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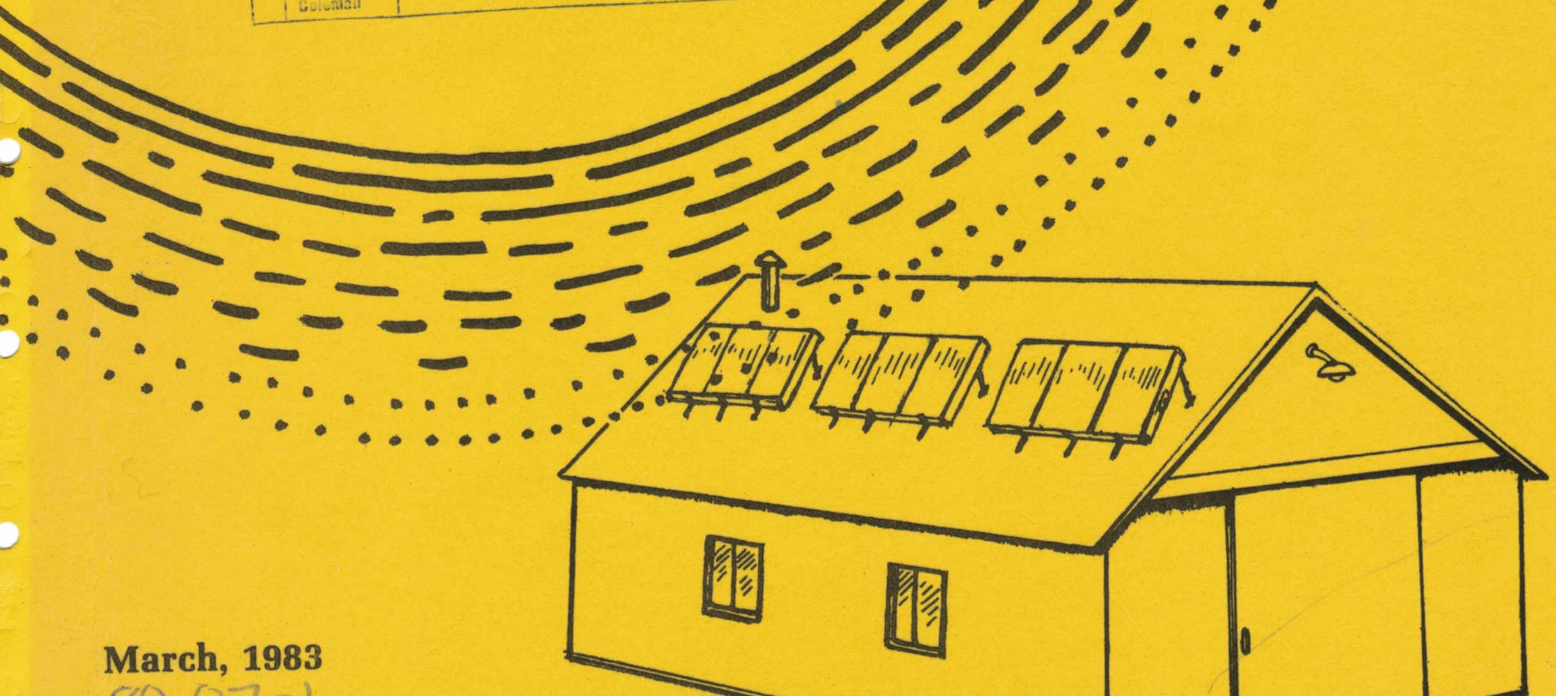
Solar Heated Maintenance Building at Chickasha



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16. ABSTRACT In December, 1980, a solar heating system was installed at the Oklahoma Department of Transportation Maintenance Building in Chickasha, Oklahoma. The system is based on an air type flat plate solar collector with an aluminum absorber plate which absorbs and transfers the sun's radiation into heat. The system has no capacity for the storage of this heat so it is lost if not used immediately. The heat is transferred to the interior of the building much as it would be in a conventional furnace system. The air is circulated from the interior of the building across the absorber plates, where it is heated, and back into the building. Conventional duct work and air blowers are used for this process. Because of the simplicity of the design it is relatively inexpensive when compared to other solar systems. The objective of this installation is to determine if such a system is an economical method for supplementing the heating for this and other small buildings maintained by the State.

The solar collectors are saving about 45 thousand cu. ft. of natural gas every year. This savings converts to about $194 a year at the present (1982) price of natural gas. The system should pay for itself in 10 to 15 years.

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SOLAR HEATED MAINTENANCE BUILDING AT CHICKASHA

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EXECUTIVE SUMMARY

In December, 1980 a solar heating system was installed at the Oklahoma Department of Transportation (ODOT) Maintenance Building in Chickasha, Oklahoma. The system consists of three independent solar units. Each unit consists of an air type flat plate solar collector with an aluminum absorber plate which absorbs the sun's radiation and heats the air flowing over its surface. The heat is transferred to the interior of the building much like it would be in a conventional furnace system. The air is circulated from the interior of the building across the collector plates, where it is heated, and back into the building. Conventional duct work and air blowers are used for this process.

The system has no capacity for the storage of heat so it is lost if not used immediately. Because of the simplicity of the design of this system it is relatively inexpensive when compared to other solar systems. The entire system was purchased in 1980 for $3,286. At 1982 prices the same installation would cost $6,000.

The objective of this project is to determine if such a system is a viable method for supplementing the heating requirement for the district maintenance buildings, rest area buildings, and other small buildings maintained by the State. This determination was made by calculating the amount of fuel conserved by this installation. The savings were primarily dependent on the heating needs of the building and heat provided by the system.

The solar collectors are saving an average of 45 thousand cubic feet of natural gas per year. This converts to about a $194 per year savings at the present (1982) price of natural gas. The system has been maintenance free since its installation. Future monetary savings are hard to predict because of the uncertain price of natural gas, but the system should pay for itself in 10 to 15 years.

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INTRODUCTION

The Oklahoma Department of Transportation (ODOT) maintains numerous buildings across the state which are costing more and more each year to heat and cool. With the increasing cost of energy and the diminishing supplies of fossil fuels, alternate energy sources are becoming an economic reality. One such energy source is the sun.

In December of 1980 a solar heating system was installed at the ODOT maintenance building in Chickasha, Oklahoma. The system consists of three independent solar units. Each unit consists of an air type flat plate solar collector with an aluminum absorber plate which absorbs the sun's radiation and heats the air flowing over its surface. The heat is transferred to the interior of the building much as it would be in a conventional furnace system. The air is circulated from the interior of the building across the absorber plates, where it is heated, and back into the building. Conventional duct work and air blowers are used for this process. The system has no capacity for the storage of this heat so it is lost if not used immediately. Because of the simplicity of the design, this system is relatively inexpensive when compared to other solar systems. The entire system was purchased from Oklahoma Sun Systems, Inc. in 1980 for $3,286. At 1982 prices the same installation would cost $6,000.

