APPENDIX - IV

भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS

Doc. No. : PRTD/AR/**PF:03**	Issue No. : 2	Issue Date 30 Sept. 2020	**Report of Action Research**

1.	**Action Research Project No.** *(as assigned by PRTD)*	AR / 0121
2.	**Title of the Action Research Project**	Review of IS 12976:1990 Solar Water Heating Systems - Code of Practice
3.	**Name & Designation of Officer**	Sumit Kumar Scientist-D
4.	**Employee No.**	063568
5.	**Deptt./BO/RO & Place of Posting**	MHD
6.	**Date of Approval of the Project**	27 November 2020
7.	**Objective of the Project**	To review IS 12976:1990 "Solar Water Heating Systems - Code of Practice" as per the latest technology
8.	**Report of Action Research Activities**	The Report is submitted as per the following annexures: Annex 1: Clause-wise review analysis Annex 2: Draft Indian Standard for revision of IS 12976
9.	**Conclusion & Recommendations**	IS 12976:1990 may be considered for revision to align with latest research and technology as per review analysis enclosed at Annex 1. If approved, the Draft Document for revision of IS 12796 is submitted as Annex 2.
10.	**Any other relevant information**	Nil

__Note__: No financial assistance has been availed for conducting the instant 'Action Research, project.

10/09/2021
Sumit Kumar
Scientist-D (MHD)

2021 PRO
__Head (MHD)__
__DDG (Standardization – I)__ 10/9/21
__DDG (PRT)__

13/9

HPRT
Sc-C(SRRA) – Prepare.
13.9.2021

पी.आर.टी.डी. आवक सं. 122
PRTD Dy. No.
आवक दिनांक 13/9/21
Incoming Date

उप महानिदेशक (पी.आर.टी. एवं एच.एम.)
DDG (PRT&HM) Dy. No. 420
दिनांक/Dated 13/09/21

DDG (Std.-I) Diary No. 5851
Dated 10/9/2021

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ANNEX 1
CLAUSE WISE REVIEW ANALYSIS OF IS 12976: 1990

Clause No.	Proposed Change	Justification	Remarks
1. Scope	A new sub-clause may be added below 1.1: *"1.2 This standard also covers the techno-economic feasibility aspects of solar water heating system."*	One of the most critical factors in the dissemination of solar water heating system (SWHS) is their financial viability. The monetary benefits accrued to the end users would depend on the amount and cost of fuel saved through the use of SWHS. The efficiency of the SWHS largely depends on the system design, the availability of solar radiation and ambient conditions. Another dimension of complexity in the financial evaluation of SWHS is the seasonal variation in the hot water demand of the household. In tropical areas, hot water may not be required during certain periods of the year. In such a situation, the effective capacity utilization of the water heating systems may be much lower resulting in increased unit cost of useful energy delivered by the SWHS.	Source Literature: B. Chandrasekar, T.C. Kandpal Techno-economic evaluation of domestic solar water heating systems in India. Renewable Energy 29 (2004) 319–332. M. Raisul Islam, K. Sumathy, Samee Ullah Khan. Solar water heating systems and their market trends. Renewable and Sustainable Energy Reviews 17 (2013) 1–25
2. Reference	**The existing clause may be replaced by following:** *"2.1 The standards listed below contain provisions which, through reference in this text, constitute provision of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreement based on this standard are encouraged*	The referred Indian Standards IS 12933 (Parts 1, 2 ,3 & 5) have since revised in 2003. IS 12933 (Part 4): 1990 has since been withdrawn.	There is no technical changes in IS 12976 on account of changes/ revision of referred Standards.

<table>
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<td><i>to investigate the possibility of applying the most recent editions of the standards indicated:</i>
<table><tr><th><i>IS No.</i></th><th><i>Title</i></th></tr><tr><td><i>12933 (Part 1) : 2003</i></td><td><i>Solar flat plate collector : Part 1 Requirements (Second Revision)</i></td></tr><tr><td><i>12933 (Part 2) : 2003</i></td><td><i>Solar flat plate collector : Part 2 Components (Second Revision)</i></td></tr><tr><td><i>12933 (Part 3) : 2003</i></td><td><i>Solar flat plate collector : Part 3 Measuring instruments. (First Revision)</i></td></tr><tr><td><i>12933 (Part 5) : 2003</i></td><td><i>Solar flat plate collector : Part 5 Test methods (Second Revision)</i></td></tr></table></td>
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<tr>
<td>3.2 Passive System</td>
<td>The line “<i>This system works without the aid of pump and instrumentation.</i>” may be replaced by the following paragraph:

“<i>Passive system uses natural convective heat transfer without aid of mechanical devices like pump and instrumentation to circulate water:</i>”</td>
<td>For better clarity and understanding.</td>
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<tr>
<td>4.1 Solar Collector</td>
<td>The words “concentrating, trough” may be replaced by “parabolic dish, parabolic trough”.

Reference to IS 12933 (Part 1 to 5) may be replaced by reference to IS 12933 (Part 1 to 3 & Part 5).</td>
<td>In the types of solar collector, the concentrating & trough are mentioned as separate types whereas the trough is type of concentrating solar collector. The parabolic dish and parabolic trough are most common types of concentrating solar collectors.

IS 12933 (Part 4) is now withdrawn.</td>
<td>Source Literature:
A. Jamar et. al. Review of water heating system for solar energy applications. International Communications in Heat and Mass Transfer 76 (2016) 178–187.</td>
</tr>
</table>

4.1.1 Collector Heat Exchanger Efficiency Factor	Include definition of term “E” used in the formula. ‘F_R’’ shall be substituted for F_R for combined performance of collector and heat exchanger	The term “E” mentioned in the formula is required to be defined since it has not been defined while other all notations are covered. The statement “When a heat exchanger is used in the system, the collector heat exchanger efficiency factor ‘F_R’ shall be substituted for F_R to calculate the combined performance of collector and heat exchanger.” is not clear.‘ F_R’’ shall be substituted for F_R for combined performance of collector and heat exchanger	Since IS 12933 (Part 4): 1990 covering performance requirement of Flat Plate Solar Collector is withdrawn, the leading equations leading to formula given in the clause are not covered in any Indian Standards. The formulae for determining collector efficiency relations may be also be included in an Indian Standard.
4.1.2 Collector Orientation	The line “latitude + 10° to + 15° for **water** months” may be substituted by “latitude + 10° to + 15° for **winter** months”.	Editorial correction.	
4.2.1	“Fiberglass” may be added in materials for storage tank construction.	Fiberglass may also be used for storage tank construction.	Source Literature: S. Sadhishkumar and T.Balusamy. Performance improvement in solar water heating systems—A review. Renewable and Sustainable Energy Reviews 37(2014) 191–198
4.2.4 New Clause	Add following new clause “*4.2.4 Stratification of tank may also be done to minimize heat losses due to the mixing of hot and cold water. The analysis of geometrical factors including different orientations (such as horizontal or vertical tanks), wall thickness, height to diameter ratio, tank material and the operational factors including the temperature differential between inlet and outlet, climatic conditions and the flow rate shall be considered for better thermal stratification.*”	Thermal loss prevention from storage tank has marked effect on efficiency of system. New technologies and innovation for stratification may be included.	Source Literature: Ruchi Shukla et al. Recent advances in the solar water heating systems: A review. Renewable and Sustainable Energy Reviews 19 (2013) 173–190

