Foundations of Cyber Physical Systems
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Lecture – 01
CPS: Motivational Examples and Compute Platforms

Hello and welcome to this course on Foundations of Cyber Physical Systems. ah So, today we will have the introductory lecture of the course. ah I believe most of you have already heard this term cyber physical systems being a very common term nowadays.

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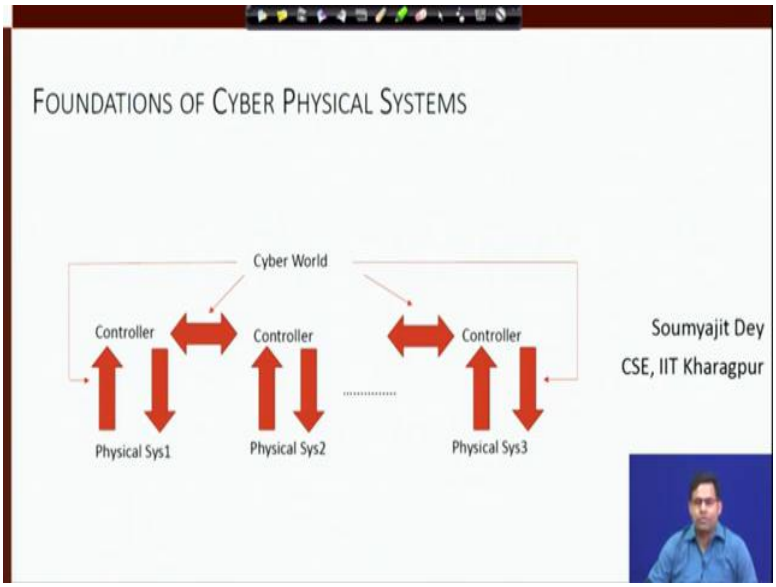

So, fine ah lets let us start the course here. So, at a very high level if you if you see I have tried to put up a picture here. I mean which is kind of trying to capture the basic architecture of cyber physical systems, the way they are deployed. So, what we have essentially is a set of physical systems, who need to be controlled. And the control law may be a software which is resident here in inside the near the system or maybe over the internet in some cloud or in some immediate processors are connected to the system.

And there is lot of communication happening ah in between these systems or maybe the physical system and the control law. ok So, this is kind of a very general architecture we are trying to show here, what we essentially mean is we are going to talk about systems and their realizations, where there is some physical system to control. So, you will need to know about how to model that physical system?

There will be some amount of software logic to execute. Which will be the brain behind deciding what to do? What command to send to the physical system? And there will be a communication infrastructure. Which can be an ethernet cable, it can be a wi-fi link, it can be a bus, it can be a real time communication link something like that. ok So that is kind of the very architectural fabric of all cyber physical systems we have around us.

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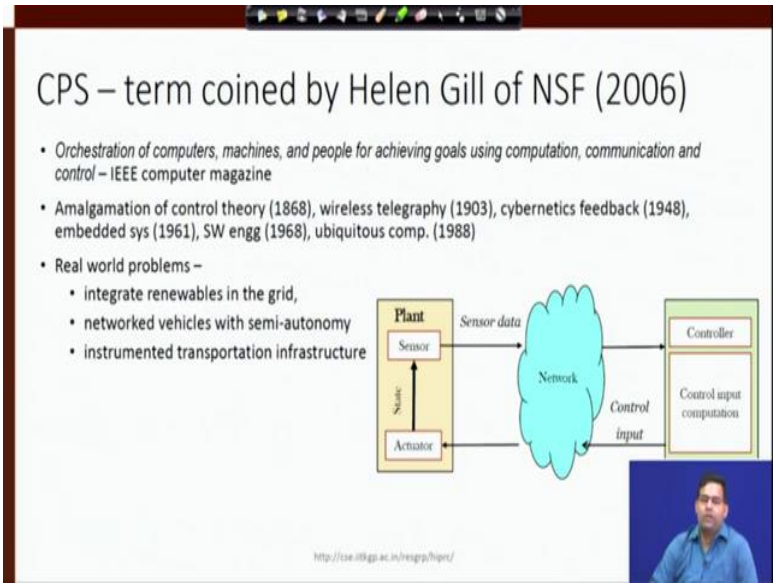

So, this term CPS was coined around 2006 by Helen Gill of National Sounds Foundation and people have tried to come up with various such definitions of what we should be calling a cyber physical system. And if you read the well-known books ah which we will be referring to ah or very often in our course. ah You will see therefore different ways in which the authors have tried to say that well this is what is a cyber-physical system.

So, instead of going into all those ah different possible interpretations. ah Let me just say ah something that the IEEE societies who work in this area they try to define it in a simplistic way. So, they say that this is something that involves orchestration of computers, machines and people for achieving goals using techniques like computation, communication and control theory. Ok

So, of course this is a very interdisciplinary area and it requires knowledge from several engineering disciplines which have evolved with the evolution of science happening over the last multiple centuries. For example, it requires significant amount of ah contributions from control theory to be applied. So, it is something like an applied control theory but along with several other artefacts.

It requires knowledge of wireless communications depending on the application if it is a wireless CPS, it requires knowledge about feedback systems, cybernetics, basic implementation details of embedded and real time systems, the real time aspects. Principles of software engineering like we understand that there are very well known principles of software engineering which needs to be followed for developing a compliant software.

Similarly, well when we are talking about cyber physical systems they also involve real-time CPS software which are a kind of special class of software programs which are fundamentally different from the way we write other programs which which are going to be used in some non-real time applications. And also, since this kind of systems are typically embedded inside the world. Right

I mean you do not see it it is inside something and it is actuating and doing stuff which I can see and observe. right So, it is also I mean the presence of CPS can be failed in many domains where in in an indirect way I would say and that also brings in the different ah kind of ah techniques that have been developed developed in this area of ubiquitous computing. So, if you are wondering what real problems in the world exist which ah we can say that they can be solvable using CPS techniques or implementations which we can term as a CPS, well there are so many around you. So, suppose you are thinking of integrating renewables in a power grid and making it a very smart grid. right So that is a problem, while this has been increasingly done, it still remains a problem that how to integrate renewables efficiently and safely in a distributed complex power grid. Ok

And there are so, many related problems in these domains of autonomous driving or semi autonomy that means increasingly, we have the vehicles around us getting intelligent. That means they have semi-autonomy at least in many countries and fully autonomous implementations in some countries right which are available for general usage. In of course, the fully autonomous usage till date is kind of quite restricted but well it is coming.

And the other important thing is we are thinking of connecting vehicles, vehicles should be able to communicate among each other coordinate their actions in the connected vehicle space. right So, these are all now this is again a area where there are so many real life problems to be solved so that newer use cases come in and for those real world use cases the solution techniques have to have some cyber physical approach.