The objective of this project is to determine if such a system is a practical method for supplementing the heating requirement for the district maintenance buildings, rest areas, and other small buildings maintained by the state. This determination was made by calculating the amount of fuel conserved by this installation. The savings were dependent primarily on the heating needs of the building and heat provided by the system. By studying the factors which affect these variables, reasonable recommendations can be made as to the practicality of similar installations in other buildings.

The calculated fuel reduction at the building is approximately 45 thousand cu. ft. (approximately 16 percent) of natural gas for an average year. At 1982 prices this results in a savings of $194.00 for one year. If the price of natural gas remains the same, it will take approximately 17 years to recapture the initial investment. If the price of natural gas is inflated at a rate of 10 percent a year, the payback period will be reduced to 11 years. If the system were installed at the present day price (1982) of $6,000, it would take 15 years to pay for itself, using a 10 percent inflation rate for the price of natural gas. From these figures it does not appear that such a system is a realistic alternative for heating this type of building. However, it may still be a economic alternative for other small buildings that have less heat loss.

MAINTENANCE BUILDING

Description

The maintenance building at Chickasha is a typical ODOT maintenance building. The structure is divided into two parts, a shop area and an office area. The shop area is 45 ft. long by 30 ft. wide by 15 ft. high. Including the loft area over the offices there are 23,000 cu. ft. of space to heat. The office area is 30 ft. wide by 14 ft. long by 8 ft. high for a total of 3,360 cu. ft. of space.

Sources of Gas Usage

Natural gas usage in the shop occurs in three areas. There is a Modine Model No. PA200A space heater which, prior to the installation of the solar collectors, supplied virtually all of the heating. This unit has an input rating of 20,000 BTU/hr and an output of 16,000 BTU/hr. There is a homemade hand warmer which was constructed years ago. This contraption consists of two gas jets fed by a 1/4 in. gas line. These jets feed into a series of 5 in diameter cast iron pipes welded together at 90 degree angles. As the flame is fed into the pipes they become hot and radiate heat. A picture of this device and the rest of the system can be seen in Appendix B. The third location is a water heater manufactured by State Stove and Mfg. Co. Inc. The model number is V130T. It has a 30 gal. capacity, with an input rating of 46,000 BTU/hr and a recovery of 38.7 gal. per hour.

Natural gas is used in the office area by two small gas space heaters, one for each office.

Considering only the ratio of the volume of the shop to that of the office, the shop would require 87 percent of the total heating need of the maintenance building. However, the shop exhibits much more heat loss than the office. The shop has two major sources of heat loss. There is a double sliding door at the west end of the shop. Each of these doors is 6 ft. wide by 14 ft. high and they provide a total opening of 168 sq. ft. There is also a standard 3.5 ft. by 6.5 ft. door on the north side. The office has only one outside door located at the east end of the building. Considering these factors it can be rationalized that the shop accounts for more than 87 percent of the total heating needs.

SOLAR HEATING SYSTEM

Description

There are three solar collectors mounted on the south side of the roof at the Chickasha maintenance building. These solar collectors utilize a flat, thin louvered aluminum plate coated on the upper side with black paint to absorb radiation from the sun. The system utilizes scattered radiation as well as direct radiation so it remains functional on cloudy days. The heat produced at the collector plates is transferred to the interior of the building by circulated air, much in the same manner as a conventional furnace system. This system does not have the capability of storing heat so it can only provide heat to the building during the daylight hours. This makes this system much cheaper to purchase, install, and maintain than the more conventional solar systems which utilize a fluid to transfer and store heat.

Installation

The system was installed by the supplier in December, 1980. Brackets bolted to the roof of the maintenance building were designed to hold the collectors tilted relative to the horizon. The optimum angle of tilt depends on the latitude of the installation. Here in Oklahoma the optimum angle is approximately 45 degrees. Once the collectors were mounted the necessary duct work and fans were connected. Because of the simplicity of the design, the entire installation was completed in one day.

Design and Operation

The design of the collector is quite simple. It is an aluminum box 40 in. wide by 136 in. long and approximately 4 in. deep. The complete unit weighs 68 lbs. The 37.78 sq. ft. transparent surface is 0.035 in. thick double glazed acrylic finished fiberglass. The absorber plate is 0.019 in. thick louvered aluminum, coated on the top side with black paint. The collector is insulated with R-6 value Thermax.

Fans are located inside the building on the hot air side of the collectors. Each fan has a 500 cu. ft. per minute rating. When the collectors are operating at maximum capacity they each have the potential of providing 9700 BTU/hr.

Sun System collectors are controlled by two thermostats. One thermostat is located in the building and determines the need for heat. The other thermostat is located in the collector. This thermostat turns the unit on and off depending on the temperature of the air in the heating box. The system will not turn on unless the temperature in the collector is at least 90°F. When the temperature drops below 70°F the unit automatically shuts off, thus preventing cold air from being circulated to the building.

At the Chickasha maintenance building two solar collectors supply heat for the shop and one for the office. The two which feed the shop have one set of thermostats which are connected to control both collectors. The third collector is independent of the other two, with its own set of thermostats.

Each solar collector has its own duct system. The duct's are flexible aluminum foil backed, fiberglass insulated, tubing with a metal coil insert. In the shop, each collector feeds its hot air through a 6 in. duct down the interior south wall and into the shop. These two ducts are approximately 10 ft. apart. The cold air returns for these collectors are suspended from the ceiling approximately 10 ft. apart at the center of the room. In the office area, the intake is located in the hallway between the two offices. The hot air duct is 6 in. in diameter and feeds into a junction above the office area. Two 4 in. ducts leave the junction with each feeding into an office.

ANALYSIS

General

In the two years since the collector system was installed it has operated flawlessly. Personnel who work in the building have indicated that the collector which supplies heat to the office provides virtually all the heat they need between the hours of 9:30 a.m. and 4:30 p.m. However, in the shop, where the majority of heat is needed, the collectors do not appear to be very effective.

Data Base

A historical profile of the natural gas consumption at the maintenance building was compiled. Included in this profile are gas usage data and the number of degree days for the time period between June of 1976 and June of 1982. The gas usage statistics were taken from the monthly gas bills for the maintenance building, and the number of degree days was obtained from monthly reports published by the National Oceanic and Atmosphere Administration (NOAA).

A degree day can be referenced to either the heating or cooling season and is an indication of the heating or cooling requirements of a building. A degree day when referenced to the heating season is the number of degrees Fahrenheit that the average daily temperature is below $65^{O}F$. For example a day that has an average daily temperature of $63^{O}F$ is said to have two degree days. Since gas usage information is only available by billing period, the degree days were totaled for all the days in a given billing period and were recorded as degree days per month.

Analysis

The heating requirement of the building is dependent on the outside temperature. Prior to the installation of the solar collectors all of this heat was provided by natural gas. An evaluation was made to determine how the relationship between natural gas usage and degree days was affected by the installation of the solar collectors. This was done through statistical linear regression models relating the dependency of gas usage to degree days for the period prior to and since the installation of the solar system. These models developed linear equations which can be used to estimate what the gas usage will be for a given month if the degree days for that month are known. By using these two equations the amount of natural gas which is being conserved by the solar system is easily determined. The process of developing these equations is explained in Appendix A.