4.4.2 New Clause	Add following new clause *"4.4.2 The most common configurations of heat exchanger are the immersed coil-in-tank, the shell-and-tube, and the mantle heat exchanger. The coil-in-tank heat exchanger is a coil containing several loops of tubing made up of either single or double wall immersed in the storage tank. The shell-and-tube exchanger has two varieties: the first type is an external heat exchanger, where the cold water is drawn from bottom of the tank by using a second circulating pump and is allowed to flow through the secondary side of the heat exchanger in a counter-flow method, and the second type is an external heat exchanger with a bypass circuit, in which a three-way valve is provided at two different heights. The mantle configuration helps in providing a large heat transfer area for a given volume of collector fluid flow in the mantle. In this design both the hot water tank and the heat exchanger are combined into one unit. The counter flow heat exchangers have larger effectiveness compared to immersed coil."*		Source Literature: Ruchi Shukla et al. Recent advances in the solar water heating systems: A review. Renewable and Sustainable Energy Reviews 19 (2013) 173–190
4.5.2 New Clause	Add following new clause *"4.5.2 In indirect or closed loop systems, in addition to properties listed at 4.5.1, the heat transfer fluid used in solar systems shall be chemically stable, non-corrosive and environmental friendly. The natural working fluids which are more suitable for environment should be preferred over the HCFCs and HFCs."*	Only direct loop system is covered in existing clause 4.5.1. Indirect loop system may also be included.	Source Literature: Ruchi Shukla et al. Recent advances in the solar water heating systems: A review. Renewable and Sustainable Energy Reviews 19 (2013) 173–190

5 Auxiliary Heating	Substitute “country” for “counter”	Editorial correction.	
New Clause Techno-Economic Analysis	Add the following new clause: *“11 Techno-Economic Analysis* *11.1 The unit cost of useful thermal energy can be determined as the ratio of the total annual cost to the annual useful thermal energy delivered by the system.* $\text{Unit Cost} = \dfrac{\{[d(1+d)^n]/[(1+d)^n-1]+m\}\ x\ C}{f.\ V.\ \rho.\ Cp\ (Tf\_Ti)\ N}$ *where:* *d = Discount rate* *ρ = Density of water.* *C = Capital cost of the Solar water heating system.* *Cp = Specific heat of water.* *N= Number of days in a year when the hot water is utilized.* *n = Useful life of the Solar water heating system.* *V = Volume of daily hot water requirement.* *f = Fraction of total annual useful energy requirement for domestic water heating provided by the solar energy.* *Tf = Outlet temperature of water.* *Ti = Inlet temperature of water.* *m = Fraction of operation and maintenance cost to total cost*	Please see justification for change in Clause 1 “Scope”.	Source Literature: B. Chandrasekar, T.C. Kandpal Techno-economic evaluation of domestic solar water heating systems in India. Renewable Energy 29 (2004) 319–332. M. Raisul Islam, K. Sumathy, Samee Ullah Khan. Solar water heating systems and their market trends. Renewable and Sustainable Energy Reviews 17 (2013) 1–25

	11.2 The amount of fuel saved annually through its substitution by solar energy by use of solar water heating system can be determined as: $SF = \frac{f.\ V.\ \rho.\ Cp\ (Tf - Ti)\ N}{C_f.\ \eta}$ *where* *Cf = Fuel calorific value* η *= Efficiency of conversion of energy stored in fuel to useful energy.* *11.3 The monetary worth of annual fuel savings can be calculated by using the relation* *MF = SF x PF where PF is unit price of fuel.* *11.4 The net annual monetary benefits (BA) by solar water heating system is determined as [MF – Mc]* *11.5 The economic feasibility of solar water heating system can be evaluated by* *11.5.1 Simple payback period: The ratio of the capital cost of solar water heating system to the net annual monetary benefits accrued to the user.* *11.5.2 Discounted payback period: The discounted payback period (DPP) can be determined using the relation:* $DPP = \frac{\ln (BA) - \ln (BA - d.\ C)}{\ln [(1 + d)]}$		

	11.5.3 Net present value (NPV) : It can be determined as the difference of present value of net annual monetary benefits to the capital cost of the system. 11.5.4 Internal rate of return (IRR) : It can be determined by equating the NPV to zero and then solving the equation for the discount rate. For the case of uniform net annual monetary benefits, it is determined by the equation: $\frac{B_A (1+IRR)^n - 1}{(IRR)(1+IRR)^n} + \frac{S}{(1+IRR)^n} - C$”		

ANNEX 2

BUREAU OF INDIAN STANDARDS

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भारतीय मानक *मसौदा*

सौर जल तापन प्रणाली – रीति संहिता

(*पहला पुनरीक्षण*)

Draft Indian Standard

SOLAR WATER HEATING SYSTEMS – CODE OF PRACTICE

(First Revision)

FOREWORD

Formal Forward Clause may be included by Concerned Technical Department (i.e. MED)

Draft Indian Standard

SOLAR WATER HEATING SYSTEMS – CODE OF PRACTICE

(First Revision)

1 SCOPE

This standard gives general characteristics of all types of solar water heating systems with flat plate or tubular collectors and their performance evaluation methods.

1.1 This standard provides the principles of corrosion, anti-freeze and overheating protection of the system.

1.2 This standard also covers the techno-economic feasibility evaluation aspects of solar water heating system.

2 REFERENCES

2.1 The standards listed below contain provisions which, through reference in this text, constitute provision of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreement based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated:

IS No.	*Title*
12933 (Part 1) : 2003	Solar flat plate collector : Part 1 Requirements (*Second Revision*)
12933 (Part 2) : 2003	Solar flat plate collector : Part 2 Components (*Second Revision*)
12933 (Part 3) : 2003	Solar flat plate collector : Part 3 Measuring instruments. (*First Revision*)
~~12933 (Part 4) : 1990~~	~~Solar flat plate collector :~~ ~~Part 4 Performance requirements and accepted criteria~~
12933 (Part 5) : 2003	Solar flat plate collector : Part 5 Test methods (*Second Revision*)

3 CLASSIFICATION

3.1 The solar water heating systems are classified by the mode of fluid flow through them.

3.2 Passive System

~~This system works without the aid of pump and instrumentation.~~ **Passive system uses natural convective heat transfer without aid of mechanical devices like pump and instrumentation to circulate water:**

3.2.1 *Thermosyphon System*

This system is shown in Fig, 1A and 1B. It works on the principle of natural convection. The water from the bottom of the tank enters the solar collector and gets heated. This heated water becomes less dense and rise again to the tank. This continues till the temperature differential at the bottom and top remain. In this system since the density difference is the driving force:

a) Pipe friction losses should be low,

b) Pipe should have minimum length with larger diameter (above 25 mm) with minimum fittings,

c) To prevent the reverse thermosyphoniog during night, the top of the collector header should be more than 50 cm below the bottom of the storage tank,

d) For very cold climates a heat exchanger with water, mixed with anti-freeze liquid is recommended, and

e) The heat exchanger is also recommended when water is very hard.

