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USE OF SOLAR ENERGY AT THE QUEEN ELIZABETH HOSPITAL IN BRIDGETOWN, BARBADOS[1, 2]

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A study was conducted in February-March 1981 to find out whether solar energy could effectively serve the Queen Elizabeth Hospital in Bridgetown, Barbados. The study indicated that a solar energy system designed to heat domestic hot water would be cost-effective, and it was recommended that the hospital proceed with plans to install a limited solar energy system of this kind.

Introduction

The Queen Elizabeth Hospital in Bridgetown, Barbados, is located near downtown Bridgetown. It is one of the most prominent, if not the most prominent, health care facility of the West Indies, and so any solar energy installation there would draw considerable attention from the medical community at large.

The purpose of the 1981 study on which this article is based was to assess the feasibility of using solar energy at the hospital to meet a portion of the facility's energy needs. The study dealt with existing hospital systems, relevant design data, locally available solar energy products, and various economic considerations.

The Hospital Buildings

The Queen Elizabeth Hospital is a rectangular five-story structure completed in 1964 with a capacity of 620 beds. It provides a full range of health care, including laboratory facilities and a well-equipped surgical service. It also has a full-service laundry.

The hospital's physical plant has three main sections known as the north block, the center block, and the south block, all interconnected as shown in Figure 1.

Solar Collector Systems

The amount of solar energy that can be collected at any site is dependent upon a number of variables such as the construction of the solar collector panels, the tilt and orientation of those panels, the operating temperatures of the system, the potential sunlight available, ambient temperatures, wind velocities, and sky cover. The amount of collectible solar energy that can ultimately be used in the building is further influenced by the size and frequency of the hot water demand and the capacity of the storage system installed to retain the excess collected energy for periods when solar energy collection is not possible.

An understanding of the anticipated energy demand is also of great importance in ensuring that the solar energy system will be optimally designed. In general, the most desirable types of heating demands for solar appli-

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[2] This article is based on portions of a document by the authors entitled "Final Report on the Advisory Services Provided to Study Solar Energy Feasibility in the Queen Elizabeth Hospital in Bridgetown for the Ministry of Health and National Insurance of Barbados, 25 February-5 March 1981." Those wishing further details about the design and economics of this system should request a copy of that document from the Unit on Hospital Maintenance, Division of Comprehensive Health Services, Pan American Health Organization, 525 Twenty-third Street, N.W., Washington, D.C. 20037, U.S.A.

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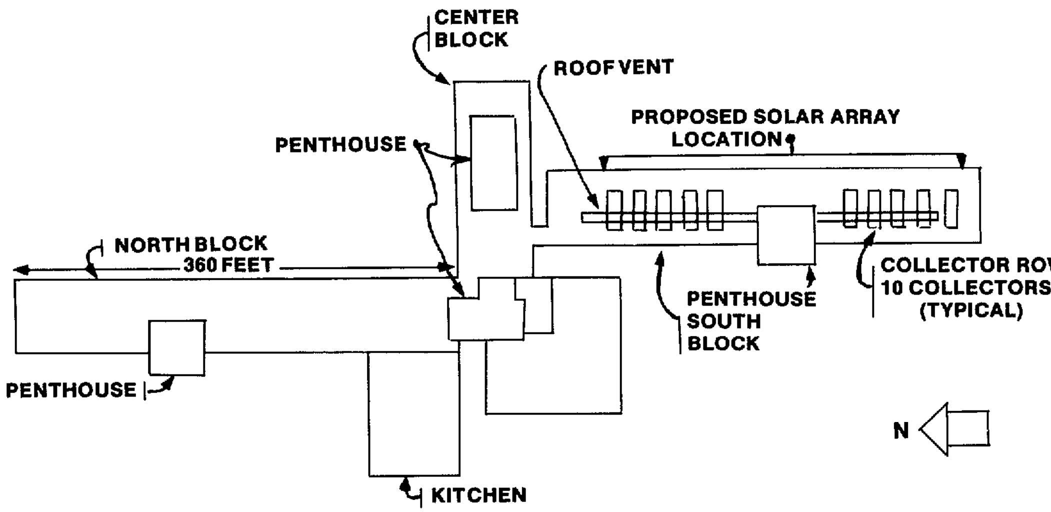
Figure 1. Plot plan of the Queen Elizabeth Hospital showing the north, south, and center blocks and the location of the proposed solar energy collectors.



