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THE DESIGN OF A SOLAR ENERGY COLLECTION SYSTEM TO AUGMENT HEATING & COOLING FOR A COMMERCIAL OFFICE BUILDING.

by Robert C. Basford

January 1977

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Analytical studies supported by experimental testing indicate that solar energy can be utilized to heat and cool commercial buildings. To verify these studies, the National Aeronautics and Space Administration (NASA) will use, in conjunction with a 50,000 square foot (4645 m^2) one-story office building at the Langley Research Center, 15,000 square feet (1393.5 m^2) of solar collectors to provide the energy required to supply 79% of the building heating needs and 52% of its cooling needs with an operation date of December 1975.

Since the beginning of the space program, control of solar energy absorbed by spacecraft has been necessary for successful space operation. The experience gained from the space program is providing the technology base for this joint project between the Langley and Lewis Research Centers with Langley being responsible for the system design and Lewis the solar collector technology.

This paper presents some of the analytical studies made to make the building design changes that were necessary to utilize solar energy; the basic solar collector design; collector efficiencies; and the integrated system design

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THE DESIGN OF A SOLAR ENERGY COLLECTION SYSTEM TO AUGMENT HEATING & COOLING FOR A COMMERCIAL OFFICE BUILDING

By Robert C. Basford

Langley Research Center

ABSTRACT

Analytical studies supported by experimental testing indicate that solar energy can be utilized to heat and cool commercial buildings. To verify these studies, the National Aeronautics and Space Administration (NASA) will use, in conjunction with a 50,000 square-foot ($4645m^2$), one story office building at the Langley Research Center, 15,000 square feet ($1393.5m^2$) of solar collectors to provide the energy required to supply 79% of the building heating needs and 52% of its cooling needs. The expected operational date is in early 1976.

Since the beginning of the space program, control of solar energy absorbed by spacecraft has been necessary for successful space operation. The experience gained from the space program is providing the technology base for this joint project between the Langley and Lewis Research Centers. Langley is responsible for the system design, and Lewis the solar collector research.

This paper presents some of the analytical studies made to make the building design changes that were necessary to utilize solar energy; the basic solar collector design; collector efficiences; and the integrated system design.

Using actual weather data from a typical year, the heating and cooling consumption for the entire year is shown in Figure 4. The total building annual energy consumption is 3.73 billion btu's (3.94x102j) with 80% required for cooling and 20% required for heating. It should be noted that the data indicates cooling is required 12 months a year. During the winter months, the system will be operating on an economy cycle, which was included in the total energy consumption.

The SEB was originally designed using a compression air conditioning system with baseboard hot water heat. In order to use solar energy, it was necessary to modify the building design to use an absorption air conditioning system which used hot water as the driving medium. In addition, the absorption system required a 600 GPM (0.0379 m^3/sec) cooling tower as compared to 520 GPM (0.0328 m^3/sec) cooling tower required for the compression system. The steam-to-hot water exchanger was increased in size from 1.2 million btu per hour (3.52×10^5j/sec) required for the baseboard heat to three million btu per hour required for the absorption machine and the baseboard heat.

As part of our energy conservation program, ventilation requirements were reduced from 20 cfm (0.00944 m^3/sec) per person to 5.5 cfm (0.00256 m^3/sec) per person by using activated charcoal filters. This change represented a 23-ton (8.09×10^4j/sec) savings in cooling requirements. The air handler coil size was increased to use 47°F (8.33°C) water in lieu of 45°F (7.22°C) water which allows the absorption system to operate at a higher absolute pressure, thereby reducing fuel consumption, pressure leaks, and maintenance problems. The heating system, which require 180°F (82.22°C) water, was connected to the secondary water circuit from the absorption system rather than from the primary circuit (241°F water) (116.11°C). The heating system was designed such that each zone will be controlled from an outside thermostat located in that zone.

In addition to these energy saving features, various thicknesses of roof insulation and thermal pane glass were also analyzed. The base building analysis was based on a four watt per square foot (43 w/m^2) lighting load, three inches (0.0762) of roof insulation, baseboard hot water heat, economy cycle on the air conditioning system, 6,240 cfm (2.94 m^3/sec) ventilation, absorption chiller using 240°F (115.6°C) water, variable volume air conditioning system and the capital investment figured for a forty year life at 6% interest. The base building requires 171 tons (6.01×10^5j/sec) of air conditioning with an annual owning and operating cost of $70,500 in 1975 dollars. The results of the analysis (Table 1) indicated that no cost advantage for the building's forty year life could be realized from varying the roof insulation or by using double pane glass. Charcoal filters pay for themselves in three years but were not included in the design because of initial capital cost. Since

INTRODUCTION

During the past 100 years, the United States alone has increased energy consumption 18 fold.

By one estimate we now consume 69 x 10^{15} btu (7.28 x 10^{19} j) a year. Conservatively, we may need 150 x 10^{15} btu (1.58 x 10^{20}j) in the year 2000. As this ravenous appetite for energy continues, thermal pollution could reach unacceptable levels, and the present fuel crunch could become a real catastrophe. Therefore, design engineers must play an important role in the designing of products and systems to consume less energy. Every commercial building today could reduce energy consumption substantially by judicious use of and better controls over air conditioning and heating systems alone. Other energy savings characteristics in building designs are insulation thickness, thermal pane glass, ventilation air requirements and lighting levels.

The annual energy requirements for the Langley Systems Engineering Building (SEB) are 80% for cooling and 20% for heating. A substantial part of these energy requirements could be supplied by solar energy, thereby reducing the drain on fossil fuels; and it appears that harvesting this energy will lead to few ecological problems. Therefore, from the technological processes of heliochemical, helioelectrical and heliothermal by which solar energy can be utilized, heliothermal can provide much of the thermal energy required to heat and cool buildings.

The decision to construct and operate a solar collector system in conjunction with the new 50,000 square foot (4645 m^2) SEB constructed at the Langley Research Center in Hampton, Virginia, was based upon the following conclusions:

(1) The long-term rate of growth in U.S. energy consumption must be slowed down.

(2) Solar energy has significant potential as an energy resource for the world.

(3) Comprehensive design procedures for solar energy systems are not available and need to be developed.

(4) The current status of collector research and development and system design indicates that solar cooling and heating of buildings to present U.S. comfort standards is attainable.

The SEB design had been completed prior to the decision to utilize solar energy for heating and cooling. Therefore, the design of the mechanical systems in the building had to be modified.

The project is a joint effort between NASA's Langley Research Center (LaRC) and Lewis Research Center (LeRC) with Langley responsible for the building and solar collector system design and Lewis being responsible for the collector research. The major objectives of this project are to (1) establish a facility to do research in solar energy in areas where NASA has experience; such as thermal design, thermal coating technology, heating-ventilating-air conditioning (HVAC) and system design; (2) obtain data in the context that give credible information such as in the building industry; and (3) make an early step toward establishing the feasibility of solar heating and cooling as our supply of fossil fuel energy sources continues to diminish.

The approach that has been taken to accomplish these objectives was the following: modify the Langley Systems Engineering Building design so that it could be used as a solar HVAC test bed; design, build and test solar HVAC systems for the building; and finally collect technical, operational and economic information to assess the feasibility of solar HVAC for commerical buildings.

Building Design for Solar Energy

The 50,000 square-foot (4645 m^2) office building is shown in Figure 1. The Solar Collector System was designed to provide a significant part of the energy required to satisfy the building's heating and cooling loads.

Several locations for the collector farm were considered: on the building roof, over the parking lot, and contiguous to the building. The prime consideration in selecting the contiguous location was convenience of changing collectors as new ones are developed. However, as research determines the optimum design of solar collectors and their actual feasibility as an energy source for heating and cooling buildings, a more suitable design could be to locate the collectors in/on the buildings. The collector farm, shown in Figure 2, indicates three types of solar collectors. These three types were used to emphasize a research and development test bed.

With the aid of NASA's Energy Cost Analysis Program (NECAP), the building's cooling and heating requirements were calculated The daily air conditioning energy consumption for the SEB (Figure 3) is based on a design day of 94^{o}F (34^{o}C) with an inside temperature of 75^{o}F (23.9^{o}C). The lights (four watts per square foot) (43 coutts/m^2) represents 47% of the total heat load to be cooled. The remainder of the heat load is made up of the building transmission, solar, people and ventilation loads.

these data were based on present day fuel costs, the cost was extrapolated out six years at which point in time the fuel costs would double based on a 15% annual increase in costs. Using these new cost data, four inches of insulation would pay for itself in 17 years disregarding the interest cost on the investment. The double glass would have a payoff in 93 years.

A simplified sketch of the mechanical system is shown in Figure 5. The hot water heating system is tied into the secondary water system from the absorption machine to save energy by utilizing lower potential water for heating purposes. Also shown are hot and cold water storage tanks. Their purpose is to provide heat to the building at night and during the day when the sun does not shine (heavy cloud cover or inclement weather). The air side of the air conditioning system is a variable volume type with supply and return fans.

Collector Design

Solar collectors are of two types - focusing and flat plate. The flat plate collectors use both direct and diffuse radiation which allows them to produce the greater amount of total heat on cloudy or overcast days. Focusing collectors produce temperatures higher than those attainable by flat plate collectors. This is accomplished by using very accurate tracking systems to concentrate direct rays from the sun. Because diffuse radiation cannot be concentrated and the complexity of tracking systems for focusing collectors is expensive most systems use the flat plate variety.

The flat plate collector is composed of five basic parts as shown in Figure 6.

(1) Glazing is generally one or more sheets of glass or a diathermanous (radiation-transmitting) plastic film or sheet.

(2) Tubes or fins are for conducting or directing the heat-transfer fluid from the inlet duct or header.

(3) Plates, generally metallic, may be flat, corrugated or grooved.

(4) Tubes or fins are attached in some manner to the plates which produces a good thermal bond.

(5) Insulation minimizes downward heat loss from the plate.

(6) Container or casing surrounds the foregoing components and keeps them free from moisture, etc.

Glass has been the principal material used to glaze solar collectors because it has the highly desirable property of transmitting as much as 90% of the incoming short wave solar radiation, 0.3 microns to 3.0 microns, while virtually none of the long wave radiation, 3.0 microns to 20 microns, emitted by the flat plate can escape outward by transmission. The solar wave length pattern is shown in Figure 7.[1] Plastic films and sheets also possess high short wave transmittance. Most possess transmission bands in the middle of the thermal radiation spectrum which may have long wave transmittances as high as 0.40.[2,3] The effect of dirt and dust on collector glazing is surprisingly small. The cleansing effect of occasional rain seems to be adequate to maintain the transmittance within 2 to 4% of its maximum value.[2,4] Glazings are used on solar collectors to admit as much solar radiation as possible and to reduce the upward loss of heat to the lowest attainable value. Glass is virtually opaque to long wave radiation which is emitted by the collector plate. The absorption of that radiation causes the glass temperature to rise and thus to lose heat to the surrounding atmosphere. This type of heat loss can be reduced by using infrared-reflecting coating on the underside of the glass. Such coatings are costly and reduce the effective transmittance of the glass for solar radiation by as much as 10%. In addition to serving as a heat-trap by admitting short wave solar radiation and retaining long wave thermal radiation, the glazing reduces heat loss by convection. The insulating of glass or glass plus plastic,[4] and the type and number of transparent covers used in a solar collector greatly influence its performance. Results of a parametric study of transparent covers[5] are presented in Figure 8. The most important result of the study was that Tedlar, a DuPont polyvinyl fluoride plastic film, is superior and cheaper than glass for any temperature. Another point made by Figure 8 is that two Tedlar covers are superior to one or three such covers for the temperature range required for cooling (220°F and slightly higher). (104.44°C)

The collector plates have the following primary functions: (1) to absorb as much as possible of the radiation reaching it through the glazing, (2) to lose as little heat possible upward to the atmosphere and downward through the back of the container, and (3) to transfer the retained heat to the transport fluid. The absorptance of the collector surface for short wave solar radiation depends upon the type of coating and the incident angle. By suitable electrolytic or chemical treatments, it is possible to produce surfaces which have high values of solar radiation absorbtance (α_s), and low values of long wave emittance (E_s).[6,7,8,9,10] Selective surfaces that have demonstrated their ability to retain their desirable properties after long exposure to intense sunshine are shown in Table 2. Solar absorptance in the range of 0.92 and long wave emittance as low as 0.10 characterize these coatings as indicated in Figure 9. Selective surfaces are of particular importance when collector surface temperatures much higher than the ambient air temperature are required. The data in Figure 10 illustrate this point.[5]

Materials most frequently used for collector plates, in decreasing order of cost and thermal conductivity, are copper, aluminum and steel. Studies[11] have been made to determine the effect of bond conductances and conclusions have been that steel pipes are just as good as copper if the bond conductance between the tube and the plate is good. There is a very large number of solar water and air heaters which have been used in the past with varying degrees of success. A new design developed by Corning Glass Works is indicated in Figure 11. It utilizes a vacuum jacket solar collector that could fall into the new development category. This concept is currently under study at Lewis Research Center.

Collection Efficiency

Efficiency of solar collectors is defined as the ratio of the amount of heat usefully collected to the total solar radiation during the period under consideration. Efficiencies that are calculated for the middle of the day (incident angle is favorable) are generally higher than day long efficiencies. The day long efficiencies include the high and unfavorable incident angles which prevail during the early morning and late afternoon hours. Detailed mathematical analysis of collector efficiency calculations are found in references 2, 4, and 12.

The major heat loss that affects the efficiency from a well insulated collector is the upward heat flow from the plate to the atmosphere. The upward heat flow is a function of the emittance of the plate (E_s, for long wave radiation), the temperature difference between the plate and the air above the glazing, and wind velocity.

The amount of radiant energy that a collector plate can absorb is the product of the incident irradiation (I_{ts}), the transmittance of the glazing (τg), and the plate's absorptance for solar radiation (α_s). For low fluid temperatures in the collector, the efficiencies are highest without any glazings. The loss due to reflection from the cover glass or glasses is approximately 4% of the energy passing through each air-glass interface (for incident angles up to 35 degrees) (.6rad). The losses are as follows: 8% for a single-glazed collector, 15% for double glazing, and 22% for triple glazing.

As the absorber temperature rises, the efficiency drops off rapidly with a single cover glass and a nonselective absorber, (see Figure 12). A good selective surface, E_s = 0.10, improves the efficiency as temperatures rise to the 200°F (93.33°C) level. Collector temperatures in the range of 250°F (121.11°C) are required to operate a conventional absorption refrigeration system. For 250°F (212.11°C) efficiencies of 40% can be attained with a triple-glazed high emittance collector, or 50% with a single-glazed collector E_s = 0.10.

To obtain a predicted performance of solar collectors in the Langley area, horizontal insolation data for February 4, 1974, were obtained and corrected to the tilt angle of 30° (0.524rad) as indicated by the top curve in Figure 13. The lower curve was obtained from the results of a Lewis Research Center computer program. The math model of a flat plate solar collector consisted of two covers with a solar absorptivity of 0.9 and infrared emissivity of 0.1. The input water temperature was 170°F (76.67°C) inlet with 210°F (98.89°C) outlet. The model was then exposed to the heat flux measured on February 4. Even though the sun rose at 7 a.m. and set at 5:30 p.m., the collector did not start to pick-up energy until 8 a.m. and stopped absorbing energy at 4:30 p.m. The collector efficiency rose from zero at 8 a.m. to a maximum of 41.5% at noon then back to zero at 4:30 p.m. During this time interval, the collector absorbed 29% of the total insolation. Based on 5,000 square feet (464.5 m^2) solar collectors, 8 million btu (8.44×10^9 j) would have been collected as compared to 7 million btu (7.39×10^9 j) required for the building. The excess heat could be stored in the hot water tank and used on a cloudy day or at night.

