Energy Conservation and Waste Heat Recovery
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Lecture - 57
Energy Storage Systems – VII

Welcome back friends to the next lecture of Energy Conservation and Waste Heat Recovery. Today what we will do is we will continue our discussion on thermal energy storage. So, in the last class, we talked about sensible energy storage and looked at pressurized water storage as an example of sensible energy storage.

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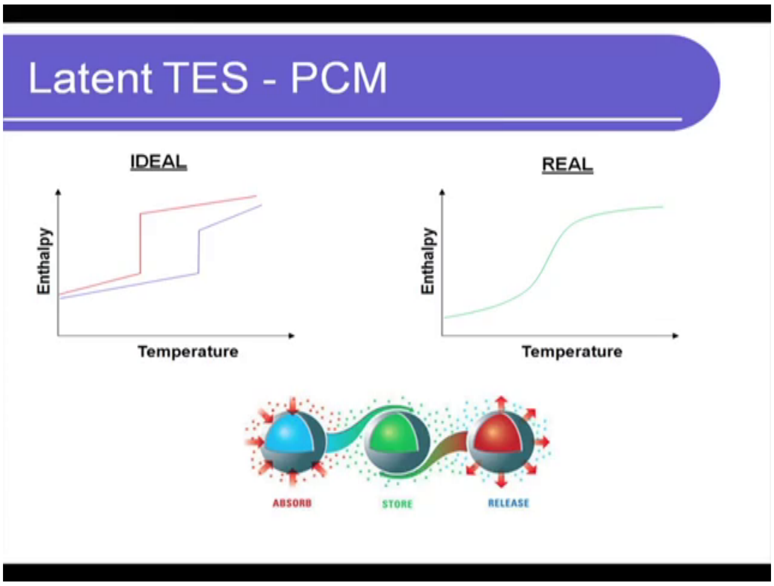

So, today what we will do is we will look at latent thermal energy storage.

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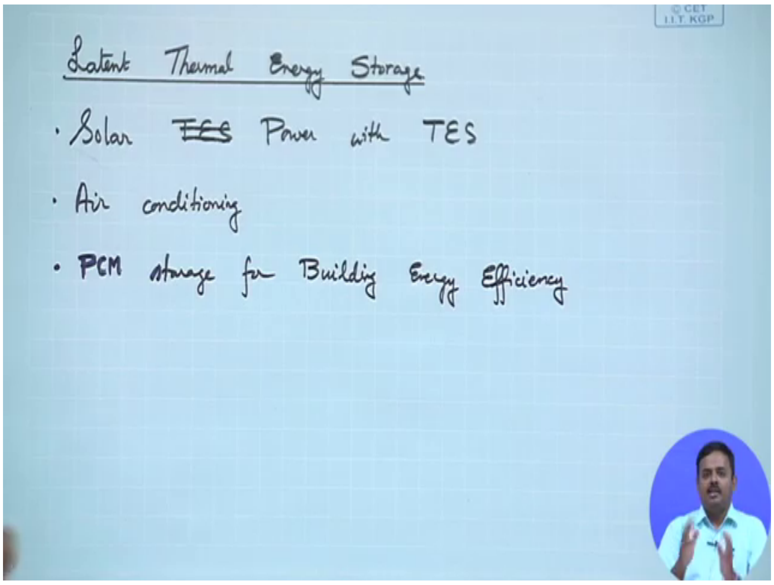

So, let me write it down. So, I will write it down as latent thermal energy storage and as we said before this is when energy stored because of change in phase. So, typically we will say left side is from solid to liquid. So, as we know as a substance melts it absorbs heat and therefore, it changes to liquid and then if we can maintain it in the liquid state then the energy is already stored and then after that if you want to release that energy we have to cool it down. So, that as it solidifies it releases that energy which we can use.

So, what we will do is this is what I am trying to show here. So, this is where what we need is we need a material PCM is called phase change material. So, this is a class of materials which can be organic in nature which can be inorganic in nature. So, the PCM that we are most commonly or we are most familiar with all of us is wax.

Paraffin wax; it is an Alkane and the way it works is as you know that if you heat the wax beyond a certain temperature it melts and if you cool it down it solidifies right. So, that is why when we write light a candle the wax melts when it; when it gets heated; so that being said if we now let us assume that it is a wax type material and let us say; we increase the temperature.

