RAC Product Design
Prof. Sanjeev Jain & Bhupinder Godara
Department of Mechanical Engineering
Indian Institute of Technology, Delhi

Lecture - 07
Compressor selection

Today we going to look at selecting components for building a system. So, to be able to build a system one of the most important parts says the compressor and we have looked at different types of compressors. Just for you to refresh yourselves we had reciprocating compressor, we had rotary compressors, we had scroll compressors, screw compressors, centrifugal compressors, a whole lot of them. The question is how do we select the right compressor for a particular application? And for that we will trying and get a little deeper into the systems today.

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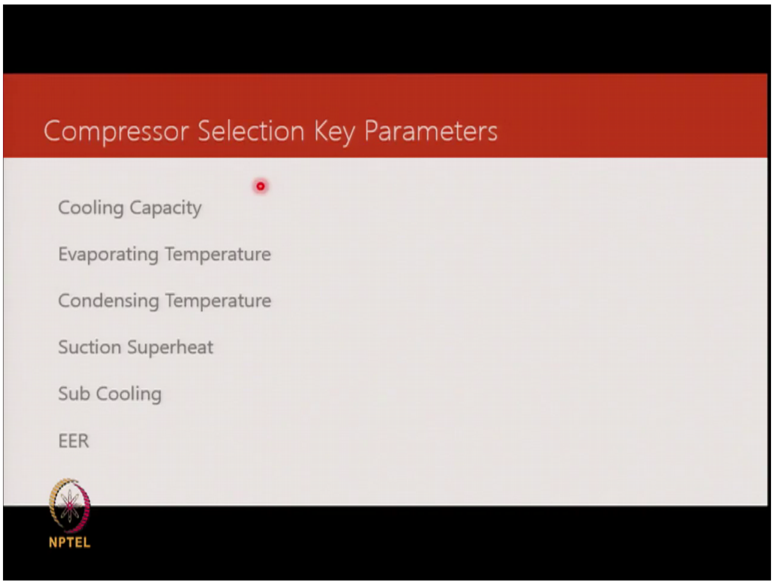

Now, the question comes, how do we select the compressor? So, the first thing is from our application we will know, what is the cooling capacity we were targeting. So, we will make a list of these parameters cooling capacity; then we look at the evaporating temperature, condensing temperature, suction superheat and sub cooling. Now if all of this is not clear, then we make some assumptions around them and then we will have a target EER. So, right in the beginning we will know we are designing a system for high efficiency or we are designing a system just to meet the basic cooling for a short duration.

So, in one case cost could be a consideration you look for a low cost system, minimizing the heat exchanger sizes, looking at low cost components maybe you will use a capillary not an expansion valve and all those things.

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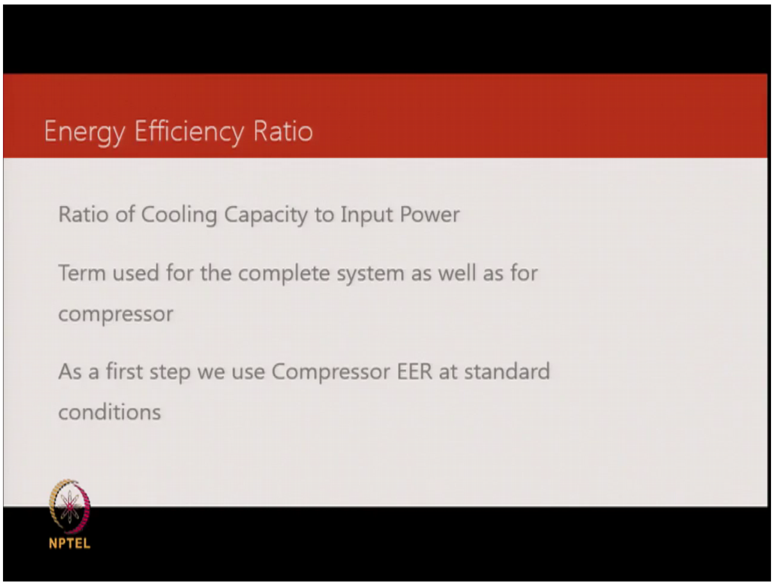

Now, energy efficiency ratio is another term I familiar with energy efficiency ratio have you encountered this in your previous courses? So, we can use energy efficiency ratio to define the conversion of electrical power into cooling. So, it is a pure dimensionless ratio, earlier when the British thermal unit systems were used then it was BTU per r per watt.

