RAC Product Design
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Lecture - 12
Case study on a railway air conditioning system

So, when you think of railway air conditioning what comes to your mind? Let us say you are the person designing an air conditioner for a rail coach application that is for comfort. So, what comes to your mind, what are the things that immediately come up, what would be a typical constraint that you would be aware of?

Student: (Refer Time: 00:37).

Yeah.

Student: (Refer Time: 00:38) it would be running (Refer Time: 00:40).

Perfect very good. So, we need to be present to Mumbai weather and Rajasthan weather at the same time, what else?

Student: (Refer Time: 00:55).

So, as you speak we will put down some of these things you know; as if we were designing it together, because that will get a flavour of the case study and how we design the product come up.

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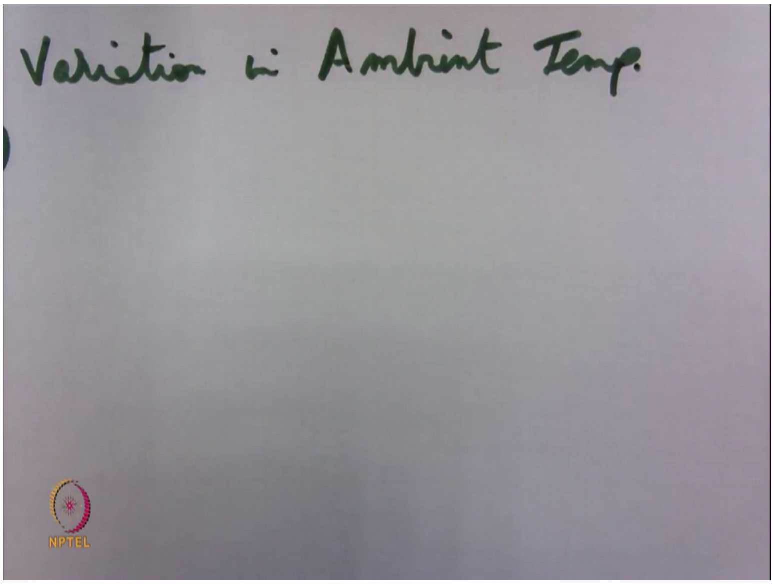

So, first thing we said was variation in ambient.

Student: (Refer Time: 01:21).

Yeah ok so, for the timing being we can remove this one and we will use it later on ok. So, this arrangement if some of you are wondering why I made this arrangement is in the course of this product design there was a consultancy project and that resulted in a paper that was published in one of the engineering journals. So, I have the originals from that time and I thought I would share that with you so, the idea was to have it not reflect so, we were going to use it later on.

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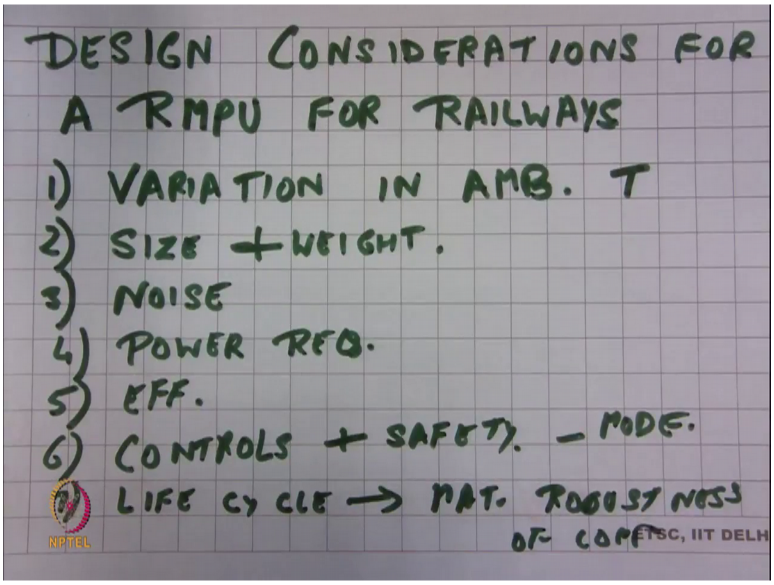

So, coming back so, design considerations let us say these design considerations. So, so in the second was someone said size very critical, because we go to use the size for the passengers or we can use it for equipment. So, should be say size and weight both what else?

Student: (Refer Time: 03:09) alright.

So, when you say noise meaning the noise in the occupied space should be minimal right. And so, for some of you are just getting connected you are looking at what are the design requirements for a roof mounted package unit for railways. So, we are going to look at a case study today, this is a product that I designed some time back and it is today a running product for Indian railways.

And I am going to give you some more idea on that, but right now let us try and connect with the first lecture you know when you are mapping requirements what are the things we look for. So, and this is something which will also help you do your assignment because, you are going to look at requirements in a different context. So, be involved and participate and I am going to make it easier for you to do the assignment and also connect to the design process. So, we have some good inputs coming in what else.

Student: (Refer Time: 04:07).

Yeah so, when you look at power requirement you are looking at single phase or three phase what voltage, what frequency? And then in railways it is a little more complex than just that we look at end on generation which is a generator car on the train from where 750 volt is transmitted across the train and then there are transformers in every unit.

So, that is another complexity that we have in a moving train and then we have some like coaches which have self generating type of coaches. So, there are batteries and there is a alternator and the alternator is powered by the movement of the coach so, it is connected to the wheels and there is an arrangement.

So, that power is not identical to the power available from end on generation type of generators, because of the wave form and again we will look at how that has an impact on reliability and performance. So, what else?

Student: (Refer Time: 05:12).

Yeah so, when you say control I will broaden to say controls and safety. So, controls includes setting the temperature so, you often noticed at night people want the temperature to be raised. I you have travelled by an AC coach you would have seen this constant tussle between different passengers, some wanting it a little cold the attendant needs to be able to vary that temperature.

Also an ability to switch from heating to cooling so, someone talked about the ambient. So, the ambient changing and you would need the ability to heat as well. So, so this would mean control of mode what else?