NOAA has calculated the normal degree days for each month of the year. These values were taken from the averages of the winters of 1941-1970. By using these data with the linear regression equations, an estimate was made of the gas usage for an average winter, with and without the solar system. By subtraction the amount of natural gas being conserved can be estimated. This value is 45 thousand cu. ft. of natural gas a year. This is about a 16 percent reduction in gas usage. At 1982 prices this would amount to a saving on the utility bill of approximately $194.00 per year.

CONCLUSIONS

The solar collectors are providing some supplemental heat to the maintenance building. The personnel who work at the building indicate that on a sunny day, between the hours of 9:00 a.m. and 4:30 p.m., the collectors supply virtually all of the heat for the office. The majority of the heating demand, however, is for the shop. The shop is 87 percent of the total volume of the maintenance building. When the large sliding doors are opened, which is frequently, virtually all of the heat in the area is lost. For this reason the solar collectors probably are not as effective as they would be in a well insulated building operated only during daylight hours.

The conclusions which can be made from this evaluation are as follows. The solar collectors are saving 45 thousand cu. ft. of natural gas every year. The system has been maintenance free since its installation. Any maintenance which might need to be performed in the future should be minimal and probably confined to the fans or thermostats since they are the only mechanical components.

The monetary savings which will be realized from this system are hard to predict because of the uncertainty of the price of natural gas. If such a system were installed in a building with less heat loss, and if the cost of natural gas continues to rise the system may have a shorter payback period. The results of this evaluation however, indicate that the payback period of any similar installation will be quite long, probably 10 to 15 years.

This evaluation indicates that this system has not yet proven itself to be an economic supplement to the present heating systems of other state buildings.

RECOMMENDATIONS

The present installation should continue to be monitored to see if its effectiveness changes with the accumulation of more data. A bigger data base might significantly effect the statistical evaluation of this system.

A similar system could be installed in a smaller building with less heat loss, so a comparison of two different types of installations can be made.

Consideration should be given to installing the cold air returns at a lower level. It seems logical that if the colder air at the lower levels of the building were circulated through the collectors, a greater efficiency could be achieved. This change should be made and monitored at the Chickasha building.

APPENDIX A

Statistical Evaluation

The first step in the statistical analysis was to modify the data to ensure statistical validity. Since each billing period is not equal in size both the gas used per billing period and the number of degree days per billing period were divided by the number of days in the billing period to obtain average gas usage and average degree days per day per billing period. Bar graphs representing these values are illustrated in Figures A-1 and A-2. The graphs are separated at December of 1980, the time when the collectors were installed.

Referring to Figures A-1 and A-2, it can be seen that natural gas is used during every month of the year, even though during three or four months of the year no space heating was required. These are the months that have zero degree days. The gas used during these months supplies the hot water heater and any pilot lights which may be burning. Since this energy consumption is independent of the energy required for heating the building, the natural gas information was modified prior to determining the relationship of gas usage and degree days.

The quantity of natural gas which is being used for purposes other than heating of the building can be determined from the months which have zero degree days. This amount fluctuates probably because the demand for hot water varies. Because of this fluctuation an exact quantity of baseline usage cannot be determined, so an average was computed. This average was taken from the gas used per day by billing period for those months with zero degree days and was found to be an average of 7.4 cu. ft. per day.

By subtracting the baseline usage from gas usage per day for those months which have degree days, the quantity of gas used per day per month for the heating of the maintenance building was determined.

The next step of this analysis was to determine the dependency of gas usage on degree days. Since the conditions for this dependency changed with the installation of the solar collectors, the periods prior to and after their installation were treated as separate data bases. Linear regression models were performed on these two periods using degree days per day per month as the independent variable and gas used per day per month as the dependent variable.

The linear regression models for both periods indicate that there is a strong linear dependency of gas usage on degree days. The coefficients of determination (R^2) are very high, both above 0.9. The model used in the analysis is of the form A=BX+C, where A is the predicted value of the dependent variable, B is the estimate of the slope, X is the value of the independent variable, and C is the intercept.

For the period prior to the installation of the solar collectors, the linear equation takes the form:

$$P_B = (0.073)\ X_B + 0.048$$

P_B = Predicted gas usage per day, per month, for the period prior to the installation of the solar collectors.

X = Degree days per day, per month, for the period prior to the installation of the solar collectors.

For the period after the installation of the solar collectors the linear equation takes the form:

$$P_A = (0.070)\ X_A - 0.077$$

P_A = Predicted gas usage per day, per month for the period after the installation of the solar collectors.

X = Degree days per day, per month, for the period after the installation of the solar collectors.

Having these two equations it is possible to predict the gas usage at the maintenance building, with or without the solar collectors, with only degree day data. Since the benefit provided by the solar collectors is dependent on sunshine and not degree days, the benefit contributed by the collectors should be almost constant regardless of the value of the degree days. This relationship can be observed by noticing the similarity in the slopes of the prediction equations. It is also illustrated in Figure A-3, where predicted gas usages using both equations are plotted against degree days per day over the range from 0 to 100. The shaded area of the graph shows the difference in the equations. This represents the volume of natural gas that is being saved by the solar collectors. An equation to predict these values can be determined by subtracting the slope and intercept of the "after solar collector" prediction equation from the "before solar collector" prediction equation. This equation will be referred to as the savings equation and is calculated to be:

