1977

Solar Energy for Supplemental Heating of Livestock Buildings

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SOLAR ENERGY FOR SUPPLEMENTAL HEATING OF LIVESTOCK BUILDINGS

BY

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A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science, Major in Agricultural
Engineering, South Dakota
State University

1977

SOLAR ENERGY FOR SUPPLEMENTAL

HEATING OF LIVESTOCK BUILDINGS

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Advisor Date

Head of Major Department Date

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to the entire Agricultural Engineering staff for their assistance and cooperation during this research. Dr. Dennis L. Moe, department head, is thanked for his assistance during the preparation of the manuscript. Appreciation is extended to Dr. W. Lee Tucker, Experiment Station Statistician, for his technical help with the statistical analysis. Karen Breeschoten is thanked for typing the manuscript.

Sincere appreciation is extended to Mr. William Witmer, Mr. Dave Goos, and the entire GTA staff at Ellis, South Dakota, for the use of their research facilities and for cooperation throughout the study.

Special appreciation is extended to Dr. Mylo A. Hellickson, major and thesis advisor, for his professional and personal advice and guidance throughout this study.

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INTRODUCTION

Solar heating appears to be a promising substitute for conventional fuels, often fossil fuels, that are required to provide supplemental heat at relatively low temperatures to livestock confinement buildings. The rising costs of conventional energy sources have increased the production costs and are of growing concern to farmers utilizing livestock confinement facilities. Peterson and Hellickson (38) indicated that current energy shortages coupled with problems of priority use and energy distribution have increased the need for developing other energy sources for agriculture.

Selection of heating methods for enclosed confinement buildings should result in a system that meets the demand at minimum cost while satisfying certain levels of reliability, size, and environmental quality. During winter months, when heating demand in livestock confinement buildings is highest, the sun's path is low and the south side of an east-west oriented building receives a large quantity of solar radiation. The substitution of solar heating as a low-cost supplementary heat supply would appear to be of considerable benefit in livestock confinement buildings as well as many other areas of agriculture. Preheating ventilation air with solar radiation will increase the moisture carrying capability of the air thereby lowering the humidity and improving environmental conditions within livestock confinement buildings. Daniels (13) indicated that using solar energy to preheat air is severely handicapped when electrical power is not available for moving the air. Ventilation equipment that exists in most livestock

confinement buildings meets that criterion and can be utilized in collector design.

The cost of energy spans a wide range at various geographic locations. Solar energy has not generally been competitive with other energy sources because of high initial capital costs per unit of energy return for most collector systems. These costs must be justified so that the benefits of the virtually free primary fuel source can become economically attractive.

Therefore the objectives of this study were established as follows:

1. Design and compare the efficiencies and total energy supplied by three types of low-cost, low-temperature rise bare plate solar collectors.
2. Evaluate the performance of solar collectors that can be readily adapted to many livestock confinement buildings currently used.
3. Evaluate the economic feasibility and potential energy savings of low-cost, low-temperature rise solar collectors for providing supplemental heat to livestock confinement buildings.

LITERATURE REVIEW

Solar energy is widely recognized as an essentially inexhaustible energy source that has the potential to make major contributions to future energy needs of the world. Contributions that solar energy has made as an alternate energy source include many agricultural applications. An extensive volume of literature exists within the scope of solar energy. However, this review will be restricted to those areas directly related to the nature of this study.

Solar heated air has many applications in agriculture. Buelow and Boyd (9) indicated that there is a year round requirement for warmed air and that a solar energy system that will heat air efficiently and economically could be used on the farm for drying hay and grain in the summer and fall and for supplying heat to farm buildings in the winter and spring. Many investigators have cited the energy savings potential of solar heated air for agricultural space heating and crop drying; Bates (3), Bauman, Finner and Shove (4), Buelow and Boyd (9), Carr, et al. (10), DeShazer (14), Foster and Peart (17), Hall (19), Harris (23), Lipper and Davis (27), Löf (30), Parker (33), Pelletier (34), Peterson (37), Peterson and Hellickson (38), Phillips (39), Reece (41), Spillman, Robbins and Koch (46), Stevens and Hicks (47), Wilkinson (50) and Williams et al. (51).

Another advantage Buelow and Boyd (9) associated with application of solar energy for agricultural purposes is that the temperature rises required for drying products and for use in ventilation of buildings are lower than those required for house heating. Peterson and

Hellickson (38) indicated for most agricultural applications satisfactory results may be obtained without high temperatures. Additionally Löf (29) concluded that potentially solar energy has all the applications of conventional energy sources. Solar energy heating systems are feasible in that it is possible to construct systems that are quite simple and do not require exotic materials.

It is necessary to know the availability and quantity of solar energy at the earth's surface for proper engineering application of this alternate energy source. The average energy received just outside the earth's atmosphere, known as the solar constant is approximately 426.7 Btu/hr sq ft (1353 w/m^2 or 1.94 cal/sq cm min) ASHRAE (1). As solar energy travels to the earth's surface it is attenuated by water vapor and dust in the atmosphere and it is also scattered, thereby forming the diffuse component of the solar energy reaching the earth. Block and Roth (6) reported that approximately 60 percent of the solar energy radiation arrives in direct form, the other 40 percent in diffuse form and that the diffuse percentage is much less dependent on collector angle placement than the direct, thus allowing a large amount of energy to be collected even on a partly overcast day. Flat plate collectors typically used for agricultural applications have the ability to utilize diffuse as well as direct solar radiation. Becker and Boyd (5) found that on cloudless days the daily total direct and sky radiation received upon a square foot of a south facing surface tilted 30 degrees from vertical varies from 2200 Btu in October to 1650 Btu in mid December and back to 2200 Btu in March at 45 degrees North Latitutde. Peterson and

Hellickson (38) reported that the amount of solar energy at right angles to the sun and at ground level is approximately 332 Btu/hr sq ft (nearly 100 watts/ft^2) (1.50 Langleys/min) in the corn belt area of the United States.

Flat Plate Solar Collectors

Liu and Jorden (28) indicated that flat-plate collectors are the simplest and one of the most effective methods of collecting solar energy for use in systems that require thermal energy at comparatively low temperatures. Daniels (13) reported that flat plate collectors are generally cheaper than focusing collectors, use heat from diffuse solar radiation as well as from direct radiation and can operate on bright or cloudy days. It was also concluded that the receiving surface should be as black as possible, thereby allowing over 95 percent absorption of the radiation. Close (12) concluded that solar air heaters of simple construction and employing cheap materials can be produced to supply air temperatures to 150° F with good efficiencies. Results from studies by Peterson and Hellickson (38) in South Dakota showed that a black-painted, bare sheet, corrugated collector can be just as efficient for collecting solar energy as plastic-covered collectors and can be installed at a lesser cost. Duffie and Beckman (16), in a study of solar heating and cooling found that thermal energy at temperatures below 100 C could readily be delivered from flat plate solar energy collectors and that solar energy incident on most buildings is more than adequate to meet these energy needs. Studies by Buelow (7) showed that it is possible to construct a solar heating unit as an integral

part of a building roof without great extra cost and with commonly available building materials. Later studies by Buelow (8) indicated that the overall design of a solar energy collector is influenced by the building orientation and shape and the internal configuration of the drying duct work. Research conducted by Hall (20) showed that solar heating could be incorporated into existing buildings by creating an air chamber beneath the roof or by adding another roof. Buelow (8) indicated that metal roofing has its best watershed characteristics when the corrugations or ridges are placed perpendicular to the ridge of the building. Also, if the metal sheets can be supported properly with rafters, it is possible to draw the outside air into the heater at the eaves and remove it from the heater at the ridge. Then, the air passages in the heater are relatively short and shallow. Buelow (8) found that a solar air heater will effectively raise the temperature of the air passing through it whenever the sun shines on the surface. On overcast days the diffuse radiation has little heating effect since the incoming energy is only about 10 percent of that on a sunny day. Thus, if a solar air heater raised the temperature 15 F on a sunny day it would raise air temperature about 1.5 F on an overcast day. Studies by Morrison and Shove (32) found that efficiencies of bare flat plate collectors increased 2.5 fold, if painted black. It was also found that some of the advantages of bare, flat-plate collectors are ease of fabrication on the farm from existing materials or relatively inexpensive materials, a minimum yearly maintenance, and low cost for operation.

Grain Drying Studies

Using solar heat for drying grain is not a new concept. Williams (52) reported that solar air heaters have a great potential for improving agricultural drying operations around the world. Numerous studies have indicated the success of solar heated air for crop drying; Akyurt and Selcuk (2), Bates (3), Bauman, Finner and Shove (4), Buelow (7), Daniels (13), Foster and Peart (17), Hammond and Winsett (21), Lipper and Davis (26), Lipper and Davis (27), Morey, Cloud and Nelson (31), Morrison and Shove (32), Peterson (35), Peterson (36), Peterson and Hellickson (38), Phillips (39), Smit and Shove (44), and Williams et al. (51).

Low temperature rise is the predominant factor in adaptation of solar energy systems for crop drying. Harris (23), reported that research has indicated that a temperature rise as small as 8 to 10 F in ambient air is enough to expedite the drying of grain to a level acceptable for storage purposes. Peterson and Hellickson (38) reported a 26 percent savings in energy requirements for drying corn with bare plate solar collectors mounted on the outside of a typical, round low temperature drying bin. Results from studies in 1974 by Bauman, Finner, and Shove (4) using the roof of a metal building as the solar collector showed that 50 percent of the required supplemental heat for drying was obtained from the metal building in the form of solar heat. This increased to 93 percent in 1975 due to the effects of weathering of the galvanized roof, different management of the system, along with 1/2 of the south wall being added to the collector area. It was indicated that 58 percent of the cost of the materials for collecting solar heat was

recovered in the form of savings in fuel costs in just two years of drying. These savings will increase with greater use of the system and with increasing costs of other fuel sources. Peterson (36) concluded that solar heat collection can be of considerable benefit for low temperature, in-storage drying of shelled corn during most drying seasons and furthermore that solar heat collection can provide enough heat for drying, with proper management, even if no fuel is available. Morrison and Shove (32) indicated that a bare plate collector installed on the south side of a grain bin may be economically feasible, when relatively inexpensive materials are used for the collector. Results of a computer simulation by Pierce and Thompson (40) of a solar grain drying system at one location in central Iowa using a fan management scheme to reduce fan energy requirements showed that energy requirements were generally lowest for solar supplemented systems and highest for systems using continuous heat. Foster and Peart (17), reporting on solar assisted drying tests conducted during 1974 at eight locations in the North Central region of the United States, found that grain could be successfully dried to safe storage moisture levels without significant spoilage and at a savings in energy costs.

Building Heating Studies

Pelletier (34) indicated that heating of livestock confinement buildings with solar energy is one of the most promising applications of solar energy. In livestock confinement buildings a vast amount of energy created in the buildings is lost through the ventilating air which is used to remove moisture from the buildings. Supplemental

heat is often added to the confinement buildings to maintain inside temperature within the range of animal comfort, to aid in maintaining moisture control and to allow a reduction in ventilation rate. The development of a low-cost solar heating system for heating incoming ventilation air would appear to have considerable potential for reducing conventional fuel energy requirements, while still maintaining suitable environmental conditions.

Claybaugh (11) suggested that solar energy could be a factor in reducing energy expenditures in poultry growing or breeding houses. Urner (49) indicated that solar energy could play a significant part in poultry house ventilation by increasing production efficiencies and by more than doubling the amount of heat available in a poultry house for moisture removal. Other possible benefits cited by Urner (49) on use of solar energy in poultry house ventilation include: increased production, more uniform inside temperatures, improved health of birds, greater growth with less feed consumption, more birds to a given floor area, drier litter, cleaner eggs, reduction in necessary labor, less change or stirring of litter and even better control of poultry disease, especially the respiratory ailments. The results of research conducted by Harman (22) and Reed (42) confirmed previous reports by Urner (49) of solar energy applications as a method to improve poultry house environment.

Studies by Carr et al. (10), using a black corrugated aluminum flat plate solar collector to reduce fossil-fuel based energy required for heating poultry production houses, revealed a 78.8 percent savings in LP gas by using solar energy and limited area brooding

versus LP gas and full area brooding. Based on a trial conducted during the winter of 1975-1976, Reece (41) found that a flat plate solar energy collection and storage system for poultry production houses in the southeast United States could be used to reduce fossil fuel energy required for heating to an insignificant amount. Harris (23), in a study of potential solar energy applications in agriculture, concluded that the range of temperatures required for broiler brooding (75 to 90 F) can be easily maintained by a solar space heating system.

Hall (18) conducted a study of a solar supplemental heating system for swine buildings in western Illinois. Hall's (19) solar collectors were constructed of corrugated roofing sheets placed vertically on 2-inch by 4-inch roof purlins creating a 1 1/2-inch air space which allowed air to flow horizontally under the sheets to central air ducts. A positive pressure ventilation system was used to move the air perpendicular to the corrugations to create a turbulence under the steel roofing and thus increase heat transfer. Results indicated that outside temperature had little effect on the amount of heat gained from the steel roofing and predominant factors affecting heat gain were insolation and wind velocity. Other results found were that conduction heat loss through the ceiling was recovered and returned to the ventilation system, a solar heating system is possible with any type of floor or pen arrangement, supplemental heat is needed at night and during extremely cold weather, either negative or positive pressure ventilation can be used, any type of corrugated or ribbed metal can be used as a collector, however dark colored surfaces absorb more heat, airflow perpendicular to corrugated roof surfaces was the most efficient, an

efficient airspace for swine buildings is 1 1/2-inches, and solar heating can be incorporated into existing buildings by creating an air chamber beneath the roof or by adding another roof. Parker (33) reported that by solar preheating air for farrowing houses during the winter months a balance can be found between the amount of heat needed to be added for both temperature comfort and for removing water vapor. Research conducted in Nebraska by DeShazer et al. (15) on a swine growing-finishing facility utilizing a flat plate collector built on the roof indicated a reduction of 25 percent of the heating requirement could be realized for a solar heating system without storage. It was also indicated that fan management is an important aspect of this solar system. Cost of the solar collector system was about $16 per square foot, including labor. Spillman (45) in studies using a solar energy collector-storage system that replaced the south wall of a swine confinement building concluded that the air heating unit has potential for reducing the demand for fossil fuel to heat animal shelter ventilating air. Reynolds (43), reporting on a flat plate solar heating system constructed on the roof of a beef confinement building, found that the warmed air absorbed moisture from air in the building thus lowering the humidity and eliminating fogging problems, which are common in some confinement buildings. Solar energy studies for milking parlor heating and cooling currently being conducted by Thompson (48) are designed to achieve a year round average load reduction of 40 percent in milking parlor energy demand.

RESEARCH PROCEDURE

The Grain Terminal Association Feed Division's modern beef research facility, located approximately four miles west of Sioux Falls, South Dakota, was used to evaluate solar supplemental heating of a livestock confinement building with three types of low cost, low temperature rise, flat plate collectors. The studies were performed under actual production and climatic conditions.

The east-west oriented beef confinement unit is a framed construction building measuring 40 feet by 48 feet long and housing six 16-foot by 14.5-foot pens, (Figure 1). The end walls were constructed of 2-inch by 4-inch studs, 8 feet long and spaced 24 inches on center. A four-mil polyethylene vapor barrier was used on the inside of the studs with 3 5/8 inches of fiberglass insulation located between the studs. The interior and exterior walls were covered with 1/2-inch and 3/8-inch exterior plywood, respectively. The 8-foot end wall sections were placed on an 8-inch core-filled concrete block foundation extending 28 inches above the slotted floor. The remainder of the side wall construction was similar to the end walls. Access to the unit was through two 5-foot by 7.5-foot insulated sliding doors.

The ceiling was constructed of 1/2-inch exterior plywood, a four-mil polyethylene vapor barrier and 6 inches of fiberglass insulation. Forty-foot trusses, spaced four feet on center, were used to support the 5/8-inch exterior plywood, 15-pound felt and asphalt shingles used on the roof. The beef confinement building has a concrete slotted floor and was further described by Hellickson, Witmer and Barringer (24).

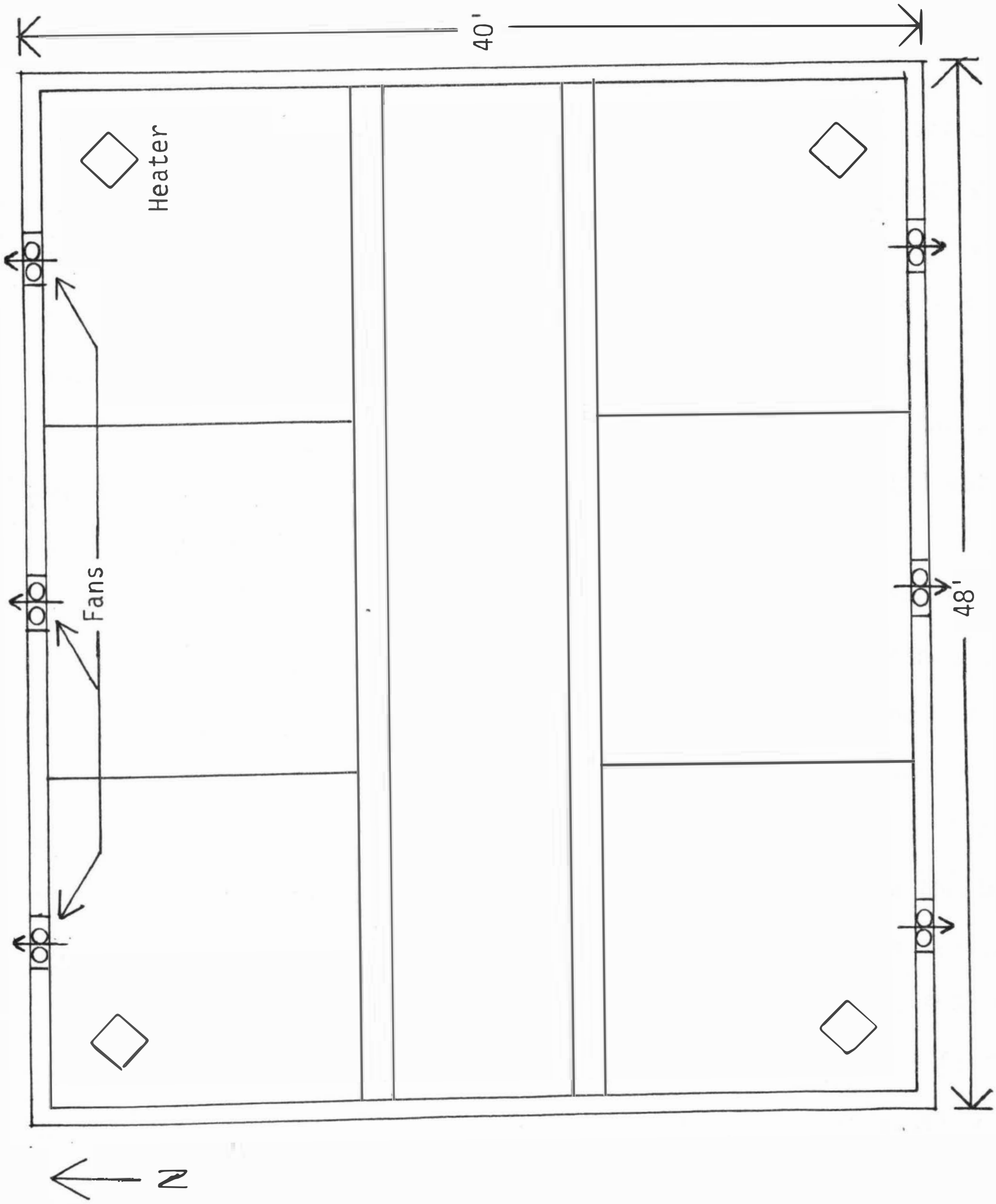

Figure 1. Closed Environment Beef Building Floor Plan.

