BUILDING ENERGY SYSTEMS AND AUDITING

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Lecture 28

Lecture 28: Building Life Cycle Analysis

Welcome to the NPTEL course on Building Energy Systems and Auditing. In module number 6, we are discussing life cycle analysis and energy audit. In lecture number 28, we will now discuss building life cycle analysis. So, in this particular lecture, we will see the other two types of energy: the operating energy and the demolition energy, and we will see the distribution of the life cycle energy and its analysis.

So, if you see the stages of the material life cycle, we can observe that a material has to be manufactured, and before manufacturing, we need to obtain raw materials. In any case, whether it is for brick, steel, cement, or glass, every material requires raw material extraction. This also requires some energy. Energy is required for the manufacturing process, which is why metals have a higher embedded energy density per m^3 or per kg compared to other materials. After manufacturing is completed, we transport the material to various locations and then to various sites, depending on demand.

We use it, maintain it, and utilize it for its total lifespan before disposing of it after a certain time period. The building may need to be demolished, or some materials may need to be replaced. These five points represent the prominent stages of a building's life cycle or a material's life cycle. If I describe it as a cyclic process, it includes raw material, then transport, then use, and finally waste.

So, in this if I now linearly if I see so it is a production from the raw then it is an industrial processing and the manufacturing process then we transport it and then we can use it and there is a end of life. So, if I say this the raw is first box the manufacturing is the second box Transportation may be the major transportation will be happening after the manufacturing and the use. The third box is the reuse and the waste and recycle may be the fourth one, the end of life. Now, there are some boundary conditions.

So, the system boundary we can say that from where to where we can see this particular energy. So, sometimes we can see that it is cradle to grave. What is cradle to grave? Cradle is the start point or the first one that is 1 to 5, stage number 1 to 5 because stage number 1 to 5 we have discussed over here. So raw material to the waste.

So, it is waste means it is grave. So, it is end of the life. And cradle is the newborn baby in a cradle. So, it is the raw material. So, it is a full lifespan of the baby.

The material. So, the total life cycle energy is how much energy is induced or incorporated in a particular material from cradle to grave. But sometimes we may go a little bit the other way, like cradle to gate. So, what we have discussed in the last discussion, the last lecture, we discussed the embodied energy of a building, a multi-story apartment building, where we actually considered the cradle-to-gate scenario.

The assessment is produced from stage 1 to stage 2. So, mostly the raw material and manufacturing, and this is the gate. Which is the gate? That is the gate of the industry.

It is leaving from the gate of the industry. So, the maximum energy that is actually embedded into a material is the raw material extraction and the production process and all. And then there is definite transportation, some construction, maybe welding and other things, and finally the end of life, but those are not as significant. much compared to the first two stages.

Sometimes people say it is the cradle to gate that will be enough to assess my energy. So, the cradle to grave or this is the cradle to gate. The last one is a little bit sustainable. So, it is cradle to cradle. So, what is cradle to cradle that we will

not the fifth one the waste and the recycling that will going to that will be going to be no more I mean there is no end or no death of the particular material the end of life will recycle it the waste recycle we will do. So, what we will do? We will skip the 5 or maybe you may say the 5 and A1, the second one, not the first one. The first one is the manufacturing raw material, raw material excursion and the second after first loop, the 5 goes in the first. So, in the horizontal flow diagram, it starts from the cradle, the material.

At the end of its life, again I try to manufacture it from that material as a raw material. So, nowadays you all know that in the sustainable development we need to do that and we need to do even we are thinking of the using the demolition material from the building and we use to do that for the new material, sorry not new material for the recycled material we use for the construction. So how much we can do that is really challenge that people are working in that area. So, but some of the metal items maybe after the end of the life we can actually reuse it plastic things we can reuse it. Only thing is that we may say that the whole 100% of the material which is actually came to the grave, we may not use as 100% as a second cradle stage because there will be some kind of the change of the property of the material or maybe there is some kind of the damage which cannot actually take care of that or so.

So, anyway, even if we cannot use the whole 100% of the material. We can actually think of using and maximizing the amount of use or recycling the material, which is actually going to be beneficial. So, the world is thinking in this way, and then we have to also think—civil engineers, architects, building consultants have to think that—and we need a little bit of research in that area. We need this little bit of our application. Testing some demo house or something like that, so that it can fulfill some of the technical demands, technical requirements in the future. Technical requirement—I mean to say is that anything you do, you need to have a kind of justification from the building code.