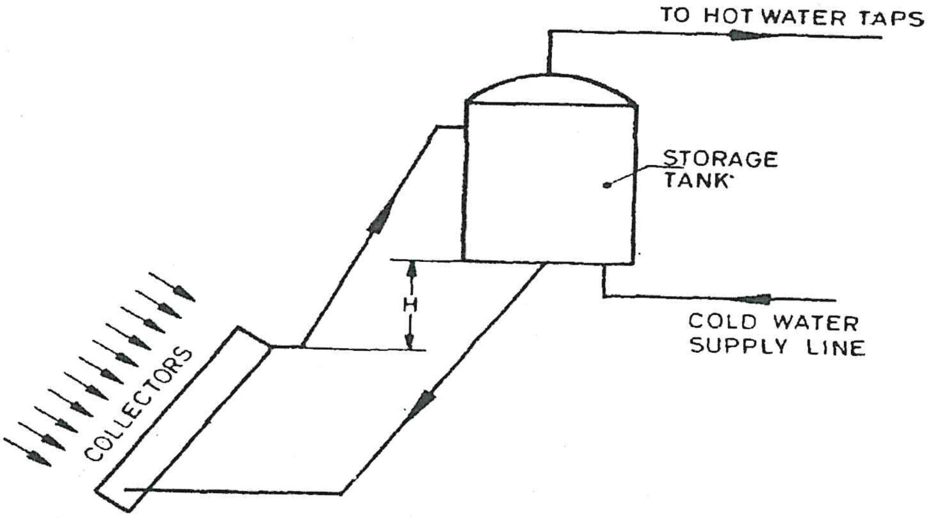

FIG. 1A THERMOSYPHON SWH SYSTEM (OPEN LOOP)

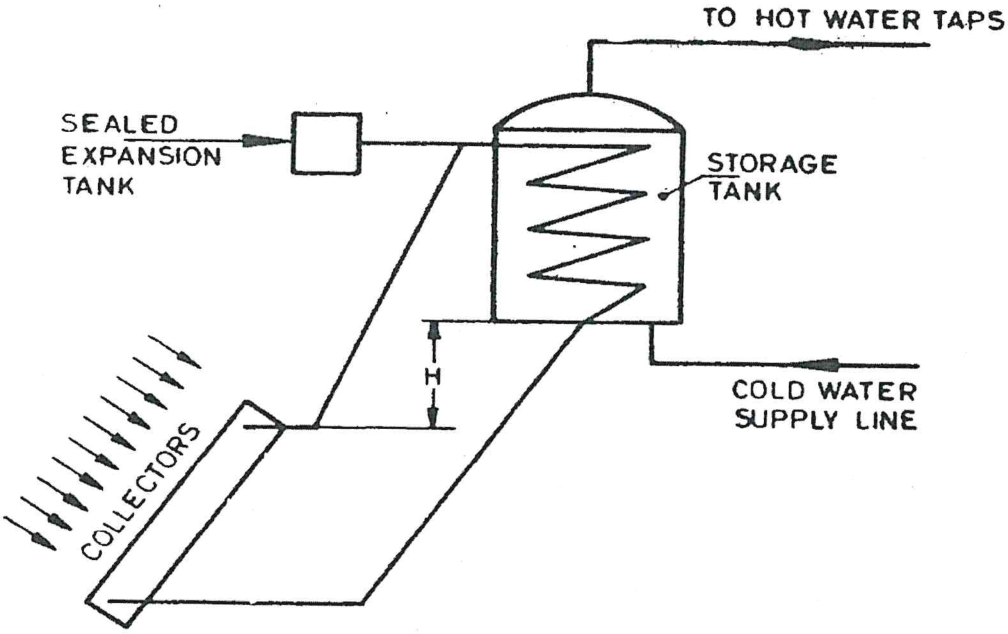

FIG. 1B TRBRMOSYPHON SWH SYSTEM (CLOSED LOOP)

3.2.2 *Built-in Storage Systems*

These systems are shown in Fig 2A. The main features of this system are:

a) The collector and storage units are integrated into one, reducing the space requirements,

b) The cylindrical unit is housed in a properly insulated parabolic or rectangular case with double glazings,

c) On the inner side of the casing highly reflective foil may be placed to direct more radiation on the unit,

d) The cylindrical metallic absorber/storage unit is covered with selective coatings which maximizes absorption during day and minimizes the heat loss in off sunshine period. The cylindrical unit may be replaced by number of small cylinders as shown in Fig 2B

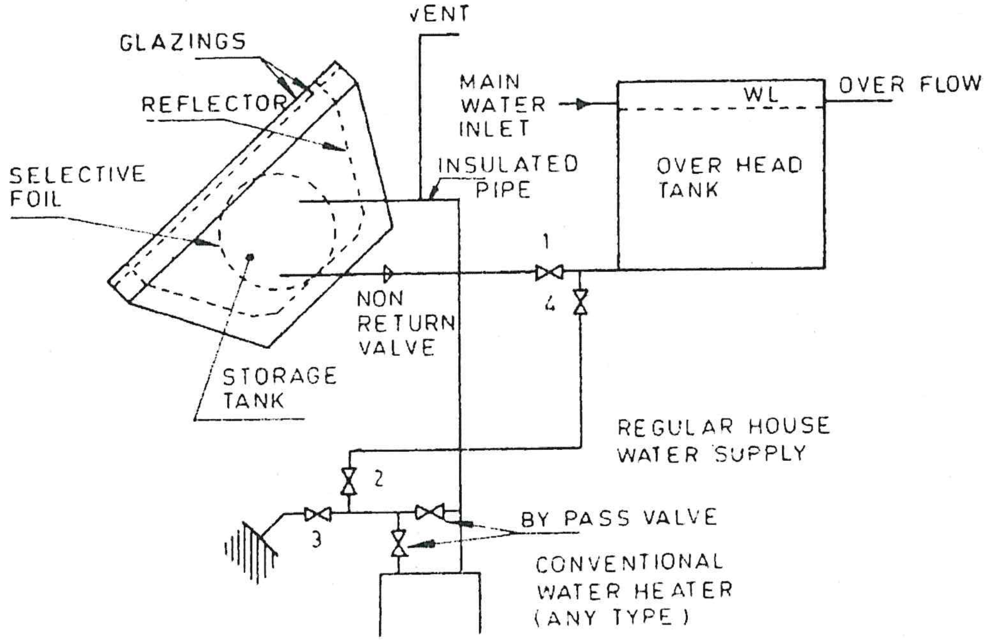

FIG. 2A SCHEMATKS OF BUILT-IN STORAGB SWH (SINGLE CYLINDER)

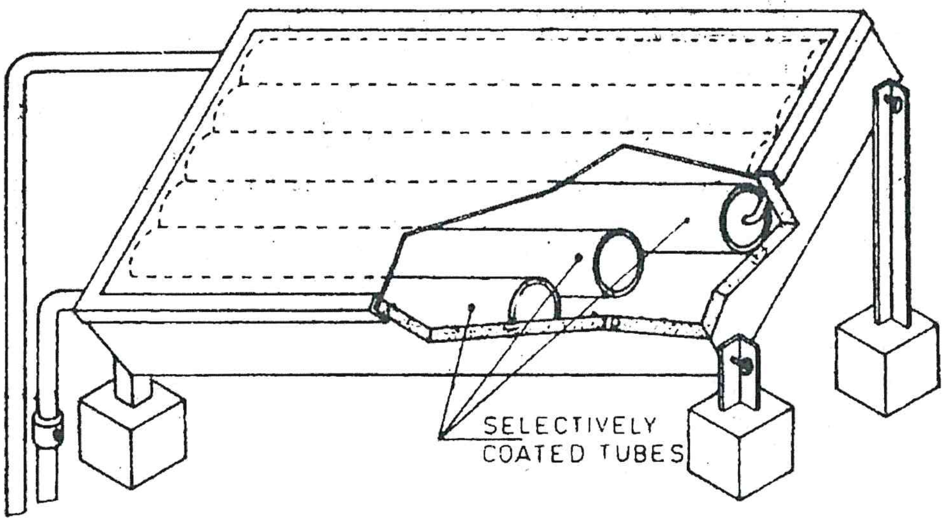

FIG. 2B SCHEMATICS OF BUILT-IN STORAGE SWH (6 CYLINDER)

3.3 Active Systems

In this system, the working fluid is transported by forced circulation which involves use of pumps and controls. The major components of these types of systems are collector, storage tank, circulation pumps and differential thermostat. In addition a complete system requires items such as auxiliary heating unit, heat exchangers and expansion tanks, valves and gauges.