System Design for Heating and Cooling

Commercially available lithium bromide-water absorption machines used in solar collector system designs for cooling require low pressure steam at temperatures greater than 250°F (96.11°C) to develop rated capacities. For water temperature less than 250°F (96.11°C), the capacity of the machines reduces as indicated in Figure 14. Hot water in the 220°F (104.44°C) to 240°F (115.56°C) range (expected) from the solar collector system means a reduction in the machine's capacity. Therefore, to meet the requirements of the SEB, a 180-ton (6.33×10^5j/sec) rated machine was required to obtain the 150 tons ((5.28×10^5j/sec) needed for the building. It can be concluded that for cooling purposes, solar collectors that produce the highest water temperature (up to 240°F) (115.56°C) need to be selected for the present system.

Since it was intended to use solar energy to heat and cool the SEB, NECAP was used to determine the amount of solar energy that is collectable in the Langley area. The analysis was based on the weather data of the year 1966 which represents a typical year in the Langley area. A collector efficiency of 50% and a tilt angle of 40° (0.7rad) were assumed as initial starting points. As test data are developed and analyzed, the efficiency of the collectors may change. The results based on the initial assumptions are shown in Figure 15. The two curves shown are for August 5, representing the minimum collectable energy for the month, and August 29, representing the maximum collectable energy. The numbers shown on the two curves are the day's temperature. These two extremes are indicative of the importance of cloud cover. Two extremes of the Langley insolation are shwon with a perfect day occurring on February 5, 1974 (Figure 16) and a total overcast sky occurring during an ice storm in February 8, 1974 (Figure 17). It should be noted that on days such as February 8, 1974, collectoable solar energy is negligible.

In determining the required solar collector size, it was necessary to match the building energy requirements with the solar collector capability. In Figure 4 the total building energy requirements are 3,732,200,000 btu/year (3.94×10^{12}j/year). Therefore, a solar collector area that will supply this amount of energy is required.

By assuming a collector efficiency of 50% and using weather data from the year 1966, NECAP was used to determine the amount of energy that can be obtained from various collector tilt angles. Four tilt angles (0^o, 35^o, 45^o, and 55^o) (0rad, 0.613rad, 0.788rad, 0.963rad) were used,(see Table 3).

The maximum energy (159,606 btu/ft^2/yr) (1.81×10^9j/m^2/yr) can be collected at a solar collector tilt angle of 35^o (0.613rad). By matching these data with the building requirements, a 23,400 ft^2 (2173.9m^2) solar collector is needed. A comparison between the building monthly energy requirements and the energy that can be collected from a 23,400 ft^2 (2173.9m^2) solar collector at a 35^o (0.613rad) tilt angle is shown in Figure 18. A solar collector that would provide all of the building requirements would be 46,000 ft^2 (4273.4m^2) and mounted at a tilt angle of 35^o (0.613rad) as indicated in Figure 19; however, this would not be economical.

A comparison between a 23,400 ft^2 (2173.9m^2) solar collector mounted at 0^o, 45^o, and 55^o (0rad, 0.788rad, 0.963rad) tilt angles and the building requirements is shown in Figure 20. It can be observed from this figure that a variable tilt angle collector can supply more energy over the total year than a fixed angle collector.

The optimum fixed collector tilt angle can be determined by plotting the collector tilt angle versus the amount of heat required from an auxiliary source necessary to supply the remaining building requirements. The data in Figure 21 for a 23,400 ft^2 (2173.9m^2) collector indicated that the optimum angle for the Langley facility is 32^o (0.56rad).

The spacing between collectors is important to prevent self-shading during various times of the year while minimizing real estate use. Therefore, NECAP was run for an eight-foot-high (2.44m) collector tilted at 32^o (0.56rad) from the ground. A dramatic reduction in energy is experienced when the solar collectors are moved closer together, Figure 22. The combination of energy, real estate, tilt angle, and associated costs must be optimized to determine the most effective collector. Ten feet (3.05m) from the front of one collector to the front of the following collector was the optimum design spacing for an 8 foot ((2.44m) collector at a 32^o (0.56rad) tilt angle. Since the Langley project is a research and development test bed for solar collectors, a fourteen-foot (4.26m) spacing is actually being used. This is to assure that shading will not occur at any time during the year. Shading would affect the results of the research program.

Initially 15,000 square feet (1393.5m^2) of collectors will be installed. This size will supply the energy for 79% of the heating needs and 52% of the cooling needs and will provide sufficient energy to exercise all aspects of the solar collector system required to operate the building. These requirements are based on using the economy cycle for cooling during the months of January, February, March, November, and December. This size field will also provide the energy required to store hot and cold water. A comparison between a 15,000-square-foot (1393.5m^2) collector and the building energy requirements is shown in Figure 23. As technology advances, space is available to expand the collector field to 46,000 square feet (4273.4m^2) (100% of the building's energy needs).

The need for storage tanks is predicated upon the fact that we do not always have clear days, and night operations require hot water. The size of the hot water tanks required during the winter months based on a 15,000-square-foot (1393.5m^2) collector is shown in Table 4. January, a critical month for cloud cover, requires 3.6 clear days to supply the building needs and at the same time heat 25,400 gallons (96.14m^3) of water to 180°F. This amount will only carry the heating system through one overcast day. Therefore, with consecutive overcast days, the system will not operate with the tank sizes listed.

Freeze protection for the collector system in the winter can be provided in one of three ways: antifreeze, continuous water circulation, or drainage of the system. There are various advantages and disadvantages of each approach. Aqueous ethylene glycol solutions will prevent the system from freezing, but the absorption chiller will experience a reduction in capacity.[13] A 20% solution of ethylene glycol is required to reduce the freeze point to 20°F (-6.67°C). By providing a continuous flow in the collector system of 0.001 gallons per minute ($6.31 \times 10^{-8} m^3/sec$) with 2 inches of insulation on the pipes, water in the collector system will not freeze at 20°F (-6.67°C), see Figure 24. Temperatures in Tidewater Virginia drop below 20°F (-6.67°C) only 2% of the time, and the collector maximum flow rate is 0.56 gallons per minute ($3.53 \times 10^{-5} m^3/sec$). Since a pump and a drain tank are included in the system, these will be used to prevent freezing as follows: circulate between 20 (-6.67°C) and 30°F (-1.11°C) and drain below 20°F (-6.67°C). The piping will be sloped such that all water can drain back through the collector to the drain tank.

The solar collector field consists of twelve rows with each row capable of containing 52 collectors, 3 feet (0.091m) wide and 8 feet (0.244m) high. Water will be supplied to each row with 1¼ inch (0.0318m) headers installed at the bottom of each row. The return header is installed at the top of each row to establish a high point for automatic air venting and pressure relief valves.

In view of the water temperature expected from the solar collector system, it is necessary to pressurize the system to prevent the water from flashing to steam. This is particularly critical at the suction of the main water circulating pump since this will be the lowest pressure point in the system.

The control philosophy selected for the system was that only quality water would be used or stored. Quality is defined as any water above 180°F (82.22°C). Therefore, each of the twelve rows of collectors will have a thermostatically controlled valve with a small hole drilled in the valve seat to allow a small amount of water to circulate through the system. When the water temperature reaches 180°F (82.22°C), the valve will open allowing full water flow. By other control valves in the system, the water can be either used for heating or cooling the building or for storing in the tank.

SUMMARY AND CONCLUSION

The analytical studies indicate that it is feasible to use solar energy for heating and cooling of the SEB using commercially available mechanical equipment. The optimum water temperature required for operating an absorption machine for the cooling mode is higher than can be expected from a flat plate collector. This problem was alleviated by derating the equipment. By doing so, the required 150 tons (5.28×10^5 j/sec) could be obtained with expected water temperature from an 180-ton (6.33×10^5 j/sec) machine.

Initially, the collector field has 15,000 square feet (1393.5m^2). This was the minimum size that would produce the desired research data. A system that would produce all the building's energy needs is not an economical size, as excess hot water would be generated eleven months out of the year. The system is currently complete and has been operational since May 1976. Data is being obtained for evluating the systems' performance, and operational characteristics, and confirming the design procedure for solar energy systems.

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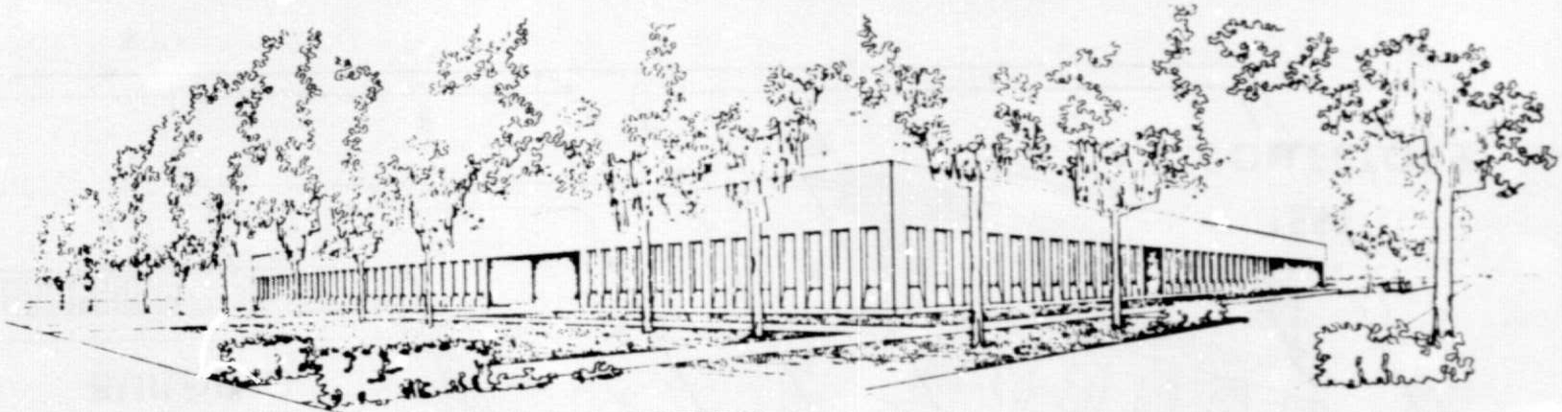
LANGLEY RESEARCH CENTER



