.00
ALIGN	2.00	1.00	1.00
ANCHOR	1.00	2.00	3.00
IDLE (NO PHAL)	2.00	1.00	1.00
IDLE (WAIT)	0.00	0.00	1.00
IDLE (CONFER)	1.00	1.00	1.00
GET TOOLS/ETC.	1.00	2.00	1.00
REPOSITION PANEL	1.00	1.00	1.00
REMOVE CLEAT	0.00	0.00	1.00
DISTRIBUTE GASKETS	0.00	0.00	1.00
MOVE FROM NORTH ROOF	0.00	0.00	1.00
MEASURE	0.00	0.00	1.00
TSTART=0.000 TFINAL=.000 TIME=.010 UNITS= 1.00 WORKS= 2.00			
THE TOTAL TALLIES FOR WORKER 1 ARE 8.00 OUT OF 8.00 POSSIBLE			
THE TOTAL TALLIES FOR WORKER 2 ARE 8.00 OUT OF 8.00 POSSIBLE			

PAGE 2

ELEMENT	WORKERS/NO. UNITS		
	1	2	3
INSTALL GASKET	1.00	0.00	2.00
ALIGN	3.00	5.00	1.00
ANCHOR	2.00	0.00	2.00
IDLE (NO PHAL)	1.00	4.00	1.00
IDLE (WAIT)	0.00	4.00	1.00
IDLE (CONFER)	0.00	0.00	1.00
GET TOOLS/ETC.	4.00	0.00	1.00
REPOSITION PANEL	0.00	0.00	1.00
REMOVE CLEAT	2.00	0.00	2.00
DISTRIBUTE GASKETS	0.00	0.00	1.00
MOVE FROM NORTH ROOF	0.00	0.00	0.00
MEASURE	0.00	0.00	1.00
TSTART=.000 TFINAL=.240 TIME=.010 UNITS= 1.00 WORKS= 2.00			
THE TOTAL TALLIES FOR WORKER 1 ARE 14.00 OUT OF 14.00 POSSIBLE			
THE TOTAL TALLIES FOR WORKER 2 ARE 15.00 OUT OF 15.00 POSSIBLE			

PAGE 3

ELEMENT	WORKERS/NO. UNITS		
	1	2	3
INSTALL GASKET	2.00	0.00	2.00
ALIGN	3.00	3.00	1.00
ANCHOR	4.00	1.00	4.00
IDLE (NO PHAL)	1.00	4.00	1.00
IDLE (WAIT)	0.00	0.00	1.00
IDLE (CONFER)	0.00	0.00	1.00
GET TOOLS/ETC.	0.00	0.00	1.00
REPOSITION PANEL	0.00	0.00	1.00
REMOVE CLEAT	0.00	0.00	1.00
DISTRIBUTE GASKETS	0.00	1.00	1.00
MOVE FROM NORTH ROOF	0.00	0.00	0.00
MEASURE	0.00	0.00	1.00
TSTART=.240 TFINAL=.335 TIME=.010 UNITS= 1.00 WORKS= 2.00			
THE TOTAL TALLIES FOR WORKER 1 ARE 10.00 OUT OF 9.50 POSSIBLE			
THE TOTAL TALLIES FOR WORKER 2 ARE 10.00 OUT OF 9.50 POSSIBLE			

Table 7-1 (con't)

PAGE 4

ELEMENT	WORKERS/NO. UNITS		
	1	2	
INSTALL GASKET	2.00	0.00	2.00
ALIGN	1.00	1.00	1.00
ANCHOR	3.00	1.00	4.00
IDLE (NORMAL)	3.00	8.00	3.00
IDLE (WAIT)	0.00	0.00	1.00
IDLE (CONFER)	0.00	0.00	1.00
GET TOOLS/ETC.	0.00	0.00	1.00
REPOSITION PANEL	0.00	0.00	1.00
REMOVE CLEAT	2.00	0.00	1.00
DISTRIBUTE GASKETS	0.00	0.00	1.00
MOVE FROM NORTH SIDE	0.00	0.00	0.00
MEASURE	0.00	0.00	1.00
TSTART= .040 TFINAL= .145 TINT= .010 UNITS= 1.00 WORK= 2.00			

THE TOTAL TALLIES FOR WORKER 1 ARE 11.00 OUT OF 10.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 2 ARE 10.00 OUT OF 10.00 POSSIBLE

PAGE 5

ELEMENT	WORKERS/NO. UNITS		
	1	2	
INSTALL GASKET	2.00	0.00	2.00
ALIGN	1.00	2.00	1.00
ANCHOR	3.00	0.00	4.00
IDLE (NORMAL)	0.00	2.00	1.00
IDLE (WAIT)	0.00	0.00	1.00
IDLE (CONFER)	0.00	0.00	1.00
GET TOOLS/ETC.	2.00	1.00	1.00
REPOSITION PANEL	1.00	0.00	1.00
REMOVE CLEAT	1.00	0.00	1.00
DISTRIBUTE GASKETS	0.00	0.00	1.00
MOVE FROM NORTH SIDE	0.00	0.00	0.00
MEASURE	0.00	0.00	1.00
TSTART= .150 TFINAL= .266 TINT= .010 UNITS= 1.00 WORK= 2.00			

THE TOTAL TALLIES FOR WORKER 1 ARE 10.00 OUT OF 9.40 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 2 ARE 10.00 OUT OF 9.40 POSSIBLE

PAGE 6

ELEMENT	WORKERS/NO. UNITS		
	1	2	
INSTALL GASKET	2.00	0.00	2.00
ALIGN	3.00	1.00	1.00
ANCHOR	2.00	1.00	4.00
IDLE (NORMAL)	4.00	2.00	1.00
IDLE (WAIT)	0.00	0.00	1.00
IDLE (CONFER)	3.00	1.00	0.00
GET TOOLS/ETC.	1.00	0.00	1.00
REPOSITION PANEL	1.00	1.00	1.00
REMOVE CLEAT	0.00	0.00	1.00
DISTRIBUTE GASKETS	0.00	0.00	1.00
MOVE FROM NORTH SIDE	0.00	0.00	0.00
MEASURE	0.00	0.00	1.00
TSTART= .040 TFINAL= .105 TINT= .010 UNITS= 1.00 WORK= 2.00			

THE TOTAL TALLIES FOR WORKER 1 ARE 13.00 OUT OF 14.40 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 2 ARE 13.00 OUT OF 14.40 POSSIBLE

Table 7-1 (con't)

PAGE 7

ELEMENT	WORKERS/NO. UNITS		
	1	2	
INSTALL GASKET	2.00	0.00	2.00
ALIGN	2.00	2.00	1.00
ANCHOR	2.00	1.00	4.00
IDLE (NORMAL)	2.00	2.00	1.00
IDLE (WAIT)	0.00	0.00	1.00
IDLE (CONFER)	4.00	3.00	1.00
GET TOOLS/ETC.	1.00	1.00	1.00
REPOSITION PANEL	0.00	0.00	1.00
REMOVE CLIP	0.00	0.00	1.00
DISTRIBUTE GASKETS	0.00	0.00	1.00
MOVE FROM NORTH ROOF	0.00	0.00	0.00
MEASURE	0.00	0.00	1.00
TSTART= .200 TFINAL= .350 TIME= 1.010 UNITS= 1.00 WORKS= 2.00			
THE TOTAL TALLIES FOR WORKER 1 ARE 14.00 OUT OF 18.00 POSSIBLE			
THE TOTAL TALLIES FOR WORKER 2 ARE 14.00 OUT OF 15.00 POSSIBLE			

PAGE 8

ELEMENT	WORKERS/NO. UNITS		
	1	2	
INSTALL GASKET	0.00	0.00	0.00
ALIGN	1.00	2.00	1.00
ANCHOR	1.00	0.00	1.00
IDLE (NORMAL)	0.00	1.00	1.00
IDLE (WAIT)	0.00	0.00	1.00
IDLE (CONFER)	1.00	2.00	1.00
GET TOOLS/ETC.	0.00	0.00	1.00
REPOSITION PANEL	0.00	0.00	1.00
REMOVE CLIP	0.00	0.00	1.00
DISTRIBUTE GASKETS	0.00	0.00	1.00
MOVE FROM NORTH ROOF	0.00	0.00	0.00
MEASURE	0.00	0.00	1.00
TSTART= .040 TFINAL= .085 TIME= .010 UNITS= 1.00 WORKS= 2.00			
THE TOTAL TALLIES FOR WORKER 1 ARE 5.00 OUT OF 4.50 POSSIBLE			
THE TOTAL TALLIES FOR WORKER 2 ARE 5.00 OUT OF 4.50 POSSIBLE			

PAGE 9

ELEMENT	WORKERS/NO. UNITS		
	1	2	
INSTALL GASKET	2.00	0.00	2.00
ALIGN	5.00	5.00	2.00
ANCHOR	10.00	2.00	17.00
IDLE (NORMAL)	5.00	14.00	2.00
IDLE (WAIT)	0.00	0.00	2.00
IDLE (CONFER)	1.00	1.00	2.00
GET TOOLS/ETC.	2.00	2.00	2.00
REPOSITION PANEL	2.00	1.00	2.00
REMOVE CLIP	0.00	0.00	2.00
DISTRIBUTE GASKETS	0.00	0.00	2.00
MOVE FROM NORTH ROOF	5.00	2.00	2.00
MEASURE	1.00	0.00	1.00
TSTART= 0.000 TFINAL= .340 TIME= .010 UNITS= 2.00 WORKS= 2.00			
THE TOTAL TALLIES FOR WORKER 1 ARE 33.00 OUT OF 33.00 POSSIBLE			
THE TOTAL TALLIES FOR WORKER 2 ARE 32.00 OUT OF 32.00 POSSIBLE			

Table 7-2. Field Study 7 (Air collector/internal manifold)

MOS		MAN-HRS			
ELAPSED TIME	1.135	2.200			
ELEMENT	NO. COMPLETED	PERCENT TIME (TOL)	MAN-HRS	MAN-HRS PER COLLECTOR	COMMENTS
INSTALL GASKET	15.00	5.40 2.90	.1311	.0175	(1)
ALIGN	10.00	10.00 4.00	.4536	.0454	
ANCHOR	51.00	15.10 4.57	.7630	.0427	(2)
IDLE (INTERNAL)	10.00	10.39 5.94	.7261	.0726	
IDLE (WAIT)	10.00	2.43 2.00	.6000	.0600	
IDLE (CORNER)	9.00	7.99 3.37	.1815	.0182	(3)
GFT TOOLS/ETC.	10.00	4.44 3.54	.2017	.0202	
REPOSITION PANEL	10.00	3.30 2.30	.0907	.0091	
REMOVE CLEFT	11.00	2.11 1.93	.0504	.0046	
DISTRIBUTE GASKETS	10.00	.42 .89	.0103	-	
MOVE FROM NORTH SIDE	3.00	3.00 2.70	.1230	-	(4)
MEASURE	4.00	.42 .89	.0101	-	
FOR PANEL MEASRD 1				.235	
ELEMENT	PERCENT TIME (TOL)				
INSTALL GASKET	10.39 5.47				
ALIGN	17.35 4.05				
ANCHOR	23.52 7.44				
IDLE (INTERNAL)	15.13 4.64				
IDLE (CORNER)	4.40 4.00				
GFT TOOLS/ETC.	10.39 4.60				
REPOSITION PANEL	4.30 3.20				
REMOVE CLEFT	4.30 3.40				
MOVE FROM NORTH SIDE	6.30 3.60				
MEASURE	.44 1.44				
FOR PANEL MEASRD 2					
ELEMENT	PERCENT TIME (TOL)				
ALIGN	70.34 7.24				
ANCHOR	4.70 4.84				
IDLE (INTERNAL)	45.74 4.00				
IDLE (WAIT)	5.04 3.04				
IDLE (CORNER)	5.74 4.84				
GFT TOOLS/ETC.	3.03 4.24				
REPOSITION PANEL	2.54 2.04				
DISTRIBUTE GASKETS	.44 1.44				
MOVE FROM NORTH SIDE	4.23 4.24				

COMMENTS:
(1) 2 PER PANEL
(2) 6 PER PANEL
(3) AVERAGED OVER 10 PANELS
(4) .040 MAN-HR PER PANEL

COMMENTS:

(1) 2 PER PANEL

(2) 4 PER PANEL

(3) AVERAGED OVER 10 PANELS

(4) .040 MAN-HR PER PANEL

FIELD STUDY SUMMARY SHEET

Study Number 8

COLLECTOR	
1. TYPE	Liquid - internal manifold
2. DIMENSIONS	1.9 m x 4.75 m (75 in x 187 in) 9 square meters (97 square feet)
3. WEIGHT	550 kg (1210 lbs)
SITE	
1. BUILDING USE	Experimental solar residence
2. SOLAR APPLICATION	Space heat, space cooling, DHW preheat
3. ARRAY PITCH	45°
4. ARRAY ACCESS	Test bed at ground level
5. ARRAY SIZE	54 m ² (582 ft ²)
6. GENERAL CONDITIONS	Grounds - level/firm, T _{amb} approx. 18°C
7. SAFETY PRECAUTIONS	None
PROCEDURE	
1. CREW SIZE/EXPERIENCE	3-4/good
2. DELIVERY/PACKAGING	Three to a crate delivered in open top trailer
3. COLLECTOR POSITIONING	Hoisted by crane to pre-installed mounting racks

FIELD STUDY 8

BACKGROUND

A prototype high efficiency collector was installed on a test bed immediately south of an experimental solar residence. The existing liquid system provides space heating, space cooling via an absorption chiller, and DHW preheat. The prototype panels were to supply energy for one heating season as part of a controlled experiment.

