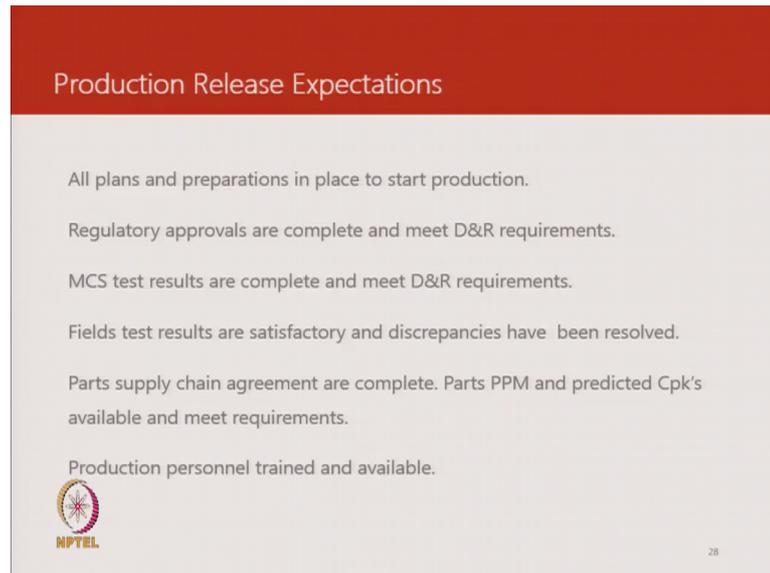


RAC Product Design
Prof. Sanjeev Jain & Bhupinder Godara
Department of Mechanical Engineering
Indian Institute of Technology, Delhi

Lecture – 15
Case Study on a telecom cooling system and Emerging technologies

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Production Release Expectations

- All plans and preparations in place to start production.
- Regulatory approvals are complete and meet D&R requirements.
- MCS test results are complete and meet D&R requirements.
- Fields test results are satisfactory and discrepancies have been resolved.
- Parts supply chain agreement are complete. Parts PPM and predicted Cpk's available and meet requirements.
- Production personnel trained and available.

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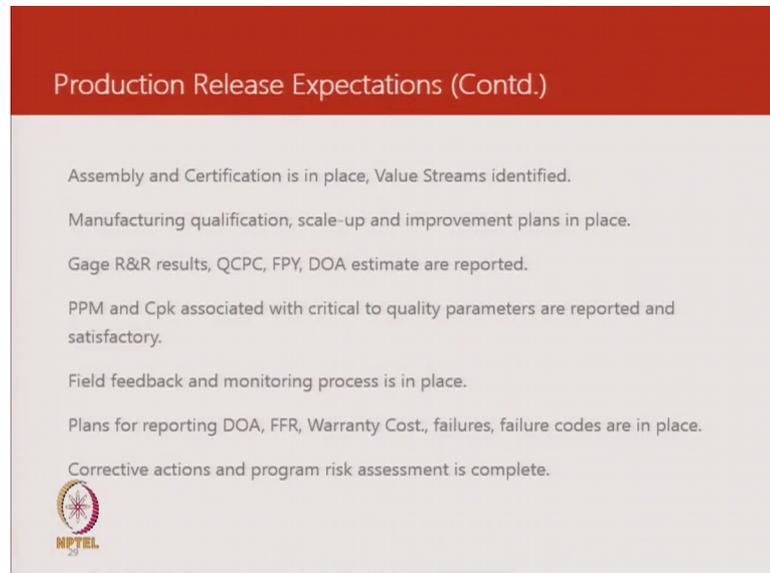
So, now, we look at what are the expectations that have to be met when the product is being released for market. So, at this stage everything that was agreed for design and reliability test is all accepted it has been proven there is no remaining activity. The first requirement, regulatory approvals a product cannot be released without that. So, again evidence of that then manufacturing has made the number of requisite number of batches to verify that they can meet the rate of production.

Field tests are satisfactory there is nothing abnormal being discovered by field test. So, field test is typically a process to discover the unknown if you look at a case study in railways vibration was something that was discovered and it was not through a planned field test, but it was discovered you know running production, but in products of high volume you do a field trial just to be sure that there is nothing that has been left out because of something not being so, obvious at the time of framing of test plans.

Again it is to reduce the risk of the commercial risk of a product launch and then parts the supply chain agreement all that is completed the needed levels of quality in terms of

acceptable parts that may turn out to be defective and all that is predicted accepted supplies of agreed and production personnel are trained and available.

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Production Release Expectations (Contd.)

- Assembly and Certification is in place, Value Streams identified.
- Manufacturing qualification, scale-up and improvement plans in place.
- Gage R&R results, QCPC, FPY, DOA estimate are reported.
- PPM and Cpk associated with critical to quality parameters are reported and satisfactory.
- Field feedback and monitoring process is in place.
- Plans for reporting DOA, FFR, Warranty Cost, failures, failure codes are in place.
- Corrective actions and program risk assessment is complete.



Then there is a whole lot of work that happens in the manufacturing domain which is assembly in certification whether it is training of people value streams manufacturing and then scale up and improvement plans and very often when there is a an external product compliance need which is mandatory like in India we have the star rating program.

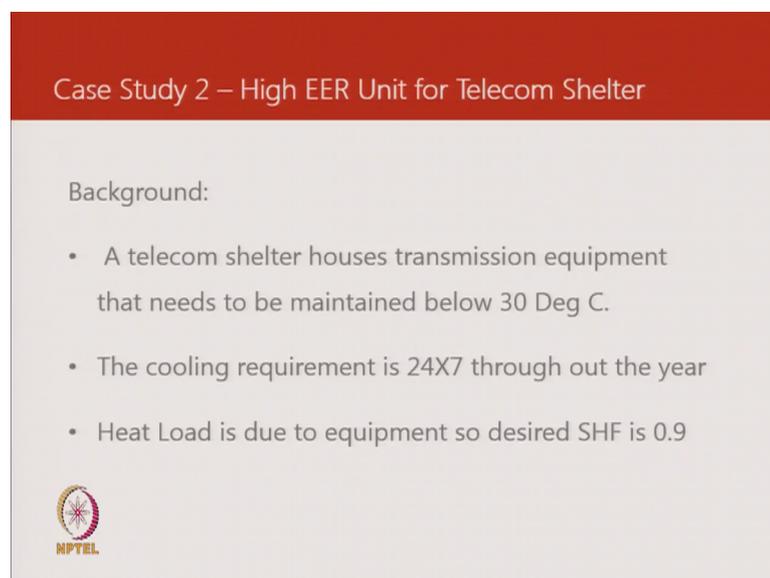
So, product can be picked up from the market put to a lab test a third party lab test and if they are not complying to what has been rated on the label of the product then there is a penalty and a risk of reputation for the manufacturer. So, to overcome all those risks at the manufacturing level that has to be Gauge, R and R and then there is a an estimate of any failures of product on a regular ongoing method then process capability is mapped for all the critical parameters. So, in an air conditioner the critical parameters would be energy efficiency ratio and cooling capacity which is a derivative again of cooling capacity and power consumption.

So, all that has to be falling within the defined norm of 3 percent at the manufacturing level if they are to meet an external requirement of 5 percent. So, now, you had asked me for another case study last time. So, the case study is here and the case study we will look at is a product designed for telecom cooling. So, the first case study was something

that I had an opportunity to be a part of in 1995 to 1998 this one is more recent it is in the period of 2008 - 2009.