So, one talked about an EER of 10 11 12. So, those were not dimensionless numbers, but if you look at the SI system, then it is watt per watt. So, you have cooling expressed in watts and this we have power consumption and watts. Now this energy efficiency ratio is different from the coefficient of performance, we look at coefficient of performance, we looking at work done by the compressor on the compressor, work done on the compressor to pump the refrigerant. Whereas, here we are talking about the total electrical power. So, the motor inefficiency is included in the energy efficiency term.

And this is increasingly used because of the use of hermetically sealed compressors and the ability to independently verify. It would be very hard to differentiate electrical power input from the work done on the compressor. So, for that reason we use energy efficiency ratio and again looking at a numbers. So, a system with an energy efficiency ratio of a 3 watt per watt and above is considered among the efficient systems, entire about 5 - 6 years ago common conventional residential air conditioners available in India had energy efficiency ratios in the region of 2.1 to 2.3.

So, before the labeling regime came in place there was very little focus in design on higher efficiency systems, it was purely designing it for high cooling and minimum cost. Now this term energy efficiency ratio can be used for both, it can be used for the complete system and it can be used for the compressor. Since we are looking at selecting a compressor our attention here will be more on the compressor selection, we can look at it for the air conditioner, we can look at for the compressor. So, when we are selecting a compressor we will compare them at certain conditions.

Now what are those conditions?

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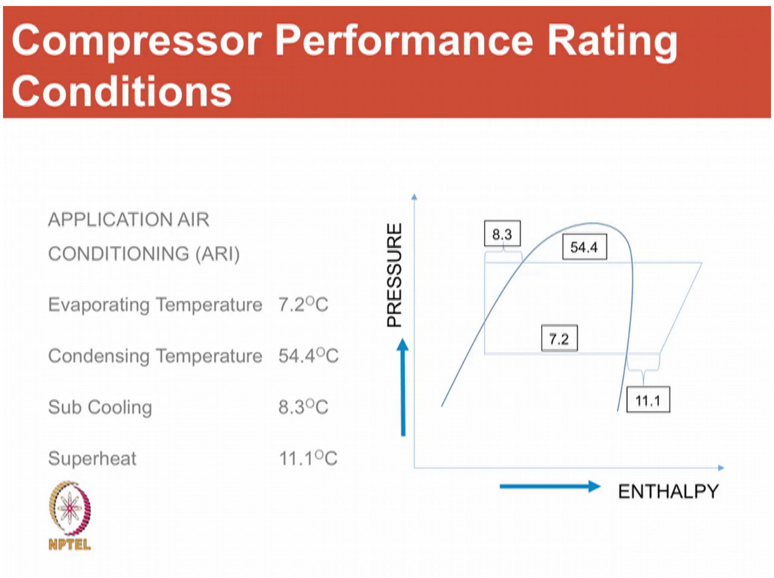

So, the American refrigeration institute has defined a set of conditions and those conditions are 7.2, 54.4, 8.3 and 11.1 for air conditioning systems. So, the chart we are looking at earlier I have just put those numbers there and the vertical axis the y axis is pressure again.

So, when we look for efficient systems we will begin with selecting a compressor that has a higher efficiency at the rating conditions and this is easy because all we need to do is refer to the compressor catalog or we look at compressor selection software which most leading manufacturers today provide. So, we put in our conditions and we can compare and make the choice of the compressor.

