'PLIED SCIENTIFIC RESEARCH CORPORATION OF THAILAND

RESEARCH PROGRAMME NO. 4
SOLAR FLARES IN RELATION TO RADIO COMMUNICATIONS
AND STUDY OF ALLIED SOLAR PHENOMENA

RESEARCH PROJECT NO. 4/6
SOLAR HEATING OF WATER

REPORT NO. 3
DESIGN DATA ON SOLAR WATER HEATERS

BY
NARINDER S. SALUJA
TECHNOLOGICAL RESEARCH INSTITUTE

ASRCT, BANGKOK 1967
(Reproduced 1970)
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F O R E W O R D

The Technological Research Institute of ASRCT has engaged in a research programme concerned with solar energy. During these researches information has been gathered on solar water heaters and tests have been carried out on a solar water heater of Israelian design.

This circular provides design data on the construction of a solar water heater suitable for use under local conditions. Officers of TRI will provide further information on request to persons interested in the manufacture of solar water heaters.

The present circular is based on local and overseas data. It has been completed by Mr. Narinder Singh Saluja of the Solar Research Unit, TRI, working in collaboration with Dr. Rawi Bhavilai.

DESIGN DATA ON SOLAR WATER HEATERS

By Narinder S. Saluja*

INTRODUCTION

Expanding population and the increased per capita consumption of energy resulting from a higher standard of living, can be expected to put a greater demand on the present sources of energy in Thailand. Consequently, unless new sources of energy are developed and utilized, the cost of conventional energy sources will increase. One such new development is the possibility of using solar energy for heating water.

Solar water heating has already reached a point of economic practicability and is now widely used in a number of countries notably the U.S.A., Israel, Australia, Japan, and South Africa. The use of solar water heaters should be particularly suitable for Thailand because of the generally high insolation+ (situated in the tropics) and the high ambient temperatures which result in a good overall efficiency of the heating system. Furthermore, due to the low seasonal variation, the system will maintain a high level of performance throughout the year. Under these conditions the solar absorber will pay for itself in a short time despite the higher initial cost than other conventional installations.

Tests conducted in Australia, Israel, and South Africa show that in climatic conditions similar to Thailand, the hot water needs of an average family can be adequately met by a simple solar water heater. However, under certain conditions it is more economical to use a solar system "boosted" by conventional sources of heat; the amount of boosting is governed by the local sunshine pattern and power charges. However, in Darwin (Lat. 12^{o}S) it has been found that solar heater without boosting is the most economical unit for heating water. As Bangkok is situated almost at a similar northern latitude one can presume that this would be true for it also, especially since electricity is more expensive.

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* Solar Research Unit, Technological Research Institute, ASRCT.

+ An average of approximately 400 g cal/cm^2 day (400 Langleys/day).

The purpose of this circular is to show how a solar heater works, how it can be most satisfactorily installed, and what properties are required of its components.

ESSENTIAL COMPONENTS AND OPERATING PRINCIPLES

There are various possible designs for solar water heating systems but basically each of them may be divided into three separate sections:

(1) The absorber unit.

(2) The circulation system.

(3) The storage tank.

The absorber unit

The absorber unit is a simple heat exchanger which absorbs radiant energy from the sun and transfers this energy to the water within. Since the temperature of the absorber, when operating, may be as much as 60°C above its surroundings, heat leakages occur. Many of the components of the solar absorber are designed simply to limit these losses.

The basic heat balance on the absorber is as follows:

Heat input from sun = heat to water + heat losses

The absorber efficiency is defined as the heat to the water divided by the solar radiation incident on the absorber cover.

In the design of a solar absorber, the compromise which must be reached is to make the heat losses as low as possible while maintaining the heat input as high as possible. Design features which achieve an increase in performance must involve a proportionately smaller increase in final cost.

By increasing the amount of heat retained by the water, features which reduce the heat leakage also enable the water to reach a higher temperature. In conventional solar absorbers, the absorber plate consists of tubes thermally bonded to a metal sheet. The transparent cover, or covers, the box and insulation all prevent heat loss by convection from the plate. They also act as a heat barrier, much like the glass in a greenhouse, in that they reduce the amount of heat loss from the absorber plate. Every extra cover placed on the absorber reduces heat losses but also diminishes the amount of solar energy received by the plate. For most applications one cover seems to be the best compromise.

Insulation at the rear of the plate also reduces heat losses at little additional cost. The box, as well as supporting the glass cover, contains the insulation and prevents it from becoming wet and hence useless.

To enable the absorber plate to absorb solar radiation falling on it, some surface preparation is used which for the present is a flat black paint. This is a very good absorber of solar energy but is also a good re-radiator of heat. To reduce this radiation heat loss between the absorber plate and cover, surfaces which are poor radiators of heat but good absorbers of solar radiation can be used. An example of such a "selective surface" is that obtained by dipping a cleaned copper plate in a warm solution of sodium hydroxide and sodium chlorite. However, due to the careful control that is required of the cleaning and degreasing process, the bath temperature and concentration, and the immersion time etc., the equipment cost is high. Consequently this process is not economically feasible for small scale manufacture. Therefore the selective surface cannot be produced locally at present.

One other factor which contributes to the efficiency of the absorber is the thermal conductivity of the absorber plate. Because of the tube and sheet construction used, lateral temperature gradients occur, the maximum temperature being midway between the tubes. This increases the heat losses from the absorber plate for a given mean water temperature. For comparison purposes an absorber plate with no lateral temperature gradients, and a mean temperature equal to the mean water temperature is taken as having a "plate efficiency" of 100 per cent. In Table 1 are shown plate efficiency factors for various sheet thicknesses and tube spacings. To obtain a comparison between the performance of absorbers fitted with plates of differing plate efficiencies, the year-round absorber efficiency is approximately 0.40 times the plate efficiency factor.

