BUILDING ENERGY SYSTEMS AND AUDITING

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Week - 06

Lecture - 26

Lecture 26 : Introduction to Life Cycle Analysis

Welcome to the NPTEL course on Building Energy Systems and Auditing. The new module will start today, Module 6. Module 6 is basically about Life Cycle Analysis and Energy Audit. Lecture 26 is on the Introduction to Life Cycle Analysis. The first 3 lectures will be on Life Cycle Analysis, and the last 2 lectures will be on Building Audit.

In this lecture on life cycle analysis, we will see the various components of building life cycle analysis. As we all know, almost 30 - 40 % of the primary energy actually goes into the building sector. This particular 30 - 40 % of energy, which actually goes into the building sector or the built environment, is responsible for 40 - 50 % of greenhouse gas emissions, which is very high. So, our building industry is looking into how that particular 30 - 40 % of energy is actually consumed in the building sector.

From that perspective, if you look into the total life cycle of a building, life cycle in the sense that, like any biological creature, it has a kind of birth, then it grows up, and finally, one day it dies. The building is also viewed from that perspective in terms of life cycle energy analysis. So, it has a construction stage, then an operating stage, and finally, one day the building will no longer be inhabited. Because it will have passed its actual life and is beyond economical repair, so we have to demolish the building.

So, there is a final some kind of energy is required to demolishing the building. So, in this way we can say that in time of construction the lot of energy is required to construct a building. Then, it is the operating stage which is a maximum time frame may be 50 years, may be 80 years, it is operating, it is operating. So, as we till now discussed in the last 5 lectures, the heat gain, heat losses is indoor temperature, indoor thermal comfort to maintain that particular scenario you require lot of energy to be produced. energy expenditure and that comes under the operation operating energy of the building.

And the finally, the destruction demolition it is a very small stage may be the required may be a month or so, not may be a month sometimes. So, you demolish that one you go for a new building construction. So, that will be earned after this operation stage, but still it is required some kind of energy. And, construction stage is also the period is little high not like demolition, but of course, very small with respect to the operation stage. You may say 1 year, 1 and half year, maybe 2 years is required for a construction.

So, the building life cycle if you see the energy building energy life cycle if you see we have to actually encounter three stages and the three stages will require some kind of the energy to be considered too if you want to consider for the LCE life cycle energy that is the embodied energy. which embodied into the building, they because of there are lot of material, lot of process material, most of the material are process material. Even if you use some stones or maybe some kind of a thatch or maybe a mud also, adobe still you require some amount of energy which is comes from the burning of the fossil fuel. After that OE the operational energy and the demolition energy DE, so the LCE the life cycle energy. Mathematically is arithmetic summation of the embodied operational and demolition energy and that has to be expressed in kWh.

Basically, all the units whatever may be the units you may calculate or estimate finally, that has to be converted to the kWh and absolute terms if you want to see then we have to divide that huge. energy value of kWh divided by the whole carpet area or the built-up area of the building, maybe the built up area of the building. And then it gives you a kWh/m^2 or that particular the unit and then you can actually make that is in absolute terms or maybe sorry not the absolute term, maybe it will be a relative term. Absolute terms are the kWh, if I divide in by the square foot area or the m^2 area of the built up area then it will be a relative term. So, time to time I am going to I have referred these papers the Asif, the Ramesh and also another paper see those papers are fantastically described those embodied energy and the operational energy, demolition energy.

and total life cycle energy of building sectors also. It is available in the internet; you can download and go through those papers. I have already mentioned over here, it is also given in the list of our references. Embodied energy is the energy utilized during the construction phase of the building. Yes, I have already told you there are some materials which we acquire from the market, sometimes we acquire from the industry, but those material has to manufacture somewhere.

If I am going to use concrete, I require lot of ingredients of the concrete, I require stone chips, I require sand. These two may be a earth material, but still, I have to blast it. So, I have to actually do some kind of a blasting which actually require some kind of energy. Then there will be some kind of a processing of the stone chips, it will be transported to my site one and that also require some kind of energy. Similarly, if you take steel, if you take cement, it requires lot of energy to produce

steel required mining from the mines we required the ores of steel and then we taken that particular ore to the steel plant. We require lot of heat and melt it and lot of other things has to be other processes and then that particular steel is actually usable for the building construction as a TMT bar or any kind of a any kind of reverse and then those bars, reverse or steel cross sections, steel structural steel sections are transported from your the industries to the various markets and from the various markets to the site. So, whole process from the mining to the to my site it required each and every process each and every sequence required the energy. So, if you sum it up and divide that by the amount of steel that may be in kg or may be

If you sum it up the what is the total amount of energy required to produce and manufacture, production and transportation of cement and by the weight of the cement or the volume of the cement. We may say that much of gigajoule or megajoule of energy per meter cube or per kg is embodied inside the particular material. And I can calculate that one how much I am using, how much steel I am using, how much concrete I am using, how much bricks I am using. how much aluminum I am using. So, those I can calculate and I can find out what is the embodied energy of my building.

So, that is one of the ways we will see in the next lecture that how that can be calculated. So, this embodied energy as the flow that its raw material mining, then the process of the material, then the material has to be transported every time you have to transport not only once. If you transport the raw material to the processing industry, the processed material can go to the product packaging also and then again you need to transport it to the product distributions. So, every stage there are the transportation requirement also. So, embodied energy is now classified into two ways.