So, what happens? The temperature at the beginning is going to rise because this is sensible heating this is still in the solid state and then at some point this temperature for this material mark in red this temperature corresponds to its melting temperature. So, then what happens here the temperature does not. So, and I am I am applying heat that is that is granted. So, as I keep on applying heat the temperature does not rise beyond this, but what happens is that enthalpy increases at a constant temperature and why this happens is because of change of phase and then once it has completely melted then again as I keep heating it; it is in the liquid state and because of sensible heating the enthalpy goes up and. So, does the temperature.

So, this is for material a this is for material b all right and let us do the vice versa now I keep cooling it down and reducing the temperature again the temperature will come down and then we will reach a point where the temperature will not change anymore, but the enthalpy will reduce and at the at this point it will give up heat and then if we cool it further the temperature we will see again is falling down.

So, this is an ideal case where in a real case you know this wax will never come as just loose material it will be encapsulated in something etcetera. So, in a real case typically we do not see such a sharp rise right what we see is a more gradual increase like this you stills you stills see that 2 phase behavior over here the change of phase behavior, but instead of it being just a sharp rise it is typical in this form clear. So, it is happening over a certain finite temperature range. So, in PCM what is the function or what is the principle on which it acts as energy storage.

So, as it absorbs it melts; it changes phase the solid becomes liquid and then it is stored and then when we cool it down; it is released and it changes its phase back clear. So, this is the principle of operation of thermal energy storage using latent heat, all right.

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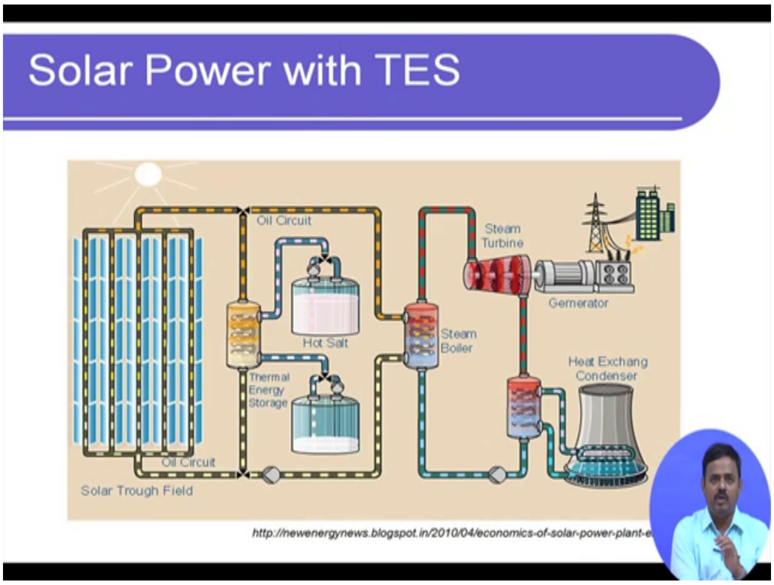

So, what we will do next is we are look going to look at 3 examples and the first one is going to be just an example here; now you can think of a lot of other variations using the same principle.

So, solar or rather I would say solar power with thermal energy storage. So, what is happening here now let us look at this picture over here and try to see that where how this works. So, we will spend a little bit of time trying to understand each and every component of this by the way solar is just one of these is it is an example as I said.

The source of heat can be anything else, but why solar is because the energy source is available to us only during daytime and not during night, but whereas, I would like to generate power throughout the day right maybe a little less at night, but still I would like to generate power I cannot switch off power generation during night just because there is no sun. So, how do I do this I need to store energy that I am getting during daytime to be used during the night?

So, what is happening over here over here this is the solar trough and where we are getting the solar energy from the sun. So, through this what happens is there is a circuit there is an oil which is a working fluid in the in the in the in the solar loop and that is denoted by this yellow line dark yellow light yellow and so on. So, let us now forget this part both this branch and this whatever this hot salt and so on whatever we are seeing let us forget now.

In a regular instance what happens is this oil gets heated up by the sun. So, its temperature rises it; it does not boil by the way its temperature rises and therefore, its enthalpy rises then it flows through this loop and comes to the steam generator and where it acts as a hot fluid. So, here what happens water goes through this steam generator or the boiler where it picks up heat from this oil and evaporates into steam or boils into steam and this steam is fed into the steam turbine and then the exhaust from the steam turbine is fed to the condenser and the condensing water goes to a cooling tower this is the standard power plant that we already know.