So, the other important thing is whenever I say cyber physical, people often ah confuse this with ah general things like Ah let us say whenever we are talking about some attribute of cyber physical systems let us say cyber physical security, it is quite different from let us say cyber security. Or any other attribute let us say cyber physical software like we have already said it is going to be quite different from a standard software.

Because of the intrinsic natures of such systems where you have feedback where you have real time requirement and stuff like that. So, the point I am trying to make here is these are systems which are around us. They are part of many important things like defence systems, like safety critical ah applications happening around us like if the domain of transportation, intelligent transportation.

You have a lot of application of CPS is the domain of AI enabled, ah AI enabled domains. For example, like we have already said semi-autonomous vehicles or let us say multiple vehicles forming a platoon and trying to drive together in an autonomous way. So, all these are examples where we have ah lot of CPS techniques to be applied. For example, robotics assisted surgery, for example medical CPS where we are trying to develop embedded systems which are looking at our body as a plant, a human body as a plant and it is trying to have control actions which

should influence the system inside our body which is the plant towards some greater goal. Let us say maintaining the blood sugar level continuously OK using some some some device like an insulin infusion pump. ok So, we have lot of upcoming applications too, specifically in this areas like medical CPS.

So, the point is all these kind of real world problems exist around us. And CPS techniques which are already there are getting applied in their design and development of this of products which are trying to solve these problems. Which are trying to assist human beings ah to to towards having a better life in terms of using ah autonomous vehicle in terms of ah kind of revolutionizing agriculture. Right

Because we have so, much autonomous systems coming in the domain of agriculture. right ah So, as you can understand this is something that is here to stay and it is good to know about what are the basics of cyber physical systems, how they are designed, what are the different computer science oriented as well as electric in general electrical sciences oriented engineering aspects which must be learned so that one is conversant to in cyber physical systems and one is able to pursue a career, I would say inside in this vertical.

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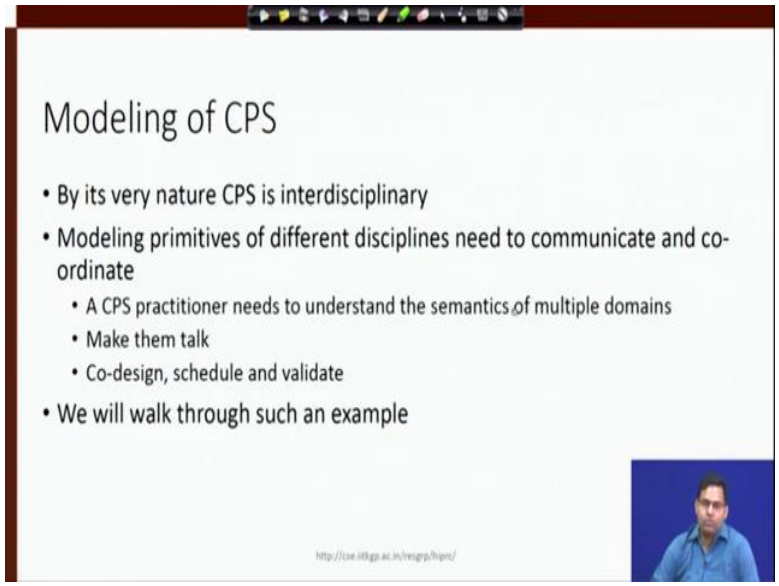

So, like we said, we will start with basic modelling ideas of CPS and cyber physical systems is definitely an interdisciplinary domain. Ok And the first example, we will take will be something which which we have quite intentionally kept here to kind of highlight that this is

really an interdisciplinary field. ok So, we will start with how CPS systems are modelled and in fact here itself, the idea of multiple disciplines talking to each other the requirement of that will will be coming into play.

So, this is an important property of an would be CPS practitioner. He or she needs to understand this different application domains and try to make them talk with each other. So that he can have a final system ready, ah where this multiple domains interact, we will walk through through such similar examples here.

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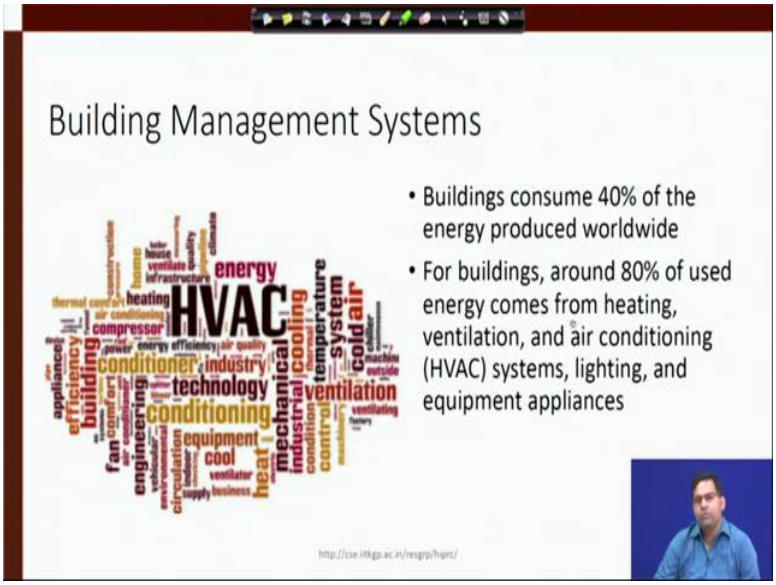

So, the example we will be taking here is that of building management systems. And a building management system Ah well what does it really do? ah Nowadays, you must have heard of this term that is smart buildings. right So, it essentially means that there is ah some amount of software logic behind the buildings operations, operations like access control into different building zones and a very important another thing which is the temperature control of different zones of the building. So, a very big building can have different segments where there can be different kind of ah requirements, there can be an office space, there can be a storage space so and so forth. And accordingly, ah there would be different kind of temperature and the temperature I mean the quality of the controlling and maintaining the same temperature.

How good the temperature is? How nicely the temperature is maintained? That requirement may vary in different segments of the building. And so that would mean there would be the

requirement of having and and heating ventilation and air conditioning system all also known as an HVAC in short form. Having a building HVAC system which should be taking care of this requirement.

And we are saying that implementation of such systems is a important CPS problem, question is why? Before getting into the why? ah of I mean why HVAC is a CPS example? First let us answer that why at all we are interested in age back here? We are trying to say it is an important problem, why is an important problem? Because ah statistical it has been shown that buildings consume about 40% of energy that is produced worldwide.

So, whenever we are talking talking about energy consumption we we are thinking of our vehicles and stuff. But think of our buildings they consume a lot of energy more so in developed countries where you have buildings which are significantly large and such buildings are more in number. ok Now, inside a building I am inside of this I mean in this 40% energy consumption about 80% of this energy goes into heating ventilation and air conditioning.