TABLE 1
COPPER PLATE EFFICIENCY FACTORS FOR VARIOUS TUBE SPACINGS AND SHEET THICKNESSES

Plate thickness (mm)	Tube spacing (cm)				
	7.62	10.16	12.70	15.24	17.78
0.2540	0.945	0.920	0.890	0.855	0.805
0.3556	0.950	0.925	0.900	0.870	0.825
0.4572	0.955	0.930	0.910	0.880	0.850
0.5588	0.960	0.935	0.915	0.890	0.865
0.7112	0.960	0.935	0.920	0.900	0.875

Copper is the preferred material for both tubes and sheet. Copper tubes are the most suitable on the basis of their excellent resistance to corrosion.

Circulation

Either natural or forced circulation may be used to pass water through the absorber and back to the tank.

Natural circulation is better for domestic applications because of its simplicity and freedom from maintenance problems. It has the advantage that it functions only when the solar energy input is high enough to heat the water in the absorber to a temperature above that of the water in the bottom of the tank.

This circulation, commonly called thermosiphon, occurs because of the variation of water density with its temperature. If water in the absorber is heated, then it rises and is replaced by cooler water from the bottom of the tank. It is necessary to place the absorber below the tank and to insulate the connecting pipes; this prevents reverse flow (cooling the storage tank) during periods when the sun does not shine.

Storage tank

Because of the intermittent nature of solar energy, a large storage tank is required. The actual size in relation to the daily demand is determined somewhat by the geographical location of the system and whether any auxiliary heat source is used.

Since hot water may have to be stored for 24 hours or more, the tank must be well insulated. In the case of an outdoor installation, the tank and hot water pipes must be weather-proofed to protect the insulation.

CONSTRUCTION

Absorber

Weathering of the absorber box and cover, corrosion of the water tubes, ultraviolet radiation damage to the absorber plate and cover, and water intrusion into the box are to be avoided by correct construction methods and by using the most suitable materials.

Glass is the best cover material available. Some plastics look promising but have not yet been proved.

Following normal hot water practice, copper tubes are used in the absorber because of their high resistance to corrosion.

Water must be excluded from the absorber box for two reasons. Firstly, open cell or porous insulation is useless if wet. Secondly, condensation on the cover reduces its transmittance of solar radiation. A watertight box must be used and it is essential to have a watertight seal between box and cover. Some air access to the box is an advantage and some holes drilled through the bottom edge of the box should be provided.

Galvanized iron is the most suitable box material. Although it requires occasional painting it has a reasonable on-site life and is light enough that installation in elevated positions is simple. The box requires internal bracing to prevent flexing and possible fracture of the glass cover. Wood and other non-durable materials are considered to be unsatisfactory except in cases where considerable maintenance can be tolerated.

The design described is one which has been proved to be satisfactory by various research laboratories. However, there are many possible variations and it is hoped that the detailed explanations in this report make obvious the changes which can be made in materials or dimensions without seriously affecting the performance or life of the absorber.

Basically the absorber plate consists of a copper tube framework of 25.4 mm and 12.7 mm (1 inch and ½ inch respectively) outside diameter tubes soldered to a 26 gauge (0.4572 mm thick) copper sheet. The 12.7 mm water tubes are brazed to the 25.4 mm headers. It is important to provide a continuous fillet of solder between the sheet and 12.7 mm tubes to give a satisfactory thermal bond.

After painting with a good quality flat black paint, the absorber plate is enclosed in a galvanized iron sheet box covered by one sheet of glass, and insulated at the rear by at least 5 cm of expanded Styrofoam. Detailed drawings of the absorber and a materials list are shown in Figures 1, 2, and 3, and Table 2.

TABLE 2
MATERIALS LIST FOR SOLAR ABSORBERS

Description	Materials	Quantity
Box bottom	Galvanized iron sheets USSG # 22 (1.25 lb/ft^2)	1015 mm x 1330 mm 1 sheet
Box sides	"	200 mm x 995 mm 2 sheets
	"	200 mm x 130 mm 2 sheets
Corner brackets	USSG # 20 G.I. sheets (1.5 lb/ft^2)	4 pcs. 100 mm x 25 mm x 60 mm
Nuts and bolts	Galvanized iron	74 each
Glass moulding	Rubber U - strip	6.10 m
Glass retaining strip	G.I. sheet 25 mm width	956 mm 2 pcs. 1270 mm 2 pcs. 905 mm 1 pc.
Self tapping screws	G. iron	36 pcs.
Solder	-	-
Insulation	Styrofoam	995 mm x 1310 mm 5 cm thick 1 pc.
Absorber plate	Copper tubes	1095 mm
Headers	25.4 mm diameter	2 pcs.
Absorber plate tube-grid	Copper tubes 12.7 mm diameter	1226 mm 6 pcs.
Absorber plate	Copper plate USSG # 26 (0.75 lb/ft^2)	1224 mm x 1027 mm
Cover	Glass plate	915 mm x 610 mm 3 mm thick

