Engineering Thermodynamics
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Lecture 28
COP of refrigerator and heat pump, second law statements

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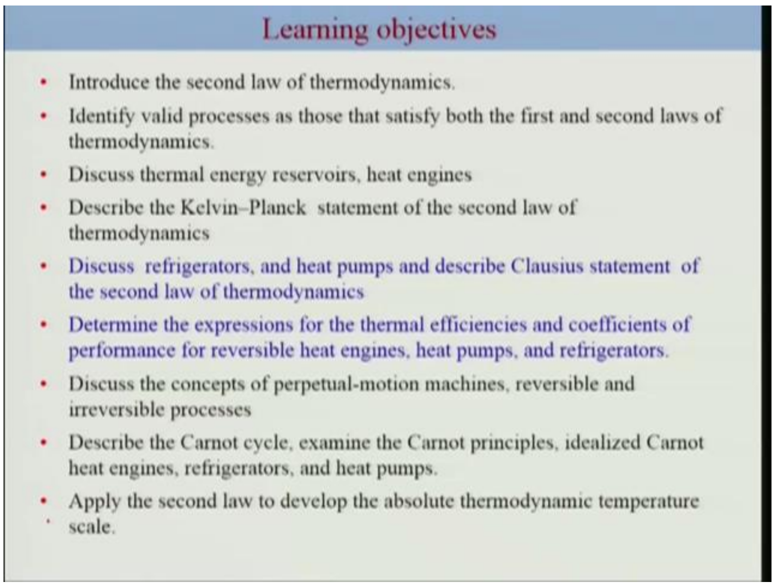

Welcome back. So we were discussing the Second Law of thermodynamics (())(0:17) of we have looked into the fact that, any process to occur should satisfy First Law and the Second Law and we also discussed about a particular statement called Kelvin Plank statement. It states that it is impossible to have a device which works on the cycle and it just takes energy from a single thermal reservoir and produces a net amount of work.

So that is impossible to have, so we will discuss in this particular lecture, refrigerators, heat pumps and describe an equivalence statement of Second Law of thermodynamics as we have already discussed the Kelvin Planck statement. In this lecture we are going to describe Clausius statement of Second Law of Thermodynamics. Okay and later we will show that Kelvin Planck statement causes statement R equivalent. Ok?

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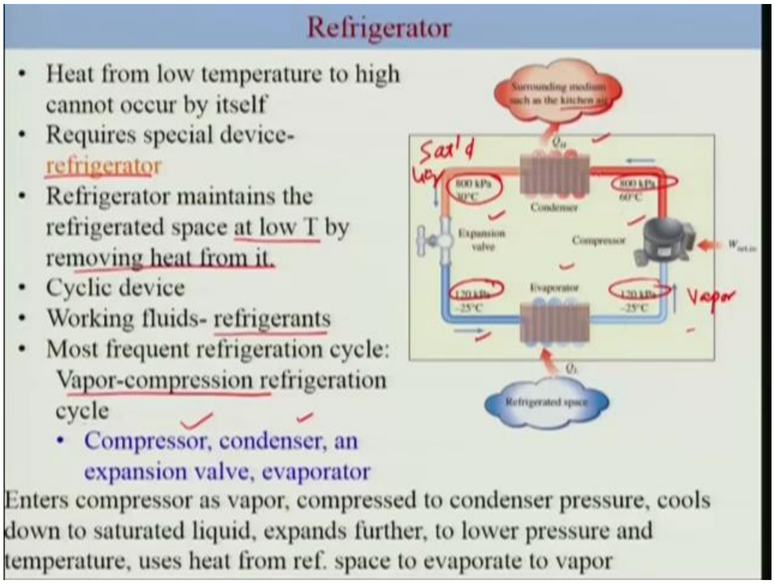

So let me start with the refrigerator. Now as we know that heat transfer from a high temperature to low temperature. Thus in order to transfer heat from a low temperature to a high temperature, it cannot be done automatically and what we need is special device and this special device is refrigerator, ok? The refrigerator basically maintains space, refrigerated space at a specific low temperature by removing heat from it.