Student: (Refer Time: 06:09).

I do not hear you properly.

Student: (Refer Time: 06:14).

So, this impacts the material use the kind of robustness that we have. So, can you think of something more so, I will help you with some other things and I got to know from experience. So, one of the ways to check the suitability of an air conditioner is how soon can we pull down the temperature in a coach. We need to have it ready for passengers to board the train in many times its standing in the sun so; the ability to pull down the temperature would be one of the requirements.

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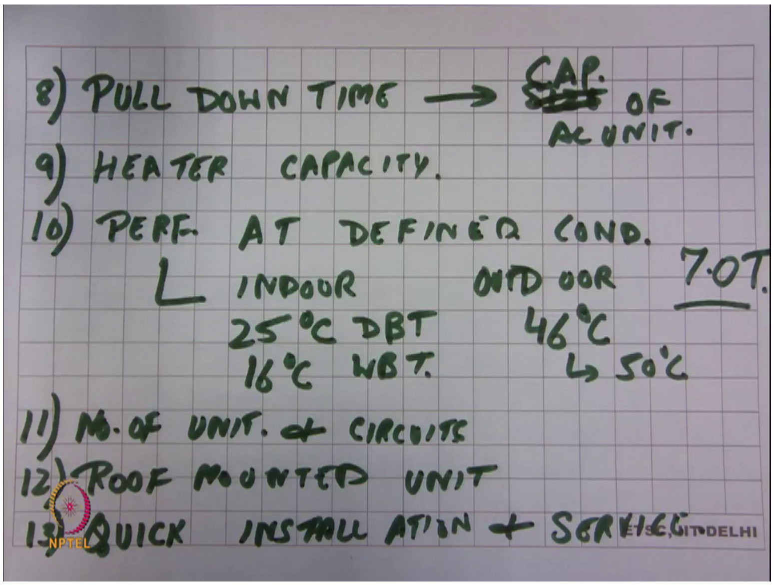

So, we were on 7 let us say this is 8 so, when we look at pull down time it has to do with the size of and my size I mean the capacity, capacity of AC unit. Then we can also look at the maximum load in the worst ambient it would be one of the critical things in Rajasthan when the yeah.

Student: That is pull down (Refer Time: 07:38).

Yes.

Student: (Refer Time: 07:39).

Right.

Student: (Refer Time: 07:41).

Right.

So, we can all right so, a from a pure analytical perspective we absolutely right, but what happens is in this the critical condition ends up being pulled down in hot weather. Because, the moment you have occupants inside an insulated compartment so, it is double glazed glass windows, then you have insulation on the walls the roof is insulated.

So, heating does not end up being a critical thing, otherwise you would say what is the time required for raising the temperature, but for sure we need to be aware of what capacity of heaters we are going to include?. And in the case study we did not find this to be a constraint, but when you are looking at it from a requirement definition you absolutely on point.

Student: In the previous unit do not do this (Refer Time: 08:36).

No, it is more like in winters if you have fairly large number of persons and in the same room which is insulated. Then even without a heater you very soon begin to feel comfortable because the lights the load of the occupants begins to raise the temperature right. But if you look at a summer condition then we have a combinations the entire coach has been heated because there was no air conditioning so, there is been conduction.

And then people are entering so, that is another heat load. So, overall the whole thing is aggressive in terms of what is needed whereas, the occupant heat load is enabling for getting the temperature to the comfort point when it is a heating applications. So, that is the main difference, but in a requirement definition yeah. So, we let us put it as heater or capacity right.

Because your question may become very relevant if you were looking at it in a climate like US where the ambient is in sub 0 conditions minus 7 and all that and how soon can we get the temperature up. So, then that could become the dominating requirement in another country. So, we also would like to define what cooling we need at what condition right so, performance at defined conditions.

So, in railways there is an organization RDSO and they were already having data based on a different kind of technology, there was a understand technology. So, these conditions were pretty much well defined in terms of indoor conditions. So, the indoor conditions 25 degree C DBT, 16 degree C WBT this was the test condition at which we had to look at capacity.

And in every coach there are two units two roof mounted package units, but then again in the requirement definition stage we will also need to say how many units in what level of redundancy. So, number of units and circuits and I will explain a little more on the circuits. So, on the performance side we have indoor conditions then we have; outdoor conditions so, the outdoor conditions were progressively redefined. So, does 46 degree centigrade in the beginning and then it was raised to 50.

Now, this is another example of deriving a condition based on real applications and a mismatch between the test condition and a real condition. So, to appreciate this point I will switch to a slide and you know give you a little more perspective on the type of assignment this was. The case study originated out of railways intent to switch from a particular type of air conditioner to roof mounted air conditioner.

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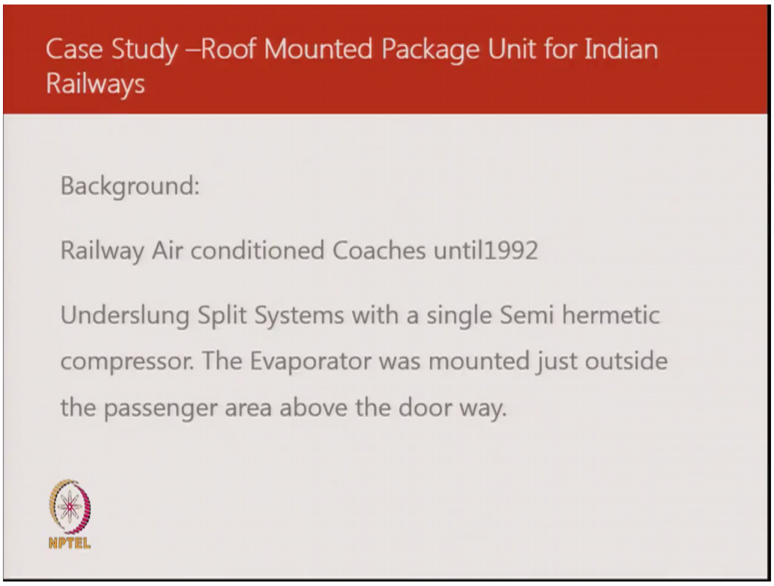

So, so, railway air conditioners until 1992 used a technology which was under slung condensing units connected to an evaporator which was mounted above the entry area. So, under slungs split systems with a single semi hermetic compressor and they used R 12 as refrigerant. You want to come back to the requirement definition, but what I am going to share with you now will put another perspective of how the requirements are flowing from an earlier design to a new design.