So, this is evaporator or the boiler this is the turbine this is condensed this is pump clear except over here the source of heat instead of being combustion gases from natural gas or coal is actually this oil hot oil which has been heated up by solar energy clear. So, this part of the loop is clear to you, all right. So, this oil when it comes out of the boiler it has given up its heat for boiling the water that came in and generating the steam.

So, therefore, what comes out is cold oil or oil at a lower temperature which is fed back to the solar panels all right. So, this is how this normal generation happens, but now if we do this only then what happens I am going to generate power from this turbine during day or when the sun is there, but; however, I will not be able to generate power during night or during a cloudy day like it is today outside I will not be able to generate, but that that cannot work, right.

So, therefore, I have to store some energy on a sunny day. So, that it can be used later during a cloudy or rainy day or during, night. So, that is what is done now by this circuit or these components what happens here what I am going to show over here is this is molten salt hot salt. So, this is an inorganic phase change material which beyond a certain temperature can be melted and as it melts its source heat and then as it solidifies it releases heat clear.

So, let us say during day time what happens the hot oil from the solar panels is actually instead of going entirely to the steam generator over here it branches off into 2 streams one of them one of it goes to the one of the streams go to the boiler and the other one flows through another heat exchanger in this heat exchanger what happens is during daytime this salt goes through and is melt and stored in a hot is in a molten state at a high temperature clear.

And then what happens is. So, what happens during the daytime I am generating some power from the steam turbine and I am also generating heated molten salt which is stored in this reservoir as expected therefore, like here the oil that comes out of the boiler is at low temperature and the oil that comes out of this heat exchanger during daytime is also at low temperature and the 2 of them merges here the 2 circuits merge here and they go back to the solar panels. So, therefore, this is how the oil circuit works during daytime, all right.

Now, what happens during night during night there is no flow from here right during night; there is no flow from here. So, therefore, the oil actually flows in this direction where the salt right now releases heat to the oil clear. So, the salt starts flowing from the top container to the bottom container and the oil moves up like this during night time or during a cloudy day the oil will move up like this and gain heat from this heated molten salt and then the cool down salt will accumulate in the lower reservoir the heated oil then will go through this circuit go to the boiler generate steam. So, that the power generation is maintained and then come back and just complete the loop like this; clear.

So, during daytime the oil branches off into 2 parts one goes to the stream to the steam generator and the other goes on to heat the salt during night time when I do not have solar energy this heated salt actually heats up the oil which is fed into the boiler and we generate steam for electricity generation clear all right. So, I hope this figure is clear now it is very nicely represented, but only thing is you need to know what is happening clear.

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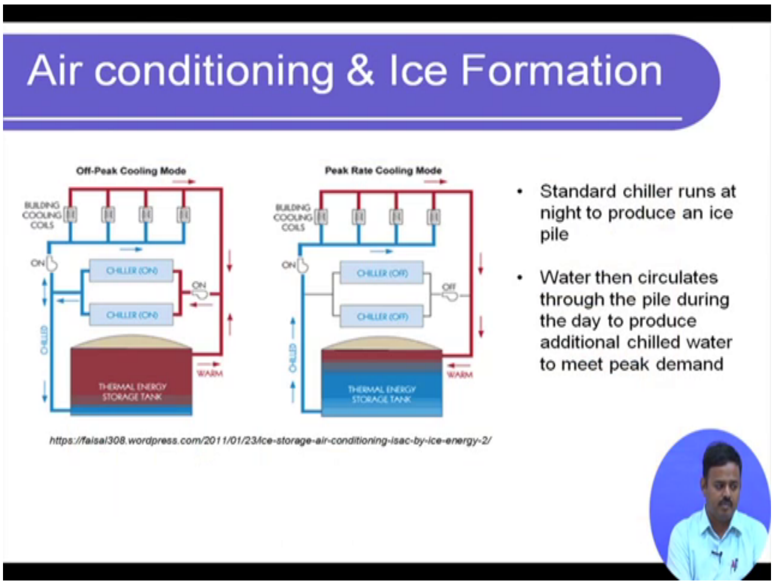

So, this is one example where I am using solar power with thermal energy storage what else this one is latent heat again or not again this is latent heat energy storage this is for an air conditioning and ice formation. So, before that see air conditioning units that the way we see the standalone split AC or the window ac actually haves the refrigerant flowing through the evaporator coils over which air is blown and that is the that is the refrigerated air or the cooled air that we get inside the room.