Ventilation was provided by six exhaust fans located approximately 6 feet above the slotted floor. Four 3430-cfm, thermostatically controlled, constant speed fans and two 720-to-3430 cfm, variable speed solid state controlled fans were used to control airflow rates. An attic divider arrangement allows use of air drawn into the attic over the north wall plate for summer ventilation and over the south wall plate for winter ventilation, (Figure 2). The ventilation system and characteristics were further described by Hellickson, Young and Witmer (25). Four 15-KW, thermostatically controlled electric heaters with circulating fans (Figure 1) provided supplemental heat for the closed environment building. Illumination was provided by nine 100-watt incandescent lamps.

Three types of flat plate solar collectors were mounted on the western 1/2 of the southern roof and side of the beef confinement facility. The three collectors were constructed of 29 gage corrugated aluminum roofing fastened to 2-inch by 2-inch vertical studs, on the side wall and similar studs along the roof slope. The studs located 18 inches on center, allowed a 1 1/2-inch airspace between the building and collector surfaces, (Figure 2). Collector A covered a 12-foot by 8-foot section of the south wall; collector B covered a 12-foot by 22-foot section of the roof; and collector C covered both a 12-foot by 8-foot section of the south wall and a 12-foot by 22-foot section of the roof, (Figure 3). The studs directly above and below the fan outlets were spaced approximately 1 foot from the outlet to allow air in the collector to pass the fan outlets. Two-inch by 2-inch studs were placed horizontally at a distance of 8 feet from the bottom of the collector

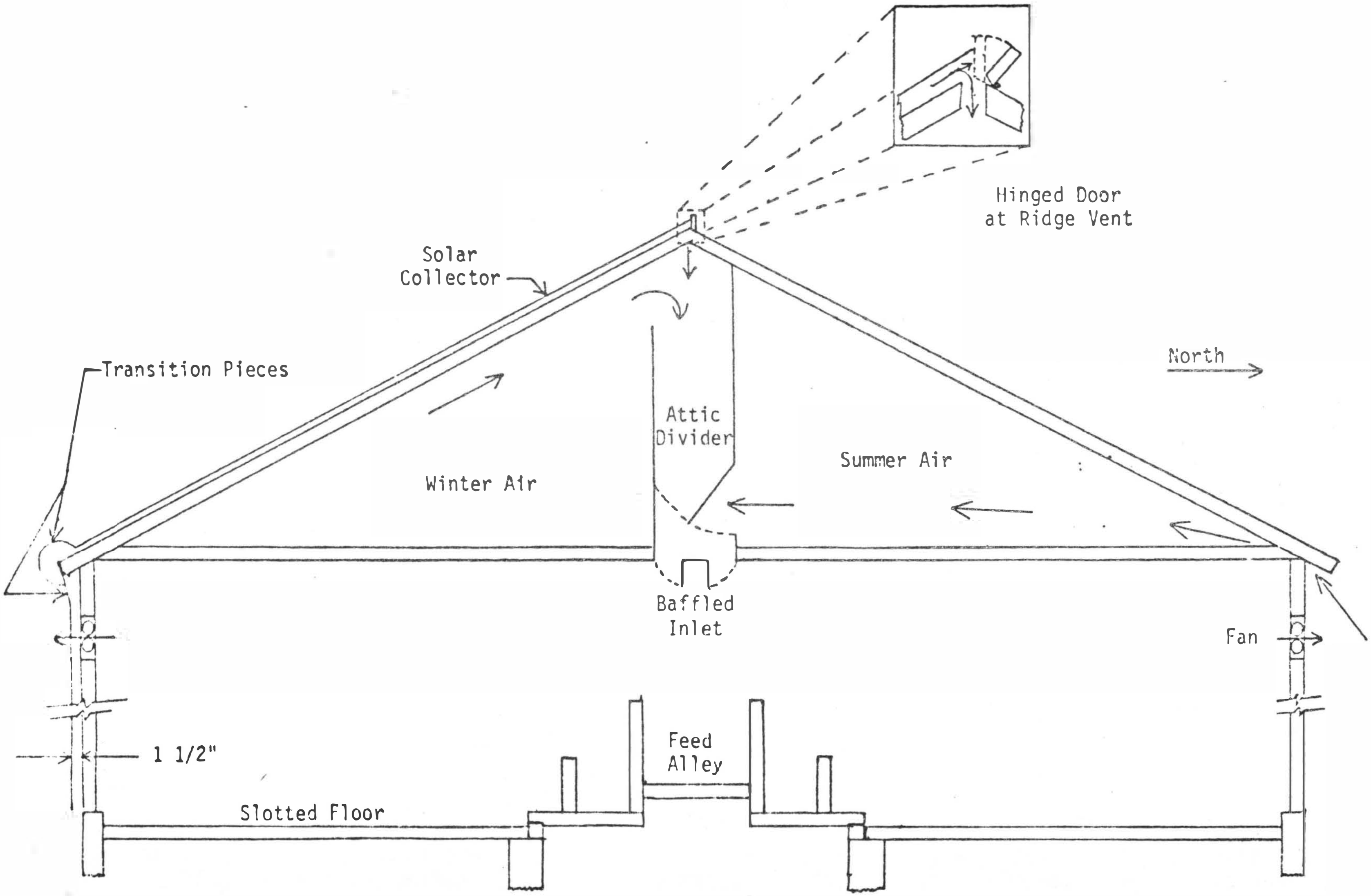

Figure 2. Building Cross-Section Illustrating the Baffled Center Ceiling Inlet System, Hinged Door at the Ridge Vent, and Transition Pieces.

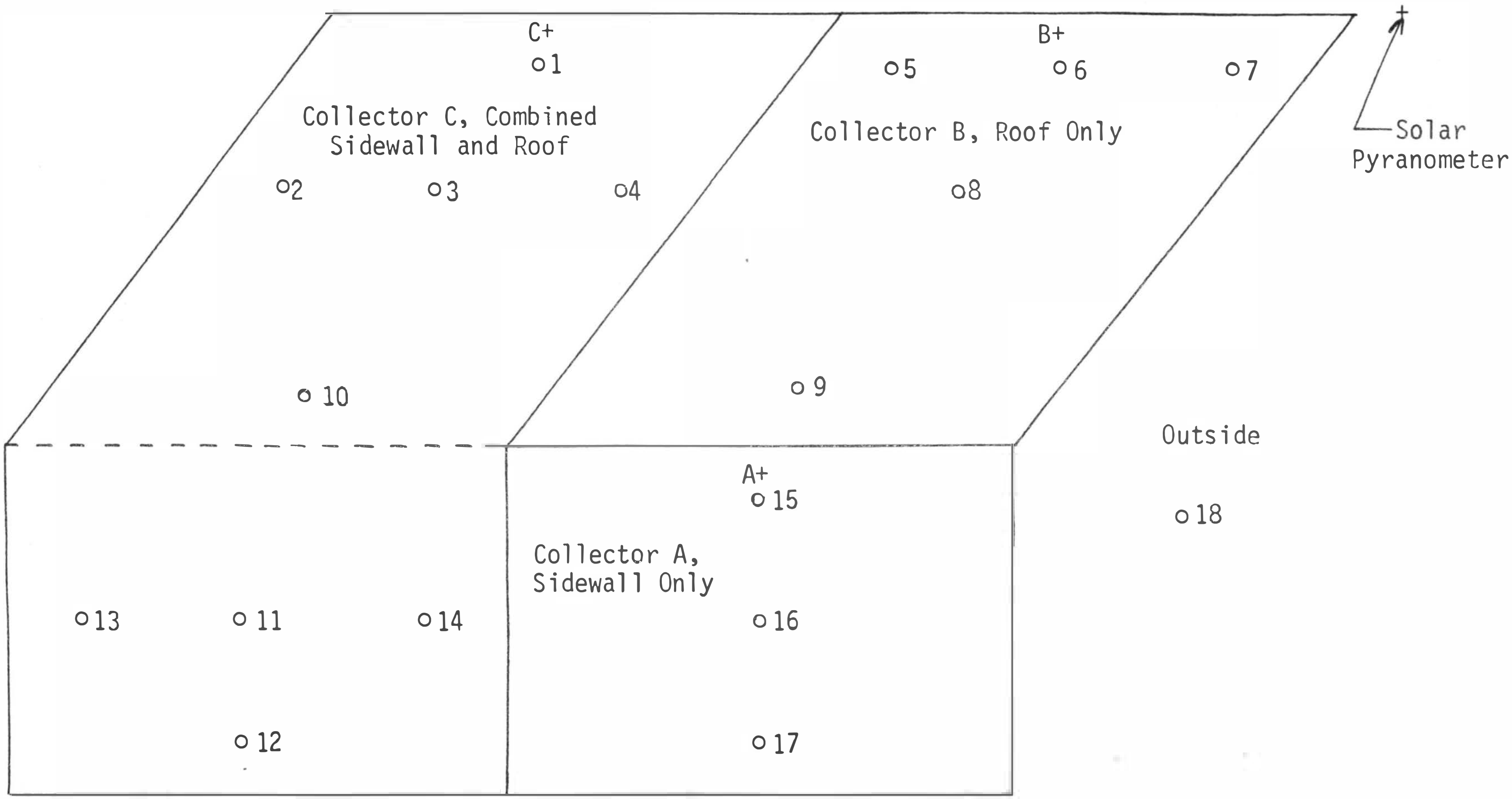

Figure 3. Locations of the Three Types of Solar Collectors and Epply Pyranometer; Numbers Refer to Temperature Measurement Locations and Letters Refer to Airflow Measurement Locations.

and were fastened directly on top of the vertical spaced studs the entire 24-foot length of the side wall collectors. This facilitated mounting of a transition piece which allowed solar heated air to enter the eave inlet on collector A and allowed solar heated air to flow from the side wall section to the roof section of collector C. A stud was also fastened horizontally on top of the studs at the base of the roof section of collector C for mounting of the transition piece.

Horizontal flat, strap, steel members 1/8-inch by 1-inch, were placed under the collector joints to add rigidity. Corrugated aluminum roofing sheets, 38 inches wide, were painted black on both sides with a commercially available flat black enamel and were fastened to the 2-inch by 2-inch studs with the corrugations parallel to the studs. The transition pieces on collectors A and C (Figure 2) were constructed of similar corrugated aluminum roofing sheets painted black on both sides and were mounted to collectors A and C with the corrugations horizontal to allow bending. The transition piece on collector A was fastened to the horizontal 2-inch by 2-inch stud on the side wall on one end and to the fascia board on the other end. On collector C the transition piece was fastened to the horizontal 2-inch by 2-inch stud on the side wall on one end and to the horizontal 2-inch by 2-inch stud at the base of the roof slope on the other end. End pieces for both collectors A and C were fabricated from 1/2-inch exterior plywood. The eave slot openings along the north side of the building and under the transition piece of collector C were blocked off using 1/4-inch by 6-inch strips of exterior plywood fastened to the soffit boards.

The existing ridge vent of the confinement building was removed for

24 feet to accommodate collectors B and C and a hinged door was constructed, (Figure 2). This door allowed airflow through the collectors to be drawn into the ridge opening during cold weather operation and to escape into the atmosphere for warm weather operation. The door was constructed of a 2-inch by 4-inch board cut to the slope of the roof fastened tightly and vertically to a 1-inch by 6-inch board with ten, 5-inch, T hinges. The 1-inch by 6-inch board was fastened on the north roof slope so that the 2-inch by 4-inch stud upon it abutted perpendicular against the ends of the 2-inch by 2-inch studs of collectors B and C. A commercially available caulking compound was used throughout construction of the three collectors to seal joints. Total cost of construction materials for the three collectors was approximately 50 cents per square foot, excluding labor.

Total solar insolation values on a horizontal surface at the beef research facility were monitored continuously with an Epply Pyranometer, and the data were recorded on a strip chart recorder. The Epply Pyranometer was located (Figure 3) on a platform 4 inches above the ridge of the beef confinement facility. Additional weather data needed for evaluation were obtained from the National Weather Service Station at Joe Foss Field in Sioux Falls. Temperatures at selected locations on the three solar collectors were measured with 26-gage copper-constantan thermocouples and were recorded by a strip chart, recording potentiometer. Location of the temperature measuring points shown in Figure 3 are as follows:

Point	Location
1	Outlet of collector C
2	Roof slope of collector C
3	Roof slope of collector C
4	Roof slope of collector C
5	Outlet of collector B
6	Outlet of collector B
7	Outlet of collector B
8	Roof slope of collector B
9	Inlet of collector C
10	Transition piece of collector C
11	Sidewall of collector C
12	Inlet of collector C
13	Sidewall of collector C
14	Sidewall of collector C
15	Outlet of collector A
16	Sidewall of collector A
17	Inlet of collector A
18	Outside air

Temperatures at the selected locations were monitored every hour from 1000 hours to 1600 hours. Airflows were measured near the exhaust outlets (Figure 3) of the collectors with a hot wire anemometer and were recorded every hour from 1000 hours to 1600 hours. A computer program was utilized to convert the solar radiation data to Btu/hr sq ft and voltages from the anemometer readings to velocity.

Total energy produced by each collector was determined by calculating the energy transferred from the collector to the airflows using the following relationship:

$$QT = \frac{(\Delta T)\ (V)\ (C)\ (A)}{v}$$

QT = total energy production, Btu/hr

ΔT = temperature change, F

C = specific heat, .24 Btu/lb-F for air

V = velocity, ft/sec

A = area of collector exhaust outlet, ft^2

v = specific volume, ft^3/lb

A stepwise multiple regression statistical technique was used to analyze the relationship between the dependent variable, energy collected by the solar collectors, and the independent variables, solar energy on a horizontal surface and outside temperature.

RESULTS AND ANALYSIS

Successful solar heating of ventilation air depends on many factors that include both the availability of solar radiation and the climatic conditions that exist during the time of application. Incident solar radiation on a horizontal surface at the research site, all monitored temperature and airflow data and collector efficiencies are presented in Appendix B. Total daily and monthly solar radiation on a horizontal surface, 10-year averages, deviations of the daily and the monthly solar radiations from the 10-year averages, average daily and monthly temperatures and the departure of the daily and the monthly temperatures from normal are presented in Appendix C. The radiation values represent data monitored at the Agricultural Engineering Building at South Dakota State University in Brookings, South Dakota, approximately 55 miles north of the research facility. The temperature values were monitored by the United States Weather Bureau Station located at Joe Foss Field in Sioux Falls, South Dakota, approximately four miles east of the research facility.

Average hourly temperature rises for all research trials, all three collectors, and incident solar energy are shown in Figure 4. The sidewall collector A showed the highest temperature rises for all three collectors in the morning hours. The combination sidewall and roof collector C had the highest average hourly temperature rise of 16.2 F at 1400 hours and had the highest average hourly temperature rises for all three collectors during the afternoon hours. The lower average hourly temperature rises of roof collector B and combination sidewall and roof

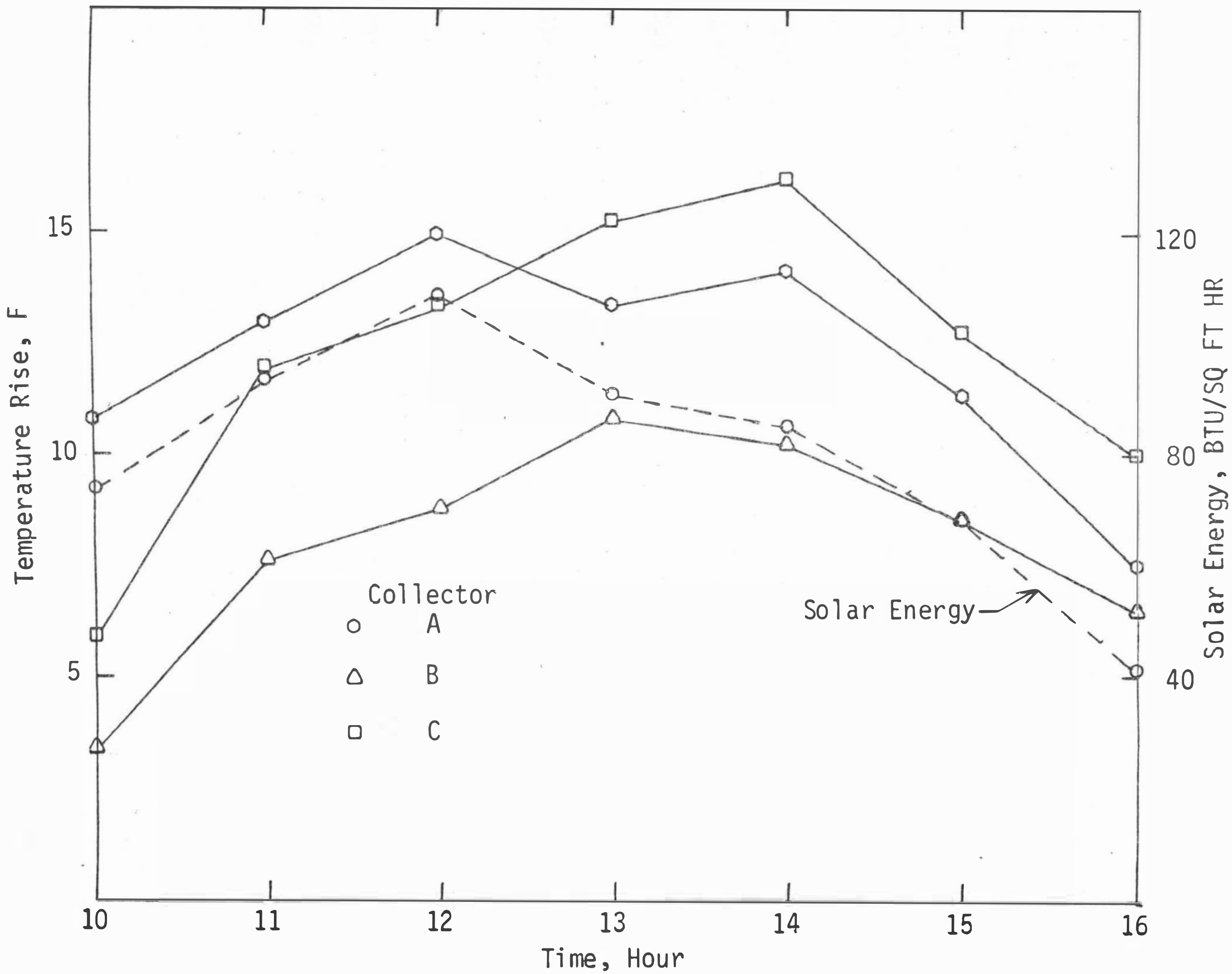

Figure 4. Average Hourly Temperature Rise as Influenced by Collector Type and Incident Solar Energy.

collector C during the morning hours is explained by frost and snow deposits that often existed on the roof on various days. Collectors B and C also had lower mass airflow rates than did collector A.