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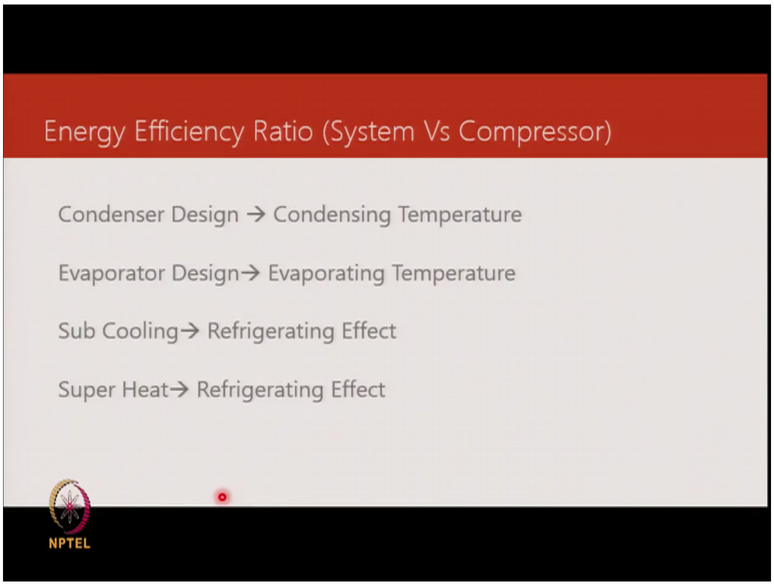

We have looked at these already, condenser design, evaporator design, sub cooling and superheat having an influence on the energy efficiency ratio. So, when we are designing our system we will make choices based on improving or increasing depending on what is the objective.

The objective is low cost we will operate at a higher temperature difference between evaporator and condenser and if the objective is to have an efficient system we will reduce the temperature difference between the condensing temperature and the evaporating temperature. Again there is an opportunity for increasing sub cooling for high efficiency and superheat is something we do not have much of a choice it is more to do with reliability.

So, we would want a superheat such that the compressor does not have any droplet us entering the suction. So, we want to ensure that compression happens in the pure vapor phase. Now let we are looking at compressor energy efficiency ratio and system energy efficiency ratio.

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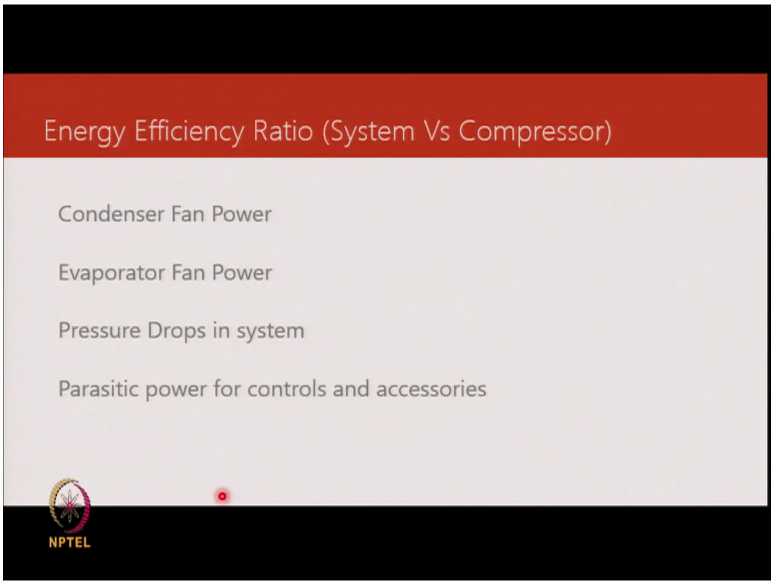

These are some of the factors that will cause the difference between the two. So, I want to go back to the previous slide first, even before that we looked at compressor performance rating conditions. So, let us say a compressor has an energy efficiency ratio of 3.5 at these conditions right now. These are conditions at which a catalog is prepared or a manufacturer makes available information so, that it is easy to select market and compare.

When you looking at a system we are going to look at actual condensing temperatures so, we were going to be moving the number away from what the compressor manufacturer has published we could be taking it upwards or we could be bringing it downwards, depending on whether it is a cost focused design or it is a performance focused design and when I say performance means getting the highest energy efficiency ratio. Similarly, there is a sub cooling number that is defined in the rating condition.