cations are those that remain relatively constant throughout the year and peak during daytime hours when maximum solar energy collection is possible. This means that the more desirable types of demands are those for domestic hot water service, kitchen hot water service, and laundry applications. These demands are generally constant throughout the year and usually occur during the daylight hours, when solar energy is available.

Solar applications for space-heating are much more difficult to justify economically than those for domestic hot water. Most heating demands are seasonal, and they peak during the night. This means that large storage systems and specially designed space-heating systems are required. Furthermore, in our particular case the potential gains are further reduced by the fact that the space-heating requirements of the Queen Elizabeth Hospital are small.

Space-cooling systems are the most difficult systems to justify economically and are rarely cost-effective. This is particularly true for island-type climates where free cooling with cross-ventilation is available throughout much of the year. Overall, it seems clear that the potential savings obtained by meeting the small demand involved would not amortize the cost of a solar cooling installation at the Barbados site.

For these reasons, our solar study focused on solar energy systems designed to heat domestic hot water. These systems are generally cost-effective, offer relatively maintenance-free operation, and have a low initial cost.

The Existing Heating System and Climate

The Heating System

The hospital is served by three package-type dual-fuel steam boilers with a combined capacity of 10,500 pounds per hour at a pressure of 100 pounds per square inch absolute. The boilers burn either oil or gas and provide steam for all the hospital's domestic hot water, sterilizing, and heating needs. The north and south blocks each have one domestic water heater and the center block has two; all these water heaters are located in the mechanical rooms of their respective blocks.

Each heater utilizes a steam-tube bundle inserted into a 600-gallon storage tank to heat water to approximately 140°F. The resulting hot water is continually circulated throughout the building by a hot-water return line and a hot-water recirculating pump with a capacity of 30 gallons per minute. The pipes used to transport this heated water are heavy-duty galvanized pipes with flange or screw-type joints.

The Climate

A quick examination of available information indicates that Barbados' climate and weather are well-suited to utilization of solar energy. The average yearly ambient temperature is 80°F, with temperature extremes ranging from a low of 61°F to a high of 92°F. Obviously, no protection against freezing is necessary, a fact which simplifies design requirements, lowers cost, and permits higher collection efficiencies. Also, the sun is out approximately 70 per cent of the time it is above the horizon, and much of the time when there is cloud cover a good deal of solar energy can still be collected.

It is also true, however, that because of the hurricane danger, estimates of the maximum wind loads to be borne by the solar collectors should be based on hurricane velocities. Collectors mounted at an angle to the roof surface on open racks can be lifted by wind striking their undersides. This wind load is in addition to the equivalent roof-area wind loads, and it should be determined according to accepted engineering procedures. While such wind load may not lift and carry off the structure, it may promote vibration that can lead to leaks through pitch boxes and other roof mounting points. Also, negative pressures induced by wind can, and often do, exceed pressure loadings; and cover-plate retainers must be adequately designed to prevent the glazings from separating from the collector frame.

The Solar Collectors

Collectors can be located wherever there is adequate space, although a location near the energy demand to which they will be applied will minimize piping losses and costs. The major factors affecting site selection include visibility, vandalism, shading, and the integrity of the mounting structure.

Regarding visibility, it is sometimes desirable to hide the collectors so as to minimize their impact on architectural appearance. However, on other occasions it may be equally or more important to have the collectors visible, so that their presence will advertise the system and help to demonstrate the savings being achieved by use of solar energy.