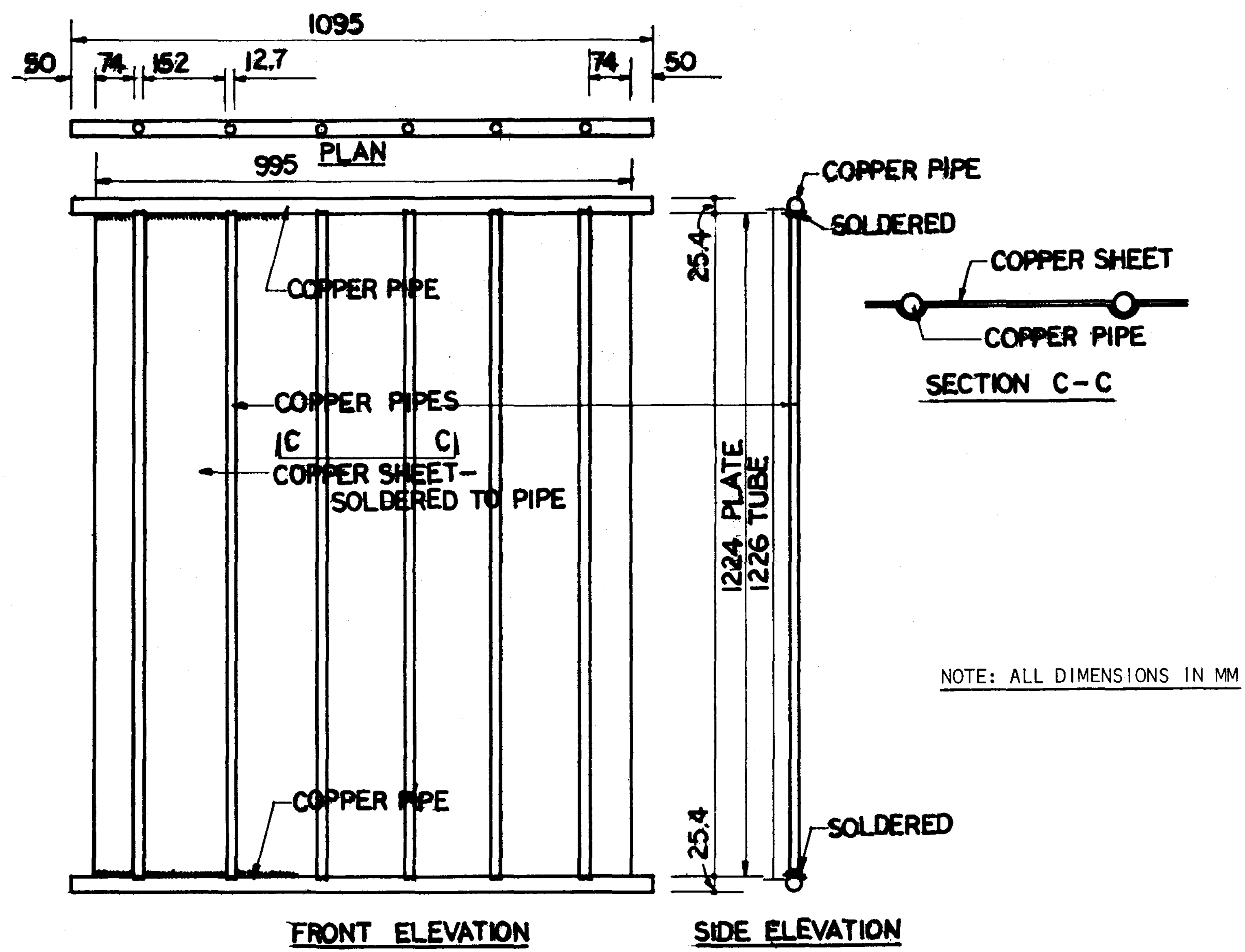

Figure 1. Absorber plate. (Not to scale.)