Some background to this is telecom shelter so, right now technology is changing. So, the air conditioning needs then a telecom shelter are coming down and with 4 G services we do not need to air condition the equipment at the transmission point, but for 2 G services and 3 G services the equipment has to be kept below 30 degree centigrade and that creates the need for some air conditioner or a specific purpose built air conditioner for meeting that need. So, this is very different from comfort. So, comfort we are targeting more in the region of 25 testing at 27 here it is 30 degrees centigrade.

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Case Study 2 – High EER Unit for Telecom Shelter

Background:

- A telecom shelter houses transmission equipment that needs to be maintained below 30 Deg C.
- The cooling requirement is 24X7 through out the year
- Heat Load is due to equipment so desired SHF is 0.9

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So, and then it is going to be year round operation 24 by 7 throughout the year. So, the energy needs have going to be much more significant and since in India we have power shortages. So, there will be times when this unit will run on or Deg C set. So, the optics will be driven by a combination of cost of power and cost of fuel. So, that is tremendous focus on keeping the energy costs the operational costs low and then the entire heat load is because of I mean it is sensible heat there is no moisture being added in this shelter.

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The slide features a red header with the text 'Customer Requirements'. Below the header, a list of requirements is presented in a light gray box. At the bottom left of the box is the NPTEL logo, which consists of a circular emblem with a stylized figure and the text 'NPTEL' underneath. To the right of the logo, the text 'Remote monitoring' is displayed.

- Maintain 30°C inside the shelter
- 3200 Watts of heat load
- Location anywhere in India
- EER of 3.0 or higher
- Low Operating cost
- Redundancy and High reliability

Remote monitoring

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So, if we try and apply this as a you know some way of mapping the customer requirements some things are pretty straightforward where you want to maintain 30 degree centigrade or lower. The heat load comes out as an input because of the equipment that is inside the shelter. So, the customer has no problem sharing this and then the location anywhere in India, which means we can look at the worst operating condition in India and then based on that design the product.

So, just for you to know if we look at the last 30 years temperature data in India we will find that the max temperature ever recorded and this is based on what I reviewed in 2008 the max ever recorded temperatures 50 degrees centigrade by the met department. After that if there have been some instances of it going by a few points above I am not sure that is kind of a number that you can remember.

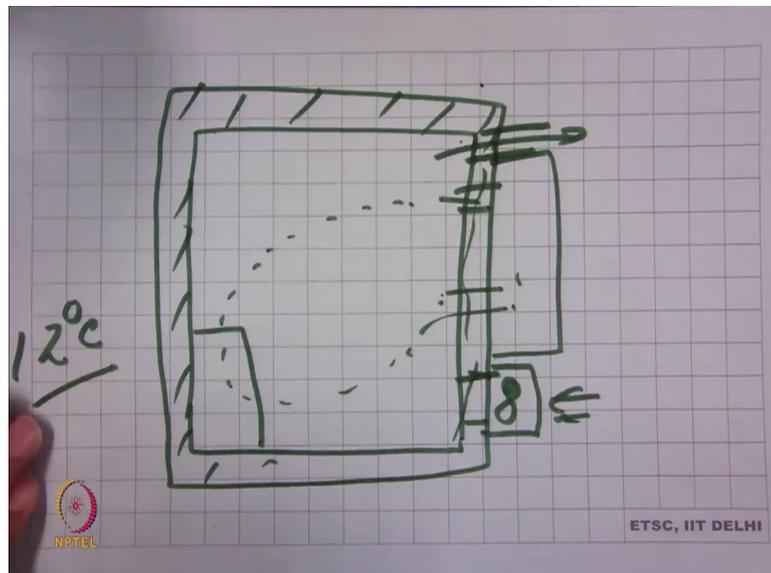
And then energy efficiency the customer wanted energy efficiency ratio of 3 or more and the other things are kind of derived because of nature of application you gone have a low operating cost and then high reliability. So, the components have to be looked at differently because they going to be in a 24 by 7 application environment and a need for remote monitoring the nature of spread of these units is such that if a service when I need to visit it would be helpful if he knew what was wrong with the unit.

So, if there could be communication to a central point about possible you know guess he could make us to what is wrong with the unit has a compressor fail fan field or is just a

damper issue. Now in this there is a unique feature opportunity because this unit is going to be operating your round, there is an opportunity in the winter months once to use the cooling that is available from ambient air.

So, you gone to maintain 30 and in winters what are the temperatures you will encounter somewhere in the region of 4 to 24 if you look at months of November to February. So, if you are really looking at it as an opportunity then how would you use this for cooling very unconventional and creates an opportunity for integrating a unique feature. So, what can we do, such that the compressor need not run in the winter months.

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This is an insulated box, this is the insulation and then we have equipment which is generating heat and we have some air conditioners which are cooling. So, we have supply air which is coming here going back to a unit another AC. So, this conventional solution is there and now we are looking at condition where the outdoor temperature is let us say 12 degree centigrade let us take case of Delhi and we want to cool this without using the compressor.

Student: (Refer Time: 08:30)

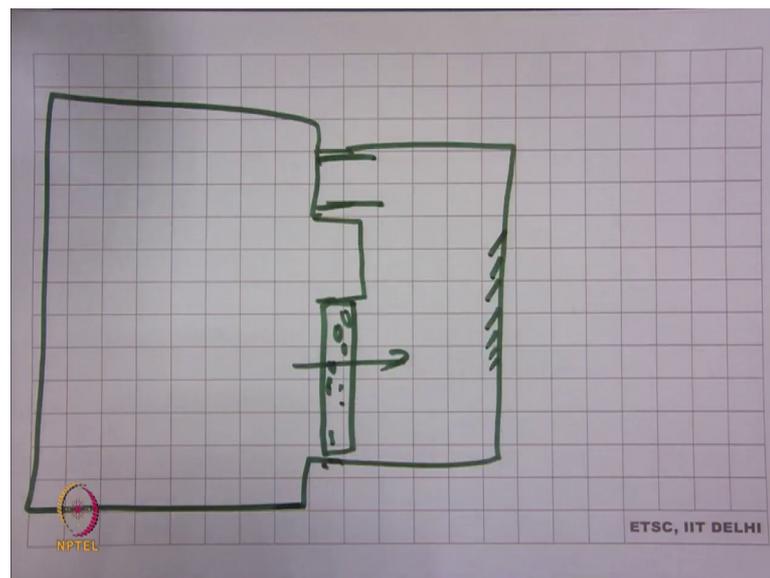
Right simple and then what do we need to do create an opening.