Vandalism is another problem at some locations, especially when the collectors are highly visible and are mounted on the ground or a low roof. In some instances it becomes a challenge to vandals to see if a collector's glass can be broken. By and large, however, our experience suggests that vandalism should not be of major concern in most areas.

Shading is of critical importance. The collectors must be located so that adjacent buildings or trees do not shade them at any time during the year. In addition, adequate space must be provided between the collectors' rows so that shading of one row by another is prevented.

The designer must also check the structural capabilities of the existing or new roof structure to insure that the added weight of the collectors does not cause overloading of either the structural members or the concrete roof slab. In addition, the collectors' support structure must be combined with the roof structure to provide a coordinated structural support system.

Because of the need to take maximum advantage of the sun, the collectors (ideally mounted on a flat roof surface) should have supports appropriate for prôviding an optimum tilt angle. The roof and supports must accommodate the dead weight of the collectors filled with fluid and their connecting piping under ordinary conditions and, of utmost importance, under maximum wind loads. The supports can be fabricated from metal angles, tubes, box struts, or treated wood. Particular care must be taken to properly flash all openings that penetrate the roof. The solar collectors can be an integral part of building wall or roof structures. All structural design should be based on generally accepted engineering practices.

The Proposed System

The solar energy field is evolving rapidly, and so it would seem inappropriate to attempt a large undertaking for the first government solar-power project in Barbados. A more reasonable approach would be to serve one of the major blocks of the hospital at this time and then expand the system later. This would allow all the personnel involved, including hospital engineering and maintenance personnel, contractors, and consultants to gain experience before proceeding with a larger project. Such an approach, in all likelihood, would produce a much more effective and successful system.

Another major consideration is the system's cost. A system designed to serve one-third of the hospital would be less costly and more likely to be funded. After this system is successfully operating, it would then provide an incentive for making further investments in solar energy.

For these various reasons, our study limited itself to providing solar energy for the hospital's south block. The south block was selected because of its unobstructed roof, the availability of space in its mechanical room, and the ease of running piping between the roof and the mechanical room.