PERSPECTIVE

FIGURE 1

SOLAR COLLECTOR SYSTEM

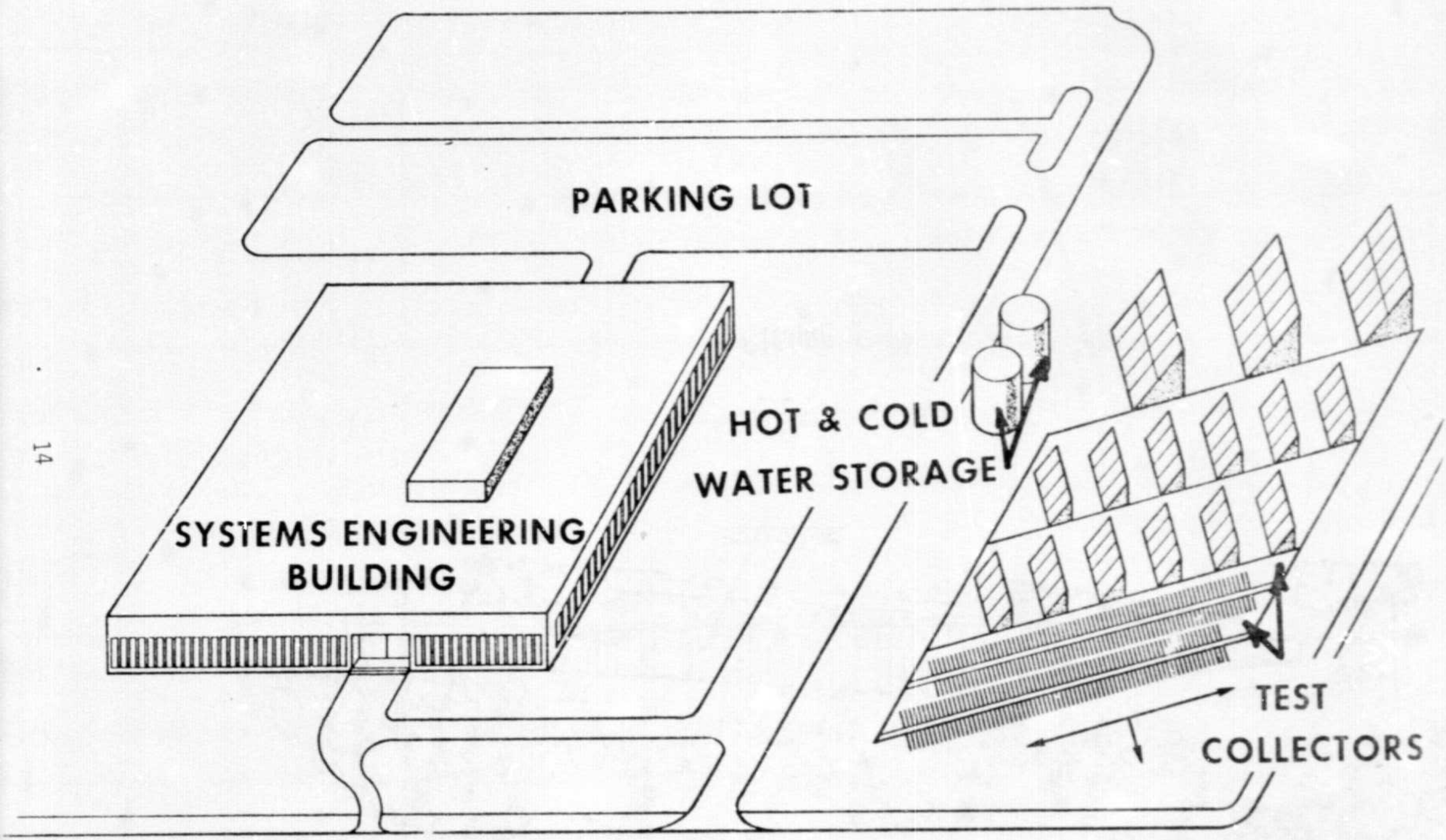


FIGURE 2

DAILY ENERGY CONSUMPTION FOR THE BUILDING AIR CONDITIONING LOAD BASED ON A DESIGN DAY

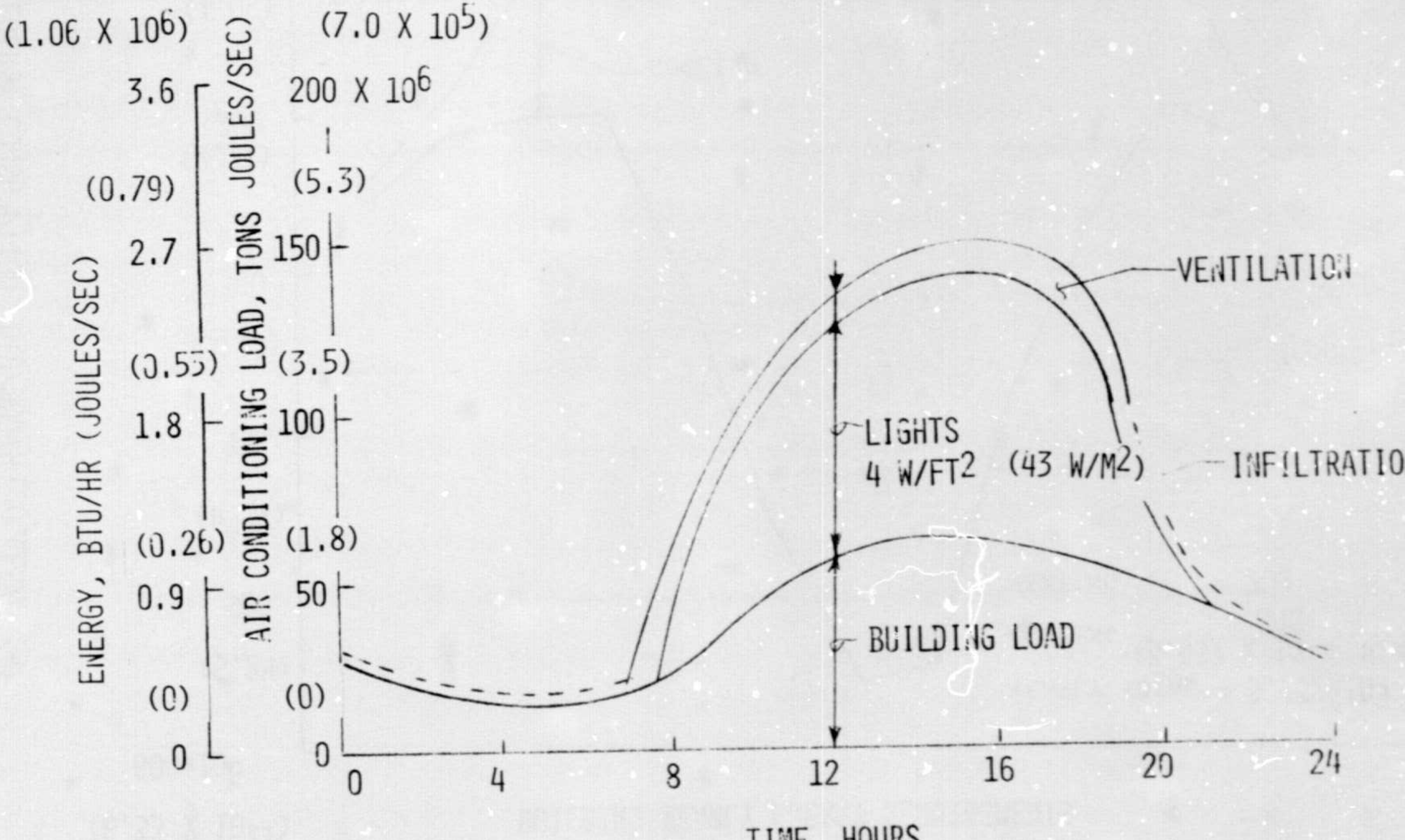


FIGURE 3

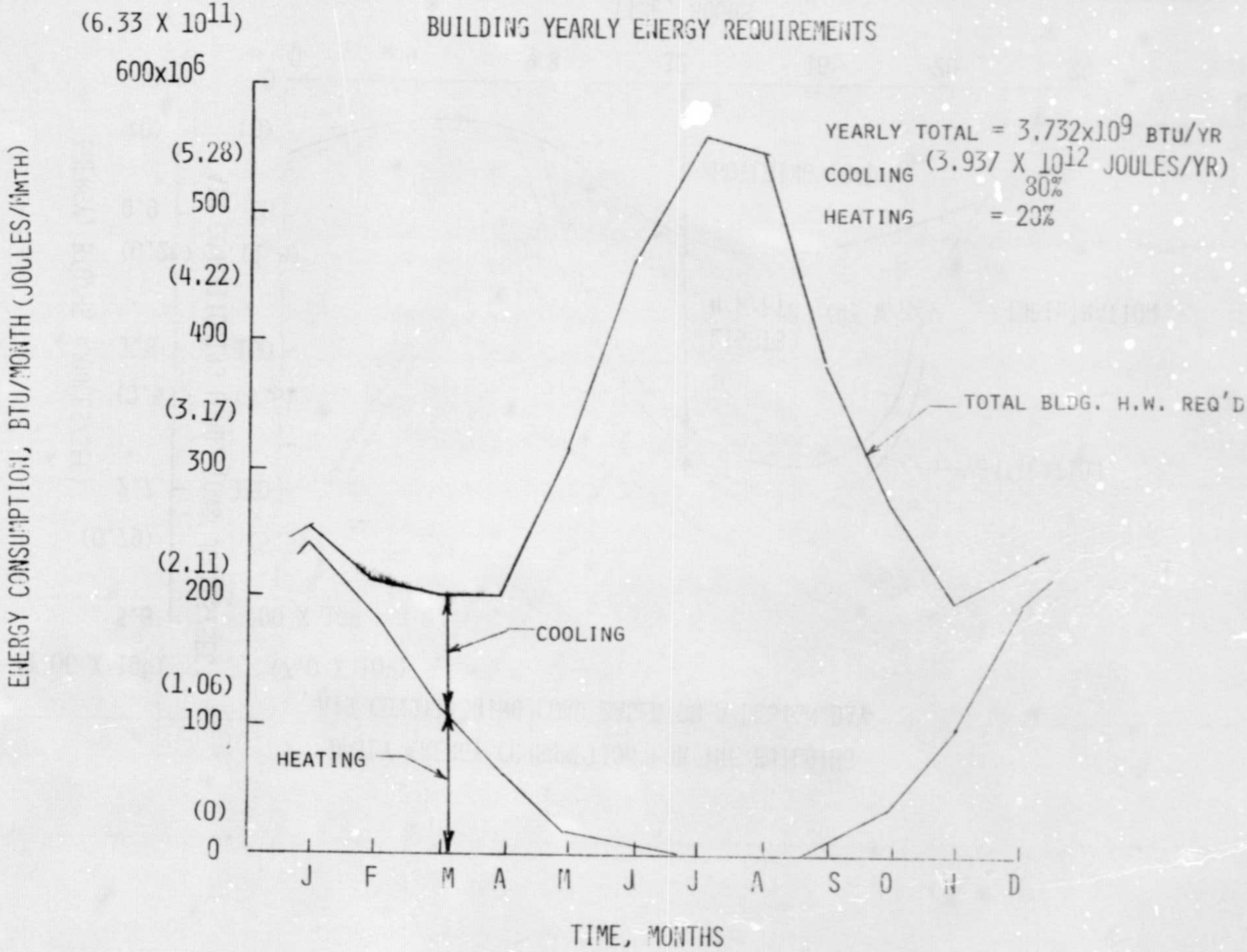

(6.33 X 10^11)
BUILDING YEARLY ENERGY REQUIREMENTS
600x10^6
(5.28)
500
(4.22)
400
(3.17)
300
(2.11)
200
(1.06)
100
(0)
0
ENERGY CONSUMPTION, BTU/MONTH (JOULES/MMTH)
YEARLY TOTAL = 3.732x10^9 BTU/YR
(3.937 X 10^12 JOULES/YR)
COOLING 80%
HEATING = 20%
TOTAL BLDG. H.W. REQ'D.
COOLING
HEATING
J F M A M J J A S O N D
TIME, MONTHS

FIGURE 4

SYSTEMS ENGINEERING BUILDING USING SOLAR ENERGY

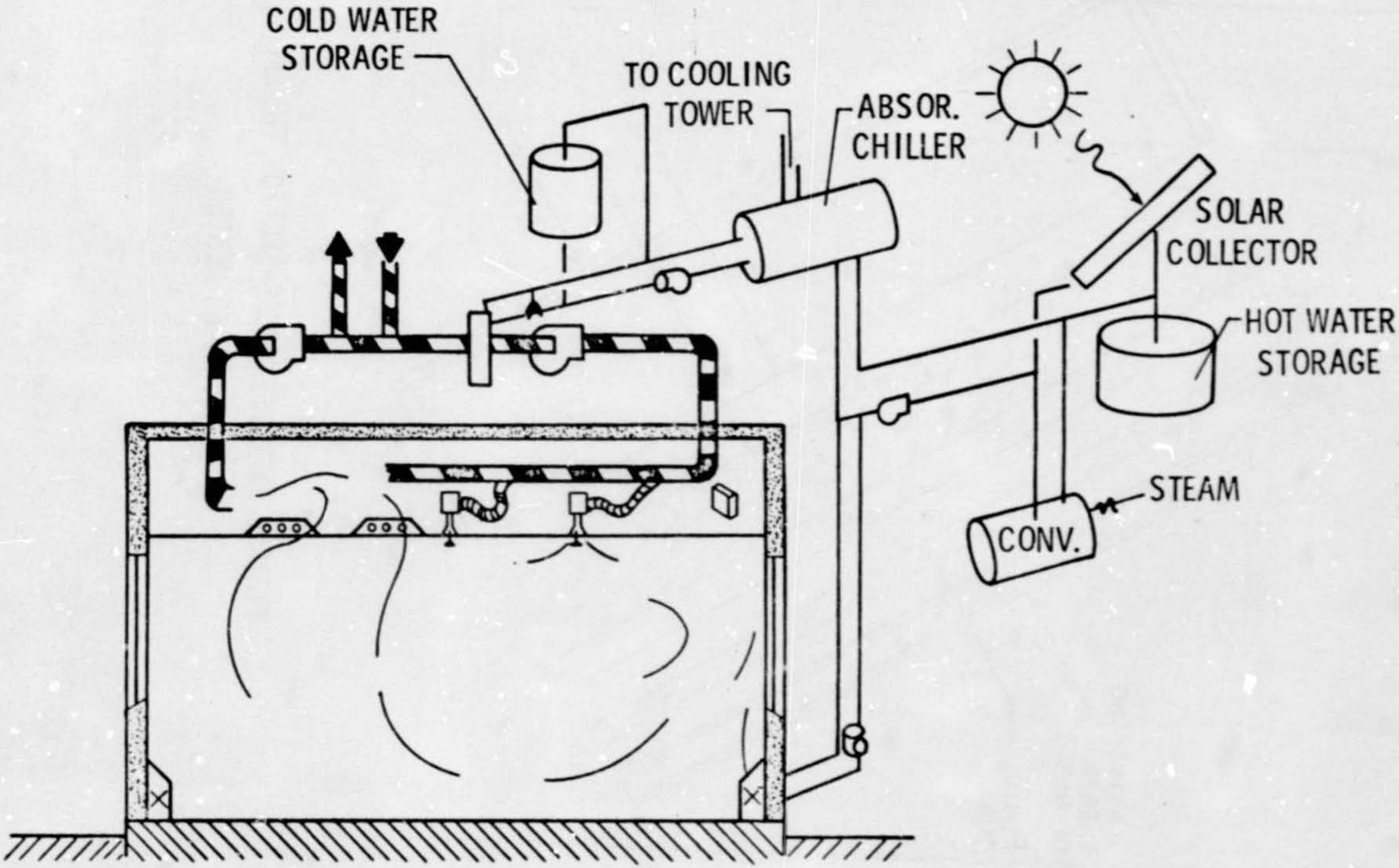
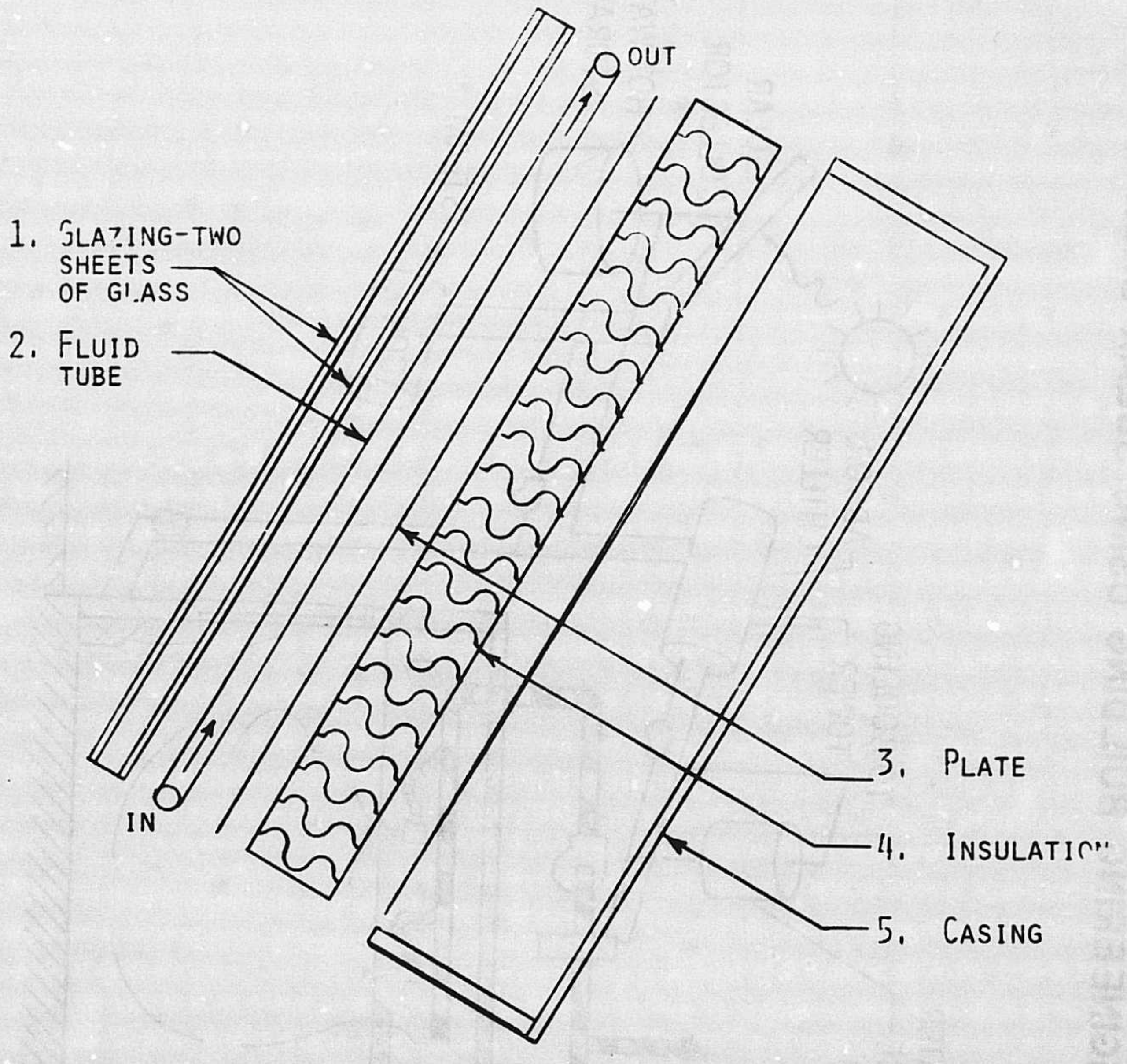


