

Sustainable Materials and Green Buildings
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Lecture: 42
Solar Water Heating

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EFFICIENCY OF PV MODULE			
PV Module Specifications	Description	Value	SI Units
P_{STC}	Power of module at standard test conditions	230	Watts
P_{PTC}	Power of module at performance test conditions	213.5	Watts
V_{mp}	Voltage at max power	41	V
I_{mp}	Current at max power	5.61	A
V_{oc}	Open-circuit voltage	48.7	V
I_{sc}	Short-circuit current	5.99	A
δ	Power temperature coefficient	-0.0038	1/C
α	Current temperature coefficient	0.000584	1/C
β	Voltage temperature coefficient	-0.00271	1/C
NOCT	Nominal operating cell temperature	45	C
η_{STC}	Efficiency at standard test conditions	0.185	
Length		1.559	M
Width		0.798	M
Weight		15	Kg
Ambient condition			
G_c	Solar radiation	800	W/m ²
T_{amb}	ambient temperature	27	C
Calculations			
A_p	Area		m ²
K	incident angle modifier Equation 3-21		
Energy balance			
T_{cell}	PV cell temperature (Equation 3-24)		C
η_{PTC}	Efficiency at T_{cell} (Equation 3-27)		
P_{PTC}	Solar power delivery (Equation 3-29)		W

Okay so we can look into the example now we see this is what are specified, first of all power under standard condition, power under standard condition right standard test condition. So let say it could value could be something like 230 watts just for sake of it.

Then performance at you know there is a standard test condition but performance I could have checked at some other condition also besides test and that value might also be available because test condition may not be 20 or 800 I might check at some other point. Then I have got voltage at maximum power.

This would be this can be measured, this will be specified by the manufacturer, current at maximum power because this characteristic that was I showed you that they would have found out in the production laboratory, you know, quality control lab of the production system. So maximum power whatever the current, corresponding current and corresponding voltage and current that would be known to us.

So then, also open circuit voltage this would be known to us, short circuit current this will be known to us this would be specified. So if you are looking buying them you can look into this kind of a chart and find out what they are supplying, right.

Then power temperature coefficient that is your alpha right, and current temperature coefficients and voltage temperature coefficient right. Okay so you can, you know, you can this is what will be given to you, alpha, beta and delta that would be given also specified. NOCT is specified because they would have measured in the laboratory and let say is 45 degree centigrade. Efficiency at standard test condition P_{stc} divided by $800 A_c$ standard test condition is this so let say 0.185

Length is given, width of the cell is given and weight is given anyway. So this will give me the area. So this is the specifications, this is how typically a PV will be specified you know PV will be specified, PV module will be specified so this is how it would be specified. If there are the number of them in series and parallel then you can look into them, so this will do.

Ambient condition has to be known right, say solar, in this case solar radiation let us say 800 (degree) watt per meter square and ambient temperature is 27 so area you can calculate it out, you can calculate out the area product of these two and incident angle modifier you can calculate out from K which is $1 + b \sin(\theta - \theta_0)$

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ENERGY BALANCE FOR A PV MODULE

$$K = 1 + b \left(\frac{1}{\cos \theta} - 1 \right) + c \left(\frac{1}{\cos \theta} - 1 \right)^2$$

K is given by above equation, θ is incident angle up to 60° and b and c are empirical constant. For $\theta > 60^\circ$ K is linearly related to θ

T_{cell} is replaced by NCOT (nominal cell operating temperature), measured at $I_c = 800\text{W/sq.m.}$ and ambient temperature of $20^\circ\text{C}.$



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Remember that I equation I gave you this was the equation one can find out from K, one can find out K from this equation right. This empirical constants are of course known, so knowing the angle of incident. Under the condition that you are looking at, right so you can find out K and then T cell you can find out, T cell.

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ENERGY BALANCE FOR A PV MODULE

$$T_{\text{cell}} = T_{\text{ambient}} + \frac{(K\tau\alpha - \eta) I_c}{U_1}$$

$$= T_{\text{ambient}} + \frac{(NOCT - 20)}{800} I_c$$

Also one can recall,

$$\eta = \frac{P_{\text{mp}}}{I_c A_c} = \frac{P_{\text{STC}}}{I_{\text{STC}} A_c}$$

$$P_{\text{solat}} = P_{\text{STC}} \frac{K I_c}{I_{\text{STC}}} [1 - \delta_{\text{mp}} (T_{\text{cell}} - T_{\text{STC}})]$$

$$= \eta_{\text{STC}} K I_c A_c [1 - \delta_{\text{mp}} (T_{\text{cell}} - T_{\text{STC}})]$$



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How do you do how do I find out a T cell? From this expression, T cell is equals to K is known to me, this tau and alpha absorptivity transmissivity, this should be known to me, how much passes through and how much is absorbed and efficiency under you know, efficiency and then this is the incident radiation, U, these are known, so ambient condition known I can find out T cell or I can find out from NOCT 20 800 and what is the incident radiation. So this I can calculate out, this I can calculate out so T cell I can calculate out. T cell I can calculate out.

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EFFICIENCY OF PV MODULE

$$\eta_{solar} = \eta_{STC} [1 - \delta (T_{cell} - T_{cell,STC})]$$

$$I_{STC} = 1000 W / m^2$$

$$P_{solar} = \left\{ \frac{\eta_{BOS} \text{ deg } r}{1000} I_c \left[1 - \delta \left(T_{ambient} + \frac{(NOCT - 20)}{800} I_c \right) - 25 \right] \right\}$$

EXAMPLE calculation

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And then efficiency, this I can calculate out from this formula right. So this I can because new standard condition is already given 0.185 so if you come to this one this is known, delta is known, T cell I have found out, T ambient plus etc. etc. so therefore I you know T cell under standard condition that is also given.

So NP solar power, solar power that I will get I can calculate out based on this formula P solar power for let say standard condition that 1000 watt per meter square at so I can find out right what is the power. So that is how one can calculate this out, that is for the data that is just there the value is, area is this much 1.24 which is product of these two, 1.559 into 0.798 meters right.