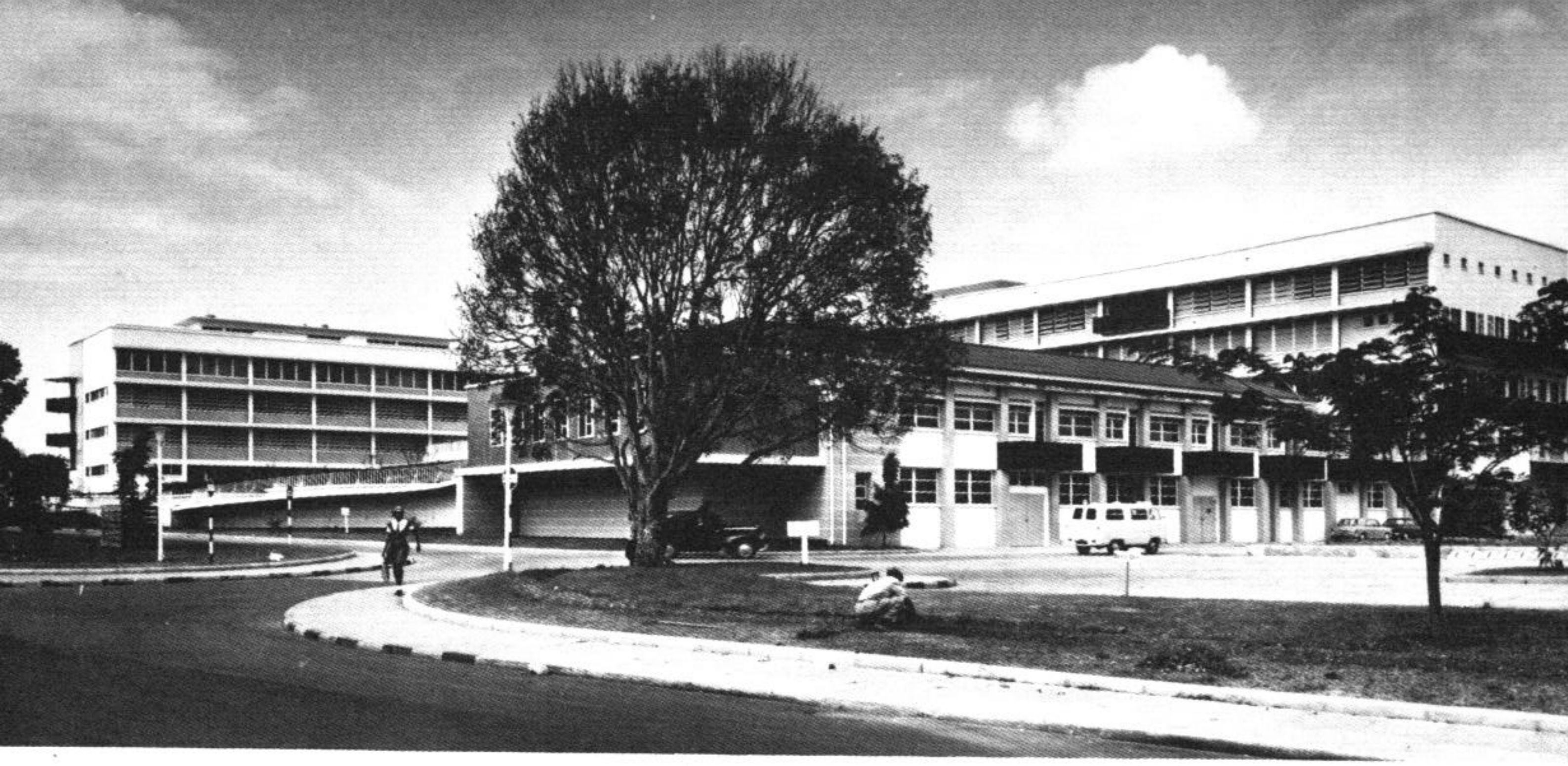
The hospital has no heating requirements, since ambient temperatures rarely drop below 70°F. The cooling requirements are minimal and are largely accomplished by natural ventilation. Therefore, the only energy demand which is reasonable to serve is the demand for domestic hot water. The demand for this is constant throughout the year and requires relatively low-temperature hot water (120°F).

The Water Storage and Circulation System

The system proposed for the Queen Elizabeth Hospital is a domestic hot water system requiring no protection against freezing. The solar collector loop would feed directly to the storage tank (see Figure 2), and the building's cold-water supply would be piped directly to the same storage tank. The hot water would then be taken from the top of the tank to the existing, steam-fired, auxiliary hot-water heaters. The auxiliary heaters would provide additional heat, if necessary, to boost the temperature to 140°F. If the water from the solar storage tank were already above 140°F, no additional heating would be needed. A three-way mixing valve would be provided in the hot-water line leaving the existing auxiliary heaters; and this would mix cold makeup water with the heated water leaving the auxiliary heaters, maintaining the building hot-water system at no more than 140°F. Experience has shown that this arrangement of equipment provides the most efficient and economical solar hot-water system when protection against freezing is not required.