$$P_S = (0.003)\ X + 0.126$$

P_S = Predicted volume of natural gas saved per day, per month

X = Degree Days per day per month

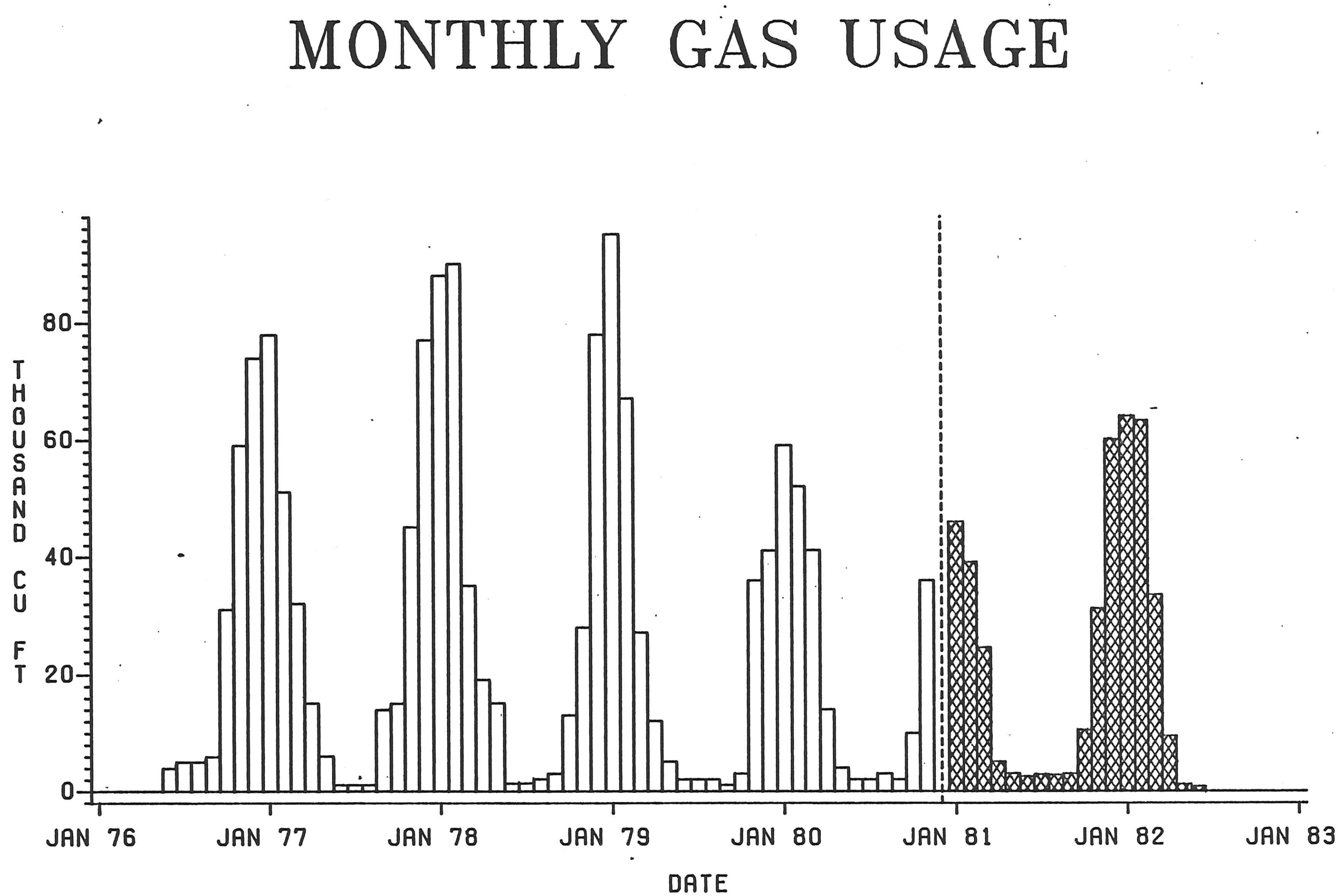

Figure A-1. Before and After Solar System Installation

MONTHLY DEGREE DAYS

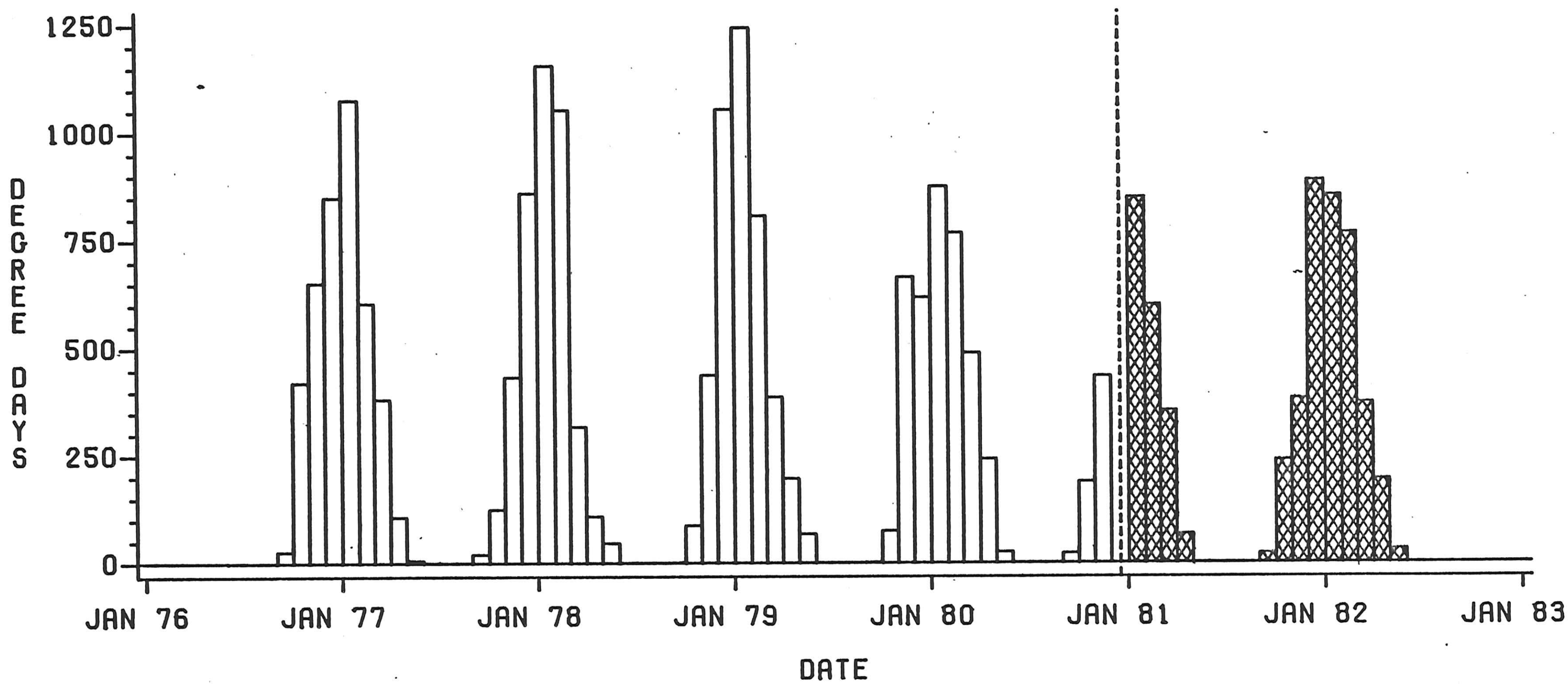