But if you look at larger installations for example, this academic complex that I am in right now hotels, etcetera; so, there what happens is you have a large air conditioning plant and where you actually produce chilled water and then the chilled water is re-circulated through the different rooms of that of that utility and that over the chilled water pipes is where we blow the air and the air cools down.

So, the evaporator units the so called coat and coat evaporator units that we see in the rooms of this let us say in this classroom or in the hotel rooms etcetera or in the office building is actually not a standalone ac and they where the refrigerant is flowing through the evaporator coil, but it is actually chilled water that is flowing and. So, it is a heat exchanger. So, cold water flows through a pipe and air flows over it and gets cooled, all right. So, that is what I mean by chiller unit.

So, now let us look at this we have a chiller unit 2 chiller units let us say working in parallel and which is producing chilled water. So, chilled water typically what happens is it goes into the building and flows through these different building cooling coils as they; what they are calling here which is typically the what we called you know these are the evaporator the soap the quote unquote evaporator units that I talked about through which chilled water flows and air flows on the outer side and it gets cooled.

So, then what happens the chilled water as it comes out of this heat exchanger or of this of this evaporator unit is now at a higher temperature; it comes back is pumped again into the chiller units where you have actually refrigerant that cools the water down in a mini axes scale by the way this chiller that I am talking about is the same that you see in a water cooler except that water we directly take from the tap and drink and in this case, in larger case that water actually is pumped through this through this plumbing lines into the rooms and where it is used for air conditioning clear.

So, now this is an example where during the daytime during the daytime or during when you have; let us even think about a situation where there are frequent power cuts. So, what will happen when there is a power cut these days in cities or in the office buildings apartment buildings we run diesel generators diesel Gensets to provide as power during power cuts.

Now, now the cost of such energy is much higher as we know diesel Genset to generate electricity out of that the kind of expenditure the cost of generating that electricity is almost I think 3 times compared to what we get from the grid. So, therefore, it is undesirable we should try to reduce that consumption if not eliminate it completely. So, that is also one example night and day is one where during the daytime maybe we can run a chiller at a; we run the chiller at full load and at night time we do not. So, let us first look at this how this works.

So, during the daytime let us say when I have or during or during off peak hour forget daytime actually during off peak hours when we have higher electrical energy available to us, then what we do is we run the chiller and produce excess cooling water. So, part of that whatever is required goes into cooling their building during off peak cooling mode and the rest of it goes in a thermal storage tank to generate ice clear, all right.

So, again I repeat what happens is when during off peak cooling mode when I do not need. So, much of cooling let us say the temperature outside temperature is not that high or the cooling load not many of the rooms if we consider for consider an academic building or an office building its a weekend let us say not too many people are working or not too many classrooms are occupied then what happens is my building cooling load is low.

So, what I will do is I do not need to feed the entire chilled water to the building instead I will only feed partially whatever is required and the rest will be used for generating ice and this is one where what we can do is this ice the water in the during the peak peaking time the water directly comes to this thermal energy storage tank where it actually loses heat to the ice as a result of which the ice melts and then it gets chilled and comes out and goes into the building.

So, this ice can produce additional chilled fluid during peaking hours. So, there is actually a new startup called Inficold, if you can look up look it up in Google; inficold dot com that company; what it is doing is it is trying to you know come up with an unit similar to this especially trying to reduce the dependence and diesel generator sets and trying to trying to reach out to farmers to dairy farms, etcetera.

Where you know normally we lose a lot of foods let us say vegetables because we cannot keep it in cold storage or in dairies we lose a lot of dairy I mean lot of dairy products go bad because we are unable to keep it at refrigerated temperatures. So, what they are trying to do is use something similar or rather something as very same principle trying to use a thermal energy storage device as a plug and play which you can which they at least claim that you can plug into any refrigerator.