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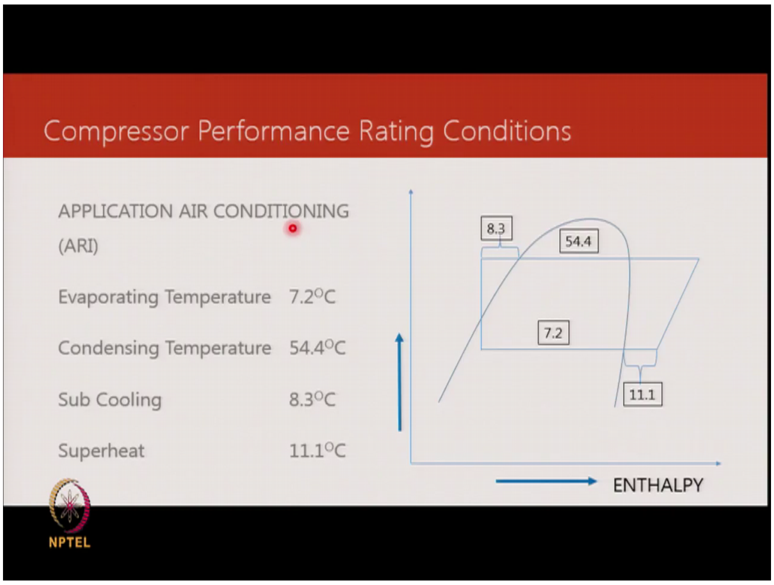

We could choose to be below this or above this and the need to be attentive to this is the system EER will be different. So, when we reduce the condensing temperature to 50 or 51 this is normally done from 54. 4 we bring it down to 51. What are we doing, we are taking the energy efficiency ratio of the compressor and that operating point to a number much above and what is that the rating condition.

So, if it is 3.5 we would take it to 3.7 so, that is a major benefit, now we have that benefit in our pocket. Now what happens to the system energy efficiency ratio does it straightaway go up, the answer is no because you are going to have these add on factors. So, we would have selected a fan that would be used for cooling the condenser, if it is an air cooled condenser, we would use another fan which would circulate air in the occupied space.

Again keep in mind I am talking about comfort systems here. So, you have fan which is typically if you look at a residential split air conditioner there is a small fan that is taking air from the room and throwing it back into the room, it is consuming a certain amount of power that power is in addition to the power consumed by the compressor. So, that will be added to the equation so, they that you shared with me.

If we if we start putting some numbers toward we would have compressive power, we would have evaporator fan motor power, we would have condenser fan motor power. And then there would be some parasitic power we should be used for maybe the thermostat, if it is an electronic thermostat and if there is a signaling system that is in place they want to be moving things like say a taking a low HP value or monitoring the discharged gas temperature.

So, all that which is there is going to lead to some parasitic power, all that put together will lower the system EER below what was available to us from the compressor at the operating condition that we selected.

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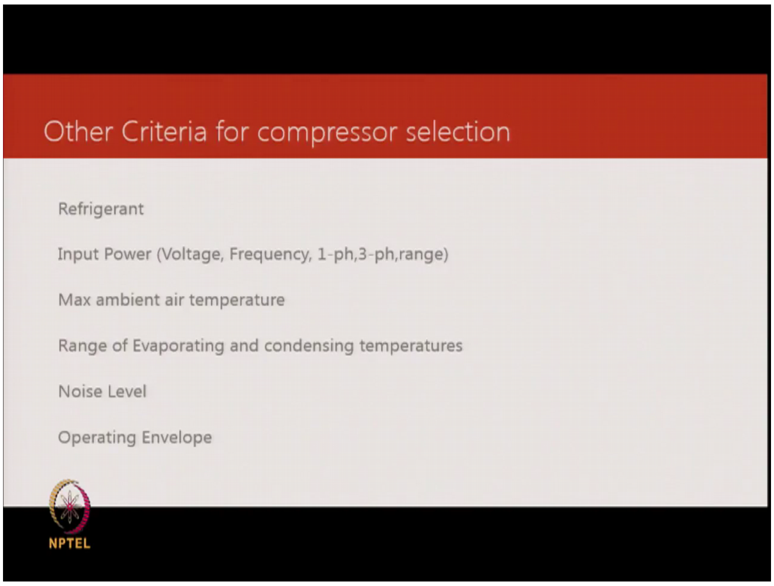

Now, other than this there would be some other criteria we would use for compressor selection. So, today there is a lot of emphasis on ozone friendly refrigerants and there have been worldwide regulations that have led to agreements worldwide to move away from ozone depleting substances.