So, in in countries where the weather is relatively cold, you need to kind of warm up the building and in tropical countries, the requirement will be typically different. right So, ah this kind of HVAC systems along with lightning and other appliances they will consume significant energy. That is why ah if I can have an HVAC design in a very efficient way, the HVAC control law is very efficient with respect to energy consumption.

It has a lot of effect that is the importance. right So, if I if I if I can even make 5% savings in the power consumption of the HVAC that will based on this this other percentage values that will make a huge kind of impact on the overall energy consumption that is really there.

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So, we have some simple examples of the different building control surfaces as you can see. So, some of these pictures and stuff have been taken from a PhD dissertation by Mehdi Maasoumy, who worked on this topic from UC, Berkeley. So, there are papers related to this work and also this PG thesis this is from which we have been taking some of these representative pictures.

So, as you can see that this picture is kind of telling you that inside of inside a building, inside a smart building you can have lot of sensors for sensing the temperature for sensing the humidity for sensing the air flow rate right and also the con amount of carbon dioxide that is there in the air. So, all these values can be sensed and in a feedback loop this those can be sent I mean they can be sent to a ah central controller who will decide that well how whether to increase the oxygen flow? Whether to increase the HVAC age air flow? Whether to decrease the chiller temperature? What what are the actions it can take? And what are the actions it should take in different zones of the building so that the overall requirement gets satisfied. Ok

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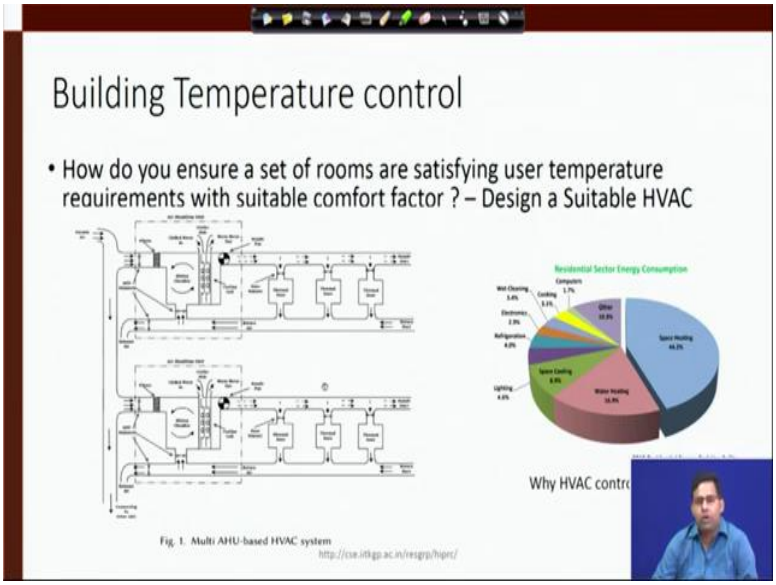

So, overall in a nutshell this would be our overall kind of problem statement of designing a suitable HVAC that how do I ensure that you are given a set of rooms and they are satisfying the temperature requirement that is provided. And that is also happening with a suitable comfort factor, the comfort factor means that how nicely the the room's temperature is maintained. Ok

So, on the left hand side, we have a exam a picture ah which is ah kind of drawn here for the purpose of this slide. Where we are trying to represent how an HVAC systems internals really look like. So, as you can see outside air flows in and there there are this mixing chambers right where ah this outside air is ah getting mixed with chilled water. right And you have a ins in this heat exchange process, you will have some cold air flowing into this different vents the HVAC vents, the main vent.

And from the main vent, the air will be routed to different thermal zones. right So, these are the inlets inside these different zones of the cold air. Similarly, there are also outlets through which the return air the the air will go back through this outlets and they will reach the return duct and through this returned duct, the air will simply go back and the air needs to be circulated. So that all the different requirements that we talked about needs to be satisfied and all that. Right

So, this is an example of an multiple AHU HVAC system. And the the problem can be modelled using a set of I mean. So, as you can see that you have ah the essential problem becomes maintaining the temperature. right So, whenever we are talking about maintaining temperatures, we must need to understand that how temperature changes depending on the surroundings. Right

How am I able to compute, how am I able to model the change of temperature? What kind of equations to consider? What are the thermal equations? So, all these questions will now start coming in. ok

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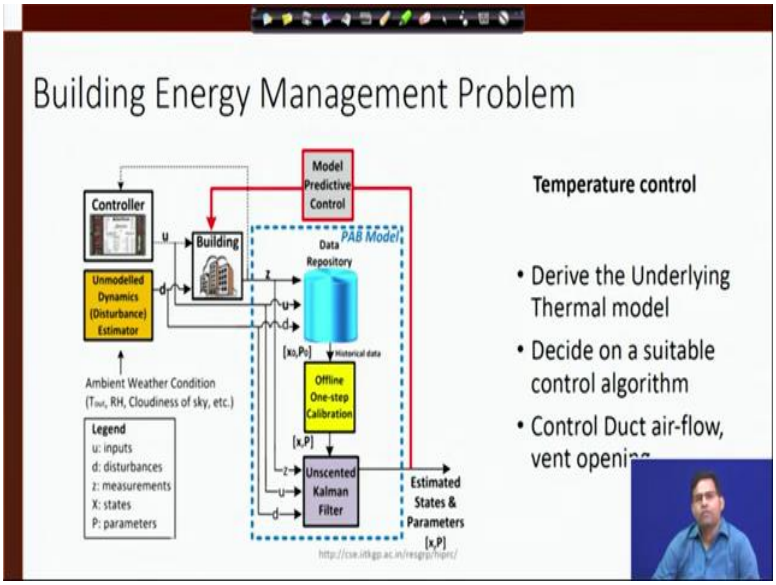

So, in a nutshell this overall process can be ah kind of ah I mean it can be represented in these following steps. So, for the temperature control problem, we will need to derive the underlying thermal model of the system. Then so, basically the thermal model represents the temperature dynamics of the system that well if the building right now is having this kind of temperature at these zones and outside temperature is something like this.

And accordingly, some heat is flowing into the building or may be out of the building and accordingly what should be the temperature be after a time step delta t. So that is that is the question that the temperature model should be able to answer. right And based on that answer, we need to decide on a suitable algorithm which will now actuate the different control surfaces in this HVAC system.

Maybe it will set the chiller temperature low or high it will increase the fan speed. So, there are different possible physical actions that can be taken in this HVAC system and those actions will be decided. So, let us understand these are physical actions right they are going to happen on some physical machinery. But those actions will be actuated by a control software and that control software will take and help of the thermal model to get an idea that well if I do something like this then the temperature will go this way if I do something like that the temperature will that way. So, overall it will form an optimization problem which will which it will then use which will it will then solve in the run time to decide that well what are the actions, I am really going to take. right So, primarily what the control algorithm do will do here is It will be contain controlling this air flow in these ducts.