Average hourly heat collected per unit area for all research trials, all three collectors and incident solar energy are shown in Figure 5. Sidewall collector A consistently had the highest average hourly heat collections and also had the highest average hourly heat collection, 140.5 Btu/hr sq ft at 1200 hours. The sharp drop in average hourly heat collection at 1300 hours for sidewall collector A is explained by a decrease in solar energy and a reduction in mass airflow through the collector resulting from open doors in the confinement building at feeding time, which allowed ventilation air to enter through the doors rather than through the collectors. Roof collector B and combination sidewall and roof collector C experienced similar average hourly heat collection rates during the day but collected considerably less energy per unit of collector area than did sidewall collector A. The lower average hourly heat collection values for roof collector B and combination sidewall and roof collector C are explained by frost and snow buildups on the roof sections during various days of the research trials, a poor angle of solar incidence that exists for the roof sections during the winter months, wind effects on the building, and a greater conduction heat loss due to the increased surface area for both collectors as compared to sidewall collector A. It should be noted that although combination sidewall and roof collector C had similar average hourly heat collection values to roof collector B, C had a collector area of 360 ft^2 versus 264 ft^2 for roof collector B,

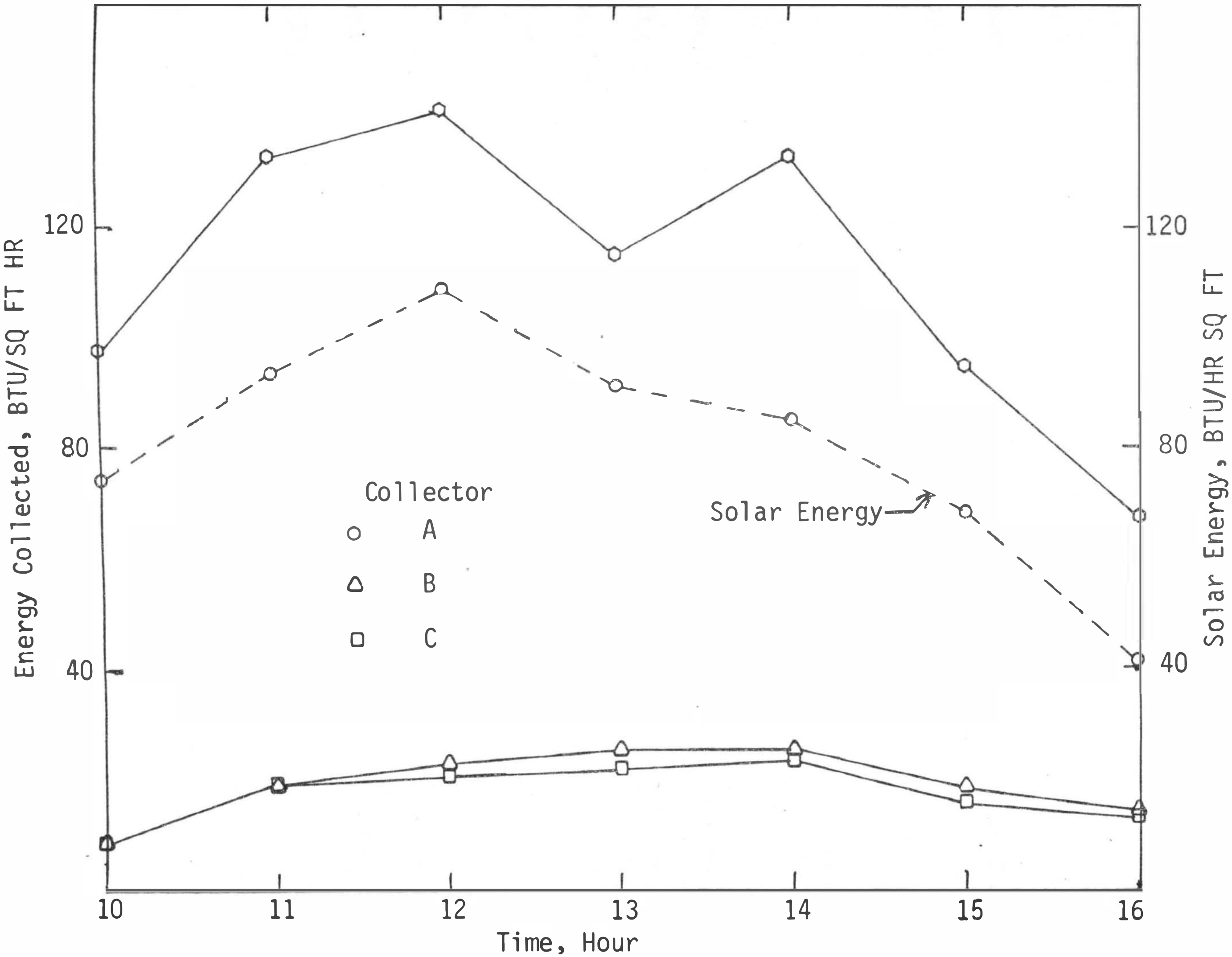

Figure 5. Average Hourly Energy Collection as Influenced by Collector Type and Incident Solar Energy.

and C had the longest distance of airflow travel for any of the three collectors tested. Maximum average hourly heat collection for roof collector B and combination sidewall and roof collector C were 25 Btu/hr sq ft and 23.5 Btu/hr sq ft, respectively, and occurred at 1300 and 1400 hours, respectively. Total average hourly heat collection for each collector can be determined by multiplying the value on the graph by the square feet of area of each collector.

Sidewall collector A had the highest average hourly efficiencies, (Figure 6). The values ranged from a low of 115 percent at 1300 hours to 161 percent at 1600 hours. These efficiencies are the ratio of energy collected per unit area to solar energy on a horizontal surface. The efficiencies of sidewall collector A that are greater than 100 percent are explained by the fact that the incident angle of the sun is closer to being normal to a vertical surface during the winter months in South Dakota than it is to being normal to a horizontal surface. Efficiencies for roof collector B and combination roof and side collector C ranged from 12 percent for both collectors at 1000 hours to 38 and 37 percent, respectively, for collectors B and C at 1600 hours.

Temperatures were recorded and averaged for ten nights to find whether any significant heat gains or losses occurred for any of the three collector systems from 1800 hours to 0800 hours. Ventilation rates were assumed to be minimum during these hours because outside temperature was consistently below that associated with minimal ventilation requirements. The average hourly temperature differences and

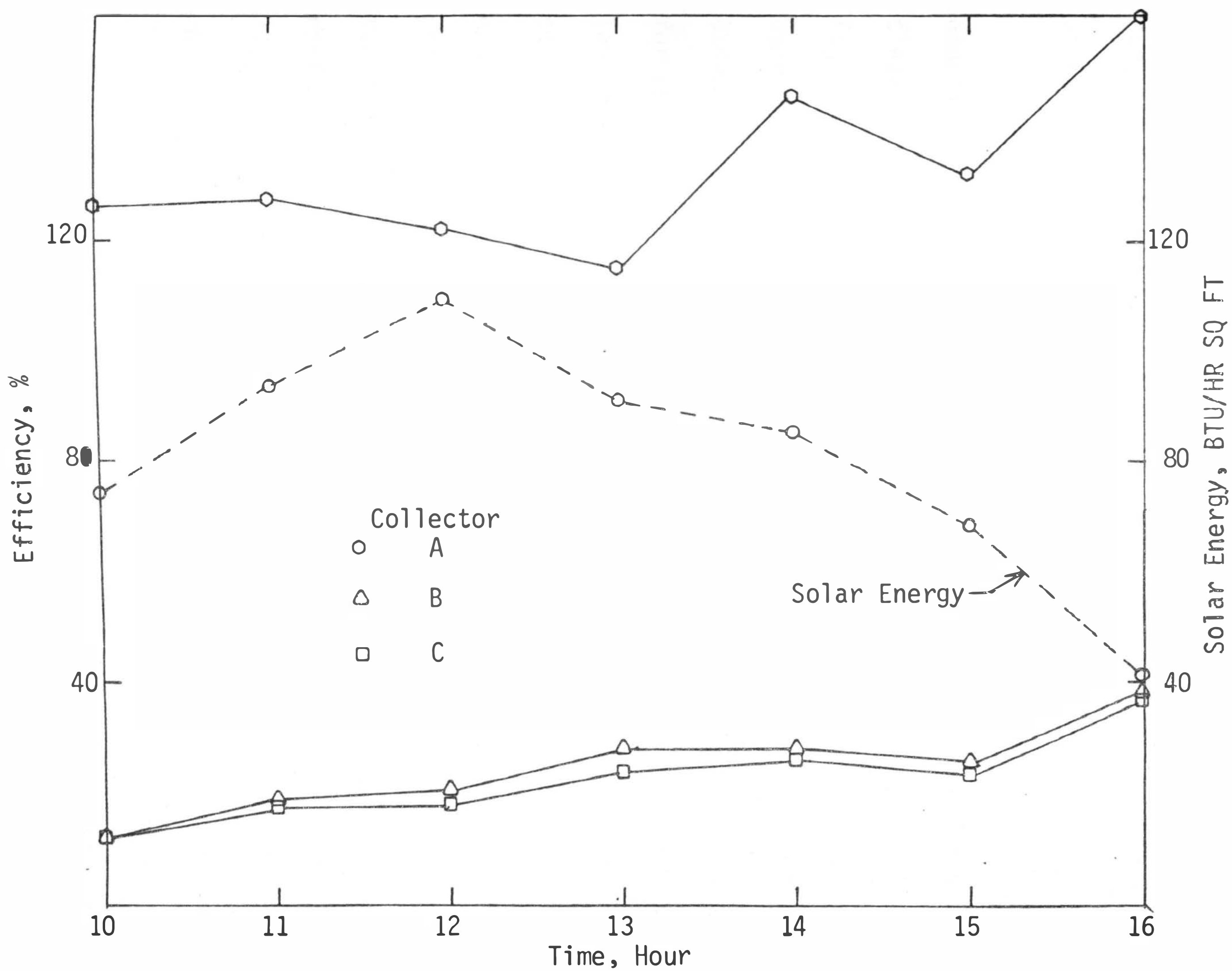

Figure 6. Average Hourly Efficiencies as Influenced by Collector Type and Incident Solar Energy.

average hourly heat collection for the three collectors during the night are shown in Figures 7 and 8, respectively. Low temperature gains and losses (-2.1 F to 1.1 F) and correspondingly low heat collection values (-2.4 Btu/hr sq ft to 3.8 Btu/hr sq ft) are not large enough to have significant effect on energy savings or losses during the night hours.

Comparisons of hourly temperature rises, hourly heat collection, hourly efficiencies, and solar incidence on a horizontal surface for a clear day, January 29, and an overcast day, January 22, are presented in Figures 9, 10 and 11. Figure 9 shows that temperature rises of 10 to over 25 F can be expected from sidewall collector A and combination sidewall and roof collector C and temperature rises of 7 to over 15 F for roof collector B, can be expected on a clear day. On overcast days temperature rises of 1 to 4 F can be expected from any of the three collector systems. The temperature rises on an overcast day are approximately 10 to 15 percent of those on a clear day and agree with previous work by Buelow (8). Figure 10 indicates that sidewall collector A had a much greater heat collection per square foot than did either roof collector B or combination sidewall and roof collector C on a clear day. Sidewall collector A also had a larger heat collection value per unit area than did the other two collectors on an overcast day, but it was not nearly as predominant as on a clear day. Hourly efficiencies on a clear and overcast day were somewhat similar for roof collector B and combination sidewall and roof collector C. However, values for sidewall collector A were highest for both days and were as high as 260 percent on a clear day.

Average differences in temperature at various points on the

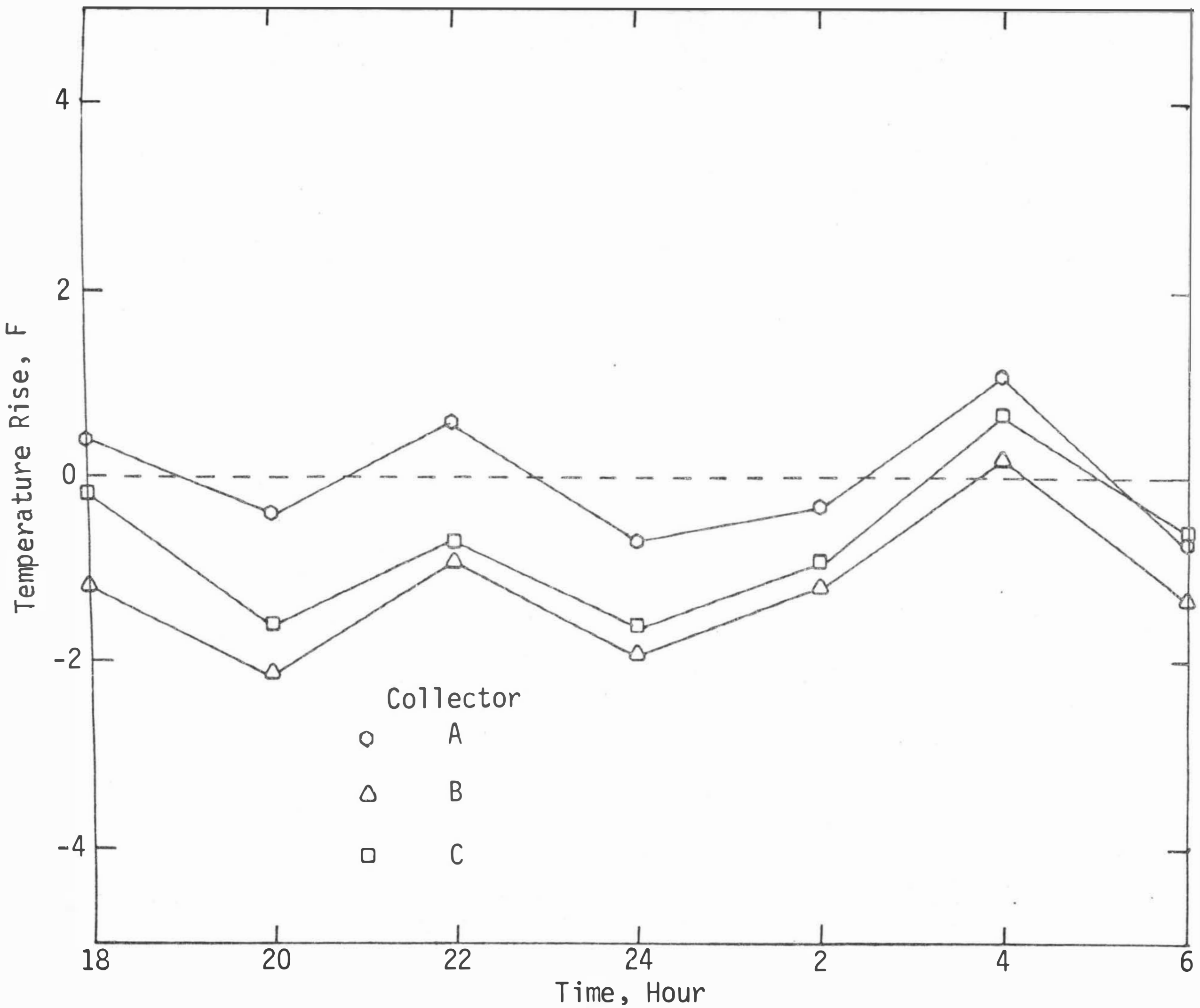

Figure 7. Average Night Hourly Temperature Rises as Influenced by Collector Type.

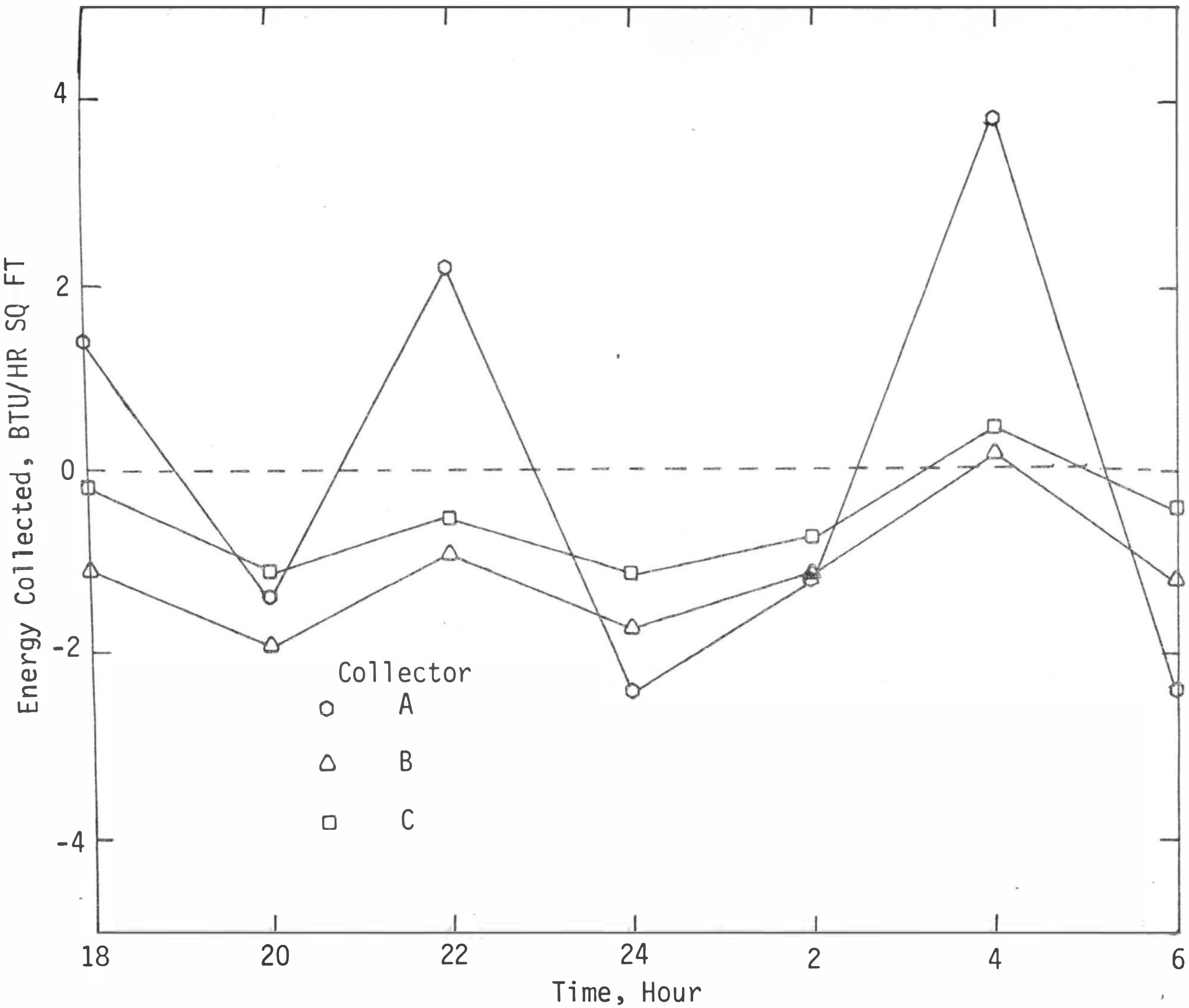

Figure 8. Average Night Energy Collection as Influenced by Collector Type.

