Energy Conservation and Waste Heat Recovery
Prof. Anandaroop Bhattacharya
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 47
Heat Pumps – I

Good morning, welcome to the next lecture of Energy Conservation and Waste Heat Recovery. Today, what we are going to discuss is a topic called Heat Pump. So, what is the heat pump let us first recap this is something that you may have studies as part of your apply thermodynamics. So, we will first start with heat what a heat pump is and then look at applications as to how a heat pump can be used in the context of our course which is waste heat recovery.

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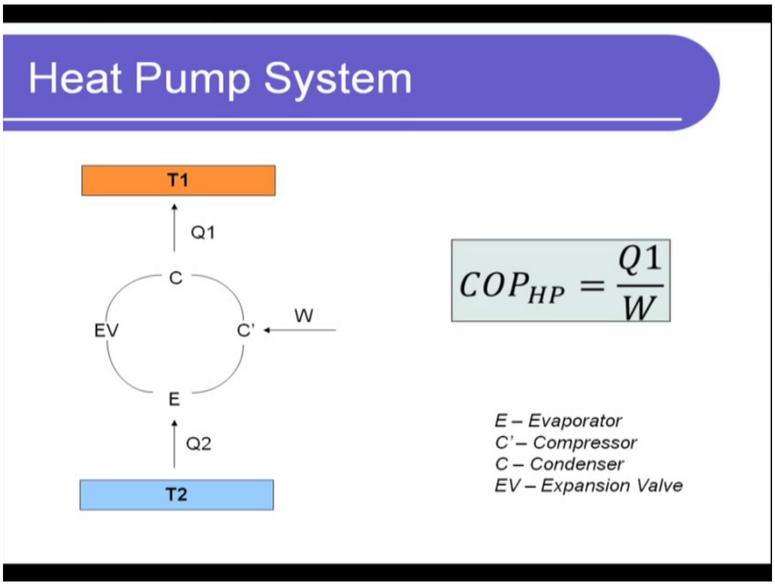

So, let us first talk about a heat pump and what it is let us come to this figure over here on the on the power point, a heat pump if you recall is pretty much a cycle if you look at it is the same as that of a refrigerator. In the sense that you have Evaporator, you have a Compressor, you have a Condenser and you have an Expansion valve, but for the time being let us leave that out and just look at the heat pump as just as a system. What heat pump does is it is able to move heat or transfer heat from a temperature which is from a temperature T 2, which is lower to a temperature T 1 which is higher.

So, typically now second law of thermodynamics states that is not possible unless we have some external energy being supplied to the system or external work being done on the system, right. So, therefore, this is not so as a result it is not possible spontaneously it is not possible. So, we have to do external work on the system and that external work is actually the compressor work that is done on the system and which enables us to move heat or to transfer heat from a temperature which is lower to a temperature which is higher or in other words transfers heat across an adverse temperature gradient, it is possible only because we supply external work on the system.

So, this is how again the same schematic as we saw over in the in this power point slide is over here as well.

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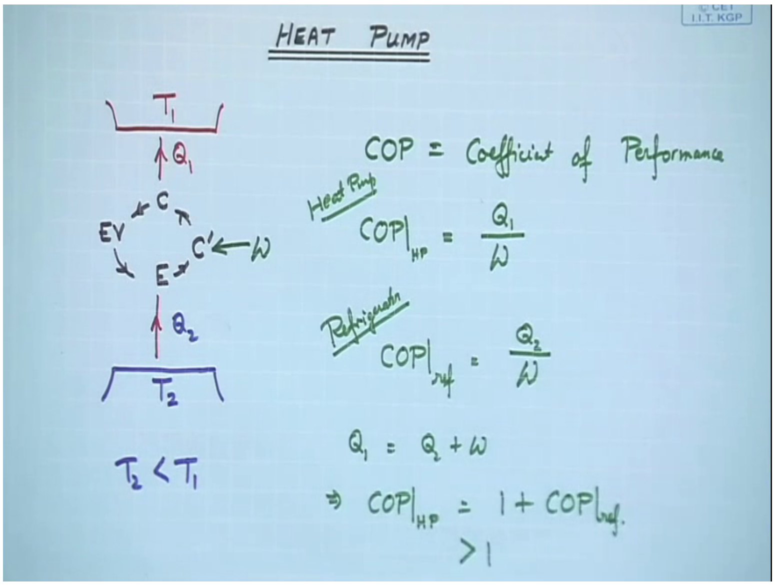

So, T 2 is definitely lower than that of T 1. So, let us make that very clear T 2 is lower than T 1. So, this movement of Q 2 from T 2 being extracted from Q 2 and rejected to T 1 that would not have been possible unless we did this external work W. So, what is the COP is coefficient of performance let us we recall that and it is defined as the desirable effect to the input that you have to give to the system. So, what is the desirable effect here? So, the desirable effect for a heat pump is Q 1, the amount of thermal energy that I have which I can use at an elevated temperature I wanted to generate thermal energy at a high temperature. So, which is a higher grade of energy and so Q 1 is my desired effect and what is the penalty that I put in that in terms of the energy that I have to spend in order to get that that is W.