Not only that as you can see that from these ducts the air is flowing inwards into different thermal zones, may be two different rooms which are thermally isolated. right So that is how we define thermal zones. So, this these vents through which the air will be going inside this small different thermal zones they will have their inlet angle and at a lower level the controller can also control those angles. Right

So, this is again another physical action that it can control. So, for building such a control algorithm there will be multiple complex steps which will be involved. So, if I look at the control theoretic picture here that how really such a building control system works? It would be something like this. So, there would be a thermal model of the building and there would be some modelling of the external disturbances which are not captured in this model.

And there may or may not be some historical data that will in history, ah let us say at this time of the year, two years back at this time of the year how was the external weather? What is the climate prediction? Because as you can understand that all those things play a role here. right So, based on these existing data and the thermal model, the system can make a prediction that well.

In future I expect the temperature to be this this, this based on the current dynamics, the current statistics etcetera. right So, using this information ah this control algorithm, it can be different kinds of here, one control algorithm name is written it can be anything else. So it will try to predict that well ah what what should I really do? What kind of physical settings of the HVAC I should choose for? Let us say another for the next one minute of the entire building. OK

And maybe after one minute or maybe after two minutes depending on what is my frequency of sampling data from the sensors, OK ah sensors for temperature ah CO2 etcetera, etcetera. ah So, for that amount of time the there will be some physical control settings said by this kind of a control software. The building thermal dynamics will accordingly change and again there will be a sense control action compute followed by actuation cycle and this thing will keep on happening on the go. Ok

So, there is a a very I mean simplistic idea about how this building energy management system would work with the objective of controlling the temperature here.

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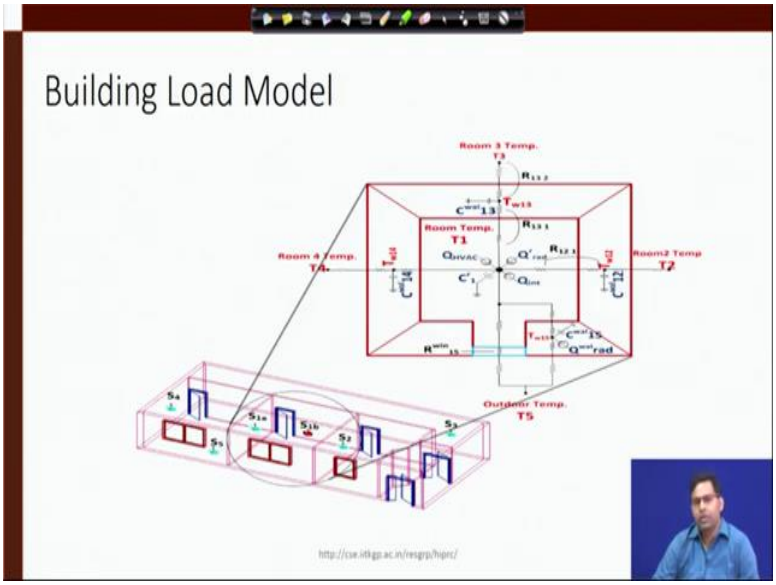

So, we talked about thermal models. right So, the building can be modelled like this so, as you can see I mean we are not going to the detail. We are trying to represent the buildings thermal dynamics using an RC circuit. So, this these examples have also been taken from the thesis we

talked about earlier, ok the reference has already been given. So, you can actually model this like an RC circuit network and you can query the model.

That well right now, these are the temperatures and based on the different thermal parameters of the model, it will tell you that well how the temperature trajectory is going to behave here? Ok

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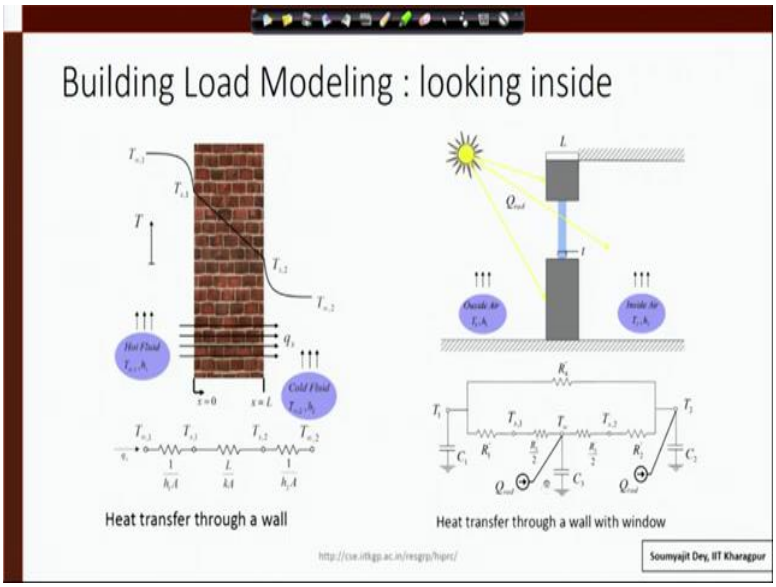

Now so, let us let us have a quick look into what really goes into building a thermal model for a building. ok So, ah for example there will be walls right and through the wall ah there will be heat flows happening which need to be modelled. And similarly, what the way the heat flow happens here for a thick wall will be different from how things happen for a glass window? Right

Accordingly, the model modelling paradigm, the model will change, the models parameters will change right all these coefficients of heat transmission that happens is going to change etcetera, etcetera. So, we are not going to the details of this models, we are trying to say that well it is possible to if you know the parameters of this different field building components or if you can estimate the parameters of these different components you can build such RC circuit based models using which you can you can simulate this model and you can have an idea that how the temperature is going to be had.