PRE INSTALLATION

Mounting frames were fabricated according to the manufacturer's specifications. These frames were installed on the test bed prior to the delivery of the solar modules. Each frame provided guides to ensure proper placement of the modules on the frame.

INSTALLATION

The collector modules were delivered three to a crate in an open top trailer. Eyelets were provided for sling attachment. The modules were lifted to the ground, where the sling was adjusted to hold the module at an angle close to the pitch of the test bed. The modules were then lifted into position on the mounting frames and anchored. Adjustment was necessary on one set of guides to ensure proper spacing between modules. In general, the positioning and anchoring proceeded smoothly as the preinstalled frames eliminated final alignment jockeying on the part of the installation crew.

POST INSTALLATION

Interpanel connections involved installing a custom-designed clamping device which drew together two manifold flanges with O-ring seal. No flashing or capstripping was provided or required. A rubber donut provided an exterior seal where the manifold ran from one panel to the next.

COMMENTS

- (1) The preinstalled mounting frame eliminated many alignment and anchoring problems observed in other more conventional array installations. The frames ensure an even mounting surface and the guide pins employed in the design provide positive final alignment. A preinstalled mounting frame offers the possibility of working with a light and manageable frame which can be anchored under somewhat less taxing circumstances and onto which the collectors can subsequently be "snapped" into place.
- (2) Novel manifold flange and clamp fixtures were employed in this design to allow the system to be dismantled, however, such fixtures also represent a fast and easy one-time coupling scheme. In the design, an exterior clamping ring draws together two flanges on an O-ring seal. The lever action clamping

ring eliminates the need for threaded or soldered fittings and, hence, the use of related and cumbersome tools on the roof.

- (3) Although the prototype modules used in this installation were roughly ten times heavier than typical flat-plate collectors available commercially (and similarly are much larger in area), the installation time was less than many "conventional" installations observed. Where a solar system is intended to supply a major fraction of space heating needs and therefore the array size is substantial (greater than 9 square meters/100 square feet), large collector modules installed by crane may be more cost-effective than arrays built up with many small modules.

Table 8-1. Installation Phase Work Elements

Study 8	Element	Man-hrs/ Panel	Percent	Fixed (man-hrs)	Source
	Remove packing	0.300	23.6		CTS
	Attach sling	0.216	17.0		CTS
	Lift from trailer	0.080	6.3		CTS
	Adjust sling	0.076	6.0		CTS
	Move to test bed	0.228	17.9		CTS
	Align	0.174	13.7		CTS
	Anchor	0.087	6.8		CTS
	Detach sling	0.028	2.2		CTS
	Foreign	0.057	4.5	0.340	CTS
	Idle (wait)	0.027	2.1		CTS
Total		1.273			

man-hrs/100 ft² = 1.31

FIELD STUDY SUMMARY SHEET

Study Number 9

COLLECTOR	
1. TYPE	Air - external manifold
2. DIMENSIONS	1.96 m x 0.9 m (77 in x 35 in) 1.7 square meters (18.7 square feet)
3. WEIGHT	61.4 kg (135 lbs)
SITE	
1. BUILDING USE	Residential
2. SOLAR APPLICATION	Space heat and DHW preheat
3. ARRAY PITCH	approx. 45°
4. ARRAY ACCESS	Ladder to garage roof, 3 m (10 ft) above ground
5. ARRAY SIZE	34.8 m ² (374 ft ²)
6. GENERAL CONDITIONS	Grounds - level/firm, temperature approx. 18°C, partly cloudy
7. SAFETY PRECAUTIONS	Movable temporary scaffold
PROCEDURE	
1. CREW SIZE/EXPERIENCE	3/good
2. DELIVERY/PACKAGING	One collector per cardboard carton stacked on-site prior to installation
3. COLLECTOR POSITIONING	Two step manual handling - ground to scaffold, scaffold to roof

FIELD STUDY 9

BACKGROUND

This installation involved an active air system with collectors mounted on the garage roof. The collector array was ducted to a mechanical room in the basement of the adjoining residence. Manifolding of these panels required two roof penetrations per module.

PRE INSTALLATION

The panels packed one per cardboard carton were stacked at the job site approximately two weeks prior to the installation. On the day of installation, one worker measured and cut the required duct penetrations for the first row of panels. The remaining two workers fabricated a temporary scaffold on the piperack of the contractor's pickup truck.

INSTALLATION

Ten panels, forming the lower row of the array, were anchored from left to right by working from the south side of the garage where the collectors had been previously stacked. One worker unpacked and moved panels over to the truck/scaffold (a distance of approximately 10 feet) and boosted each one up to the other two workers on the scaffold. These two workers then raised the panel into position. Using a drill motor, the anchoring screws were then driven into the roof sheathing.

Butyl tape was applied to a tab running the length of the side of the panel and the next panel was raised into place and anchored. The butyl was pinched between adjacent panels, forming a partial weather seal. The side tabs of adjacent collectors overlapped and were ultimately drawn together by the capstrip screws. These tabs also served as a gauge for spacing between panels. See Fig. 9-1 for rendition of collector cross-section and capstrip scheme.

All interpanel ducting was done using flex-duct beneath the roof sheathing, therefore extremely careful alignment between panels was not required. The rubber gasket which accepts the capstrip plate allowed for some variation in alignment between adjacent panels.

Panels for the top row of the array were carried by two workers to the north side of the garage and raised from the ground to the scaffold and from the scaffold to the north roof of the garage. The third worker during this time was cutting duct penetrations for the top row. The procedure for anchoring the top row was essentially the same as for the bottom row with the exception that the panels, now on the north roof, were carried by two workers up to the peak and handed over to the third worker standing on the bottom row of panels.

FIGURE 9-1

POST INSTALLATION

The crew did not have prior experience with the capstripping procedure for the type of panels used in this installation. Approximately one hour was spent trying out several approaches. A special tool existed to install the capstrips and it was the crew's intention to procure the tool for the installation of the remaining capstrips.

COMMENTS

- (1) Since the panels sat on-site for several weeks, the packing cartons were damaged by the elements. One panel, packed in the cardboard shipping carton but without a cover, exhibited a filmy deposit behind the glazing assembly which may possibly be due to the exposed collector's stagnating during the day. Manufacturers need to consider potential problems arising from unusual field conditions, such as packaging that will not protect the panels after some days of adverse weather and possibly forewarn installers of potential problems.
- (2) As in other phases of an installation, the lack of an appropriate tool can add significantly to installation time. Such was the case in this installation in experimenting with capstripping methods. A conscientious crew should have a tool list, possibly supplied by the manufacturer, and ensure that necessary tools are procured for an installation.
- (3) Manual handling of panels at this site was extremely fatiguing and time consuming. Use of a lightweight crane is recommended.

Table 9-1. Field Study 9 (Air collector/external manifold)

PAGE 1

ELEMENT	WORKERS/NO. UNITS			
	1	2	3	4
REMOVE PKG.	0.00	0.00	0.00	0.00
MOVE TO NORTH SIDE	0.00	0.00	0.00	0.00
LIFT PANEL TO EAVE	0.00	0.00	0.00	0.00
LIFT PANEL TO PEAK	0.00	0.00	0.00	0.00
CUT DUCT PENETRATION	0.00	0.00	11.00	12.00
INSTALL TFP, CLEAT	0.00	5.00	0.00	20.00
APPLY BUTYL TAPE	0.00	0.00	0.00	0.00
ALIGN/MEASURE	0.00	0.00	0.00	0.00
ANCHOR	0.00	0.00	0.00	0.00
REPOSITION LADDER	1.00	1.00	1.00	20.00
REPOSITION TRIM	0.00	0.00	0.00	0.00
PREPARE CAPSTRIP	0.00	0.00	0.00	0.00
INSTALL CAPSTRIP	0.00	0.00	0.00	0.00
GET TOOL / MISC.	0.00	1.00	0.00	20.00
IDLE (WAIT)	0.00	0.00	0.00	20.00
IDLE (NORMAL)	0.00	2.00	0.00	20.00
IDLE (CHIEF)	12.00	6.00	1.00	20.00
TSTART=0.000 TFINAL= .130 TIME= .610 UNITS=12.00 WORKS= 3.00				

THE TOTAL TALLIES FOR WORKER 1 ARE 13.00 OUT OF 13.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 2 ARE 13.00 OUT OF 13.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 3 ARE 13.00 OUT OF 13.00 POSSIBLE

PAGE 2

ELEMENT	WORKERS/NO. UNITS			
	1	2	3	4
REMOVE PKG.	4.00	10.00	9.00	0.00
MOVE TO NORTH SIDE	0.00	0.00	0.00	0.00
LIFT PANEL TO EAVE	15.00	0.00	14.00	0.00
LIFT PANEL TO PEAK	0.00	0.00	0.00	0.00
CUT DUCT PENETRATION	0.00	0.00	0.00	0.00
INSTALL TFP, CLEAT	0.00	0.00	2.00	0.00
APPLY BUTYL TAPE	11.00	0.00	15.00	0.00
ALIGN/MEASURE	0.00	0.00	8.00	0.00
ANCHOR	13.00	0.00	14.00	0.00
REPOSITION LADDER	10.00	2.00	15.00	0.00
REPOSITION TRIM	0.00	0.00	0.00	0.00
PREPARE CAPSTRIP	0.00	0.00	0.00	0.00
INSTALL CAPSTRIP	2.00	0.00	0.00	1.00
GET TOOL / MISC.	10.00	42.00	8.00	0.00
IDLE (WAIT)	5.00	4.00	14.00	0.00
IDLE (NORMAL)	16.00	5.00	8.00	0.00
IDLE (CHIEF)	1.00	12.00	1.00	0.00
TSTART=0.000 TFINAL=1.150 TIME= .610 UNITS= 2.00 WORKS= 3.00				

THE TOTAL TALLIES FOR WORKER 1 ARE 99.00 OUT OF 114.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 2 ARE 97.00 OUT OF 114.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 3 ARE 90.00 OUT OF 115.00 POSSIBLE

Table 9-1 (con't)

ELEMENT	WORKER/HR, MINUTE			
	1	2	3	
REMOVE PKG.	1.00	0.00	0.00	7.00
MOVE TO NORTH SIDE	1.00	0.00	0.00	7.00
LIFT PANEL TO ROOF	4.00	0.00	0.00	7.00
LIFT PANEL TO DECK	12.00	0.00	0.00	7.00
CUT DUCT PENETRATION	0.00	1.00	31.00	20.00
INSTALL TEMP. FLAT	0.00	0.00	0.00	0.00
APPLY BUTYL TAPE	0.00	22.00	1.00	7.00
ALIGN/MEASURE	10.00	0.00	0.00	7.00
ANCHOR	0.00	11.00	0.00	7.00
REPOSITION (ANCHOR)	0.00	0.00	0.00	0.00
REPOSITION TIEBAR	0.00	0.00	0.00	0.00
PREPARE CARSTRIP	0.00	0.00	0.00	0.00
INSTALL CARSTRIP	0.00	0.00	0.00	0.00
GET TOOL / MISC.	0.00	0.00	0.00	7.00
IDLE (WAIT)	0.00	0.00	0.00	7.00
IDLE (NORMAL)	13.00	0.00	1.00	7.00
IDLE (CONCRETE)	2.00	0.00	0.00	7.00
TOTAL=0.000 TOTAL= .900 TIME= .010 MINUTE= 7.00 WORKER= 3.00				
THE TOTAL TALLIES FOR WORKER 1 ARE 49.00 OUT OF 90.00 POSSIBLE				
THE TOTAL TALLIES FOR WORKER 2 ARE 44.00 OUT OF 90.00 POSSIBLE				
THE TOTAL TALLIES FOR WORKER 3 ARE 46.00 OUT OF 90.00 POSSIBLE				