So, if you design a building, if you design structural elements of the building like beams, columns, or whatever, you have to actually follow some code—the IS code, IS 456, or something like that—we have to follow. So, similarly, if you use recycled aggregate or recycled steel or maybe anything with a new part—of course, I mean cement may be new or whatever—then you need to have some justification from the technical point of view. So, you need a code. So, to develop a new code for the recycling of concrete or so, you need research. So, it will require some time for that kind of thing, but before we actually design for a large stock of housing or so, or the buildings, we can actually think of doing some kind of demo housing or something like that.

So, the awareness, people's awareness, and all these things are there. So, that is why I have introduced these things. So, there are three things: the cradle to grave, cradle to gate, and cradle to house. So, the last two lectures we have mostly focused upon the modern energy. If you remember, there are two types of embodied energy we discussed: one is the initial, and one is the recurring.

So, next is the operating energy. As you understand, a building will take maybe 2 years to construct and it will stay for 50, 60, 70, or 80 years for its life, its operating life. And then maybe it will require 2 months or 3 months to demolish if the life is over. So, the maximum part of the building's life cycle is actually in the operating stage, and we need to find out the operating energy of the building. It is a very simple conceptual equation, I must say. It looks very simply, but it is not so simple. We have already started discussing that from the very first chapter, building physics, and all the heat gains and all those kinds of things.

We will also discuss next week, in week number 7, how to calculate or estimate the operating energy. After this particular lecture, the next lecture on the 29th and 30th, we will see what is the way to find out the operating energy of a building in running conditions or so. So, in this particular paper by Ramesh et al., it is given that the operating energy is the annual operating energy which is EoA and multiplied by the life of the building. But this EoA, the annual operating energy of the building, is not very static; it fluctuates.

If I say that I will calculate only one day and then multiply it by the running number of days or so, it probably won't be the same. So, you need some kind of investigation or so. It is not going to be the same. The energy in the year 2024 will be different from the energy in the year 2030, which will be a little bit more or less. So, it is a little bit of a hazy area, but still, we have to find out the particular yearly footprint of the energy. So, that is why I say that this equation looks very easy or very slick, but it is not so easy to do. And then finally the

It is again conceptual that the demolition energy is the summation of the energy required for demolition, the energy required for the destruction of the building, and the transportation of those waste materials from the site. So, now let us go to the overall life cycle understanding, the proportion of the life cycle also. So, as I said, the initial 2-3 years will be spent on the construction of the building. So, if I spend 2-3 years or maybe a little less than that on construction, I require some kind of embodied emissions or so. So, the y-axis is the amount; if I say this y-axis is the total amount of energy.

So, the initial embodied energy is not so high, but the intensity of the initially invested energy is high. The intensity means that within 2 to 3 years, the per-year amount of energy I am going to spend on the building is high. So, this rectangle is not the greatest rectangle out of the four, but this rectangle is the inverted rectangle. So, the footprint of the rectangle/year is very, very high.

Is it clear? It has been very well explained in this particular paper, Ibn Muhammad. In that paper, this has been wonderfully clarified, and it suggests incorporating this particular diagram in the process of estimating the life cycle energy. If you see the next smaller one, this rectangle, the lower rectangle, represents the recurring embodied energy, which will occur after the construction. That is why it is after the yellow rectangle.

So, it starts from after 3 years and continue till 40 to 60 years the total life period of the building. So, this is the recurring embodied energy. Total footprint is also not so high, but it is elongated till the end or so. And then this green part, the maximum part is the operating energy, the operating energy and operational operating the emissions or so. So, in that if you see what is written here, it is because of the energy uses, it is accumulated over time.

It is mainly due to the operation and the occupant, it is written. But embodied energy does not depend upon the occupant. It is the building primary energy for the material used. And this is for the occupant, the operational energy, green one. The pattern of the energy use, how I am using the energy, what is the building, what is the type of the building.

Based on that, what is the function of the building. So, this green rectangle is the total impact of the operating energy over the span of the building life of 40 to 60 years. So, that is the another. The last one is the demolition energy. It is shown the demolition footprint is also quite high, may be high or low depending upon the how much is your building height and building total the footprint areas or so.