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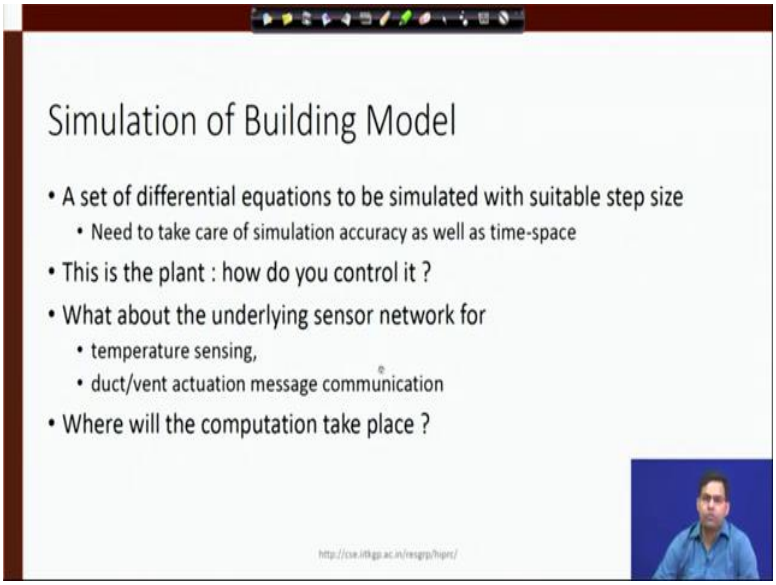

So, overall how does that model look like? It will be a set of differential equations which need to be simulated with suitable step size. Ok Now, ah the question is how am I going to use this information to control the actual plan. ah So that that is the real control problem which is underlying this model. Now, ah shall I use some control, I mean traditional controller? Shall I use an AI/ML based controller? Ah

All these things are possible and all these things are practically done. right Now, the question is you also have a real time aspect here which is like well, how frequently am I am going to do the sensing of temperature? And how frequently I am going to change the different control activations of the physical controls on the HVAC? right And more importantly this computation of the control law that means how much to set the air flow?

How much to set the vent angle? These things will require some hardware resource on which it needs to be done. right So, it will require a physical computer on which the control software should run. So, overall that is how your simulation model of the building has to be working in loop with the control software for your testing phase. And once the testing phase of your software is over you are going to deploy it to the real system.

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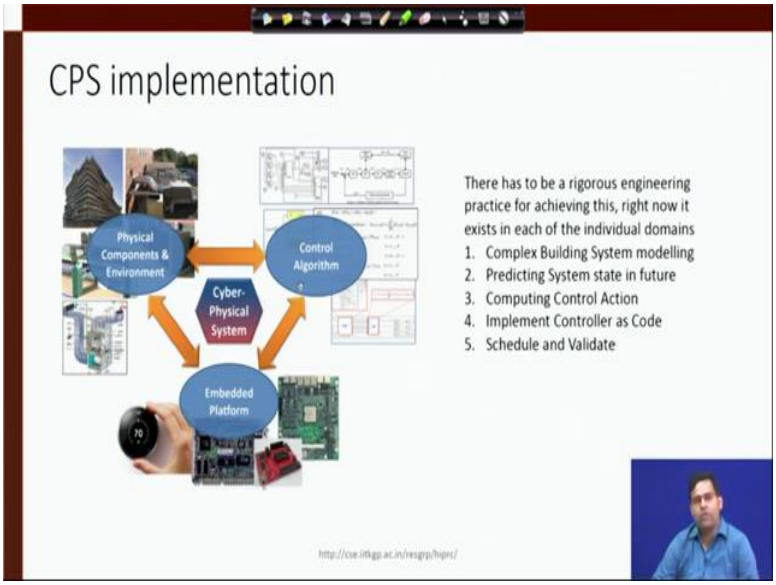

So, if I am trying to develop this kind of a system and implement it, you see I already have ah kind of at a high level spoken about different paradigms of engineering research. So, you will need to understand how thermals is thermal modelling needs to be done for the building environment? You need to know, how control algorithms can be developed. They may be AI/ML based, they may be rule based they may be like traditional control algorithms. Right

How this algorithm needs to be turned to a software? And then how to make that software run on a platform in real time. So that all the actuations that go into the HVAC they happen in a timely manner. ok Not only that there is a significant amount of sensing and networking also. Because implementing this in the physical world would require you to set up all those different kinds of sensor at different strategic positions in the building. Right

And those values needs to be computed and those values needs to be communicated to this platform right where the control law will execute. So, the control law needs to be designed in some high level language. Let us say using some Matlab toolbox from that you will need you Will you will kind of simulate the controller. right So, let us say you develop the thermal model and you develop the control law using some simulation platform.

You will need to co-simulate them together and finally for the implementation, you will need to generate some program which replicates the behaviour of the control algorithm that you did

in Matlab. And you so, the and that is quite possible because nowadays Matlab provides you lot of code generators from the high level Matlab model itself, you can generate code and you can compile the code on that platform. Ok

So, you have the sensing issue and not only that you need to transmit the messages to this platform so, there is also a networking issue. right So, as you can see when you are talking about implementing a CPS, you need to have some knowledge on embedded hardware, you need to have some knowledge on sensing, you need to have some knowledge on how actuators are built. So, these are things, we will try to cover at the basic level in our course after the introductions.

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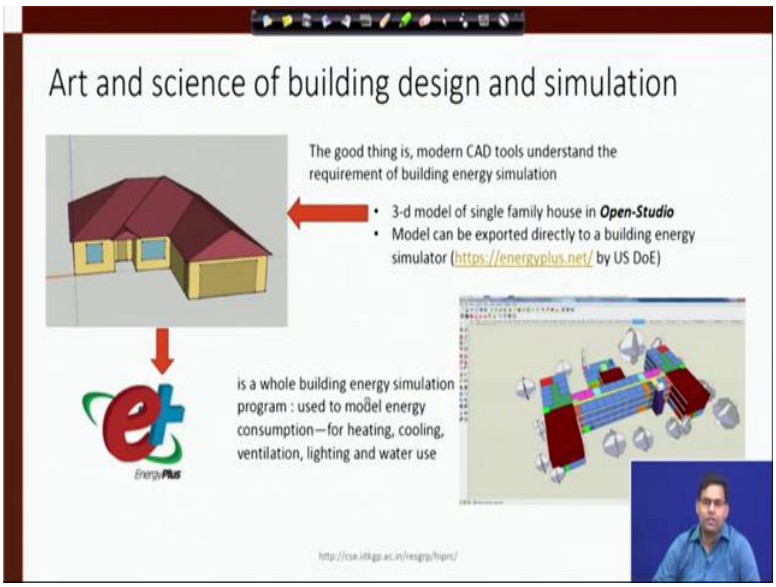

So, getting into a bit more of building building ah temperature control problem like ah the reason we are going into is this is an example where we have ah lot of simulators available. So, we will just like to introduce you to that that how How can somebody ah really create this kind of a thermal model? Because it looks quite difficult right there are some networks there are lot of parameters, how can somebody just do this without I mean I mean without having the necessary background on developing thermal models let us say. Right

Well as a toy example it is really easy what you can do is? There are some well-known software's for example there is a software called Open-Studio, using which you can build a simple building model. Well, it looks like a toy example really but it can also be used to create

a serious level building model. And not only that the interesting thing is so, this is like a GUI based tool through which you can actually build this model. Ah

But at the back end what it does is this Open-Studio software interfaces with an extremely important simulator called energy plus which was developed by US department of energy. Now, the good thing about energy plus is it is a building energy simulation program and it has calibrated models of different building components walls, glass, panes etcetera, etcetera. So, the important thing is those are calibrated models.