Figure A–2. Before and After Solar System Installation

COMPARISON OF EQUATIONS

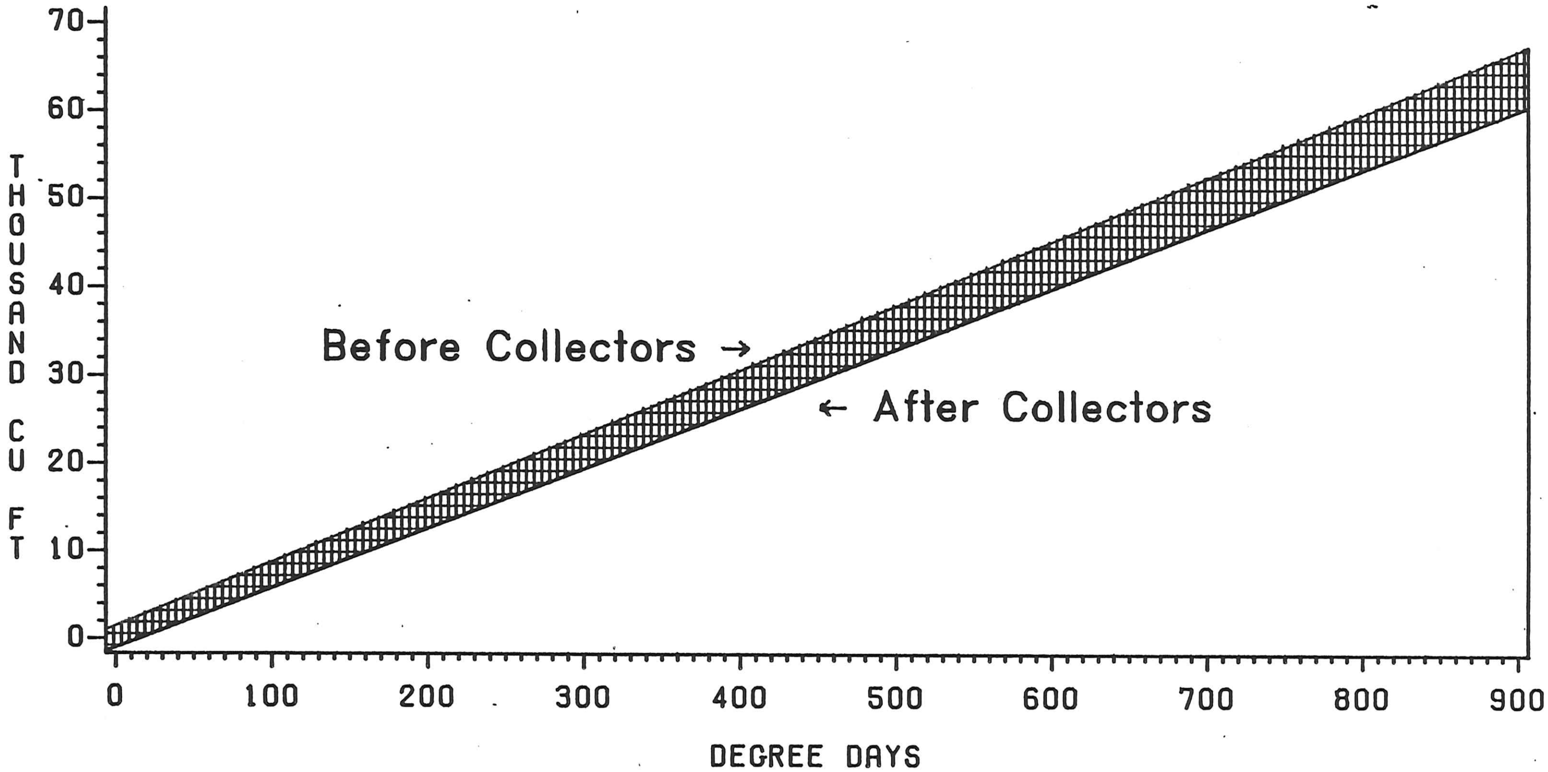

Figure A–3. Filled Area Shows Gas Savings

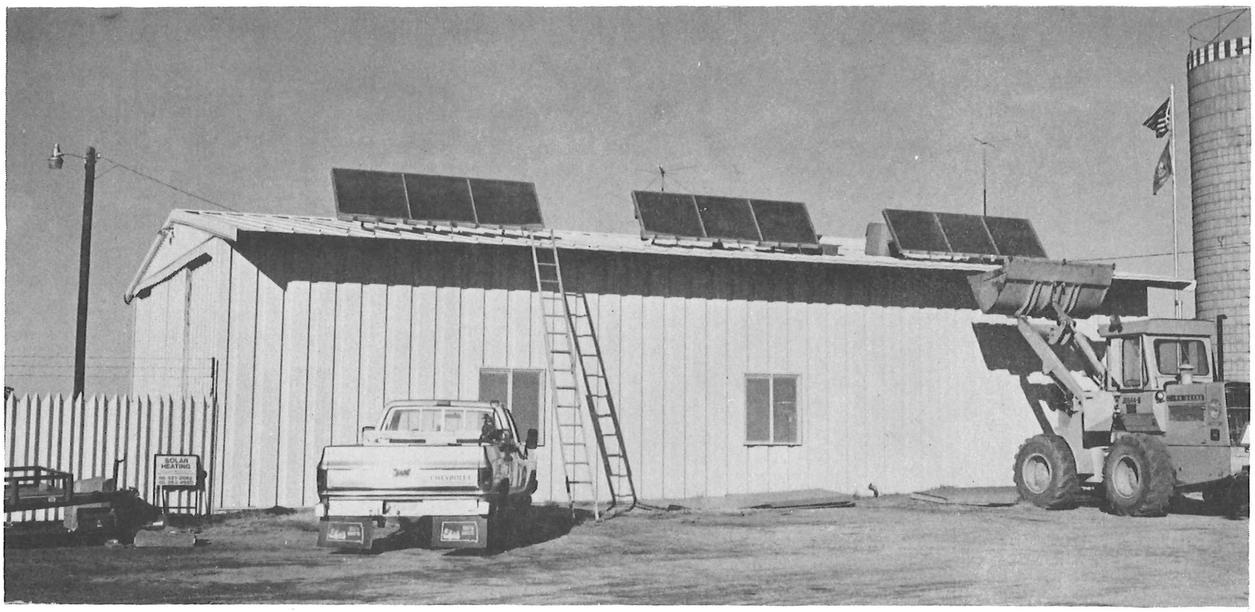

Figure B-1. Maintenance Building with collectors.