Figure 5



TYPICAL EXPLODED CROSS-SECTION THROUGH
A SOLAR WATER HEATER

Figure 6

SOLAR COLLECTOR WAVE LENGTH RANGES

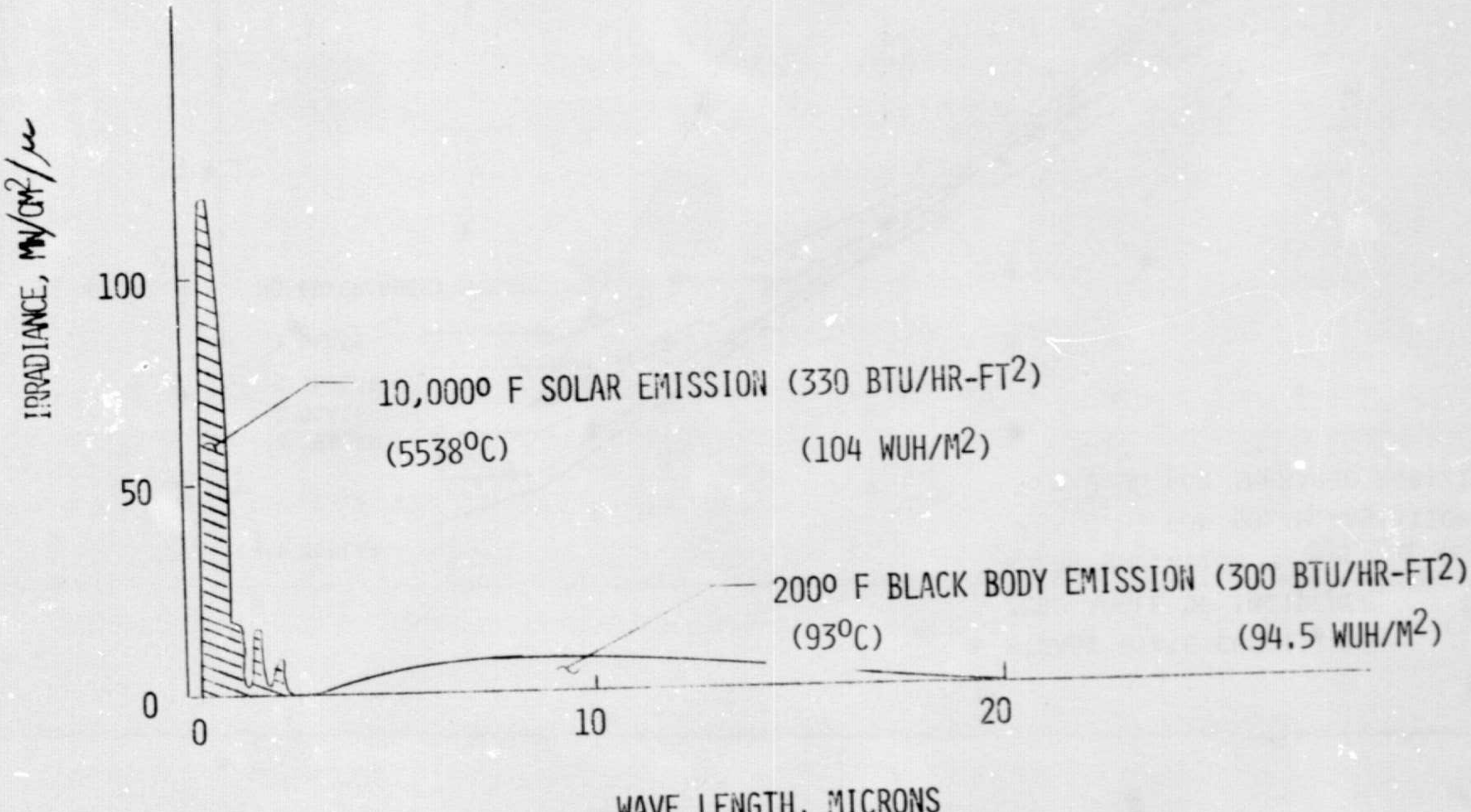


Figure 7

SOLAR COLLECTOR PERFORMANCE FOR DIFFERENT COVER MATERIALS

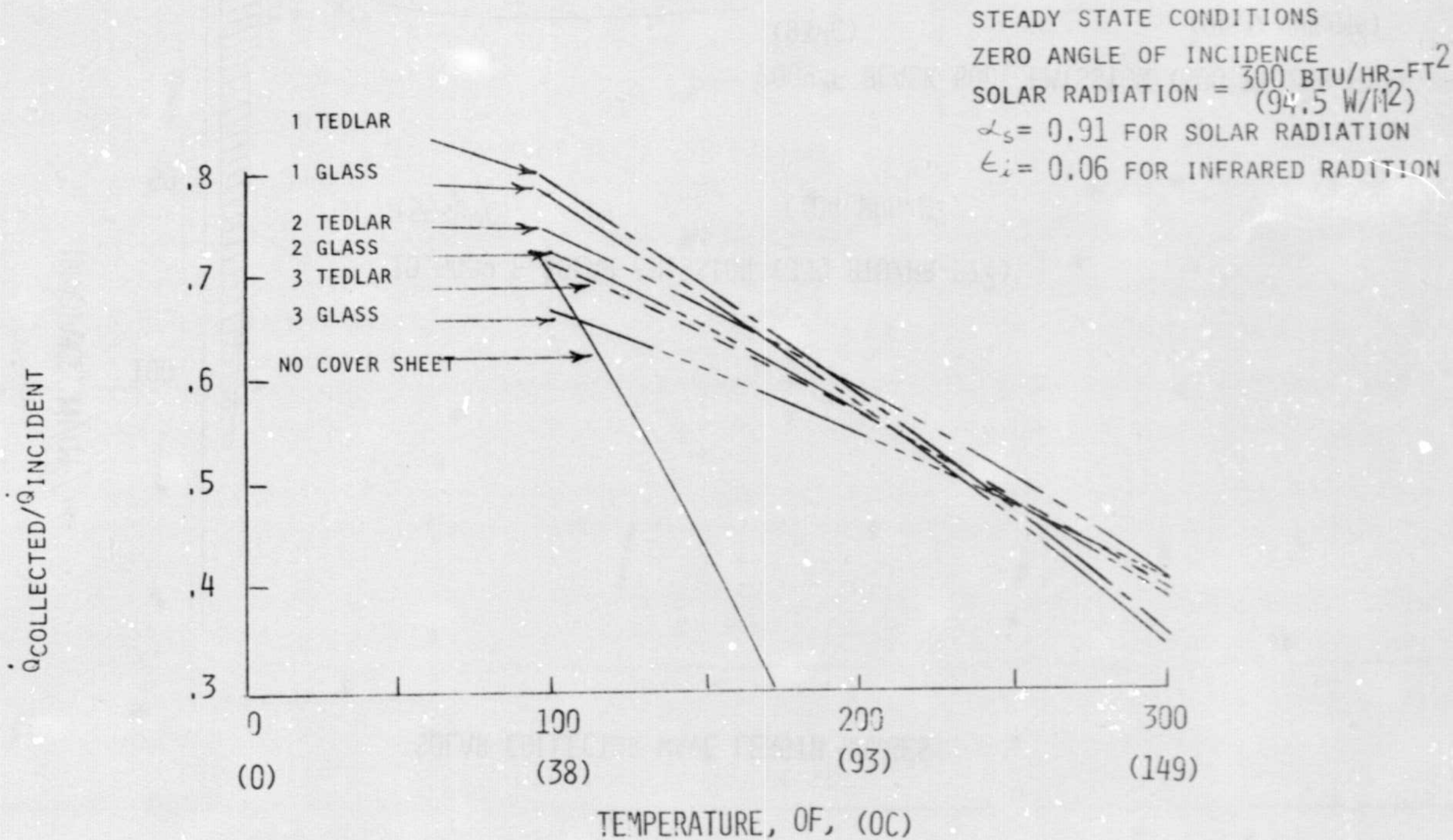


Figure 8

SOLAR COATINGS

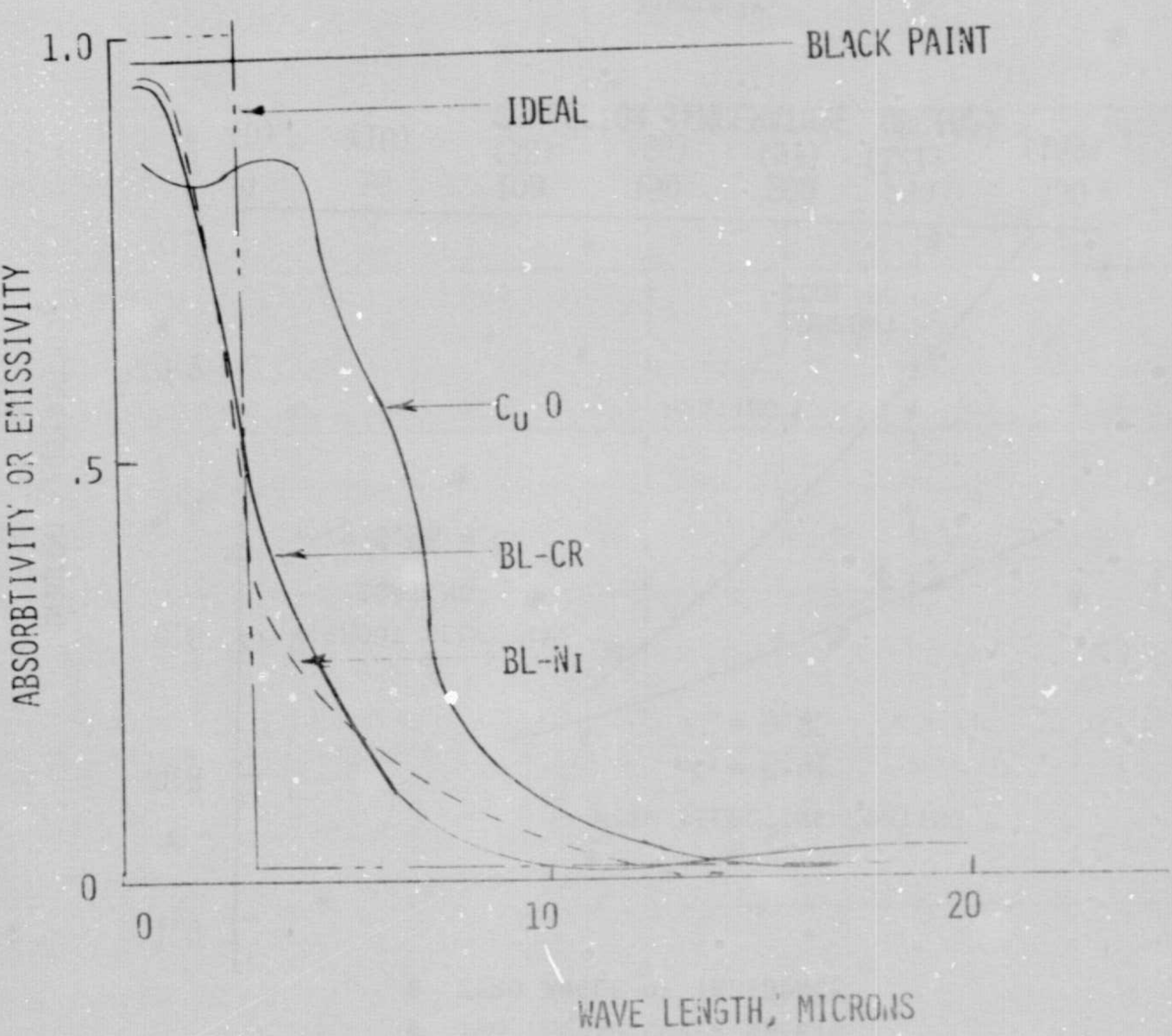


Figure 9

EFFECT OF SELECTIVE COATING ON COLLECTOR EFFICIENCY

- STEADY STATE CONDITIONS
- SOLAR RADIATION = 300 BTU/HR-FT^2 (94.5 W/M^2)
- TWO TEDLAR COVER SHEETS
- ZERO ANGLE OF INCIDENCE