So, for a heat pump this is the definition for a refrigerator which has the same components and works in the same principle the COP of a refrigerator, the desired effect is different the desired effect is the amount of feed that I can extract from the cold temperature to maintain it at that lower temperature. So, what is the amount of heat that I have to extract and reject to the outside or reject to the high temperature? So, for a refrigerator my desired effect is Q 2, the heat that is supplied to the evaporator and of course, the penalty paid or the work done is the same clear.

So, now from first law of thermodynamics I can conclude that since Q 1 is equal to Q 2 plus W, I can show that the COP of a heat pump is 1 plus the COP of a refrigerator. So, COP of a heat pump is always greater than 1 all right. So, this is just from mathematics we are saying it is always (Refer Time: 05:52) and it better be very much greater than 1 if we are going to design a good heat pump all right. So, this is from thermodynamics point of view or thermodynamic recap of what is heat pump. Now what are we going to use it in the context of waste heat recovery is the next question.

So, in the context of waste heat recovery what we will do is we are going to use a heat pump which of course, needs additional input of energy in the form of mechanical work like in a compressor. We are going to use a heat pump to upgrade energy or sub grade thermal energy which I have at my disposal what do I mean by upgrade. Let us say a thermal energy available to me at a lower temperature let us say at ambient let us say 30 degree centigrade, but I need the thermal energy at a high temperature let us say 80 degree centigrade. So, how do I upgrade thermal energy from 30 degrees to 80 degrees heat pump is one way by which I can do of course, it does not come for free I have to put in additional energy external energy to it here.

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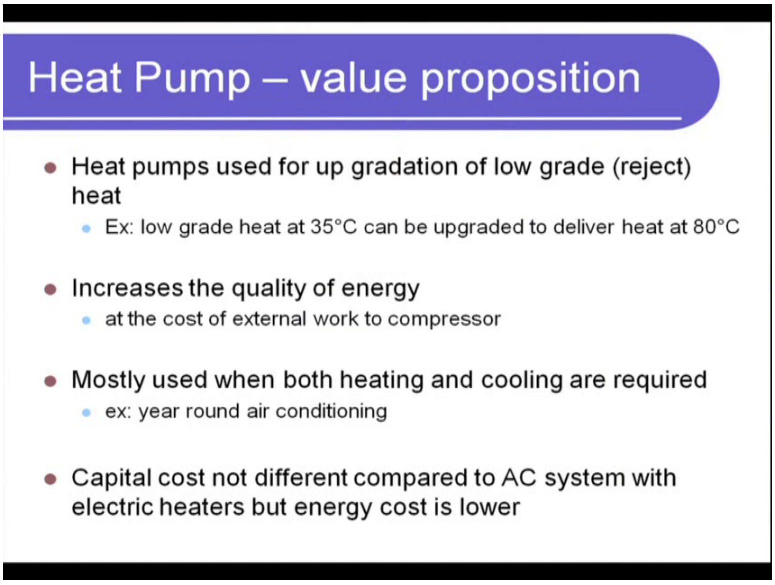

So, let us look at the next slide which is what we are saying here what is the value proposition of a heat pump; the heat pump is used for up gradation of low grade or reject heat. So, let us say low grade heat at 35 degrees can be upgraded to deliver heat at 80 degree centigrade this is 35 and 80 are just 2 numbers that I have picked. So, essentially at a low temperature to higher temperature so that is the value proposition, how do I do this clear and or why do I do this in the first place.

It increases the quality of energy we know that right the thermal energy at a higher temperature is at higher grade compared to thermal energy available at a lower temperature clear. So, that is what I am showing here; that is what I want to do. I want to upgrade the energy which means improve the quality of the energy that is available to me and again I have to spend something in order to do that clear. So, that is why I said at cost of external work to the system, it is you know heat pump actually if you again look at the cycle; what happens? I am removing heat from the lower temperature using the evaporator.