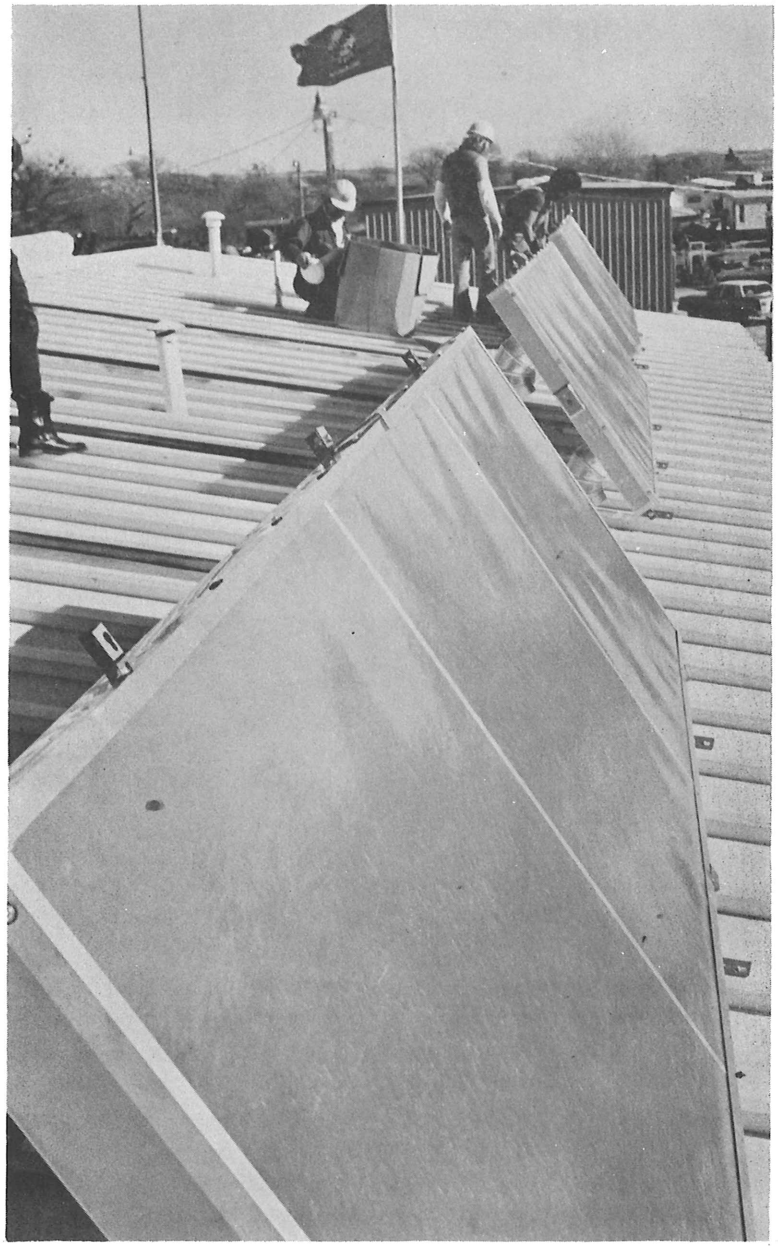

Figure B-2. Double glazed acrylic finished fiberglass. Top of collector.

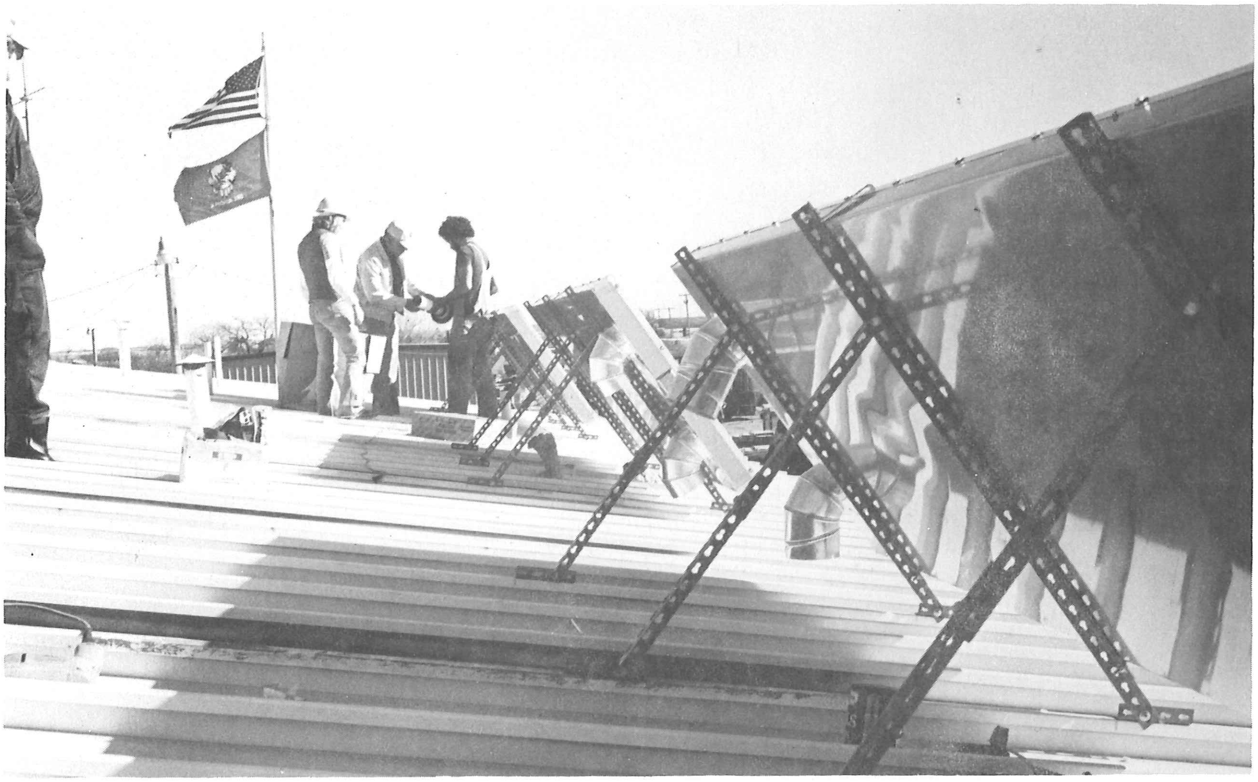

Figure B-3. Mounting brackets bolted to roof holding collectors at 45° angle.

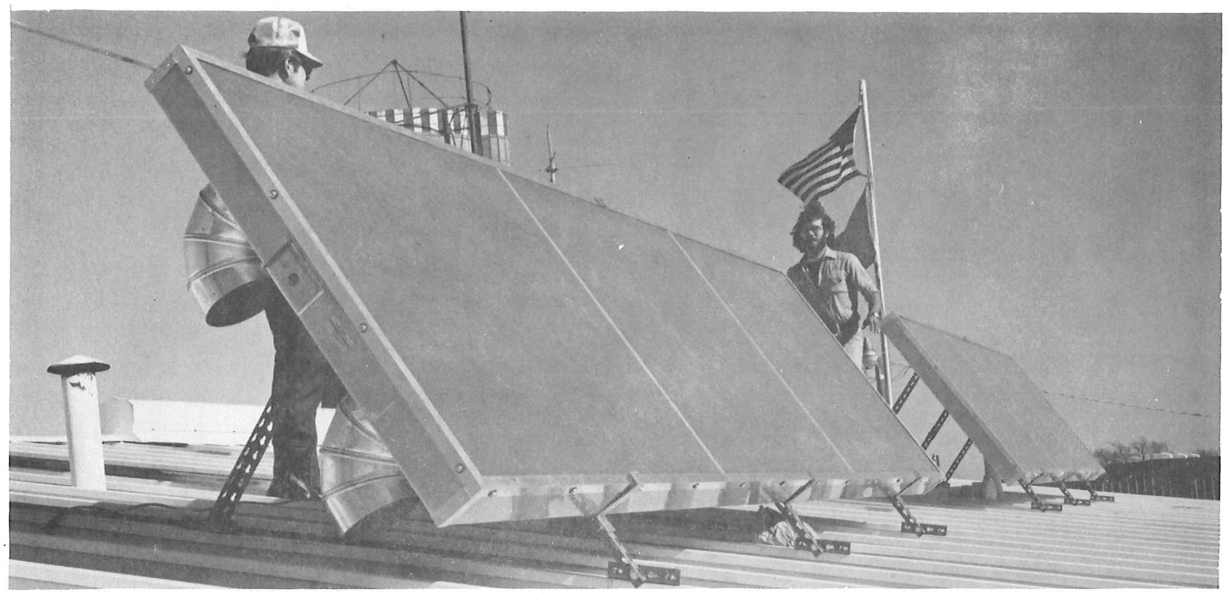

Figure B-4. Front view of collectors bolted to roof prior to connecting duct work.