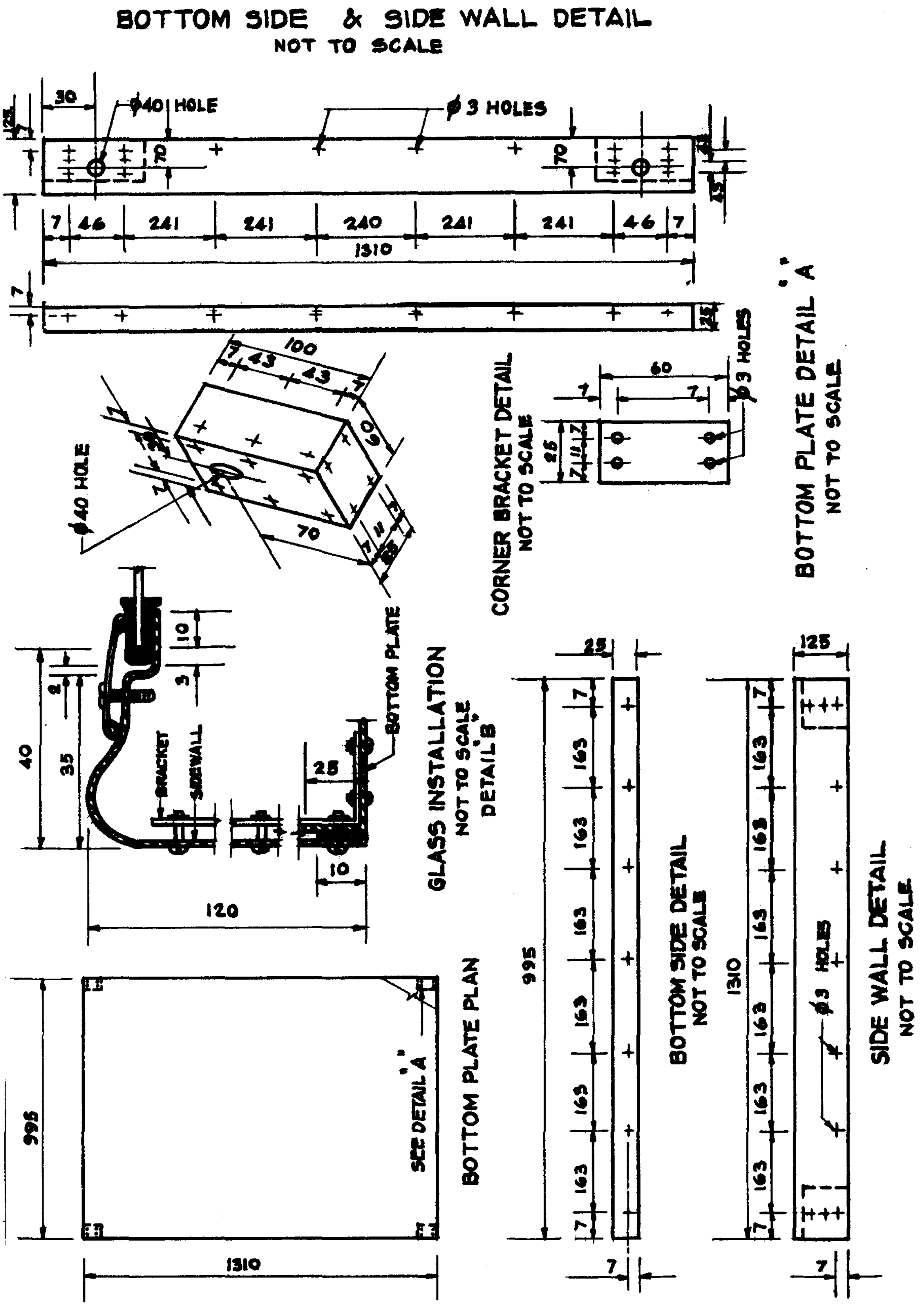

Figure 2. Absorber box construction.

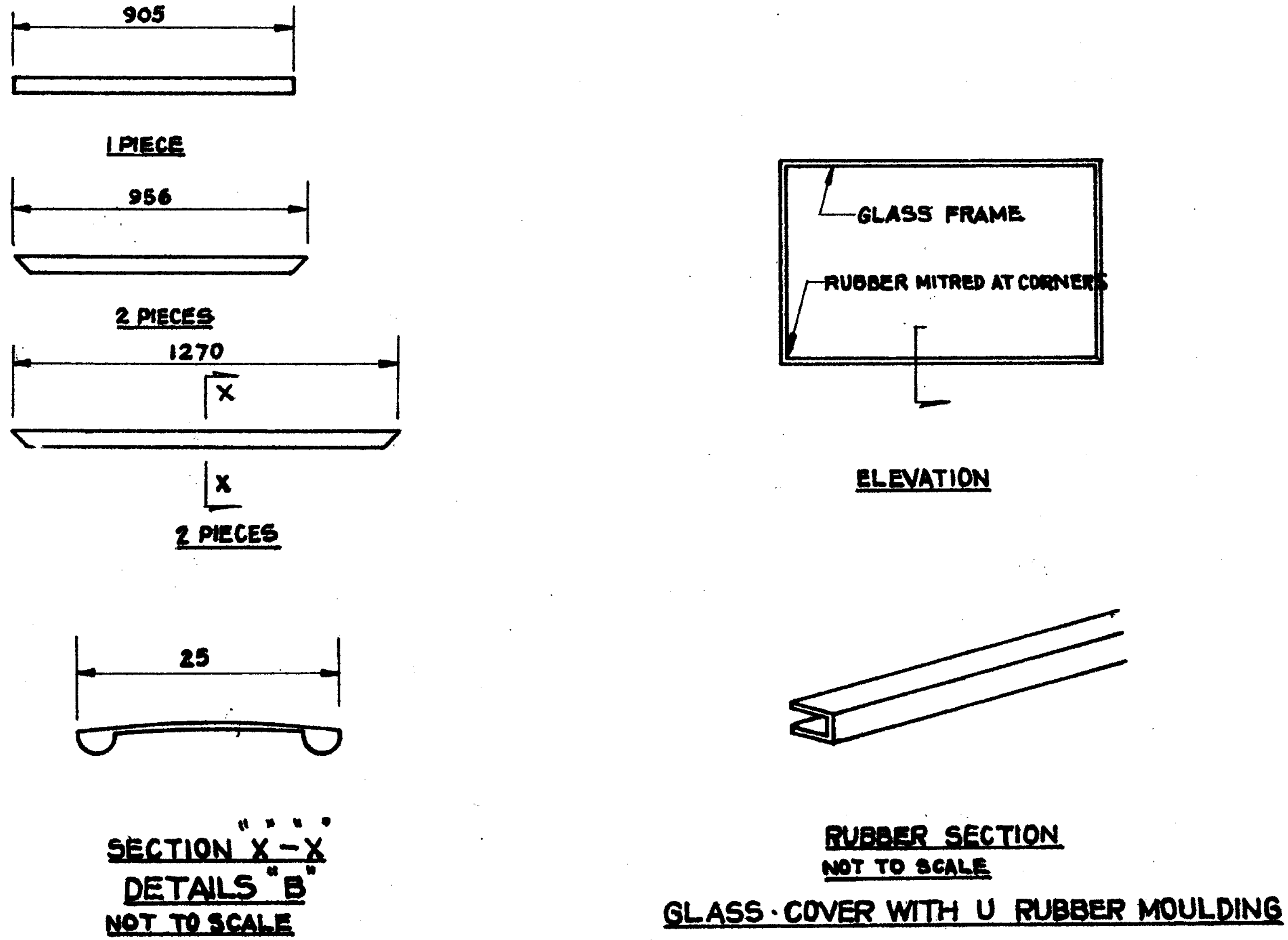

Figure 3. Glass cover with U rubber moulding.