And during when you have additional electricity or energy available to you to you can you can use it to generate ice which can be used later let us say during a power cut in this manner where the chiller is off now in a power cut the chiller will be off. So, use it for chilling in this manner clear. So, this is another example. So, let me write down as a second example air conditioning, right.

The third one is also air conditioning, but in a little different manner. So, this is building energy storage the way it is done is let us say the walls of the building think about it.

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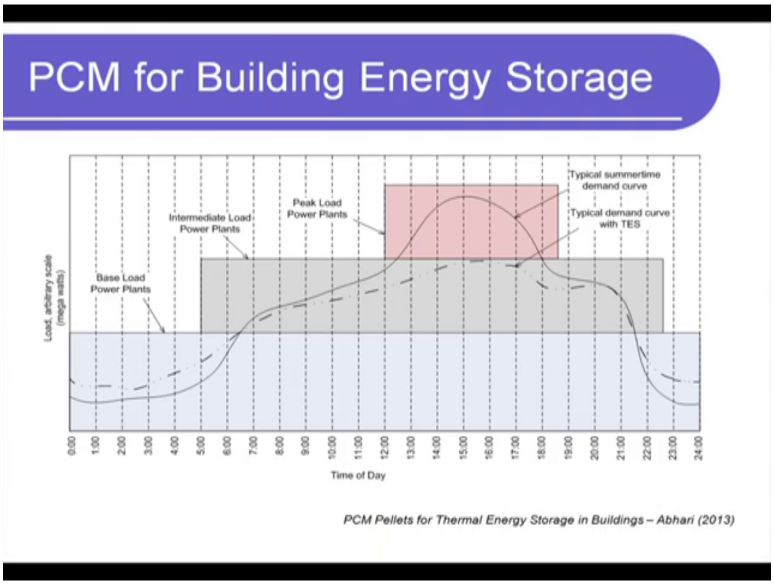

If we can put some phase change material in the walls of the building what will happen that is the overall objective of this exercise what I am showing you is actually a case study it was it was done by a company and I have of harry who is one of the probably the principal investigator he published this work and this is what I am trying to show.

So, if you look at the time of the day if you look at the load of the air conditioning load during the time of the day what happens is as we saw even yesterday also what happens is the load goes up like this and comes down. So, there we talked about electricity generation required or electricity load as the day progresses here they are showing the air conditioning load not its similar, right.

So, what will happen what we are trying to say is that during some hours you will have peak load sometimes intermediate load sometimes based loads what he is trying what the objective is if we use thermal energy storage it may be possible to bring down this curve down to here. So, the electricity that is required to meet the load it will be much lesser because thermal energy storage can fill up this gap, right. So, the demand curve will come down.

How is that going to help it is going to help because you know that if you for different residential purpose, if you look at your bill you will see that beyond a certain point beyond a certain units of usage the electricity the cost of electricity per unit goes up there are certain slabs right. So, if I can keep myself below the slab then it will it will save me a lot of money right because not only it is additional electricity, but this is additional electricity at elevated rates clear.

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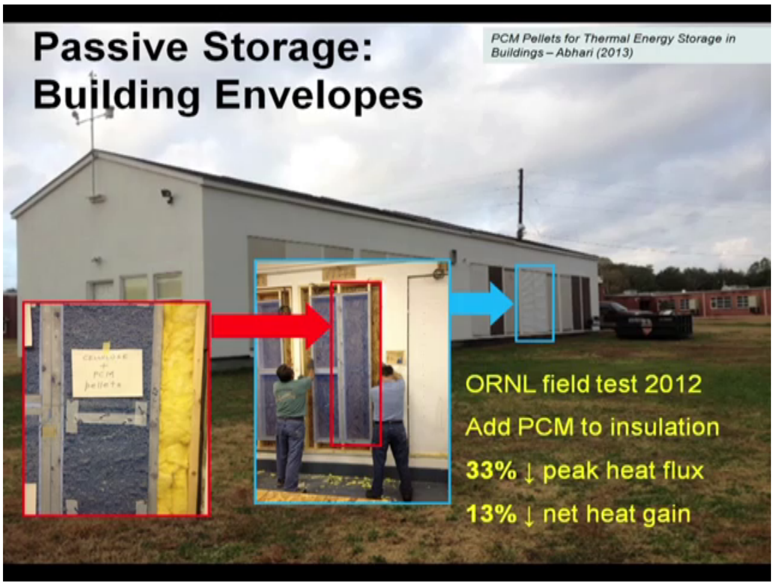

So, this is the motivation. So, what they did was they actually this building material the outer wall they added some PCM to the insulation remember this is here I mean the walls right now over here is not just your brick and brick and concrete, but it will have several layers. So, it has cellulose plus PCM pellets. So, this is some kind of a phase change material that they use.