It works on a cyclic device and it has a working fluid which we call refrigerants. Most frequent refrigeration cycle is a vapour-compression refrigeration cycle which consists of compressor, condenser, expansion valve, evaporator. This is just illustration here. So you have your compressor, your condenser, expansion valve, evaporator; the refrigerant which enters compressor as vapour.

So this is here as vapour, ok? Just compressed outlet of the compressor contains a compressed refrigerant at a pressure which is the condenser pressure. So this pressure is much higher than this. Ok? And here the condenser rejects heats to the surrounding. So this particular condenser is a typically the coils at the back of your household refrigerator. Ok so it reject heat to the surrounding medium which is basically the kitchen here.

So here, this is a vapour and then this condenses to a saturated liquid here. Ok? So this is your saturated liquid. It gets expanded, so it lowers its pressure and then from here at this evaporator, it takes heat from the refrigerator's space and evaporates to a vapour state. Ok? From this particular state which is a liquid to the vapour state. So this a overall cycle and this is a cyclic device.

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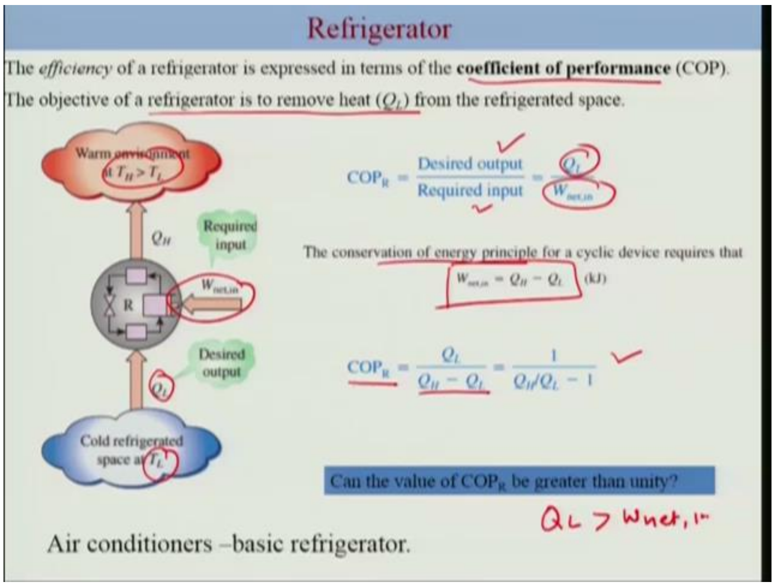

Now let us look at how you define the efficiency. Recall that heat engines that we described where in order to convert the heat to work we needed a device called heat engine, we define thermal efficiency, ok?

Here we are going to describe the efficiency of refrigerator as coefficient of performance, ok? So this is to discriminate from heat engine efficiency and you will see very clearly why. The definition as far as the efficiency is concerned is the same where that efficiency is nothing but the ratio of this desired output and required input, ok? But the objective of the refrigerator is different from that of heat engine.

Here the objective is to remove heat from the cold refrigeration space which is at a specific temperature T l. Ok, so essentially what is the desired output, desired output is Q l and work is needed in order to remove this, that means transfer the heat from a T l, low temperature to a high temperature, ok warm temperature. So the required input is W net in, so that will be the coefficient of performance for (())(4.13).

That will be the efficiency as far as refrigerator is concerned. Now if you can apply a conservation of energy principle, and write W net in as simply as a difference between Q h minus Q l. Ok? Thus you can write your coefficient of performance simply as Q l divided by Q h minus Q l or in this form. So the question is can the value of coefficient of performance for a refrigerator be greater than unity and the answer is yes.