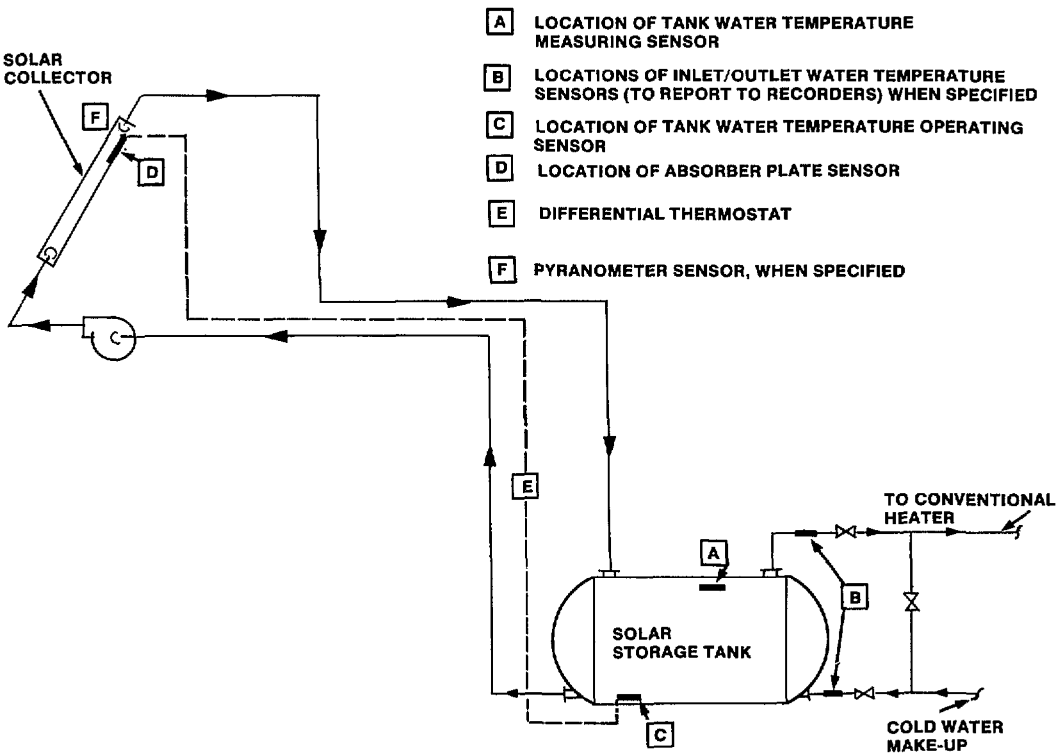
Basic Specifications

The optimum size and type of the solar collector array, angle of tilt of the collectors, and size of the storage tank, as indicated in Table 1, were calculated on the basis of economic considerations. Computer inputs and other information obtained from personnel at the hospital were used for these calculations.



The site of the proposed solar power project. Above, a general view of the Queen Elizabeth Hospital. At left, the hospital's south bloc[k]. Below, the roof of the south block.

Figure 2. A typical solar energy system for providing domestic hot water when protection against freezing is not required.



Recommendations

As the figures in Table 1 show, our calculations indicated that using solar energy to heat domestic hot water would be cost-effective. We have therefore recommended that the Queen Elizabeth Hospital proceed with design drawings to implement a solar energy system that would provide approximately 95 per cent of the domestic hot water for the south block of the hospital.

The recommended system's design should be based on the following parameters:

1) The collector array should consist of 1,800 net square feet of flat-plate solar collectors. The collectors should have a single cover and a "flat black" absorber surface. The overall array should consist of modular, factory-assembled collectors measuring approximately 3 feet by 7 feet that are mounted in 10 rows of 20 collectors each, with 10 feet being left between each row. The approximate weight of each collector would be 140 pounds, plus the weight of the mounting system. No collector should be considered for this project unless it has been tested in accordance with ASHRAE[5] Test 93-77.

2) Each collector should have a copper absorber plate with a "flat black" painted absorber surface. The housing should be constructed of either aluminum or galvanized steel with noncorrosive fasteners.

3) Several possible collector array sites were investigated, and it was found that the only logical

[5]The American Society of Heating, Refrigerating, and Air Conditioning Engineers.

Table 1. Optimum characteristics and potential cost-efficiency of the proposed solar energy system, assuming an average net fuel price increase of 15 per cent per year.