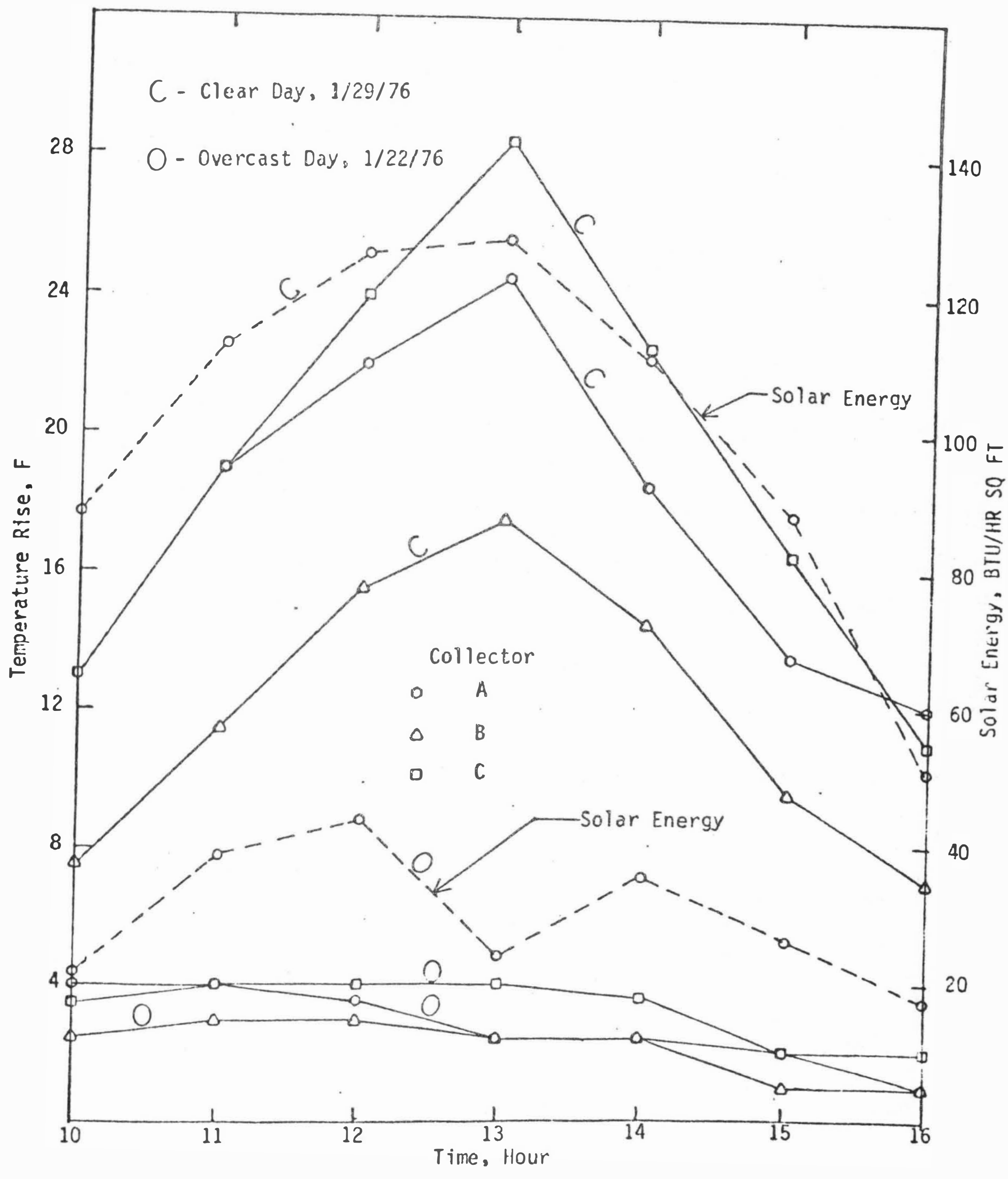

Figure 9. Hourly Temperature Rises on a Clear Day and an Overcast Day as Influenced by Collector Type and Incident Solar Energy.

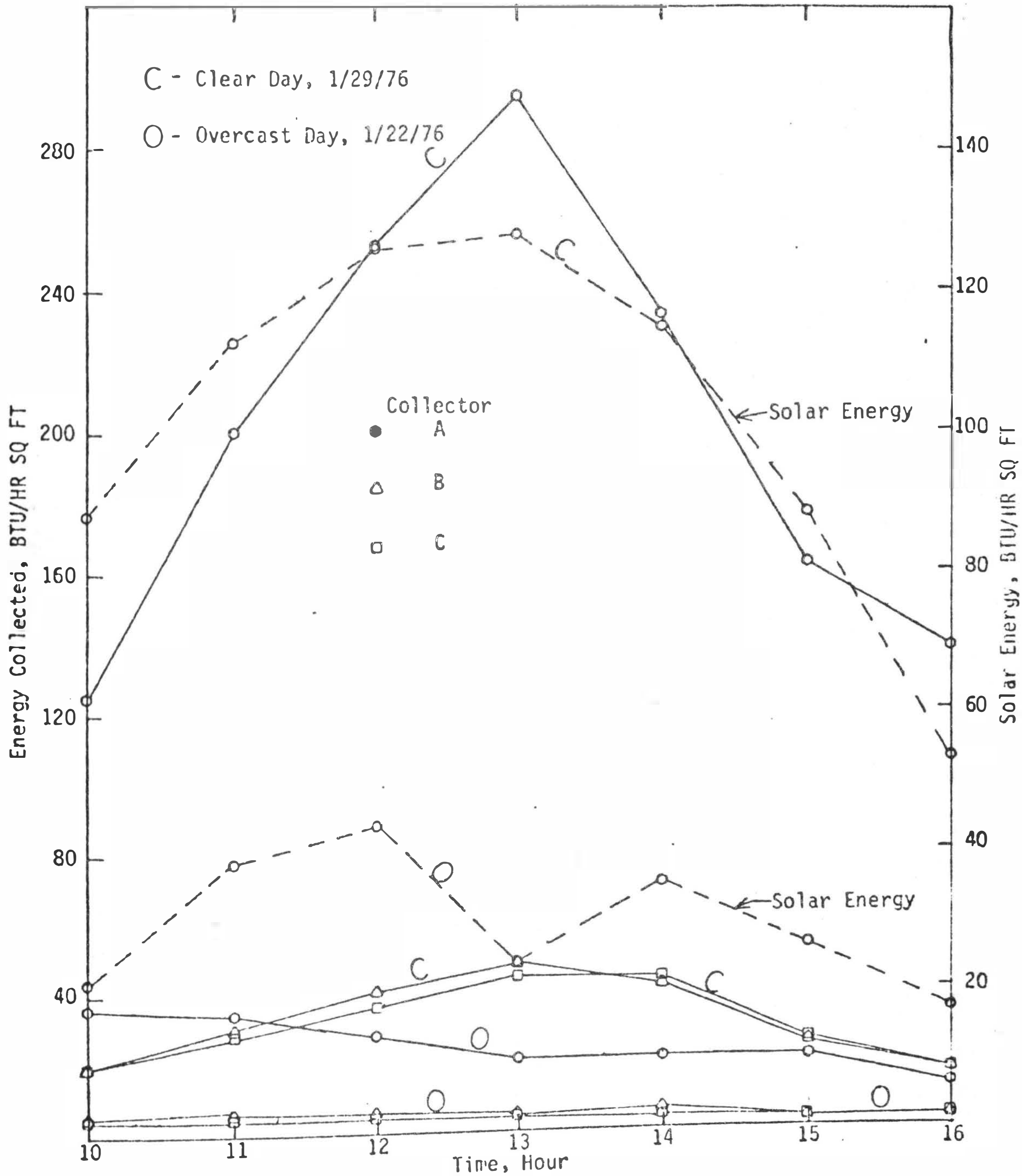

Figure 10. Hourly Energy Collection on a Clear Day and an Overcast Day as Influenced by Collector Type and Incident Solar Energy.

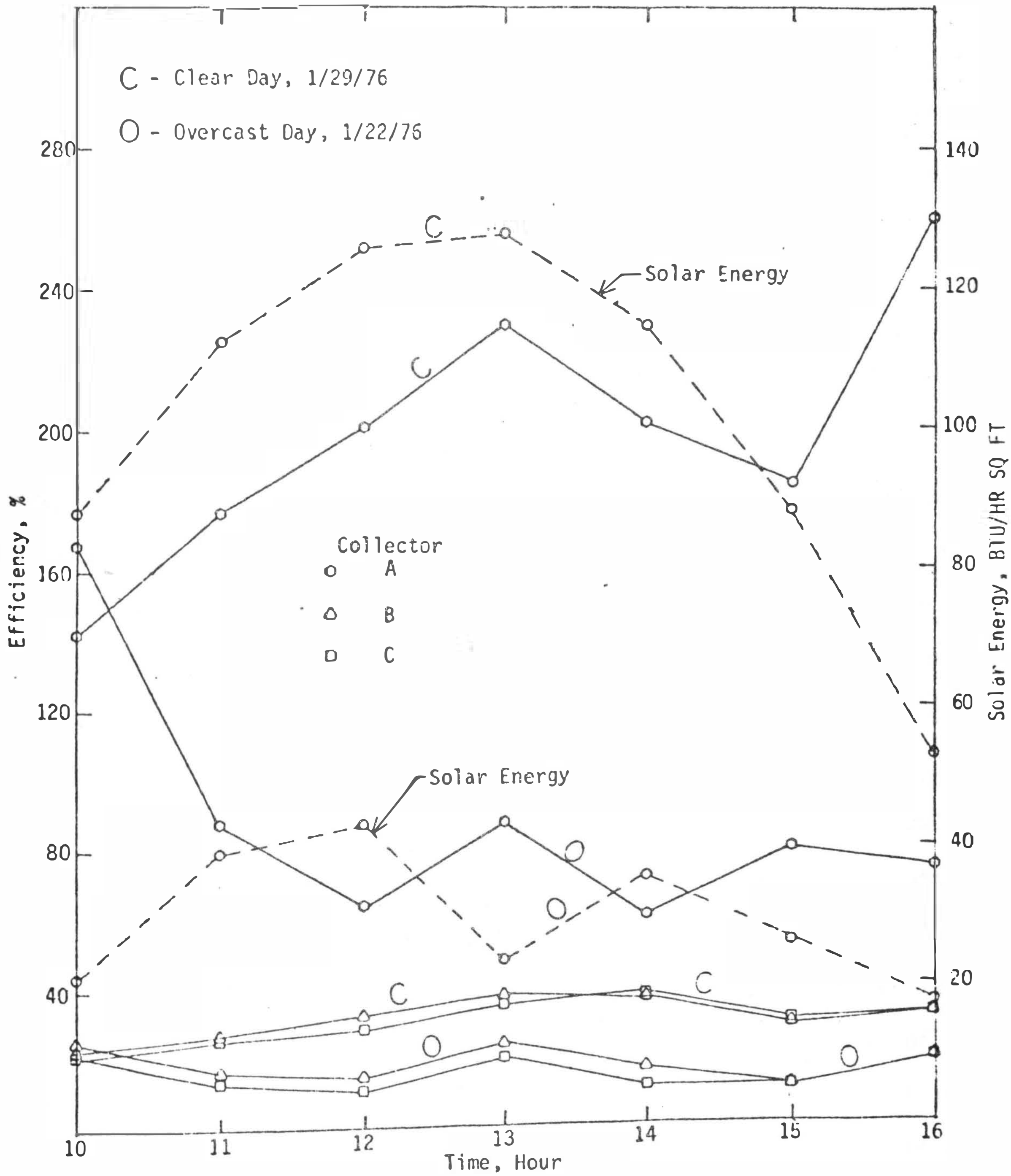

Figure 11. Hourly Efficiencies on a Clear Day and an Overcast Day as Influenced by Collector Type and Incident Solar Energy.

collector for the clear and overcast days previously discussed are presented in Figure 12. On a clear day the profile across the sidewall section of combination sidewall and roof collector C showed a 3 F difference between the left and center of the collector. This is possibly caused by increased wind speed and turbulence around the corner of the building creating a greater conduction heat loss from this section of the collector. With the exception of point 12, where monitoring problems were encountered, relatively uniform temperatures were noted on the collectors, Figure 12.

Heat conduction coefficients for the confinement building and corresponding heat conduction loss data are presented in Appendix D. Note that the heat conduction losses are for the entire collector area of each of the three collectors per degree difference between inside and outside temperature. Daytime conduction losses, using the temperature values on Figure 12, for a clear day will vary from 0 at the outlet to 42 Btu/hr near the inlet for sidewall collector A, 0 at the outlet to 114 Btu/hr near the inlet for roof collector B and 0 for both the outlet and inlet areas of combination sidewall and roof collector C. Values of conduction losses on an overcast day from the outlet to near the inlet are 134 to 139 Btu/hr, 240 to 264 Btu/hr and 359 to 391 Btu for collectors A, B, and C, respectively. These data provide an indication of the amount of conduction heat flow from the inside of the building that is potentially available to be picked up by airflow in the solar collectors.

Energy collected per unit area was found to be significantly related to incident solar radiation on a horizontal surface for the three collectors. The following linear prediction equations indicate

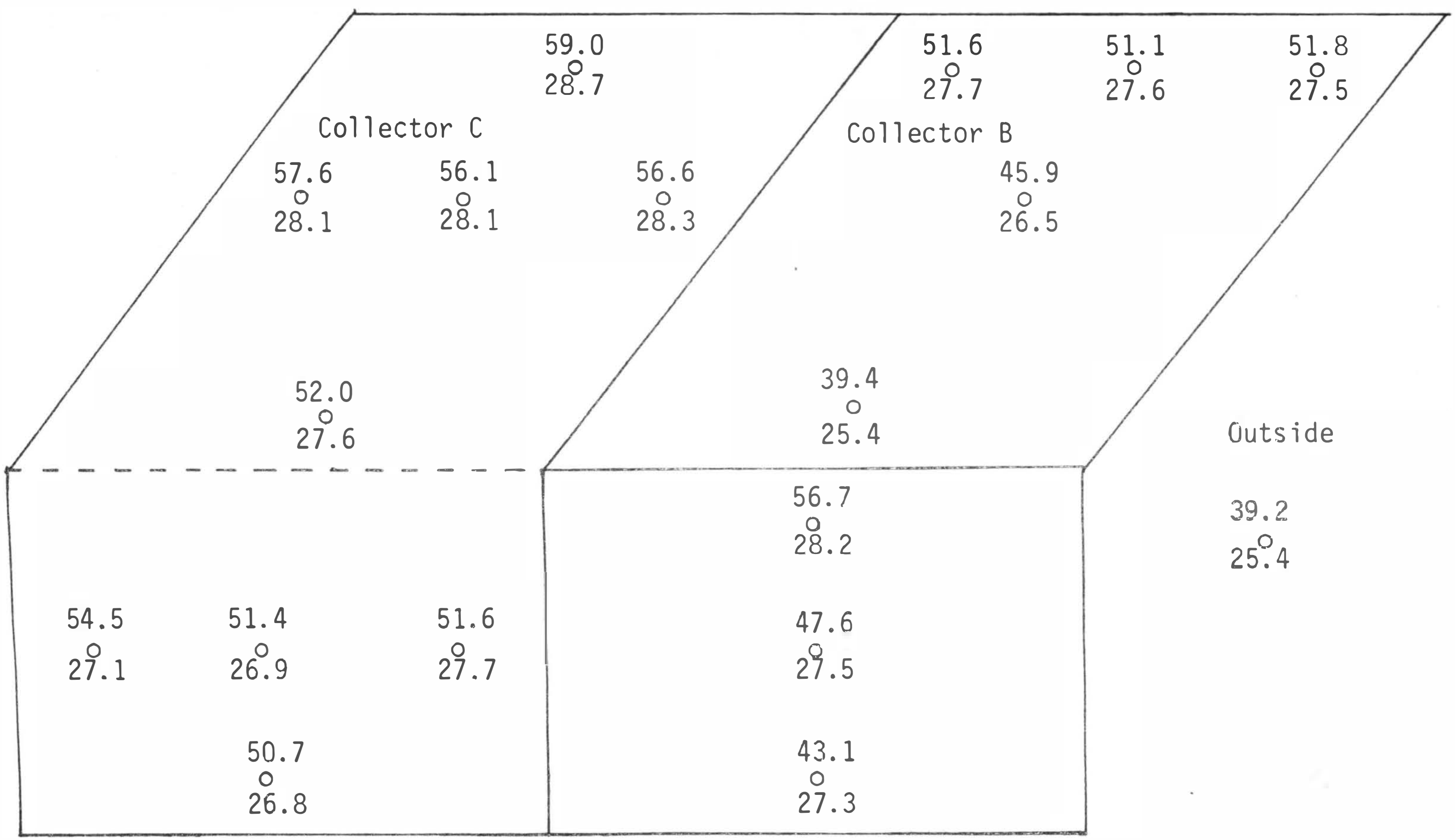

Figure 12. Average Temperatures at Monitored Points on a Clear Day (Top Number) and an Overcast Day (Bottom Number).