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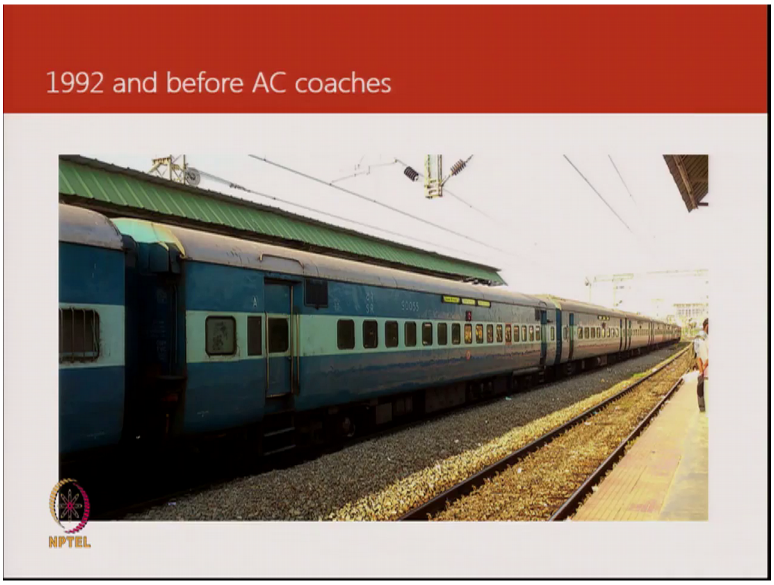

So, this is a view of a train and if you look at the area; so, this is the area where the condensing unit is there and this part is not so clear so, the next slide we can see it a little more clear.

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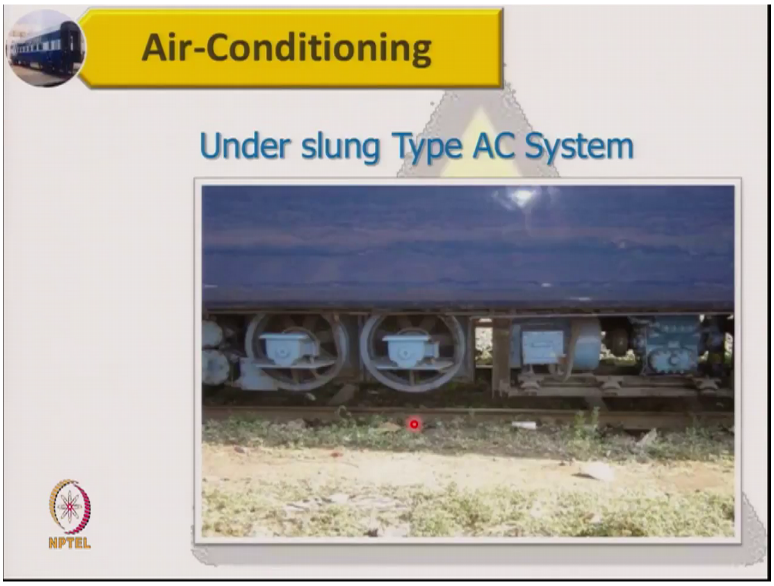

So, there are two fans there axial flow fans and then there is a semi hermetic compressor which is driven by an electric motor. So, this is a very bulky equipment which was using R 12 as a refrigerant it was imported and then a part of it was indigenized stone India was a company that was the only supplier for these equipments.

So, railways was in a having a need to put in a large number of air conditioned coaches at the time this project was envisaged. And the intention was to go in for something which is locally developed, at the same time it is easy to install and it is relatively more affordable. So, that a large number of air conditioning air conditioned coaches can be introduced in Indian railways.

So, that was more or less the background and it was also the time when I joined Fedders Lloyd as manager for R and D. So, my predecessor had already done some prototyping work based on RDSO project which was given to Fedders Lloyd and one other company to make a prototype and test out the concept of a roof mounted packaged unit. So, what does the roof mounted package unit lead to? It leads to a unit of this type.

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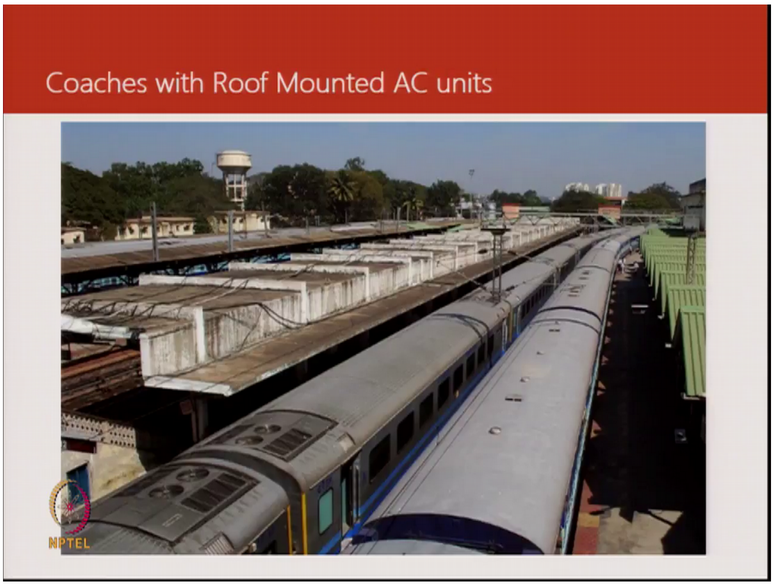

So, if you look at these two units these are on the roof of a train and they are connected via ducts to the occupied space. So, every coach would have two units on either side and this is for the standard application. If there are smaller coaches or first AC coaches they could have 1 unit or different capacities, but the time when I was involved the project in the case study I am referring to it was 2 units to 1 coach.