So, I am cooling at the evaporator region it is it results in cooling of the surroundings and at the condenser I reject heat to the higher temperature which is the amount of additional heat that I get that is the up gradation that we are talking about. So, if I have an application where I need both heating as well as cooling this is a very ideal scenario right. So, if I need simultaneously heating and cooling or even if it is not simultaneous, it can be at different points of time or different points in space heat pump is very ideal clear.

So, for example, year round air conditioning let us think about a place with extreme climate let us say Delhi or Rajasthan it gets very hot in summer it gets very cold in winter . So, I would need air conditioning during the summer months and I would need heating room heating during the winter months I am talking about residential use right now. So, it is possible to use a heat pump.

Let us say I use ambient air itself and I use a heat pump. So, that I can get air conditioning during summer using the same setup with a slight modification using primarily the same equipments I can have heating in some I can have heating in winter and cooling in summer, all right.

So, the last point I want to make over here is the capital cost in the sense is not very different compared to an ac system because here also I primarily need more or less the same equipment. So, I need a compressor I need an expansion valve and I need 2 heat exchangers which is which will work as evaporator and condenser. So, I can have an AC with electric heaters and do the same thing, but the energy cost in this case will be much lower the capital cost is the same, but the energy cost will be lower if we use heat pumps keep that in mind.

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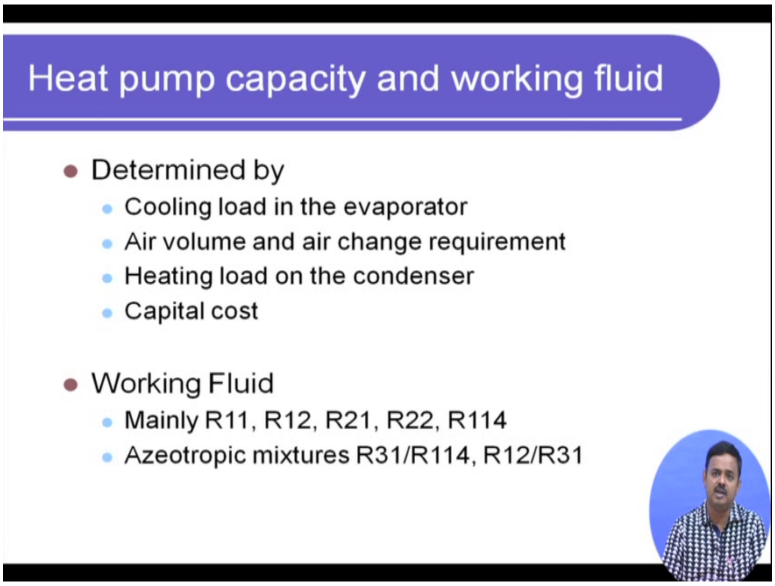

So, with that I will say what is the heat capacity and working fluid. So, what is the capacity going to depend on it is going to depend on what is written in on the slide it is going to depend on the cooling load on the evaporator. So, let us say I am using it for cooling in summer what is the amount of heat that I need to reject. So, in our AC we call that 1 ton of refrigeration 1.5 ton of refrigeration. So, similarly what is the cooling load on the F refriger in the evaporator, right?

The air volume and air changed requirement heating load on the condenser, if you are using it as a heat pump and I the heating is my primary goal, then what is the heating load that I need and of course, last, but not the least the capital cost. What is the how big a compressor I need? What is the rating of the compressor? How big heat how big of an heat exchanger do I need at the evaporator and the condenser what kind of an expansion wall would I use and so on.

The working fluid typically can be refrigerants. So, R 11, R 12, R 21, R 114 and all these things are well known to us as your tropic mixtures of 2 or more of these fluids is also used as heat pump fluids.