the direct relationships for the three collectors:

$$Y_A = -10.11 + 1.52\ X_{SE}$$

$$Y_B = -\ 3.86 + 0.29\ X_{SE}$$

$$Y_C = -\ 1.76 + 0.24\ X_{SE}$$

Y_A, Y_B, Y_C = heat collected, Btu/hr sq ft for collectors A, B and C, respectively

X_{SE} = solar energy on a horizontal surface, Btu/hr sq ft

The coefficients of determination and the standard errors of estimate were .48 and 63.11, .39 and 14.25, and .38 and 12.28 for collectors A, B and C, respectively. Statistical comparisons of slopes and intercepts of the above equations (Figure 13) revealed that sidewall collector A provided significantly more energy than did either roof collector B or combination sidewall and roof collector C. Typical examples of energy collected with a solar energy reading of 100 Btu/hr sq ft are:

Collector	Energy Collected Btu/hr sq ft
A	141.9
B	25.1
C	22.2

Significant multiple linear relationships, Figures 14 and 15, were developed between energy collected and solar energy and outside temperature for roof collector B and combination sidewall and roof collector C. The analysis of variance summary tables for collectors A, B and C are shown in Appendix E. The resulting equations and the corresponding coefficients of determination and standard errors of estimate are:

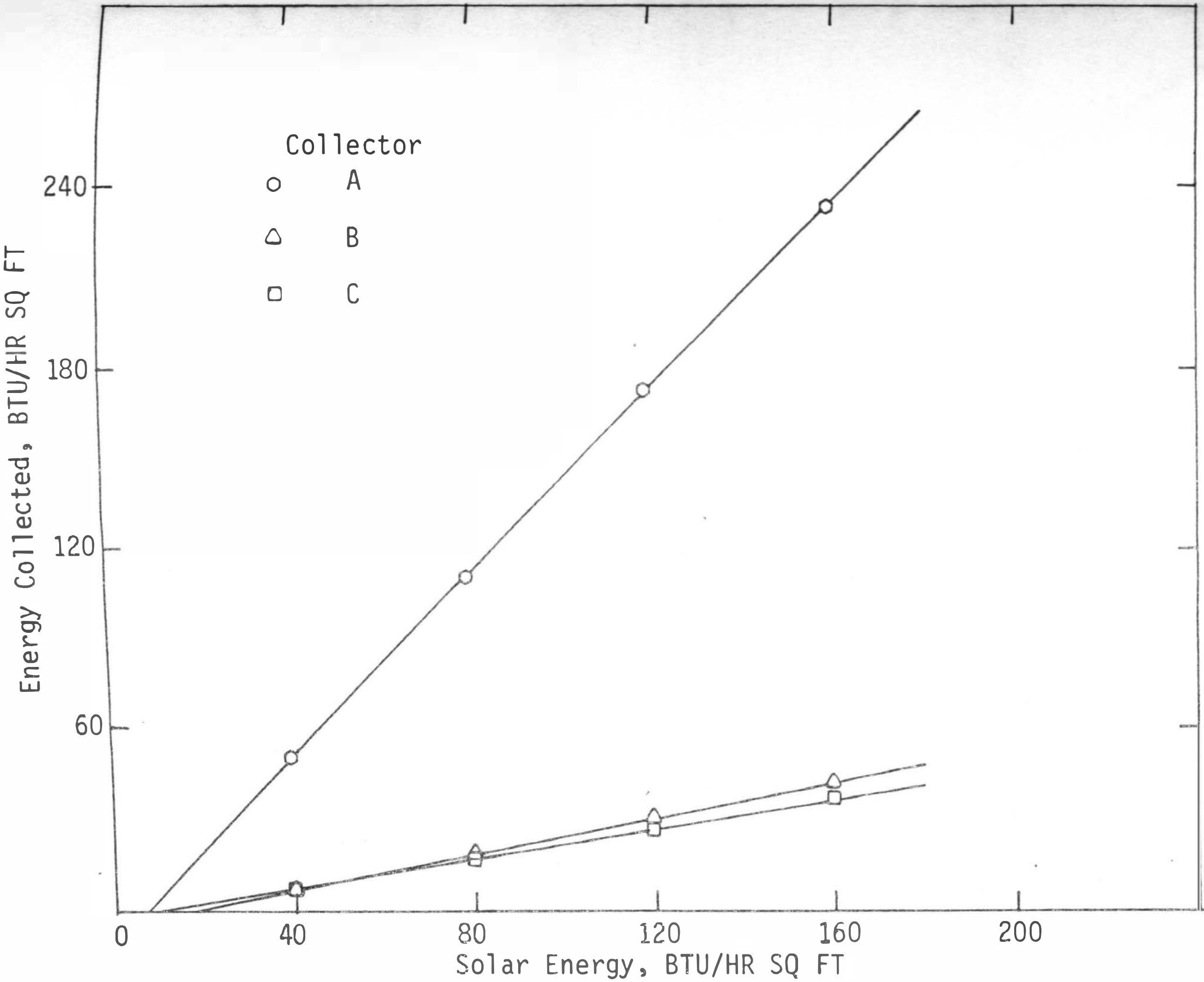

Figure 13. Energy Collected as Affected by Collector Type and Incident Solar Energy.

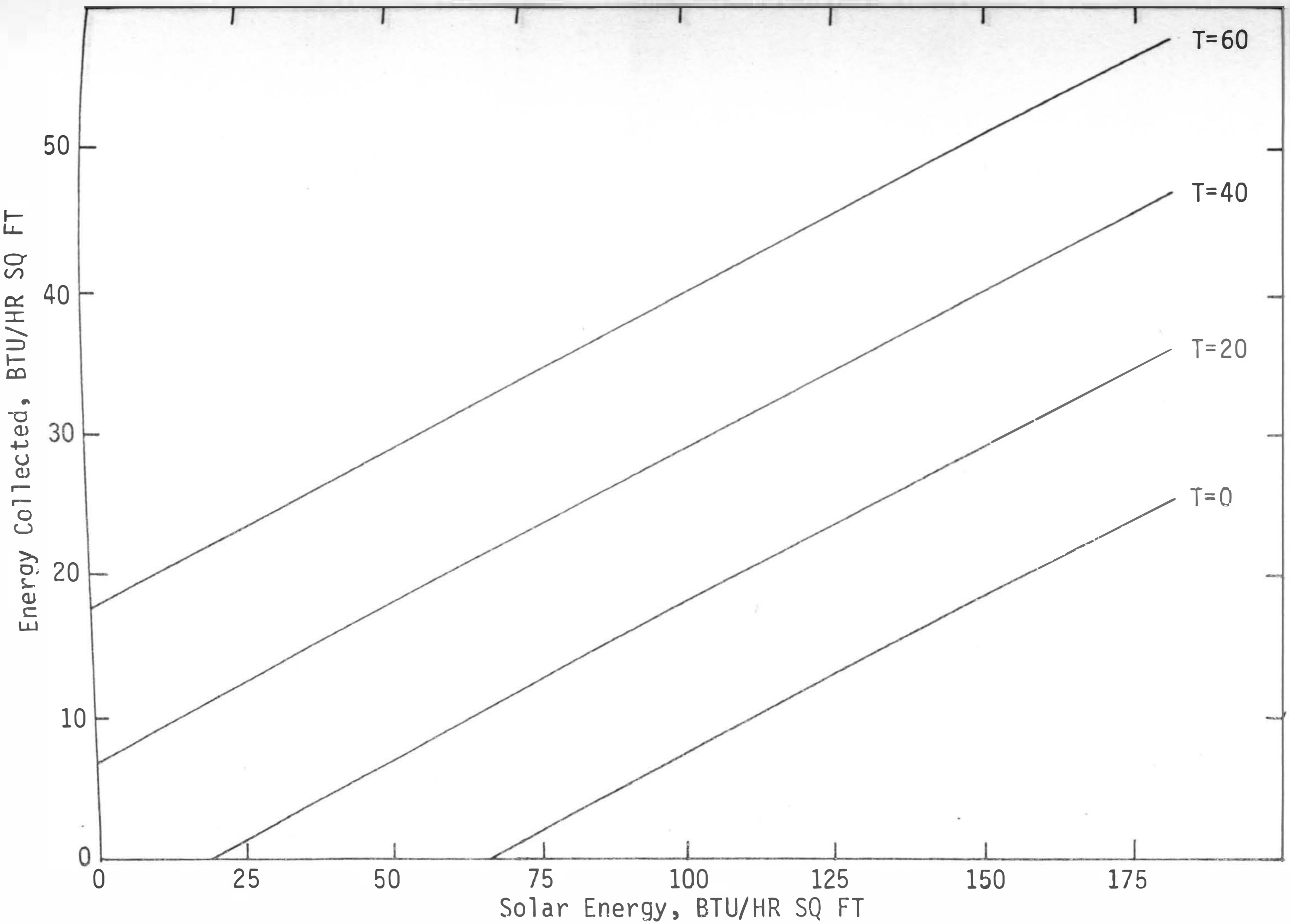

Figure 14. Energy Collected by Roof Collector B as Affected by Incident Solar Energy and Temperature.

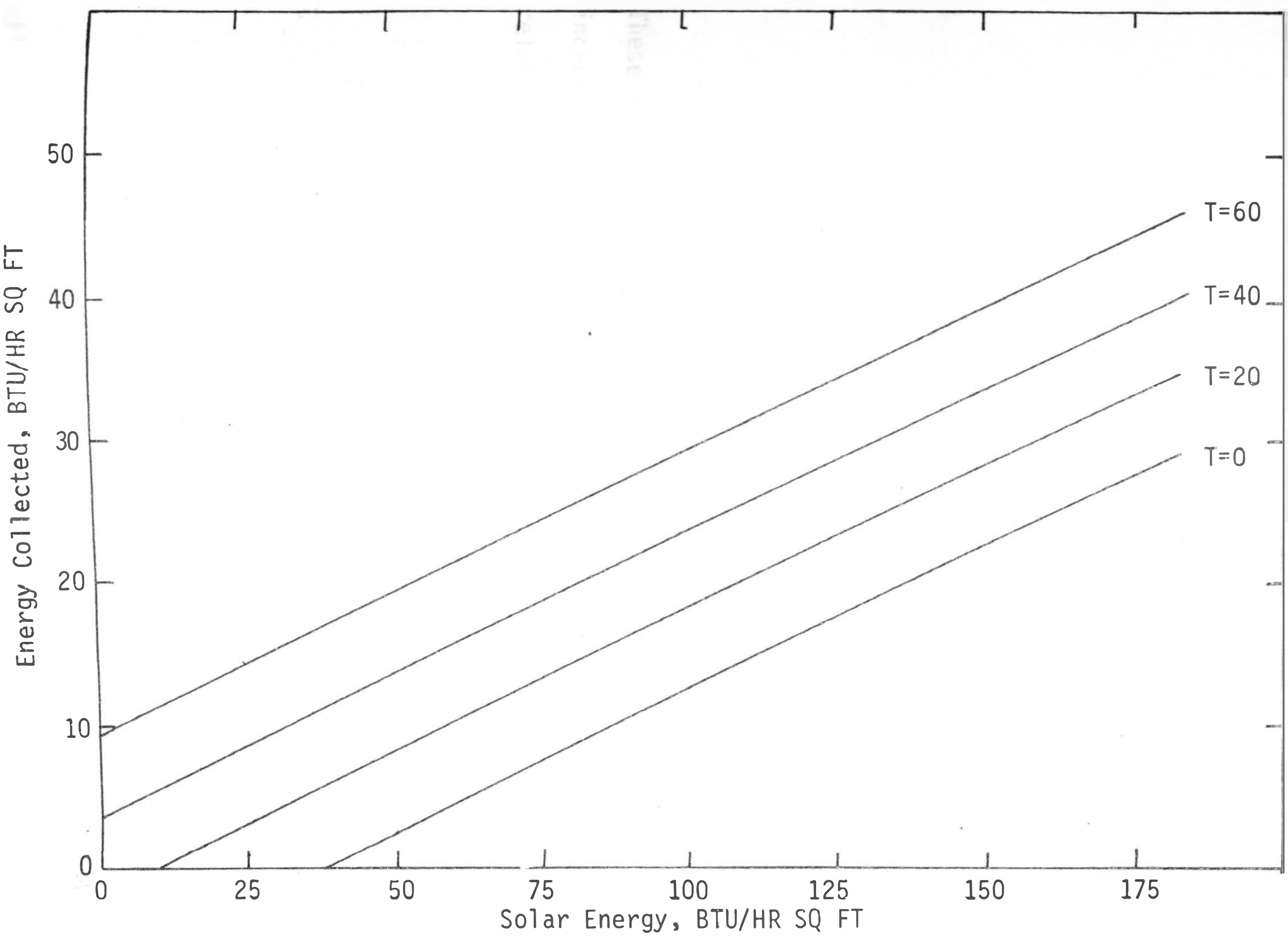

Figure 15. Energy Collected by Combination Sidewall and Roof Collector C as Affected by Incident Solar Energy and Temperature.

$Y_B = -14.79 + 0.22\ X_{SE} + 0.54\ X_T$

Coef of Determination, $(R^2) = 0.54$

Std Error of Estimate: 12.5

$Y_C = -7.40 + 0.20\ X_{SE} + 0.28\ X_T$

Coef of Determination, $(R^2) = 0.43$

Std Error of Estimate: 11.8

Y_B, Y_C = heat collected, Btu/hr sq ft for collectors B and C, respectively

X_{SE} = solar energy on a horizontal surface, Btu/hr sq ft

X_T = outside temperature, F

These relationships indicate an increasing energy collection with an increasing outside temperature. There are several reasons for this relationship:

1) Snow buildup on the roof sections on the various days of the research trials.
2) Frost buildup on the roof sections at various times during the research trials.
3) An improving sun angle for roof collector B and the roof section of combination sidewall and roof collector C that coincides with typically warmer temperatures.

No attempt was made to isolate these factors and to determine the effects. The equations with outside temperature included were used to construct the heat production relationships in Figures 14 and 15. The outside temperature values indicated coincide with ranges of outside temperature values during the research trials. The figures illustrate

that between 0 and 60 F, values of energy collected had a maximum range of 32.4 Btu/hr sq ft for roof collector B, (Figure 14) and a maximum range of 16.8 Btu/hr sq ft for combination sidewall and roof collector C, (Figure 15).

The addition of temperatures as an independent variable increased the coefficient of determination by 14.6 percent for collector B and 5.3 percent for collector C. However, the energy values provided by roof collector B and combination sidewall and roof collector C are considerably less than those provided by sidewall collector A and the added precision is probably not justified in terms of the increased demands for input data and increased equation complexity. Therefore prediction equations utilizing solar incidence as the only independent variable are recommended for most applications.

The average monthly solar radiation data in Appendix C can be used with the prediction equations that contain solar insolation on a horizontal surface as the only independent variable to develop the data in Table 1. Shown in Table 1 are the energy collected per unit area, total energy collected per day, and electricity, kilowatt hours, and propane gas, gallons, equivalents of the total energy collected per day for each collector. Multiplying the daily totals by the days in each month gives the average monthly savings that can be expected from each collector. Summation of the monthly totals gives the amount of energy that can be expected to be saved during this time period.

Figure 16 on electrical energy and Figure 17 on propane gas energy can then be used to estimate the energy savings in dollars once the units of energy saved and the cost per unit of energy are known. The

Table 2. Energy Collected and Electrical and Propane Equivalents.

Month	A		B		C	
	BTU / Day SQ FT	BTU / Day	BTU / Day SQ FT	BTU / Day	BTU / Day SQ FT	BTU / Day
Dec	744.8	71,504	140.2	37,006	117.4	42,279
Jan	989.9	95,034	186.9	49,352	156.1	56,211
Feb	1319.8	126,705	249.9	65,969	208.2	74,964
Mar	1678	161,091	318.2	84,010	271.3	97,657

Month	A		B		C	
	Electrical Equivalent KWH	Propane Equivalent Gal	Electrical Equivalent KWH	Propane Equivalent Gal	Electrical Equivalent KWH	Propane Equivalent Gal
Dec	20.96 (649.76)	.78 (24.18)	10.85 (336.35)	.40 (12.4)	12.39 (384.09)	.46 (14.26)
Jan	27.85 (863.35)	1.03 (31.93)	14.46 (448.26)	.54 (16.74)	16.47 (510.57)	.61 (18.91)
Feb	37.13 (1039.64)	1.38 (38.64)	19.33 (541.24)	.72 (20.16)	21.97 (615.16)	.81 (22.68)
Mar	47.21 (1463.51)	1.75 (54.25)	24.62 (763.22)	.91 (28.21)	28.62 (887.22)	1.06 (32.86)
Total	4016.26	149	2089	77.51	2397	88.71

Electricity = 3412.2 BTU/KW-HR
Propane = 92,000 BTU/gal
Numbers in parenthesis indicates monthly total.

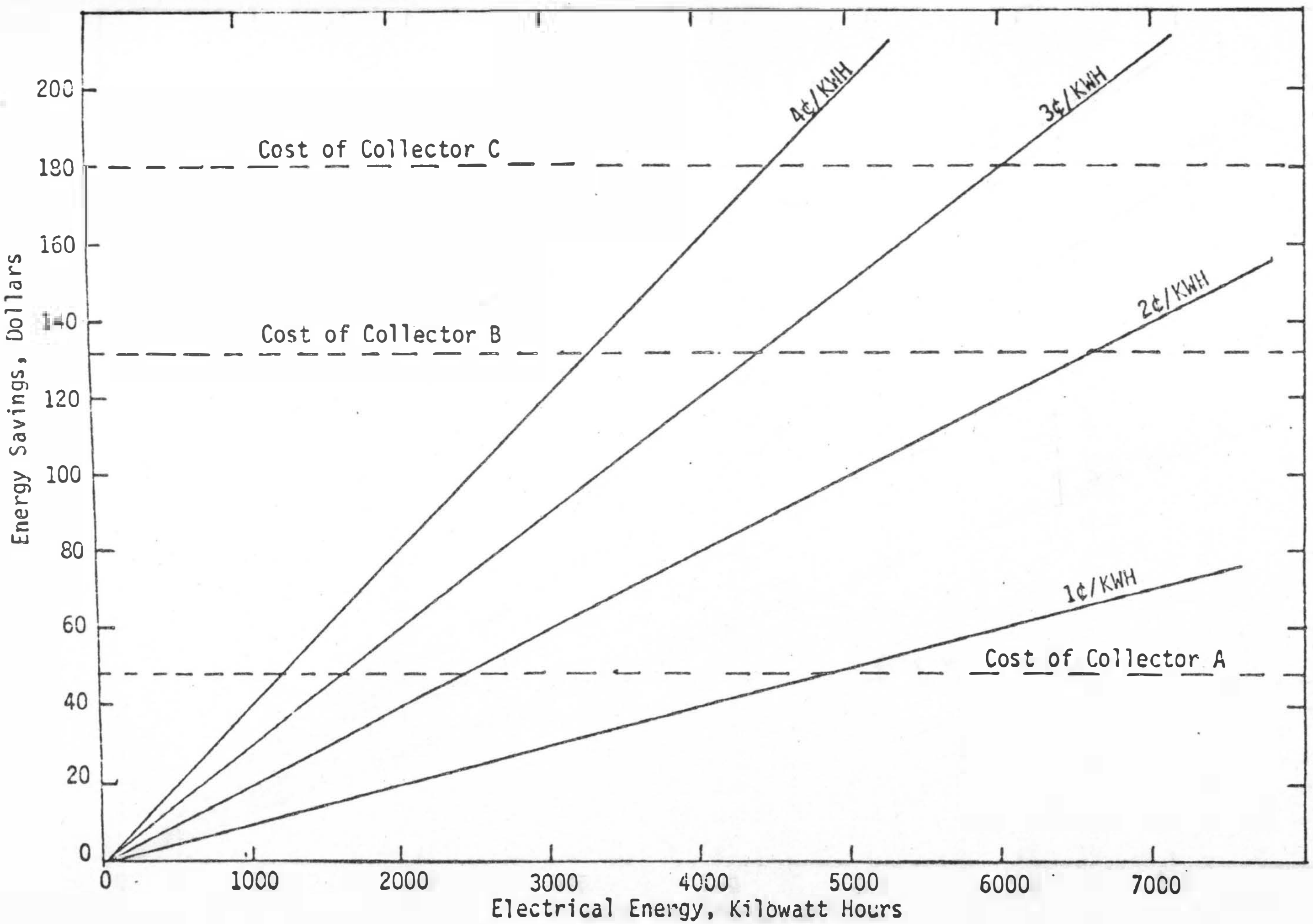

Figure 16. Potential Energy Savings for Collectors A, B, and C at Selected Electrical Rates.