Care should be taken to secure glass of proper size to fit the individual box. A satisfactory seal between the box and the glass must be accomplished. To do this the edge of the box on which the glass rests must be flat. A U-rubber strip is then fitted to the glass as shown in Figure 3 and the glass clamped to the box with a metal strip as in Figure 2 detail B which also shows how the strip is fastened to the box.

Owing to the effect that insulation has on absorber performance, it is recommended that at least 5 cm of polystyrene expanded "Styrofoam" (thermal conductivity $\underline{k}$ = 0.000087 cal/ (s.cm.deg C)) be used. Reduction in insulation will lead to disproportionately large reductions in absorber performance.

Circulation system

A suitable amount of insulation should be used on the connecting pipes both to limit heat loss and to prevent reverse cycling. Formed Styrofoam pipe insulation of 2.5 cm thickness is considered adequate. The insulation can be weather-proofed by winding polyethylene strip over it. By starting at the bottom, and overlapping the polyethylene strip at each turn, water intrusion is prevented.

Tank

The capacity of the storage tank should be about 25 litres greater than the amount of hot water the absorber is designed to produce. For instance, for the 1.37 m^2 absorber shown, a 100 litre storage tank should be adequate. (One m^2 of absorber area produces on the average about 50 litres per day of water at about 60°C.)

Considering the hot climate of Thailand, it is felt that the daily consumption of hot water per person should not exceed 20 litres. Therefore the proposed system should provide adequate hot water for a family of 4 persons.

Since the water is stored longer in a solar heated tank than in a normal electric storage system, it needs more insulation than is usually provided. At least 10 cm of polystyrene foam or its equivalent should be incorporated in the sides and top of the tank.

Solar water heaters become less efficient at high temperatures. It is therefore important to store the water at the temperature at which it will be used rather than mix it with cooler water. The size of the storage tank should be varied to store the water at the temperature desired.

INSTALLATION

The amount of insolation on a flat plate absorber is a function of the time of the year, the latitude of the place, the inclination from the horizontal and the geographical orientation of the surface of the absorber.

Research work carried out in Australia has shown that the maximum year-round insolation is obtained if the surface is facing toward the equator and is inclined at 0.9 times the latitude angle. Equal collections at midsummer and midwinter are obtained when the absorbers are inclined at 1.5 times the latitude angle.

However, in latitudes less than 30°, neither the orientation nor the inclination is very critical. One can deviate to some extent from the above general rule without serious loss in the collector efficiency. For instance, the annual insolation on a surface inclined at 27° at latitude 30° north will only be about 6 per cent less when deviating 45° from south, as compared with one facing due south. Similarly a change from 27° inclination to 45° inclination only results in a 5 per cent annual loss for a surface facing due south at latitude 30° north.

Having decided on the leading dimensions of the system, it is necessary to plan the layout of the installation. As pointed out in a previous section, it is necessary to mount the absorbers below the storage tank if thermosiphon circulation is used. The recommended spacing is for the upper header of the absorbers to be at least 30 cm below the cold water outlet from the tank to the absorbers. This is shown in Figure 4-a.