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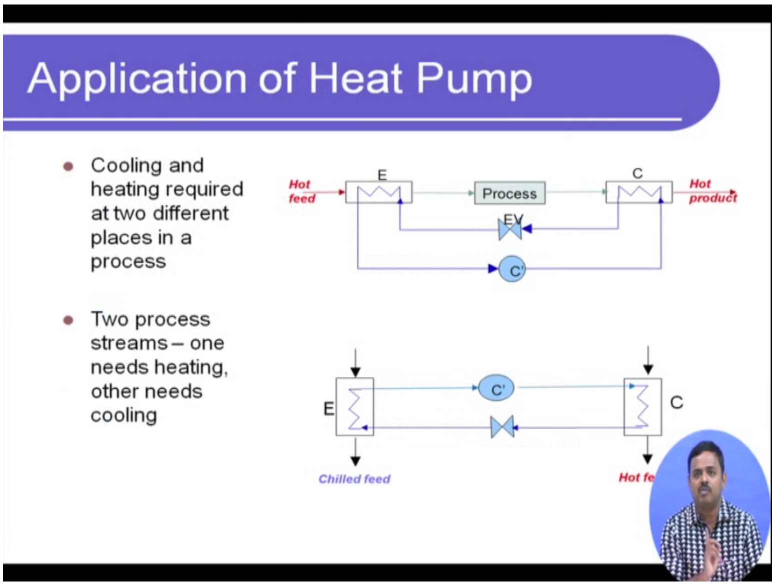

So, with that background let us now look at one application where not application this is more of a generic I would say how do we use heat pump. So, heat pump if we think about 2 scenarios the first one as I am showing in the in the slide, in the first case, I am saying that I have a process stream and in 1 place I need heating, in another place I need cooling. So, look at here heating and cooling required at different places in the same process. So, I have a hot feet coming out I have a hot feed available with me and my 5 final product is also needed to be heated, but there is an intermediate process which needs to happen at a lower temperature. So, then what will I do?

So, I will use a heat pump where I will first have the hot feed go over the evaporator, in the evaporator what happens the refrigerant evaporates or boils goes from a liquid state to the vapor state. So, therefore, what happens; it absorbs heat and the hot feed becomes cold. So, as it comes to this process over here it is at a lower temperature and it is lower temperature sufficiently low, that the process can happen at that temperature. So, the process then takes place very nice the input is lower temperature the output is also at low temperature, but finally, when it goes to the next stage the product need to go out product that came out of the process needs to be heated up.

So, in that case what I will do is I will let it pass over the condenser in the condenser what happens the refrigerant which is coming out of the compressor at a higher pressure condenses as it condenses this rejects heat and that feed is picked up by this product that is coming out of the process and therefore, the output from the condenser will be hot product which can now go to the next stage.

So, this is a process where at 1 point I need a low temperature, but later on in the next process I need a high temperature. So, what do I do? I use a heat pump I first use the evaporator to bring down the temperature and which provides the input to the process at the which needs to happen at a low temperature and then the product of the process which is at a low temperature needs to be heated up for the next stage and that is done at the condenser clear and again just let us recap what happens in the heat pump the same as a refrigeration cycle you have a refrigerant which is at a low temperature and pressure at the inlet of the compressor, it is compressed by the compressor where it goes up to a higher pressure.

And therefore, at a higher temperature and the higher temperature it condenses and rejects heat and becomes liquid at the higher pressure still and then you use any as an expansion valve where is it there is an isenthalpic expansion where the liquid condensate or the other liquid refrigerant at the high pressure is suddenly brought down through this expansion valve to a low pressure, where it is typically where it is typically still liquid or at the 2 phase region with low quality.

And then it passes through the evaporator where it boils and becomes vapor and as it boils and become vapor it extracts or absorbs heat and thereby cooling the ambient of the of the evaporator right before and then it comes to the compressor and the cycle repeats, all right.

The second one are 2 process streams 2 process streams not the same process stream to process streams one needs heating the other needs cooling. So, here what happens is the same thing you have to process feeds one over here. So, where you need chilling you let that process stream go through the evaporator and where you need heating you let that process stream go through the condenser. So, the first feed as it comes out is chilled the second feed as it comes down is heated, why because the refrigerant has rejected heat and condensed and thereby heating up this feed in the condenser over here the refrigerant at the low pressure has converted from liquid to vapor and while doing. So, it has absorbed heat from this feed one if we call it so and as a result the feed has lost heat and it has become chilled or cold.

So, you can appreciate the fact that how a heat pump can be used in case of a I mean in a certain process where you require where you may require in the same process stream heating at one place cooling at another place or 2 different process stream one need heating the other needing cooling. The source of heat in this case is still waste heat, but not at sufficiently high temperature and that is why we can use for in the context of waste heat recovery the waste heat that we have available at our disposal is not at sufficiently high temperature and the heat pump is used to upgrade that clear.

So, let us look at an application like that.