Student: (Refer Time: 08:40)

So, one simple straightforward thing could be that we create a cutout over here we have a unit which has a fan and then we create another cutout maybe somewhere here. So, when we are taking air from here it is passing over this throwing it out right, now what would it look like if this feature has to be integrated into the AC

Student: (Refer Time: 09:10)

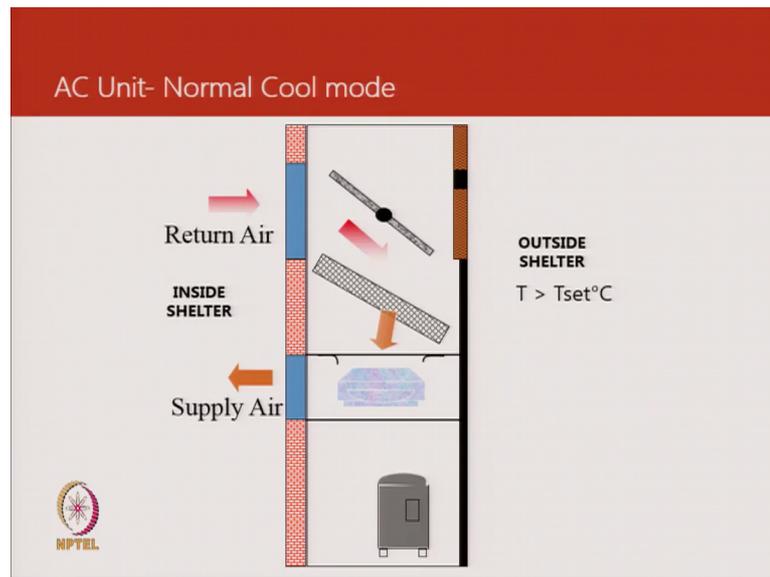
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What we said is feasible, but it would require someone manually switching that unit on switching the air conditioner off. So, one of the things we can derive is that if there was a sensor related switch which could switch off and switch on from a technology specter he already provide that and one simple unit so, that air conditioner is unique.

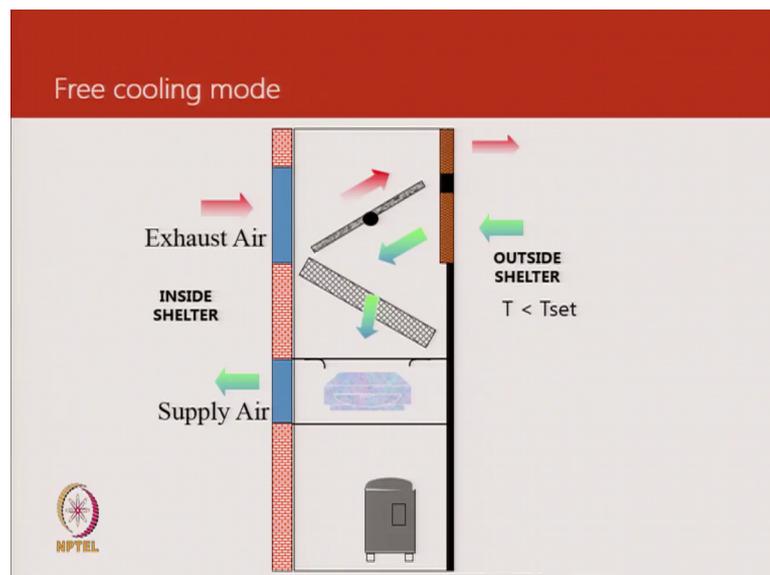
So, the air conditioner we can say is so, this is the evaporator coil and here is a supply air. So, this is normal circulation how could we integrate within the AC some combination of controls, dampers to take outside air when the temperature is sufficiently low. So, the opening that you talked about instead of having it in the shelter we could have it in the AC. So, let us say we create an opening in the AC and then we would need to have a means of blocking this and opening it. So, this is what was created as a feature. So, instead of drawing it all over again I will use this sketch.

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So, in the normal cooling mode return air comes in, this damper in the normal position is actually sealed on this side as well as this side. So, the return air comes over the cooling coil into the blower and soon back into the shelter and this is when the compressor is in operation and the outside temperature is higher than the set point for the free cooling mode.

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So, in the free cooling mode when the temperature outside the shelter is lower than the set point then what do we have, a damper moves it from its position and outside air

comes. So, the same blower is used to take air from outside and throw it into the room and the exhaust air goes through another part of the opening into the environment. So, this whole thing gets integrated together and it creates a unique opportunity. Now how big is this opportunity in terms of energy savings.

(Refer Slide Time: 12:09)

City	Outdoor Air	Annual Hours	Power Watts
Delhi	DBT <= 20	2629	125
	20 < DBT <= 26	1688	250
	26 < DBT <= 35	3755	1250
	DBT > 35	688	1350
		8760	
			0.728
			5623
			1.265

So, if you look at the temperature of Delhi the outdoor air temperature number of hours in a year this is the number of hours in a year when the temperature is below 20 and then this is the number of hours when it is between 20 and 26 and very soon will come to the reason why we have categorized these 2 parts separately and then here is the condition where it is between 26 and 35 clearly the number of hours when the unit will operate with the compressor on and then this is the number of hours when it is greater than 35.

So, when we operate the unit in a free cooling mode for temperatures below 20 the enthalpy of air is low. So, we have much more opportunity for the same quantity of air so, we drop down the CFM of air by just operating one unit. So, this is an example where we are looking at either 2 units so, 2 free cooling units operating or one free cooling unit operating out of a shelter.

And we can come back to this detail a little more after we have seen the design of the unit, but what it translates into is effectively a total average power consumption of 728 watts 0.728 kilowatts versus what it would be is some average of these 2 numbers if we were not using the free cooling mode.

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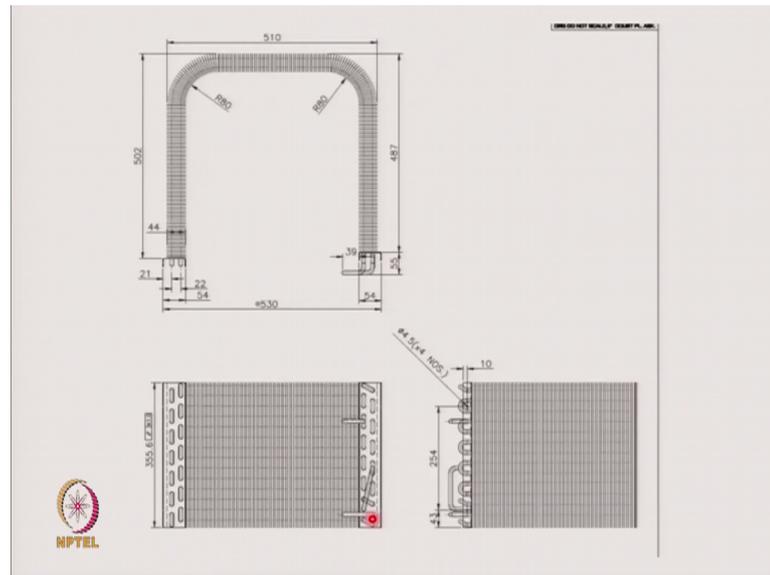
	D	E	F	G	H	I	J
6		Outdoor Air	Annual Hours	Power Watts			
7		DBT<=20	2629	125		328.6	
8		20<DBT<=26	1688	250		422	
9		26<DBT<=35	3755	1250		4694	
10		DBT>35	688	1350		928.8	
11			8760			6373	
12						0.728	
13						5623	
14				0.53795364		1.265	
15						43%	

So, this is the number, n is again in kilowatts if we were using just the compressor cooling mode so, the savings that we are generating here. So, 42 percent energy we are saving by integrating this concept and then if you start doing the maths of the number of shelters and all that it becomes a very strong business case.

And that was the reason why a telecom sector was very quick to take these units the specs were formed compute the specs of frame the competition units the benchmark with the each other and orders were placed. And there is one thing which was the roll out of telecom infrastructure and the rollout of these specialized units integrated with free cooling was can wrap it in driven by this particular savings opportunity.