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EFFICIENCY OF PV MODULE

Calculations			
A_c	Area	1.24	m ²
K	incident angle modifier Equation 3-21	0.836	
Energy balance			
T_{cell}	PV cell temperature (Equation 3-24)	52	C
η_{solar}	Efficiency at T_{cell} (Equation 3-27)	0.166	
P_{solar}	Solar power delivery (Equation 3-29)	138.13	W


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ENERGY BALANCE FOR A PV MODULE

$$T_{cell} = T_{ambient} + \frac{(K\tau\alpha - \eta) I_c}{U_l}$$

$$= T_{ambient} + \frac{(NOCT - 20)}{800} I_c$$

Also one can recall,

$$\eta = \frac{P_{mP}}{I_c A_c} = \frac{P_{STC}}{I_{STC} A_c}$$

$$P_{solar} = P_{STC} \frac{K I_c}{I_{STC}} [1 - \delta_{mP} (T_{cell} - T_{STC})]$$

$$= \eta_{STC} K I_c A_c [1 - \delta_{mP} (T_{cell} - T_{STC})]$$


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Incident angle modifier calculated is 0.836 right, so incident angle modifier calculated is, K is calculated from the formula that I have given and its 0.836. T cell calculated out comes out to be 52, T ambient plus you know that formula that was there, this formula was there, so based on this you can calculate out T ambient plus KT, K tau alpha minus nu divide by U_i I_c, so these data were all supplied and you can calculate out and it comes out to be 52, efficiency is point and the power comes out 138.13 Watt so that is the power, solar power you can draw.

So that is such the specification and some basics behind them and the efficiency and the amount of power you will get you can calculate or that is the procedure we have discussed.

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AREA OF PANEL

$$P_{load,max} = \sum_{i=1}^N i_{load,i} v_{load,i} / \eta_{BOS} \times Diversity\ factor$$

BOS=efficiency of system in terms of battery efficiency, inverter efficiency etc

$$E_{load} = \sum_{i=1}^N i_{load,i} v_{load,i} / \eta_{BOS} \times \Delta t$$

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So P load maximum would be i load v load divided by efficiency into some diversity factor, what is diversity factor because all will not be loaded to their maximum peak simultaneously right, building services we talk about that. For example this room is connected to let say number a of lamps and each draws 5 ampere right, now probability that all the lamps in all the rooms will be on simultaneously is not 100 percent, it is less.

So if a cable is connected altogether to all of them, that cable will not be, not 5 multiplied by n but 5 multiplied by n multiplied by what is called diversity factor. So this is what it is, it is what is this efficiency system in terms of battery efficiency and v load etc. etc. So for all of them one can calculate out power, that is maximum.

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AREA OF PANEL

$$A_c = \frac{E_{load,day}}{I_{C,min,day} \eta_{BOS} \eta_{solar} \text{deg } r}$$

deg r is deg radation due to age

BOS=efficiency of system in terms of battery efficiency, inverter efficiency etc

$$E_{load} = \sum_{i=1}^N i_{load,i} v_{load,i} / \eta_{BOS} \times \Delta t$$

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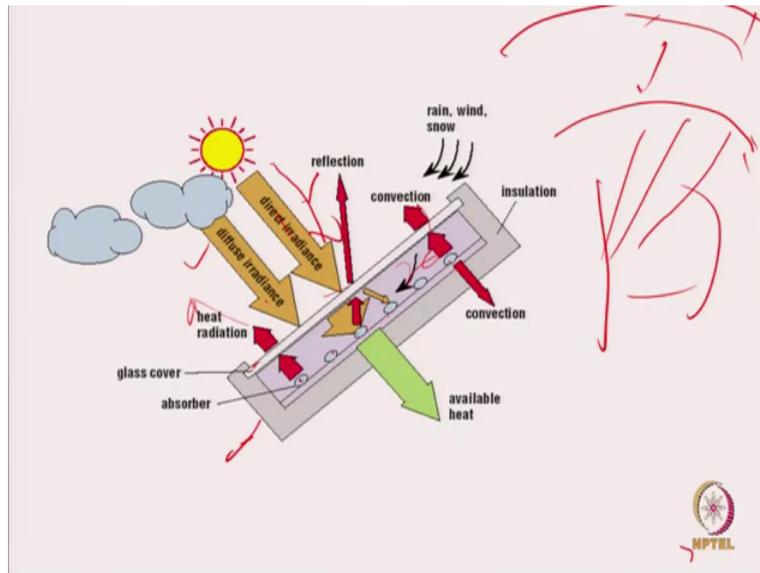


And correspondingly you know area of panel E_{load} during the day so i_{load} , v_{load} , you know how many number you need right, how many number you need you can find out so efficiency of system in terms of battery efficiency, inverter efficiency, etc. etc. because to restore them and so on.

So that is how that is related to what you can use in buildings, photovoltaics, building integrated photovoltaics which I think an introduction to you and if you are implementing them then you know how much is the you know the specification, what should be the specification and additional calculation provided in terms of efficiency and power.

I think that finishes out discussion on this right, we will obviously break for a while but in the meantime let us look for something else then we will break and then have some question answer session right.

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Quickly we will try to look into some other things, solar water heating, so you know this what is called flat plate collectors right. So you have direct radiation and some diffused radiation. What is direct radiation, if the sun is here direct radiation fall into this but even in this or vertical surface let assume this side the sky volt is there, so radiation come from sky volt because sun is too large, so radiation come from all direction, from direction of the sun obviously the side on which it is night it will not receive that.

So 50 percent half the hemisphere, half the globe receives the sun's radiation that stops atmosphere so if the atmosphere is at top the sun's radiation will come into that and then a process absorbs it in all directions, so beam radiation comes from the direct, from the direction of the sun but diffuse radiation will come even other ways right.