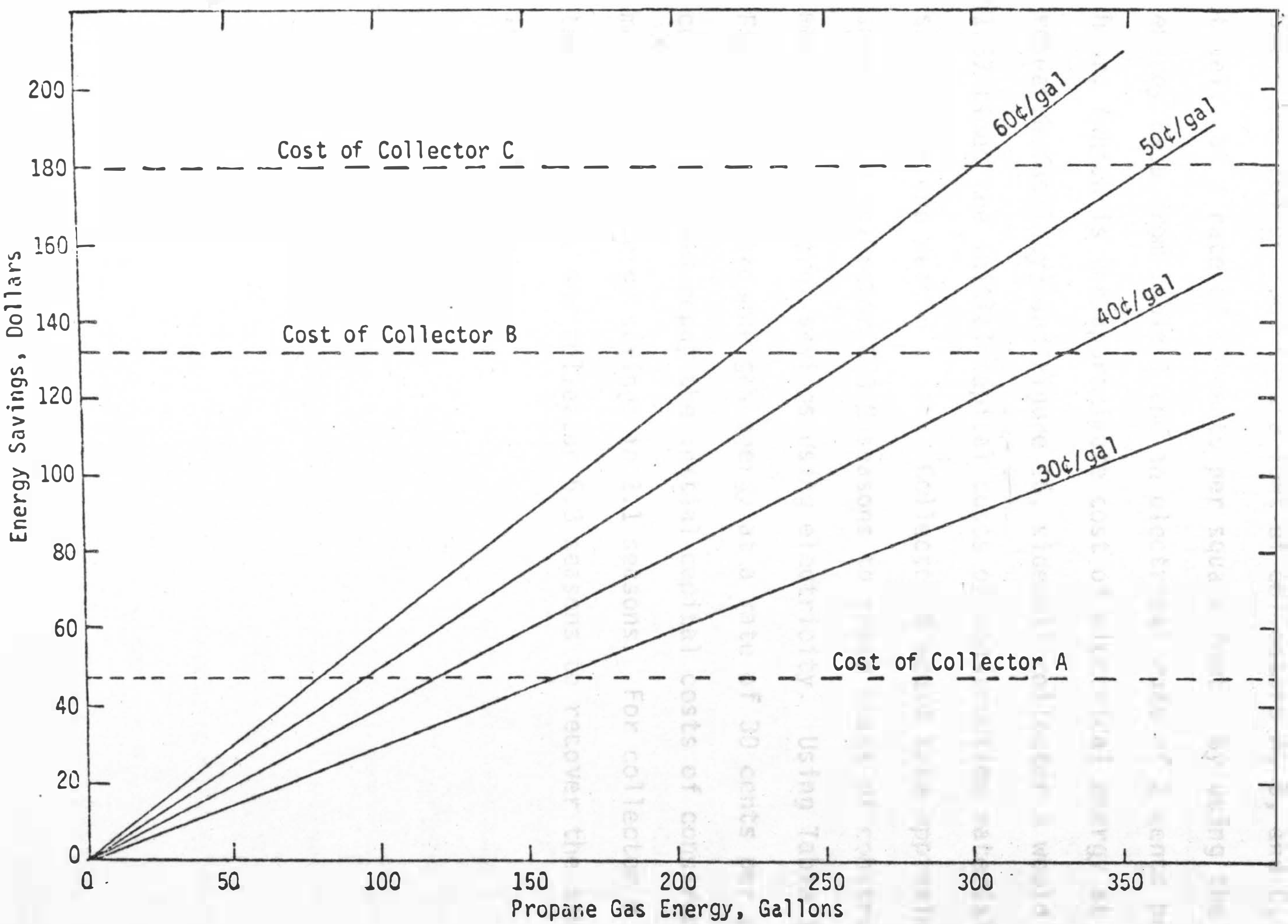

Figure 17. Potential Energy Savings for Collectors A, B, and C at Selected Propane Gas Rates.

dotted lines on Figures 16 and 17 represent the cost of materials to build 96, 264 and 360 square feet of collectors A, B, and C, respectively, at a rate of 50 cents per square foot. By using the total energy data from Table 1 and an electrical rate of 2 cents per kilowatt-hour, (which is the approximate cost of electrical energy at the research facility) and Figure 16, sidewall collector A would repay 1.67 times the initial capital costs of construction materials in energy savings in one season's use. Collector B would take approximately 3.1 seasons and collector C 3.8 seasons to repay costs of construction materials in energy savings using electricity. Using Table 1 and Figure 17 with propane gas energy at a rate of 30 cents per gallon collector A would repay the initial capital costs of construction materials in energy savings in 1.1 seasons. For collector B it would take 5.7 seasons and collector 6.8 seasons to recover the same costs in energy savings.

CONCLUSIONS

The following conclusions were reached during this study:

1. A low-temperature rise, bare plate solar collector constructed on the vertical south wall of a beef confinement building provided significantly more heat per unit of area to the ventilation air than did similar solar collectors constructed along the roof slope or along both the sidewall and roof slope.
2. Average hourly heat collection ranges for the sidewall, roof, and combination sidewall and roof solar collectors, respectively, were: 67.5 to 140.5 Btu/hr sq ft, 9.0 to 25.0 Btu/hr sq ft, and 9.0 to 23.5 Btu/hr sq ft. Average hourly efficiency ranges for the sidewall, roof and combination sidewall and roof solar collectors, respectively, were: 115 to 161 percent, 12 to 38 percent and 12 to 37 percent.
3. Significant, linear and direct relationships, based on solar insolation, accounted for 48, 39, and 38 percent of the variation in energy collected by the sidewall, roof, and combination sidewall and roof collectors, respectively.
4. The sidewall, roof, and combination sidewall and roof collectors are predicted to provide the equivalent of 4016 and 149, 2089 and 78 and 2397 and 89 kilowatt-hours and gallons of electricity and propane, respectively, per heating season.
5. Repayment periods for sidewall, roof, and combination sidewall and roof solar collectors, respectively, were: 0.6 and 1.1, 3.1 and 5.7, and 3.8 and 6.8 heating seasons for electricity

at a rate of 2 cents per kilowatt hour and propane at a rate of 30 cents per gallon, respectively.

SUMMARY

Solar heating appears to be a promising substitute to provide supplemental heat at relatively low temperatures to livestock confinement buildings. Only a limited amount of data on bare-plate solar collector performance as a means of providing low cost supplemental heat to ventilation air is available. Therefore, a study was conducted to evaluate three different types of low cost, low temperature rise, bare-plate solar collectors utilized to preheat ventilation air under actual production and climatic conditions.

A study was conducted at the Grain Terminal Association Feed Division's modern livestock research facility located approximately four miles west of Sioux Falls, South Dakota. Incident solar radiation, outside temperature, temperature at various locations in the solar collectors and airflow rates were monitored from 1000 hours to 1600 hours during December, 1975 through March, 1976.

The bare plate solar collector constructed on the vertical south wall provided significantly more heat to the ventilation air than did similar collectors either along the roof slope or along both the wall and roof slope. The sidewall collector also had the largest average hourly heat collection values per unit of area and the largest average hourly efficiencies of the three collectors evaluated.

Significant, linear and direct prediction equations were developed relating energy collected to solar insolation on a horizontal surface for the sidewall, roof and combination sidewall and roof collectors. From these equations relationships between energy savings in dollars

and the amount of energy that could be saved by each collector type using electricity or propane gas at given costs per unit, were developed.

Results indicated that the sidewall collector would repay the cost of construction materials in the form of energy savings in 0.6 seasons using electricity and 1.1 seasons using propane gas. This compares with 3.1 seasons using electricity and 5.7 seasons using propane gas for the roof solar collector, and 3.8 seasons using electricity and 6.8 seasons using propane for the combination sidewall and roof solar collector.

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APPENDIXES

APPENDIX A

LIST OF SYMBOLS

LIST OF SYMBOLS

Symbol	Description
YR	Year.
MO	Month.
DA	Day.
HR	Hour.
AVOLT	Anemometer voltage for sidewall collector A, V.
BVOLT	Anemometer voltage for roof collector B, V.
CVOLT	Anemometer voltage for combination sidewall and roof collector C, V.
SOLAR	Solar radiation received on a horizontal surface, langleys.
A-VEL	Velocity of the airflow in sidewall collector A, ft/sec.
B-VEL	Velocity of the airflow in roof collector B, ft/sec.
C-VEL	Velocity of the airflow in combination sidewall and roof collector C, ft/sec.
Btu Horizontal	Langleys converted to Btu on a horizontal surface, Btu/hr sq ft.
HEFFA	Efficiency of collector A using solar radiation on a horizontal surface as the denominator.
HEFFB	Efficiency of collector B using solar radiation on a horizontal surface as the denominator.
HEFFC	Efficiency of collector C using solar radiation on a horizontal surface as the denominator.

APPENDIX B

INCIDENT SOLAR RADIATION ON A HORIZONTAL SURFACE
AT THE RESEARCH SITE, MONITORED TEMPERATURE AND
AIRFLOW DATA, AND COLLECTOR EFFICIENCIES

Table B1. Incident Solar Radiation on a Horizontal Surface at the Research Site, Monitored Temperature and Airflow Data, and Collector Efficiencies

TRIAL	YR	MO	DA	HR	AVOLT	BVOLT	CVOLT	SOLAR	A-VEL	B-VEL	C-VEL	BTU HORIZONTAL	HEFFA	HEFFB	HEFFC
1	75	12	8	15	10.75	8.75	9.00	0.08	4.97	0.97	1.48	17.70	1.25	0.18	0.18
2	75	12	15	14	11.15	10.70	10.50	0.40	6.97	4.77	4.09	88.48	2.06	0.14	0.28
3	75	12	15	15	11.35	10.70	10.50	0.26	8.31	4.77	4.09	57.51	1.92	0.17	0.34
4	75	12	16	10	10.75	10.65	10.50	0.35	4.97	4.58	4.09	77.42	1.42	0.01	0.07
5	75	12	16	11	11.00	10.65	10.40	0.45	6.12	4.58	3.80	99.54	0.55	0.10	0.15
6	75	12	16	12	11.20	10.60	10.35	0.48	7.28	4.41	3.67	106.17	2.36	0.12	0.16
7	75	12	16	13	11.00	10.50	10.40	0.45	6.12	4.09	3.80	99.54	2.12	0.15	0.20
8	75	12	16	14	11.00	10.50	10.40	0.37	6.12	4.09	3.80	81.84	1.91	0.13	0.20
9	75	12	16	15	10.80	10.40	10.20	0.19	5.17	3.80	3.31	42.03	2.32	0.27	0.30
10	75	12	16	16	10.80	10.35	10.25	0.03	5.17	3.67	3.43	6.64	4.76	1.22	1.37
11	75	12	22	10	11.65	11.10	11.00	0.10	10.85	6.67	6.12	22.12	0.27	-0.06	-0.04
12	75	12	22	11	11.75	11.15	11.00	0.22	11.84	6.97	6.12	48.66	0.13	-0.09	-0.02
13	75	12	22	12	11.75	11.15	11.00	0.28	11.84	6.97	6.12	61.93	0.95	0.18	0.16
14	75	12	22	13	11.60	11.10	10.80	0.22	10.37	6.67	5.17	48.66	1.66	0.36	0.31
15	75	12	22	14	11.10	10.70	10.50	0.12	6.67	4.77	4.09	26.54	0.84	0.29	0.27
16	75	12	22	15	11.00	10.75	10.35	0.08	6.12	4.97	3.67	17.70	1.54	0.45	0.34
17	75	12	22	16	11.00	10.75	10.35	0.04	6.12	4.97	3.67	8.85	0.77	0.22	0.37
18	75	12	23	11	11.40	11.05	11.00	0.26	8.68	6.39	6.12	57.51	0.59	0.09	0.11
19	75	12	23	12	11.40	11.05	11.00	0.24	8.68	6.39	6.12	53.09	0.82	0.17	0.19
20	75	12	29	10	11.60	11.05	10.85	0.36	10.37	6.39	5.39	79.63	2.67	-0.05	0.01
21	75	12	29	11	12.10	11.40	11.10	0.52	15.86	8.68	6.67	115.02	2.30	0.17	0.27
22	75	12	29	11	12.40	11.50	11.40	0.51	20.30	9.48	8.68	112.81	3.20	0.34	0.50
23	75	12	29	11	10.15	9.55	9.65	0.36	3.21	2.27	2.40	79.63	0.85	0.14	0.17
24	75	12	29	12	11.35	11.05	10.70	0.56	8.31	6.39	4.77	123.87	1.94	0.37	0.26
25	75	12	29	13	11.35	10.85	10.60	0.40	8.31	5.39	4.41	88.48	1.98	0.30	0.30
26	75	12	29	14	11.65	11.10	10.75	0.41	10.85	6.67	4.97	90.69	2.72	0.37	0.40
27	75	12	29	14	12.00	11.35	11.00	0.38	14.61	8.31	6.12	84.05	3.95	0.53	0.55
28	75	12	29	14	12.15	11.50	11.30	0.37	16.53	9.48	7.95	81.84	2.91	0.30	0.53
29	75	12	29	14	12.20	11.60	11.35	0.42	17.22	10.37	8.31	92.90	2.06	0.56	0.61
30	75	12	29	14	10.30	9.80	9.75	0.35	3.54	2.61	2.54	77.42	1.19	0.19	0.20
31	75	12	29	16	11.75	11.00	10.65	0.14	11.84	6.12	4.58	30.97	3.18	0.51	0.50
32	76	1	8	10	10.80	10.05	9.95	0.40	5.17	3.02	2.84	88.48	0.68	-0.05	-0.00
33	76	1	8	11	10.80	10.10	9.95	0.49	5.17	3.11	2.84	108.38	1.51	0.12	0.11
34	76	1	8	12	10.80	10.05	9.95	0.53	5.17	3.02	2.84	117.23	1.03	0.08	0.12
35	76	1	8	14	10.80	10.40	9.75	0.47	5.17	3.80	2.54	103.96	0.99	0.09	0.11
36	76	1	8	15	11.00	10.25	10.10	0.42	6.12	3.43	3.11	92.90	1.10	0.04	0.11
37	76	1	8	16	10.80	10.25	10.10	0.25	5.17	3.43	3.11	55.30	1.92	0.15	0.20
38	76	1	13	10	10.90	10.75	10.60	0.38	5.62	4.97	4.41	84.05	1.49	0.12	0.11
39	76	1	13	11	11.40	10.80	10.50	0.46	8.68	5.17	4.09	101.75	2.60	0.32	0.25
40	76	1	13	12	11.40	10.90	10.65	0.52	8.68	5.62	4.58	115.02	2.05	0.24	0.25
41	76	1	13	13	10.75	10.55	10.15	0.52	4.97	4.24	3.21	115.02	1.41	0.19	0.16
42	76	1	13	14	10.75	10.10	10.00	0.43	4.97	3.11	2.93	95.11	1.68	0.19	0.13
43	76	1	13	15	10.75	10.30	10.10	0.33	4.97	3.54	3.11	72.99	1.93	0.25	0.22
44	76	1	13	16	10.80	10.60	10.40	0.17	5.17	4.41	3.80	37.60	2.14	0.30	0.31
45	76	1	15	10	11.40	10.80	10.60	0.22	8.68	5.17	4.41	48.66	2.77	0.17	0.17