So, the details of which I think they may or may not have revealed in this paper, but anyway this is a phase change material that they have used an organic material that I know and what they did was they tested it in oak ridge national lab in us its one of the science national labs in us very well known. So, there this testing was done they call it building envelopes and passive storage and why passive storage I will come to that when we talk about active storage we will know.

So, in this wall they actually put in some phase change material. So, what happens during night time or during colder days what happens is the phase change material solidifies and as it solidifies it releases heat which is because it is anyway a cold day I really do not need that and that and the room temperature therefore, even if it releases heat the room temperature inside is still within our own limits actually it is good; it may be good at or I will not say it is good, but it may be good it may be more comfortable, all right.

and then or during night time for example, when you do not in a moderate climate where the days are hot and nights are pleasant I can choose a material a phase change material whose melting point is typically somewhere in between what is the average day temperature and the average night temperature. So, during night the PCM solidifies and as it solidifies it gives up the heat maybe to the outside and the inside of the room and that keeps you warm which is not bad and during the day time when the temperature goes up it absorbs the heat and prevents it from going inside, it absorbs the heat at the wall itself and melts and therefore, it does not go through the wall into the inside of the building.

So, therefore, what happens the air conditioning load goes down because the temperature inside the room is already reduced to certain extent the heat flux that needs to be removed the heat load that needs to be removed is less. So, this is what they showed that adding PCM to the insulation actually reduced the peak heat flux by 33 percent and the net heat gained by 13 percent.

Why because part of the heat was absorbed by the phase change material and this was nothing this was just the building the wall itself had one layer where they have cellulose and PCM pellets.

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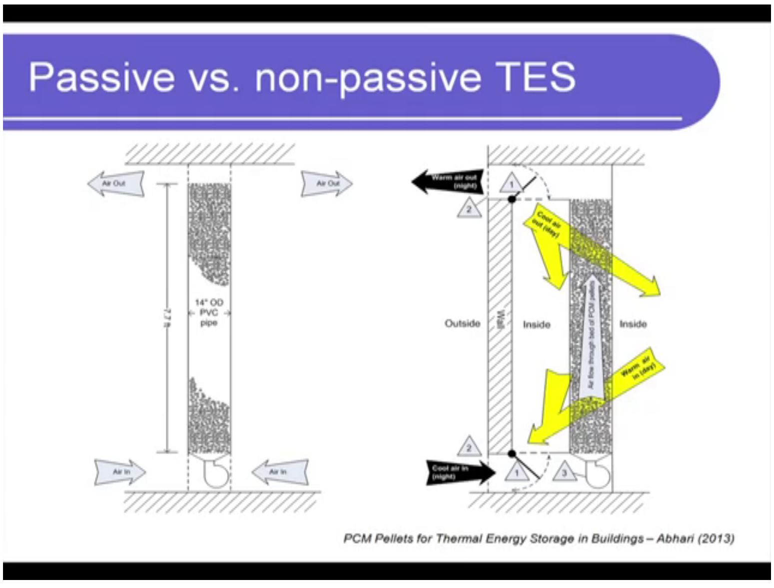

So, in the next one what I am going to show is passive versus non passive thermal energy storage. So, in a non passive what happens is we have a fan actually.

So, here it was just you know the heat was coming through the walls trying to get conducted through the walls and it was absorbed by the phase change material. So, in this case what happens is they actually have pillars filled with PCM pellets and so this is for example, that outside wall then you have these pillars and then you have the inside you know the room.

So, what they do is during the night time the cold air comes in and actually flows through the PCM and the warm air goes out during night clear and during the day time, the cool air comes in and goes out in this manner. So, this is the inside. So, what is happening over here is let us just think about this is a very nice artist rendition I really like this picture that is why I kept it here.