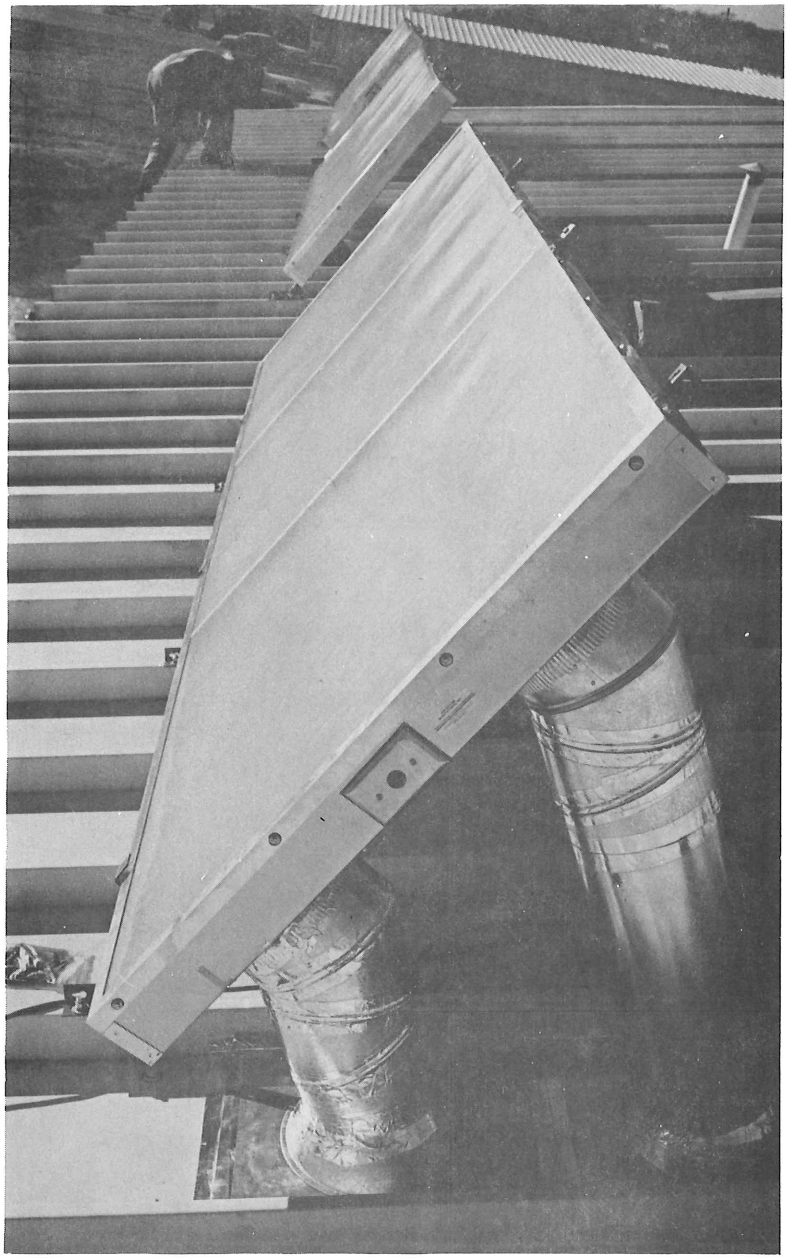

Figure B-5. Air ducts connecting collector to building interior.

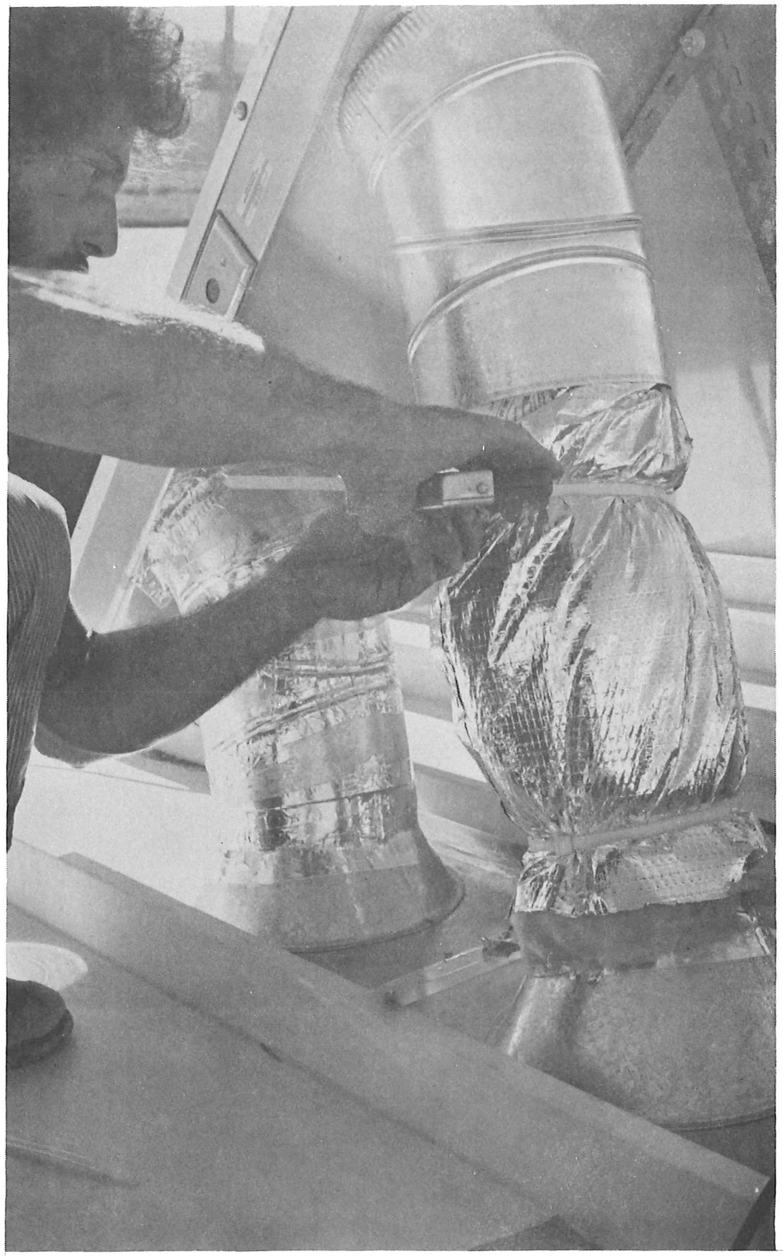

Figure B-6. Foil backed insulation put around air ducts.