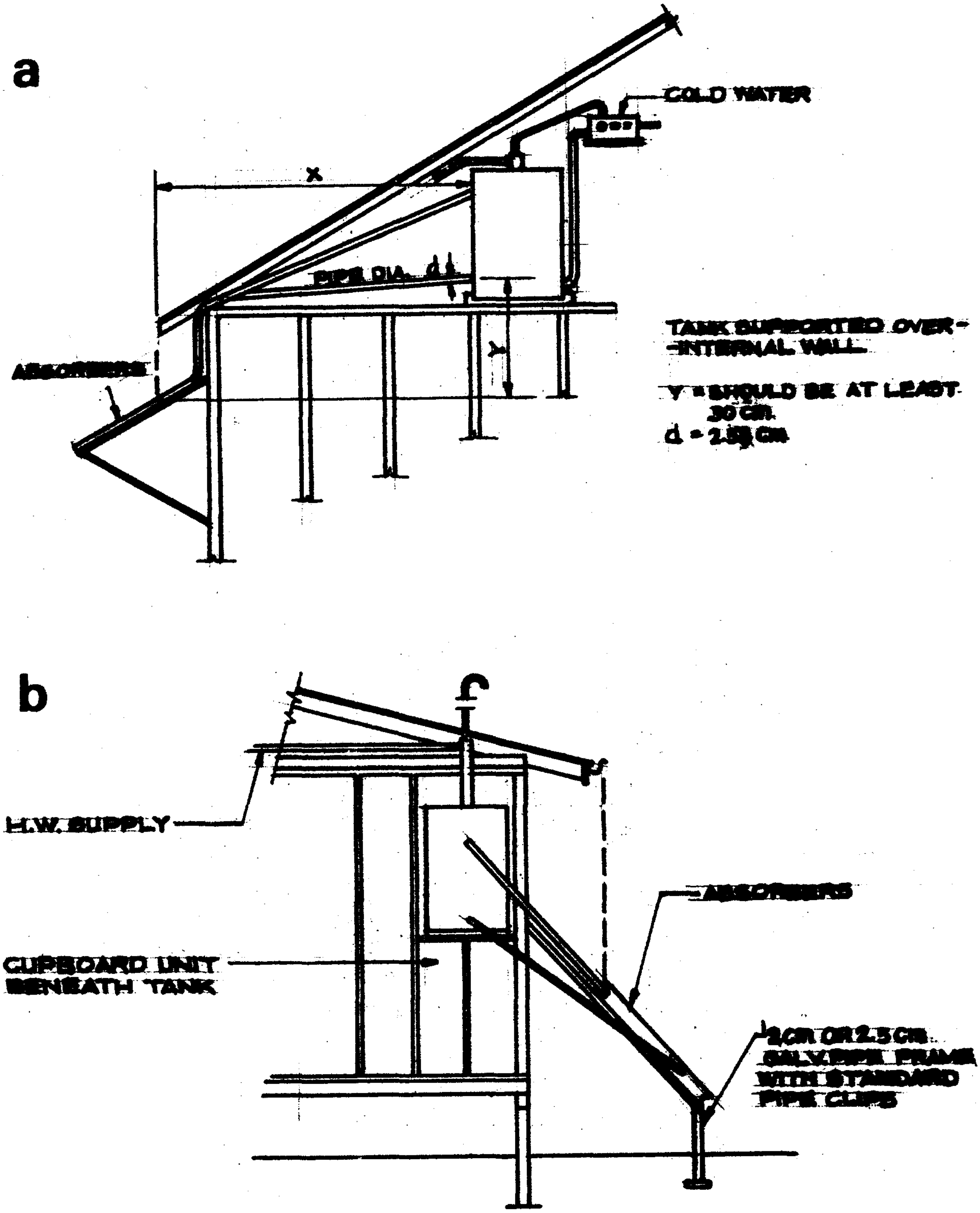

Figure 4. Absorbers mounting. (a) Awning type absorber with indoor tank. (b) Absorbers mounted at ground level and tank built into cupboard unit.

If the tank is to be placed near floor level then the absorbers must be mounted on the ground as in Figure 4-b. This shows the absorbers mounted clear of the eaves so that bird droppings are not deposited on the glass. It should be remembered that ground mounted absorbers are subject to breakage from stones, and to shading during part of the day.

Arrangement of the absorbers as an awning over windows, or placed directly on the roof normally removes the two objections mentioned above, but means that the tank has to be mounted in the roof space or on the roof. Possible arrangements are shown in Figures 5-a, 5-b, and 6-a.

When mounting absorbers, care must be exercised so that shading of them does not occur at any time during the year. Figure 6-b shows in diagram form the rules to be observed so that shading is avoided.

According to the location of the components, care must be taken in positioning of the connecting pipes and sizes of pipes used. For most domestic installations of up to 5 m^2 absorber area, 2.54 cm (1 inch) diameter piping is sufficient. One other factor which must be taken into account is the possibility of formation of air pockets in the connecting pipes, and to prevent this a continuous upward grade must be maintained. If this is not done then circulation may cease. For a similar reason the absorbers are set up so that the header-pipes slope continuously down from the tee where the connecting pipe to the tank joins the header extensions. This prevents by-passing of one or more of the absorber water tubes.

As mentioned previously, adequate insulation and weather proofing of the connecting pipes and the tank are essential.

During installation of the absorbers no water will be passing through them and in consequence the absorber plate will become very hot. To prevent cracking of the glass due to the very high absorber temperature, the absorbers should be covered by some opaque material, for example, paper or hardboard.

When the tank of a domestic heater cannot be mounted above the absorbers or when the hot water is required in very large quantities, for instance in an industrial plant, then the thermosiphon principle of water circulation is not practical. In such cases a pumped system