PAGE 4

ELEMENT	WORKER/HR, MINUTE			
	1	2	3	
REMOVE PKG.	0.00	0.00	0.00	3.00
MOVE TO NORTH SIDE	3.00	0.00	0.00	3.00
LIFT PANEL TO ROOF	4.00	0.00	0.00	3.00
LIFT PANEL TO DECK	2.00	0.00	0.00	3.00
CUT DUCT PENETRATION	0.00	0.00	0.00	0.00
INSTALL TEMP. FLAT	0.00	0.00	0.00	0.00
APPLY BUTYL TAPE	0.00	0.00	0.00	3.00
ALIGN/MEASURE	2.00	0.00	0.00	3.00
ANCHOR	0.00	0.00	0.00	3.00
REPOSITION (ANCHOR)	0.00	0.00	0.00	0.00
REPOSITION TIEBAR	0.00	0.00	0.00	0.00
PREPARE CARSTRIP	0.00	0.00	0.00	0.00
INSTALL CARSTRIP	0.00	0.00	0.00	0.00
GET TOOL / MISC.	0.00	0.00	0.00	3.00
IDLE (WAIT)	0.00	0.00	0.00	3.00
IDLE (NORMAL)	1.00	0.00	0.00	3.00
IDLE (CONCRETE)	0.00	0.00	0.00	3.00
TOTAL=0.000 TOTAL= .270 TIME= .010 MINUTE= 3.00 WORKER= 3.00				
THE TOTAL TALLIES FOR WORKER 1 ARE 27.00 OUT OF 27.00 POSSIBLE				
THE TOTAL TALLIES FOR WORKER 2 ARE 22.00 OUT OF 27.00 POSSIBLE				
THE TOTAL TALLIES FOR WORKER 3 ARE 20.00 OUT OF 27.00 POSSIBLE				

Table 9-1 (con't)

PAGE 5

ELEMENT	WORKERS/UNIT TIME			
	1	2	3	
REMOVE PKG.	0.00	0.00	0.00	0.00
MOVE TO NORTH SIDE	0.00	0.00	0.00	0.00
LIFT PANEL TO EAVE	0.00	0.00	0.00	0.00
LIFT PANEL TO PEAK	0.00	0.00	0.00	0.00
CUT DUCT PENETRATION	0.00	0.00	0.00	0.00
INSTALL TEMP. FLASH	0.00	0.00	0.00	0.00
APPLY BUTYL TAPE	0.00	0.00	0.00	0.00
ALIGN/PLASTER	0.00	0.00	0.00	0.00
ANCHOR	0.00	0.00	0.00	0.00
POSITION LADDER	0.00	0.00	0.00	0.00
POSITION TOWER	0.00	0.00	0.00	0.00
PREPARE PARTS	4.00	0.00	0.00	4.00
INSTALL PARTS	4.00	0.00	0.00	4.00
GET TOOL / RING	0.00	0.00	0.00	0.00
DOE (WALL)	2.00	2.00	1.00	3.00
DOE (DOWEL)	12.00	2.00	5.00	3.00
DOE (CONCRETE)	2.00	1.00	2.00	3.00
TSTART=0.000 TFINAL= .410 TIME= .010 UNITS= 3.00 WORK= 2.00				
THE TOTAL TALLIES FOR WORKER 1 ARE 37.00 OUT OF 41.00 POSSIBLE				
THE TOTAL TALLIES FOR WORKER 2 ARE 37.00 OUT OF 41.00 POSSIBLE				
THE TOTAL TALLIES FOR WORKER 3 ARE 37.00 OUT OF 41.00 POSSIBLE				

Table 9-2. Field Study 9 (Air Collector/external manifold) Summary

ELAPSED TIME	HRS	MAN-HRS				
	.117	.397				
ELEMENT	NO. COMPLETED	PERCENT TIME (TOL)	MANHRS	MANHRS PER COLLECTOR	COMMENTS	
CUT DUCT PENETRATION	12.00	28.21 14.10	.1100	.0183	(1)	
INSTALL TEMP. CLEAT	20.00	12.92 10.44	.0500	.0025		
REPOSITION LADDER	20.00	7.69 6.34	.0300	-		
GET TOOL / MISC.	20.00	2.54 4.08	.0100	-		
IDLE (INTERNAL)	20.00	5.13 4.02	.0200	-		
IDLE (EXTERNAL)	20.00	43.59 15.96	.1700	.0085		
				<u>.0293</u>		
FOR CREW MEMBER 1						
ELEMENT	PERCENT TIME (TOL)					
REPOSITION LADDER	7.69 14.43					
IDLE (EXTERNAL)	52.21 14.43					
FOR CREW MEMBER 2						
ELEMENT	PERCENT TIME (TOL)	COMMENTS				
INSTALL TEMP. CLEAT	28.24 24.26	(1) 2 PENETRATIONS PER PANEL				
REPOSITION LADDER	7.69 14.43					
GET TOOL / MISC.	7.69 14.43					
IDLE (INTERNAL)	10.44 19.41					
IDLE (EXTERNAL)	20.77 28.02					
FOR CREW MEMBER 3						
ELEMENT	PERCENT TIME (TOL)					
CUT DUCT PENETRATION	24.42 13.11					
REPOSITION LADDER	7.54 14.43					
IDLE (EXTERNAL)	7.54 14.43					

Table 9-3. Field Study 9 (Air Collector/external manifold)

HRS		MAN-HRS			
ELAPSED TIME	1.140	3.490			
ELEMENT	NO. COMPLETED	PERCENT TIME (TOL)		MANHRS	MANHRS PER COLLECTOR
REMOVE PKG.	2.00	0.45	3.17	.2914	.0324
LIFT PANEL TO CAV	9.00	17.54	9.91	.4429	.0492
INSTALL TEMP. CLEAR	2.00	.49	.93	.0233	
APPLY BUTYL TAPE	9.00	8.78	2.27	.2010	.0331
ALIGN/MEASURE	9.00	5.41	2.58	.1265	.0207
ANCHOR	9.00	9.17	3.28	.3167	.0350
REPOSITION LAMBER	9.00	7.43	2.69	.2504	.0285
REPOSITION TRUCK	9.00	5.04	1.96	.1049	.0117
INSTALL CAPSTRIP	1.00	.49	.93	.0233	
GET TOOL / MISC.	2.00	20.61	4.41	.7110	.0700
IDLE (WAIT)	9.00	8.45	3.17	.2914	.0329
IDLE (NORMAL)	9.00	9.89	3.49	.3386	.0376
IDLE (CONFER)	9.00	4.73	2.47	.1632	.0181
FOR CREW REPORT 1					.370
ELEMENT	PERCENT TIME (TOL)				
REMOVE PKG.	4.04	7.04			
LIFT PANEL TO CAV	14.19	7.04			
APPLY BUTYL TAPE	11.11	6.79	FOR CREW REPORT 2		
ALIGN/MEASURE	8.08	5.27			
ANCHOR	13.13	6.44			
REPOSITION LAMBER	10.10	5.04			
REPOSITION TRUCK	4.04	3.89			
INSTALL CAPSTRIP	2.02	2.77			
GET TOOL / MISC.	10.10	5.04			
IDLE (WAIT)	5.05	4.21			
IDLE (NORMAL)	16.16	7.24			
IDLE (CONFER)	1.01	1.97			
FOR CREW REPORT 3					
ELEMENT	PERCENT TIME (TOL)				
REMOVE PKG.	3.17	3.24			
LIFT PANEL TO CAV	14.14	6.84			
INSTALL TEMP. CLEAR	2.02	2.77			
APPLY BUTYL TAPE	15.15	7.04			
ALIGN/MEASURE	8.08	5.27			
ANCHOR	14.14	6.44			
REPOSITION LAMBER	10.10	5.04			
GET TOOL / MISC.	8.04	5.97			
IDLE (WAIT)	16.16	7.29			
IDLE (NORMAL)	8.08	5.97			
IDLE (CONFER)	2.01	1.07			
ELEMENT	PERCENT TIME (TOL)				
REMOVE PKG.	18.17	7.47			
LIFT PANEL TO CAV	9.16	5.79			
REPOSITION LAMBER	2.04	2.20			
REPOSITION TRUCK	5.10	4.34			
GET TOOL / MISC.	43.94	9.87			
IDLE (WAIT)	4.04	3.97			
IDLE (NORMAL)	5.10	4.34			
IDLE (CONFER)	17.24	6.40			

Table 9-4. Field Study 9 (Air collector/external manifold)

ELAPSED TIME	NO.	MANHRS				
	1,177	3,410				
ELEMENT	NO. COMPLETED	PERCENT TIME (TOTL)	MANHRS	MANHR PER COLLECTOR	COMMENTS	
REMOVE PNC.	10.00	2.81 1.81	.0987	.0099		
MOVE TO NORTH SIDE	10.00	2.11 2.00	.2852	.0285		
LIFT PANEL TO CAV.	10.00	2.44 2.05	.2062	.0216		
LIFT PANEL TO PEAK	10.00	4.79 3.14	.3291	.0329		
CUT OUT RESTRAINTS	20.00	10.00 2.20	.3510	.0351	(1)	
APPLY BUTYL TAPE	10.00	11.74 2.46	.3049	.0315		
ALIGN/MEASURE	10.00	17.91 2.33	.3620	.0362		
ANCHOR	10.00	4.63 2.74	.3400	.0340		
GET TOOL / MISC.	10.00	2.12 2.00	.2852	.0285		
TOLE (WATT)	10.00	12.81 2.42	.4388	.0434		
TOLE (INCHES)	10.00	6.94 2.71	.2302	.0230		
TOLE (CONCRETE)	10.00	2.21 1.81	.0987	.0099		
END TASK				.351		

ELEMENT	PERCENT TIME (TOTL)		
REMOVE PNC.	2.81	1.81	
MOVE TO NORTH SIDE	2.11	2.00	
LIFT PANEL TO CAV.	2.44	2.05	
LIFT PANEL TO PEAK	4.79	3.14	
APPLY BUTYL TAPE	11.74	2.46	
ALIGN/MEASURE	17.91	2.33	
ANCHOR	4.63	2.74	
GET TOOL / MISC.	2.12	2.00	
TOLE (WATT)	12.81	2.42	
TOLE (INCHES)	6.94	2.71	
TOLE (CONCRETE)	2.21	1.81	

COMMENTS

(1) 2 PENETRATIONS PER CALCULATOR

FOR CREW MEMBER 2

ELEMENT	PERCENT TIME (TOTL)		
REMOVE PNC.	2.81	1.81	
MOVE TO NORTH SIDE	2.11	2.00	
LIFT PANEL TO CAV.	2.44	2.05	
LIFT PANEL TO PEAK	4.79	3.14	
CUT OUT RESTRAINTS	10.00	2.20	
APPLY BUTYL TAPE	11.74	2.46	
ALIGN/MEASURE	17.91	2.33	
ANCHOR	4.63	2.74	
GET TOOL / MISC.	2.12	2.00	
TOLE (WATT)	12.81	2.42	
TOLE (INCHES)	6.94	2.71	
TOLE (CONCRETE)	2.21	1.81	

FOR CREW MEMBER 3

ELEMENT	PERCENT TIME (TOTL)		
REMOVE PNC.	2.81	1.81	
MOVE TO NORTH SIDE	2.11	2.00	
LIFT PANEL TO CAV.	2.44	2.05	
LIFT PANEL TO PEAK	4.79	3.14	
CUT OUT RESTRAINTS	10.00	2.20	
APPLY BUTYL TAPE	11.74	2.46	
ALIGN/MEASURE	17.91	2.33	
ANCHOR	4.63	2.74	
GET TOOL / MISC.	2.12	2.00	
TOLE (WATT)	12.81	2.42	
TOLE (INCHES)	6.94	2.71	
TOLE (CONCRETE)	2.21	1.81	

Table 9-5. Field Study 9 (Air collector/external manifold)