	Type of collector surface	
	Flat black absorber surface	Selective coated absorber surface
Optimum collector array size	1,800 sq. ft.	1,700 sq. ft.
Optimum tilt angle	15°	15°
Optimum storage-tank size	2,250 gal.	2,125 gal.
Estimated total system cost	US$113,000	US$115,500
Present worth of total life-cycle costs (The lower the value the better the rate of return on the investment)	US$146,981	US$150,670
Total gallons of oil saved per year	5,425 gal.	5,417 gal.
Total cost of oil saved:		
Year 1	US$ 10,850	US$ 10,834
Year 25	US$350,245	US$349,754
Total fuel savings after 25 years	US$2,529,341	US$2,525,792
Rate of return on solar investment	22.4%	22.1%

choice was a roof location. A ground-level location would not be suitable for this project. Primarily because the proposed solar energy system is to service only the south block, the most logical location is the roof of the south block.

4) The collector array should be mounted on the roof of the south block and tilted at a 10° angle. The mounting structure should be galvanized steel, sized to sustain hurricane-force winds.

5) The existing roof structure of the south block will have to be analyzed by a structural engineer to determine the proper mounting system and any additional structural work that may or may not be necessary.

6) The storage tank should be made of steel and should be approximately 6.5 feet in diameter by 9 feet high, with a capacity of 2,300 gallons. The tank should be insulated on the outside with approximately 3.5 inches of fiberglass or its equivalent, and should be coated on the inside with a protective coating suitable for potable domestic hot water use.

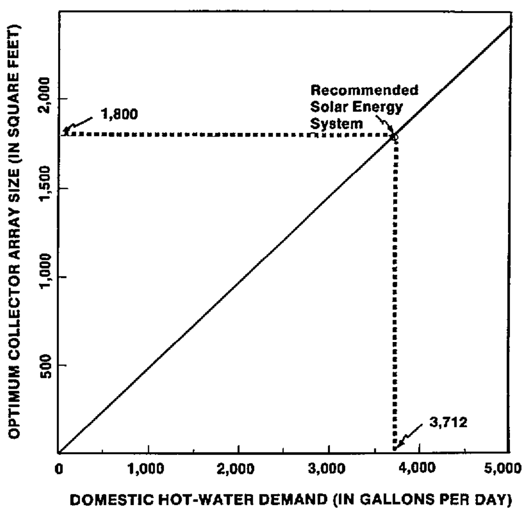
7) The storage tank should be located in the south block mechanical equipment room on the basement level, and the piping to and from it and the collectors should run exposed down the west side of the building, between the roof and the mechanical room.

8) To verify the above design recommendations, a hot-water consumption meter should be installed to accurately record the south block's actual daily hot-water usage and time of usage. Past experience has shown that water usage rates dramatically affect the optimum collector array size.

Concluding Remarks

To give some idea of how varying economic and building parameters affect the proposed solar energy system's feasibility, Figure 3 compares the average daily hot-water con-

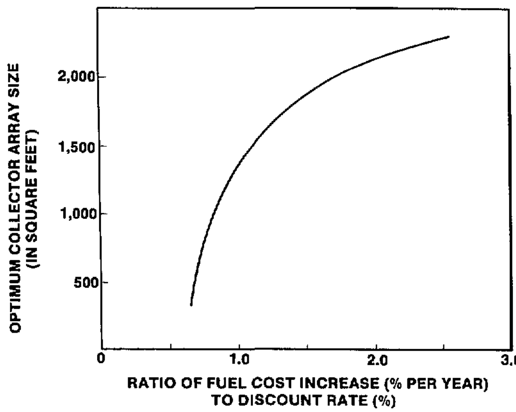
Figure 3. Relationship between domestic hot-water demand and optimum collector array size, assuming an average overall fuel price increase of 15 per cent per year.



sumption in gallons per day to the optimum collector array size. As may be seen, this consumption figure plays a key role in determining ideal collector array size. In a similar vein, Figure 4 compares fuel cost increases (i.e., the ratio of the percentage annual fuel rate increase divided by the percentage discount rate) to the optimum collector size. The optimum collector size was ultimately selected by finding the array size with the lowest total life-cycle cost.