3.3.1 *Closed Loop Systems*

These systems are shown in Fig. 3A. These systems use a heat transfer fluid and heat exchanger to heat service water. In very cold climate, this system is recommended to protect the freezing. It is also used where water is too hard or acidic which may cause scale deposits that clog or corrode the fluid passage. The closed loop systems require an expansion tank to accommodate pressure changes.

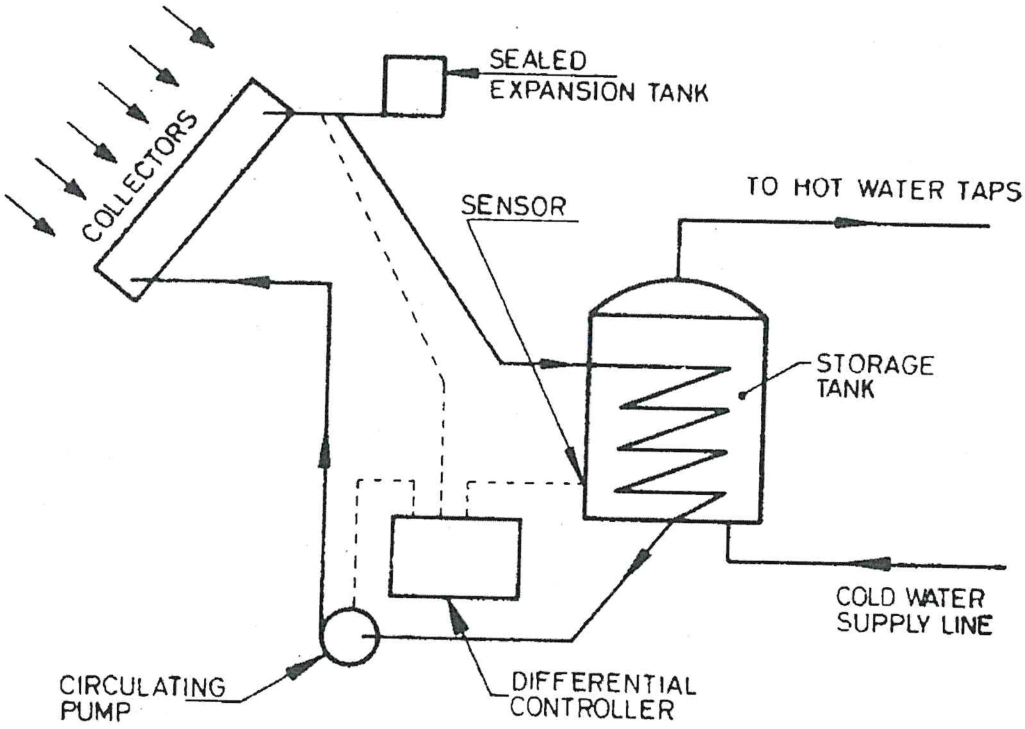

FIG. 3A ACTIVE SWH SYSTEM (CLOSED LOOP)

3.3.2 *Open Loop Systems*

These systems are shown in Fig. 3B. In open loop system, service water is heated directly through the collector. Being in contact with the outside air, this system is more susceptible to corrosion. Therefore, adequate precaution for its prevention are necessary in this system.

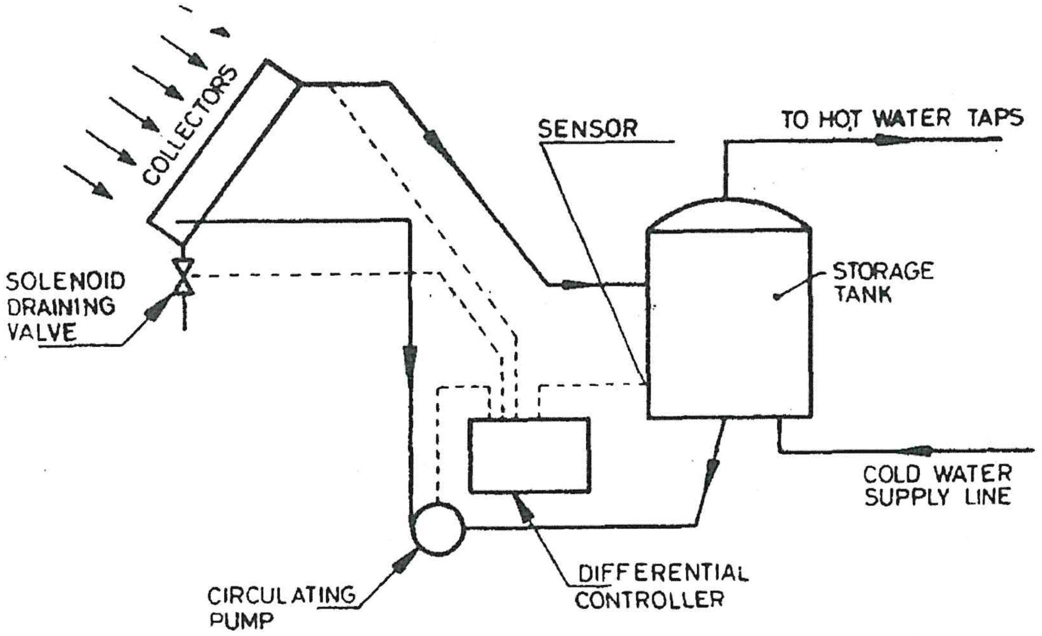

FIG. 3B ACTIVE SWH SYSTEM (OPEN LOOP)

4 COMPONENTS OF SOLAR WATER HEATING SYSTEM

The major components of solar water heating system are given below.

4.1 Solar Collector

The part of the system which collects the energy. They may be of many types such as evacuated tube, parabolic dish ~~concentrating~~, parabolic trough or flat plate depending upon the temperature required and climatic conditions. Most widely used collectors are flat plate type in accordance with IS 12933 (Part 1 to ~~5~~ 3 & Part 5).

4.1.1 *Collector Heat Exchanger Efficiency Factor*

When a heat exchanger is used in the system, the collector heat exchanger efficiency factor 'F_R' shall be substituted for F_R to calculate the combined performance of collector and heat exchanger. The ratio $\frac{F_R'}{F_R}$ is the correction factor, varying from 0 to 1. $\frac{F_R'}{F_R}$ may be determined as a function of collector's performance, heat exchanger flow rate and heat exchanger effectiveness as:

$$\frac{F_R'}{F_R} = \left[1 + \frac{F_R U_L}{mC_P} \frac{A\,.\,m\ C_P}{E\,.\,Cmin^{-1}}\right]^{-1}$$

Where

F_R is the solar heat removal factor, dimensionless,

U_L is the solar collector heat transfer loss co-efficient in $Wm^{-2\circ}C$,
m is the mass flow rate of the transfer fluid in kg/s,
C_p specific heat of the transfer fluid in J/kg°C,
A is the collector area in m^2, and
C_{min} smaller of the two fluid capacitance rates in the heat exchanger.
E is …… **(E in formula need to be defined)**

4.1.2 Collector Orientation

Solar collector should always be kept facing due south at an inclination so that it receives maximum radiation. This inclination depends on the utility pattern of hot water. The optimum value for inclination of the collector with the horizontal is latitude for year round performance and latitude + 10° to + 15° for winter ~~water~~ months and latitude – 10° to – 15° for summer months. When a row of collectors are mounted, to avoid shading, the minimum distance between the two collectors (D) is given by:

$$D = \frac{\sin\theta \times \text{collector length}}{\tan(66.5^\circ - \text{latitude})}$$

where θ is the collector tilt with the horizontal as shown in Fig. 4.