So this is absorbed here, some radiation, long wave radiation goes back some convection losses takes place and convection is accelerated by rain, wind etc. There is a glass absorber here, glass cover, what it does, glass will trap the sun's radiation because glass allows shortwave radiation to come in but it will block all the long wave radiation so this will get, this portion will get heated up glass cover.

But you like to reduce down this convection as much as possible so even some people have been trying vacuum and double glass layer things like that but anyway. So there will

be some convection setup here and these are the ones basically some sort of blackened pipes carrying water so heat gets absorbed, so these are kind of absorbers and this available heat through this one is then transmitted elsewhere.

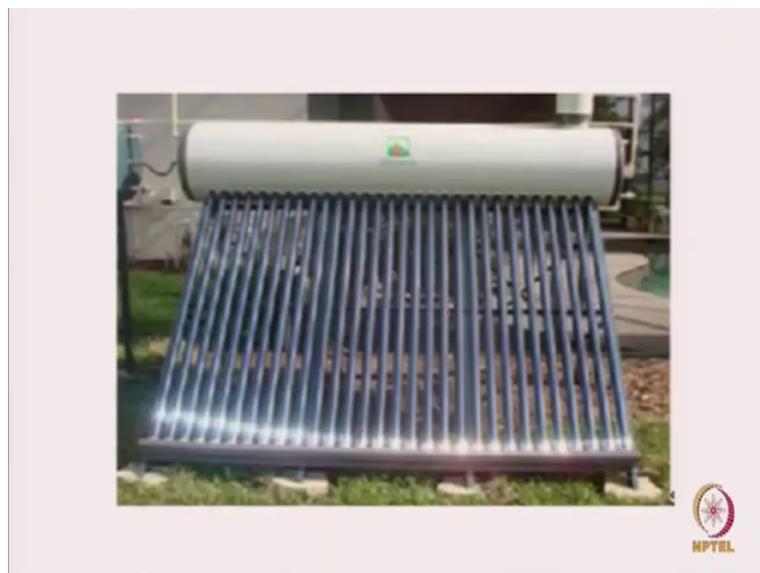
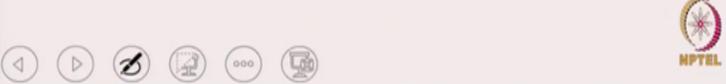
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Solar Water Heating System

A solar thermal device captures and transfers the heat energy available in solar radiation which can be used for meeting the requirements of heat in different temperature ranges.

Three main temperature ranges used are -

Low temperature	Hot water - 60°C to 80°C
Medium temperature	Drying - 80°C to 140°C
High temperature	Cooking & power generation - > 140°C

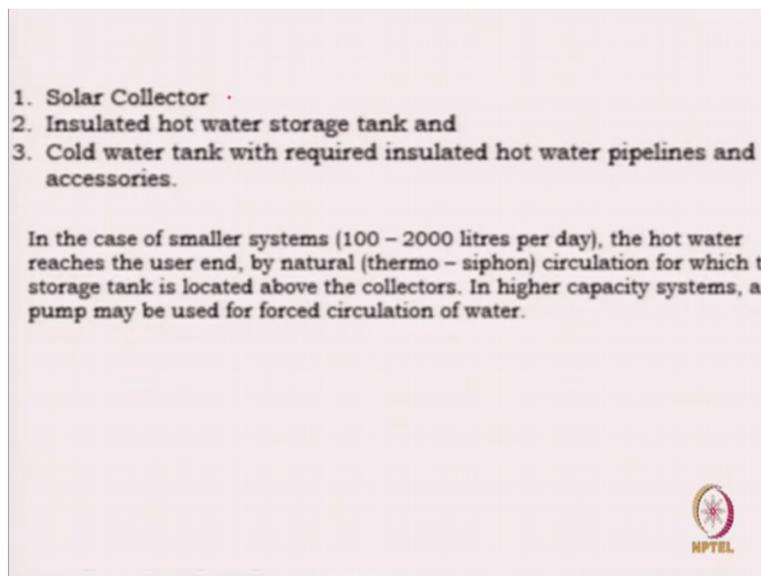


So part of a power incident will be absorbed, part be converted to, ok this is for photovoltaics that we have done, this is already done this we have already talked about I think this is a repetition, this is coming to solar water system, this is how it would look like, you know this is how it can look like.

So these are the ones, the blue colored was that we talked about, this ones and this absorbs the water and since hot water has the tendency to go up it will go up and then of course you can use them. So usually a solar thermal device captures and transfers the heat energy available in solar radiation which can be use for meeting the requirements of heat in different temperature ranges.

So there are, you can have low temperature ones, hot water 60 to 80 degree, medium temperature 80 to even 140 but then water would not be the liquid, high temperature if you can generate than cooking and power generation that also you can do right.

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So this is one of those solar collector, insulated hot water storage tank, so this is the storage tank hot water storage tank, cold water tank with required insulated hot water pipelines and accessories. In case of smaller systems the hot water reaches the user by natural thermosiphonic process because hot water move upward, it will move upward right, cold water come from the bottom gets heated up, it will move upward. So thermosiphonic effect right because of convection (12:32) effect and storage tank located above the collector in higher capacity system you might need a pump.

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Flat Plate Collectors (FPC) based Solar Water Heaters

The solar radiation is absorbed by Flat Plate Collectors which consist of an insulated outer metallic box covered on the top with glass sheet. Inside there are blackened metallic absorber (selectively coated) sheets with built-in channels or riser tubes to carry water. The absorber absorbs the solar radiation and transfers the heat to the flowing water.

Capacity (in LPD) for 60°C SWHS	Recommended Collector Area (in Sq. m)
100	2
200	4
300	6
500	8
1000	16



So this is, this was there in the hostels, some of our hostels this were there actually for using them in the kitchen, sometime you can connect this water as a pre heating system for hot water system in hot water system you know hot water supply system because you will get partial heating by the solar water and that you supply to a hot water tank where you will have a heater it will further heat it up and then you can recirculate.