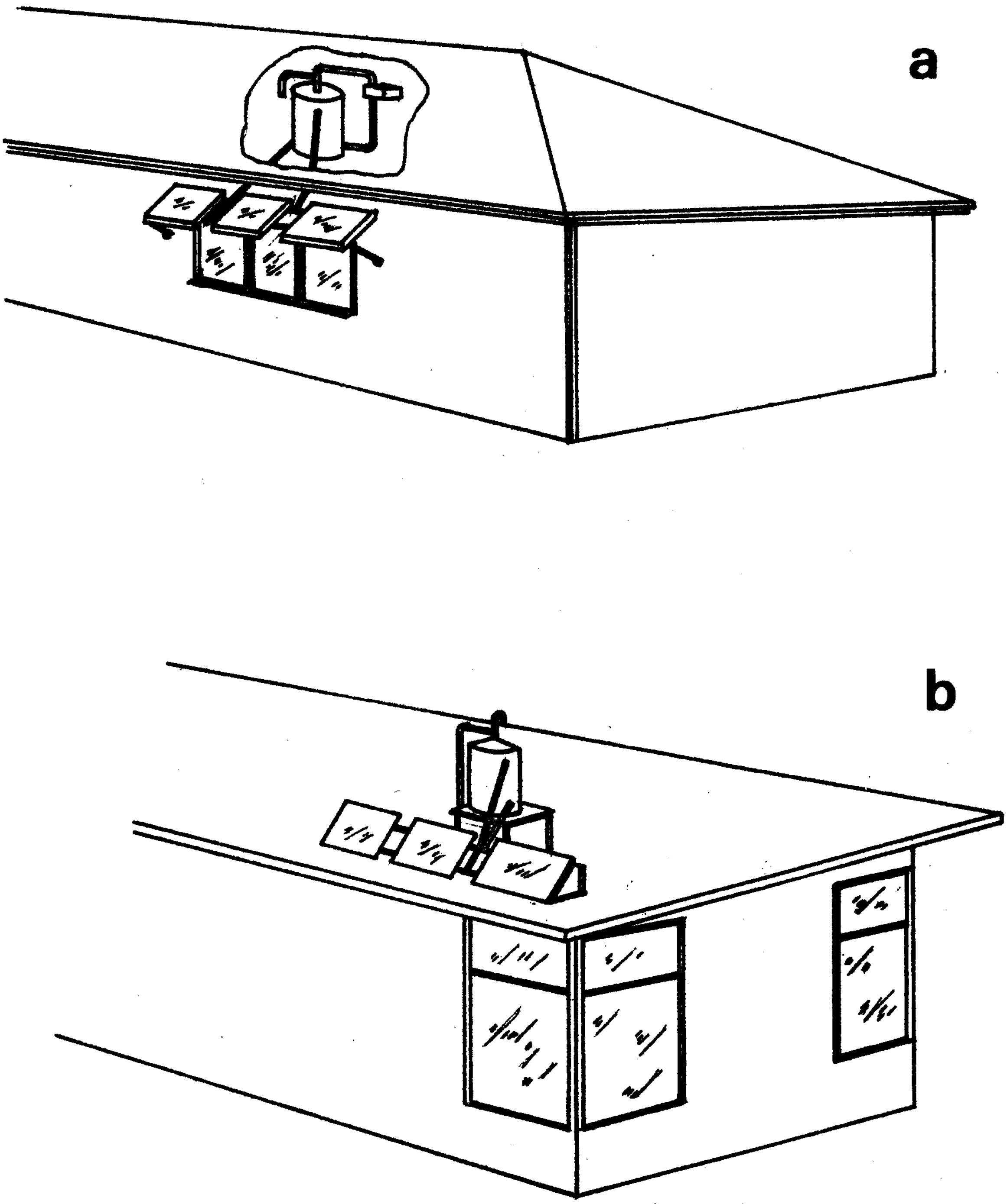

Figure 5. Absorbers and tank mounting. (a) Absorbers mounted as awnings over window tank in roof space. (b) Absorbers and tank—roof mounted.