ELAPSED TIME	HRS	MANHRS		
	.410	3.230		
ELEMENT	NO. COMPLETED	PERCENT TIME (TOL)	MANHRS	MANHRS PER COLLECTOR
PREPARE CAPSTRIP	3.00	9.77 3.63	.0464	.0155
INSTALL CAPSTRIP	3.00	24.54 8.39	.3017	.1006
GET TOOL / MISC.	3.00	34.91 9.09	.4293	.1431
IDLE (WAIT)	3.00	5.64 4.40	.0696	.0232
IDLE (NORMAL)	3.00	22.44 7.07	.2785	.0928
IDLE (COMPLETE)	3.00	8.49 5.31	.1044	.0348
FOR CPEL METHOD 1				.410
ELEMENT	PERCENT TIME (TOL)			
PREPARE CAPSTRIP	12.50 11.46			
INSTALL CAPSTRIP	24.13 15.94			
IDLE (WAIT)	4.25 8.39			
IDLE (NORMAL)	27.50 14.77			
IDLE (COMPLETE)	15.53 12.54			
FOR CPEL METHOD 2				
ELEMENT	PERCENT TIME (TOL)			
INSTALL CAPSTRIP	18.92 12.47			
GET TOOL / MISC.	31.35 14.11			
IDLE (WAIT)	8.11 8.60			
IDLE (NORMAL)	18.92 12.67			
IDLE (COMPLETE)	2.70 5.23			
FOR CPEL METHOD 3				
ELEMENT	PERCENT TIME (TOL)			
INSTALL CAPSTRIP	27.03 14.71			
GET TOOL / MISC.	49.65 14.11			
IDLE (WAIT)	2.70 4.74			
IDLE (NORMAL)	13.51 11.79			
IDLE (COMPLETE)	6.11 8.60			

FIELD STUDY SUMMARY SHEET

Study Number 10

COLLECTOR	
1. TYPE	Liquid - internal manifold - selective surface - single glazing
2. DIMENSIONS	1.85 m x .96 m (73 in x 37.8 in) 1.79 square meters (19.17 square feet)
3. WEIGHT	73.0 kg (161 lbs)
SITE	
1. BUILDING USE	Single family residence, collectors mounted on detached equipment room
2. SOLAR APPLICATION	Solar assisted heat pump, space heating, DHW preheat
3. ARRAY PITCH	55°
4. ARRAY ACCESS	Ladder, 1 m (3 ft) from ground
5. ARRAY SIZE	17.8 m ² (192 ft ²) 10 panels
6. GENERAL CONDITIONS	Hot, sunny day
7. SAFETY PRECAUTIONS	Chicken ladder
PROCEDURE	
1. CREW SIZE/EXPERIENCE	3/none
2. DELIVERY/PACKAGING	Panels delivered to garage of house, no packaging
3. COLLECTOR POSITIONING	Manual

FIELD STUDY 10

BACKGROUND

The installation of collectors for a solar assisted heat pump system was observed. Approximately 17.8 square meters (192 ft²) of liquid collectors were mounted on a storage shed behind the single family residence. Also housed in the storage shed were the liquid storage tank and heat pump equipment. The south roof pitch of the storage shed was 55 degrees and the roof extended down to about three feet from ground level.

The array was set out in two rows of five panels each and the panels were connected as shown in Fig. 10-1. Prior to installation, the collectors were delivered and stored in the garage of the residence. The installation crew consisted of three workers, totally inexperienced in solar collector installation.

PRE INSTALLATION

The roof area was measured and chalk lines were made to determine the approximate location of upper and lower rows of collectors. Since the collectors were not supplied with any mounting hardware, a piece of approximately 1.3 cm (0.5 in) by 61 cm (24 in) angle iron was mounted under the intended position of each collector to serve as a mounting bracket.

INSTALLATION

A collector was moved by hand from the garage to the backyard, where it was set on saw horses. The pipe fittings on the collectors were cleaned and prepared with teflon tape and standard galvanized steel unions and elbows were connected. The roof surface under the collector was painted with a tar-like roof preparation and the collector was carried to the edge of the roof. Two men pushed the collector into position from below and one man guided the collector into position on the angle bracket from above.

The five collectors on the top row were installed in this manner and the connections between these collectors were completed. The bottom row of collectors were installed by two men pushing the collector from the bottom until the connection to the upper panel could be made. It was noted that the panel did not rest on the angle iron bracket due to imprecise installation of the galvanized steel unions and elbows. This problem became more severe as subsequent panels were installed on the bottom row. As a collector was attached to the collector above, the connection to the adjacent panel was noticeably out of alignment. Most of the connections throughout the array had to be loosened and the collectors had to be moved around until all of the unions lined up. The connections were then completed.

Fig. 10-1

Fig. 10-2

POST INSTALLATION

The collectors were later anchored and flashing was installed between each collector and around the edge of the array.

COMMENTS

Many of the problems that occurred pertaining to panel alignment could have been avoided by a change in the manifolding scheme. By using the scheme shown in Fig. 10-2, connections between the upper and lower row of panels would be eliminated. This would greatly increase the allowable tolerance for the installation of pipe unions, since the upper and lower rows are installed independently. A simple gauge made out of plywood would speed the attachment of unions and help maintain reasonable alignment. A problem with the design of manifolding schemes for internally manifolded liquid collectors is that no information is provided regarding the number of collectors that can be installed in parallel while maintaining a reasonable flow distribution. Also, problems with thermal expansion of the long common headers, which result when a large number of panels are connected in parallel, are not addressed.

As noted in Field Study 6, problems arise when anchoring hardware is not provided by the manufacturer. In this case, an inadequate anchoring scheme was employed. The panels were anchored to a piece of angle iron at their bottom edge only, thus relying on the connecting piping and flashing to do the remaining anchoring.

Table 10-1. Field Study 10 (Liquid collector/external manifold)
Taken from time lapse film review

PAGE 1

ELEMENT	WORKER'S MOVEMENTS			
	1	2	3	
PANEL PREP	8.00	3.00	1.00	1.00
STRAIGHT CONNECTION	1.00	0.00	0.00	0.00
ELBOW CONNECTION	2.00	0.00	0.00	1.00
ANGLE BRACKET	0.10	0.00	0.00	0.00
MEASURE/ALIGN/ADJUST	3.00	2.00	0.00	1.00
TAP PIPES	0.00	2.00	2.00	1.00
GET COLLECTION	0.00	2.00	2.00	1.00
POSITION ANGLE	2.00	2.00	2.00	1.00
GET TUBES, ETC.	2.00	2.00	2.00	1.00
IDL	12.00	12.00	10.00	1.00
DEFECTS	1.00	0.00	0.00	0.00
READJUST TUBES	1.00	0.00	0.00	0.00
REPOSITION PANEL	0.00	0.00	0.00	0.00
READJUST ANGLE	0.00	0.00	0.00	0.00
TOTAL TIME: 60.00 MINUTES = 1.00 HOURS = 3.00				

THE TOTAL TALLIES FOR WORKER 1 ARE	1 JOB	24.00 OUT OF	24.00 POSSIBLE
THE TOTAL TALLIES FOR WORKER 2 ARE	2 JOBS	32.00 OUT OF	32.00 POSSIBLE
THE TOTAL TALLIES FOR WORKER 3 ARE	3 JOBS	36.00 OUT OF	36.00 POSSIBLE

PAGE 2

ELEMENT	WORKER'S MOVEMENTS			
	1	2	3	
PANEL PREP	9.00	11.00	1.00	1.00
STRAIGHT CONNECTION	2.00	0.00	1.00	1.00
ELBOW CONNECTION	3.00	0.00	0.00	1.00
ANGLE BRACKET	2.00	2.00	0.00	1.00
MEASURE/ALIGN/ADJUST	1.00	0.00	0.00	1.00
TAP PIPES	0.00	2.00	2.00	1.00
GET COLLECTION	0.00	2.00	2.00	1.00
POSITION ANGLE	1.00	2.00	2.00	1.00
GET TUBES, ETC.	2.00	12.00	12.00	1.00
IDL	26.00	21.00	20.00	1.00
DEFECTS	0.00	0.00	0.00	0.00
READJUST TUBES	0.00	0.00	0.00	0.00
REPOSITION PANEL	0.00	0.00	0.00	0.00
READJUST ANGLE	0.00	0.00	0.00	0.00
TOTAL TIME: 80.00 MINUTES = 1.00 HOURS = 3.00				

THE TOTAL TALLIES FOR WORKER 1 ARE	1 JOB	54.00 OUT OF	54.00 POSSIBLE
THE TOTAL TALLIES FOR WORKER 2 ARE	2 JOBS	66.00 OUT OF	66.00 POSSIBLE
THE TOTAL TALLIES FOR WORKER 3 ARE	3 JOBS	75.00 OUT OF	75.00 POSSIBLE

Table 10-1 (con't)

PAGE 3

ELEMENT	WORKERS/HO. UNITS			
	1	2	3	
PANEL PREP	0.00	1.00	1.00	1.00
STRAIGHT CONNECTION	0.00	1.00	1.00	2.00
ELBOW CONNECTION	0.00	0.00	0.00	2.00
ANGLE BRACKET	0.00	0.00	0.00	0.00
MEASURE/ALIGN/ADJUST	1.00	0.00	0.00	1.00
VAR POOF	0.00	0.00	0.00	0.00
GET COLLECTOR	0.00	1.00	1.00	1.00
POSITION/HOLD	0.00	0.00	0.00	0.00
GET TOOLS ETC.	1.00	2.00	0.00	1.00
TOTAL	21.00	24.00	21.00	1.00
OFFSITE	13.00	14.00	12.00	1.00
READJUST UNIONS	2.00	0.00	1.00	2.00
REPOSITION PANEL	2.00	2.00	2.00	1.00
READJUST ANGLE	4.00	0.00	0.00	2.00
TSTART= .010 TOTAL=1.520 TIME= .010 UNITS= 1.00 WORKS= 3.00				

THE TOTAL TALLIES FOR WORKER 1 ARE 41.00 OUT OF 41.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 2 ARE 42.00 OUT OF 41.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 3 ARE 40.00 OUT OF 41.00 POSSIBLE

PAGE 4

ELEMENT	WORKERS/HO. UNITS			
	1	2	3	
PANEL PREP	2.00	1.00	0.00	1.00
STRAIGHT CONNECTION	3.00	0.00	0.00	1.00
ELBOW CONNECTION	1.00	0.00	0.00	1.00
ANGLE BRACKET	2.00	2.00	2.00	1.00
MEASURE/ALIGN/ADJUST	1.00	1.00	1.00	1.00
VAR POOF	0.00	0.00	0.00	1.00
GET COLLECTOR	2.00	1.00	2.00	1.00
POSITION/HOLD	1.00	1.00	1.00	1.00
GET TOOLS ETC.	4.00	0.00	1.00	0.00
TOTAL	16.00	22.00	19.00	1.00
OFFSITE	15.00	16.00	19.00	1.00
READJUST UNIONS	2.00	1.00	2.00	2.00
REPOSITION PANEL	5.00	4.00	4.00	2.00
READJUST ANGLE	0.00	0.00	0.00	0.00
TSTART=1.430 TOTAL=7.120 TIME= .010 UNITS= 1.00 WORKS= 2.00				

THE TOTAL TALLIES FOR WORKER 1 ARE 40.00 OUT OF 40.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 2 ARE 40.00 OUT OF 40.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 3 ARE 40.00 OUT OF 40.00 POSSIBLE

Table 10-2. Field Study 10 (Liquid collector/external manifold)
Taken from time lapse film review

ELAPSED TIME	MINS 2.000	MANHRS 6.270				
ELEMENT	NO. COMPLETED	PERCENT TIME (TOL)	MANHRS	MANHR PER PANEL		
PANEL PREP	4.00	6.34 1.51	.4000	.1000		
STRAIGHT CONNECTION	4.00	7.07 1.17	.1300	.0327		
ELBOW CONNECTION	5.00	2.55 1.23	.1600	.032		
ANGLE BRACKET	2.00	3.35 1.41	.2100	.1050		
MEASURE/ALIGN/ADJUST	4.00	1.50 .00	.1000	.0250		
TAP ROOF	3.00	2.71 1.22	.1700	.0567		
GET COLLECTOR	4.00	4.47 1.42	.2600	.0700		
POSITION/ANGLE	3.00	2.03 1.34	.1900	.0633		
GET TOOLS ETC.	4.00	10.21 2.27	.6400	.1600		
TOL	4.00	40.23 3.85	2.5600	.6400		
OFFSITE	2.00	15.43 2.04	.5600	—		
READJUST UNIONS	5.00	2.22 1.16	.1400	.0140 (U)		
REPOSITION PANEL	4.00	3.67 1.47	.2300	.0575 (U)		
READJUST ANGLE	3.00	1.22 .00	.0800	.0080 (U)		
FOR CREW MEMBER 1				1.33		