So, now we switch back to the requirement definition and this was to give you a glimpse into what was. So, to have it on the roof, this was another and this kind of answers the earlier question about size as well and what else beyond that quick installation and service.

So, earlier the unit would require 4 days to install in a coach this would be installed in 4 hours. So, that was the kind of design intent that was there.

Student: Load on system.

Sorry.

Student: Load on system.

I did not get the question.

Student: Velocity of this system.

So 7 tons, add these conditions this is how it was originally. Some more requirement that you can think of you begin to think and I am happy about that. So, you are getting engaged so, when you drop a requirement for a new product design this is the thing you will do, you will have something very explicitly stated by the customer and here it was that it has to be on the roof.

It has to be quick to install, there were certain capacity requirement given and then there were certain things which were not really known. So, at the time I was in one of the project I did not know all the parameters I knew what was on paper.

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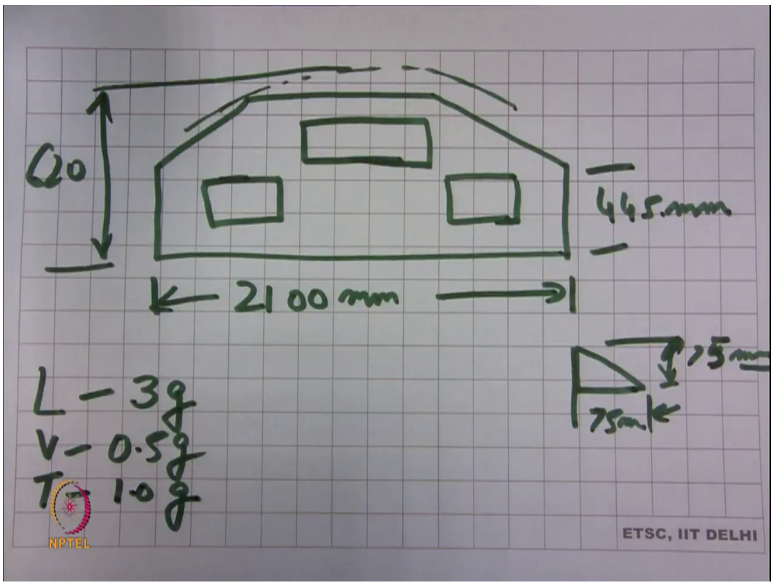

So, there was an there was a requirement from the customer which was on the size which came in like this. So, this is 2100 millimetres, this was directly related to the width of the coach and the required interface for mounting it. And then the rest of it was all for us to design except the ducts. So, there was a duct here for a return layer to come in, another duct here for return I had to come in you know supply air duct on top. And then there was a requirement here which was 445 millimetres and then there was a curve.

So, the max limit was 620 and this was to take care of the coach clearing any hurdles on the way so, this is the max height limit. And this is to do with the space constraints then, we had to look at interfaces on how to mount it? So, if you look at this area or typical mount would include a projection on the side, which was again defined by the customer as 75 millimetres here another 75. And then it is not defined that there needs to be a vibration isolation at what level, but the vibration conditions were defined.

So, in railways there is something called shunting shocks when coaches are being assembled together, joined together so, there will be a shock. So, we need to define the level of a shock. So, in the longitudinal direction the shock is defined as 3 g shunting shock so, instantaneous momentary shock. And then, vertically 0.5 g and then there will be your transverse number which was 1.0 these were the kind of conditions. So, you can relate to it that while the coach is in movement there will be some movement perpendicular to the track some up and down, because of the joints and then while talked about shunting shocks.

Now, how do those all these things matter in our component selection and in a design of piping we need to be aware of all these things to be able to withstand the full life of a AC unit. Now with all these things given we began by looking at design of the unit first of all component selection. So, we have gone through a lot of component selection exercises earlier I have shared with you different compressors all that. So, here the 7 ton requirement was split into two compressors two independent refrigeration circuits. So, each compressor was having a capacity of 4.3 tons and this came out from what was standard available.

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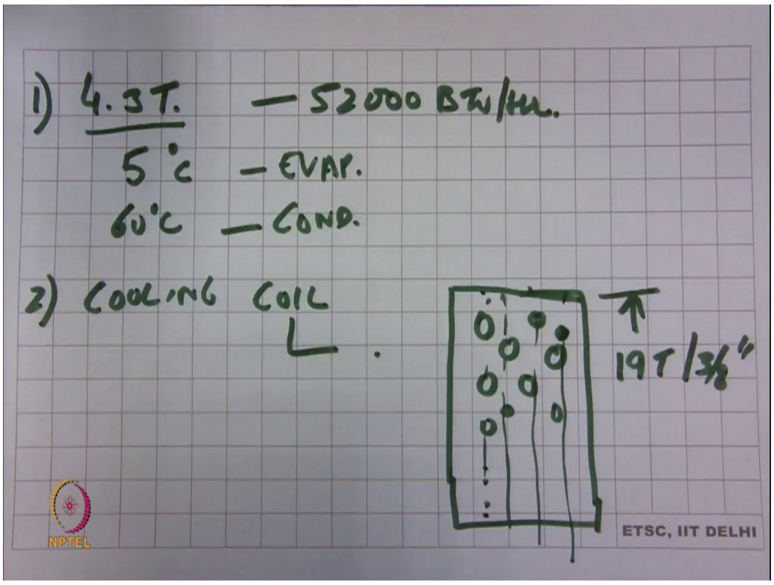

So, there was something available at 45000 BTU and then 50 52000 BTU per hour and all that. So, we selected 52000 BTU per hour compressor as a baseline based on the railway requirement and the evaporating and condensing temperatures of this compressor right. So, what are those conditions at 2516 we opted to look at 5 degree centigrade evaporating temperature. Do you remember some of these parameters from the thermodynamics that we discussed, can you relate to evaporating temperature for a compressor? If you cannot we can talk about there also if you can nice.