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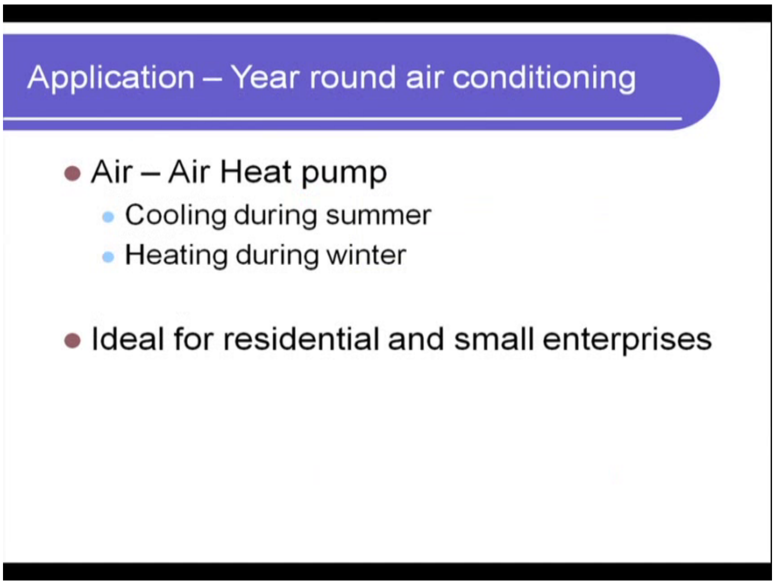

We will look at an air heat pump where which we can use for cooling during summer or heating during winter and heating during winter this typically ideal for a residential and small enterprise and let us see how it works.

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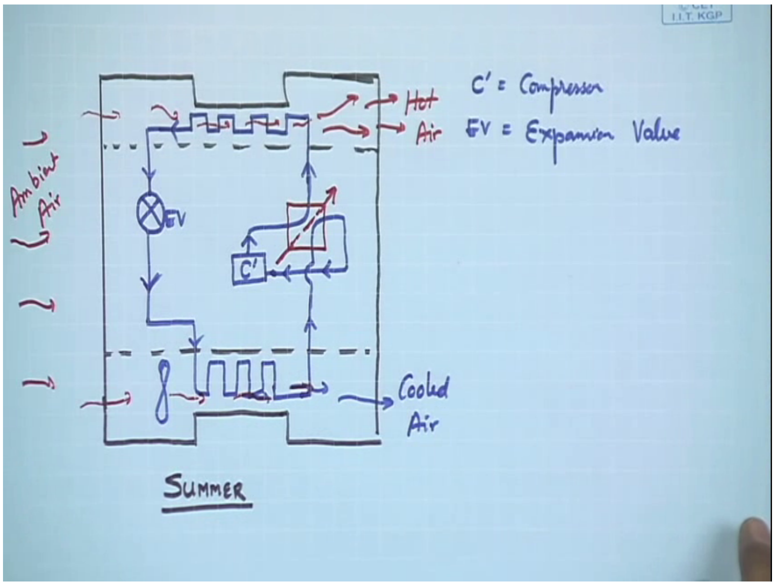

So, I will draw a picture over here where let us see that during summer I need cooling right. So, I will say this is summer. So, I have a room which I need to cool down and I have another outside unit where I will do something I am not I will see what we will do over there and say this is my overall control volume.

So, now let us draw the components of the heat pump first this is a heat exchanger, this is an expansion valve that we denoted in this manner, this is one more heat exchanger which is placed in the room and this is how it goes up. Now what I will do is I will draw a compressor over here denoted by C prime again let me write C prime is compressor EV is expansion valve.

So, this is where a certain unit becomes very important and it is called a 4 way switch. So, this is a 4 way switch; and let us say, this is one position of the switch. So, what happens here is in one case I am going to draw this one this compressor. So, I have drawn it in this manner and let me put some arrows over here.

Now, this is the room that I want to cool. So, therefore, what happens what do I have in summer months; I have ambient air. So, ambient air is more or less at an elevated temperature. So, this is my ambient air coming over here and then I will let it pass through over here and what leaves from here is cold air why because I am operating this heat pump in such a manner that this heat exchanger inside my room is the evaporator let me put a fan also. So, that it helps in blowing there and give rise to force conversion. So, this is this acts as the evaporator, clear.

So, the refrigerant liquid at the low pressure coming out of the expansion valve flows with it is a heat exchanger where it absorbs heat from the hot ambient air that is coming in thereby cooling this ambient air to a low temperature and this then goes to the room clear and then of course, the refrigerant vapor goes to the compressor where it is compressed comes out as high temperature high pressure vapor, where again the ambient air flows over it and comes out as even higher temperature clear you can use this heat for something else also.