That can be if the amount of heat extracted or removed from the cold space is more than work input work required in order to achieve this transfer of heat from the T l to higher temperature. So yes the answer is that the C O P r can be greater than unity if your Q l is greater than W net in.

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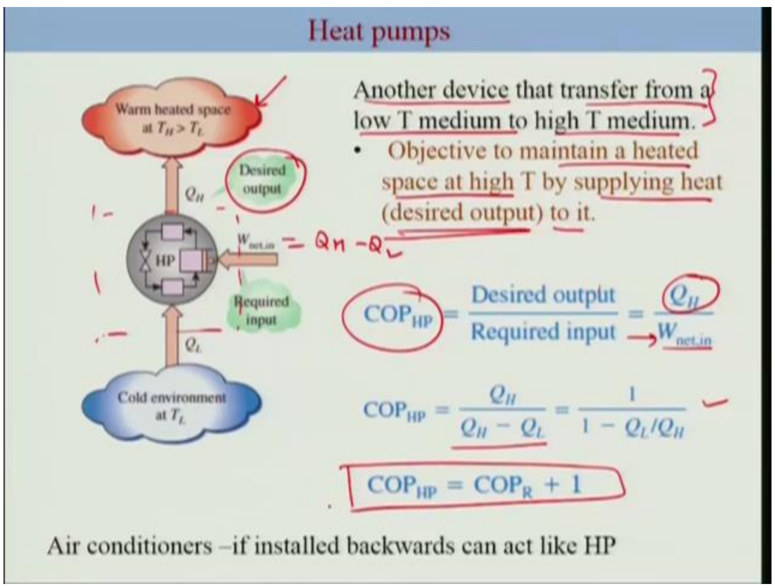

Ok so in the similar philosophy you have heat pumps where the process is almost similar however the desired output is different from that of refrigerator than the desired output is the heat transfer to a specific space which is basically the your room. For example you want to heat it so you want to keep that particular room temperature at a specific temperature. So that will be your heat pump.

So this is another device that transfer from a low temperature medium to a high temperature medium, but the objective is different from that of a refrigerator and it is to maintain the heat. So this is the space which you want to maintain at T h, ok? By supplying heat, so the supplying heat becomes a desired output. Ok? So overall the schematic is almost similar to what the refrigerator we have used except the fact that the desired output is different from that of a refrigerator.

For the for the case of refrigerator the desired output is of that of the Q l. So C O P, coefficient of performance for heat pumps again we will write it in this form, the desired output divided by required input. Ok but the desired output is not anymore Q l, it is Q h. Ok? And the required input is W net in. So you can rewrite in this form, you can use your First Law of Thermodynamics and describe W net in here, ok? There is nothing but Q h minus Q l ok? And that is what you are going to write here and then you can rewrite in this form. Ok?

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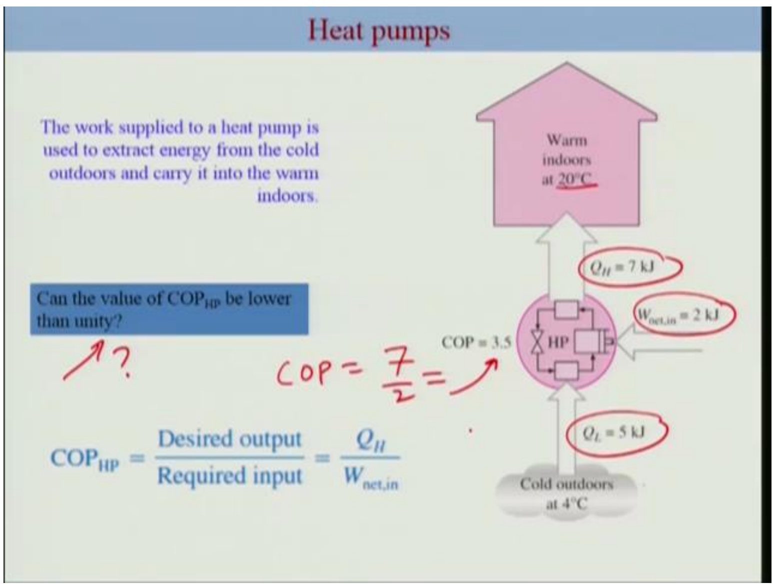