ELEMENT	PERCENT TIME (TOL)				
PANEL PREP	6.34 1.51				
STRAIGHT CONNECTION	7.07 1.17				
ELBOW CONNECTION	2.55 1.23				
ANGLE BRACKET	3.35 1.41				
MEASURE/ALIGN/ADJUST	1.50 .00				
GET COLLECTOR	4.47 1.42				
POSITION/ANGLE	2.03 1.34				
GET TOOLS ETC.	10.21 2.27				
TOL	40.23 3.85				
OFFSITE	15.43 2.04				
READJUST UNIONS	2.22 1.16				
REPOSITION PANEL	3.67 1.47				
READJUST ANGLE	1.22 .00				

ELEMENT	PERCENT TIME (TOL)				
PANEL PREP	6.57 3.70				
STRAIGHT CONNECTION	6.48 .93				
ANGLE BRACKET	4.79 2.74				
MEASURE/ALIGN/ADJUST	1.43 1.00				
TAP ROOF	5.71 3.14				
GET COLLECTOR	5.71 3.14				
POSITION/ANGLE	2.86 2.04				
GET TOOLS ETC.	12.14 4.45				
TOL	3.70 .00				
OFFSITE	16.17 4.00				
READJUST UNIONS	.45 .03				
REPOSITION PANEL	2.41 2.00				

ELEMENT	PERCENT TIME (TOL)				
PANEL PREP	1.47 1.61				
STRAIGHT CONNECTION	.32 1.33				
ANGLE BRACKET	3.34 2.44				
MEASURE/ALIGN/ADJUST	.50 .04				
TAP ROOF	2.42 2.00				
GET COLLECTOR	4.76 3.42				
POSITION/ANGLE	3.84 2.13				
GET TOOLS ETC.	9.70 3.04				
TOL	48.70 6.81				
OFFSITE	17.30 5.14				
READJUST UNIONS	1.92 1.04				
REPOSITION PANEL	3.84 2.04				

FIELD STUDY SUMMARY SHEET

Study Number 11

COLLECTOR	
1. TYPE	Air - external manifold - single glazing - selective surface
2. DIMENSIONS	.61 m x 3 m (2 ft x 10 ft) 1.8 square meters (20 square feet)
3. WEIGHT	48.8 kg (112 lbs)
SITE	
1. BUILDING USE	Commercial laundry, panels mounted on special outside rack
2. SOLAR APPLICATION	Laundry drying air preheat
3. ARRAY PITCH	45°
4. ARRAY ACCESS	Ladder, rack 1 m (3 ft) from ground
5. ARRAY SIZE	40.9 m ² (440 ft ²) 22 panels
6. GENERAL CONDITIONS	Clear, hot
7. SAFETY PRECAUTIONS	Chicken ladder
PROCEDURE	
1. CREW SIZE/EXPERIENCE	4/none
2. DELIVERY/PACKAGING	Delivered morning of installation/none
3. COLLECTOR POSITIONING	Manual

FIELD STUDY 11

BACKGROUND

This installation involved the use of solar air collectors for pre-heating air used for commercial laundry dryers. The collectors are mounted on a rack constructed next to the south wall of the laundry building. Ambient air is heated in the collectors and is ducted to three large dryers inside the building. Each collector has its own inlet port with air filter. The outlets from each collector connect to a common manifold for distribution to the dryers. The collectors are the same make as the ones studied in Field Study 3.

PRE INSTALLATION

The collectors were delivered early in the morning on the day of the installation. They were unloaded by hand and stacked near the mounting rack. As in Field Study 3, the array was measured and laid out, and a starter strip was installed. The holes for the collector inlets and outlets were already cut into the plywood roof sheathing.

INSTALLATION

The installation crew consisted of four workers. Two workers moved the panels from the stack to a temporary position on the ground where two mounting brackets were attached to the west side of the panel. Sheetmetal screws, driven by an electric drill, were used to anchor the brackets to the collector. Then two workers would move the panel over to the mounting rack where, along with the two other workers, the panel was lifted into place. The panel was then aligned and anchored with lag bolts driven into the sheathing. A connecting strip was fed into a channel formed between two adjacent collectors and two pieces of capstrip were placed over the space between the panels and mounted by driving sheetmetal screws into the connecting strip. An alternate methodology was also used where the connecting strip was placed into the channel on one collector which was already anchored and the next collector was brought up and maneuvered into place. This rather cumbersome procedure eliminated the need to slide the connecting strip into the channel formed by two adjacent collectors, where it often caught on protrusions into the channel. The panel was then anchored and capstripped as before.

POST INSTALLATION

The array was insulated around the exterior and flashed as per the manufacturer's instructions. The outlet manifold was constructed and connections to the panels were made. Time estimates to install connecting ductwork as supplied by the sheetmetal contractor are shown in Table 11-3.

COMMENTS

Due to the easy array access and simple mounting procedures, the installation of the panels went smoothly. The only problem noted was that of the connecting strip jamming in its channel. The time study represents the last four collectors of the 22 total installed, and the average time is therefore not representative of the total array average time. As in Field Study 3, the cap strip hold down screws were difficult to start, causing the same problems noted in that study.

Fig. 11-1

Table 11-1. Field Study 11 (Air collector/external manifold)

PAGE 1

ELEMENT	WORKERS AND UNITS				
	1	2	3	4	
MOVE COLLECTOR	0.00	2.00	0.00	2.00	1.00
ALIGN	2.00	1.00	3.00	1.00	1.00
ANCHOR	2.00	0.00	1.00	0.00	3.00
FEED CONNECTOR STRIP	2.00	0.00	1.00	0.00	2.00
FEED CAP STRIP	0.00	0.00	2.00	2.00	1.00
ANCHOR CAP STRIP	0.00	0.00	1.00	1.00	1.00
INSTALL ANCHORS	0.00	2.00	0.00	2.00	3.00
FOREIGN	2.00	1.00	2.00	0.00	1.00
GET TOOLS/PARTS ETC.	0.00	0.00	1.00	1.00	1.00
IDLE1 (WAIT)	5.00	7.00	2.00	2.00	1.00
IDLE2 (INSTRUCTIONS)	1.00	0.00	0.00	0.00	1.00
IDLE3 (NORMAL)	0.00	0.00	0.00	0.00	0.00
TSTART=0.000 TFINAL=.140 TINT=.010 UNITS= 1.00 WORKS= 4.00					
THE TOTAL TALLIES FOR WORKER 1 ARE 14.00 OUT OF 14.00 POSSIBLE					
THE TOTAL TALLIES FOR WORKER 2 ARE 12.00 OUT OF 14.00 POSSIBLE					
THE TOTAL TALLIES FOR WORKER 3 ARE 17.00 OUT OF 14.00 POSSIBLE					
THE TOTAL TALLIES FOR WORKER 4 ARE 13.00 OUT OF 14.00 POSSIBLE					

PAGE 2

ELEMENT	WORKERS AND UNITS				
	1	2	3	4	
MOVE COLLECTOR	0.00	2.00	0.00	2.00	1.00
ALIGN	3.00	0.00	1.00	2.00	1.00
ANCHOR	2.00	0.00	2.00	0.00	3.00
FEED CONNECTOR STRIP	1.00	0.00	1.00	2.00	2.00
FEED CAP STRIP	0.00	0.00	0.00	0.00	1.00
ANCHOR CAP STRIP	1.00	0.00	4.00	4.00	1.00
INSTALL ANCHORS	0.00	0.00	0.00	1.00	2.00
FOREIGN	0.00	0.00	0.00	0.00	0.00
GET TOOLS/PARTS ETC.	0.00	2.00	1.00	1.00	1.00
IDLE1 (WAIT)	0.00	0.00	5.00	1.00	1.00
IDLE2 (INSTRUCTIONS)	0.00	0.00	0.00	0.00	0.00
IDLE3 (NORMAL)	0.00	0.00	0.00	0.00	0.00
TSTART=.140 TFINAL=.285 TINT=.010 UNITS= 1.00 WORKS= 4.00					
THE TOTAL TALLIES FOR WORKER 1 ARE 15.00 OUT OF 14.50 POSSIBLE					
THE TOTAL TALLIES FOR WORKER 2 ARE 12.00 OUT OF 14.50 POSSIBLE					
THE TOTAL TALLIES FOR WORKER 3 ARE 16.00 OUT OF 14.50 POSSIBLE					
THE TOTAL TALLIES FOR WORKER 4 ARE 13.00 OUT OF 14.50 POSSIBLE					

Table 11-1 (con't)

PAGE 3

ELEMENT	WORKERS/NO. UNITS				
	1	2	3	4	
MOVE COLLECTOR	1.00	2.00	1.00	2.00	1.00
ALIGN	1.00	0.00	2.00	0.00	1.00
ANCHOR	2.00	0.00	2.00	0.00	3.00
FEED CONNECTED STRIP	0.00	0.00	0.00	1.00	2.00
FEED CAP STRIP	1.00	0.00	0.00	0.00	1.00
ANCHOR CAP STRIP	2.00	0.00	1.00	2.00	1.00
INSTALL ANCHORS	0.00	4.00	0.00	4.00	3.00
FOREIGN	2.00	0.00	0.00	2.00	1.00
GET TOOLS/PARTS ETC.	0.00	2.00	1.00	0.00	1.00
TOLE1 (WAIT)	2.00	2.00	2.00	2.00	1.00
TOLE2 (INSTRUCTIONS)	0.00	0.00	0.00	0.00	0.00
TOLE3 (NOOP)	0.00	0.00	0.00	0.00	0.00
TSTART = .240 TFINAL = .400 TINT = .010 UNITS = 1.00 WORKS = 4.00					

THE TOTAL TALLIES FOR WORKER 1 ARE 11.00 OUT OF 10.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 2 ARE 11.00 OUT OF 10.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 3 ARE 9.00 OUT OF 10.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 4 ARE 13.00 OUT OF 10.00 POSSIBLE

PAGE 4

ELEMENT	WORKERS/NO. UNITS				
	1	2	3	4	
MOVE COLLECTOR	0.00	1.00	0.00	1.00	1.00
ALIGN	3.00	0.00	1.00	1.00	1.00
ANCHOR	2.00	0.00	2.00	0.00	3.00
FEED CONNECTED STRIP	0.00	0.00	0.00	0.00	2.00
FEED CAP STRIP	0.00	0.00	0.00	0.00	1.00
ANCHOR CAP STRIP	0.00	0.00	0.00	2.00	1.00
INSTALL ANCHORS	0.00	2.00	0.00	2.00	3.00
FOREIGN	1.00	0.00	1.00	0.00	1.00
GET TOOLS/PARTS ETC.	1.00	1.00	2.00	1.00	1.00
TOLE1 (WAIT)	2.00	4.00	3.00	2.00	1.00
TOLE2 (INSTRUCTIONS)	0.00	0.00	0.00	0.00	0.00
TOLE3 (NOOP)	0.00	0.00	0.00	0.00	0.00
TSTART = .100 TFINAL = .197 TINT = .010 UNITS = 1.00 WORKS = 4.00					

THE TOTAL TALLIES FOR WORKER 1 ARE 10.00 OUT OF 9.70 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 2 ARE 10.00 OUT OF 9.70 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 3 ARE 10.00 OUT OF 9.70 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 4 ARE 10.00 OUT OF 9.70 POSSIBLE

Table 11-2. Field Study 11 (Air collector/external manifold)

START TIME	HRS	MIN	SEC
14:20	4-2	1.02	

ELEMENT	NO. COMPLETED	PERCENT TIME (T-1)	MANHRS	MANHRS PER COLLECTOR
MOVE COLLECTOR	4.00	8.70 3.99	.1498	.0400
ALIGN	4.00	11.92 4.57	.2298	.0575
ANCHOR	12.00	7.77 3.78	.1498	.0375
FEED CONNECTOR STRIP	4.00	4.15 2.81	.0799	.0200
FEED CAP STRIP	4.00	7.59 3.24	.0499	.0125
ANCHOR CAP STRIP	4.00	9.84 4.20	.1898	.0475
INSTALL ANCHORS	12.00	9.77 4.15	.1798	.0450
FOREIGN	2.00	5.72 3.27	.1099	.0275
GET TOOLS/PARTS ETC.	4.00	7.77 3.78	.1498	.0375
IDLE1 (WAIT)	4.00	32.12 6.50	.6194	.1544
IDLE2 (INSTRUCTIONS)	1.00	.52 1.01	.0100	-
FOR CREW MEMBER 1				.480