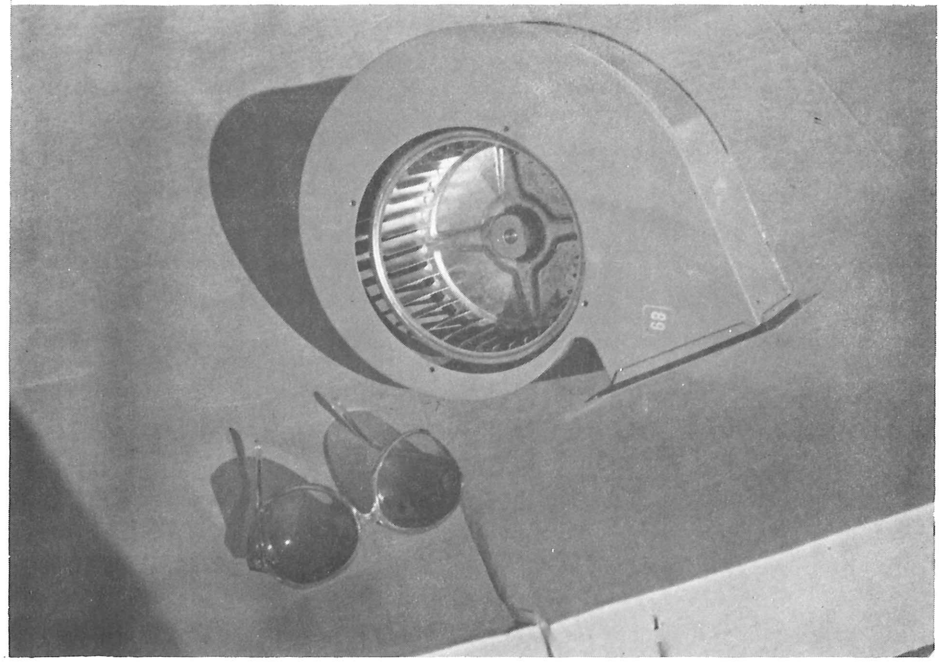

Figure B-7. Small fan used to circulate air.

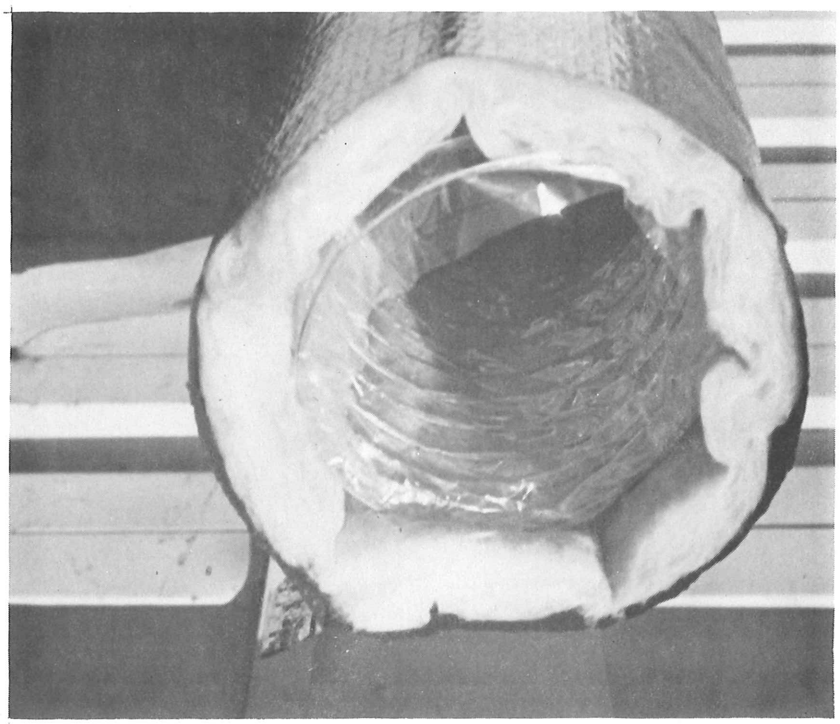

Figure B-8. Coil supports duct material used in building.

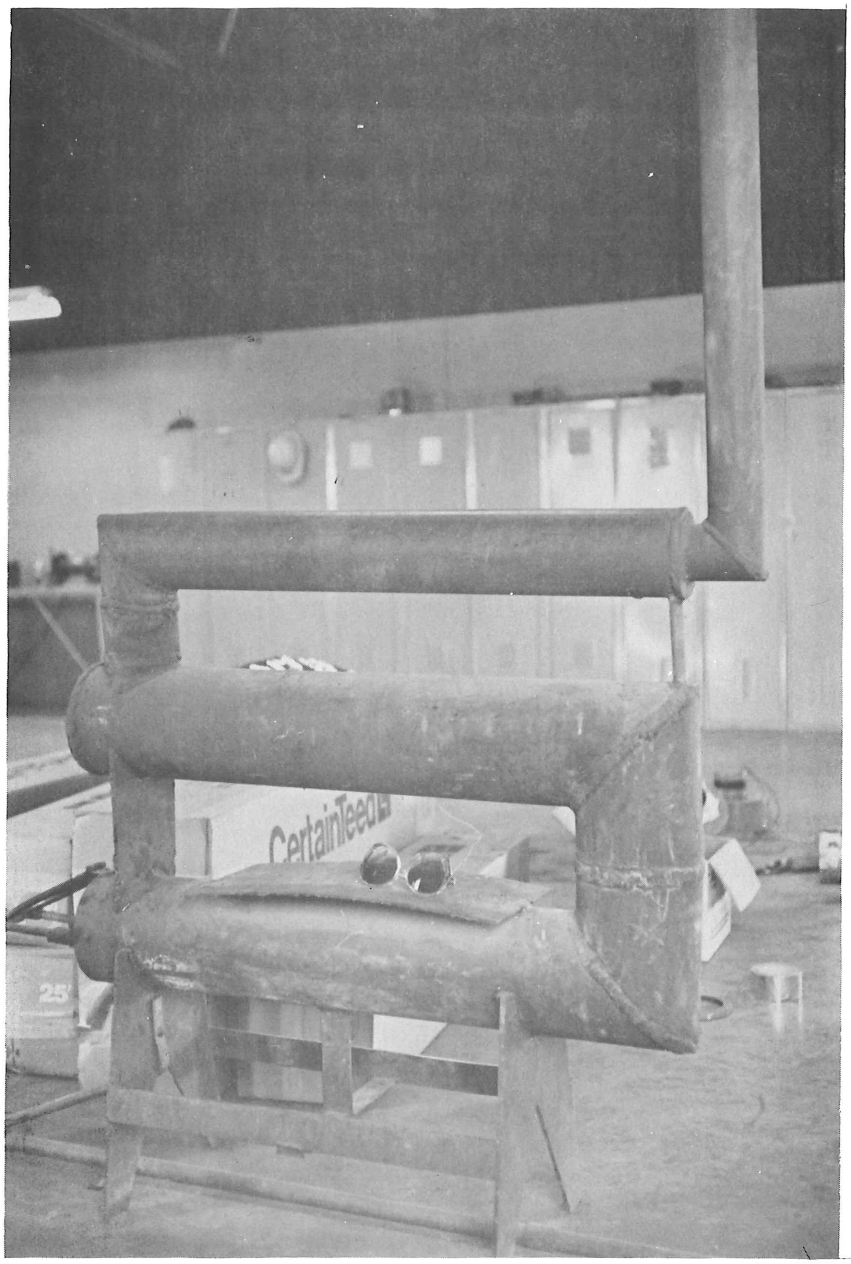

Figure B-9. Homemade gas heated handwarmer.