So, the intent was that at these conditions we should be able to get 3.5 tons from this compressor. So, these are off design conditions is not the rated condition this 4.3 ton is the rating condition. Now, having selected a compressor we also need to look at selecting the cooling coil and here and there was a big challenge for me. Because, in the organization there was not any heat transfer software that was available, I had not done anything during my stay in IIT on designing a heat exchanger. So, what was available to me was existing product designs and some way to scale them up or down based on an application.

So, the closest reference I had was a 3 ton unit and based on applying scaling and the need to circuit balance we made a coil design which look like this. It was a 4 row coil staggered and the total height was equal to 19 tubes 3 by 8 inch diameter. And then the next question was how many circuits? So, how do you look at the number of circuits in this whole design? So, if you put this as 1 row, this as the 2nd row, this as the 3rd row and this is the 4th row or before doing this let me also share with you one of the schematics of this unit as to what the layout look like.

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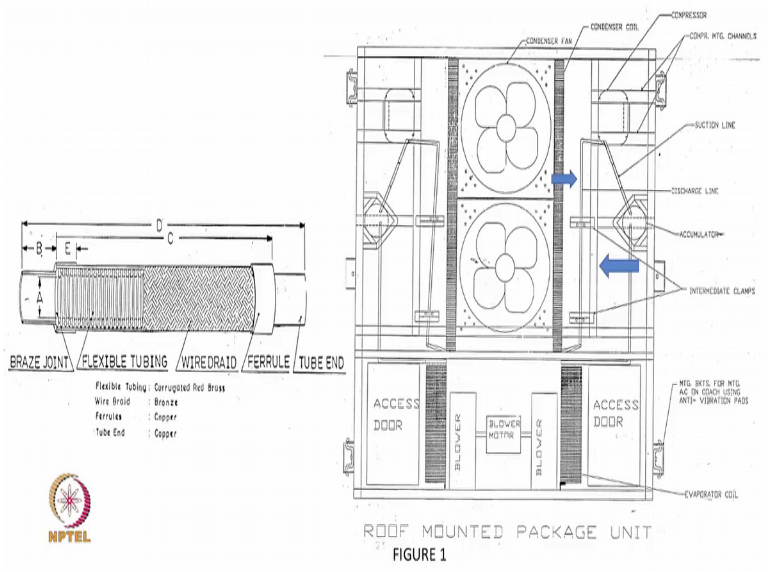

So, now is it so, this is the evaporator coil that I am talking about, there are two of them. And then this was the overall layout so, from the dimensional requirements we tried to fit everything within the available space. So, there is a compressor here which is exposed to the ambient there is a condenser coil which is vertical. The second condenser coil which is vertical there are two axial flow fans, propeller fans, in the condenser and then there is 1 blower motor connected to 2 blowers and then each of the blower is drawing air over the coil here and here.

So, the circuit that I was sharing with you was for these two coils. So, we came to the dimensions based on scaling of equivalent configurations then, we also had reference of what was working already in railways. So, based on that, we made some calculations to ensure that there is no condensate carryover and, if you refer my notes 2.5 to 3 years an acceptable phase velocity for no condensate carryover. So, keeping that in mind we had the airflow selection done and the circuit by circuit balance was one of the challenging things as to how do we have the same circuit load per circuit.

We did this through trial so, we did experiments to see which circuit was being fed refrigerant, which is a little higher than required and which was being fed a little lower than required. And that requires a certain understanding of some other components of a refrigeration circuit.

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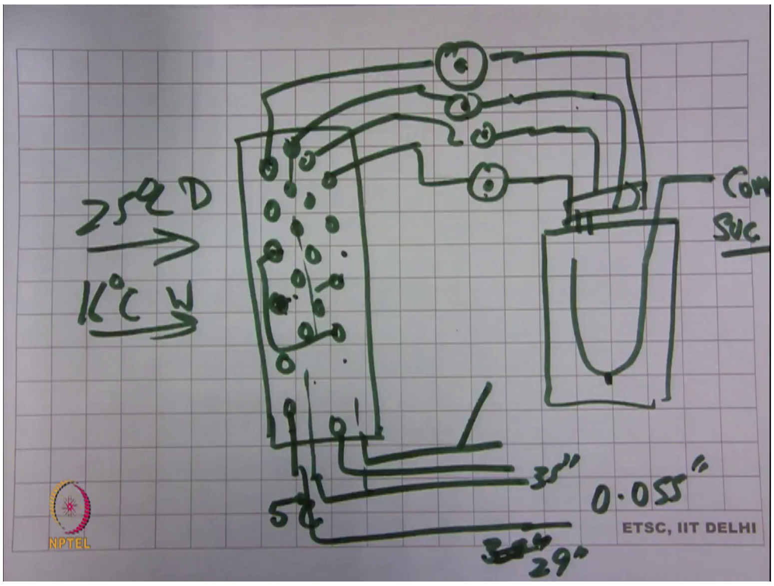

So, let us say we have air coming in at 25 degree centigrade, 16 degree centigrade, this is dry bulb, this is wet bulb and then we have different tubes in each of these circuits. So, if you look at the temperature difference for all the tubes in this section, they would encounter the highest temperature difference. If we were having refrigerant entering at 5 degree centigrade and this side would have the lowest temperature difference. So, one way of balancing is that midway in the coil we swap. So, we have a tube which connects this to this and we connect this through another loop to this tube. So, we kind of manage balancing the circuit and this we could do it even before doing our first trials.

So, we could envisaged that there is going to be a difference and then the two inside circuits again midway in the coil design we swap them. And then, there were four outlets available from each of these circuits. So, we put a side glass in each of these circuits. So, side glass essentially allows for refrigerant to enter that device then, there is a glass opening and there is an indicator for moisture.