ELEMENT	PERCENT TIME (T-1)
MOVE COLLECTOR	2.00 3.99
ALIGN	14.90 10.49
ANCHOR	14.90 10.19
FEED CONNECTOR STRIP	4.00 4.99
FEED CAP STRIP	2.00 3.99
ANCHOR CAP STRIP	4.00 4.99
FOREIGN	10.90 9.99
GET TOOLS/PARTS ETC.	2.00 3.99
IDLE1 (WAIT)	32.12 13.94
IDLE2 (INSTRUCTIONS)	2.00 3.99
FOR CREW MEMBER 2	

ELEMENT	PERCENT TIME (T-1)
MOVE COLLECTOR	2.13 4.19
ALIGN	14.90 10.19
ANCHOR	14.90 10.19
FEED CONNECTOR STRIP	4.26 5.77
FEED CAP STRIP	4.26 5.77
ANCHOR CAP STRIP	14.90 10.19
FOREIGN	4.26 6.00
GET TOOLS/PARTS ETC.	7.77 9.59
IDLE1 (WAIT)	25.92 12.47
FOR CREW MEMBER 3	

ELEMENT	PERCENT TIME (T-1)
MOVE COLLECTOR	14.90 9.99
ALIGN	12.24 9.19
FEED CONNECTOR STRIP	4.12 6.71
FEED CAP STRIP	4.08 5.94
ANCHOR CAP STRIP	14.90 17.46
INSTALL ANCHORS	20.91 11.29
FOREIGN	4.26 5.94
GET TOOLS/PARTS ETC.	4.12 6.21
IDLE1 (WAIT)	14.29 9.99
FOR CREW MEMBER 4	

**Table 11-3. Time to Construct External
Collector Outlet Manifold**

Part (material)	Amount	Time	Time per Collector
Outlet Plenum (fiberglass ductboard)	42 feet	14 man-hours	.636 man-hours
Panel to plenum connecting tubes (rigid round fiberglass) Includes spin-ins, sealing, etc.	5	6 man-hours	1.2 man-hours

FIELD STUDY SUMMARY SHEET

Study Number 12

COLLECTOR	
1. TYPE	Air - internal manifold - single glazing - selective surface
2. DIMENSIONS	.89 m x 1.96 m (35 in x 77 in) 1.74 square meters (18.7 square feet)
3. WEIGHT	61.2 kg (135 lbs)
SITE	
1. BUILDING USE	Experimental solar home (single family residential design)
2. SOLAR APPLICATION	Solar assisted heat pump, space heating and DHW preheat
3. ARRAY PITCH	45°
4. ARRAY ACCESS	Scaffold, ladder from north roof 6.1 m (20 ft) from ground
5. ARRAY SIZE	55.7 m ² (600 ft ²) 32 panels
6. GENERAL CONDITIONS	Clear, hot
7. SAFETY PRECAUTIONS	Scaffold, chicken ladder, rope and safety belt
PROCEDURE	
1. CREW SIZE/EXPERIENCE	4/good
2. DELIVERY/PACKAGING	Panels delivered and unloaded prior to installation/2 collectors per box
3. COLLECTOR POSITIONING	1) crane to roof, manual final position 2) crane to final position

FIELD STUDY 12

BACKGROUND

This study involved the installation of internally manifolded air collectors. As in Field Study 6, this study involved the installation of new collectors on an experimental solar house. An effort was made for the purposes of this study to perform the installation in a manner representative of an actual commercial installation. A crew of four workers, plus a crane operator, was used for the installation. The collectors were delivered to the job site a few days beforehand.

The collectors were the first of a new design to be installed in a system. The roof pitch was 45 degrees and the edge of the roof was approximately 6.1 m (20 ft) from the ground. A fork truck mounted scaffold was available as a working platform.

PRE INSTALLATION

The roof surface was covered with new roof felt and was measured to determine array layout. A length of angle iron was fastened for a starter strip. Holes were cut into the roof for duct penetrations. The collectors were unpackaged, inspected for damage, cleaned, and stacked near the job site. All of the necessary tools were gathered before the installation, and a sling was fashioned to lift the collectors at the same angle as the roof (see Fig. 12-1).

INSTALLATION

The array was divided into two sections (see Fig. 12-2). Two general installation methods were used, one for each half of the array. For the west array, a crane was used to lift all of the collectors into a temporary position on the roof. The workers then slid the panels one by one into their final positions as the installation progressed (see Figs. 12-3 and 12-4). For the east array, the crane lifted the panels one by one as they were installed. The collectors were guided into their final positions and anchored immediately upon arrival at the roof (see Figs. 12-5 and 12-6).

Regardless of the scheme for moving the panels to the roof, the remaining installation procedures were as follows. An internal manifold port gasket with mounting frame was inserted into each port (Fig. 12-7). A capstrip hold down, which was a long strip of foam insulation backed by a sheetmetal strip, was inserted between an already anchored panel and the panel being installed (Fig. 12-8). The collector was then pushed up against the adjacent panels and anchored with lag bolts driven through mounting holes in the collector body and into the roof sheathing (Fig. 12-9). Capstrip pieces were installed by driving self-starting screws through pre-drilled holes in the capstrip into the metal backing of the capstrip hold down.

In this particular installation, the capstrip hold down was pre-drilled on-site to relieve problems encountered with starting the capstrip screws.

Figure 12-1

Figure 12-2

Fig. 12-3

Fig. 12-4

Fig. 12-5

Fig. 12-6

Fig. 12-7

Fig. 12-8

Fig. 12-9

Fig. 12-10

Fig. 12-11

Fig. 12-12

POST INSTALLATION

Capstrip finish pieces were fastened at the panel corners, and the manufacturer-supplied array perimeter insulation was installed (Fig. 12-13). The array perimeter was flashed and the remainder of the roof was covered with shingles.

COMMENTS

Panel alignment was difficult to maintain during anchoring. Due to the angle of the anchoring holes in the collector (see Fig. 12-9), the panels had a tendency to move toward an adjacent panel as the anchors were tightened. This was helpful in ensuring a tight seal between the panels, but it made the capstrip installation difficult. A provision for positive contact between panels could serve as a gauge for correct alignment. This contact could be made by stiff rubber knobs on the corners of the panels that would compress under array thermal expansion but serve as a positive locator for collector alignment. A simpler technique would be to use a removable gauge block to aid in panel alignment (see Fig. 12-10).

The use of self-starting screws for capstrip installation has presented a problem in this and other installations (see Field Study 3). Excessive pressure is needed to start the screws, causing time delay, worker fatigue, and an unsafe working situation. A better self-starting screw design or factory pre-drilled capstrip hold downs are needed. As with all air collectors, testing of array air leakage, including in-field tests, is warranted to establish the adequacy of the design.

Fig. 12-13

Table 12-1. Field Study 12 (Air collector/internal manifold)

PAGE 1

WORKERS/INT. UNITS						
ELEMENT	1	2	3	4	5	6
PANEL PREP	4.00	12.00	2.00	2.00	14.00	4.00
ATTACH SLING/GUINE	28.00	10.00	0.00	0.00	4.00	4.00
RECEIVE/POSITION	0.00	0.00	12.00	11.00	0.00	4.00
IDLE (NORMAL)	1.00	1.00	0.00	0.00	0.00	4.00
IDLE (WAIT)	2.00	10.00	21.00	21.00	0.00	4.00
IDLE (CONFER)	3.00	2.00	1.00	2.00	0.00	4.00
GET/REPOSITION EQPT.	0.00	2.00	6.00	7.00	0.00	4.00
OFFSITE	0.00	0.00	2.00	0.00	27.00	4.00
DELAY/PRESET TOWER	4.00	4.00	4.00	4.00	0.00	4.00
DELAY/CLEAN PORTS	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL TIME = 50.00 HOURS 1.10 UNITS 4.00 WORKS 4.00						

THE TOTAL TALLIES FOR WORKER 1 ARE	40.00 OUT OF	50.00 POSSIBLE
THE TOTAL TALLIES FOR WORKER 2 ARE	40.00 OUT OF	50.00 POSSIBLE
THE TOTAL TALLIES FOR WORKER 3 ARE	50.00 OUT OF	50.00 POSSIBLE
THE TOTAL TALLIES FOR WORKER 4 ARE	40.00 OUT OF	50.00 POSSIBLE
THE TOTAL TALLIES FOR WORKER 5 ARE	50.00 OUT OF	50.00 POSSIBLE

PAGE 2

WORKERS/INT. UNITS						
ELEMENT	1	2	3	4	5	6
PANEL PREP	0.00	22.00	4.00	0.00	20.00	0.00
ATTACH SLING/GUINE	40.00	18.00	0.00	0.00	6.00	0.00
RECEIVE/POSITION	0.00	0.00	12.00	12.00	0.00	0.00
IDLE (NORMAL)	0.00	0.00	0.00	0.00	0.00	0.00
IDLE (WAIT)	0.00	1.00	20.00	20.00	0.00	0.00
IDLE (CONFER)	0.00	0.00	1.00	1.00	2.00	0.00
GET/REPOSITION EQPT.	0.00	0.00	2.00	2.00	0.00	0.00
OFFSITE	0.00	0.00	0.00	0.00	24.00	0.00
DELAY/PRESET TOWER	0.00	0.00	0.00	0.00	0.00	0.00
DELAY/CLEAN PORTS	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL TIME = 100.00 HOURS 1.10 UNITS 4.00 WORKS 4.00						

THE TOTAL TALLIES FOR WORKER 1 ARE	40.00 OUT OF	52.00 POSSIBLE
THE TOTAL TALLIES FOR WORKER 2 ARE	51.00 OUT OF	52.00 POSSIBLE
THE TOTAL TALLIES FOR WORKER 3 ARE	51.00 OUT OF	52.00 POSSIBLE
THE TOTAL TALLIES FOR WORKER 4 ARE	51.00 OUT OF	52.00 POSSIBLE
THE TOTAL TALLIES FOR WORKER 5 ARE	52.00 OUT OF	52.00 POSSIBLE

PAGE 3

WORKERS/INT. UNITS						
ELEMENT	1	2	3	4	5	6
PANEL PREP	0.00	4.00	0.00	0.00	2.00	2.00
ATTACH SLING/GUINE	12.00	2.00	0.00	0.00	2.00	2.00
RECEIVE/POSITION	0.00	0.00	0.00	2.00	0.00	2.00
IDLE (NORMAL)	0.00	2.00	0.00	0.00	0.00	2.00
IDLE (WAIT)	0.00	0.00	0.00	0.00	0.00	2.00
IDLE (CONFER)	0.00	2.00	0.00	0.00	0.00	2.00
GET/REPOSITION EQPT.	0.00	0.00	0.00	0.00	0.00	0.00
OFFSITE	0.00	0.00	0.00	0.00	0.00	2.00
DELAY/PRESET TOWER	0.00	0.00	0.00	0.00	0.00	2.00
DELAY/CLEAN PORTS	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL TIME = 30.00 HOURS 1.10 UNITS 4.00 WORKS 4.00						

THE TOTAL TALLIES FOR WORKER 1 ARE	20.00 OUT OF	18.00 POSSIBLE
THE TOTAL TALLIES FOR WORKER 2 ARE	20.00 OUT OF	18.00 POSSIBLE
THE TOTAL TALLIES FOR WORKER 3 ARE	10.00 OUT OF	18.00 POSSIBLE
THE TOTAL TALLIES FOR WORKER 4 ARE	10.00 OUT OF	18.00 POSSIBLE
THE TOTAL TALLIES FOR WORKER 5 ARE	10.00 OUT OF	18.00 POSSIBLE

Table 12-2. Field Study 12 (Air collector/internal manifold)
Moving collectors into approximate position on roof by crane

ELAPSED TIME	MDC	MAM-MDC				
	1.777	4.000				
ELEMENT	NO. COMPLETED	PERCENT TIME (TOL)	MANNPS		MANN2 PER COLLECTOR	COMMENTS
PANEL PREP	14.00	14.67 2.44	.8773		.0627	
ATTACH SLING/SHIELD	14.00	20.67 3.75	1.2403		.0394	
RECEIVE/POSITION	14.01	8.67 2.75	.5143		.0367	
TOLE (NORMAL)	4.00	.25 .75	.0504		.0036	(1)
TOLE (WAIT)	14.00	27.14 3.74	1.3311		.0151	
TOLE (CONFER)	14.00	3.57 1.49	.2118		.0151	
GET/REPOSITION CONT.	12.00	3.33 1.47	.1916		.0131	(1)
OFFSITE	14.00	11.43 2.57	.6956		-	
DELAY/PRESET TRUCK	4.00	0.41 2.75	.5647		.0403	(1)
DELAY/CLEAN PORTS	4.00	4.29 1.91	.3227		.0231	(1)
FOR CREW MEMBER 1					.379	