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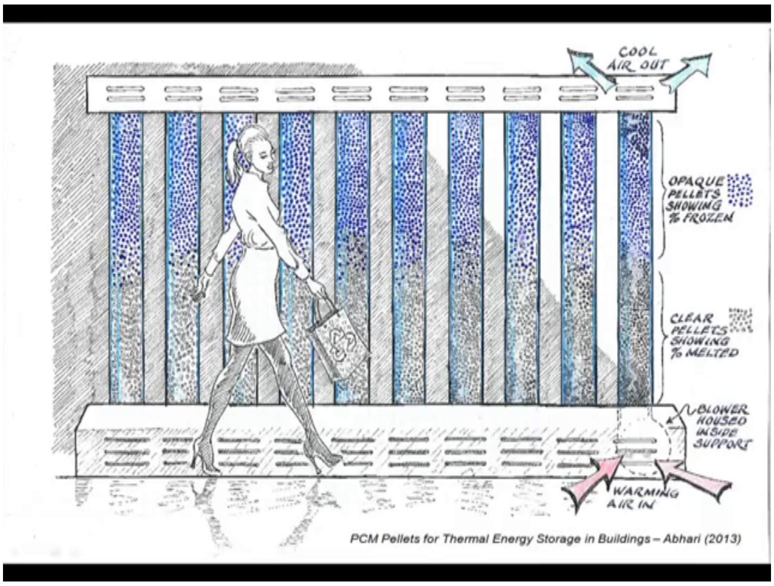

So, it is warm air that is coming in, but remember in these pillars you have PCM pellets which are solidified which are already cooled. So, then what happens through this the warm air goes in and as it goes in the PCM gets melted and the warm air also loses heat and the air therefore, cools down as it flows through these pillars filled with PCM pellets these are porous material and then a a porous material or maybe they flow from the outside and then what happens is outside what comes out of these exhaust vents is actually cool air.

So, imagine a room wall with a series of these pillars filled with PCM pellets. So, as the air is pumped through then what happens is it; it gives up its heat the warm air gives up its heat to melt the PCM and comes out as cold air which is used for air conditioning clear and the artists renditions also shows very nicely that at any point of time during the day what you will see is part of the or whatever certain fraction of the PCM pellets will be melted and some of it will still be in the solid phase.

And then of course, as the day goes by this boundary between gray and blue is going to shift from down to up and hopefully by the end of the day by the time the entire PCM has melted in all the columns we already are in maybe during the evening time where the air conditioning load will come down or the ambient temperature has also come down, right.

So, this is another example; what I would say is PCM storage sorry why am I would use the same color pen PCM storage for building energy efficiency. So, again let us summarize what we discussed this time we talked about latent thermal energy storage and what we try to do here is and look we already I mean the basic principle as to how this energy storage is taking place is known to us we all understand that.

So, what I try to do here is I try to show you 3 case studies the first one was using that solar where you know where we were generating using solar energy to generate electricity and what we were doing is on a sunny day and during day time we were storing part of the solar energy was stored in molten salt which was used during the time when solar energy was not available to us.

In the second one we used thermal energy storage to augment and air conditioning chiller unit where we showed that part of the chilled water from a chiller plant was used to generate ice and I said that this ice that is generated can augment the air conditioning load or can help in meeting the peak air conditioning load during peak hours or I also gave you an example of a new company where they are trying to use this principle to provide air conditioning where there is power outage or when there is power outage and the and the cost of generating electric electrical power or electrical energy using diesel Gensets is very very high.

And the third one was for building energy efficiency I showed a case study in a little more detail where they actually in one case they put PCM pellets on the wall and what happened is the PCM absorbed heat during the day time and preventing it from going into the inside of the room and during night time, it gave up the heat and this is another example that was passive and then there is also an active version of that where we can actually blow air using blowers over the PCM during daytime.

So, that it releases heat that goes to melting the PCM. And therefore, the air that comes out is chilled is cooled air used for air conditioning and the vice versa happens during the nighttime. So, again when we actually melt the PCM and store energy it is called charging. And when we do the rivers when we solidify the PCM and extract the energy out it is called discharging.

So, I would just end this lecture with that on that note and in the last 2 lectures what we have seen therefore, is thermal energy storage examples of thermal energy storage the first one was sensible energy storage and the second was latent energy storage.

Thank you very much.