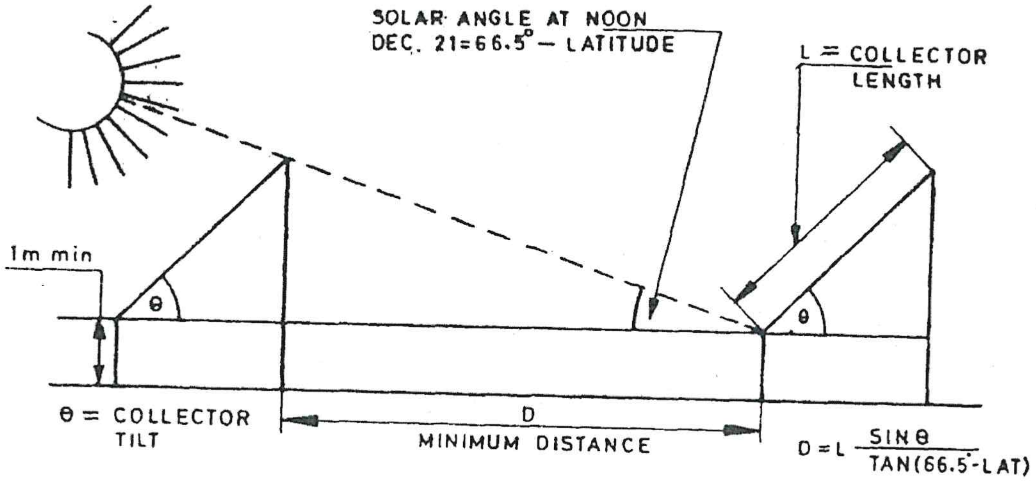

FIG. 4 MINIMUM DISTANCE REQUIRED BETWEEN ROWS OF COLLECTORS

4.1.3 *Collector Combination (Arrays)*

A number of collectors are connected in series/ parallel combination in large systems. The type of combination and number of collectors in series will depend upon the flow rate, pressure drop in the system and the temperature desired. Also, the performance characteristics of the collector should be known. Some possible combinations are known in Fig. 5.

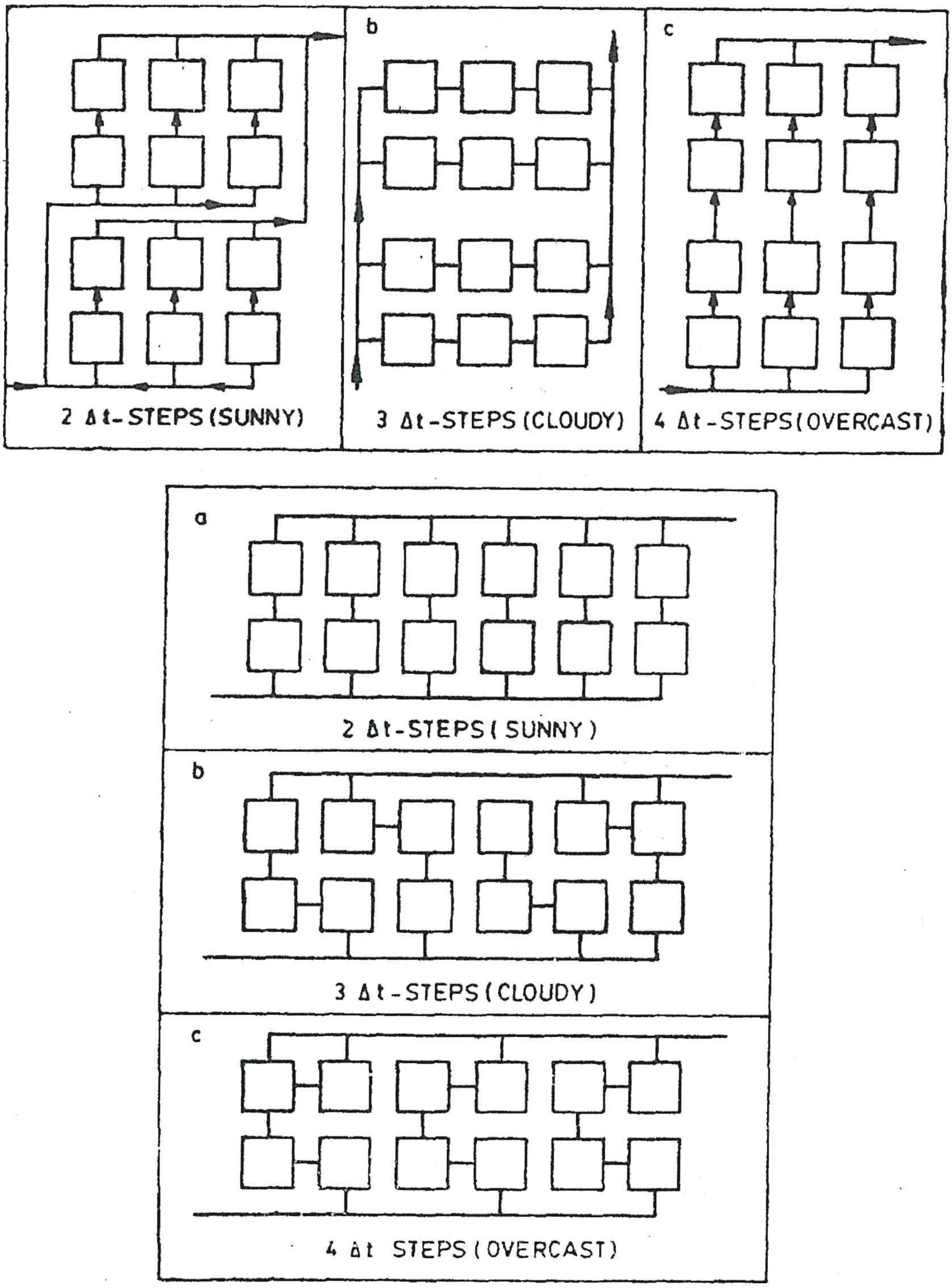

FIG. 5 ALTERNATIVE ARRANGEMENTS FOR COLLECTOR COMBIKATIONS (6 X 2 SYSTEM)

4.2 Storage Tanks

The thermal energy storage in solar water heating system is in one or two tanks. It should be such sized as to store 1.5 to 2 times the average daily hot water usage. The tank capacities are generally chosen between 40 to 100 liters m^{-2} of collector area.

4.2.1 The material used for tank may be copper, steel, aluminium, fiberglass or concrete. But the inner side of the tank must be of a material which does not contaminate water (if direct system), is non-corrosive, and stable at maximum operating temperature.

4.2.2 The tank outlet to the collector should be about 10 cm above the tank bottom to prevent scale deposits from being drawn into the collector. The hot water outlet pipe should be at the top end to increase stratification in thermosyphon system.