ELEMENT	PERCENT TIME (TOL)
PANEL PREP	1.15 3.74
ATTACH SLING/SHIELD	14.91 2.77
TOLE (NORMAL)	.84 1.44
TOLE (WAIT)	5.04 4.77
TOLE (CONFER)	2.52 2.47
DELAY/PRESET TRUCK	11.76 5.79
DELAY/CLEAN PORTS	4.72 4.59

FOR CREW MEMBER 2

ELEMENT	PERCENT TIME (TOL)
PANEL PREP	31.93 9.34
ATTACH SLING/SHIELD	24.37 7.71
TOLE (NORMAL)	3.75 3.74
TOLE (WAIT)	0.24 5.79
TOLE (CONFER)	10.42 5.49
GET/REPOSITION CONT.	1.48 2.31
DELAY/PRESET TRUCK	13.74 5.79
DELAY/CLEAN PORTS	4.72 4.59

FOR CREW MEMBER 3

ELEMENT	PERCENT TIME (TOL)
PANEL PREP	1.56 2.31
RECEIVE/POSITION	21.45 7.47
TOLE (WAIT)	47.00 8.67
TOLE (CONFER)	1.88 2.31
GET/REPOSITION CONT.	1.72 4.50
OFFSITE	1.58 2.31
DELAY/PRESET TRUCK	11.76 5.79
DELAY/CLEAN PORTS	5.72 4.59

COMMENTS:

(1) AVERAGED OVER ALL 10 PANELS

FOR CREW MEMBER 4

ELEMENT	PERCENT TIME (TOL)
PANEL PREP	1.69 2.31
RECEIVE/POSITION	21.19 7.17
TOLE (WAIT)	44.31 9.67
TOLE (CONFER)	2.56 2.04
GET/REPOSITION CONT.	2.43 4.77
DELAY/PRESET TRUCK	11.86 5.81
DELAY/CLEAN PORTS	4.74 4.74

FOR CREW MEMBER 5

ELEMENT	PERCENT TIME (TOL)
PANEL PREP	34.17 9.43
ATTACH SLING/SHIELD	10.00 9.37
OFFSITE	15.42 4.89

Table 12-3. Field Study 12 (Air collector/internal manifold)

PAGE 1

ELEMENT	WORKERS TIME, MINUTES			
	1	2	3	4
PUSH INTO PLACE	1.00	2.00	1.00	2.00
REMOVE CLEAR	0.00	0.00	2.00	2.00
ALIGN	0.00	0.00	0.00	2.00
ANCHOR	1.00	1.00	2.00	16.00
GASKET	0.00	1.00	0.00	2.00
C.S. HOLD DOWN	0.00	0.00	0.00	1.00
CAP STRIP	8.00	16.00	2.00	1.00
IDLE (NORMAL)	24.00	12.00	20.00	2.00
IDLE (WAIT)	0.00	0.00	0.00	2.00
IDLE (CHECK)	16.00	12.00	12.00	2.00
GFT PARTS, TOOLS, ETC.	1.00	1.00	12.00	2.00
MODIFY GASKETS	1.00	1.00	0.00	2.00
REMOVE TAPE	2.00	2.00	1.00	2.00
CLEAN GLASS	0.00	0.00	2.00	1.00
EXPERIMENT WITH C.S.	20.00	21.00	20.00	1.00
REPOSITION COLLECTION	1.00	1.00	0.00	1.00
TSTART=0.000 TFINISH=0.010 TIME=0.010 MINUTE=2.00 WORKS=3.00				

THE TOTAL TALLIES FOR WORKER 1 ARE 70.00 OUT OF 81.00 POSSIBLE

THE TOTAL TALLIES FOR WORKER 2 ARE 70.00 OUT OF 81.00 POSSIBLE

THE TOTAL TALLIES FOR WORKER 3 ARE 62.00 OUT OF 81.00 POSSIBLE

PAGE 2

ELEMENT	WORKERS TIME, MINUTES			
	1	2	3	4
PUSH INTO PLACE	4.00	0.00	2.00	1.00
REMOVE CLEAR	0.00	0.00	2.00	1.00
ALIGN	1.00	0.00	0.00	1.00
ANCHOR	1.00	0.00	2.00	4.00
GASKET	0.00	2.00	1.00	1.00
C.S. HOLD DOWN	0.00	0.00	2.00	1.00
CAP STRIP	0.00	1.00	10.00	1.00
IDLE (NORMAL)	24.00	25.00	6.00	1.00
IDLE (WAIT)	1.00	1.00	1.00	1.00
IDLE (CHECK)	22.00	22.00	21.00	1.00
GFT PARTS, TOOLS, ETC.	2.00	2.00	2.00	1.00
MODIFY GASKETS	0.00	2.00	0.00	0.00
REMOVE TAPE	0.00	0.00	0.00	0.00
CLEAN GLASS	0.00	1.00	0.00	1.00
EXPERIMENT WITH C.S.	0.00	0.00	0.00	0.00
REPOSITION COLLECTION	0.00	0.00	0.00	0.00
TSTART=0.220 TFINISH=0.870 TIME=0.650 MINUTE=1.00 WORKS=3.00				

THE TOTAL TALLIES FOR WORKER 1 ARE 56.00 OUT OF 81.00 POSSIBLE

THE TOTAL TALLIES FOR WORKER 2 ARE 54.00 OUT OF 81.00 POSSIBLE

THE TOTAL TALLIES FOR WORKER 3 ARE 57.00 OUT OF 81.00 POSSIBLE

Table 12-4. Field Study 12 (Air collector/internal manifold)

ELAPSED TIME	NO. COMPLETED	PERCENT TIME (TTL)	MANHRS	MANHRS PER COLLECTOR	COMMENTS
PUSH INTO PLACE	4.00	1.47 1.47	.1081	.0360	
REMOVE CLAMP	2.00	.74 .74	.0433	.0144	
ALIGN	2.00	.74 .74	.0104	-	
ANCHOR	24.00	9.79 1.94	.1627	.0541	(1)
CASSET	2.00	.74 .74	.0324	-	
C.S. HOLD DOWN	2.00	1.44 1.12	.0649	.0467	(1)
CAP STRIP	2.00	2.44 2.74	.3784	.1839	
IDLE (CLOCK)	2.00	24.99 6.44	1.3086	.436	
IDLE (WATT)	2.00	.74 .74	.0324	-	
TOTAL (C)	2.00	24.49 6.31	1.1480	.3813	
GET PAPER, THERMISTOR	2.00	1.47 2.44	.2812	.0937	
MONITOR CASH IS	2.00	.44 .44	.0216	-	
REMOVE TAP	2.00	1.73 1.00	.0541	.0271	
CLEAN CLAMP	2.00	.74 .74	.0324	-	
EXPERIMENT WITH C.S.	1.00	15.74 7.44	.1547	.2199	(3)
REPOSITION THERMISTOR	2.00	.44 .44	.0216	-	
END PANEL NUMBER 1				1.60	

ELEMENT	PERCENT TIME (TTL)	FOR PANEL NUMBER 2	PERCENT TIME (TTL)	FOR PANEL NUMBER 3
PUSH INTO PLACE	3.70 3.10			
ALIGN	.74 1.44			
ANCHOR	4.44 2.44			
CAP STRIP	4.44 3.04			
IDLE (CLOCK)	17.79 8.79			
IDLE (WATT)	.74 1.44			
IDLE (CLOCK)	24.15 7.39			
GET PAPER, THERMISTOR	2.79 2.74			
MONITOR CASH IS	.74 1.44			
REMOVE TAP	1.44 2.04			
EXPERIMENT WITH C.S.	15.74 7.44			
REPOSITION THERMISTOR	.74 1.44			
PERCENT TIME (TTL)				
PUSH INTO PLACE	3.70 3.10			
REMOVE CLAMP	2.00 2.00			
ANCHOR	2.15 2.44			
CASSET	.74 1.44			
C.S. HOLD DOWN	4.44 2.44			
CAP STRIP	4.44 3.04			
IDLE (CLOCK)	24.15 7.39			
IDLE (WATT)	.74 1.44			
GET PAPER, THERMISTOR	2.79 2.74			
MONITOR CASH IS	.74 1.44			
REMOVE TAP	1.44 2.04			
CLEAN CLAMP	.74 1.44			
EXPERIMENT WITH C.S.	15.74 7.44			
REPOSITION THERMISTOR	.74 1.44			

Comments: (1) 8 per panel
 (2) 3 per 2 panels
 (3) Averaged over 3 panels

Table 12-5. Field Study 12 (Air collector/internal manifold)

PAGE 1

ELEMENT	WORKERS/NO. UNITS			
	1	2	3	
RECEIVE, REMOVE SLING	1.00	1.00	0.00	1.00
ALIGN	3.00	3.00	0.00	1.00
ANCHOR	2.00	3.00	0.00	1.00
GASKET ASSY.	2.00	3.00	0.00	3.00
C.S. HOLD DOWN	0.00	1.00	0.00	1.00
CAP STRIP	0.00	6.00	0.00	1.00
IDLE (NORMAL)	7.00	0.00	0.00	1.00
IDLE (WAIT)	8.00	6.00	0.00	1.00
IDLE (CONFER)	7.00	6.00	0.00	1.00
GET PARTS, TOOLS, ETC.	8.00	0.00	0.00	1.00
REMOVE/INSTALL CLAY	1.00	1.00	0.00	1.00
PULL TAP	0.00	0.00	0.00	0.00
THERMOCOUPLES	0.00	0.00	0.00	0.00
OTHER EXPENSE	0.00	0.00	0.00	0.00
TSTART=0.000 TFINAL=.370 TIME=.010 UNITS= 1.00 WORKS= 2.00				
THE TOTAL TALLIES FOR WORKER 1 ARE 35.00 OUT OF 37.00 POSSIBLE				
THE TOTAL TALLIES FOR WORKER 2 ARE 36.00 OUT OF 37.00 POSSIBLE				
THE TOTAL TALLIES FOR WORKER 3 ARE 0.00 OUT OF 37.00 POSSIBLE				

PAGE 2

ELEMENT	WORKERS/NO. UNITS			
	1	2	3	
RECEIVE, REMOVE SLING	1.00	1.00	1.00	1.00
ALIGN	1.00	0.00	1.00	1.00
ANCHOR	1.00	0.00	1.00	1.00
GASKET ASSY.	1.00	0.00	0.00	3.00
C.S. HOLD DOWN	2.00	0.00	1.00	1.00
CAP STRIP	3.00	0.00	3.00	1.00
IDLE (NORMAL)	0.00	3.00	2.00	1.00
IDLE (WAIT)	6.00	6.00	6.00	1.00
IDLE (CONFER)	4.00	3.00	4.00	1.00
GET PARTS, TOOLS, ETC.	3.00	4.00	3.00	1.00
REMOVE/INSTALL CLAY	0.00	1.00	0.00	1.00
PULL TAP	0.00	0.00	0.00	0.00
THERMOCOUPLES	0.00	0.00	0.00	0.00
OTHER EXPENSE	0.00	0.00	0.00	0.00
TSTART=.000 TFINAL=.210 TIME=.010 UNITS= 1.00 WORKS= 3.00				
THE TOTAL TALLIES FOR WORKER 1 ARE 22.00 OUT OF 23.00 POSSIBLE				
THE TOTAL TALLIES FOR WORKER 2 ARE 22.00 OUT OF 23.00 POSSIBLE				
THE TOTAL TALLIES FOR WORKER 3 ARE 22.00 OUT OF 23.00 POSSIBLE				