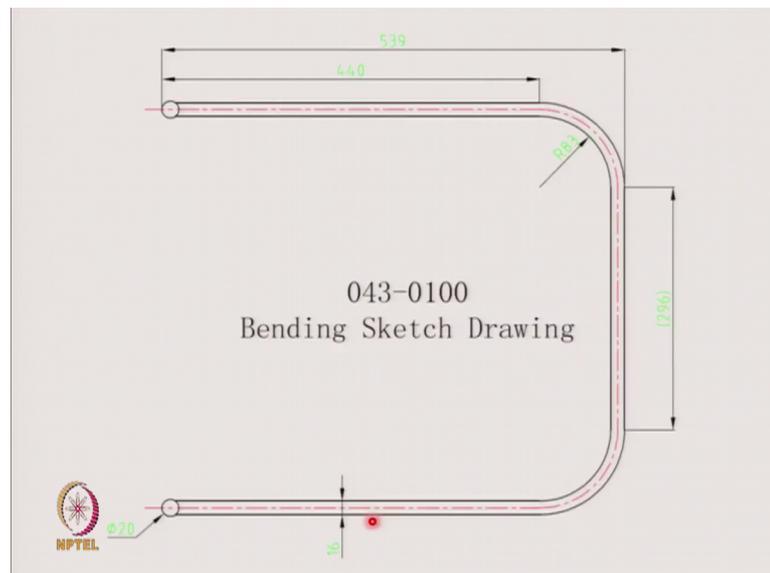
With one of things to remember is that when you do a new product design if you get to something unique as unique as this and you can be sure that if you are among the first to market you have a real opportunity for making good profits if your own companies and for yourself or for the company that you are working for.

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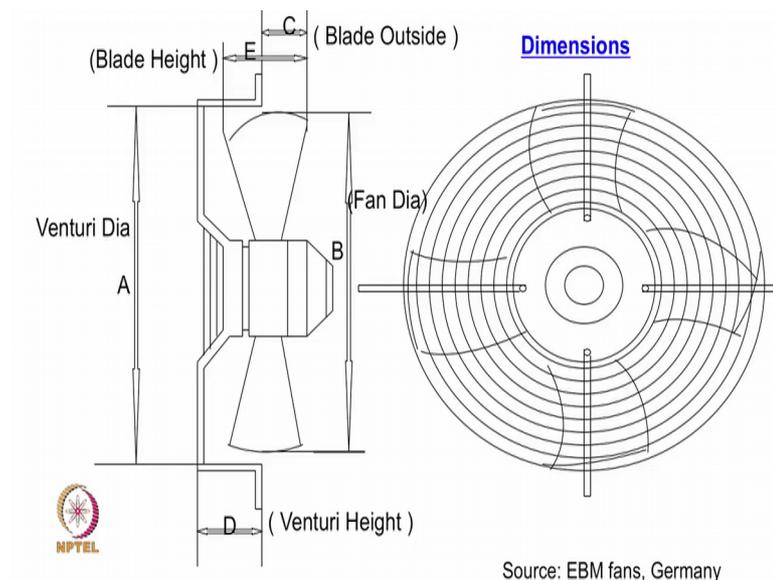
But to get to good performance at high ambient temperatures condenser coil which was bent into a U shape was used and the discharge was kept a vertical. Then there was also a need for looking at a high pressure refrigerant 410 A for some markets and for that there was a new type of a heat exchanger that was considered.

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This is a special micro channel heat exchanger with fringe stacked between flat tubes of aluminium it is similar to what you see in car radiators and this is today also being used in the residential sector for lower cost condenser coils.

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Then here we have the fan. So, for purposes of ensuring high reliability a German fan was utilized for this application such from IBM and again it had to undergo the usual qualification processes for withstanding shower tests. So, that if installed in vertical condition it is not going to have water ingress failure of motors because of that reason.

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Specification comparison

Models	New VBM	VBM	EBM	EBM (DC Fan)
RPM	1200	1250	1400	1800
Current	0.55	0.55	0.5	2
Power Supply	230 v 50 Hz	230 v 50 Hz	230 v 50 Hz	48 V DC
power consumption	120 W	122 W	110 W	90 W
Capacitor	4mfd	4mfd	4mfd	-
Rotation	Anti clockwise	Anti clockwise	Anti clockwise	clockwise

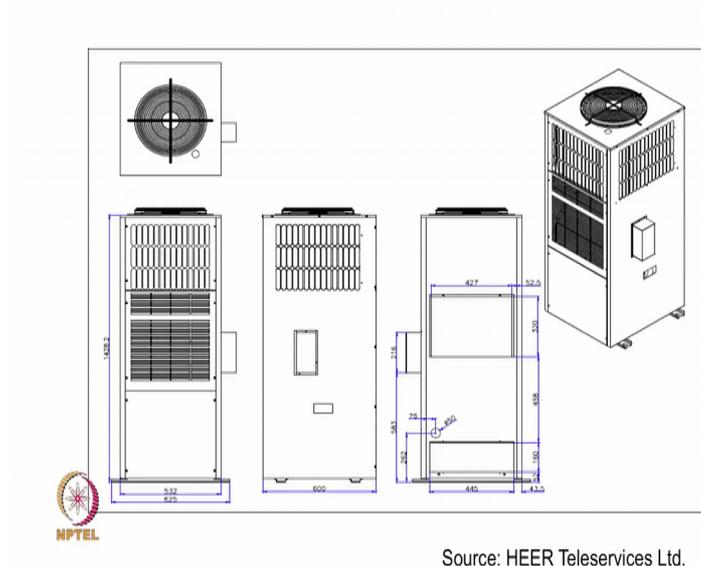
The NPTEL logo is located in the bottom left corner of the slide.

Then to give you a glimpse of the kind of specification comparison that goes in before one invests on a important component of high cost. So, different fans were benchmarked

and before I go forward I must also mention that these telecom shelter unit cooling units need to be performing for short durations on battery. And if there is not enough power available then the blower can be made to operate on 48 volt DC.

So, for that reason by this unique specification for this product that blower would run at 48 volt DC and if there was no power available for short durations the blower itself in the free running mode will keep the unit under acceptable temperature conditions it may not stay below 30, but it will still went to the. So, this was a just to illustrate how components are benchmarked and compared so, in addition to performance for cost as well.

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And these are the drawings of the final unit you can see the condenser discharging vertically up these are air intake points and this surface is the one which is flush with the shelter. What you see here is a damper so, the damper actuator is outside and this moves the damper from one point to another when we switch from regular cooling to free cooling. Now, there is only this much that I can show you of such productional shape product picture of the real product.

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Source: HEER Teleservices Ltd.

FUNCTION :

HEER specially designed to maintain desired temperature in Telecom Shelters. It works in different cooling modes based on ambient as well as shelter conditions to maximize the energy savings. It enhances the electronics equipments life by removing excess heat from telecom shelter.

VARIOUS FEATURES:

Structural Features

1. Wall mounted outdoor unit
2. Bottom discharge
3. Easy installation, maintenance & service

Operational Features

1. Direct cooling (AC)
2. Energy saving Free Cooling
3. Emergency cooling

Controller Features

1. Can control up to two units
2. High temperature alarm
3. Fault alarm
4. HP & LP protection
5. Indoor fan speed control
6. 7 segment display
7. Various status and faults indicating LED
8. High & low voltage protection

So, this product was called high efficiency energy efficient high energy efficiency unit HEER and it was designed to maintain temperature in telecom shelters, it is all that we already talked about for energy savings ambient temperatures as well as free cooling. So, it was a factory charged unit it did not require any field charging and to that extent was a simple quick and direct installation.