So, that becomes one criteria for selecting the refrigerant and then there is another criteria which is global warming. So, there is increasing concern about the global warming potential of refrigerants and for that reason there is a move away from some refrigerants. So, all this is happening, we need to make a conscious choice today if you were designing a new system in India for air conditioning, you would not do it with R 22 because R 22 is one of the controlled substances that has to be phased out.

So, that would govern a choice of a refrigerant. So, we would look at 410 A which is another refrigerant which has no ozone depleting potential, but it has a global warming potential and there is work in a progress to identify what could be replacing R 410 A. So, making design choices for systems would mean firstly, we would make the choice of the refrigerant because that governs what compressor we will choose? What thermostatic expansion valve we will choose? What kind of heat exchangers? What will go into the circuit design of heat exchangers?.

What kind of distributor, filter dryer, all that is very interrelated and more because the lubricants that are useful with the newer refrigerants are for different type. Mineral oils were used well with our 12 and R 22 and they were less concerns on the refrigerant picking up moisture from the system, but now what is happening is, the newer synthetic lubricants which are needed with R 410 A and R 134 A are very hygroscopic.

So, short exposure to the environment leads to the lubricant losing it is property and creating problems and performance. The next part would be input power, if you looking at a residence low power we look at single-phase and then depending on country here we would look at 230 volt 50 hertz here in Saudi Arabia look at different voltage based on the local grid there and accordingly you will make your selection of the compressor.

The choice between single phase and 3 phase system is dependent on size, we prefer 3 phase compressor motors when you are looking at capacities 5 ton and above 3 ton it is both options there available. If you want lower current you do not want to load the grid asymmetrically then you would opt for the 3 phase system and for 3 ton system and then it also is governed by what is available.

So, a lot of newer systems even though having cooling capacities of 6 tons and above are running 1 single phase just because they are targeted for residences where we cannot guarantee 3 phase power supply availability. So, that becomes another selection of criteria. Now how many of you are familiar I have been using this term ton as if all of you know what 1 ton of air conditioning is. So, are you aware what 1 ton of air conditioning is, how is it defined? Anyone what is 1 ton of air conditioner?

Student: (Refer Time: 12:14).

It is a unit of unit defining cooling.

Student: One kind of (Refer Time: 12:18).

Yeah perfect that is it yeah. So, it is a rate of cooling and this is how it is defined at 0 degree centigrade what would it take to remove heat such that 1 ton of water gets converted to 1 ton of ice thank you. So, then you can convert that into different units. So, 1 ton would correspond to some kilocalories per hour how much is it 3 0 to 4 or and not necessary to remember I do not have to have it by heart it is more that if I am practicing I would have these numbers handy.

Otherwise you can always look up a book and do the conversion, but 3.5 kilowatt is a good number to remember is 1 ton of air conditioning. So, if you are looking at SI systems that is how or 1 and a half ton what is prevalent as a popular model today 5.2 kilowatt is what it would come to rounded off and approximately.

Then we would also look at the maximum ambient air temperature in which this compressor must operate and you would wonder why, because the compressor motor you needs some cooling. So, part of the cooling is by the refrigerant some part of the cooling is by loss of heat to the outside air. So, depending on what compressor we are picking up, if there is a requirement of external cooling then we need to be sure what environment will be around the compressor. So, it is 1 of the variables that we will pick up in our requirement definition.

Then we normally target performance at a fixed rating point for air conditioners we would target 35 degrees outdoor air temperature 27 degrees dry bulb in 19 degrees wet bulb indoor air temperature this is defined in the Indian standard and then it allows a very easy way of comparing systems.