So, the indicator which is at the centre turn changes colour based on whether there is moisture or not and that is a separate requirement for a refrigeration system. And the other part is you can see whether you are getting 100 percent vapour or a mixture of vapour and liquid. This setup enable us to look at which circuit was overfed with refrigerant and which circuit was starved of refrigerant, when you are doing the circuit balancing.

So, the feed to each of these circuits was again through a capillary and it was possible to resize the capillary which is the expansion device. So, that finally, there is a balanced load and this was the purely experimental approach to getting to a balanced circuit. So, this is one part of the design and it also illustrates that when we do not have the best analytical software, we can still achieve the objective of a design by looking at some very fundamental.

And direct ways of measuring the performance of a subsystem sub system here being the evaporator coil. The next risk in a system is of a low load leading to some refrigerant in liquid form getting to the compressor. So, what we did was we put in an accumulator and I have not discussed with any of you an accumulator before right, now, you just a device which will take care of all liquid getting entrapped and only vapour going to the compressor. So, so this circuit actually gets into a header and the header is feeding the accumulator and inside the accumulator there is a tube which goes to the compressor suction.

This tube has a small opening at the bottom allowing for oil to be picked up. So, that it continues to be in the system, I had fun actually designing this product because, it was my first real product and I had given up what others considered as a very good company. So, I work for ICI Imperial Chemical Industries before that I worked for talking gamble and each of these companies gave me good perks, but no real content to create a new product. When I was here I was actually driving everything, all the decisions for this product were my domain no interference. Except one occasion where chairman came up and said you know why not doing what the competitor is doing and that was the only one instance where I found that there was some authority trying to dictate what I should be doing.

And I could handle it on the shop floor in front of 10 other people, I said look there are two ways of doing this, either you tell me what component I will use. And then you are responsible for the result or you let me choose the components and then I will be responsible for the result. And fortunately, that guy was very mature he was like 17 at time, he understood he backed off and post that so, I had my freedom.

So, I had all the fun all the experimental freedom to choose components try them out, but ultimately responsible for delivering the product. And the product delivery main use railways will come in so, they will have a set of senior persons along with some technicians.

They will test the product, they will do their own bit of verification on specs, they will count the number of fins that we said we will put in the evaporator coil, the number of circuits what source of components we are using, what compressor we are using and all that. And that is the some part, but before we could reach there we had to make sure that the product is really worth presenting to the railway officials and it meets the spec. And these are some of the things that we did which were which you would not find in textbooks. Which were making use of what I learned here, but it was also applying something using what some of the component suppliers were sharing other information and some of my own innovation.

So, where were we were on designing the evaporator coil so, the basis of design was scaling up a 3 ton coil. So, it was simple then balancing the circuits so, we know that there is a temperature difference which is very different here then, it is over here and somewhere in between. So, we apply very fundamentally simple rule that we are going to have the same number of tubes on one side and then the other side and expect that to balance out. And then whatever remains we will change the length. So, we use capillaries and if I remember this was 0.055 inch capillaries.

And they were two different lengths so, for the outer circuits the two outer circuits we could use 35 inches and the inner circuits had to be no do the other way around. So, these are 29 inches more refrigerant flow and these were 35 inches in the centre and this was done. So, that finally, we see clear side glasses at the outlet of each circuit.

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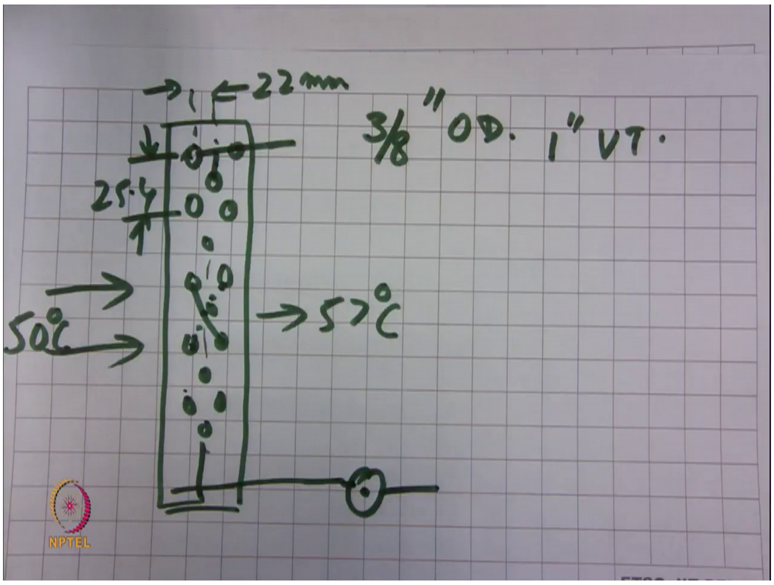

Now, having done the evaporator, then the condenser was relatively more simple we made use of a 3 row condenser coil, again staggered 3 by 8 inch diameter. So, for those of you who want to take some notes is a 3 8 inch outer diameter 1 inch vertical pitch and the distance between this applies actually to both the evaporator and the condenser. So, this distance was 22 millimetres row to row and this was 1 inch or 25.4 in both the types of coils. So, here we had discharge gas coming in on top so, we make a header which feed then these two and the central circuit and we apply the same principle.

So, in a condenser what is going to happen; when we doing testing we would not have hot air come in at 50 degree centigrade. And leave it somewhere like 57 degree centigrade, again we need to balance the circuits and here there was not any capillary available to adjust the flow. So, it was what it was and there was a certain inefficiency which we knew would happen. But, 3 circuits made this whole thing a little simpler so, one circuit we would just get it right down into a header here and these we would swap midway. So, this tube would connect here and this tube would connect to the other side.

And again we would put in a side glass with a moisture indicator right at the bottom of this coil to be sure that when we are charging refrigerant we are having liquid sub cooled liquid at the outer to the condenser. So, with this done and the capillary selection was arrived at by some experimental means we had a product ready for testing.