And the emergency cooling that is listed here as a feature is the one I talked about using a DC fan and then there was a controller which would take care of 2 units. So, there is a feature required for onetime equalization you invested on 2 units you might as well get the max out of the units where rotating the duties. So, the second unit is on standby in case one unit fails, the other one will come in operation and in this controller would communicate to the central point for a service the need for maintenance.

Then the features of high pressure low pressure were both built in and they will display to indicate the temperature as well as set point and this also had the high end low voltage protection features and status a lead indicating if there is any fault in the unit. So, between the time this unit was designed and a year 20000 units were installed.

So, it is rapid commercialization once the product matrix desired objective and there was competition so this product was tested you know third party lab where inter tech in a balanced ambient calorimeter there is a second type of test method where in a room you maintain a certain temperature and then the entire heat added in that room is measured.

So, you do not rely on the air enthalpy method for getting the capacity you look at the real heat and moisture addition that is happening the room on both sides.

So, we qualified this product and it was the best of all that was benchmarked based on the customer report and nothing no saying whatever was measured because the lab was independent the customer had his own orders for testing the product and it of course, generated tremendous confidence on the company to supply.

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TECHNICAL SPECIFICATION		
VERSION	Unit	HEER
AC MODE		
Maximum air flow	l/sec	293
	cfm	600
Cooling capacity	BTU/Hr	12284
	Watts	3600
Power consumption	Watts	1200
EER		3.0
SHF		0.9
Refrigerant		R22
FCU MODE		
Maximum air flow	l/sec	425
	cfm	900
Cooling capacity	kw ($\Delta T=7^{\circ}C$)	3.53
	BTU/Hr	12052
Cooling capacity in w/K	W / K	505
Power consumption	W	120
COMPONENT SPECIFICATION		
Evaporator blower	DC/AC	48 VDC
Blower Maximum current	A	3
Blower Maximum power consumption	W	120
Condenser fan	DC/AC	230 VAC
Fan maximum current	A	0.57
Fan Maximum power consumption	W	120
Filter	microns	20
ELECTRICAL SPECIFICATION		
Phase	Ø	1
Voltage	VAC	230 ± 10%
Frequency	Hz	50
DIMENSION		
Height	mm	1430
Width	mm	532
Depth	mm	604
Intake air cut out dimension	mm x mm	427x320
Supply air cut out dimension	mm x mm	427x130
Net weight (Approx)	kg	90

These are some details about the product in terms of how much of airflow; primarily it had 600 CFM of air in the AC mode and 900 CFM of air in the free cooling mode. And that would lead to a certain cooling capacity in the free cooling mode which is 3.53 kilowatt or you could also look at free cooling as a watt per degree Kelvin which is listed 505. So, based on the enthalpy difference or just the dry bulb you can easily calculate the cooling capacity of the unit using fresher.

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Condenser Fan Testing VBM /EBM on 8/8/08

EBM Fan					VBM Fan					NEW VBM Fan					EDM (DCFan)				
SL No. KAO14686					S.R. No. 040708 FA23/3514/RBG54					SR. NO. 040808 FA23/3514/RBG53					WIG 300 - CE33 - 52				
40	42	42	42	48	37	39	36	38	46	39	43	41	41	47	47	44	45	45	47
34	38	38	37	43	30	35	33	35	41	35	38	37	36	40	44	40	39	38	46
29	34	35	34	40	26	32	30	30	37	30	34	35	34	39	36	35	36	35	41
28	33	32	30	37	27	32	29	28	33	30	32	32	32	37	30	30	33	31	40
41	44	46	41	41	38	40	41	41	42	39	43	43	43	42	42	44	46	45	44
39	40	41	39	38	36	36	38	36	34	38	40	38	38	38	41	41	43	41	40
36	39	37	35	33	33	33	34	32	30	37	37	35	33	34	39	39	38	36	38
34	34	35	31	29	30	29	32	30	27	33	33	33	32	32	33	35	35	34	36
41	37	40	43	39	35	35	37	37	33	40	38	40	38	38	41	41	43	40	38
35	36	39	40	37	31	33	34	36	33	36	36	38	37	37	36	39	40	40	37
32	34	36	37	36	30	32	32	35	32	33	33	35	36	36	37	39	39	38	38
34	33	34	37	35	30	33	32	33	32	34	31	34	35	35	33	37	39	38	39
FPM 371					FPM 339					FPM 365					FPM 390				
Venturi height : 35 Venturi Dia : 357 Fan Dia : 330					Venturi height : 35 Venturi Dia : 357 Fan Dia : 350					Venturi height : 35 Venturi Dia : 357 Fan Dia : 350					Venturi height : 75 Venturi Dia : 320 Fan Dia : 300				
CFM =1652					CFM =1151					CFM =1626					CFM =1739				
Power Consumption : 120 W Amp 0.6 Volt 230 VAC Blade Height : 90 Blade Outside : 90					Power Consumption : 120 W Amp 0.6 Volt 230 VAC Blade Height : 50 Blade Outside : 10					Power Consumption : 110 W Amp 0.5 Volt 230 VAC Blade Height : 65 Blade Outside : 42					Power Consumption : 81.6W Amp 1.7 Volt 48 VDC Blade Height : 65 Blade Outside : Upto Venturi Periphery.				
<p>Observation: 1) Compare to EBM Fan (371 FPM), New Sample Provided by VBM is giving 365 FPM which is very close to EBM and also the Power consumption is 10 W less than EBM Fan.</p> <p>2) Using 48 VDC Fan in the same Unit giving higher CFM as compare to other 230 VAC Fans.</p> <p>Measuring Instrument used : Anemometer Vane Probe (S.L - D3582), Fluke Power Analyzer , Multimeter , 48 VDC Power supply.</p>																			

And this is just showing again in the product how the 2 fans performed a locally manufactured equivalent of a German fan and for reasons of reliability of course, the design continued to make use of imported fan.

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High Efficiency AC

ACME High Efficiency 1.0 Ton Unit applied to a 24Trx Shelter

Cooling Capacity	3517 Watts
Power Input	1265 Watts
SHF	0.9
CFM	600
CFM in Free Cooling Mode	900
No of Units	4
Free Cooling Mode for 24Trx	
• Active for temperature	<=26 Deg C
• CFM of free cooling for Outdoor DBT<=20	1800
• Blower Power	250Watts
• CFM of free cooling for 20<Outdoor DBT<=26	3600
• Blower Power	500Watts

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This is a way to look at an application from a unit spec point of view as I was talking to you I will look at some payback calculations using the number of units. So, here we look at in the cooling capacity 3517 watts with 1265 watts of power consumption a sensible heat factor of 0.9 and the CFM in the free cooling mode is 900.

So, for an application which makes use of 4 units of such type, one can look at some energy analysis.

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High Efficiency AC with Free Cooling

Outdoor Temperature	Hours/Year	Operating Mode
DBT <=20	2629	Free Cooling @125Watts
20<DBT<=26	1688	Free Cooling @250Watts
26<DBT<=35	3755	AC Cooling @ 1250 Watts
DBT>35	688	AC Cooling @ 1350 Watts
Total	8760	

High Efficiency 1.0 Ton Unit

- Compressor Cooling Mode
 - Active for temperature > 26 Deg C
 - Power Consumption for 26<Outdoor DBT <=35 1250 Watts
 - Power Consumption for 35<Outdoor DBT 1350 Watts
 - Average Power Consumption with compressor for Delhi 1265 Watts
 - Overall Annual Average Power including free cooling 728 Watts



And this is essentially derived from the same sheet that I just shared with you. So, the compressor cooling is eliminated and leads to something in the region of 40 percent energy savings.