4.2.3 The exterior of the tank must be properly insulated so that the hot water temperature does not decrease by more than 8°C in about 16 hours time. Generally thickness of 7-10 cm of fibreglass or cork insulation is provided.

4.2.4 **Stratification of tank may also be done to minimize heat losses due to the mixing of hot and cold water. The analysis of geometrical factors including different orientations (such as horizontal or vertical tanks), wall thickness, height to diameter ratio, tank material and the operational factors including the temperature differential between inlet and outlet, climatic conditions and the flow rate shall be considered for better thermal stratification.**

4.3 Expansion Tank

The volume change of fluid in closed loop system must be accommodated by an external expansion tank. The sizing of this tank must account for the variation of density with temperature for the fluid used in loop. Generally expansion tank is $\frac{1}{2}$ to $\frac{1}{4}$ of the total volume of storage tank. The maximum operating temperature of these tanks should be taken as equal to collector stagnation temperature.

4.4 Heat Exchangers

4.4.1 Heat exchangers are used for protection against freezing, scaling and corrosion. Heat exchanger selection considers its effectiveness, pressure drop, flow rate and total protection of the potable water from contamination if the working fluid is toxic. It must be properly insulated and thermally compatible with system design para meters. Its overall heat transfer co-efficient and heat transfer area should be large. The exchanger effectiveness is given as:

$$E_{hx} = \frac{Q_{hx}}{(mC_P)_{min}}\,(T_{hI} - T_{cI})$$

where Q_{hx} is amount of heat transferred, $(mC_p)_{min}$ is the minimum of the capacitance rate of the two fluids, T_{hI} is the hot stream inlet temperature and T_{cI} is cold stream inlet temperature. Generally a heat exchanger effectiveness of 0.7 to 0.8 is recommended.

4.4.2 **The most common configurations of heat exchanger are the immersed coil-in-tank, the shell-and-tube, and the mantle heat exchanger. The coil-in-tank heat exchanger is a coil containing several loops of tubing made up of either single or double wall immersed in the storage tank. The shell-and-tube exchanger has two varieties: the first type is an external heat exchanger, where the cold water is drawn from bottom of the tank by using a second circulating pump and is allowed to flow through the secondary side of the heat exchanger in a counter-flow method, and the second type is an external heat exchanger with a bypass circuit, in which a three-way valve is provided at two different heights. The mantle configuration helps in providing a large heat transfer area for a given volume of collector fluid flow in the mantle. In this design both the hot water tank and the heat exchanger are combined into one unit.** The counter flow heat exchangers have larger effectiveness compared to immersed coil.

4.5 Heat Transfer Fluid

4.5.1 In direct or open loop systems, water is most common fluid. The liquid to be used in solar systems should have high specific heat, low viscosity, particularly at low temperatures, low vapour pressure/high boiling point, **low freezing point**, relatively high surface tension (to avoid leaks), high density and high thermal conductivity to provide efficient heat transfer over a wide range of temperatures.

4.5.2 In indirect or closed loop systems, in addition to properties listed at *4.5.1*, the heat transfer fluid used in solar systems shall be chemically stable, non-corrosive and environmental friendly. The natural working fluids which are more suitable for environment should be preferred over the HCFCs and HFCs.

4.6 Pumps

The selection of pump must consider the head and discharge requirements and the operating temperature and pressure losses. In solar water heating system usually a centrifugal pump is recommended. When oil or hydrocarbon (high microns liquids) is used in the loop, positive displacement pump should be used with a relief valve on the pump outlet.

4.7 System Piping and Fittings

The material of the pipe must be compatible with the working fluid, its velocity of flow and with the material of riser tubes in the collector.

4.7.1 The collector array and piping should be properly insulated to avoid heat loss. After insulation they are covered by aluminium foil to avoid damage to insulation.

4.8 Valves and Gauges

The valves and its seals should be such that it is able to bear maximum temperature and compatible with fluid used. These valves must be placed properly such that its function cannot be deactivated by anything.

4.9 Control Systems

In an active solar water heating system, control systems are used to switch on a circulation pump whenever energy gain is possible through solar collectors. Otherwise, it automatically switches off the pump. A differential thermostat is recommended as it optimizes the energy gain for the system. A fixed point controller is used when the system is employed for process applications.

5 AUXILIARY HEATING

In hot weather or tropical **country** ~~counter~~, auxiliary heating system is not required, but in cold climate low solar radiation regions, an auxiliary heating unit run by electricity, fuel or gas is needed.

6 SIZING AND LOAD CONSIDERATION

The size of the solar water heating system depend on the local weather conditions, the daily demand and load pattern.

7 SYSTEM PERFORMANCE EVALUATLO METHOD

7.1 '*f*' Chart Method

The '*f*' chart method of estimating the performance of a system is applicable to active system designs shown in Fig. 6.

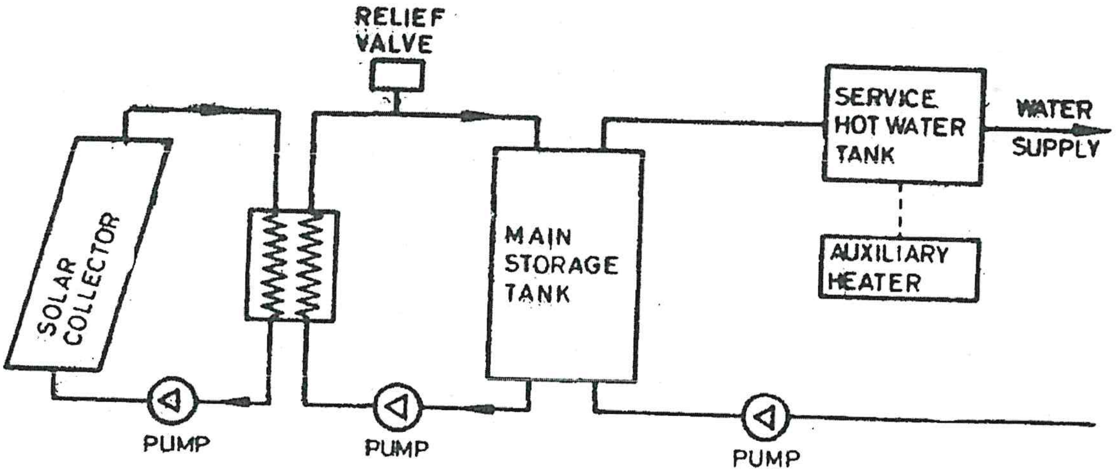

FIG. 6 SOLAR HEATING SYSTEM

This method requires only the monthly average metrological data for the estimation of long term thermal performance of the system as a function of major system design parameters. The solar heating fraction '*f*' is a function of dimensionless groups 'which relate the system properties and weather data for a month to the monthly heating requirements. The several dimensionless parameters are grouped into solar parameters '*Y*' and loss parameters '*X*'. The '*f*' chart method is recommended for the following design parameters:

Collector flow rate :	0.015 l/s
Collector heat exchanger correction factor :	F_R'/F_R 0.9
Storage capacity :	50 to 100 l/m^2
Load heat exchanger :	1
Collector slope :	*L* ± 10°C due south
Preheat tank storage capacity :	1.5 to 2 times capacity of conventional water heater