So this is a simple illustration of a heat pump. We have a house which you want to keep at a temperature 20 degree C inside. And in order to do that you need to supply heat at 7 kiloJoules and the outside temperature is 4 degree Celsius so in order to achieve this if you apply W net 2 kilo Joules and the Q l is 5 kilo Joules, then the COP would be simply Q h divided W net which is nothing but 7 by 2 and that is turns out to be 3.5. So the question is can the value of COP be lower than unity and this is possible if you have lot of heat losses through pipes and other devices which is part of this heat pump.

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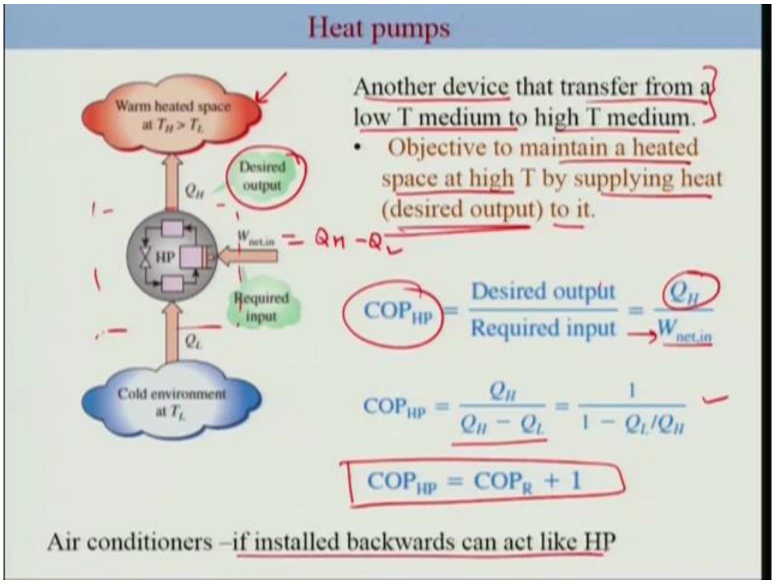

So in practice it can be possible. Ok note that the Air conditioners are the basic refrigerator, ok? So there the room becomes the the refrigeration space. So in the refrigerator there the freezer becomes for example the refrigeration space. For the case of air conditioner, the room itself becomes the refrigeration space. Now if you turned AC around in the backward and install such that the refrigeration space is outside then it can act like a heat pump. So Air conditioner if installed backward can act like a heat pump.

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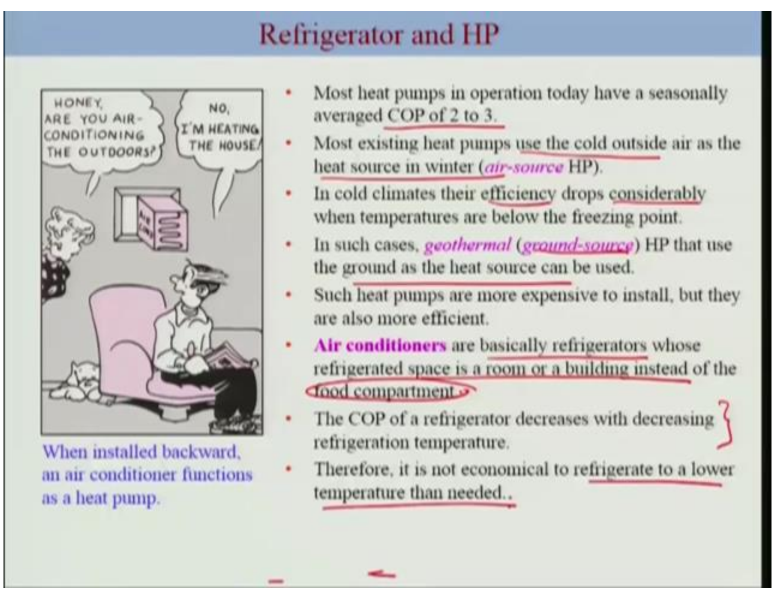