So generally depending upon the area, the capacity you know 60 degree etc. collector area in square meters, this kind of guidelines are available, so which consists of an insulated outer metal box I have already explain to you and the glass sheet, inside there is a blackened metallic absorber, blackened tube sheets with built-in channels or riser tubes to carry water the absorber absorbs the solar radiation transfer the heat to flowing water.

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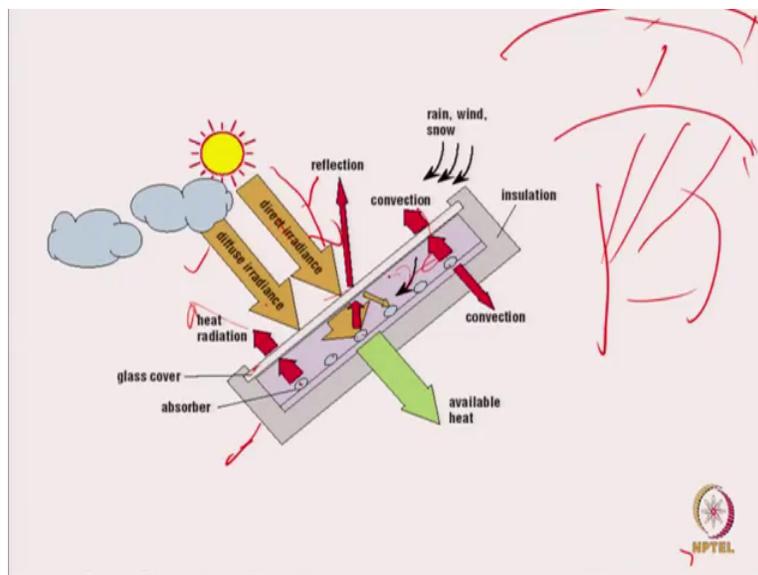
Something like this for example these are the flat plate collector and it can collect hot water will move and there is a storage etc.

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Evacuated Tube Collectors (ETC) based Solar Water Heaters

Evacuated Tube Collector is made of double layer borosilicate glass tubes evacuated for providing insulation. The outer wall of the inner tube is coated with selective absorbing material. This helps absorption of solar radiation and transfers the heat to the water which flows through the inner tube.

Capacity (LPD)	Tube size			Collector Area (Sq.m)
	Dia:47mm Length:1500mm	Dia:47mm Length:1800mm	Dia:58mm Length:1800mm	
100	14nos	12	10	1.5
125	18	15	13	1.93
150	21	18	15	2.25
200	28	23	19	3.0
250	34	28	23	3.75
300	40	33	27	4.5
400	52	43	35	6
Above 500LPD	12 Tubes per 100LPD	10 Tubes per 100LPD	8 Tubes per 100LPD	1.3sq.m/100LPD



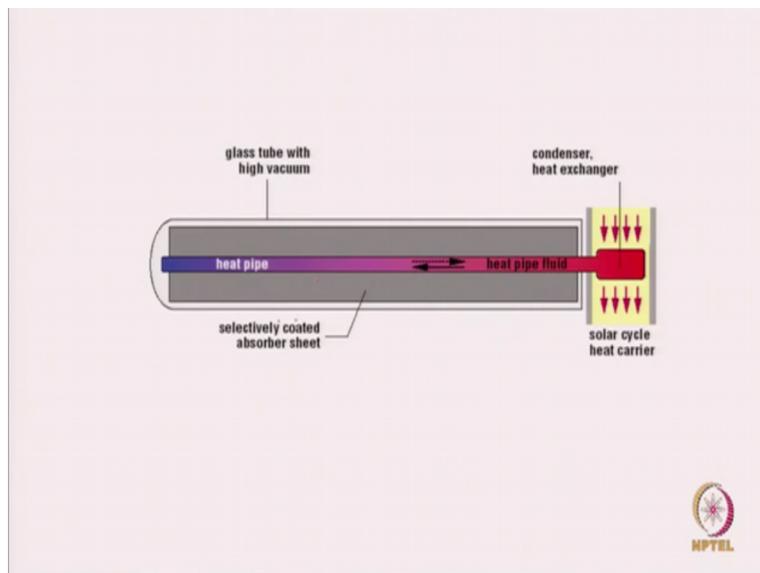
Some as I said people do use evacuated tube collector and solar water heater so these are made of double layer borosilicate glass because convection losses you do not want to reduce, what happens is if you go to the first one, first slide itself this portion it will get heated up because this is glass this will not allow radiation to go in but this will absorb but this will also get heated up because air is there, convection current will set in.

So if you put two glass layers here, the circulation is going to be less because the depth of the circulation is less and if you evacuate it, no air then convection would be minimized

even. So that is what is done sometime right, that is what evacuated tube collector but its efficiency has to be seen, cost efficiency has to be seen, it is a double layer borosilicate glass tube evacuated for providing insulation.

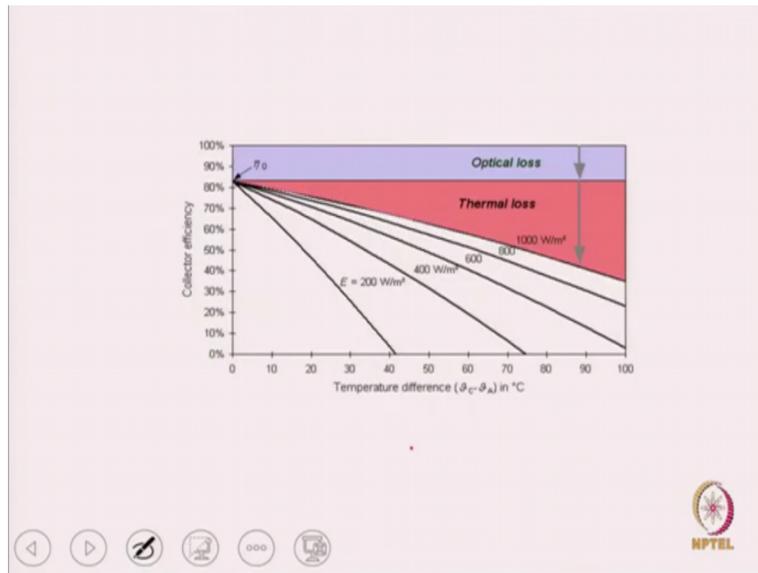
The outer wall is an inner tube is coated with selective absorbing material this helps absorption of solar radiation and transfers heat to the water which flows through the inner tube. So this is a kind of thin capacity and collector area so on such guidelines are available basic principle or something of this kind right.