So, we can quickly get to what will be the corresponding condensing and evaporating temperatures for compressor selection, but that becomes the performance rating point of the appliance. We also need to be aware of the range of operation between what limits will the evaporated temperature vary during the course of a operation. So, we could look at something to predict what would be the highest ambient and the highest ambient could also determine what would be the highest condensing temperature that we would need to consider.

Then in design we always like to put in some factors of safety. So, when we test a system with a new condenser in a lab the heat transfer is as designed maybe perhaps a little better, but very soon there will be time and there will be dust from the environment there will be some clogging happening and that will have a detrimental effect on the compression on the condenser.

So, all these will lead to the compressor having to work at a certain point higher than what it is tested at the performance reading point. So, one thing we know for sure is 35 is not the ambient temperature all the time, we have looked at 43, 46 in some parts of India temperature is going to 50 for short durations.

So, if we make a system we would not want a customer to call that when the temperature outside is the highest the compressor has tripped in a service engineer is going running to find out what happened and all that happened was the compressor was not tested for that condition. So, we will put in that condition and then we will put in a factor. So, if we are going to see exposure of 50 degrees centigrade for 1 hour maximum in India we may want to test it at 50 with the condenser partially blocked.

So, that we guarantee performance and for that reason we would up the compressor the max temperature limit the max condensing temperature against which it needs to operate. The compressor manufacturer is continually work on this and they assess what most customers are likely to encounter and therefore, they put in buffers. So, compressors which are tested for performance at 55 or 54.5 would typically be tested for adverse operating conditions up to 68 degrees centigrade condensing temperature and then there is the issue of evaporating temperatures.

So, while condensing temperature the risk was going high in the evaporator the risk is going low, we need to have a continuous supply of heat for the evaporating temperature to remain at the design point. How we can ensure that? Yeah.

Student: (Refer Time: 16:46).

Right, but in even when we have control systems we normally have seen clogged filters. So, just like what was happening in the condenser, there was a lower heat transfer then designed similarly that happens in the evaporator, but in the evaporator the temperature would go lower because there is not enough heat transfer happening. So, we are stretching the compressor from it is design condition to an aggressive condition in which it should operate and at the design stage we need to upfront define it. So, that we have not having to do the rework of coming back to the compressor selection again.

So, we will put in a number which would estimate what can happen and then there are also tests that happen for an appliance to prove that it will operate reliably even if the coil is choked or there is no air flow happening and even the Indian standard for example, defines a of a condition where you choke the total airflow that is going into the appliance it gets covered with ice and still the compressor is expected to perform.

So, that leads to us defining an operating envelope for the compressor, the maximum and minimum temperature limits then which it should operate. Now when I say temperature continue to relate to the pressure part as well because under saturation conditions both are interrelated. Then we would have some concerns on noise so, consumer preferences have changed earlier it was enough to get cooling today it is necessary that not only should it cool well it should be silent.

So, compressor noise contributes significantly if it is a window or a split wall system whereas, if the outdoor unit is outside then we may have lesser concerns about noise, but we still will have concerns about what is the maximum excepted noise for reasons of standards for not disturbing the neighbors for that reason we will put that as a factor.

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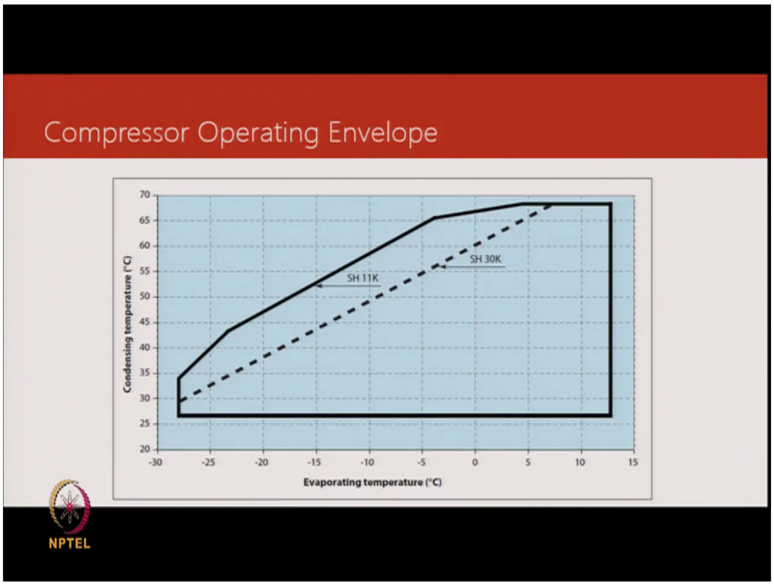