Ok so let me talk about the salient features of refrigerator and heat pumps. Most heat pumps in today's operations have a typical C O P of 2 to 3. Ok most existing heat pumps use the cold outside air as the heat source in winter. The efficiency of heat pump drops considerably when the temperature are below the freezing point.

In such case you can make use of geothermal heat pump where the ground becomes as a heat source for such geothermal heat pumps. It is more expensive to install geothermal heat pumps but it is more efficient. The air conditioners are basically refrigerators who is refrigeration space is a room for a building as I already mentioned instead of the food compartment.

Ok? The COP of a refrigerator with decreasing refrigeration temperature which essentially means that it is not economical if you further if you reduce the amount of temperature or the temperature you want to keep it for the refrigeration. Thus refrigerating to a lower temperature is not sensible at all.

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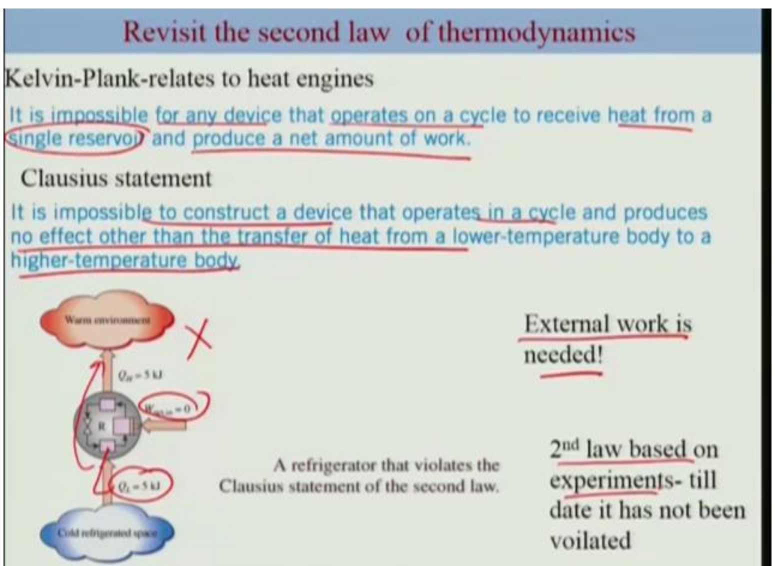

Ok let me revisit the second law of thermodynamics, we already talked about Kelvin Planck statement of second law of thermodynamics which is that is impossible for any device that operates on a cycle to the receive heat from a single reservoir and produce a net amount of work. So now we will discuss the Clausius statement for the second law of thermodynamics. It states that it is impossible to construct a device that operates on a cycle and produces no effect other than the transfer of heat from a lower temperature body to a higher temperature body.

Now in both the cases it says that you have hundred percent efficiency, so it tells you that hundred percent efficiency is not possible. So let me first discuss the bit more of Clausius statement and then we will talk about the equivalence of both the statement. So Clausius statement tells you that device such as this is not feasible, ok because it says that you have no effect other than transferring this heat to a warmer environment completely. Ok?

Which means there is no work input ok? So this is not possible as far as the Clausius statement is concerned. This refrigerator violets the Clausius statement of the second law. So in other word you need an external work to transfer heat from now low temperature to a high temperature and as of now the second law is based on experiments and till date it has not been validated. Ok, so let me discuss the equivalence of the two statement, both the statements are equivalent, ok?