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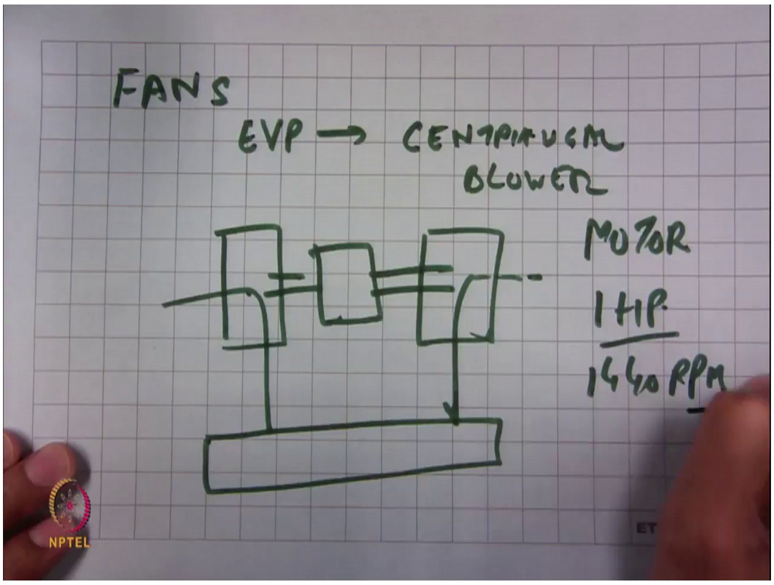

So, the other components that we had to select were fans and motors. So, the fans for evaporator we had a centrifugal blower and as I shared with you there were 2 blowers on 2 sides of a motor. So, with air coming in and leaving here again air coming in and leaving and this was fed into a common supply air duct which is connected to the coach central duct. So, for the condenser or let me also define for you. So, the blower motor was 1 HP 14 40 RPM and here in the condenser we had 24 inch propeller fans.

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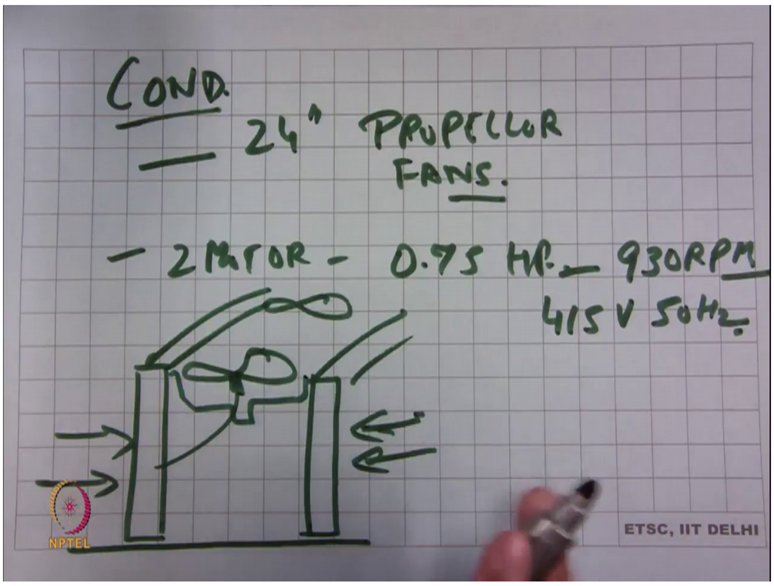

So, some of this heat exchanger design was also simple based on experimental data that is available for other package unit. So, let us say a 7 and a half ton package unit is available with the testing run at 35 degree centigrade. So, it is possible to upsize or down size that coil and get a data point. So, the condenser, we have and 2 motors, this was 0.75 HP and 930 RPM. So, again all of them were 4015 volt 50 hertz rated condition both for the blower and for the condenser.

So, we made a selection on the compressor we made a selection on the evaporator, fan condenser and blower. On the condenser if you want a little more detail it was length between tube sheets was 1320, the height was 22 tubes, effectively 22 inches and they were vertically. So, the condenser if we were to look at would be a configuration where there would be a fan over here and another condenser on this side and this would be the base. So, an ambient air comes in from both sides and if you look at it longer tube may there would be another fan at the back like this.

And then, this would be fed in towards this and a mounting was a flange mounting. A lot of this engineering detail I am not in a position to share because whatever company I worked for does their property and all that. But whatever was used in some research papers I am going to share with that in a vibration study that fitted right. So, then this was a we came to a point where we had a prototype which could be tested. And then there are certain things that were to be considered after the prototype was made. So, things like how do you drain condensate?

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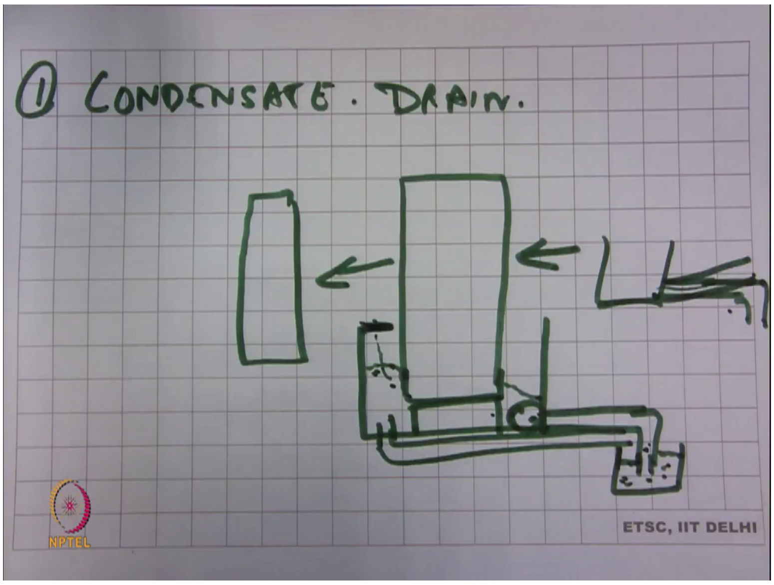

So, this becomes more complex in a railway application because, you have water and the water is not a splash because the movement and then there is going to be static. So, you have a powerful motor drawing air over a coil which is 4 row thick, then there is a filter and all that put together means a static, no static of a 20 millimetres will tend to hold condensate between the blower and the evaporator coil.