So, from that point of view, this particular diagram is a very wonderful diagram that depicts the proportion, the intensity, and the variation in the length of the different types of energy. Next is another, and this particular paper—the Eben-Mohammeders paper—also suggested a lot of other things. The first one, let us discuss the right-hand side graph, where it has suggested that the operational energy is quite high and almost about 80%. If you see the y-axis, it gives 0 to 100 for the total life cycle. Out of that, this triangle—the area of the triangle or whatever may be the total amount—is 80%, yes. And this, the embodied, includes both the embodied, the recurring, and the initial, which is about 20% or so. So, this is the nature of the embodied versus the operational, but if you contribute a little bit more in the embodied, your operation may sometimes come down.

We will discuss the change in the variation of the embodied versus the operational when you go to the next week for the retrofitting chapters. In the left-hand side graph. which again has been proposed by this paper, has 1, 2, 3, 4, 5 lines if you see. The first lower one is the initial embodied energy, which is a constant kind of scenario, and then the recurring embodied energy is the green one. This is the initial.

This is the recurring, and this is some of the data that they have used in that particular paper. The second one, the orange one, is your total embodied energy. That means if you add this one—the dark blue and the green—if you add these two, you will get this. Now we are left with one more. They have not definitely taken the demolition energy, demolition energy or so.

They have taken the operating energy, which is the red color line—the operating energy, which is this. This is OE. So, if you see, the total energy is again this. This is, I may say, the total embodied Total embodied energy plus the operating energy gives you the total energy—whatever total energy, which is the black line again.

And now, if you see, the total embodied energy, which is the addition of the recurring and the initial, and if you see the operating energy, these two are the sloping lines, but the TEE, the total embodied energy, slopes a little less because it is not so intensified. It is less—20% of it—so it is less. But the operating energy stiffness is higher, and the inclination is higher than the total embodied energy inclination. So, after certain years, after certain years, after certain years,

It is going to cross the imprint, or the amount of the total energy—embodied energy—the operational energy is going to cross, and that is called the overtaking time. That is called the overtaking time. So, based on this particular fundamental concept, we have—let us discuss this problem. So, this problem is already explained in Lecture Number 26. I have mentioned—you can go back and see—if you remember, we have discussed two parts in that lecture.

Once we have this data, we have found out the EEI, that is the embodied energy, initial embodied energy, which is something like 5,83,000 something, and also in that particular problem, we also discussed or calculated the recurring energy, which is 55,000 something. But if you remember, if you see that, it has a 50-year life period. And a 5-year material life. So, there are 9 times I have to repeat the repair or the renovation because it is 50 minus 5 minus 1.

So, minus 1 because it is already taken into the time of the construction or so. So, this 9-time total amount of energy is 55,462.5. So, I can divide that by 9, this 55,462, and that will be the division. Whatever comes after the division, the quotient of the division, will be how much recurring energy I require each time after 5 years or so. So, first, let us draw a graph on the time versus energy scale. So, the first one is static, which is your 5 lakhs.

Which one is this? This, which is a flat, right? And then the ER is 55,462, and if I divide by 9 because I have to do it 9 times, the recording is 9 times. And 9 times after every 5 years. So, each time, I have to actually pay 6,162.5 mJ of energy for 5 times. So, each one of these is your 6,162.5.

Each one. Each step. Those small small steps. And finally, after 50 years you have total of this much 55462. So, what we can do?

We can do that instead of going this step or whatever. we can this it is the ei plus er is this much if you add up so what we can do we can draw a sloping line instead of the step line or whatever we can draw a sloping line sloping line will give almost the same character of the energy footprint of the recurring and the slope will be I will divide the whatever 55,462.5 by 50, the amount, the number of years or so. So, I may say that per year, this is per year of out of this 50 year/year ER. So, it is maybe said that this is small ER, the per year, this much amount of the recurring energy is required.

mJ/year. So that is defining by this dotted line. So, what we do is that so if I again little bit go back so I can say that this is this one is actually your it starts from and this goes like this something like this. and this is like this. So, finally, it looks like this.

I have removed the steps. So, this is the recurring. Now, suppose in a certain case, this is the sloping line which shows the recurring and the next line is your is your total EI line or so. So, finally, this is your EI plus ER line because I am adding each time.