Table B1. Continued

TRIAL	YR	MO	DA	HR	AVOLT	BVOLT	CVOLT	SOLAR	A-VEL	B-VEL	C-VEL	BTU HORIZONTAL	HEFFA	HEFFB	HEFFC
46	76	1	15	11	11.35	10.80	10.55	0.20	8.31	5.17	4.24	44.24	0.73	0.16	0.14
47	76	1	15	12	11.25	10.75	10.45	0.19	7.61	4.97	3.94	42.03	0.60	0.14	0.10
48	76	1	15	13	11.10	10.50	10.35	0.09	6.67	4.09	3.67	19.91	0.74	0.29	0.30
49	76	1	15	14	10.95	10.75	10.20	0.20	5.87	4.97	3.31	44.24	0.37	0.13	0.09
50	76	1	15	15	10.90	10.70	10.15	0.12	5.62	4.77	3.21	26.54	0.47	0.40	0.27
51	76	1	15	16	10.80	10.60	10.10	0.04	5.17	4.41	3.11	8.85	0.0	0.30	0.26
52	76	1	20	10	11.35	10.90	10.60	0.44	8.31	5.62	4.41	97.32	1.99	0.17	0.23
53	76	1	20	11	11.08	10.85	10.55	0.45	6.56	5.39	4.24	99.54	1.43	0.15	0.23
54	76	1	20	12	11.20	10.80	10.50	0.42	7.28	5.17	4.09	92.90	0.74	0.21	0.18
55	76	1	20	13	11.05	10.70	10.45	0.42	6.39	4.77	3.94	92.90	0.38	0.21	0.18
56	76	1	20	14	10.90	10.60	10.40	0.34	5.62	4.41	3.80	75.20	0.71	0.12	0.11
57	76	1	20	15	11.20	10.80	10.50	0.32	7.28	5.17	4.09	70.78	0.40	0.09	0.09
58	76	1	20	16	11.50	11.00	10.60	0.18	9.48	6.12	4.41	39.81	0.40	0.31	0.21
59	76	1	22	10	11.35	10.90	10.70	0.10	8.31	5.62	4.77	22.12	1.67	0.25	0.22
60	76	1	22	11	11.30	10.90	10.70	0.18	7.95	5.62	4.77	39.81	0.89	0.17	0.14
61	76	1	22	12	11.20	10.90	10.50	0.20	7.28	5.62	4.09	44.24	0.64	0.15	0.11
62	76	1	22	13	11.25	10.95	10.50	0.11	7.61	5.87	4.09	24.33	0.87	0.24	0.20
63	76	1	22	14	11.25	11.00	10.45	0.16	7.61	6.12	3.94	35.39	0.60	0.17	0.11
64	76	1	22	15	11.50	11.20	10.70	0.12	9.48	7.28	4.77	26.54	0.79	0.11	0.11
65	76	1	22	16	11.75	11.35	10.90	0.08	11.84	8.31	5.62	17.70	0.74	0.19	0.19
66	76	1	24	9	11.35	10.90	10.60	0.16	8.31	5.62	4.41	35.39	1.69	-0.19	-0.09
67	76	1	24	10	11.40	10.90	10.60	0.37	8.68	5.62	4.41	81.84	0.53	-0.12	-0.06
68	76	1	24	11	11.40	10.90	10.60	0.51	8.68	5.62	4.41	112.81	1.71	0.19	0.08
69	76	1	24	12	11.40	10.90	10.60	0.56	8.68	5.62	4.41	123.87	1.48	0.21	0.15
70	76	1	24	13	11.25	10.90	10.60	0.56	7.61	5.62	4.41	123.87	1.33	0.25	0.17
71	76	1	24	14	11.25	10.90	10.60	0.47	7.61	5.62	4.41	103.96	1.26	0.35	0.26
72	76	1	24	15	11.05	10.90	10.60	0.32	6.39	5.62	4.41	70.78	0.95	0.35	0.30
73	76	1	27	10	11.05	10.75	10.80	0.36	6.39	4.97	5.17	79.63	0.80	0.17	0.16
74	76	1	27	11	11.20	10.95	10.70	0.50	7.28	5.87	4.77	110.60	1.32	0.30	0.27
75	76	1	27	12	11.30	11.10	10.60	0.58	7.95	6.67	4.41	128.29	1.44	0.30	0.24
76	76	1	27	13	11.20	11.10	10.45	0.59	7.28	6.67	3.94	130.50	1.27	0.31	0.23
77	76	1	27	14	11.10	11.10	10.30	0.52	6.67	6.67	3.54	115.02	1.32	0.30	0.21
78	76	1	27	15	11.20	11.10	10.40	0.40	7.28	6.67	3.80	88.48	1.46	0.36	0.26
79	76	1	27	16	11.30	11.10	10.50	0.23	7.95	6.67	4.09	50.87	1.91	0.45	0.33
80	76	1	29	10	11.40	11.10	10.80	0.40	8.68	6.67	5.17	88.48	1.42	0.23	0.22
81	76	1	29	11	11.50	11.10	10.80	0.51	9.48	6.67	5.17	112.81	1.77	0.27	0.26
82	76	1	29	12	11.60	11.10	10.80	0.57	10.37	6.67	5.17	126.08	2.01	0.33	0.29
83	76	1	29	13	11.65	11.15	10.85	0.58	10.85	6.97	5.39	128.29	2.30	0.38	0.35
84	76	1	29	14	11.70	11.20	10.90	0.52	11.33	7.28	5.62	115.02	2.02	0.37	0.38
85	76	1	29	15	11.65	11.10	10.85	0.40	10.85	6.67	5.39	88.48	1.84	0.29	0.30
86	76	1	29	16	11.60	11.00	10.80	0.24	10.37	6.12	5.17	53.09	2.60	0.32	0.32
87	76	2	3	10	11.60	11.00	10.80	0.48	10.37	6.12	5.17	106.17	1.30	0.07	0.05
88	76	2	3	11	11.55	10.90	10.70	0.56	9.91	5.62	4.77	123.87	1.47	0.13	0.11
89	76	2	3	12	11.50	10.80	10.60	0.60	9.48	5.17	4.41	132.71	1.59	0.09	0.12
90	76	2	3	13	11.05	10.70	10.40	0.20	6.39	4.77	3.80	44.24	0.48	0.37	0.30

Table B1. Continued

TRIAL	YR	MO	DA	HR	AVOLT	BVOLT	CVOLT	SOLAR	A-VEL	B-VEL	C-VEL	BTU HORIZONTAL	HEFFA	HEFFB	HEFFC
91	76	2	3	14	10.60	10.60	10.20	0.26	4.41	4.41	3.31	57.51	0.21	0.18	0.16
92	76	2	3	15	10.75	10.60	10.10	0.20	4.97	4.41	3.11	44.24	0.37	0.22	0.17
93	76	2	3	16	10.90	10.60	10.00	0.20	5.62	4.41	2.93	44.24	1.48	0.24	0.18
94	76	2	5	10	11.20	10.70	10.50	0.37	7.28	4.77	4.09	81.84	0.74	0.0	0.05
95	76	2	5	11	11.10	10.60	10.45	0.37	6.67	4.41	3.94	81.84	0.59	0.0	0.06
96	76	2	5	12	11.00	10.50	10.40	0.53	6.12	4.09	3.80	117.23	0.52	-0.03	0.03
97	76	2	5	13	11.00	10.50	10.40	0.58	6.12	4.09	3.80	128.29	0.64	0.06	0.05
98	76	2	5	14	11.00	10.50	10.40	0.40	6.12	4.09	3.80	88.48	0.65	0.17	0.18
99	76	2	5	15	11.20	10.60	10.40	0.42	7.28	4.41	3.80	92.90	1.78	0.09	0.13
100	76	2	5	16	11.40	10.70	10.40	0.16	8.68	4.77	3.80	35.39	0.95	0.22	0.35
101	76	2	10	10	11.40	11.10	10.90	0.10	8.68	6.67	5.62	22.12	0.22	0.18	0.15
102	76	2	10	11	11.10	11.10	11.35	0.32	6.67	6.67	8.31	70.78	0.37	0.17	0.19
103	76	2	10	12	10.80	11.10	11.80	0.70	5.17	6.67	12.35	154.83	0.70	0.21	0.31
104	76	2	10	13	11.25	11.15	11.40	0.36	7.61	6.97	8.68	79.63	0.42	0.26	0.34
105	76	2	10	14	11.70	11.20	11.00	0.40	11.33	7.28	6.12	88.48	2.13	0.25	0.16
106	76	2	10	15	11.70	11.20	11.00	0.40	11.33	7.28	6.12	88.48	1.85	0.40	0.23
107	76	2	10	16	11.70	11.20	11.00	0.38	11.33	7.28	6.12	84.05	1.87	0.36	0.29
108	76	2	17	10	11.70	11.30	11.00	0.10	11.33	7.95	6.12	22.12	0.85	0.43	0.24
109	76	2	17	11	11.70	11.30	11.00	0.12	11.33	7.95	6.12	26.54	0.95	0.36	0.27
110	76	2	17	12	11.70	11.30	11.00	0.18	11.33	7.95	6.12	39.81	0.79	0.28	0.18
111	76	2	17	13	11.65	11.30	11.05	0.19	10.85	7.95	6.39	42.03	0.57	0.42	0.27
112	76	2	17	14	11.60	11.30	11.10	0.18	10.37	7.95	6.67	39.81	0.72	0.40	0.35
113	76	2	24	10	11.70	11.20	11.00	0.55	11.33	7.28	6.12	121.65	1.65	0.34	0.30
114	76	2	24	11	12.00	11.45	11.15	0.66	14.61	9.07	6.97	145.99	2.33	0.55	0.40
115	76	2	24	12	12.30	11.70	11.30	0.70	18.69	11.33	7.95	154.83	2.28	0.64	0.51
116	76	2	24	13	11.95	11.45	11.15	0.72	14.01	9.07	6.97	159.26	1.76	0.47	0.44
117	76	2	24	14	11.60	11.20	11.00	0.67	10.37	7.28	6.12	148.20	1.67	0.50	0.44
118	76	2	24	15	11.60	11.20	10.95	0.58	10.37	7.28	5.87	128.29	2.02	0.47	0.42
119	76	2	24	16	11.60	11.20	10.90	0.40	10.37	7.28	5.62	88.48	1.89	0.54	0.43
120	76	3	9	11	11.00	10.50	10.00	0.50	6.12	4.09	2.93	110.60	0.34	-0.02	-0.02
121	76	3	9	12	10.30	10.00	9.90	0.72	3.54	2.93	2.76	159.26	0.42	0.0	0.0
122	76	3	9	13	10.45	10.10	10.00	0.49	3.94	3.11	2.93	108.38	0.75	0.22	0.11
123	76	3	9	14	10.60	10.20	10.10	0.48	4.41	3.31	3.11	106.17	0.65	0.21	0.12
124	76	3	9	15	10.70	10.20	10.05	0.31	4.77	3.31	3.02	68.57	0.93	0.35	0.20
125	76	3	9	16	10.80	10.20	10.00	0.12	5.17	3.31	2.93	26.54	0.43	0.40	0.29
126	76	3	18	10	11.60	11.20	10.90	0.63	10.37	7.28	5.62	139.35	0.91	0.26	0.15
127	76	3	18	11	11.60	11.10	10.85	0.75	10.37	6.67	5.39	165.89	1.04	0.29	0.19
128	76	3	18	12	11.60	11.00	10.80	0.82	10.37	6.12	5.17	181.38	0.79	0.22	0.16
129	76	3	18	13	11.60	11.10	10.85	0.55	10.37	6.67	5.39	121.65	0.85	0.33	0.22
130	76	3	18	14	11.60	11.20	10.90	0.55	10.37	7.28	5.62	121.65	0.95	0.41	0.24
131	76	3	18	15	11.60	11.20	10.90	0.62	10.37	7.28	5.62	137.14	0.88	0.28	0.16
132	76	3	18	16	11.60	11.20	10.90	0.33	10.37	7.28	5.62	72.99	0.79	0.40	0.27

Table B1. Continued

TEMPERATURES

TRIAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	41.5	38.0	39.5	40.0	42.5	42.0	41.5	40.5	36.0	38.0	35.5	35.0	36.0	37.0	38.0	37.5	36.5	34.0
2	39.5	40.5	40.0	44.5	25.5	25.5	27.0	24.5	18.0	37.0	34.5	24.5	30.0	25.0	42.5	26.5	18.0	19.0
3	35.0	30.5	33.5	35.0	24.0	24.0	25.0	22.0	17.0	27.5	23.5	29.5	20.0	17.5	31.0	22.0	15.5	19.0
4	19.0	23.5	22.0	27.0	14.5	15.0	15.5	16.5	15.5	30.5	31.0	22.5	24.0	21.5	34.5	21.5	14.0	14.5
5	25.5	30.5	28.0	33.5	18.0	18.0	18.5	19.5	16.5	35.0	35.0	26.0	31.0	33.5	20.5	31.0	23.5	12.5
6	29.0	32.0	30.5	36.0	21.5	21.0	21.5	21.0	18.5	38.0	38.5	28.0	31.5	27.5	44.5	29.0	16.5	13.5
7	30.0	31.0	31.0	36.5	22.0	21.5	22.0	21.5	22.0	39.0	36.5	28.5	32.5	25.5	43.5	29.5	20.5	12.5
8	28.0	28.0	27.5	31.5	21.0	20.0	19.5	18.5	15.5	33.0	32.0	23.5	27.0	25.5	36.5	21.5	16.5	13.5
9	22.0	20.0	21.5	24.0	17.5	16.5	16.0	15.0	13.0	20.5	18.5	12.5	14.0	12.0	26.0	17.5	12.5	9.0
10	14.5	11.5	13.0	13.0	12.0	11.0	10.0	9.0	9.0	13.0	9.5	9.0	9.5	8.0	11.0	8.0	10.5	5.5
11	24.0	24.0	24.0	25.0	23.5	24.0	23.5	22.5	22.5	22.5	23.0	23.0	22.0	23.5	25.0	26.0	25.0	24.5
12	27.5	27.5	27.0	28.0	26.5	26.5	26.5	25.5	24.5	26.0	26.0	26.0	25.0	25.0	28.5	28.0	26.0	28.0
13	30.0	31.0	29.0	30.5	28.5	28.5	28.0	26.5	24.0	28.5	28.5	27.5	26.5	26.5	29.0	28.0	27.0	24.5
14	33.0	31.0	31.0	32.0	30.0	29.5	29.5	26.0	23.5	27.0	25.0	25.0	24.5	25.0	30.0	26.0	26.5	23.0
15	29.5	28.0	28.5	29.0	27.5	27.5	27.5	25.0	22.5	25.5	26.0	24.0	24.5	23.5	26.5	24.5	24.5	23.5
16	27.5	26.0	26.5	26.5	26.0	26.0	26.0	24.5	22.5	25.0	25.0	25.0	25.5	24.5	26.0	24.0	25.0	22.0
17	26.5	25.0	25.5	26.0	25.0	24.5	24.0	23.0	22.5	25.5	25.5	24.0	24.5	23.0	24.5	24.0	27.0	23.5
18	20.0	20.0	19.5	20.5	18.5	18.5	18.5	16.5	16.5	18.0	17.5	15.5	16.5	17.5	20.0	21.5	18.5	16.5
19	22.5	23.0	22.0	23.0	20.5	20.5	20.5	18.0	17.5	19.5	18.0	17.0	18.0	19.5	21.5	21.0	18.5	17.0
20	27.0	30.0	28.0	32.5	25.0	25.0	25.0	24.0	24.5	37.0	32.5	30.0	28.5	28.0	45.0	30.0	26.5	26.5
21	46.0	48.0	43.5	47.0	35.5	35.5	36.5	31.0	24.0	39.5	36.0	33.0	34.5	31.0	45.0	29.0	23.0	30.0
22	52.0	53.5	48.0	53.0	39.5	40.0	40.5	32.0	23.0	42.0	40.5	33.5	32.0	32.5	46.0	35.0	29.5	30.0
23	50.0	50.5	47.0	52.0	42.5	43.5	42.0	39.5	33.0	45.5	46.0	39.5	40.5	36.0	50.0	40.0	29.0	31.0
24	53.5	57.0	52.0	59.0	47.5	48.5	48.5	40.5	29.0	53.5	55.0	45.0	49.0	39.0	56.5	39.5	29.0	30.5
25	54.5	47.5	49.0	51.5	46.0	46.5	47.5	42.0	34.0	46.5	43.0	39.0	43.0	37.0	53.0	40.0	32.5	34.0
26	61.0	58.5	56.0	61.0	50.0	49.0	50.5	41.0	32.5	53.0	50.5	42.5	43.5	40.5	57.0	42.5	37.0	36.5
27	60.0	58.0	55.0	59.0	48.5	48.0	49.0	40.0	32.0	51.0	46.5	40.0	43.0	39.5	55.0	41.5	36.5	34.5
28	58.5	57.0	54.5	57.0	47.5	46.5	47.5	39.5	32.0	49.0	45.5	41.0	41.0	40.0	53.0	43.0	39.0	40.0
29	58.0	56.5	54.0	56.5	47.5	47.5	48.0	41.0	34.0	45.5	39.5	47.0	38.5	39.0	45.0	36.5	34.0	35.0
30	55.0	52.5	51.5	52.0	48.0	48.5	48.0	44.0	36.0	50.0	47.5	42.0	53.0	47.5	58.0	48.0	40.5	34.5
31	41.5	38.0	39.0	38.0	36.5	36.5	36.5	33.5	30.5	39.0	40.5	37.5	37.0	34.0	37.5	33.0	33.0	30.0
32	5.0	6.5	4.5	8.5	-1.0	1.5	2.5	1.0	-3.0	10.0	13.5	3.5	17.0	0.5	16.0	5.0	-5.0	5.5
33	12.0	13.0	12.0	18.0	5.0	8.0	10.0	8.0	2.0	19.5	15.0	12.5	28.5	10.5	26.0	9.5	-1.0	-2.5
34	22.5	24.0	22.5	28.0	11.0	13.5	15.0	14.5	9.0	31.5	35.5	27.0	26.0	16.0	26.5	15.0	7.0	5.5
35	23.5	20.0	20.0	24.0	12.5	14.5	16.5	13.0	5.5	23.0	20.5	12.0	33.5	10.0	26.5	12.5	4.5	8.5
36	23.0	21.0	20.0	23.5	12.5	14.5	16.5	12.5	6.0	23.5	26.0	23.0	26.0	10.5	27.0	12.5	7.5	12.0
37	16.0	12.0	14.0	14.0	9.0	10.0	11.0	7.5	2.5	12.0	10.0	10.5	9.0	5.0	22.5	8.5	3.0	4.0
38	37.0	45.0	37.5	45.5	33.5	35.0	33.5	36.5	34.0	46.0	42.0	32.0	39.0	32.0	50.0	35.5	32.5	30.0
39	51.0	55.0	50.0	58.5	45.0	45.0	45.5	40.0	30.5	50.5	49.5	38.5	46.5	38.0	57.0	42.5	30.5	29.5
40	55.5	57.0	53.5	61.5	46.5	47.0	48.5	42.5	35.0	54.0	53.0	44.0	50.0	43.5	59.0	43.5	35.5	34.5
41	49.5	49.5	48.5	53.0	43.5	43.0	44.5	37.5	32.5	53.5	55.0	43.0	53.0	42.0	59.5	43.0	34.0	30.0
42	43.5	44.5	45.5	48.5	42.5	43.5	44.0	40.5	34.0	54.5	56.5	45.0	51.0	39.0	58.0	41.5	33.0	29.0
43	40.0	38.5	40.0	42.0	35.5	35.5	37.0	32.0	26.5	40.0	39.5	27.5	35.0	34.0	48.0	33.5	28.5	22.5
44	33.0	32.0	31.5	31.5	30.0	29.0	30.5	27.0	24.0	31.5	29.0	29.5	29.0	25.5	36.5	35.5	22.0	22.5
45	43.5	47.5	45.0	50.5	41.5	41.0	42.0	42.0	38.5	52.0	55.0	48.0	51.0	46.0	51.0	42.0	38.0	37.0