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Power for 11.25KW Load (24Trx)

Shelter Sensible Load	11.25KW
AC Sensible Cooling Capacity	$0.9 \times 3.5167 = 3165 \text{ Watts}$
Shelter Temp.	32 Deg C
No of Units	4
Total Sensible Cooling capacity	12.66KW
Compressor operation	88.9%



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Power for 11.25KW Load (24Trx)

	KW	Hours/Year	Total Units/Year
Compressor ON	5.06	3948	19985
Compressor Off	0.32	495	158
Free Cooling @1800CFM	0.25	2629	657
Free Cooling @3600CFM	0.50	1688	844
Total Annual Units Consumed			21645

Std 2 X 2.0 Ton Solution

	KW	Hours/Year	Total Units/Year
Compressor ON	5.92	7784	46099
Compressor Off	0.656	976	640
Total Annual Units Consumed			46739



And, if you apply it on different shelters then we can look at the annual savings opportunity you know your versus different alternative scenarios.

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High Efficiency AC Option

ACME High Efficiency 1.0 Ton Unit applied to a 12Trx Shelter

Cooling Capacity	3517 Watts
Power Input	1265 Watts
SHF	0.9
CFM	600
CFM in Free Cooling Mode	900
No of Units	3

Free Cooling Mode for 12Trx

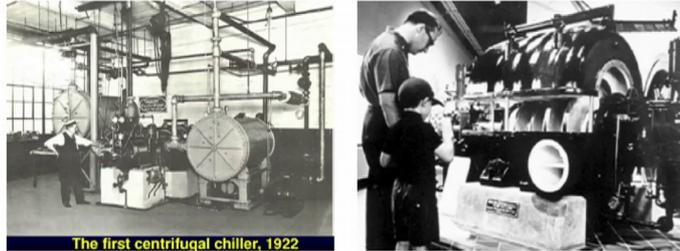
- Active for temperature ≤ 24 Deg C
- CFM of free cooling for Outdoor DBT ≤ 24 1800
- Blower Power 250Watts



So, with this the case study is more or less complete in the business case the design and the comparison for components. Now we look at some of the emerging technologies that are coming up. So, and one of the newer technologies is an oil free compressor which is used for chillers so, you going to look at that.

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The first Centrifugal Chiller



- 1922 Willis Carrier
- Compressor: open drive 3600 rpm four-stages



Source: NMAH, Washington

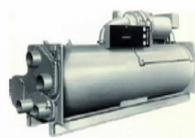
So, before we go there let us start looking at the history of chillers. So, the first Centrifugal Chiller was introduced in 1922 by Willis Carrier, there was an open drive compressor running at 3600 RPM and had 4 stages.

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Centrifugal Chiller Evolution



The first production centrifugal chiller, 1923



Field assembled
Separate HX design
Cast HX shells
Falling film evaporator
dielene as refrigerant

Factory assembled
Rolled HX shells
Flooded evaporator
Modern refrigerants

Oil Free
Highest Efficiency
Intelligent
Redundancy
Active Surge control
No vibration low noise



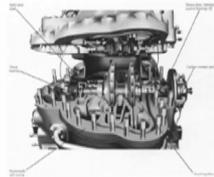
Source: NMAH, Washington

From then there has been evolution and technology. So, from field assemble units so, it is moved to factory assembled units and instead of building it site using cast heat exchangers shells, now we are looking at rolled heat exchanger shells flooded evaporator and newer refrigerants. And the latest is oil free high efficiency compressor system

where there is redundancy and active search control which means capacity control and low vibration and noise.

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Centrifugal compressor evolution



Multistage
Open drive
Riveted impellers



Single stage
IGV for capacity control
Internal transmission



Oil Free
Variable Speed
Two Stage
Direct Drive
High Speed



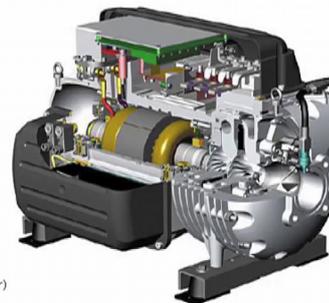
Source: Danfoss Turbocor Compressors

So, here the one on the right is the newer technology. So, the company I worked for Danfoss had has a separate division called Danfoss Turbocor and that is the company to first introduce a oil free bearing, where the compressor rotating shaft is magnetically levitated and there is complex electronics to keep it in a fixed distance from the metal surfaces using magnetic forces.

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Latest Technology Centrifugal Compressor

Highest-efficiency
High speed 48000 RPM
Oil-free, Magnetic bearings
Two amps to start the compressor
Variable speed Integrated VSD
Permanent magnet motor
Two stage Compressor, economizer.
Made in USA
Only one moving part



Compressor 90Tn > 200Tn (300>500 K.wr)
Chiller 90Tn > 1000Tn (300>3500 K.wr)
R134a / R1234ZE



Source: Danfoss Turbocor Compressors

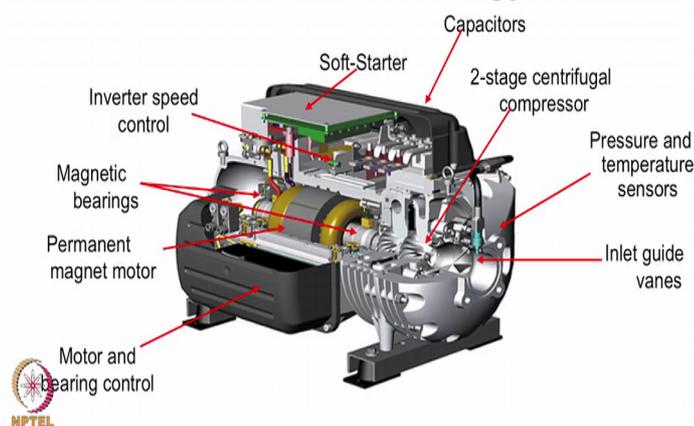
So, what are you going to see here next is so, we looking at about 3600 RPM when it was introduced in 1922 and now we looking at 48000 RPM. So, one can ask this question as to why do we need to go oil free. So, if we looked at some of the reliability concerns earlier it was around oil coming back to the compressor or oil being there in the compressor and that was to address a longer life if we eliminate the need for lubrication we have created a unique opportunity where refrigerant flows without any obstruction, without any real compatibility issues with any oil.

We talked about oils leading to short exposure times or compressors because they are hygroscopic that is eliminated, there would be pressure drops because of oil in the system pipelining that would be eliminated. So, the oil free magnetic bearings are one of the unique things in emerging technologies and the this is finding increasing acceptance and also more companies are trying to find ways to beat any patents that one company has by doing some work around on the technology.

The capacities that are available 90 tons to 200 tons for the compressor, but the chillers can go right up to 1000 tons using multiple compressors and right now, this product is manufactured in the US only.