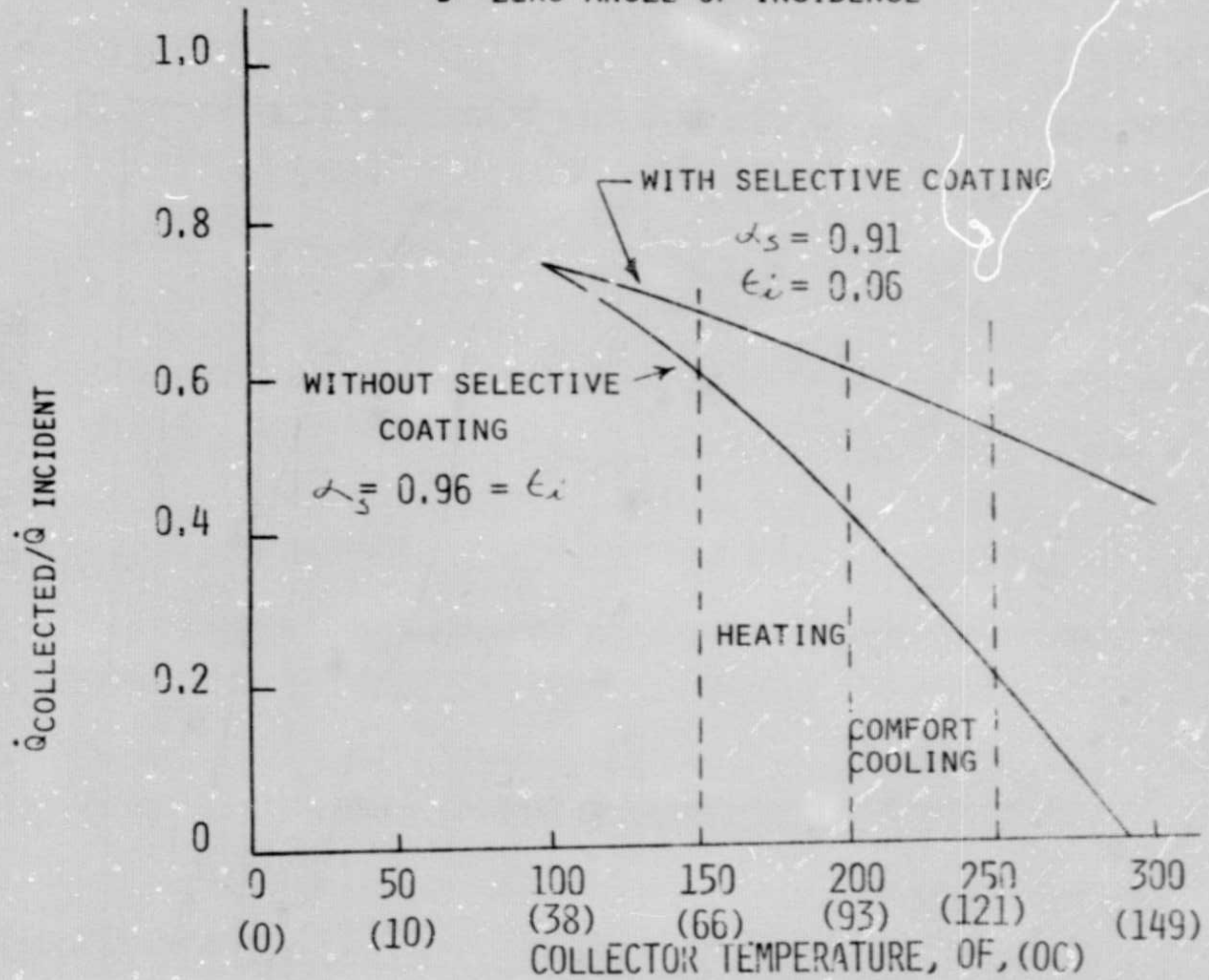


Figure 10

VACUUM INSULATED COLLECTORS

TYPICAL DIMENSIONS - 4 IN. DIAMETER X 10 FT. LONG

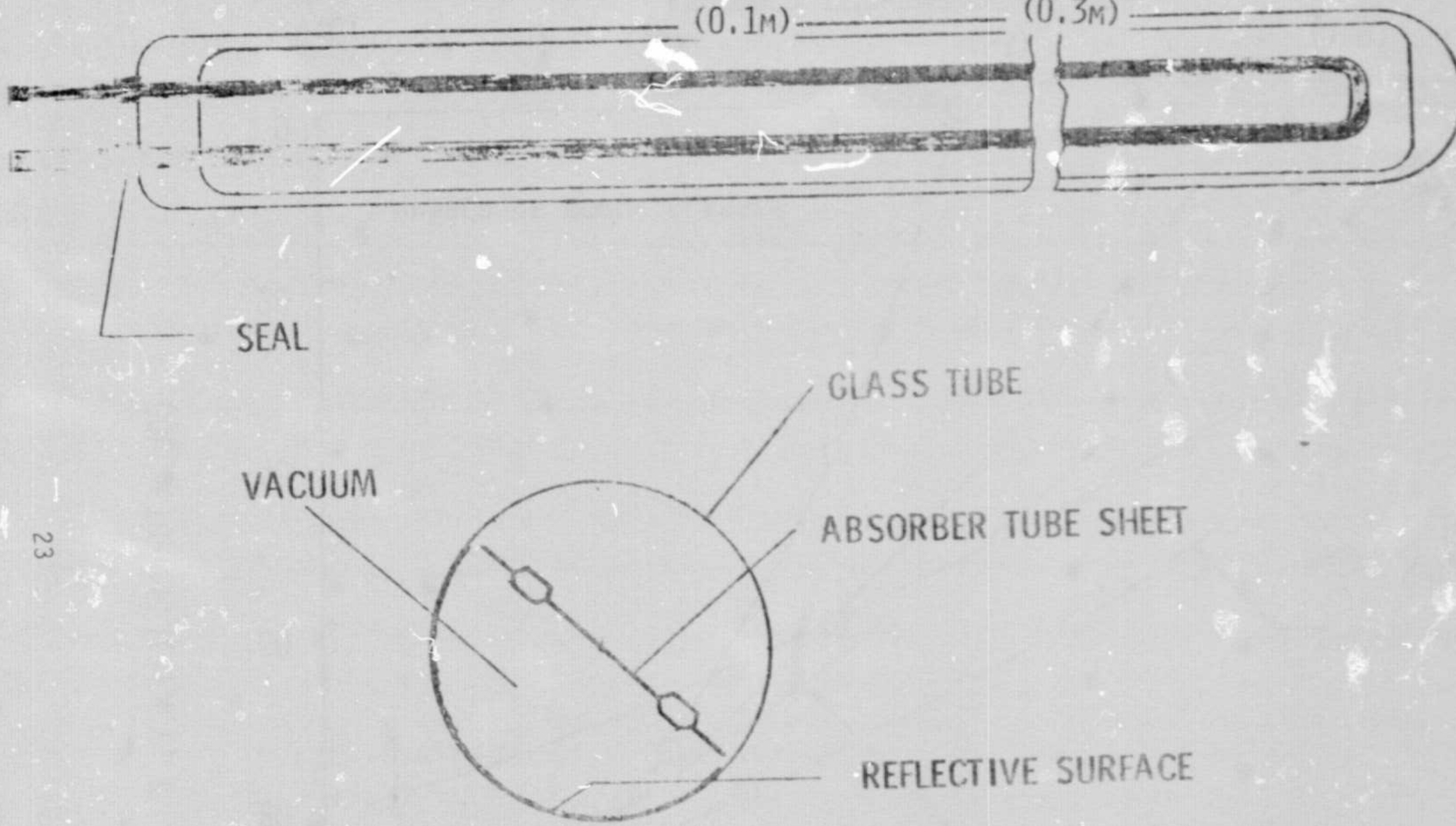
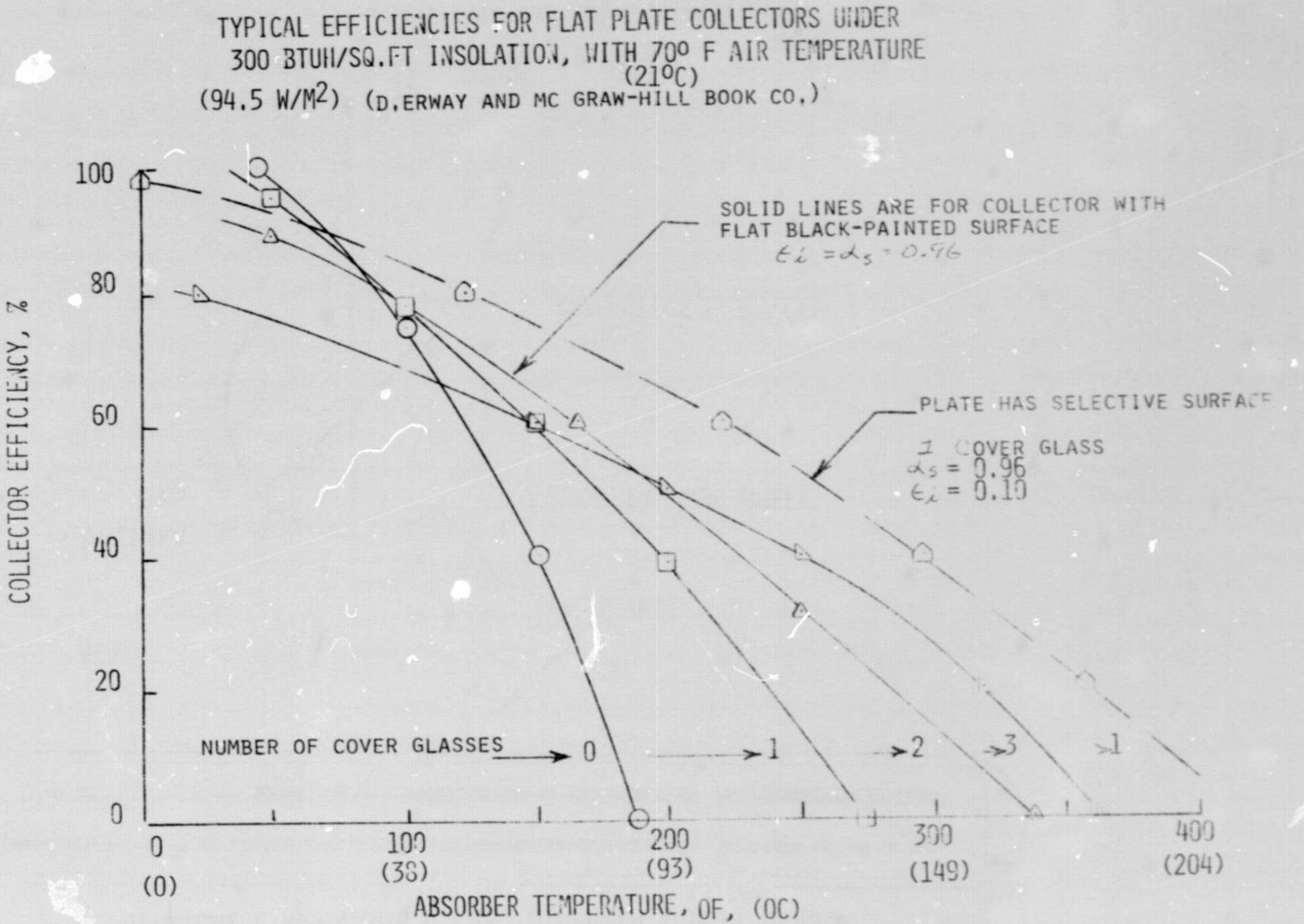


Figure 11



TYPICAL EFFICIENCIES FOR FLAT PLATE COLLECTORS UNDER
300 BTUH/SQ.FT INSOLATION, WITH 70° F AIR TEMPERATURE
(21°C)
(94.5 W/M2) (D.ERWAY AND MC GRAW-HILL BOOK CO.)
SOLID LINES ARE FOR COLLECTOR WITH
FLAT BLACK-PAINTED SURFACE
PLATE HAS SELECTIVE SURFACE
1 COVER GLASS
NUMBER OF COVER GLASSES
0
1
2
3
1
COLLECTOR EFFICIENCY, %
100
80
60
40
20
0
ABSORBER TEMPERATURE, OF, (OC)
0
(0)
100
(38)
200
(93)
300
(149)
400
(204)