That means they have been simulated they have been calibrated against real buildings. So, the coefficient parameters of the different components in the model they are quite realistic. So that means if you just use this GUI drag and drop thing to create a model. And then you interface it with this back end energy plus model, right you generate generate the energy plus more extract version the energy plus model from this Open-Studio what you get is a building model which kind of faithfully represents the thermal dynamics. Ok

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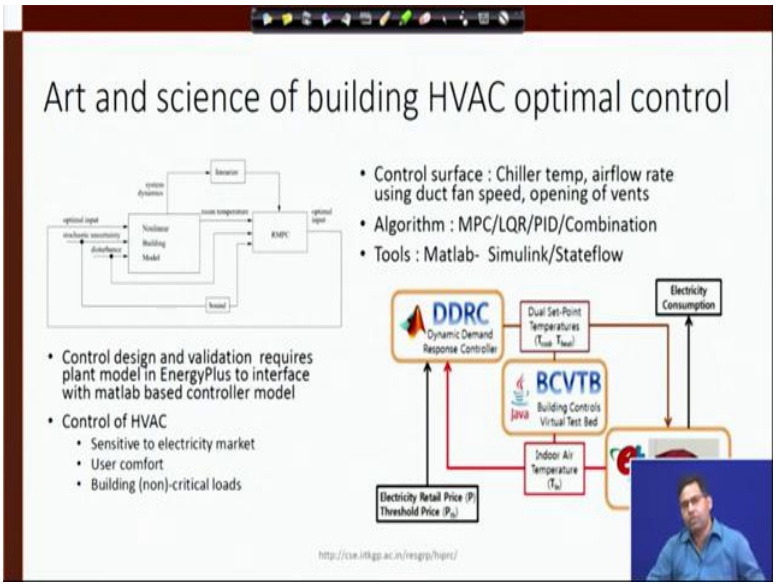

So that is a nice thing which these developers have done. And now you can use your knowledge of control theory to develop some controllers and you can do some optimal control of this building energy system etcetera, etcetera. So, these are the well-known control algorithms things we will be touching upon in this course. So, you can use this model thermal model along with this controller and you can do some simulation in some tool like Matlab. OK

And you can see that well how you are more moderate as well as the controller is performing. Not only that there are some specialized test beds for this purpose ah some of these you can just search over net. So, you have this test beds and I mean software simulators available along with some Matlab toolboxes which are specifically tuned for this kind of work. ok So, when we talk about building HVAC control ah use.

I mean, we have to we have talked about the importance of thermal models, com control algorithm development then program generation from the model. Then porting them to an embedded platform the importance of embedded platforms, sensing data. right When I am trying to now implement this simulation level model on the platform and I am going to deploy this platform to the real physical system which is the building I would need to use those sensors to get the real data give it to the emirate platform so that the emirate platform transmits back, the actual actuation commands to the different control surfaces. right Now, the problem if you look at ah from the from I mean from a deeper perspective it is even more complex. Why? Because modern smart buildings at least in the developed countries. right In several countries ah they are also going to talk with the electricity grid what do I mean by?

They will talk is a smart grid is supposed to not only send the power it is also supposed to update to the consumer. That what is right now the pro the price of the power that the grid is selling, the real time price. So, there are real time pricing algorithms that run inside the grid operator's side and they provide along with the power they will also provide you an information exchange method through which ah that that that price value will come to your smart meter Ok and the smart meter is attached to your building. So now, you see there is a more complex issue because the HVAC controller that you are designing can be much more intelligent. Because at some times of the day, the price of power may be ah very low Right and some times of the day the price of power may be quite high.

So, if the price of power is high ah how much energy should the HVAC really invest towards running the energy energy system there towards running the temperature control system? It can

decide. right ah So, what I am trying to say is just a simple example, even if the user is in some room zone ah is trying to go for let us say 24 degree celsius. But right now, the power is quite high and that room is not a very critical room, ah the HVAC system may decide that well ah let us let us keep it at 25.

Because if I save some power, right now the power the price of energy is quite high so, it is a big gain I make right or maybe. So, there there are other use cases which can think of. The the point I am trying to make is this problem can become increasingly complex that is why ah I mean data oriented approaches, data oriented approaches using ML and AI techniques are increasingly finding their application in this domain.

And not only if we talk about smart buildings you may be thinking of some specific kind of ones like office buildings or let us say malls, think of data centres. Because they represent a huge HVAC load nowadays. right So, all the big companies with so much of ah increase so much of penetration with cloud computing. We have so much of data centres and data centre cooling is the most important problem in green computing.

So that really needs to be addressed in the most efficient possible way. So that is why ah this is a very important problem to be to be looked into and this also has all the characteristics of a CPS. Because of it is interdisciplinary nature because of it is modelling requirement because of it is hardware Hardware implementation. May be the real time aspect is not there that much but still I wanted to start with this problem because of it is importance in itself. Ok

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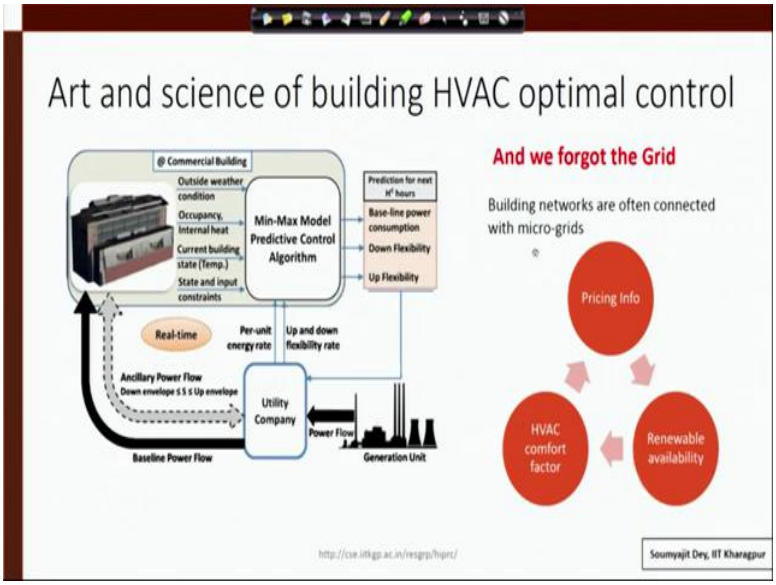

So, just like I was saying that you can just bring in the grid here and when you bring the grid into the system and then the utility company. So, we have a picture here so, here we are showing the building along with the grid and as you can see that there can be several more complex control algorithms. Which will now decide that when and how the control algorithm works ah based on the real time price.