So, this is what our typical operating envelope for a compressor looks like, we have evaporating temperature as one criteria on the x axis and we have the condensing temperature.

So, you can see a compressor has a pretty wide operating envelope we can go down to minus now this is not standard for all, but I am convert a particular compressor and go down to temperatures below minus 25 on the higher side it can go to 12 and half on the evaporating side and condensing can go right up to 68 and then you will see these 2 lines, now what these 2 lines represent is the superheat.

So, when you look at the refrigeration system cycle we will looking at a certain superheat now when that superheat goes up the discharge temperature goes up and that compromises the operating envelope. And the reason this gets compromised is the metallurgy limit after a certain temperature and pressure combination the compressor where characteristics will change it may have seizures and for that reason we need to keep the limits clearly well defined and during our design we must prove and under no conditions will the safety controls allow the compressor to go into those zones.

We talked so much about the compressor also because it is a very expensive part of the refrigeration system design, if you put the entire system cost together a close to 35-40 percent would be just the compressor. So, we do a lot in design to make sure that once we have selected the right compressor we also make sure last for it is life and typical compressor life is 10 to 12 years in a residential application.

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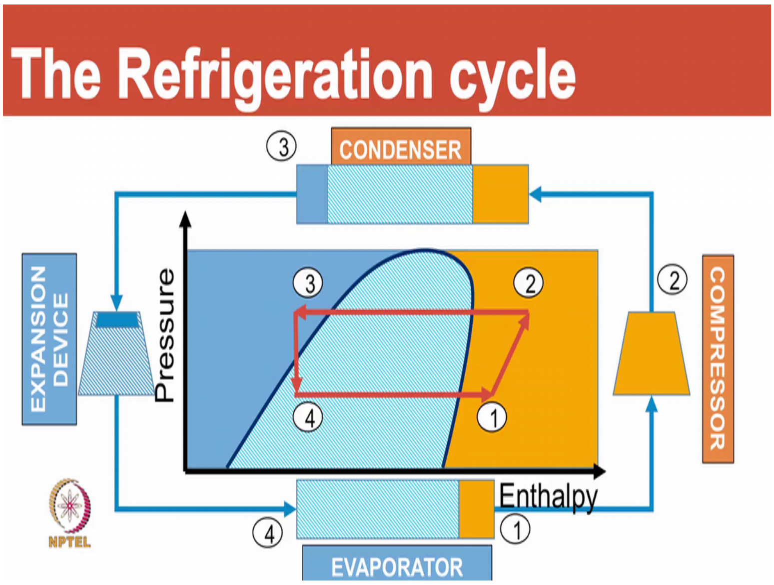

So, now, we come back to the refrigeration cycle to have a look at one other components, this 2 to 3 is what happens in the condenser right this would vary. So, we would see this line move up when the temperature goes up when the condenser gets clogged when there is overloading in the compressor because of more heat transfer in the evaporator all those reasons in a real system this would be a varying a line.

Also while we try and compare this with the inverse Carnot cycle, you need to remember that we are rejecting heat to ambient air at 35, but we are having the refrigerant at 55 50 51. So, that is a big inefficiency we are introducing versus the irreversible inverse Carnot cycle. So, the opportunities I had discussed during my first lecture of having room for improving energy efficiency of systems lies in that that there is a big gap between what the inverse Carnot cycle efficiency is and what real systems are at. So, the more we approach those conditions the higher efficiency systems we can target.