Figure 12

PREDICTED PERFORMANCE OF A FLAT-PLATE COLLECTOR

BASIS: MEASURED LANGLEY WEATHER, FEBRUARY 4, 1974

CALCULATED COLLECTOR EFFICIENCY

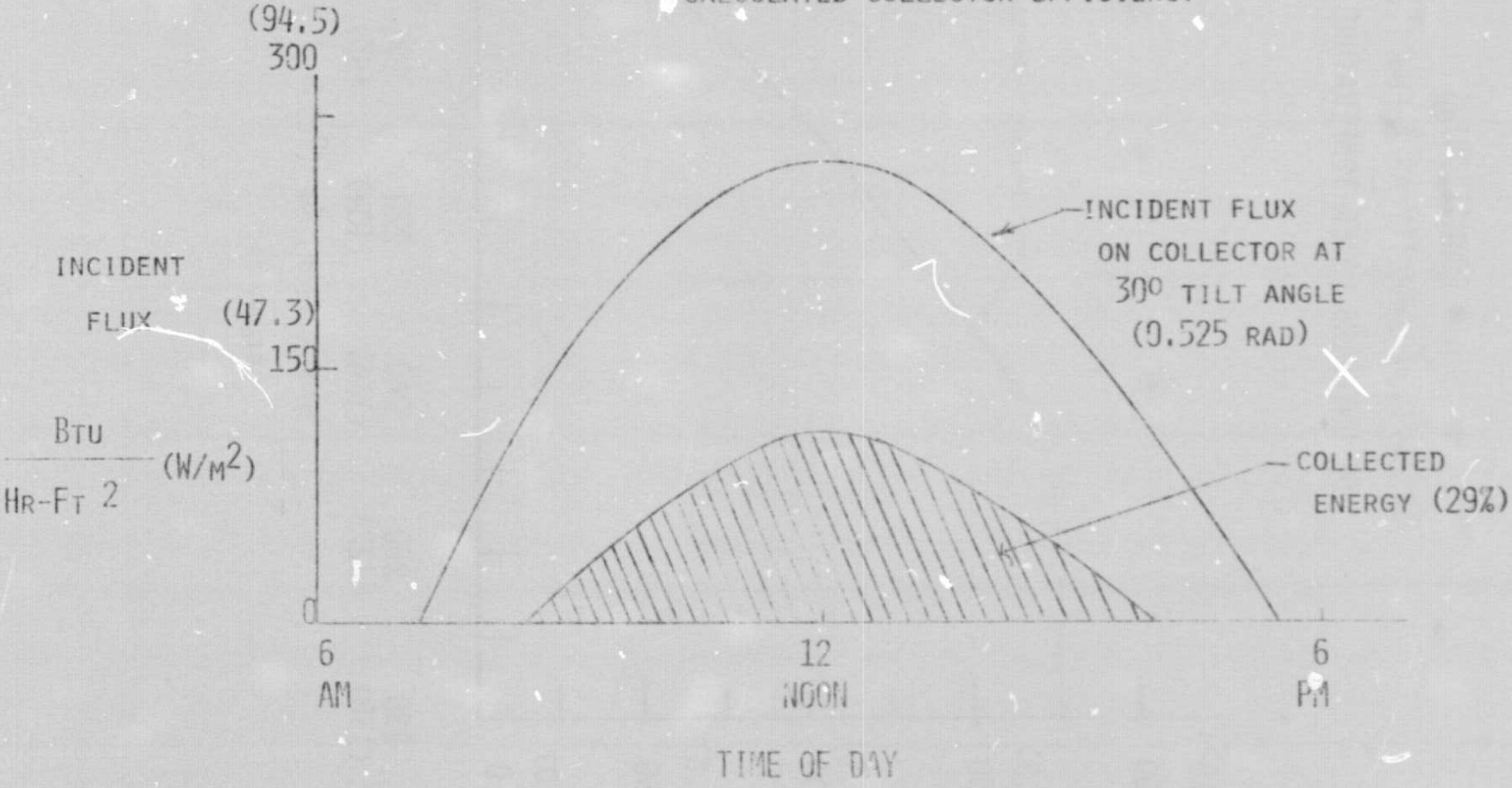


Figure 13

AIR CONDITIONING
ABSORPTION CAPACITY AS A FUNCTION
OF ENTERING WATER TEMPERATURE

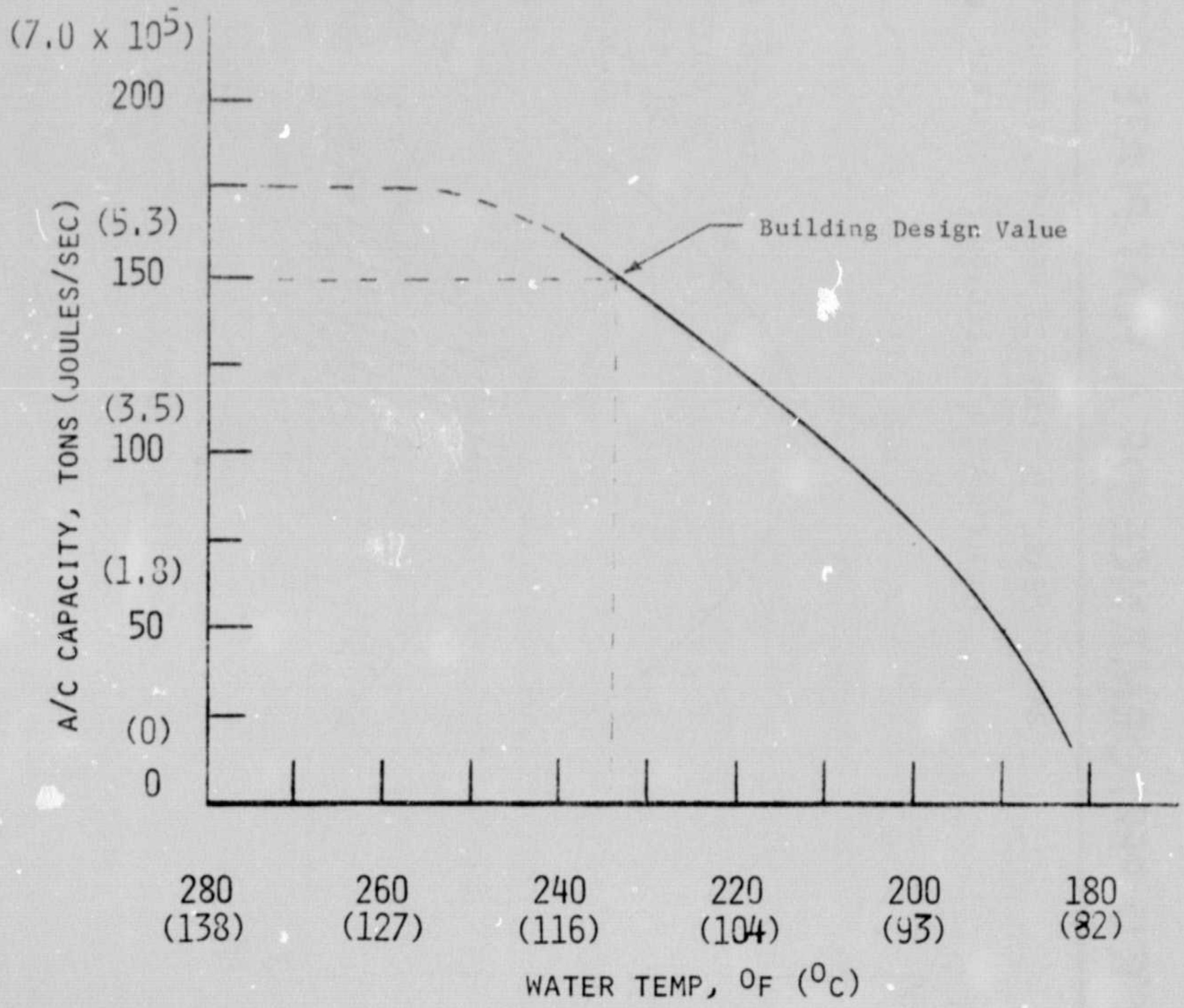


Figure 14

LANGLEY SOLAR COLLECTABLE ENERGY LIMITS FOR THE MONTH OF AUGUST IN 1966

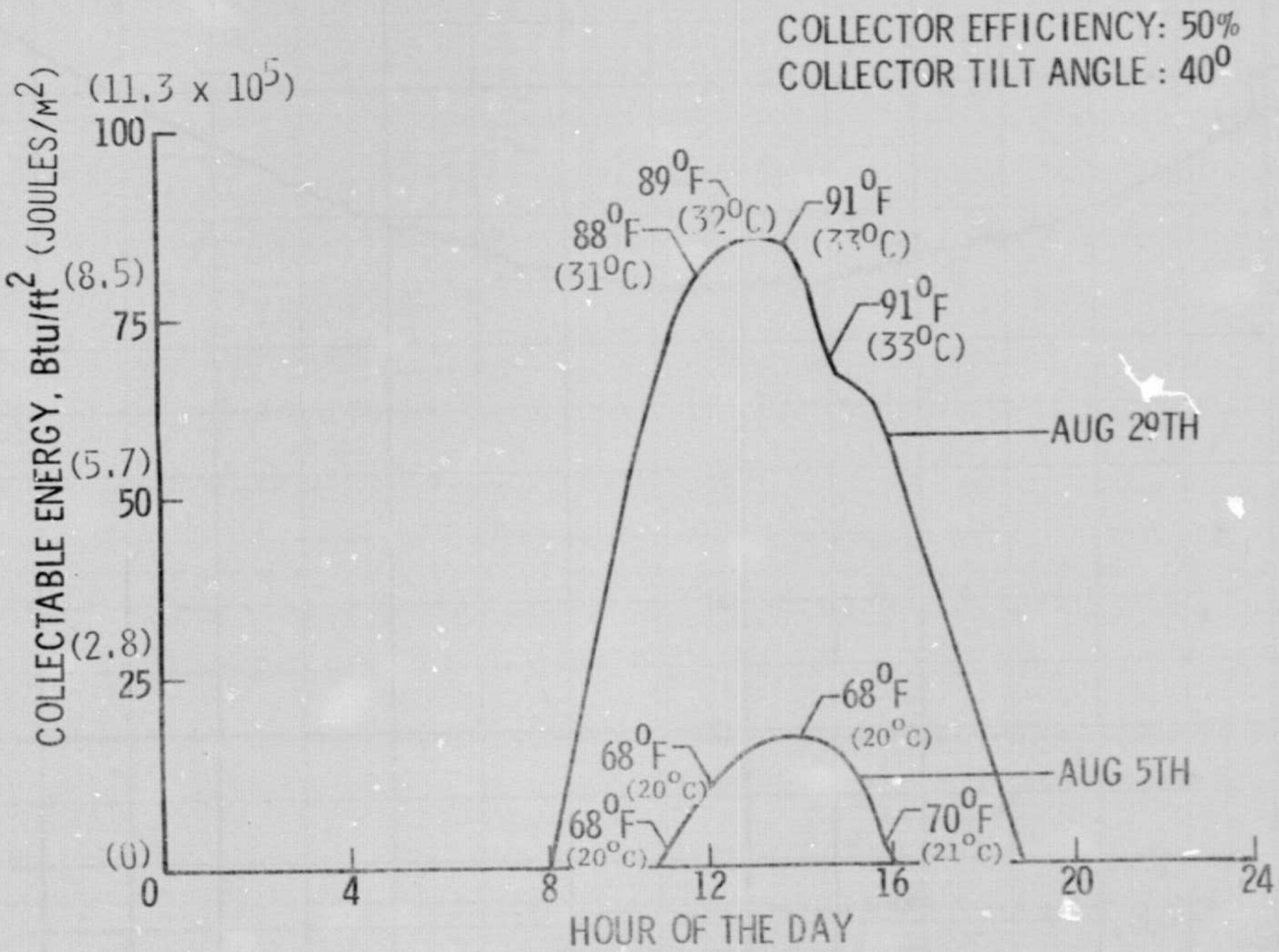


Figure 15

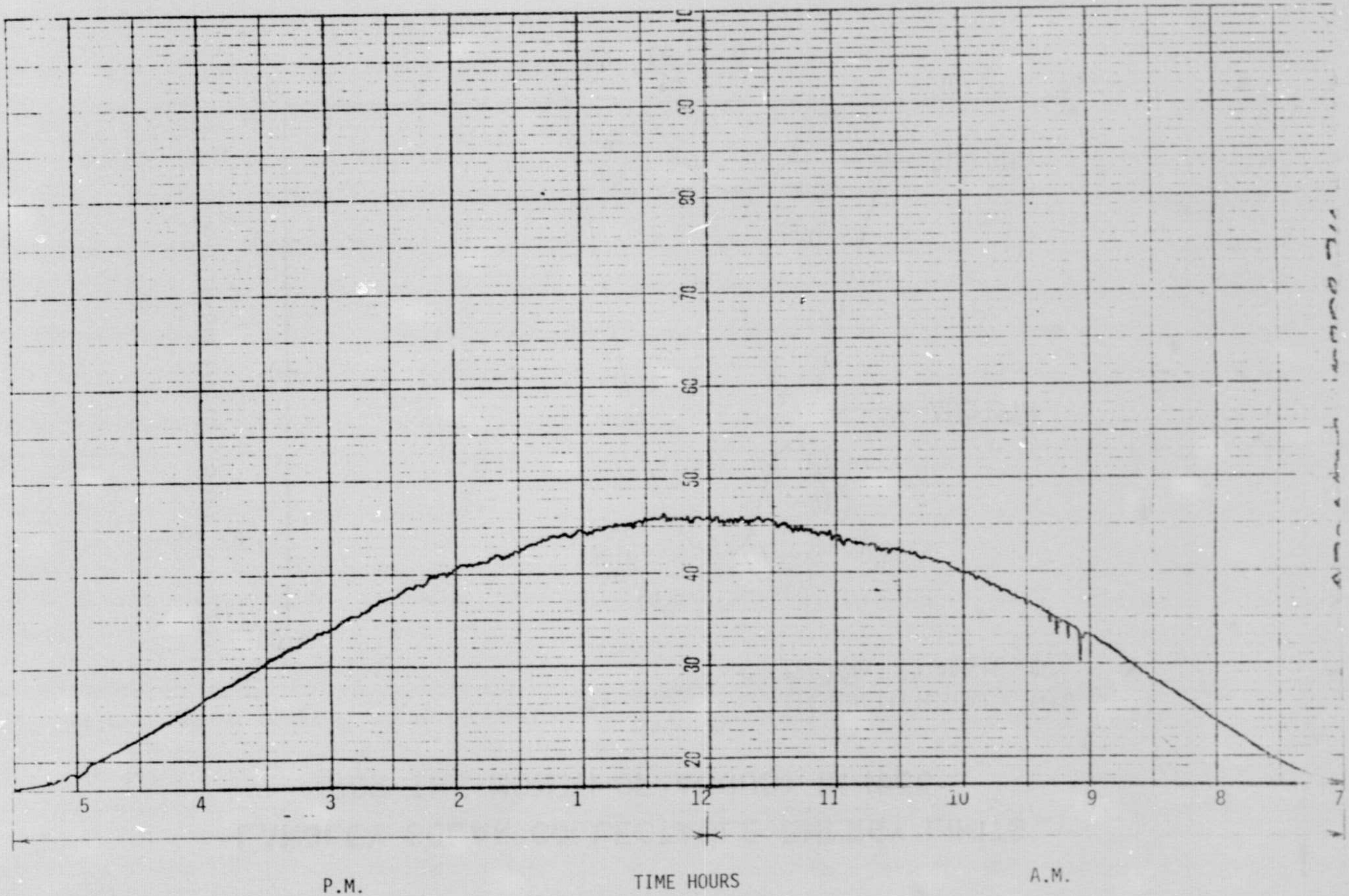


Figure 16 - Solar insolation data recorded at Langley on February 5, 1974. Each ordinate line represents 6.64 BTU/HR - FT^2 (2.09 W/m^2). The total area under the curve represents 1,208 BTU/FT^2 - Day. (1.4 x 10^7 j/m^2 - Day)

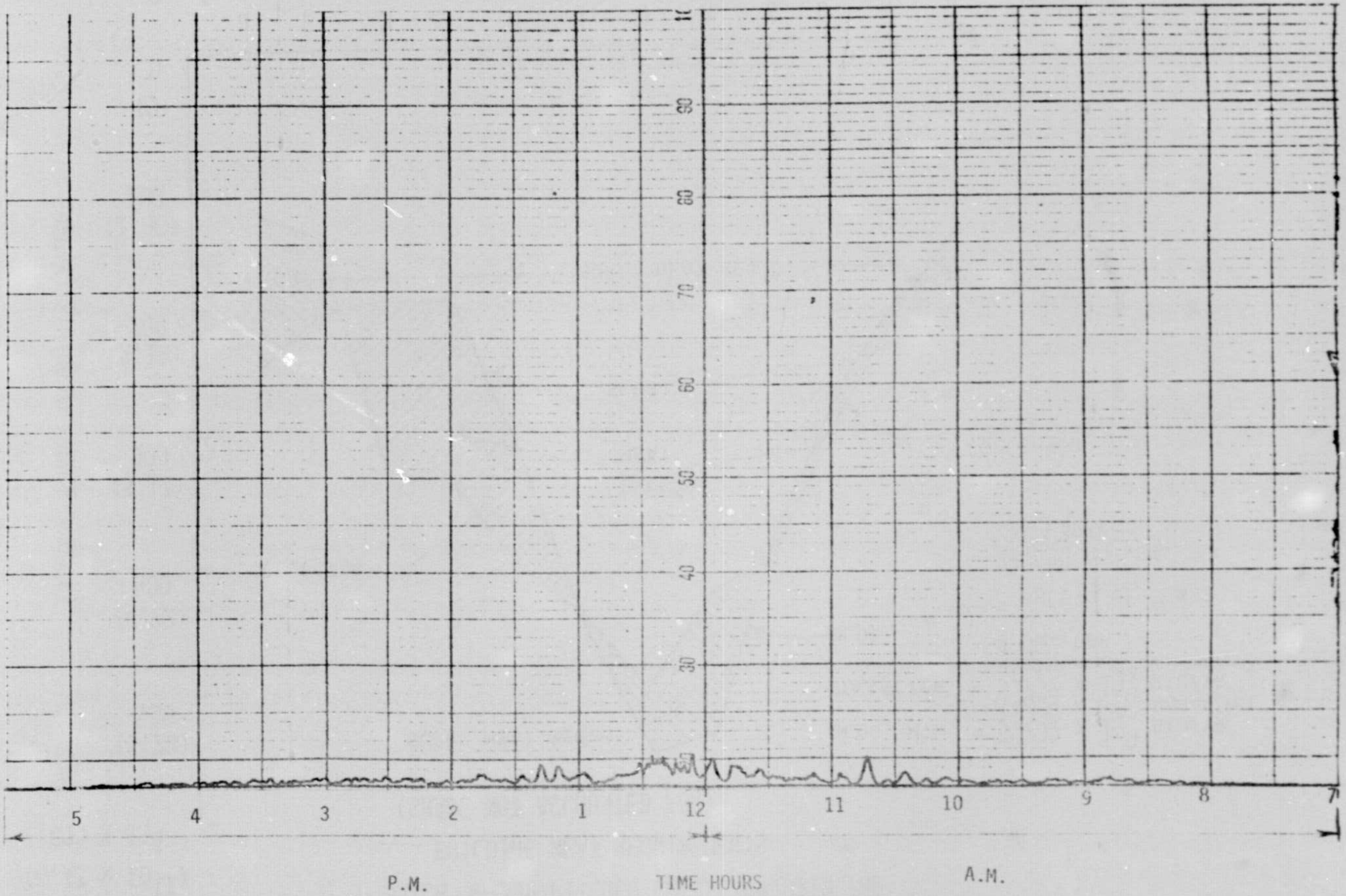


Figure 17 - Solar insolation data recorded at Langley on February 8, 1974. An ice storm on this particular dat prevented the collection of any useful energy.

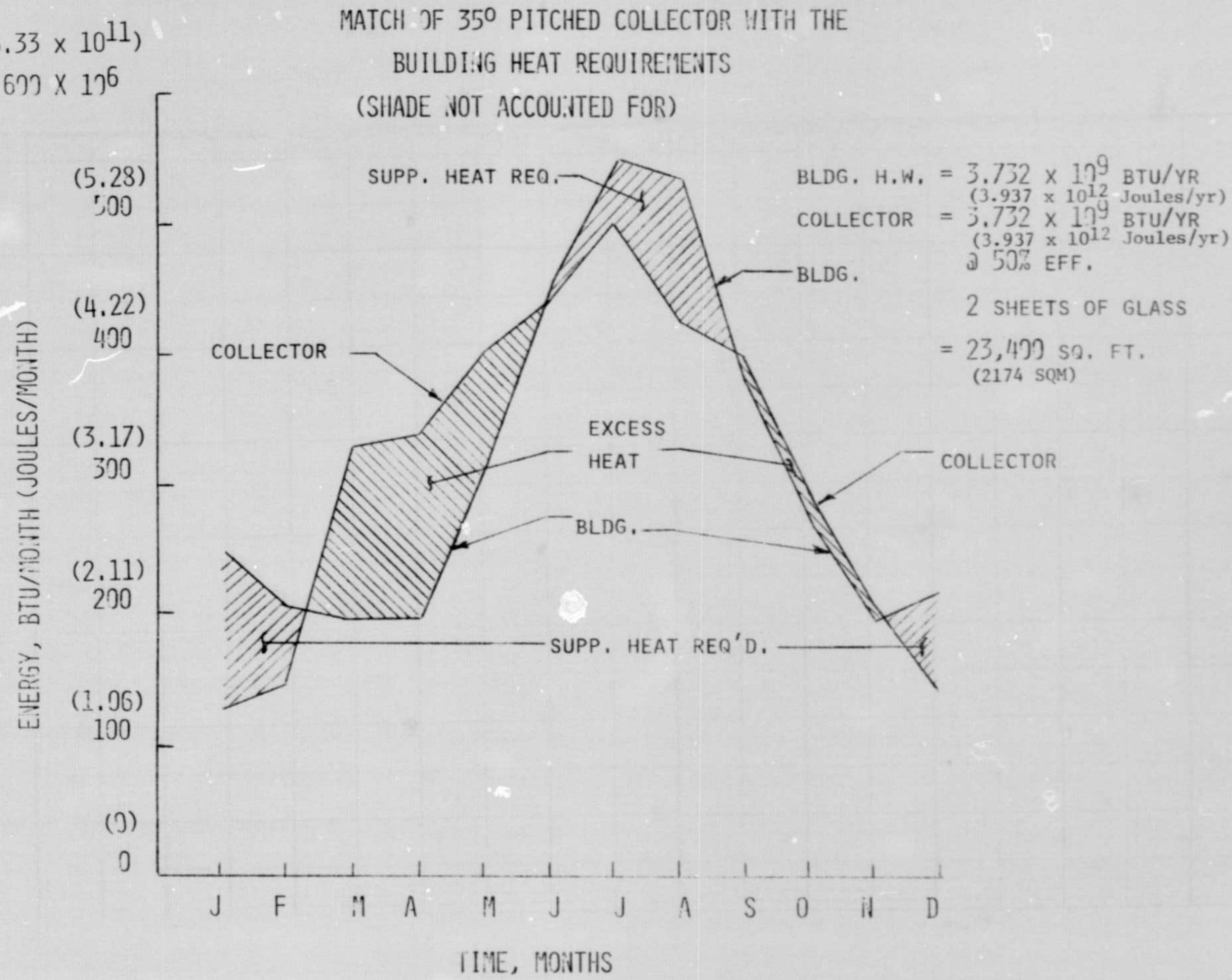

MATCH OF 35° PITCHED COLLECTOR WITH THE
BUILDING HEAT REQUIREMENTS
(SHADE NOT ACCOUNTED FOR)
(6.33 x 10^11)
600 X 10^6
(5.28)
500
(4.22)
400
(3.17)
300
(2.11)
200
(1.06)
100
(0)
0
ENERGY, BTU/MONTH (JOULES/MONTH)
J F M A M J J A S O N D
TIME, MONTHS
SUPP. HEAT REQ.
COLLECTOR
EXCESS
HEAT
BLDG.
SUPP. HEAT REQ'D.
BLDG.
COLLECTOR
BLDG. H.W. = 3.732 x 10^9 BTU/YR
(3.937 x 10^12 Joules/yr)
COLLECTOR = 3.732 x 10^9 BTU/YR
(3.937 x 10^12 Joules/yr)
@ 50% EFF.
2 SHEETS OF GLASS
= 23,400 SQ. FT.
(2174 SQM)