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Danfoss Turbocor technology



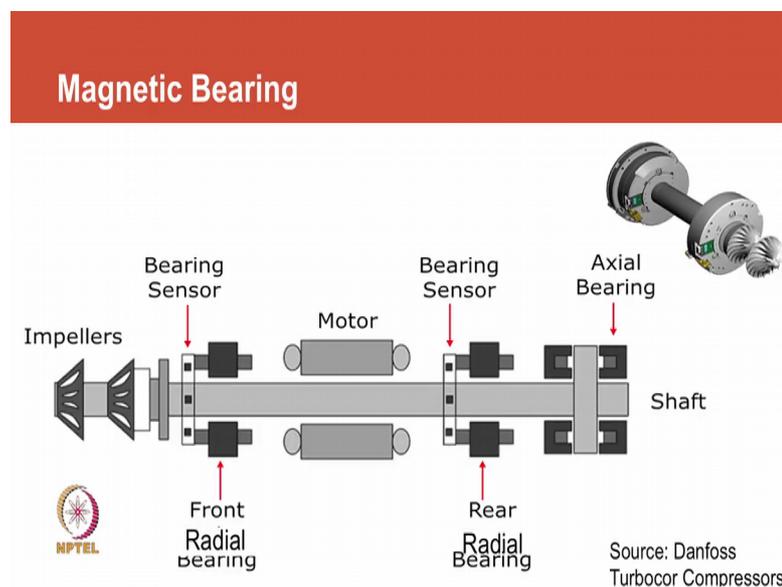
Source: Danfoss Turbocor Compressors

If you look at some of the components this compressor has an inbuilt variable speed control what is written here as inverter speed control. It has a soft start so, big compressor 90 ton compressor just has 2 amperes of start current. A typical residential

compressor may have 40 to 60 amperes of locked rotor current. That is the kind of technology evolution that happens when it is a 2 stage centrifugal compressor with lot of instrumentation.

So, there are pressure and temperature sensors to monitor this then inlet guide vanes for modulating the capacity and then there is a motor and bearing control region along with the permanent magnet motor and the magnetic bearings. So, let us look at it a little more in detail as to what this whole technology is around.

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So, here we have the 2 impellers which lead to 2 stages of the compression process and there is one bearing sensor together whether radial bearing you just ignore this radial bearing. It is a radial bearing so, the front radial bearing and the other rear radial bearing and then there is one axial bearing. So, if the whole technology is to pick up the location of the shaft and adjust the magnetic forces.

To centralize it and doing this continuously at a very high rapid speed is what makes this technology feasible. You know like you know you hold this pen and then if you can control the forces. So, you do not let it drop you do not let it touch the top side and do not move it actually if you have done that successfully using magnetic forces then you have an oil free compressor. This is the only moving part in this compressor.

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Magnetic Bearing System

The rotor shaft is held in position with ten separately controlled electro magnetics which continually changes in strength to keep the shaft centrally positioned.

Sensors monitor the position of the shaft over 6 million times a minute.



Source: Danfoss Turbocor Compressors

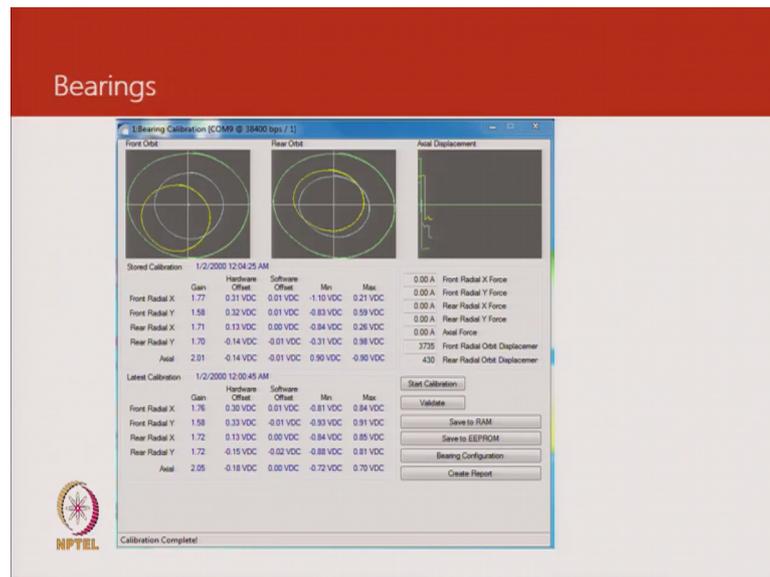
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Well the people who developed this technology who have found it successful with the high speeds and one of the reasons they have used high speeds is to reduce the cost, overall size and cost of the compressor. See when we run a normal motor the governing factor is the frequency that is available. So, you would have 50 hertz in India 60 hertz in the US and more or less that so, multiples of that would determine the rotating speed.

The moments you have converted electrical power into DC and you using magnetic forces then you have an opportunity to run it whatever speeds you want to. So, you can alter the frequencies and if you are doing an r and d program you would like to create a unique value where others cannot quickly catch up with. So, with high speeds and smaller sizes you can make the overall chiller footprint smaller so, that becomes one of the (Refer Time: 30:29)

So, the rotor shaft is held in position with 10 separately controlled electro magnetics which continually change in strength to keep the shaft centrally positioned axially and radially and senses monitor the position over 6 million times a minute. So, look at the level of processing power that would be needed to make this work.

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To illustrate whatever saying about centralizing the shaft inside the bearing so, these are some of the details of how the radial axial part is actually the 2 radial bearings and then the 1 axial bearing.

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- Energy and cost savings**: Outstanding part load and high full load energy efficiency providing the lowest total life cycle cost operation.
- Oil-free operation**: 100% oil-free operation with magnetic bearings eliminates oil management system.
- Low sound and vibration**: Low vibration and quiet operation eliminates the need for ear protection.
- Less complexity**: Only one major moving component delivers less mechanical complexity and reduces maintenance and warranty costs.
- High Reliability**: Proven & reliable compressors dedicated to specific applications to increase efficiency, improve margins and drive differentiation.
- Variable Speed**: Variable speed adjusts to changes in load and/or condensing temperature design – No reduction in performance.
- Soft Start**: Soft start module significantly reduces high in-rush current at startup.
- Compact and light weight**: Easy to install.
- Refrigerant**: R134a and environmentally progressive ultra low GWP HFO1234ze(E).
- Digital electronics**: On-board digital electronics control and manage the compressor operation proactively to optimize performance.

So, if you look at the summary of benefits of this type of a compressor.

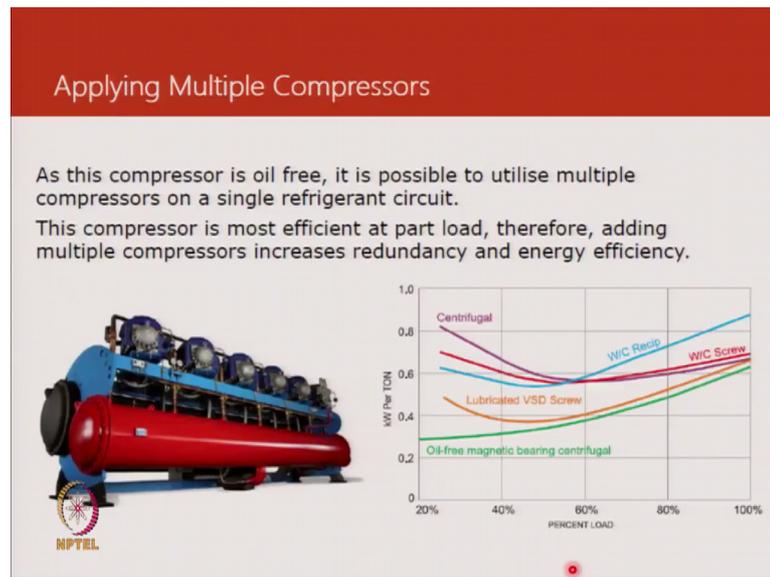
Student: (Refer Time: 31:28)

So, when a product is designed using let us say this compressor then the contamination levels that are acceptable in the system would be more demanded they would be more demanding for sure. But in any case in a refrigeration system and there is a lot of requirement for cleanliness even without magnetic bearings because any, let us say there is a metal forming process, you cutting the tube even the current level of specs without using a magnetic cool elaborated compressor require that they are kept within a certain specified limit not for reasons of magnetic, but because they can come between moving parts of the compressor and cause (Refer Time: 32:39)

So, the whole efficiency of a compressor water is driven by how much of a gap you have between the stator and rotor. So, that has already been limiting the level of contamination that is acceptable and a lot of contamination gets generated in the compressor when there is no metal to metal contact then you are actually in this design creating an opportunity of not having this contamination come up. So, because of this higher level of calibration you needed to run the shaft centrally you will have low noise and vibration.