So, this was what we started with we had a coil like this, with some padding at the bottom and I am showing one side of the coil. So, this is going here and we have the blower. So, because it is static over here there would be an accumulation so, if you looked at water it would be higher on this side and relatively low on this side.

And then, if we try to drain this water to the outside where the static is atmospheric there will be a build up. So, this is something we never got from railways as a requirement we did not know it until we put the unit on a train and it went a couple of times to Bombay. And then we got passengers complaining that there is water being thrown in, our first guess was that Bombay is humid there is rain and therefore, it is rainwater from the trough [laughter].

So, we went and you know it was rainy and we found that there was water from the trough which could also spill in and that was another thing that railways had to take care of. But then, we also found that this was a concern area. So, the design had to undergo some changes so, the changes were to put some kind of redesigned drain pan. So, that if there is any splashing the water will not go out, but will fall back in. And then the drain was to go out into a cup a siphon kind of an arrangement. So, that the static was effectively addressed. Again this is not something you would find in books you need to find an innovative way to solve the problem when it occurs, it is totally unknown at the time we were making this design.

And this effectively solved it so, we created a head of a 25 millimetres and then there was no problem for water and we put the drain on this side. So, the water could actually come in and then get drained without any issue. But it took some trips to a real working unit finding out and also addressing other things. So, other than this part there is a slope that is required between this and the connecting part. So, before we made this arrangement the condensate from the drain pan so, if you make another drain pan was directly connected to the coach and was expected to go down, there was a height difference between this and the drain pan.

So, instead of water flowing like this, they are created a condition where it was unique is design to accumulate. So, you have static and then you also have a difference in level. But all these were related to you know solving problems that essentially, did not addressed some things which were system level things and certain other things you should do with the interface.

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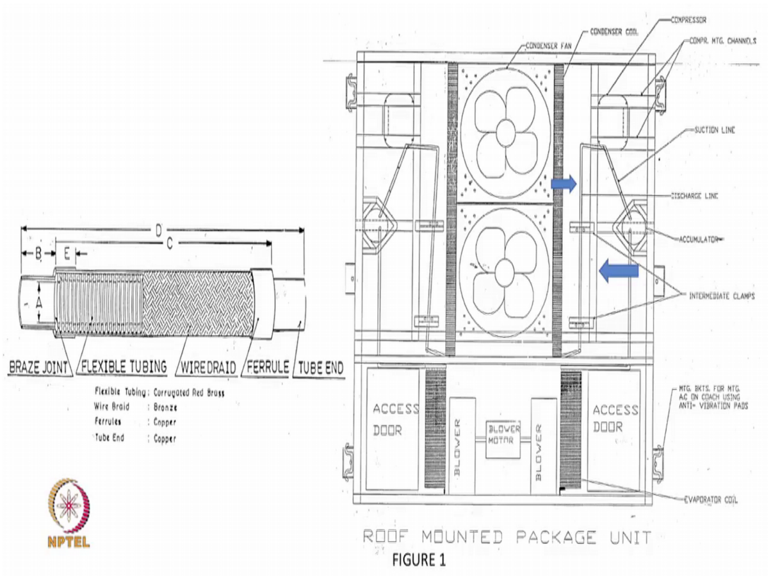

So, in this design we can look at some other unique things that were needed for a AC design for mobile application. So, you see a flexible connector so, this connector has a bellow which is made of copper, which is this part. And then there is a braid, which is again made of wire copper wire and this is to imparts strength and then there are two connectors. The intention of using this between the compressor and the rest of the system was to allow for flexibility. So, that because of train vibration and the heavy mass of the compressor there is no fatigue on the tubing. However, when we put this unit in service between Delhi and Bombay, there were no issues, we were very happy and we got repeat orders from the customer.

So, 4 units went straight up to 8, it was still like a pilot phase to prototype to 4 units to 8 units and those 8 units were put in service from [FL] Amritsar so, Amritsar to Delhi. And within the first few trips we got complaints that the units are leaking and the first doubt normally goes to something to do with workmanship. So, there were technicians there was a whole team so, they were repaired and they would go in service again and return back with the same complaint, the failure was exactly at the same point. So, we had a major loss of credibility what was happening with the design? And if there is a repeat failure exactly at the same point then, it is clearly and not a workmanship or a manufacturing issue it is a design issue.

So, someone who was very happy about having designed product that works was suddenly under scrutiny, Bhupinder what I have you done? You know so; the credibility was a major question mark. And everyone had ideas on to how the piping design should have been done [laughter]. So, I had a major you know a difficult period for that 1 week, handling railways, handling internal customers and the company management as to what had gone wrong in the product and I realized that I did not have all the answers.

So, the first thing that I had to accept was that I did not have all answer I did not have a clue as to why this is failing. And also I had deliberately stayed away from vibration because, I founded to complex a subject. I mentioned there is not many early lectures and [FL] you know [FL], but [FL] it requires too much of mathematics. So, here I am in field having done a product design and I am hit by failures because of vibration. So, the next best thing was [FL] you know I was still a few years out of college. So, I said lets sign a concept consultancy project.

So, the moment I got management to agree on a consultancy project between IIT Delhi and Fedders Lloyd, everyone was advising me was suddenly shut because, now whatever they say was subject to scrutiny. So, if someone was wondering to advice to use two pack less vibration isolators type of tubes like this to better take care of vibrations they are no more saying that.

Again I got the freedom to do what I wanted to do? Which means the do a systematic study as to what is the root cost? At a tremendous cost. So, for 6 months we had no orders from the customer, but then there was no other way, unless we get to the source of the issue the design issue there is no point going forward. So, we did that and that was what led to this research paper, which I will you know take in the next lecture.