The two dimensionless parameters *X* and Y are calculated as:

$$X = \frac{A \,.\, b\,(100 - T_a \,.\, n \,.\, 24 \,.\, C_2 \,.\, C_3 \,.\, C_4}{L \,.\, 1000}$$

$$Y = \frac{\text{Absorbed solar energy}}{\text{Heating load}}$$

$$= \frac{A \,.\, a \,.\, H \,.\, n \,.\, c_1 \,.\, c_2}{L}$$

where

n is the number of days in the month
H is daily average radiation on the collector kW/hm^{-2}
T_a is the average air temperature for the month °C
L is the monthly heating load given by
$$L = V \,.\, a \,.\, C_P \,.\, (T_w \,.\, T_a) \,.\, n$$
V is the volume of hot water required per day
σ is the density of water

C_P is the specific heat of water
T_w is the minimum acceptable temperature of water
a is the no loss coefficient (first constant)
$a = F_R (\tau_a)$ – determined by collector performance test in accordance with IS 12933 (Parts 1 to 5) : 1990

b is the loss co-efficient (second constant)

$b = F_R U_L$ – determined by collector performance test in accordance with IS 12933 (Parts 1 to 5) : 1990

C_1 is the correction term for glazing
= 0.85 for single glass
= 0.75 for double glass

C_2 is the correction term for heat exchangers in the circuit
= 1 for direct system
= 0.97 for counter flow heat exchangers
= 0.95 for an average heat exchanger
= 0.90 (lowest value)

C_3 is the correction term if the storage/ collector ratio is other than 75 l/m^2 collector area (between the limits of 37.5 and 300 l/m^2)

$$C_3 = \frac{[\text{Storage/Collector Ratio}]^{-0.25}}{75}$$

C_4 is the correction term for the system given by

$$C_4 = \frac{11.6 + (1.18\, T_W) + (3.86\, T_c) - (2.32\, T_\sigma)}{100 - T_a}$$

Where T_c is the cold water supply temperature after finding the values of 'X' and 'Y', the solar fraction 'f' is calculated by:

$$f = 1.029\, Y - 0.065\, Y - 0.245\, Y^2 + 0.0018\, X^2 + 0.0215\, Y^3$$

for $0 < Y < 3 : 0 < X < 18$

A sample calculation for performance evaluation is given in Annex A.

8 SYSTEM PROTECTION

8.1 Freezing

Since freezing in winter may altogether damage the system, freeze protection is important.

8.1.1 *Antifreeze System*

In closed loop systems, an antifreeze material is added to the loop and heat exchanger is employed to heat potable water. The concentration of antifreeze material depend on severity of freeze conditions expected.

8.1.2 *Drain Down System*

One method of freeze protection is to drain the collector when a freezing condition is sensed, that is, when temperature in the collector falls below 4°C. An automatic air vent is located at highest post of the system. When the collector array is filling, air vents out and vents close. When the pump stops either freeze conditions or due to power failure, the vents get open under atmospheric pressure and collector array drains water into storage tank (Fig. 7).

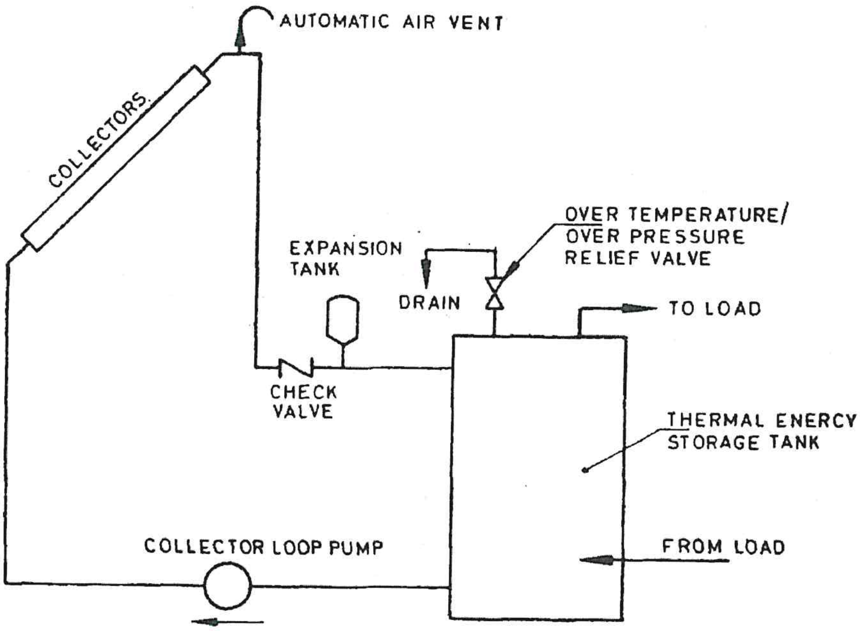

FIG. 7 AIR ASSISTED DRAIN-DOWN SYSTEM SCHEMATIC

8.2 Over Heating

During periods of high radiation and low hot water demand, over heating may occur in the collector or storage tanks. Protection against overheating must be considered for all portions of the solar water heating system. Liquid expansion or excessive pressure may burst piping or storage tanks. Steam or other gases within a system may restrict liquid flow, making the system inoperable. In indirect systems where antifreeze fluids such as glycol are used, over temperature protection is needed to limit the fluid degradation at higher temperature closing collector stagnation.

The most common method of overheat protection is to stop circulation in the collector loop until the storage temperature decreases or using a heat exchanger as means of heat rejection.

9 CORROSION PREVENTION

Most components of the system are metals and use water or fluid for heating it. It is, therefore, essential to prevent corrosion of the system components to enhance its life.

9.1 Types of Corrosion and Prevention

Corrosion in metals in the system may occur both internally within the fluid passages of the collector and system pipe work and externally on the surfaces of the collector box and absorber plate.

9.1.1. *Oxidation Corrosion*

Oxygen dissolved in heat transfer .fluid oxidize the metal and cause corrosion. This is easily prevented in closed loop system where the fluid is not in direct contact with air. In drain drum system, air enters the system through vents and may cause corrosion.

9.1.2 *Bimetallic or Galvanic Corrosion*

This corrosion occurs between two dissimilar metals when in contact with an electrolyte. In such cases dimetallic insulating couplings like PTFE tape in threaded joints should be used specially when water is the fluid and two dissimilar metals are joined. This corrosion may also be prevented by putting a sacrificial anode of higher electromotive potential than any other metal in the system like in copper collector with steel tubes, magnesium as anode is put witch disssolves, protecting both the metals.

9.1.3 *Ion Exchange Pitting Corrosion*

It occurs when the fluid carry heavy metals ions, deposit them on another metal in the presence of an electrolyte. It is a localized attack that may result in penetration and subsequent leakage. Heavy metal ions may be present in the fluid naturally or may appear due to corrosion in other part of the system. To suppress the ion exchange between the metal and ion, corrosion inhibitors be added in transport fluid. These ions present in the fluid alter the *p*H. Therefore *p*H should be constantly monitored to retain its neutrality.

9.1.4 *Crevising Corrosion*

It is similar to pitting corrosion and results in a rapid metal loss inside a crevice. The crevice formation may be the result of bad fittings, leaky gaskets, scale deposits, blockages or unusual flow patterns. The fluid passage should not be blocked and in system some inhibitors should be added.

9.1.5 *Scaling*

Water contains variety of metallic and non metallic impurities such as calcium and magnesium compounds. These impurities precipitate as scales under certain influences. To avoid scaling, deionized/neutral pH water should be used or some inhibitors should be added.

10 SYSTEM INSTALLATION

Proper installation of the system is most important for its proper functioning and maintenance.