And it may even happen that right now, the building is provide I mean building is having some renewables attached to it. And when of course, the the seller on the grid is providing energy at a higher higher price, I may you I may choose to use some of those renewable resources stored energy. right So, there is also another very important aspect which needs to be looked into so, all these things have to work together like pricing information, edge facts, control law comfort factor and the renewables availability all these names need to be factored in. So, it is quite an important problem to solve. Right

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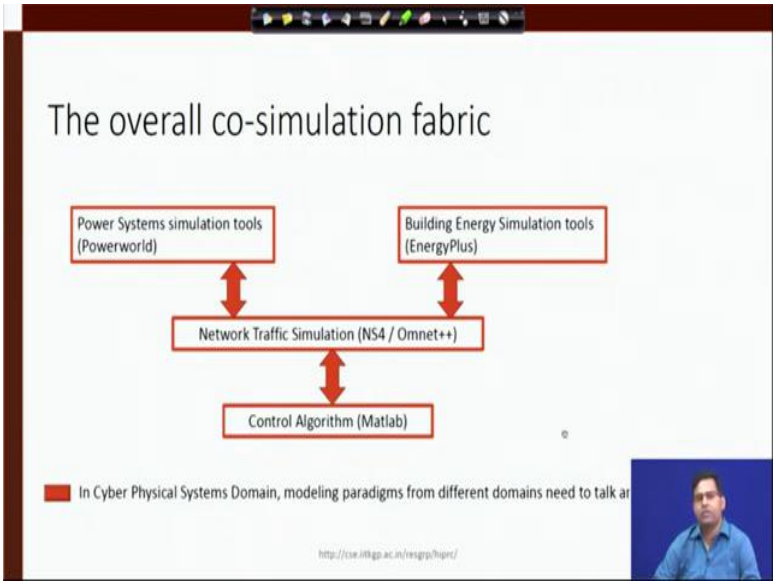

So, now suppose I am trying to co-simulate all these things together what are what are the different technologies as CPS practitioner wanted we really need to know? So, to to model power flow, let us say your building has some renewables and it is producing some energy. And also, from the grid operator you are getting some power right over over an electrical bus. So, you will like to model those parts using some power simulator there can be Matlab toolboxes there can be simulators like Powerworld all examples can be there.

You can use the buildings thermal model ah which is there in a simulator like energy plus or you can build the thermal model and run in Matlab. Because eventually the thermal model is nothing but a simulation of a collection of differential equations. And they kind of represent I mean if you just show it in a figure it is like a access service network. ok Now, the next question is well, ah when I am trying to replicate this problem in completely in a simulation framework.

I have the thermal model which is representing the building but now as we remember in the real building temperature values will be sensed along with that other other things may be sensed and they need to be sent over a network. right A network may have delays a network may have packet drops. So, if I want my simulation to be realistic, I will also like to interface this with some kind of a network simulator who will model this communication happening between the plant side and the control algorithm which may be running in Matlab here? So and also the final flow of ah actuation commands to the HVAC system Ah and maybe actuation commands to the renewables. ok So, the point is if I want a very detailed simulation I may require multiple

simulators to work together. A same problem can work in the domain of autonomous driving. Right

You will need a vehicle model and not only that let us suppose I am trying to think of two vehicles coordinating their actions together. I will need the vehicle models, the controller models as well as the communication model, modelled using some soft different software. right So, this is a domain where if I want to have a true representation of the real CPS in a simulation fabric I will I will always have this requirement of interfacing simulators ok that is also something that makes it very interesting. Ok

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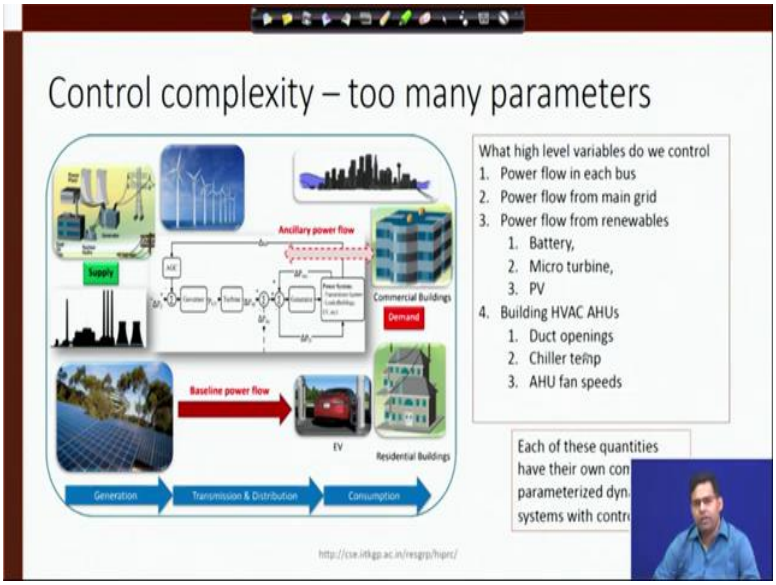

Now, coming back to this problem of building energy management. As we have already said that this is quite a complex problem and if you think critically there are so many pair of parameters. Now, if I look to the power system side of the problem there is power flowing in the busses of the grid, there is power flow from the renewables. That you may have and then you have finally you have to account from those things and you have to also control the HVAC different control surfaces. Right

So, overall each of these things have got their own individual parameter as dynamical models and controllers and that that makes it a very complex problem.

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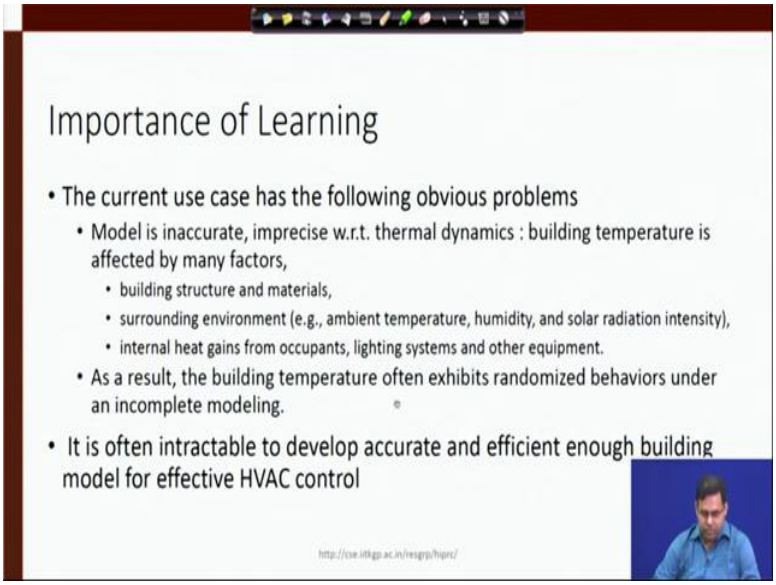