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So supposing I use a heat pipe and then use a vacuum tube with high vacuum there, the convection losses will be minimized here, so hot water travels through this right and solar cycle heat carrier of course and you know so this is high vacuum system one can adopt this kind of system as well.

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Right, so generally temperature difference and collector efficiency, larger the temperature difference you know if there is a temperature difference is high, thermal losses increases because the temperature difference is high, losses increases because it would be convective loss or radiative loss is a function of temperature differences, there be some optical losses in the glass itself, there will be some absorption.

So when there is no temperature difference, there will be no losses but that is not possible. So if the, you know efficiency would, energy is 200 watt per meter square 400 so depending upon the energy that is incident. So efficiency depends upon the temperature difference between the actual system and surrounding, higher of this, thermal losses will be more optical losses will be there anyway.

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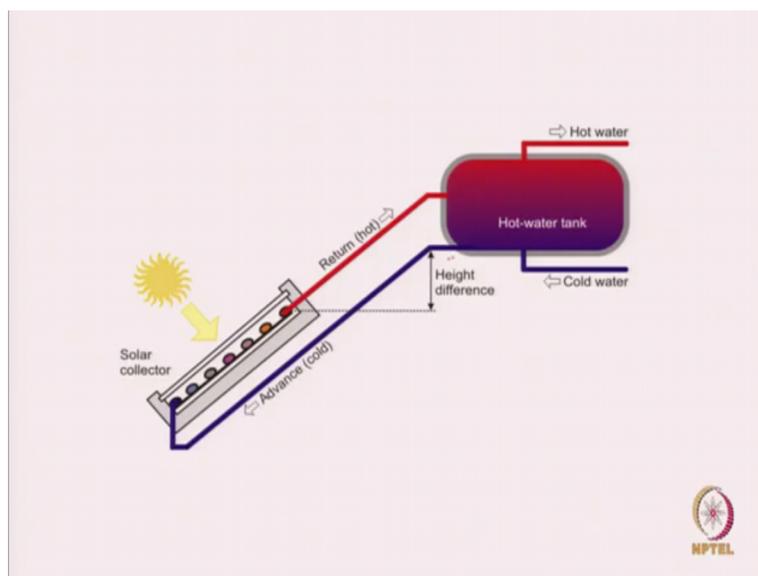
Collector Efficiency

In order to compare collectors, test institutions usually estimate efficiency curves based on measurements of collector performance. These curves are given for different irradiances E and a variety of temperature differences between collector T_C and ambient air T_A . The commonly used empirical equation for the collector efficiency η_{cC} is:

$$\eta_{cC} = \eta_{c0} - (a_1 \cdot (T_C - T_A) + a_2 \cdot (T_C - T_A)^2) / E$$


So in order to compare collector test institutions usually estimate efficiency curves based on measurements of collector performance. These curves are given for irradiance or incident radiation value and at a variety of temperature, T_c and ambient temperature, so collector temperature T_c and ambient temperature T_a , the commonly used empirical equation is given as this. So T_c is the collector temperature, this ambient temperature, this must be a constant and is a parabolic equation, this a incident radiation right.

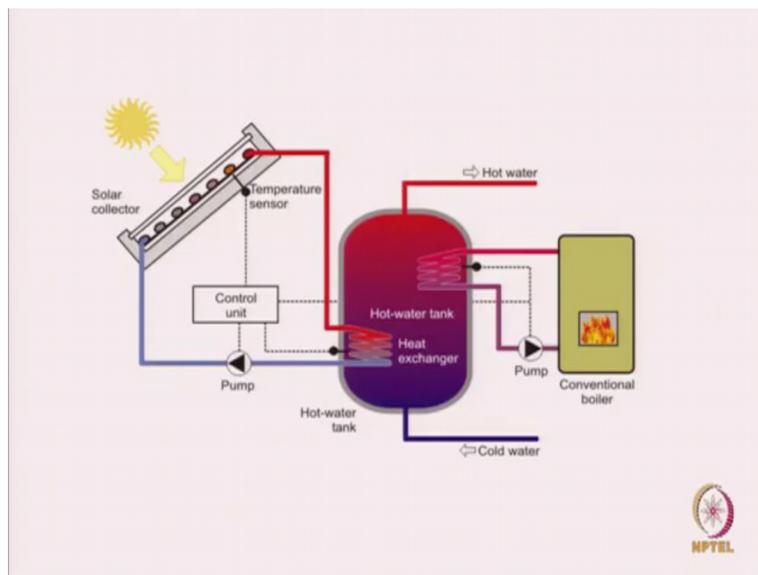
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So that is how it will be, so as I was saying partially you can you know this what it look like, so the cold water could be stored at the bottom and it comes like this cold and this of course travels through this, this pipelines travels through this and absorbs the solar radiation and when it is going out of this return this is in warm and this and then you can take it to the water supply or connect to a boiler or something like that you know heater where it can be further heated and domestic supply also can be.

This is been used for swimming pool and similar sort of situation quite often, used for swimming pool and similar sort of situation often for many years now it is you know maybe 30, 40 years people are using similar kind of system so that is what I was saying.