10.1 Collector Mounting

Solar collectors are usually mounted on the ground on flat or pitched roofs. A roof location necessitates the penetration of the building envelope for mounting hardware, piping control and wiring.

When mounted on racks the collector array becomes more vulnerable to wind gusts as the angle of the moment increases. Collectors may be uplifted by wind striking the undersides. This wind load, in addition to the equivalent roof area should be determined according to accepted engineering procedures.

10.2 Storage Tank

Storage tank should be placed as near to the collector as possible to reduce piping length and heat losses. The tank should be properly insulated. After insulation it may be covered by reflective aluminium foil. In an active system the tank may be placed inside the building.

10.3 Piping and Fitting

The piping length should be as small as possible with minimum joints and elbows. They must be leak proof. Pipe bends should be preferred to elbows since they have less pressure drop. The pipe must be properly insulated and made weather proof by covering with aluminium foils.

10.3.1 The slope of the pipe should be such that proper draining of the collector array is ensured. There should be no inverted U shape loop to avoid air traps.

10.3.2 In the system all valves must be accessible for rapid turn-off if emergency shut down is required. The wiring used to connect sensors to the control unit must be impervious to moisture and should be placed away from power lines to avoid electromagnetic interference.

11 Techno-Economic Analysis

11.1 The unit cost of useful thermal energy can be determined as the ratio of the total annual cost to the annual useful thermal energy delivered by the system.

$$\text{Unit Cost} = \frac{\{ [d\,(1+d)^n] / [(1+d)^n - 1] + m \} \times C}{f.\ V.\ \rho.\ C_p\ (T_f \_ T_i)\ N}$$

where:

d = Discount rate

ρ = Density of water.

C = Capital cost of the Solar water heating system.

C_p = Specific heat of water.

N= Number of days in a year when the hot water is utilized.

n = Useful life of the Solar water heating system.

V = Volume of daily hot water requirement.

f = Fraction of total annual useful energy requirement for domestic water heating provided by the solar energy.

T_f = Outlet temperature of water.

T_i = Inlet temperature of water.

m = Fraction of operation and maintenance cost to total cost

11.2 The amount of fuel saved annually through its substitution by solar energy by use of solar water heating system can be determined as:

$$S_F = \frac{f.\ V.\ \rho.\ C_p\ (T_f - T_i)\ N}{C_f\ .\ \eta}$$

where

C_f = Fuel calorific value

η = Efficiency of conversion of energy stored in fuel to useful energy.

11.3 The monetary worth of annual fuel savings can be calculated by using the relation

$M_F = S_F \times P_F$ where P_F is unit price of fuel.

11.4 The net annual monetary benefits (B_A) by solar water heating system is determined as $[M_F - Mc]$

11.5 The economic feasibility of solar water heating system can be evaluated by

11.5.1 Simple payback period: The ratio of the capital cost of solar water heating system to the net annual monetary benefits accrued to the user.

11.5.2 Discounted payback period: The discounted payback period (DPP) can be determined using the relation:

$$DPP = \frac{\ln (B_A) - \ln (B_A - d.\,C)}{\ln [(1 + d)]}$$

11.5.3 Net present value (NPV) : It can be determined as the difference of present value of net annual monetary benefits to the capital cost of the system.

11.5.4 Internal rate of return (IRR) : It can be determined by equating the NPV to zero and then solving the equation for the discount rate. For the case of uniform net annual monetary benefits, it is determined by the equation:

$$\frac{B_A\,(1+IRR)^N - 1}{(IRR)(1+IRR)^N} + \frac{S}{(1+IRR)^N} - C$$

ANNEX A

(*Clause* 7.1)

SAMPLE CALCULATION FOR SYSTEM SIZING

The procedure is best illustrated by an example. It is required to have a SWH system to provide 5000 l/d at 55°C at Bombay (Lat 19.12). The collector is of area 1100 m^2 and is doubly glazed with direct system. The collector constant are:

$$F_R\,(\tau_a) = a = .75$$

$$F_R\,U_L = b = 3.8$$

The storage/collector ratio is 40 lit/m^2. The tank is cylindrical with diameter and length each being 4 m, insulated by 100 mm polyurethane insulation (thermal conductivity 0.28 w/m^2k).

CALCULATIONS

Since

a = ‘75

b = 3’8

C_1 = .85 (for double glazing)

C_2 = 1 (for direct system)

$$C_3 = \left(\frac{40}{75}\right)^{-0.25}$$

$$C_4 = \frac{11.6 + (1.18\ T_W) + (3.86\ T_C) - (2.32\ T_\sigma)}{100 - T_a}$$

Now these values and load is calculated for the month and put in the table as shown in Table A_1. col 1 is the month and col 2 is the average daily radiation and col 3 is average daily ambient temperature, col 4 is the average cold water temperature and col 5 is number of days in a month. Now daily load is calculated by the expression:

$$L = V\ .\ \rho\ .\ C_P\ (T_w - T_a)\ .\ n$$
$$= 1.16 \times 50\,000 \times 31 \times (55 - 26.6\ )$$

After this the daily average load is entered in col 6. Then the calculation for X and Y made and ‘f compared are put in col 7, 8 and 9 respectively. Finally annual solar fraction is computed.

Table A1 '*f*' Chart Tabulations

Month	***H***	t_a	t_c	n	**Daily Load (KWH)**	C_4	X	Y	f	**Monthly Load** $mC(T_1 - T_a)$	**Solar Contribution**
1	4.104	23.4	26.6	31	1663.23	2.08	11.2	3.0	0.960	51 560.0	49 497.6
2	6.929	24.6	27.9	28	1587.23	2.14	11.9	3.1	0.957	44 44.24	42 531.4
3	6.803	26.4	29.2	31	1510.87	2.20	12.6	3.3	0.967	4 6837.0	45 291.4
4	6.662	28.3	30.7	30	1422.92	2.28	13.5	3.3	0.951	4 2687.7	40 596.0
5	6.499	29.7	31.5	31	1375.8	2.32	13.9	2.2	0.751	4 2649.8	32 030.0
6	4.716	28.7	29.7	30	1480.74	2.22	12.6	1.7	0.614	4 4422.2	27 275.2
7	3.805	27.3	27.9	31	1586.86	2.13	11.5	1.7	0.637	49 161.5	31 315.9
8	3.805	26.8	27.4	31	1615.09	2.11	11.2	2.1	0.777	50 067.9	38 902.8
9	4.829	26.9	27.9	30	1586.05	2.13	11.2	2.1	0.777	47 581.6	36 970.9
10	6.042	27.6	29.9	31	1469.70	2.24	12.9	2.9	0.909	45 560.7	41 414.7
11	6.830	26.6	30.0	30	1464.37	2.24	13.2	3.3	0.956	43 931.2	41 998.2
12	6.942	24.7	25.4	31	1732.17	2.01	10.0	2.9	0.962	53 697.2	51 656.7
									Total	562 599.2	479 480.0

Month – Month under consideration.
H – Total hourly solar radiation for Bombay latitude 19.12, longitude 72.85 tilt factor 22.50
t_a – Temperature of ambient air in °C.
t_c – Temperature of cold water in °C.
Load – in kWH
n – Number of days in a month
f – Solar faction

$$\text{Annual Solar Faction} = \frac{\sum_{n=1}^{n=12} \text{Solar contribution}}{\sum_{n=1}^{n=12} \text{Monthly load}}$$

$$= \frac{479\,480.8}{562\,599.2}$$

$$= 0.852\,26$$