And like we have been saying that this is exactly where database methods have been found to be increasingly applicable. Like how How can I learn control actions for such a model? How can I learn good control actions, energy saving control actions for this kind of a system? Because of the intricate nature of the So, of the of the modelling space here, ah AI based techniques are increasingly applicable in this domain. Ok

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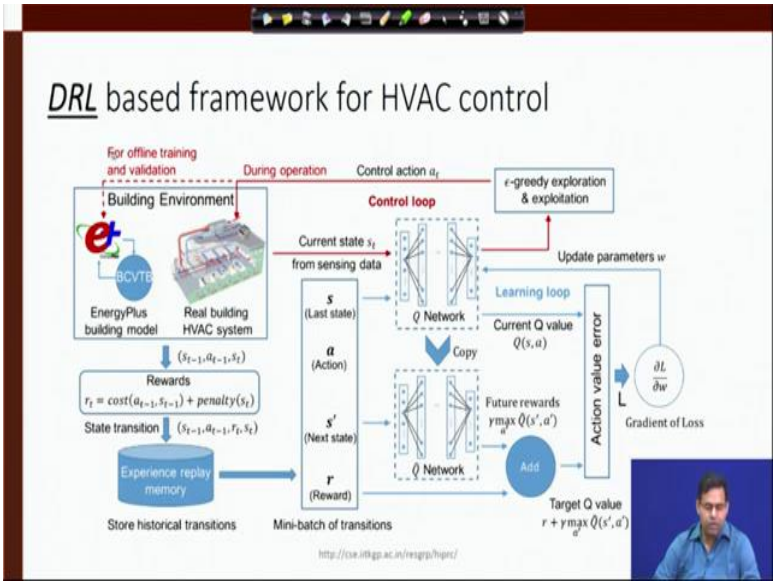

Now, just as an example ah there was this work by a group which was published in DAC and they showed that well ah it is possible to have learning-based strategies. And for example deep reinforcement learning based strategies which can really be used for HVAC control. So, this is ah figure which I have borrowed from their paper in DAC, the top conference in this design automation area where they show, what is the architecture of the systems.

As you can see that they have the simulation system of the building. And they have their own neural I mean RL based model through which they are trying to generate the control action. ok So, this is an in the loop system so, you have the buildings ah simulation happening based on that the thermal feedback is coming to the control side. And then this AI based controller is sending back some control of control actions.

For example, well ah the duct the duct openings should change, ah the vent openings should change, the air flow should be something like this etcetera, etcetera. And with this modified values of these control parameters, the building will be simulated again and again temperature sensed values will be sent back and the loop will continue.

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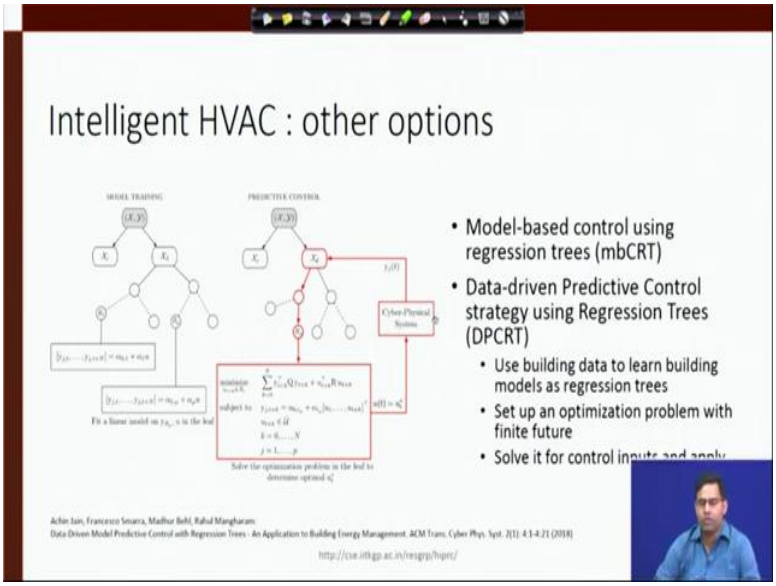

And we actually found that this approach works very nicely and that actually is an example where we show, we can show that AI based methods are very nice in this domain. Ok And there can be other techniques also so, this is another AI based technique where you have ah you are actually using regression trees to model control actions ah for doing the temperature control. So, this is taken from another paper which is cited here. So, this is their technique, I am trying to say that there can be a whole lot of different data data centric techniques for doing this edge back control. And we have already established that why this is an important and complex problem. Right

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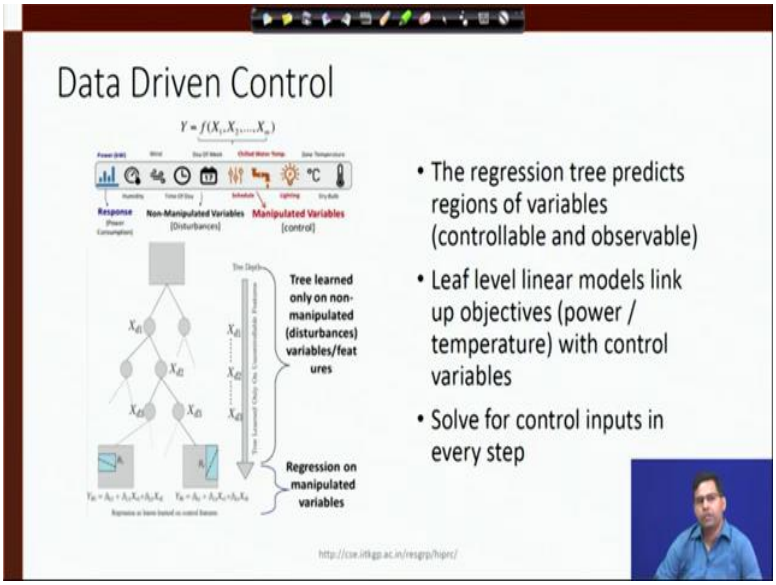

So, even this final implementations can be can be used ah to build some nice app, let us say you have an app which you which will provide you with some nice statistics about your building. And you can actually ah give suitable requirements to the building operator through this kind of a mobile app. Right that then also be possible and that was an idea also which these authors carried forward.

So that is that is more about ah an example which wanted to discuss where we talk about ah building temperature control. And we showed that it is an interdisciplinary example and it involves it is a classic example of a cyber-physical system. May not be that much in the real time sense but more in this sense that there are lot of interdisciplinary areas which really merge while solving problems Ah in this space. With this I will be ending this lecture, ah thanks for your attention.