So, this is your EI initial and the recurring together. So, I consider the total this is the total EE line or so and this is my operating the slope of operating I have taken OE. the oe the smaller letters are your maybe some kWh/year or mJ/year some some unit and similarly this is also can be written as the kWh/year or mJ/year or so So that means this is the point before that. So, if I say that the building is running after some time, maybe after some time, maybe after some time, maybe after 30 years, 30 is too much, 20 years.

If you do not do any kind of maintenance or so due to the lack of maintenance, operating energy will be very, very high. It will not be going to the way it was there in the first 20 years or so. There may be some damage in the roof there may be some kind of damage in some insulation spot there may be some damage in the roof chhajas or so so it will or maybe some the window panes are not giving you its maybe It has some kind of the insulations or maybe some kind of the black flints or these are not maybe working.

There will be some gaps in the window frames, so that it leaks or it is going to infiltrate the outside air. So, without that kind of proper maintenance—regular maintenance—if you do not do it, your operating energy line will go up. But if you do maintenance, it can be brought down or at least maintain the same initial slope. But if you do some kind of a energy retrofit, so if I do the energy retrofitting after some 20 years, you feel that you could do something to reduce the energy footprint or operating energy. Yes, you can do that. We'll discuss that in the next week. The two lectures will be on energy retrofitting, so we can do that also.

So, next one, let us see that again. So, here what we understand is that you need to do some kind of minimum maintenance just to lower that energy and go with the blue or the green line also. We may not want to reduce it, but if I do some kind of retrofitting—because new materials may be coming after 20 years or so, which I have not thought of in today's design—I can introduce that after 20 years, and then the operating energy will go down. So, in this, we can actually say that after a certain time, this green line is going to overtake this rooted line. That is called the overtaking time, and the overtaking time can be calculated by this formula.

I have taken that this OE into OT. OT is overtaking time. OE is the operating energy intensity in kW-hour/year, and the EER is the recurring embodied energy intensity in kW/year. Overtaking time in years, and EEI is the embodied energy. So, if you see that, actually, what does overtaking mean?

At this particular point the total amount of green is equal to the total amount of red dotted portions of the triangle and the below portion. The below portion is my E E I capital E E I and this portion this portion is my EER into this x or y I have written as y that means this is my y or sorry not y OT sorry sorry it is OT overtaking time. This is the one part and the green was green one the green one is the ot o e so that part is the o e into the o t so this must be equal to this plus this this plus this so finally the i got so if i if i reduce the o e if i if you reduce the o e definitely

the OT will be higher. So, you will cross it afterwards and that is good. I mean that is good because otherwise you cross it afterwards means your green slope is less and that is definitely good. So, I have taken some problem, a building having 650-meter square of the built-up area, lifespan of the building is 80 years, the life cycle related data are given embodied energy initially is almost 1700 kW/hour/m^2, recurring embodied energy is

5500 kW/year. So, this is your EER, this is your EEI, of course you have to calculate with multiply with the

the building built up area and this is OE. So, based on that you can calculate the what is your EI, this is your recurring embodied energy for 80 years and this is your operating energy. So, it is a total operating energy for the building for this 650 I am multiplying because it is per year. sorry not per year per m^2 not per year m^2 and this is this 80 I am multiplying is for the per year. So, this total embodied is the per m^2 and this is per year.

So, if you do that, this total life cycle energy I can calculate, and also, I can say that 80% is the total operating energy, 6% is the total recurring energy, and the 14% is the total embodied in initial embodied energy. And by this formula, the OE intensity, I know how much kW-hour per year from the last slide if you go back. If you see this, it is that this OE Then this is the initial embodied 11th house. This is the EEI. These three data are required, this data is required, and also this one is the 5500 per year. This is the year data. So, based on that, if I calculate, I can get the So, 15.24 is a 15.24-year overtaking time, and finally, I can say this is the last slide.

So, there can be many ways of cutting through. This is the operating energy cutting, you know, almost a 45° inclination or so, or maybe this middle funnel. So, it is a normal efficiency. If it is cutting like the above, then it is a low efficiency. It is very stiff, and if it is below the peak, so it is, you can say, a high efficiency. So, we discussed the embodied energy, which is about 15 to 20% of the total life cycle energy, and we conclude this particular embodied energy part with this lecture. Operating energy has a major share, we see, and we see how to reduce the footprint by controlling the operation energy. Thank you very much.