PAGE 3

ELEMENT	WORKERS/NO. UNITS			
	1	2	3	
RECEIVE, REMOVE SLING	2.00	2.00	2.00	1.00
ALIGN	1.00	1.00	0.00	1.00
ANCHOR	1.00	2.00	0.00	1.00
GASKET ASSY.	0.00	0.00	0.00	0.00
C.S. HOLD DOWN	3.00	1.00	1.00	2.00
CAP STRIP	4.00	2.00	2.00	2.00
IDLE (NORMAL)	6.00	6.00	6.00	1.00
IDLE (WAIT)	3.00	3.00	3.00	1.00
IDLE (CONFER)	2.00	1.00	3.00	1.00
GET PARTS, TOOLS, ETC.	0.00	2.00	0.00	1.00
REMOVE/INSTALL CLAY	0.00	1.00	0.00	1.00
PULL TAP	1.00	1.00	1.00	1.00
THERMOCOUPLES	0.00	0.00	0.00	0.00
OTHER EXPENSE	0.00	0.00	0.00	0.00
TSTART=.220 TFINAL=.440 TIME=.010 UNITS= 1.00 WORKS= 3.00				
THE TOTAL TALLIES FOR WORKER 1 ARE 21.00 OUT OF 21.00 POSSIBLE				
THE TOTAL TALLIES FOR WORKER 2 ARE 21.00 OUT OF 21.00 POSSIBLE				
THE TOTAL TALLIES FOR WORKER 3 ARE 21.00 OUT OF 21.00 POSSIBLE				

Table 12-5 (con't)

PAGE 4

ELEMENT	WORKERS/NO. UNITS			
	1	2	3	
RECEIVE, REMOVE FLNG	3.00	3.00	3.00	1.00
ALIGN	0.00	1.00	0.00	1.00
ANCHOR	2.00	1.00	0.00	1.00
GASKET ASSY.	3.00	1.00	0.00	4.00
C.S. HOLD DOWN	0.00	0.00	0.00	1.00
CAP STRIP	4.00	0.00	4.00	1.00
IDLE (NORMAL)	2.00	2.00	4.00	1.00
IDLE (WAIT)	5.00	5.00	5.00	1.00
IDLE (CONFER)	1.00	2.00	1.00	1.00
GET PARTS, TOOLS, ETC.	5.00	4.00	5.00	1.00
REMOVE/INSTALL CLEAT	0.00	1.00	0.00	1.00
PULL TAPE	2.00	1.00	1.00	1.00
THERMOCOUPLES	2.00	5.00	2.00	1.00
OTHER FOREIGN	4.00	4.00	4.00	1.00
TSTART= .150 TFINAL= .520 TIME= .010 UNITS= 1.00 WRS= 3.00				
THE TOTAL TALLIES FOR WORKER 1 ARE 34.00 OUT OF 37.00 POSSIBLE				
THE TOTAL TALLIES FOR WORKER 2 ARE 34.00 OUT OF 37.00 POSSIBLE				
THE TOTAL TALLIES FOR WORKER 3 ARE 35.00 OUT OF 37.00 POSSIBLE				

PAGE 5

ELEMENT	WORKERS/NO. UNITS			
	1	2	3	
RECEIVE, REMOVE FLNG	1.00	1.00	1.00	1.00
ALIGN	0.00	1.00	4.00	1.00
ANCHOR	1.00	5.00	0.00	1.00
GASKET ASSY.	1.00	1.00	1.00	3.00
C.S. HOLD DOWN	1.00	0.00	0.00	1.00
CAP STRIP	2.00	0.00	2.00	2.00
IDLE (NORMAL)	15.00	4.00	12.00	1.00
IDLE (WAIT)	2.00	2.00	0.00	1.00
IDLE (CONFER)	0.00	0.00	0.00	1.00
GET PARTS, TOOLS, ETC.	2.00	4.00	4.00	2.00
REMOVE/INSTALL CLEAT	0.00	2.00	0.00	1.00
PULL TAPE	1.00	0.00	0.00	1.00
THERMOCOUPLES	0.00	0.00	0.00	0.00
OTHER FOREIGN	0.00	0.00	0.00	0.00
TSTART= 0.000 TFINAL= .270 TIME= .010 UNITS= 1.00 WRS= 3.00				
THE TOTAL TALLIES FOR WORKER 1 ARE 27.00 OUT OF 27.00 POSSIBLE				
THE TOTAL TALLIES FOR WORKER 2 ARE 27.00 OUT OF 27.00 POSSIBLE				
THE TOTAL TALLIES FOR WORKER 3 ARE 27.00 OUT OF 27.00 POSSIBLE				

PAGE 6

ELEMENT	WORKERS/NO. UNITS			
	1	2	3	
RECEIVE, REMOVE FLNG	2.00	3.00	2.00	1.00
ALIGN	2.00	3.00	2.00	1.00
ANCHOR	1.00	1.00	0.00	1.00
GASKET ASSY.	0.00	0.00	0.00	0.00
C.S. HOLD DOWN	2.00	1.00	0.00	1.00
CAP STRIP	0.00	1.00	0.00	1.00
IDLE (NORMAL)	2.00	4.00	4.00	1.00
IDLE (WAIT)	2.00	1.00	1.00	1.00
IDLE (CONFER)	3.00	3.00	0.00	1.00
GET PARTS, TOOLS, ETC.	3.00	4.00	1.00	1.00
REMOVE/INSTALL CLEAT	0.00	4.00	0.00	1.00
PULL TAPE	2.00	0.00	0.00	1.00
THERMOCOUPLES	0.00	0.00	0.00	0.00
OTHER FOREIGN	6.00	6.00	2.00	1.00
TSTART= .290 TFINAL= .900 TIME= .010 UNITS= 1.00 WRS= 2.00				
THE TOTAL TALLIES FOR WORKER 1 ARE 27.00 OUT OF 30.00 POSSIBLE				
THE TOTAL TALLIES FOR WORKER 2 ARE 31.00 OUT OF 30.00 POSSIBLE				
THE TOTAL TALLIES FOR WORKER 3 ARE 31.00 OUT OF 30.00 POSSIBLE				

Table 12-5 (con't)

PAGE 7

ELEMENT	WORKERS (NO. UNITS)			
	1	2	3	
RECEIVE, REMOVE SLING	2.00	2.00	2.00	1.00
ALIGN	1.00	2.00	1.00	1.00
ANCHOR	1.00	1.00	1.00	1.00
GASKET ASSY.	2.00	0.00	0.00	2.00
C.S. HOLD DOWN	0.00	0.00	0.00	1.00
CAP STRIP	2.00	0.00	0.00	1.00
IDLE (NORMAL)	5.00	11.00	10.00	1.00
IDLE (WAIT)	1.00	1.00	1.00	1.00
IDLE (CONFER)	0.00	0.00	0.00	1.00
GET PARTS, TOOLS, ETC.	0.00	2.00	0.00	1.00
REMOVE/INSTALL CLEAT	0.00	1.00	0.00	1.00
PULL TAP	0.00	2.00	0.00	0.00
THERMOCOUPLES	0.00	0.00	0.00	0.00
OTHER FOREIGN	0.00	0.00	0.00	0.00
1 START, 0.10 FINISH = .200 TIME, .010 UNITS, 1.00 WORKER, 3.00				

THE TOTAL TALLIES FOR WORKER 1 ARE 10.00 OUT OF 27.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 2 ARE 10.00 OUT OF 27.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 3 ARE 10.00 OUT OF 27.00 POSSIBLE

PAGE 8

ELEMENT	WORKERS (NO. UNITS)			
	1	2	3	
RECEIVE, REMOVE SLING	2.00	2.00	2.00	1.00
ALIGN	1.00	0.00	2.00	1.00
ANCHOR	1.00	2.00	0.00	1.00
GASKET ASSY.	0.00	0.00	0.00	0.00
C.S. HOLD DOWN	1.00	1.00	1.00	2.00
CAP STRIP	0.00	3.00	7.00	2.00
IDLE (NORMAL)	9.00	5.00	5.00	1.00
IDLE (WAIT)	1.00	1.00	1.00	1.00
IDLE (CONFER)	3.00	2.00	2.00	1.00
GET PARTS, TOOLS, ETC.	1.00	2.00	0.00	1.00
REMOVE/INSTALL CLEAT	0.00	2.00	0.00	1.00
PULL TAP	1.00	0.00	0.00	1.00
THERMOCOUPLES	0.00	0.00	0.00	0.00
OTHER FOREIGN	0.00	0.00	0.00	0.00
1 START, 0.10 FINISH = .210 TIME, .010 UNITS, 1.00 WORKER, 3.00				

THE TOTAL TALLIES FOR WORKER 1 ARE 20.00 OUT OF 31.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 2 ARE 20.00 OUT OF 31.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 3 ARE 20.00 OUT OF 31.00 POSSIBLE

PAGE 9

ELEMENT	WORKERS (NO. UNITS)			
	1	2	3	
RECEIVE, REMOVE SLING	2.00	2.00	2.00	1.00
ALIGN	2.00	1.00	2.00	1.00
ANCHOR	2.00	2.00	0.00	1.00
GASKET ASSY.	1.00	0.00	0.00	2.00
C.S. HOLD DOWN	2.00	2.00	0.00	2.00
CAP STRIP	1.00	2.00	6.00	2.00
IDLE (NORMAL)	0.00	0.00	12.00	1.00
IDLE (WAIT)	4.00	2.00	4.00	1.00
IDLE (CONFER)	2.00	2.00	2.00	1.00
GET PARTS, TOOLS, ETC.	0.00	0.00	2.00	1.00
REMOVE/INSTALL CLEAT	0.00	0.00	0.00	1.00
PULL TAP	1.00	0.00	0.00	1.00
THERMOCOUPLES	0.00	0.00	0.00	0.00
OTHER FOREIGN	0.00	0.00	0.00	0.00
1 START, 0.10 FINISH = .240 TIME, .010 UNITS, 1.00 WORKER, 3.00				

THE TOTAL TALLIES FOR WORKER 1 ARE 27.00 OUT OF 33.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 2 ARE 27.00 OUT OF 33.00 POSSIBLE
 THE TOTAL TALLIES FOR WORKER 3 ARE 27.00 OUT OF 33.00 POSSIBLE

Table 12-6. Field Study 12 (Air collector/internal manifold)
Installation of east array - crane moves collectors
up as the installation progresses

ELEMENT	NO. COMPLETED	PERCENT TIME (TOT)	HOURS	MAN HR PER COLLECTOR	COMMENTS
RECEIVE, BENCH SLING	9.00	7.77	2.01	.5448	.0605
ALIGN	9.00	4.94	1.41	.3392	.0371
ANCHOR	9.00	6.77	1.74	.4009	.0445
GASKET ASSY.	12.00	7.35	1.14	.1645	.0142 (1)
C.S. HOLD DOWN	12.00	2.49	1.17	.1747	.0202 (1)
CAP STRIP	12.00	11.59	2.40	.6320	.1015 (1)
IDLE (INTERNAL)	9.00	23.17	9.17	1.6740	.1804
IDLE (EXITS)	9.00	11.04	2.42	.8326	.0925
IDLE (CONCRETE)	9.00	8.40	2.12	.6167	.0685
GET PARTS, TOOLS, ETC.	9.00	11.00	2.33	.7709	.0857
REMOVE OLD STILL CLIP	9.00	2.44	1.20	.1850	.0206
PULL TAG	6.00	1.74	.90	.1233	.0206
THRESHOLD JOINT	1.00	1.33	.44	.0825	-
OTHER PEOPLE	2.00	6.40	1.50	.3289	-
FOR CREL H. WORK					.7569

Comments: (1) 5 per 2 panels (2) 3 per 2 panels

ELEMENT	PERCENT TIME (TOT)	ELEMENT	PERCENT TIME (TOT)	ELEMENT	PERCENT TIME (TOT)
RECEIVE, BENCH SLING	7.90	3.33	RECEIVE, BENCH SLING	9.47	3.89
ALIGN	2.00	2.74	ALIGN	4.95	2.00
ANCHOR	4.24	3.76	ANCHOR	2.10	1.37
GASKET ASSY.	4.17	2.53	GASKET ASSY.	.50	.07
C.S. HOLD DOWN	3.33	2.77	C.S. HOLD DOWN	1.49	1.67
CAP STRIP	9.17	9.44	CAP STRIP	19.20	5.60
IDLE (INTERNAL)	24.17	5.47	IDLE (INTERNAL)	23.70	4.30
IDLE (EXITS)	12.02	4.94	IDLE (EXITS)	10.40	4.91
IDLE (CONCRETE)	9.17	3.44	IDLE (CONCRETE)	9.20	4.17
GET PARTS, TOOLS, ETC.	9.17	3.44	GET PARTS, TOOLS, ETC.	7.00	1.77
PULL TAG	3.92	2.97	PULL TAG	.49	1.37
THRESHOLD JOINT	.44	1.17	THRESHOLD JOINT	.49	1.37
OTHER PEOPLE	2.74	2.74	OTHER PEOPLE	3.15	2.40