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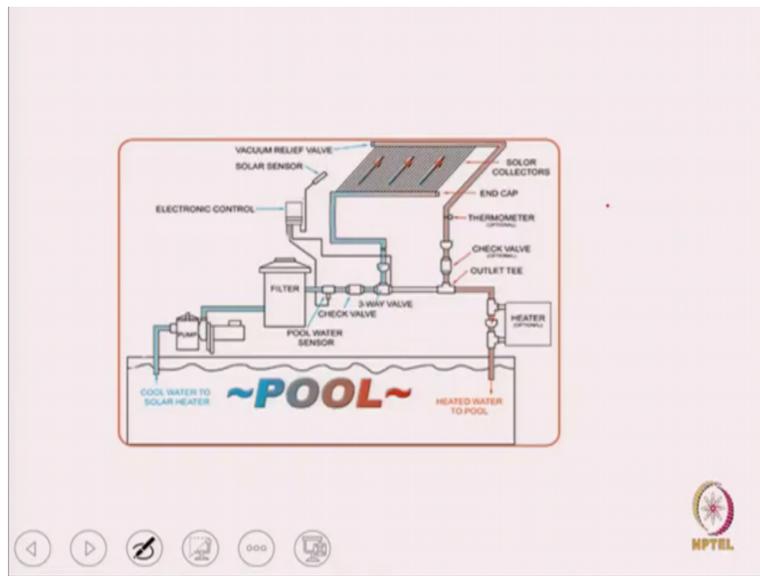


So if you have a water heater, this comes here, so this come here, this is a hot water tank and this is my heater, so where I am heating the water again hot water is coming like this and pumped right, so that is how the hot water is you know I mean whatever the heating system, heating liquid fluid I am using that will be circulated and this one is the other fluid which passes through this.

Finally the water, this is the water, hot water, cold water here so cold water feed is there, hot water outlet is there, so in a building hot water system you can use this and it can actually save a lot of your you know and if you have installed this kind of system as you

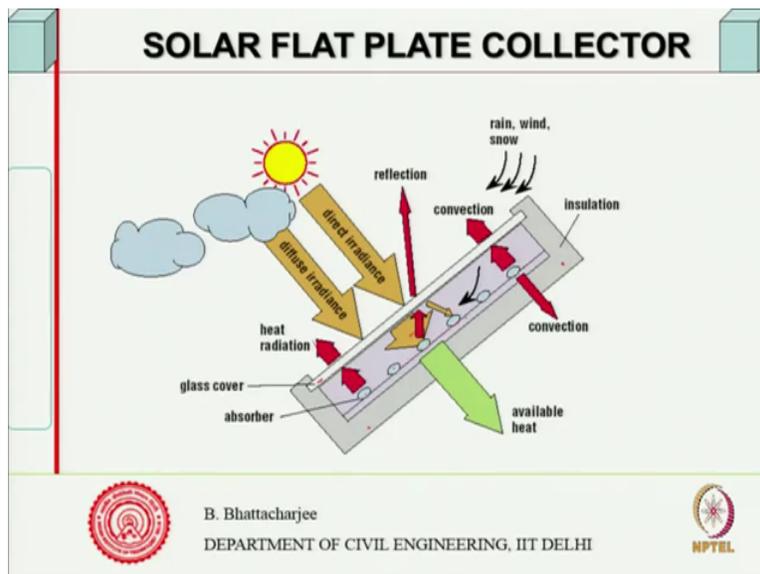
can see when you talked of ECBC the efficiency is higher, you know in terms of compliance it is much better.

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So that is what it is, the other system is something like putting into a swimming pool so the hot water comes put into the heated to the pool, cold water goes circulated filter etc. etc. and so either for building heating, building hot water supply system or swimming pool one can use that.

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And that is what the device looks like I think sometime I just mention but I will go through it again. So essentially if you see this is an insulation and you have you know basically a glass cover which will trap the solar radiation and then there is some kind of an absorber which is usually tubes right this is the absorber and you know that space is in between so rain, winds, snow etc. etc. So when solar radiation falls into is diffused and direct radiation, part of it of course goes back through convection and radiation, the glass is itself will get heated up, rest all penetrates into this and they heat up this portion.

There is a convection current which can be set up, which can you know which can set up in between the space and some convection losses can be there and whatever is you know this one traps that is what is available heat.

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Flat Plate collector resistance

$$\frac{1}{U_f} = R_{a-g} + R_{g-o}$$

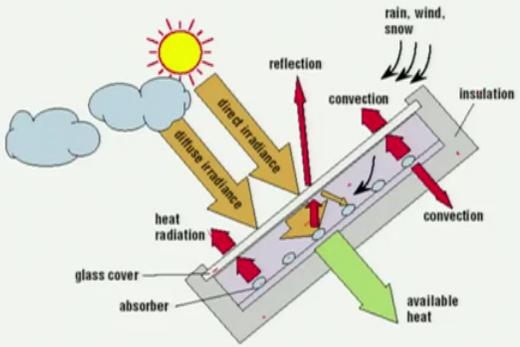
Glass to air resistance and resistance of standing air layer :→makes U

$R_{a-g} = 0.1-0.2 \text{ m}^2 / \text{W K};$
 $1/R_{g-o} = h_{g-o} = 5-6 \text{ W/m}^2 \text{ K};$
 $U_f = 5.3 \text{ W/m}^2 \text{ K};$

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SOLAR FLAT PLATE COLLECTOR



The diagram illustrates the components and heat transfer processes of a solar flat plate collector. It shows the sun providing direct and diffuse irradiance, which is partially reflected. The collector consists of a glass cover, an absorber, and insulation. Heat is transferred from the absorber to the glass cover via radiation and convection. The glass cover loses heat to the outside air through convection and radiation. The insulation prevents heat loss from the back of the collector. The final output is available heat.

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So usually if you look at it two things are important, glass to air resistance and resistance of the standing air layer there is the U. So U value of the air to glass and glass to outside I mean basically there two component so this, this is a glass so how much is a heat loss if I am looking at, so this is the outside temperature, outside the, this is a absorber, outside is this, air is this.