Figure 18

COLLECTOR SIZES VERSUS SUPPLEMENTAL HEAT REQUIRED FROM AN AUXILIARY HEAT SOURCE

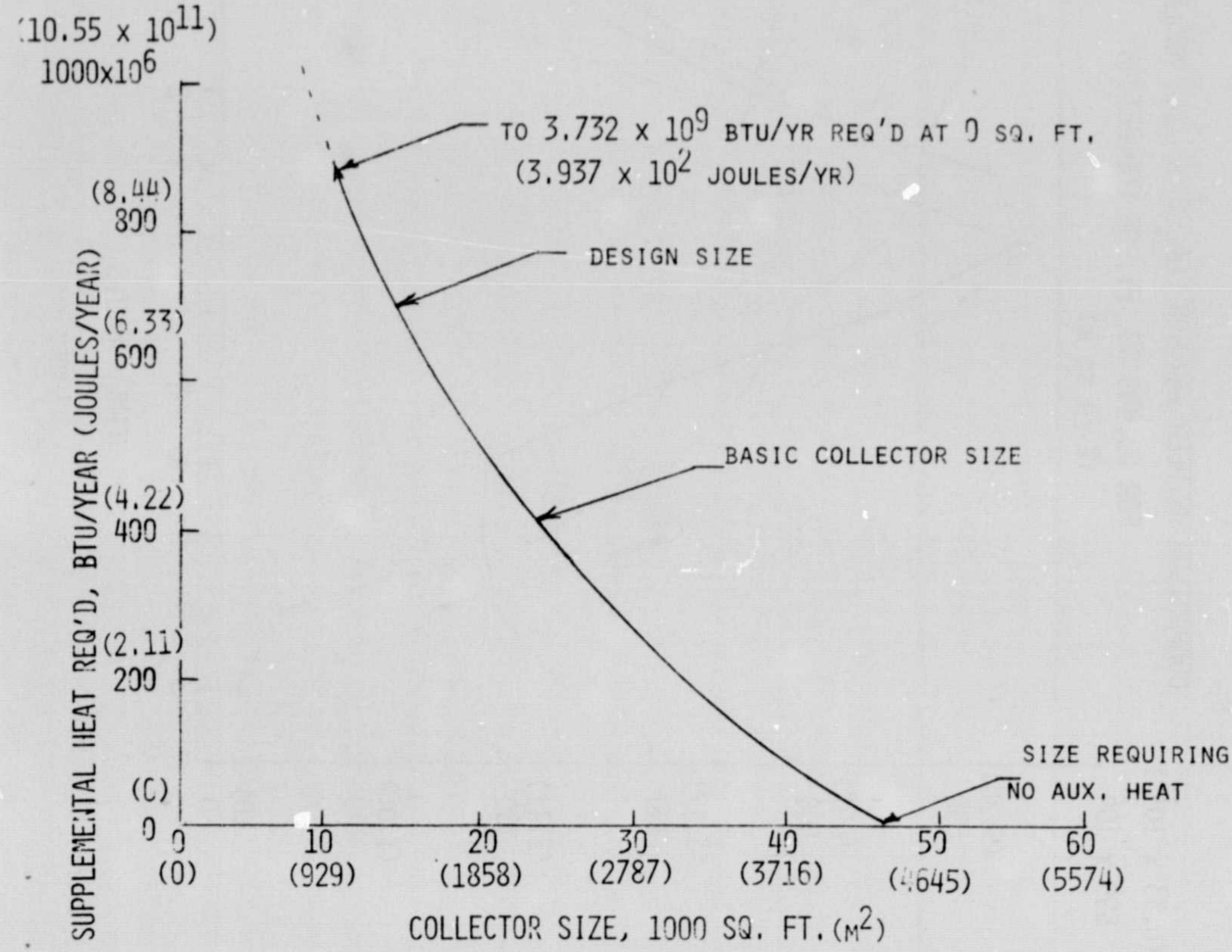


Figure 19

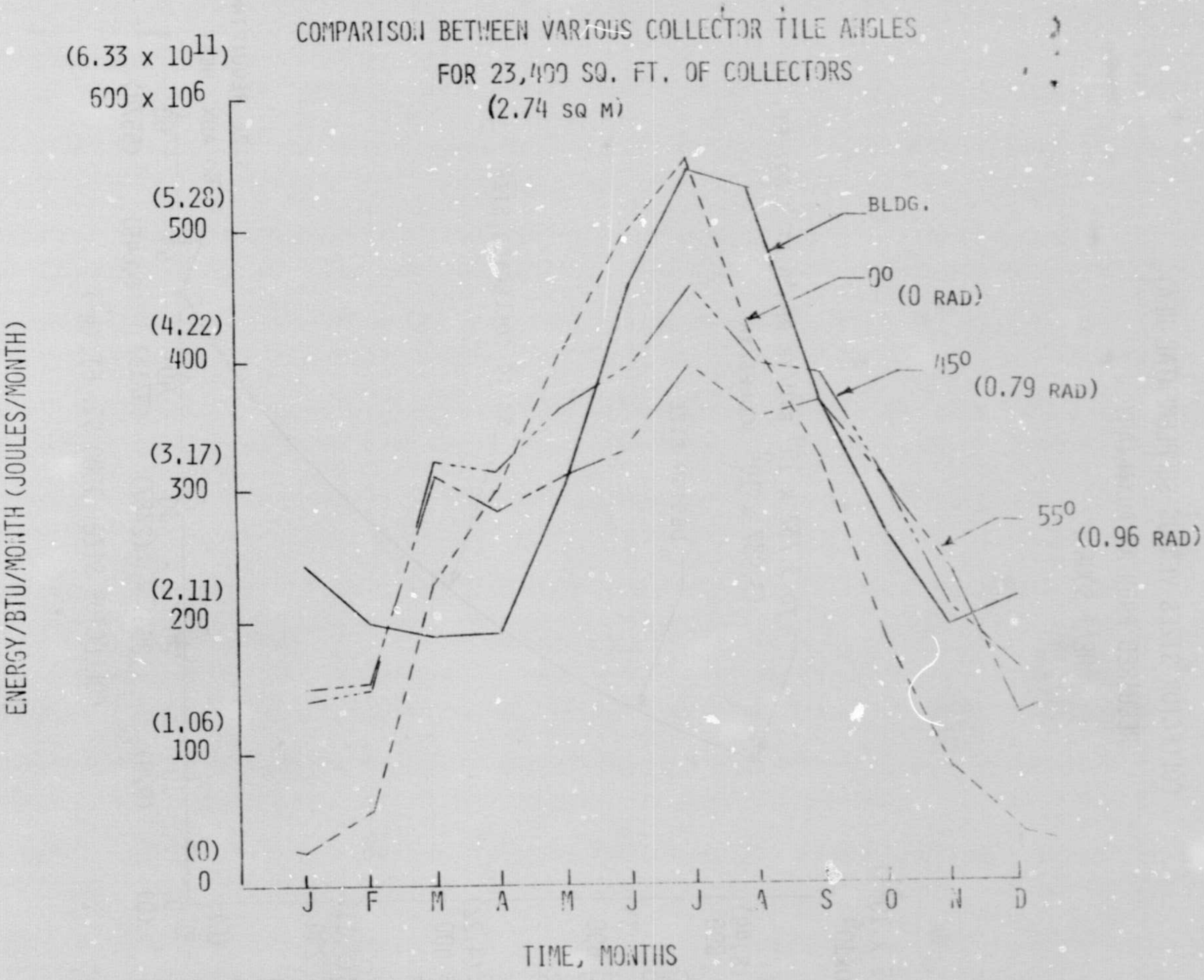

COMPARISON BETWEEN VARIOUS COLLECTOR TILE ANGLES
FOR 23,400 SQ. FT. OF COLLECTORS
(2.74 SQ M)
ENERGY/BTU/MONTH (JOULES/MONTH)
(6.33 x 10^11)
600 x 10^6
(5.28)
500
(4.22)
400
(3.17)
300
(2.11)
200
(1.06)
100
(0)
0
BLDG.
0° (0 RAD)
45° (0.79 RAD)
55° (0.96 RAD)
J F M A M J J A S O N D
TIME, MONTHS

Figure 20

OPTIMIZING 23,400 SQUARE FEET
(2174 m^2)
OF SOLAR COLLECTOR TILT ANGLE

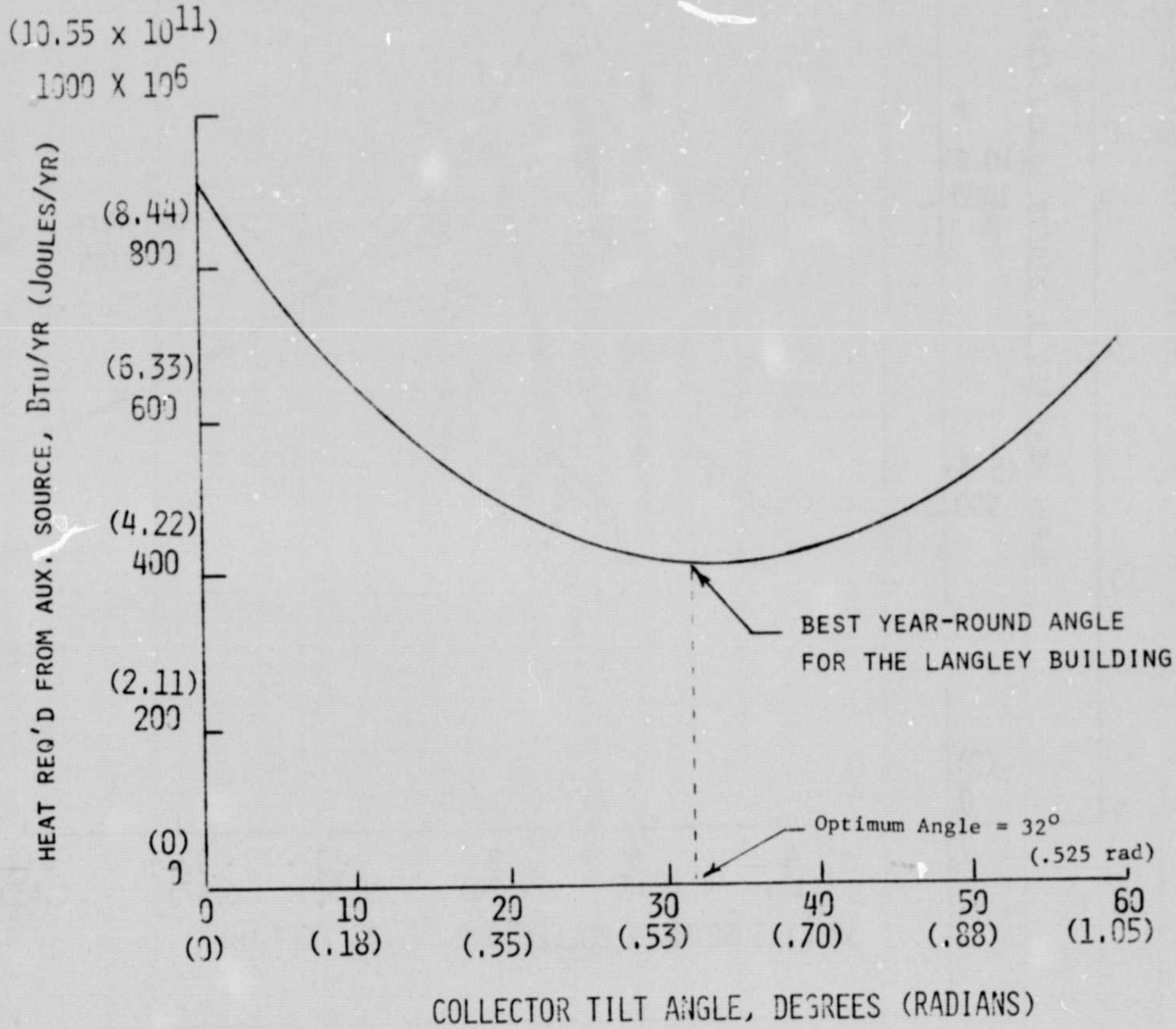


Figure 21

OPTIMIZING COLLECTOR REAL ESTATE AND SPACING BETWEEN COLLECTORS FOR 23,400 SQ. FT. (2174 m^2) OF COLLECTORS AT A TILT ANGLE OF 32° (.525 RAD)