Table B1. Continued

TEMPERATURES

TRIAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
46	40.0	40.5	40.5	42.0	38.5	38.5	38.5	38.0	36.0	38.5	39.5	37.5	38.0	38.5	38.5	37.0	35.5	35.0
47	38.0	38.0	38.0	38.5	37.5	37.5	37.5	37.0	35.5	37.5	37.0	36.0	37.5	38.0	37.5	36.0	34.5	34.5
48	38.0	37.5	37.5	38.0	36.0	36.0	36.5	35.5	34.5	35.5	35.0	34.5	34.5	34.5	34.5	33.5	32.5	32.5
49	35.0	34.5	35.0	35.5	34.0	34.0	34.5	33.0	31.0	33.5	33.0	32.5	34.0	33.5	33.5	32.0	31.0	31.0
50	34.5	33.5	34.0	34.5	32.5	32.5	32.5	30.5	29.0	30.5	30.0	29.5	29.0	30.5	29.0	27.5	26.5	27.0
51	27.5	26.0	27.0	28.0	26.5	26.5	27.0	25.5	24.5	25.5	24.5	24.5	24.5	24.5	25.0	24.0	23.5	25.0
52	30.5	33.5	29.0	29.0	22.0	21.0	21.5	17.0	12.0	30.0	32.0	22.5	33.0	38.0	34.5	26.0	18.0	13.5
53	39.5	42.0	37.0	38.5	30.5	28.5	31.0	25.5	17.5	34.0	37.5	25.0	36.0	38.5	41.0	29.5	22.0	21.5
54	38.5	35.0	35.5	37.0	35.5	34.5	35.0	30.5	26.5	34.0	32.0	28.0	31.0	33.0	33.5	28.0	25.0	25.0
55	42.0	38.0	38.5	39.5	38.5	37.5	38.0	32.0	27.0	36.0	33.5	29.0	30.5	31.0	32.5	29.5	27.5	27.5
56	39.0	36.0	36.5	37.5	36.5	36.5	37.0	33.5	29.5	34.0	34.5	31.0	35.0	37.5	40.0	35.5	31.5	31.5
57	40.0	37.5	37.5	38.0	37.0	37.5	38.0	35.5	33.5	37.0	40.5	35.5	39.5	36.5	38.0	36.0	34.5	34.5
58	40.0	40.0	39.0	39.0	38.0	38.5	38.5	36.0	34.5	37.0	34.5	33.5	35.5	34.0	35.0	33.5	32.5	33.5
59	25.0	24.5	24.5	25.0	24.0	24.0	23.5	23.0	22.0	24.5	24.0	23.0	23.5	25.5	25.5	25.0	24.0	21.5
60	26.5	26.5	26.0	26.5	25.5	25.5	25.5	24.5	23.5	25.0	24.5	24.5	25.5	27.0	26.5	25.5	25.0	22.5
61	28.0	27.5	27.5	27.5	27.0	27.0	26.5	25.5	24.0	27.0	25.5	25.5	26.5	26.5	27.5	26.5	27.0	24.0
62	29.0	29.0	28.0	28.0	28.0	27.5	27.5	26.5	25.0	28.0	26.5	27.0	27.5	27.0	27.5	27.0	27.0	25.0
63	30.5	29.0	30.0	30.0	29.5	29.5	29.5	27.5	26.5	28.5	28.0	28.0	28.0	28.5	29.5	28.0	28.0	27.0
64	30.5	29.5	30.0	30.0	29.5	29.5	29.5	28.5	27.5	29.5	29.5	29.5	29.0	29.5	30.5	30.0	29.5	28.5
65	31.5	30.5	31.0	31.0	30.5	30.5	30.5	30.0	29.0	30.5	30.0	30.0	30.0	30.0	30.5	30.5	30.5	29.5
66	23.5	25.5	24.5	25.0	23.0	23.0	23.0	23.5	24.0	28.0	31.5	27.5	33.5	33.0	32.5	29.0	25.5	26.0
67	25.5	25.5	26.0	27.5	25.0	25.0	25.0	25.5	25.0	28.5	30.0	29.5	35.5	33.5	34.0	33.5	30.0	29.5
68	37.5	41.0	39.0	41.0	38.5	40.0	40.0	38.0	33.5	44.0	46.5	44.0	0.0	50.0	50.5	42.5	31.5	30.5
69	53.0	52.5	51.0	52.5	49.0	50.5	50.5	46.0	38.5	51.0	52.5	45.0	59.0	56.0	58.0	48.0	40.0	39.0
70	56.0	59.0	55.0	58.0	53.0	54.0	53.5	47.5	40.5	54.0	54.5	48.5	60.0	57.5	59.5	47.5	41.5	40.0
71	61.0	59.5	59.0	62.0	56.0	56.0	56.0	53.5	41.0	50.5	51.5	46.0	56.0	53.0	55.5	45.0	42.5	40.0
72	51.5	48.0	49.0	51.0	46.5	46.0	47.0	41.5	36.5	43.0	38.5	36.0	37.0	39.5	44.5	39.0	36.5	35.0
73	22.5	25.0	22.0	23.0	21.5	21.0	21.0	16.5	10.0	23.5	22.5	19.5	24.0	23.5	23.0	21.5	15.0	14.0
74	38.5	37.0	35.0	36.0	31.5	31.0	32.0	25.0	17.0	34.0	33.5	30.5	35.0	34.5	35.0	30.0	23.0	17.0
75	45.0	41.0	40.5	40.0	35.5	35.5	36.0	29.5	21.0	37.5	39.0	34.5	42.0	38.5	42.0	35.0	30.5	21.0
76	47.0	44.0	43.0	41.5	37.0	36.5	36.5	29.0	22.5	38.0	39.0	35.0	40.0	37.5	42.0	33.0	27.5	21.5
77	48.0	43.0	43.0	42.0	38.0	38.0	38.0	32.0	25.0	39.5	38.5	35.5	45.0	40.0	45.5	37.0	33.5	25.0
78	46.5	42.5	42.5	41.0	37.5	38.0	37.5	32.5	27.5	39.5	38.0	38.5	41.0	36.5	42.0	34.5	32.0	26.0
79	40.5	37.5	37.0	37.5	35.0	35.0	34.5	30.0	26.5	33.0	34.0	32.5	36.0	31.5	37.5	30.5	28.0	26.5
80	45.5	48.5	45.0	45.5	40.5	40.0	40.0	36.0	32.0	43.5	44.0	43.5	47.5	45.0	45.5	37.5	35.0	32.5
81	55.0	54.0	52.5	53.0	48.0	47.5	48.0	42.5	37.0	50.0	51.0	50.5	54.0	51.0	55.0	46.5	40.5	36.0
82	62.0	60.0	58.5	58.5	54.0	53.5	54.0	47.5	39.5	55.0	56.0	56.0	59.0	55.5	60.0	50.0	44.5	38.0
83	69.0	67.5	64.0	64.0	58.5	58.0	59.5	52.0	41.0	59.5	58.5	58.0	61.0	57.5	65.0	52.5	47.5	40.5
84	67.0	65.5	63.0	63.0	56.0	55.0	56.0	47.5	40.0	55.0	52.5	49.5	57.0	53.0	59.0	50.0	44.5	40.5
85	59.5	56.0	58.0	58.5	53.0	52.5	53.5	48.0	43.0	52.0	49.0	47.0	52.5	51.5	56.5	49.5	45.0	43.0
86	55.0	52.0	52.0	54.0	51.0	51.0	52.0	48.0	43.5	49.0	48.5	46.0	50.5	47.5	56.0	47.0	44.5	44.0
87	44.0	46.5	44.5	46.0	42.5	43.5	43.0	41.5	38.0	50.0	45.5	44.5	0.0	53.0	52.5	41.0	39.0	40.5
88	52.0	56.0	57.5	54.0	49.0	49.0	49.0	48.0	45.0	57.0	57.0	51.5	61.5	55.5	58.5	48.5	43.0	42.0
89	52.0	52.5	51.0	52.0	47.0	46.0	46.0	45.0	42.0	54.5	58.5	54.0	64.5	59.5	60.0	50.0	43.5	40.0
90	46.0	43.0	44.5	46.0	43.0	42.5	43.0	39.0	35.0	40.0	37.0	35.0	37.0	36.0	37.0	34.0	32.0	34.0

Table B1. Continued

TEMPERATURES

TRIAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
91	35.0	31.5	33.0	34.5	32.0	31.5	32.5	28.5	25.5	28.5	27.0	26.5	28.0	27.0	28.0	26.0	25.0	25.5
92	33.0	31.5	32.5	33.0	31.0	30.5	31.0	28.5	26.0	31.5	29.0	27.5	27.5	27.5	28.0	26.5	25.0	25.0
93	31.5	30.0	31.0	31.5	29.0	28.5	30.0	26.0	24.0	30.5	29.5	24.5	28.0	29.0	33.0	26.5	22.5	22.5
94	14.5	16.5	14.5	15.5	11.5	11.0	10.0	10.5	7.5	17.0	15.5	11.0	13.0	18.5	18.5	13.0	12.5	11.0
95	16.5	17.5	16.0	17.5	12.5	12.0	11.5	10.0	7.5	16.0	14.5	9.0	11.5	17.0	18.5	14.5	15.0	12.0
96	23.0	27.0	23.0	24.0	18.0	18.0	17.5	16.5	13.0	27.0	26.0	17.0	22.0	25.5	29.0	18.5	12.0	20.0
97	21.5	28.0	26.5	27.0	21.0	20.5	20.5	17.0	13.0	25.5	22.5	16.5	22.0	22.5	28.0	16.5	11.5	16.0
98	28.0	29.5	27.5	28.0	24.0	23.0	23.5	18.5	12.5	24.5	19.5	15.5	19.5	18.0	22.5	14.5	11.0	14.0
99	27.5	29.5	28.0	28.5	22.0	21.0	21.5	18.0	16.0	24.5	27.0	18.5	24.0	29.5	37.0	22.5	16.5	16.5
100	24.5	22.5	23.0	23.0	18.5	17.5	18.0	14.0	12.0	15.0	14.0	12.5	15.0	13.5	17.0	16.0	17.0	13.5
101	35.5	34.4	35.0	35.0	35.0	35.0	35.5	34.5	33.5	34.5	33.5	34.0	33.5	34.0	34.0	34.0	33.0	33.5
102	41.0	41.0	40.0	40.0	39.5	40.0	40.0	39.0	36.5	38.5	37.5	37.0	38.0	38.0	39.0	36.5	35.5	35.5
103	53.5	52.5	53.0	54.0	51.0	52.5	51.0	49.0	44.0	55.0	56.0	46.5	52.0	53.5	59.5	48.5	40.0	40.5
104	48.0	46.5	46.0	47.0	45.0	45.0	45.0	42.5	38.0	41.0	41.5	40.5	41.5	41.0	41.5	40.0	39.5	37.5
105	48.5	49.0	49.0	51.0	49.0	48.0	47.0	44.0	39.5	44.0	46.0	43.0	49.5	52.0	55.5	47.0	39.5	40.5
106	50.0	50.0	48.0	49.5	48.0	50.5	51.5	48.5	41.5	48.5	50.5	44.0	50.0	51.5	51.5	45.0	41.5	38.5
107	55.[illegible]	53.0	52.5	53.5	52.0	52.0	52.0	47.5	41.5	48.5	45.0	41.5	50.5	48.5	54.0	45.5	42.0	41.5
108	38.0	37.5	37.5	37.5	38.0	38.0	37.5	37.0	35.5	36.5	36.0	35.5	36.0	37.0	36.5	36.0	36.0	35.0
109	39.5	39.0	38.5	38.5	38.5	38.5	38.5	37.5	36.5	37.5	37.0	37.0	37.0	36.5	37.5	37.0	36.5	35.5
110	41.5	40.5	40.5	40.5	40.5	41.0	41.0	40.0	38.0	39.5	39.5	39.0	39.5	39.5	40.0	40.0	39.0	37.5
111	45.0	45.0	44.0	43.5	44.5	44.5	44.0	42.0	39.0	41.0	41.0	40.0	40.0	40.5	41.0	40.5	41.0	39.0
112	47.5	47.5	46.0	45.5	46.0	45.5	45.5	43.0	40.0	42.5	42.5	41.5	42.0	43.0	43.0	43.0	41.0	40.5
113	71.0	75.0	68.0	69.0	65.0	65.0	66.0	58.0	51.5	63.5	64.5	57.0	65.0	65.0	67.0	57.0	52.0	51.0
114	78.0	77.0	74.5	75.0	72.5	71.5	72.5	63.5	54.0	66.0	63.5	53.5	64.5	65.0	70.5	56.5	48.5	49.5
115	85.5	87.0	81.0	80.0	75.5	74.0	76.0	63.0	54.0	66.5	64.0	58.0	62.0	66.0	69.0	60.0	54.0	52.0
116	88.0	85.0	81.0	79.5	76.0	74.5	76.5	64.0	52.5	68.0	65.5	59.5	61.0	67.0	72.0	61.5	57.5	54.0
117	90.0	86.5	83.5	81.5	80.0	79.5	81.0	68.0	56.0	72.0	70.0	65.0	68.5	71.5	75.5	66.0	60.0	54.0
118	87.0	88.0	79.5	79.5	78.0	76.0	78.5	67.0	56.5	72.0	70.5	65.0	70.5	70.0	78.0	67.5	61.0	55.5
119	78.0	79.0	73.5	72.5	72.0	71.5	73.0	63.5	55.5	68.0	66.0	61.5	65.0	65.0	69.5	62.5	57.0	55.0
120	35.5	39.5	39.0	39.0	36.0	36.5	36.0	41.5	43.5	44.0	45.5	48.0	49.5	50.5	43.5	48.0	45.0	38.0
121	42.0	48.5	45.5	45.0	43.0	42.0	41.0	48.0	51.5	52.5	63.5	68.0	72.5	70.5	59.0	53.5	53.0	42.0
122	57.0	56.0	58.0	56.5	58.0	62.5	60.5	57.5	55.5	58.5	65.0	57.0	59.0	58.5	62.0	54.5	45.5	43.5
123	59.0	62.5	58.5	58.0	59.5	62.0	62.0	57.0	52.5	56.5	57.0	50.0	58.0	56.5	59.5	53.5	48.0	45.5
124	59.0	59.5	57.0	57.5	58.0	61.5	62.0	54.5	48.0	54.0	53.0	48.0	53.5	54.5	55.5	50.0	45.0	43.5
125	51.5	49.5	49.0	49.0	50.0	50.5	51.0	47.0	42.5	44.5	42.5	41.5	43.0	43.5	44.5	43.0	41.5	42.5
126	70.0	71.5	68.5	69.5	69.5	70.0	70.0	66.0	60.0	65.0	65.5	62.0	67.5	67.5	68.5	65.0	59.0	57.5
127	82.0	90.0	81.0	81.5	80.5	80.5	81.5	76.5	68.0	75.0	76.0	77.5	74.5	76.5	77.5	73.5	66.0	62.5
128	84.5	85.0	81.0	81.5	81.5	81.5	82.5	76.0	68.0	74.0	76.0	69.0	75.5	77.5	78.0	75.0	69.0	65.5
129	81.5	82.5	78.5	79.5	80.0	79.5	80.0	74.5	68.5	72.5	72.5	68.0	71.5	71.5	73.5	71.0	67.0	64.5
130	82.5	84.5	80.0	80.5	82.0	82.0	82.5	77.0	69.5	73.5	74.5	70.0	74.0	75.0	75.0	71.0	68.5	65.0
131	82.5	85.0	80.0	80.0	82.5	82.0	82.5	76.5	70.5	74.5	75.0	74.0	81.0	78.5	79.5	76.0	71.5	69.0
132	77.0	75.0	74.5	75.0	75.5	75.0	76.0	70.5	66.0	69.5	68.5	67.0	68.0	68.0	70.0	68.0	66.0	65.0

APPENDIX C

LOCAL SOLAR RADIATION AND TEMPERATURE DATA

Table 1. Local Solar Radiation and Temperature Data

Date	Solar Radiation Langleys Brookings, South Dakota 10 YR AVG	Actual	Deviation from 10 YR AVG %	Temperature, F Joe Foss Field Average	Departure from Normal
12/ 8/75	133.21	77.0	-42	27	6
12/15/75	127.62	158.7	24	6	-14
12/16/75	124.43	161.9	30	9	-11
12/22/75	109.92	89.2	-19	22	4
12/23/75	129.76	27.4	-79	18	0
12/29/75	135.13	136.6	1	24	8
1/ 8/76	167.44	208.1	24	-11	-25
1/13/76	162.24	187.9	16	14	0
1/15/76	164.21	61.1	-63	24	11
1/20/76	156.41	150.4	- 4	15	1
1/22/76	128.77	87.0	32	24	10
1/24/76	167.19	168.4	1	29	15
1/27/76	159.96	226.0	41	8	- 7
1/29/76	192.15	227.8	19	35	20
2/ 3/76	214.77	124.4	42	21	5
2/ 5/76	198.84	148.4	25	4	-13
2/10/76	260.23	147.6	43	35	17
2/17/76	238.14	140.5	41	36	16
2/24/76	278.34	310.7	12	43	21
3/ 9/76	249.98	238.3	5	31	5
3/18/76	245.77	333.9	36	51	21
		Monthly Averages			
DEC	134.6	99.7	-26	20.4	.4
JAN	178.3	166.4	- 7	15.6	1.4
FEB	237.12	224.8	- 5	29.5	10.1
MAR	300.98	308.3	2	34.8	4.8

APPENDIX D

HEAT TRANSMISSION COMPONENTS

Table D1. Heat Transmission Components

Material	Resistance	Conduction Coefficient
Roof	24.63	.0406
Side Walls	15.57	.0642

HEAT CONDUCTION LOSSES:

Collector A (Vertical South Wall)	6.14 Btu/hr
Collector B (Roof Section Alone)	10.72 Btu/hr
Collector C (Combination Vertical South Wall and Roof)	16.86 Btu/hr

Heat conduction loss values are per degree Fahrenheit difference between the inside building temperature and the temperature within the solar collectors for the entire area of each solar collector.

APPENDIX E

ANALYSIS OF VARIANCE FOR SIDEWALL, ROOF AND COMBINATION SIDEWALL AND ROOF COLLECTORS

Table E1. Analysis of Variance for Sidewall, Roof and Combination Sidewall and Roof Collectors.

Analysis of Variance for Sidewall Collector A

Source	DF	SS	MS	F
Total	131	995,929.1		
Due to SE	1	478,109	478,109.0	119.1**
Due to TEMP	1	137.2	137.2	.03
Error	129	517,682.9	4,013.0	

**Significant at the 0.5% level.

Analysis of Variance for Roof Collector B

Source	DF	SS	MS	F
Total	131	43,407.0		
Due to SE	1	17,002.6	17,002.6	109.2**
Due to TEMP	1	6,327.1	6,327.1	40.6**
Error	129	20,077.3	155.6	

**Significant at the 0.5% level.

Analysis of Variance for Combination Roof and Sidewall Collector C.

Source	DF	SS	MS	F
Total	131	31,551.0		
Due to SE	1	11,957.7	11,957.7	86.2**
Due to TEMP	1	1,685.2	1,685.2	12.14**
Error	129	17,908.2	138.8	

**Significant at the 0.5% level.