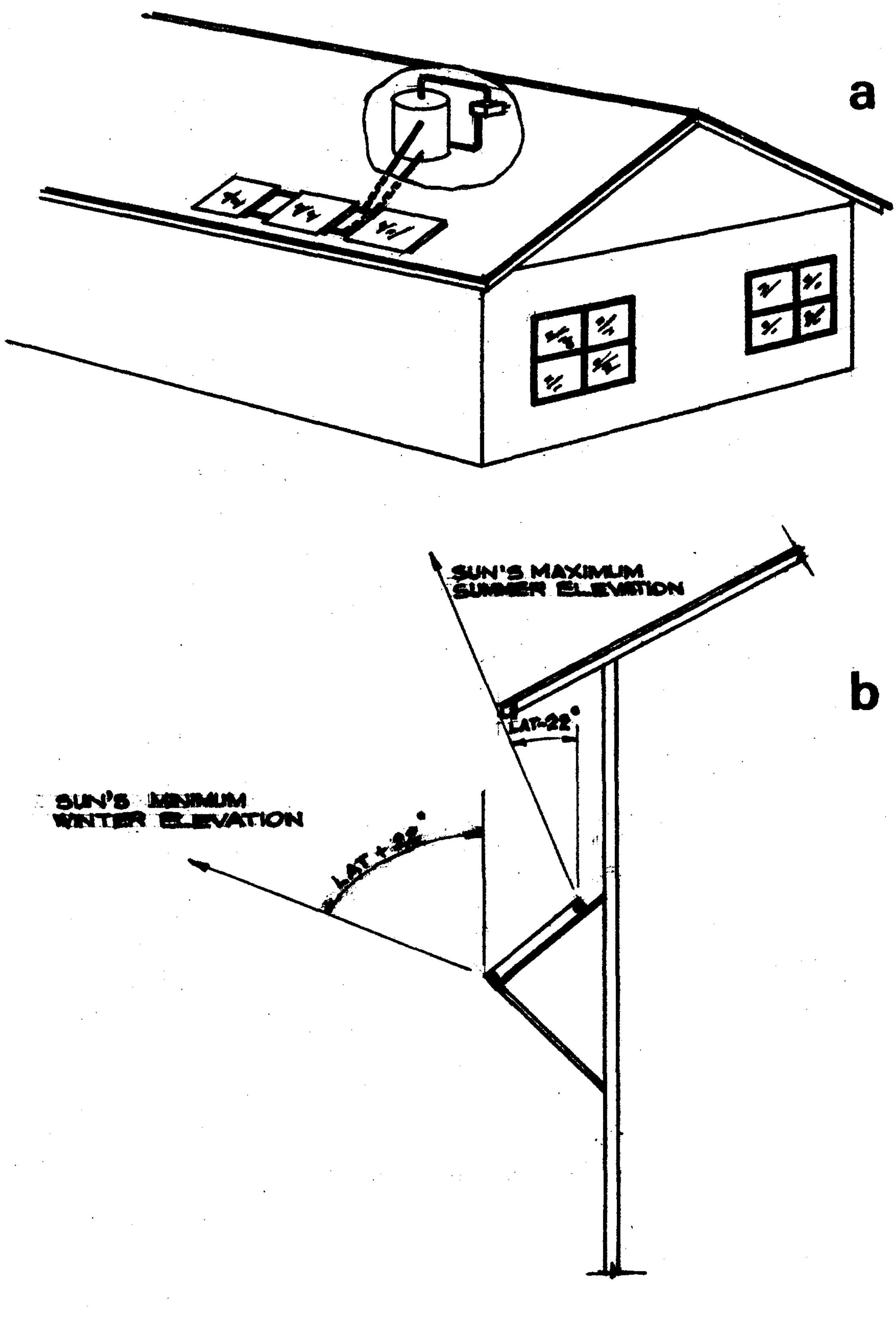

Figure 6. Absorbers roof mounted. (a) Absorbers roof mounted tank in roof. (b) Shaded geometry for solar absorbers.

has to be used. In addition, to ensure a steady supply of hot water at all times, an auxiliary electric heater could be incorporated in the system. One large pumped system with an electric booster is shown in Figure 7. The operation of the pump is controlled by an immersion-type thermostat placed in the upper header of the outlet absorber (point A in Figure 7). This thermostat is set at 50°C and, during periods of low or intermittent solar heat input, switches the pump on and off as the temperature in the header rises to or falls below the setting temperature. If the absorbers are not located below the storage tank, a non-return valve should be included in the circuit to prevent reverse circulation. A pumping rate of 50 litres per hour per m^2 of absorber area gives a satisfactory temperature rise through the absorbers.

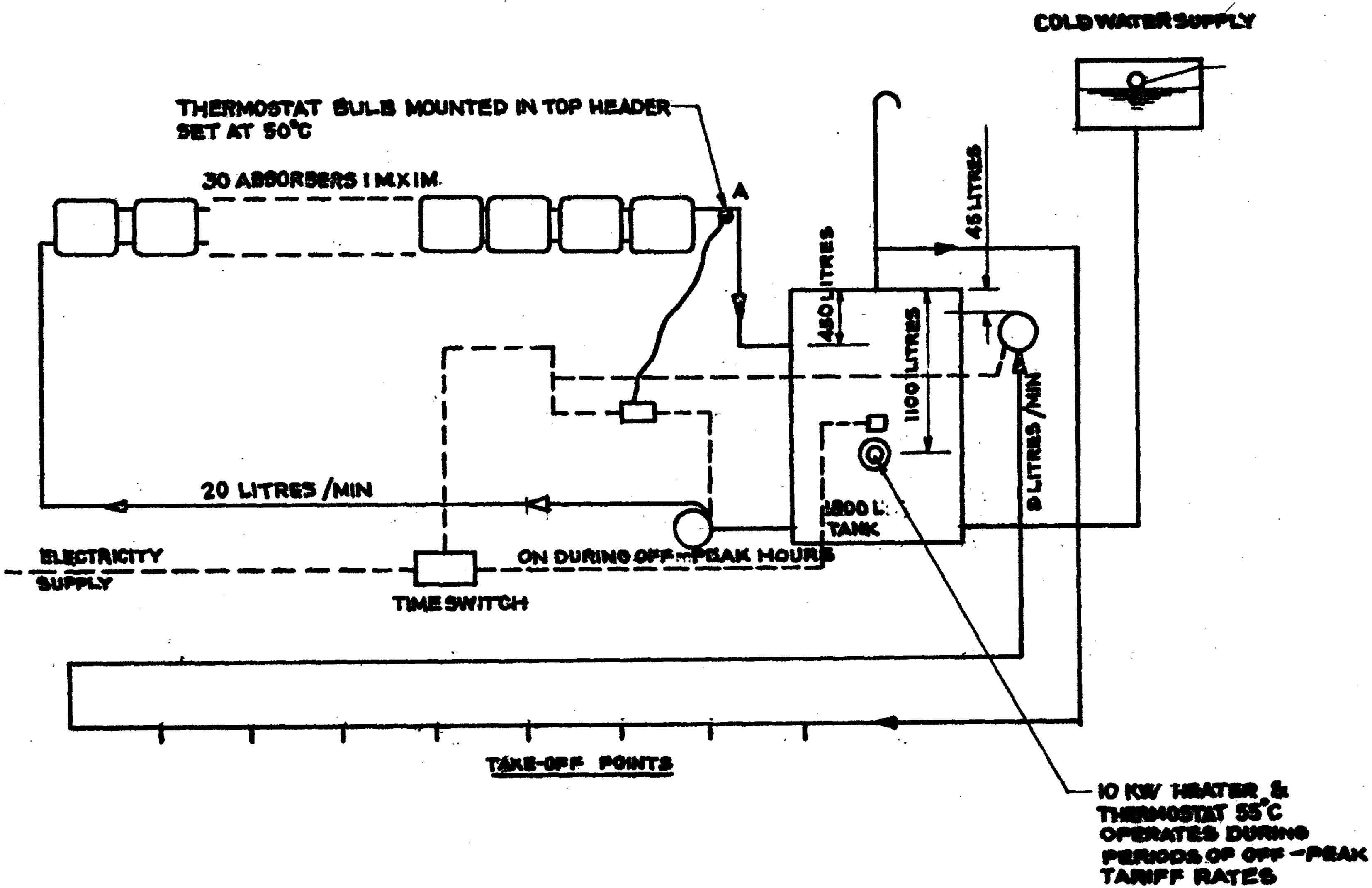

Figure 7. Circuit for solar water heater. (Not to scale.)

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