So, this is hot air, this is cooled air, and this is ambient air which is at an elevated temperature in summer months clear. So, this is how it works. So, this is nothing different not very different from what we have for in a in a regular is air conditioning unit. Now the trick over here is the following in the winter months what happens is the following.

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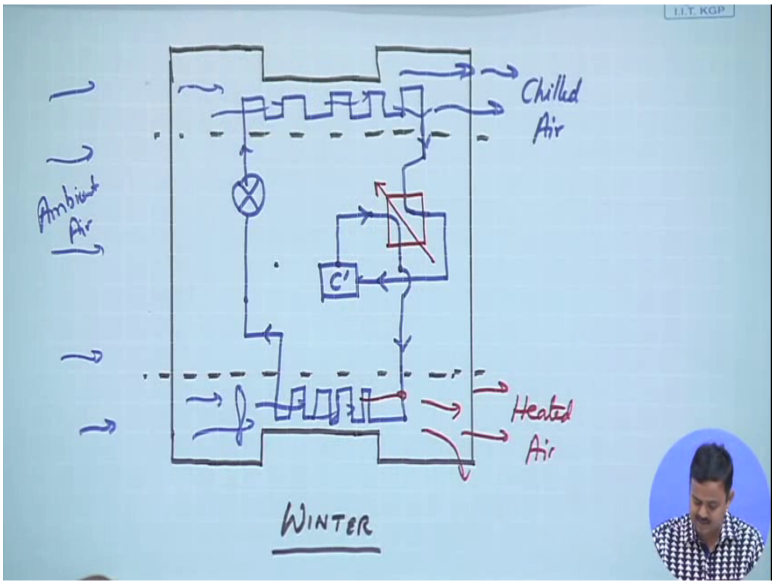

So, again let me draw the same thing over here what happens is the switch is going to change it is position. So, let me draw it again I apologize for doing it once more, but I think for our understanding it will help if we go a little slow that is the reason I am not showing it in a power point and rather drawing it over here. So, it is the same thing now this is during winter.

Let me draw the same expansion valve comes out and it goes up like this I have the compressor over here against C prime and I have the 2 waste of this the 4 way switch also over here , but in this case now the position of the switch is changed. So, if the position of the switch is changed this is what happens to the flow stream. So, here this flow stream goes like this and from the compressor it comes down in this manner.

So, this is the input to the compressor because of switch is changed. So, the input to the compressor the output comes through this the flow is reversed and this is how it happens so, now, what happens? During winter my outer temperature is cold. So, again let me draw a fan over here, but then what happens is this ambient air starts getting heated and comes out like this. So, this is heated air and over here what comes out is even chilled air. So, this is Chilled Air. So, this is how it is. So, what has happened; essentially, this is during winter.

So, let us compare the 2 depending on this for summer. So, depending on the position the heat exchanger inside the room acted as the evaporator what I did was I switched this.

So, that the streams entering the compressor and exiting the compressor are changed and essentially what I have done is now the direction of the refrigerant loop is reversed and the over here the heat exchanger which acted as evaporated during summer now will act as the condenser clear. So, let me write it down again here with the maybe the green ink. So, this is the condenser in winter and this was a evaporator in summer. Last thing I want to pointed out this chilled air also has application I mean, this chilled air can be used for let us say water cooler let us say if it is a small industrial enterprise you can use this chilled air for some of your processes which needs chilling.

So, for example, let us say in a diary form you need to keep the dairy products in a chilled environment you can do that let us say in an injection molding unit or plant you can use this chilled air to cool down the moulds or the molten plastic to cool it down and take it takes take form. And similarly over here when you get in summer months if you get hot air and if you are again talking about a small industrial enterprise hot air has lots of applications. If nothing else this hot air can be used for a vapor absorption refrigeration cycle which you know which you have studied this is I have upgraded the heat energy from ambient which was probably at around let us say Delhi summer will be 40-45 degrees centigrade, I can upgrade it to almost 78 degree centigrade use this for something useful for waste heat recovery clear.

So, this is how a heat pump is an air to air reversible heat pump, which is what I started by showing over here air round air conditioning using an air to air heat pump we can achieve cooling during summer, heating during winter in during summer when we are cooling the room we are also getting a heated air stream which can be used for various other purposes and similarly during winter when you are heating the room we are also getting in the evaporator section chilled air which can have several other applications right. So, for this lecture we will stop here and we will continue our discussion on heat pumps in the next lecture.

Thank you very much.