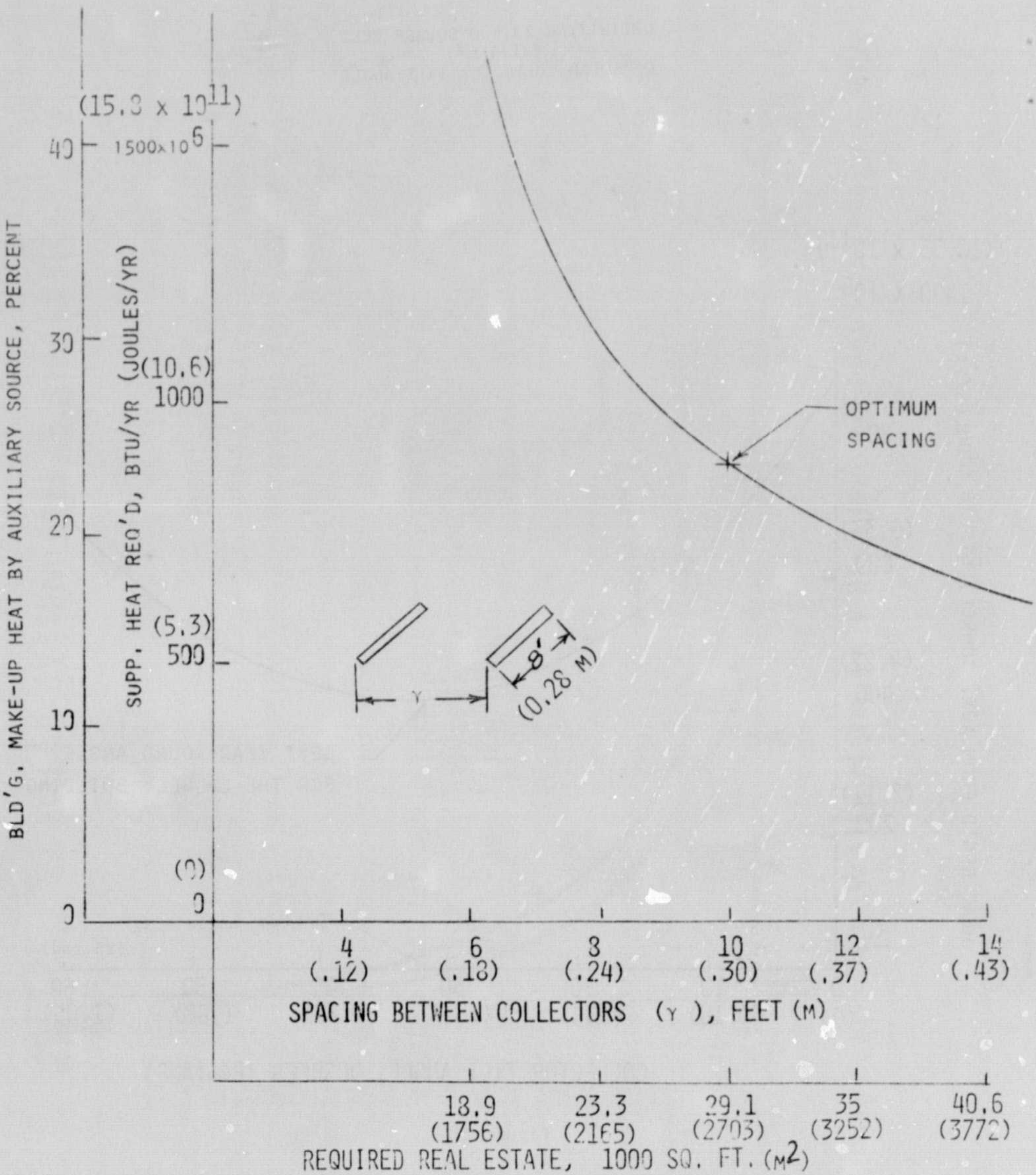
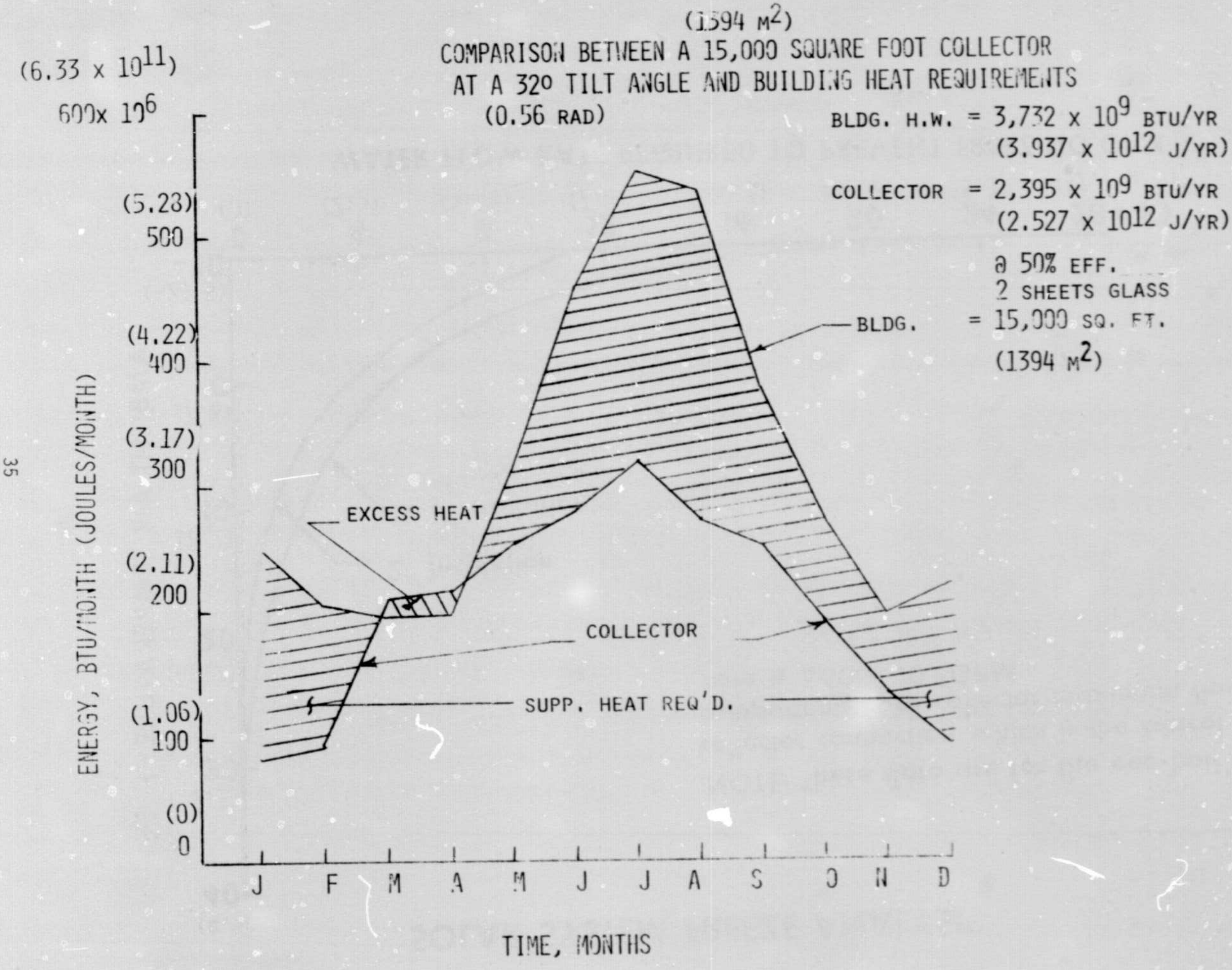


Figure 22



(1394 M2)
COMPARISON BETWEEN A 15,000 SQUARE FOOT COLLECTOR
AT A 32° TILT ANGLE AND BUILDING HEAT REQUIREMENTS
(0.56 RAD)
BLDG. H.W. = 3,732 x 10^9 BTU/YR
(3.937 x 10^12 J/YR)
COLLECTOR = 2,395 x 10^9 BTU/YR
(2.527 x 10^12 J/YR)
@ 50% EFF.
2 SHEETS GLASS
BLDG. = 15,000 SQ. FT.
(1394 M2)
(6.33 x 10^11)
600x 10^6
(5.28)
500
(4.22)
400
(3.17)
300
(2.11)
200
(1.06)
100
(0)
0
ENERGY, BTU/MONTH (JOULES/MONTH)
EXCESS HEAT
COLLECTOR
SUPP. HEAT REQ'D.
BLDG.
J F M A M J J A S O N D
TIME, MONTHS

Figure 23

SOLAR SYSTEM FREEZE ANALYSIS

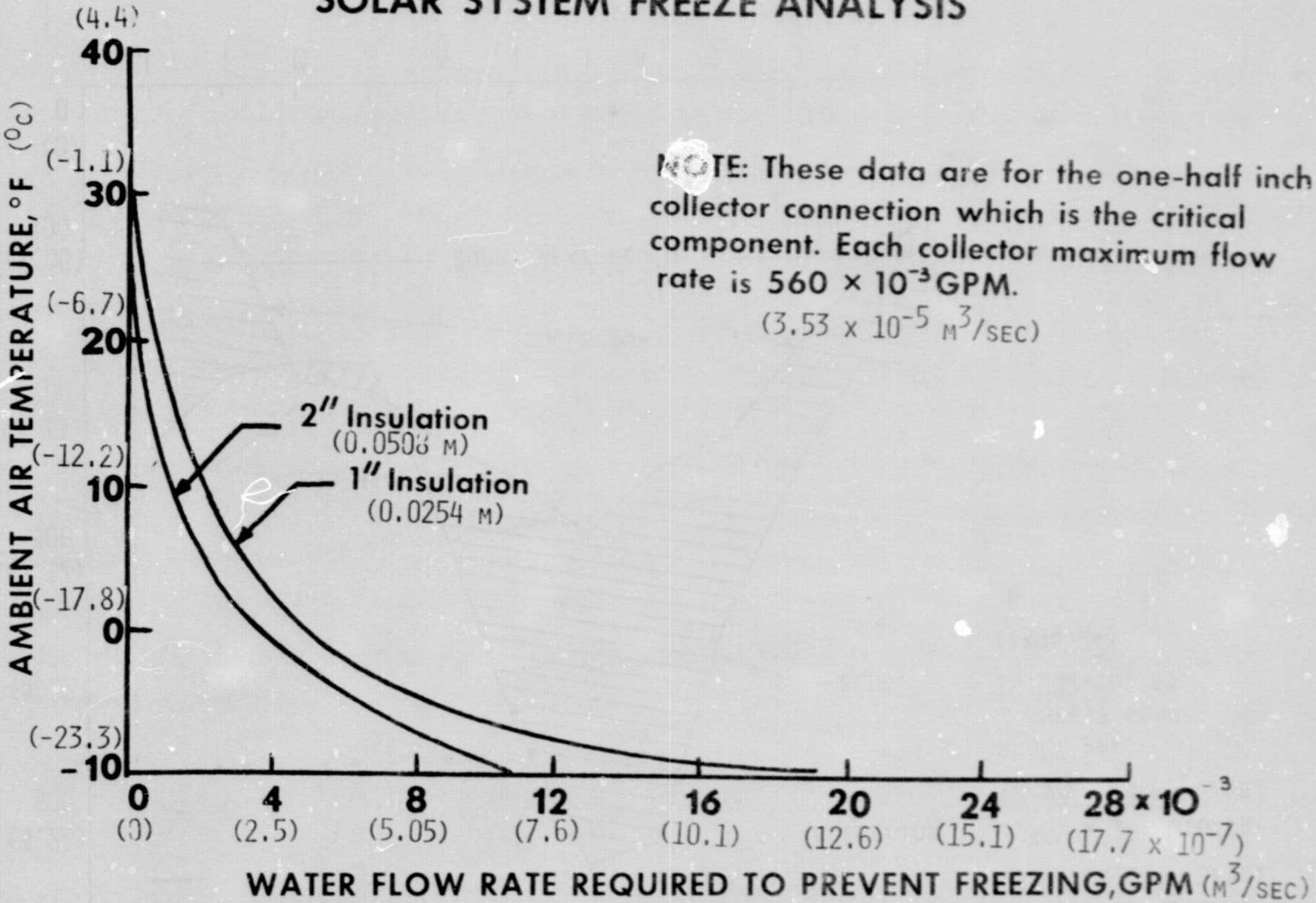


Figure 24

BUILDING ENERGY SYSTEMS FEATURES INVESTIGATED

	A/C SIZE (TONS) (JOULES/SEC)	ENERGY SAVINGS, % OVER BASE BLDG.	ANNUAL OWNING AND OPERATING COST PER YEAR
BASE BUILDING	171 (6.01×10^5)	--	\$70 500
CHARCOAL FILTERS	148 (5.21×10^5)	8.5%	\$67 500
2" ROOF INSUL.	175 (6.15×10^5)	-5.0%	\$71 250
4" ROOF INSUL.	167 (5.87×10^5)	3.5%	\$71 000
DOUBLE GLASS	170 (5.98×10^5)	1.0%	\$72 000

- CONVERSION TO CHARCOAL FILTERS PAYS FOR ITSELF IN 3 YEARS. NO COST ADVANTAGE FOR OTHERS WITHIN 40 YEAR BUILDING LIFE.

TABLE I

SOLAR SELECTIVE COATINGS

	Cu O	BLACK Ni	BLACK CHROME
COST	LOW	LOW	LOW
SOLAR PERFORMANCE	REQ. HIGH CONTROL	GOOD	GOOD
DURABILITY	GOOD	GOOD (HUMIDITY SENSITIVE?)	GOOD
APPLIC. PROCESS	SPRAY CHEMICAL	ELECTROPLATE	ELECTROPLATE
AVAILABILITY	SPECIAL	SPECIAL	COMMERCIAL

TABLE 2

SOLAR ENERGY

MONTH vs COLLECTOR TILT

(JOULES/M^2 - SEC) / (JOULES/M^2 - MM)

MAX RATE IN BTU/SQ. FT./HR / BTU/MON/FT^2

MONTH \ ANGLE X (RAD)	0° (0)	35° (0.61)	45° (0.79)	55° (0.96)
JAN	22 (69) / 1149 (1.3x10^7)	56 (176) / 5307 (6.0x10^7)	61 (192) / 6015 (6.8x10^7)	64 (202) / 6404 (7.3x10^7)
FEB	40 (126) / 2494 (2.8x10^7)	65 (205) / 6139 (7.0x10^7)	66 (208) / 6573 (7.5x10^7)	66 (208) / 6662 (7.6x10^7)
MAR	79 (249) / 9902 (1.1x10^8)	98 (309) / 14053 (1.6x10^8)	98 (309) / 14001 (1.6x10^8)	95 (299) / 13366 (1.5x10^8)
APR	98 (309) / 12793 (1.5x10^8)	104 (328) / 14214 (1.6x10^8)	99 (312) / 13382 (1.5x10^8)	91 (287) / 12061 (1.4x10^8)
MAY	101 (318) / 18162 (2.1x10^8)	98 (309) / 17105 (1.9x10^8)	91 (287) / 15479 (1.8x10^8)	81 (255) / 13359 (1.5x10^8)
JUNE	108 (304) / 21297 (2.4x10^8)	101 (318) / 18684 (2.1x10^8)	93 (292) / 16666 (1.9x10^8)	82 (258) / 14162 (1.6x10^8)
JULY	107 (337) / 23689 (2.7x10^8)	101 (318) / 21467 (2.4x10^8)	93 (292) / 19430 (2.2x10^8)	83 (261) / 16864 (1.9x10^8)
AUG	100 (315) / 17867 (2.0x10^8)	105 (331) / 18231 (2.1x10^8)	100 (315) / 17050 (1.9x10^8)	93 (292) / 15371 ((1.7x10^8)
SEP	93 (293) / 13938 (16.x10^8)	105 (331) / 16971 1.9x10^8)	102 (321) / 16576 (1.9x10^8)	98 (309) / 15628 (1.8x10^8)
OCT	69 (217) / 7712 (8.7x10^7)	93 (292) / 12594 (1.4x10^8)	94 (296) / 12936 (1.5x10^8)	91 (287) / 12865 (1.5x10^8)
NOV	37 (117) / 3426 (3.9x10^7)	66 (208) / 8823 (1.0x10^8)	70 (221) / 9607 (1.1x10^8)	71 (224) / 9980 (1.1x10^8)
DEC	30 (95) / 1356 (1.5x10^7)	64 (202) / 6012 (6.8x10^7)	69 (217) / 6842 (7.8x10^7)	72 (227) / 7341 (8.3x10^7)
TOTAL	133,792 (1.622x10^9)	159,606 (1.798x10^9)	154,611 (1.76x10^9)	144,059 (1.63x10^9)

TABLE 3

HOT WATER STORAGE TANKS

COLLECTOR AREA: 15,000 FT^2 BASED ON 50% EFFICIENCY
($1394\ M^2$)

MONTH	PERCENT OF ENERGY SUPPLIED	STORAGE FOR ONE AVERAGE DAY (GALLONS) (M^3)	CLEAR DAYS TO FILL STORAGE & SUPPLY BLDG.
JANUARY	32	25,400 (96.3)	3.6
FEBRUARY	43	23,000 (87.2)	2.4
MARCH	106	20,000 (75.6)	1.6
APRIL	107	20,000 (75.8)	1.6
MAY	81	31,000 (117.5)	2.8
JUNE - SEPTEMBER	-	-	-
OCTOBER	68	28,000 (106.1)	1.9
NOVEMBER	68	19,500 (73.9)	1.5
DECEMBER	41	22,000 (83.4)	2.1

TABLE 4