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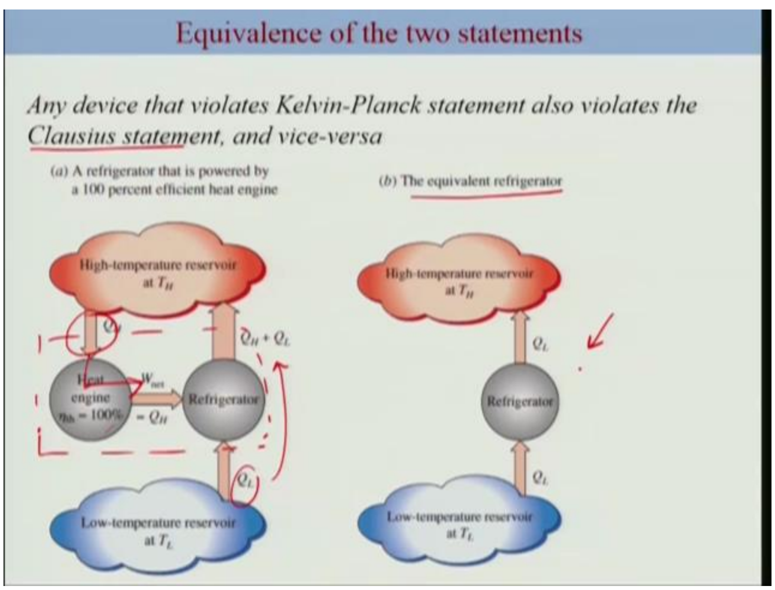

So which means any device with violates Kelvin Planck statement also violates Clausius statement and vice versa. So let us consider refrigerator that is powered by a hundred percent efficient heat engine. So which essentially means that your heat engine violates or this fictitious violates second law of thermodynamics. But let us assume that such a heat engine exists. So which essentially means that you have heat engine which converts heat to completely to work and this work is the input to the refrigerator which transfer heat from the lower temperature to the higher temperature.

So this is now the overall device. So we can consider this collectively we put this together and then, since Qh is same as Qh, this will cancel out effectively. One can describe this device in this form. Ok? Now what it means that there is no external work required to transfer heat from lower temperature reservoir to a higher temperature reservoir. And this is the equivalent refrigerator and this particular refrigerator violates the Clausius statement. Ok?

And thus, it tells you that if one particular statement is violated, the other statement would get violated as well and vice versa.

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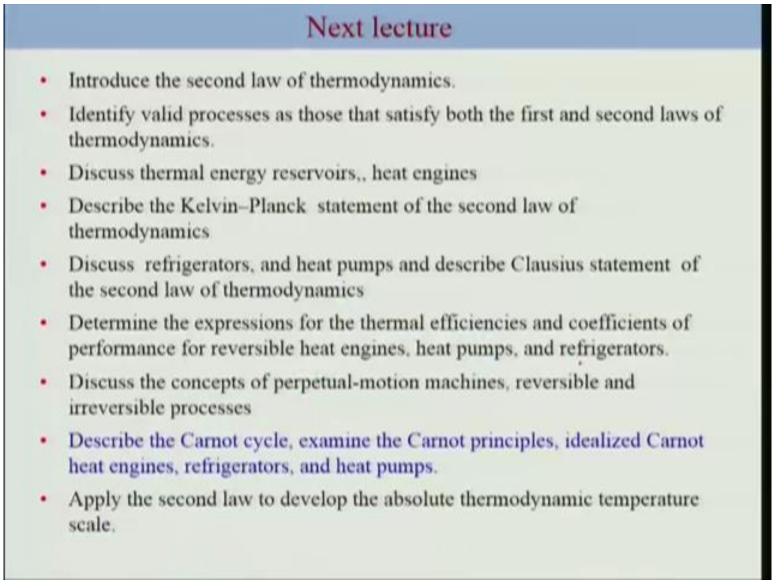

Ok so that will be the end of this particular lecture. So in the next lecture we are going to describe the the perpetual motion and reversible and irreversible processes. So I'll see you in the next lecture.