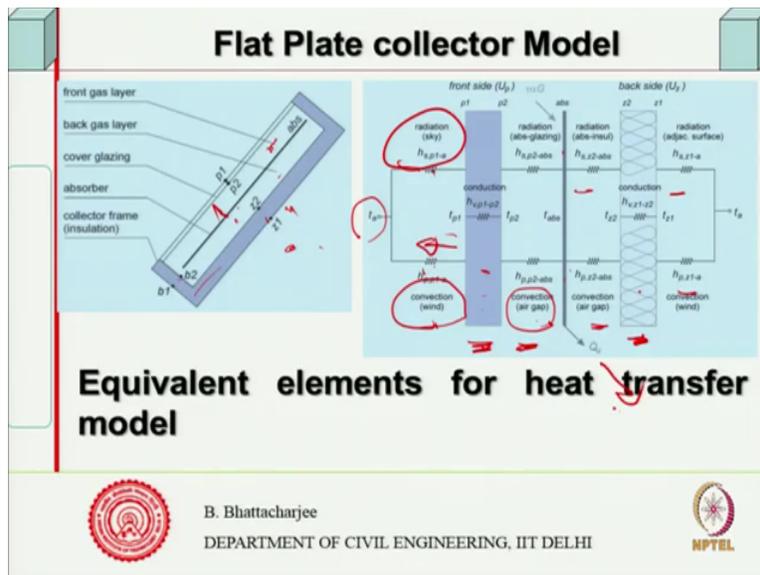
So these two resistances are, forms $1/U$ right and glass to air resistance and resistance of the you know makes this U actually and this is of the order of around 0.1 to

0.2 meter square Watt Kelvin right. So basically this is a resistance from air to glass and inside this is 1 over this h you know like this is, sorry the air inside, this is inside and this outside.

So outside there is a, outside if you look at it, from outside, from here this we can express it in terms of h not surface conductance which we did earlier because there is a convection and there is a radiation and this resistance is of the order of h go is 5 to 6 Watt meter square Kelvin right.

So that means what we are getting, we are getting, how much the U value of this particular one value here so far we have looked U value in this particular one. So U_f stands for this, actually U value of this. So U_f is the order of around 5.3 Watt meter square Kelvin typically this is the kind of order.

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And if you look at this beyond this of course, so this is the you know this is a cover glazing that is what I was talking at and I looking at its resistances right now, this is a absorber of some form which might be tubes of water or something of that kind and then the, you know the cover glazing absorber as I said and then this is the outside frame right, insulation generally insulation so that every, all heat is conserved I mean you know

trapped here. And there could be some sort of gas layer or I mean which could be air or you know gas layer or something.

So this modeling of this one would look something like this, basically I have a resistance outside air temperature and this side is also outside air temperature, this is the insulation, this is the glass part of it and then there is a air gap right and then this is the absorber and then there is a air gap again. So this can be model in this manner that means I have the convection and radiation so h not actually I was taking care of.

So equivalent resistance time I can think of because you remember h o, 1 over h o is conductance, surface conductance which is got two component, one is a convection, one is a radiation. So the radiation you know this I can model as equivalent resistances then conduction through the glass, just now we looked into it, conduction through the glass and then there is convection in the air gap and there can be some radiation in the air gap as well right.

Then the absorber there is a heat taken out because it will absorb the heat which is whatever is coming and but still sound the will be lost basically so there is a convection and radiation to this. The insulation you know insulation through this insulation conduction would occur and then from the surface to outside again there is a radiation and convection.

So the equivalent you can model it in this manner the complete thing. So this, there be kind of h not here or 1 over h not, that is the resistances of both then the glass resistance then equivalent resistance of this air gap then this will have the you know some heat will, it will be absorbing some heat which would be mass into specific heat of the material that is flowing rate of mass flow into specific heat of the material plus temperature difference of this one and outer air.

Then there is again convection and radiation because this will be you know, this will be at higher temperature and how much is a loss, so efficiency of the system can be calculated based on this right so equivalent elements for heat transfer model look something like this.

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Flat Plate collector Efficiency

$$Q = I\tau\alpha A_C$$
$$Q_O = UA_C(T_C - T_A)$$

Heat Stored through fluid

$$Q_U = mc_p(T_o - T_i)$$

Collector heat removal factor

$$F_R = \frac{mc_p(T_o - T_i)}{A[I\tau\alpha - U_L(T_o - T_i)]}$$

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And if you want to calculate out, this is a incident radiation if it is I, absorption is alpha, rest all get reflected, transmitted is tau into area of the collector will give you how much heat is coming in right and then there will be, this is collected temperature to air temperature so there is a loss.

So conduction heat loss outside right and then heat stored in the fluid would be mass rate in fact mass rate specific heat and outside air temperature and inside the absorber, inside the absorber is T_i , T_i is a temperature inside the absorber. So this the temperature difference right and mass, so this is a mass into specification of the temperature and that is what it is absorbing alright.

And then there is a removal factor. So removal factor is given by this, this is what is absorbed, divided but this is what was coming in, minus this is what is lost because both side I have air and inside you know so this is the inside of the absorber. So total U all known both sides that is called heat removal factor, there is a proportion of heat absorbed by the absorber divided by whatever you know heat that is coming in, radiation coming in minus whatever is lost so that is called is a collector heat removal factor right.

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Flat Plate collector Efficiency

Maximum Energy

$$Q_U = F_R A [I \tau \alpha - U_L (T_o - T_i)]$$

Efficiency

$$\eta = \frac{F_R A [I \tau \alpha - U_L (T_o - T_i)]}{A I}$$

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Now maximum energy that you can get who depend upon this heat removal factor right heat removal factor, heat removal factor is what, it is the ratio of heat absorbed by heat that is, that came in minus net heat that was actually coming in right.

So if I this is what in you know in fact if you will see you know the FR, FR is this divided by this term A I t alpha minus U_L minus T_i. So F multiplied by this, this gives me the heat absorbed actually. So efficiency is defined in terms of these divided A into I what is coming. Is that you know heat removal factor gives me what this gives me the heat stored so this is heat stored can be written as mcp T_o minus T_i can be written as a FR into this, this FR into to A into I t alpha I tau alpha right minus U_L.