As Table 1 and the calculations in Appendix C of our original report (see footnote 2 on page 140) clearly show, if we assume that existing fuel prices will increase by approximately 15 per cent per year, the recommended solar energy system would appear to be an extremely good investment. That is because there are very few areas where one could invest money and earn a yearly 22 per cent return, while at the same time conserving oil, creating local construction jobs, and promoting a local solar industry.

Figure 4. Relationship between fuel price increases and optimum collector array size, assuming an average domestic hot-water demand of approximately 3,700 gallons per day.



SUMMARY

A PAHO study was conducted in February-March 1981 to assess the feasibility of using solar energy to meet some of the energy needs of the Queen Elizabeth Hospital in Bridgetown, Barbados. The hospital, a well-equipped five-story structure with three principal wings that was completed in 1964, has a capacity of 620 beds.

Because solar installations designed to meet space-heating needs are harder to justify than those designed to heat domestic hot water, and because the Queen Elizabeth Hospital's space-heating needs are small, the study concentrated on a solar energy system that would heat domestic hot water. The system was also envisaged as serving only one wing of the hospital, known as the "south block," in order to limit the project's size and initial cost. It was felt that once this small system was operating successfully, it would provide an incentive for making further investments in solar energy.

The optimum size and type of the solar collector array, angle of tilt of the collectors, and size of the proposed hot-water storage tank were calculated. These calculations indicated that using solar energy to heat domestic hot water would be cost-effective. Therefore, a series of recommendations was made regarding specific characteristics of the system, and the hospital was advised to proceed with design drawings for a system that would provide approximately 95 per cent of the south block's domestic hot water needs.

BIBLIOGRAPHIC REFERENCES

(1) American Society of Heating, Refrigerating, and Air Conditioning Engineers. *ASHRAE Handbooks and Product Directory.* Atlanta, 1979-1982. (Separate volumes on equipment, systems, fundamentals, and applications, respectively, were published in 1979, 1980, 1981, and 1982.

(2) American Society of Heating, Refrigerating, and Air Conditioning Engineers. *ASHRAE Hand-*

book: Applications. Atlanta, 1978, Chapter 58.

(3) Duffie, J., and W. Beckman. *Solar Energy Thermal Processes.* Wiley Inter-Science, New York, 1974.

(4) Edwards, D. K. *Solar Collector Design.* Franklin Institute Press, Philadelphia, 1977.

(5) Kreith, F. *Principals of Heat Transfer.* International Textbook, Scranton, 1968.

(6) Kreider, J., and F. Kreith. *Solar Heating and Cooling.* McGraw Hill, New York, 1975.

(7) Ametek. *Solar Energy Handbook Theory and Applications.* McGraw Hill, New York, 1975.

(8) National Association, Sheet Metal and Air Conditioning Contractors. *Fundamentals of Solar Heating.* (Reprint No. HCP/M4038-910REV.) Vienna, Virginia, 1978.

(9) Argonne National Laboratories, Solar Energy Group. *Design and Installation Manual for Thermal Energy Storage.* No. ANL-79-15. Argonne, Illinois, 1979.

(10) Solar Energy Industries Associates. *Solar Energy Index.* Washington, D.C., 1981.

(11) Solar Vision. *Solar Products Specifications Guide.* Harrisville, New Hampshire, 1981.

(12) United States Department of Energy. *DOE Facilities Solar Design Handbook.* Washington, D.C., 1978.

(13) International Telephone and Telegraph Corporation. *Solar Heating Systems Design Manual.* Bulletin TESE-576. Morton Grove, Illinois, 1976.

(14) Bell and Gossett. *Bell and Gossett Engineering Design Manual: Air Control for Hydronic Systems.* Manual No. 2100. Morton Grove, Illinois, 1966.

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Both of these programs award the degree of Master of Public Health. Inquiries concerning them should be made to Dr. Helen M. Wallace, Professor and Head, Division of Maternal and Child Health, Graduate School of Public Health, San Diego State University, San Diego, California 92181, U.S.A.