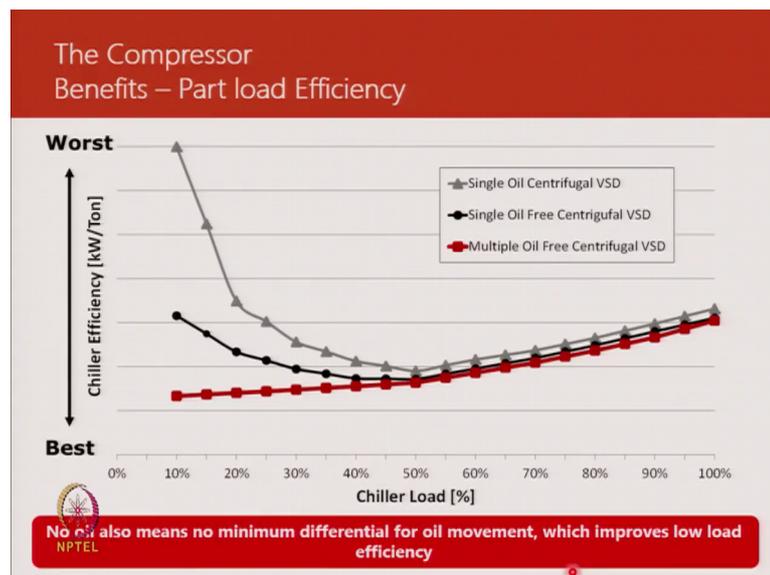
The single rotating component makes the manufacturing less complex and the reliability is higher because of fewer components is very simple, variable speed becomes possible because of the investment made in an inverter. So, capacity regulation is the key benefit soft start I talked to you about low current 2 amperes and then it makes use of an environment friendly refrigerant R 134a which is non ozone depleting, but it has a global warming potential and then we have a new refrigerant HFO1234ze and that is a new refrigerant with a very low global warming potential as well as 0 ODP and of course, the benefits of digital electronics.

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Then because of it is being oil free it is possible to run it slower when conventional compressors which rely on oil for lubrication below a certain speed oil will not return back to the compressor when you need a certain pressure drop pressure buildup for lubricating oil to flow. So, all those things are eliminated and then you can use multiple compressors together, allowing a lower part load operation.

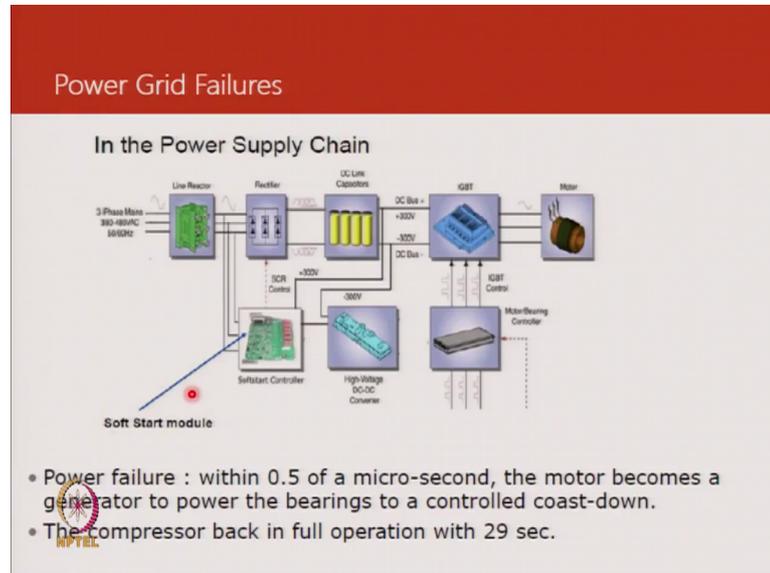
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This is a comparison between a single centrifugal variable speed compressor which is the first one.

And then a single oil free centrifugal variable speed compressor and multiple oil free centrifugal variable speed compressors. So, as you can see the multiple oil free centrifugal variable speed compressors all offer the highest part load efficiencies.

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Then we can look at some robustness issues so, we looked at failures that happen because of power delay things. So, what happens to this compressor? It has been made so, sensitive, it is dependent on electronics and suddenly you have no power what is going to happen.

So, that is been built into the design so, within half of a microsecond this compressor would begin to generate power. So, it switch from being a power consumer to generating power and that power is used to slow it down so that it gradually comes to rest, it done bang on the thing in the absence of and then when power resumes it is back in operation in 29 seconds.

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Higher Compression Ratio

Due to the high speed of the shaft the Oil-free compressor can achieve compression ratios of 5.5 making the compressor available for a wide scope of applications.

Water-Cooled



Air-Cooled



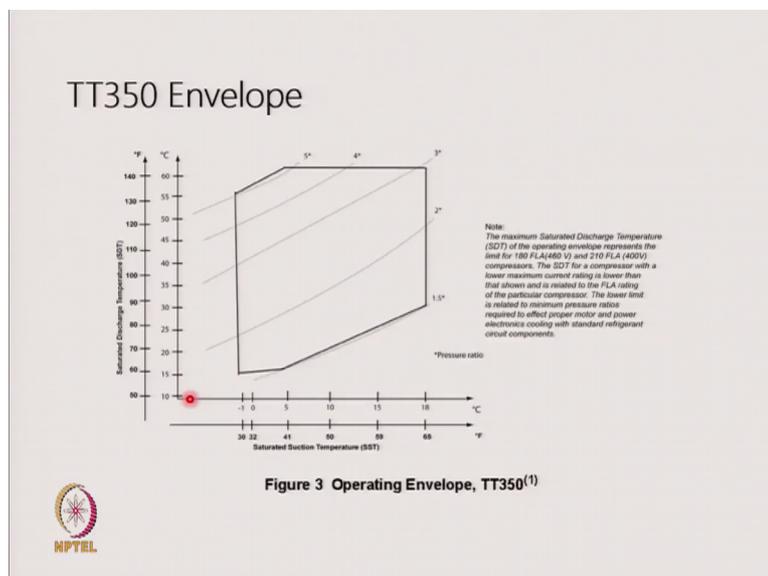
Adiabatic Pads





Now, this high speed of shaft of oil free compressor can achieve compression ratios of 5 and a half making the compressor suitable for a wider set of applications, wider meanings can be used for a cold in addition to water cooled and there is an increasing trend of using adiabatic pads with some condenser coils. So, I do not know too much of detail about that, but it is one option.

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This is a little bit on the operating envelope of this compressor. So, there are different models and TT350 is one of them, but this I would like to close the lecture and also it is the final session. So, I open up.

Thank you