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Flat Plate collector Efficiency

$$Q = I\tau\alpha A_C$$

$$Q_O = UA_C(T_C - T_A)$$

Heat Stored through fluid

$$Q_U = mc_p(T_o - T_i)$$

Collector heat removal factor

$$F_R = \frac{mc_p(T_o - T_i)}{A[I\tau\alpha - U_L(T_o - T_i)]}$$


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So if I write, if I take this onto the other side, if I take onto the other side, if I take this to the other side, storage factor be FR multiplied by this that is the amount of heat absorbed right.

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Flat Plate collector Efficiency

Maximum Energy

$$Q_U = F_R A [I\tau\alpha - U_L(T_o - T_i)]$$

Efficiency

$$\eta = \frac{F_R A [I\tau\alpha - U_L(T_o - T_i)]}{AI}$$

$$\eta = F_R \tau \alpha - F_R U_L \frac{(T_o - T_i)}{I}$$


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So amount of heat absorbed can be written like this divided whatever is coming in that is A into intensity of radiation that is the efficiency of a system right. So efficiency now if I

divide by A , I will get cancel here I will be left with A will also cancel. So $FR \tau \alpha$ minus this FR multiplied by T_o you know A A gets cancel both the places so I will be left with FR , $FR UL T_o$ minus T_i , A gets cancel by I .

So efficiency is given by $FR \tau \alpha$ minus $FR UL \tau_o$ minus outside you know air temperature and inside divided by I . So that is the efficiency of the system, that is what you know basically the efficiency of the system.

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SOLAR FLAT PLATE COLLECTOR



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SOLAR FLAT PLATE COLLECTOR



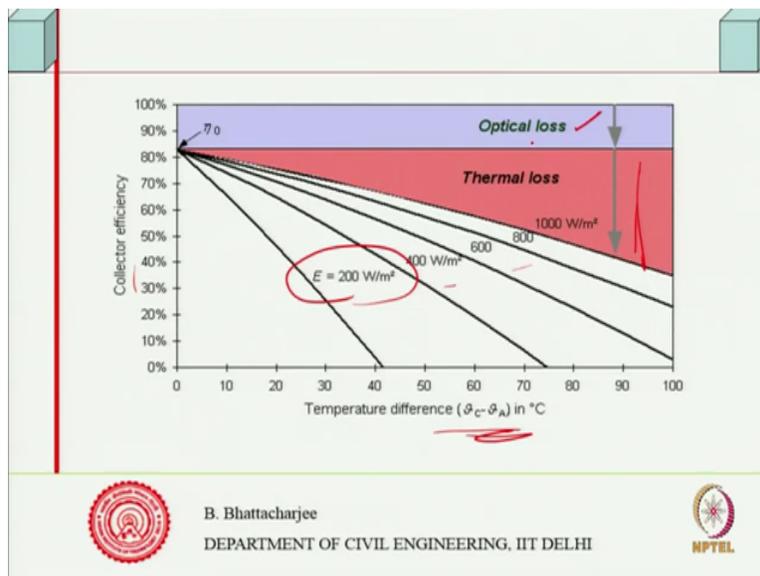
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So this I think we have looked into so essentially if it is water then mass, rate of mass flow into specific heat into temperature difference will give you temperature of the water and air surrounding will give the amount of heat that is been absorbed and this is the similar one where it is stored, there is a construction that we looked into right.

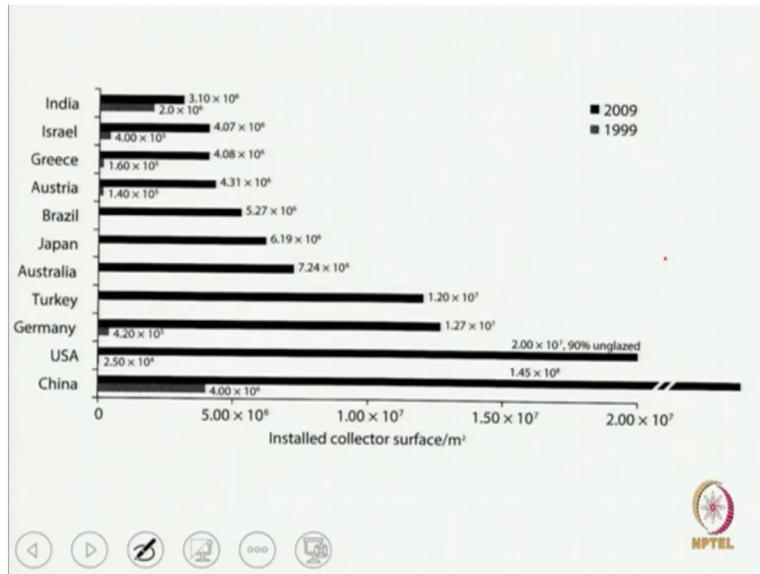
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And one can actually find out that if that depending upon the temperature differences the air and the collector, collector efficiency is a function of this temperature right with the input energy E 200, 400, 600. So thermal losses increases as your temperature differences

increases that is understandable and also there is a radiation received is more, radiation received is more. So there some optical losses and the thermal losses they tend to increase optical losses by enlarge constant because transmission is taking care of that right reflectance and transmitter of the glass so that is why enlarge is a constant so that is efficiency is given by this.

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And use in different countries if you see, installed collector India is some where here, China uses this much, USA uses this much, so quantum wise somewhere Australia, Brazil, Japan and so on. So, 2009 and 1999, so this is 2009 I mean sorry 2009 there is 1999, this is 2009 so the increase Israel has increased, Greece has increased, Australia and so on so there is an increasing trend and use of this kind of technology right.

So I think we will break here so if you have some question now I will like to answer and maybe start from here itself so if you have some question I would like to answer.