One is called the initial embodied energy. This energy is this particular initial embodied energy is occurred in the very early stage of the construction. You have to construct a building. So, the very first stage of the new building. So, when you are going to construct the energy required for this material point of view transportation etcetera will be the initial embodied energies.

In second part of the energy embodied energy is called the recurring embodied energy. which you require for the repair. After a construct a building today, you may have to repair the building after each and after 10 years or may be 15 years or so big repair is required. May be small some touch up requires repair is required or some kind of a maintenance touch up is required may be after 3 to 5 years or so. So, that also should be included as a one type of embodied energy which is called the recurring embodied energy.

And, then the whole picture of your the total embodied energy for your whole life of the building life cycle of the building will be clear. We cannot just only take the initial one. So, we have to think for the recurring one also. So, initial embodied energy if you see again the same, I have to manufacture it, I have to transport it and I have to erection from the erection time also after transporting it in mixing for some time welding, sometimes it is lifting from ground to the upper floors, so you require energy.

We can say this particular the energy the embodied energy the initial embodied energy is the E manufacturing that is the energy required for the manufacture, energy required for the transportation to the site and the energy required for the construction. This particular the mathematical modeling I have taken from one paper by Dr. K. Adalbert of the Lund University Sweden, it is a fantastic paper, it is available in the internet or I can also send you by the our the forum. So, I have taken that paper and so many other papers are also taken that paper as the benchmark to model this embodied energy. So, this is the equation for the manufacturing embodied energy.

$$E_{Manuf} = \sum_{i=1}^{n} m_i \left(1 + \frac{w_i}{100} \right) \times M_i$$

Where this small m is the quantity, the total amount of material you required to construct some kind of the building, maybe wall. So, m will be your mortar, m will be your brick, something like that. wi is the ith, so it is i equal to 1 to n that means, there are lot of material required for the construction, so not only one. So, i is i1 is for one first material, i2 is a second material. wi is the wastage factor of the ith material.

So, in that paper it is wonderfully mentioned the material some list of material and how much is the kW per ton embodied energy and what is the percentage of the waste and this total is multiplied with the capital MI which is the embodied energy of the material. So, multiplying the kg with the kilo joule or sorry kilo watt hour per ton or per kg will give you finally, a kilo watt per hour kilo watt hour. Similarly, we can do the same way you can find out the transportation energy also only thing only change is that mi is now replaced with ti into tc that is the distance travel because it is a transportation to site. So, how much distance you are travelling di for suppose the ith material suppose brick you are collecting from local market. So, maybe 20 km, but the maybe the marble you are transporting from the Rajasthan. So, maybe it is 1000 km. So, the D fluctuates and Tc is the amount of the transportation energy So, if it is the short distance, it is 0.75 it is given of course, those values are based on the Sweden prospective not the Indian prospective or some other countries prospective.

So, we need to have our own data bank to do that, but this particular mathematical model formula is fantastic in that way it has taken care of all the parameters all together. The third one is the construction energy, the process energy. So, that means, pj is into capital Pj. So, there are j, now it is not i, now it is depended upon the type of construction.

So, there are j type of construction. So, j1 may be mixing j2, j equal to 2 may be lifting something like that. So, how much the number of materials is under that particular construction type and what is the impact of that construction as an energy point of view is capital Pj. that can be multiplied with each other. So, I can get the value of the reconstruction the energy required for the construction.

So, here in that particular paper, a table has been given for some of the excavations, the crane lifting, and the smoothing of the soil. So, how many kWh/ton of soil or some material is lifted from one place to another. So, it is 2 kWh/ m^2 that is required, the energy is required. So, finally, we can find out. So, I have a small problem here I want to show.

So, an amount of 2000 tons of concrete is used for pavement construction. I am considering a 10 % wastage factor. The ingredients of the concrete are transported from an average distance of 25 km. Let us suppose those are the assumptions. And we have to find out the initial embodied energy of this construction with the following data.

The energy required for manufacturing that concrete is 210 kWh/ton. So, I know how much the tonnage is, I know how much the wastage is, I can directly use the first equation and find out that the manufacturing energy is almost about 4,600 to 5,000 kWh.

So, I have this m as the amount of So, I think the amount of concrete is 2000 tons, okay. This wastage factor is my 10 %, and m is given here; this is my m.

So, this is your 210. So, I have placed everything over 2010 and this. So, this is the first, but this is the manufacturing. The second data have given for the transportation conveying the particular thing and the third one is for the process. So, the second one is the transportation.

So, same first part the material and the wastage are taken into account 2000 ton 2000 ton and 10 percentage of the wastage of material, but D into T, D is 25 km given assumption and T is given over here. The energy required for the conveyance of the concrete is 0.75 kWh. per ton km. So, 1 ton 1 km if you want to transport that concrete material or whatever you require 0.75 kWh. So, this is your distance km and this is your

energy and those. So, finally, this 41250 kWh is your transportation energy required for this particular construction. The third one is the third component of the embodied initial embodied energy is the E construction that is the energy required for the construction which is the 2 multipliers. Just two things one is the amount of process. So, I have to actually 2000 ton amount of concrete I have to process, I have to mix, I have to lift or whatever.

So, that particular process has been mentioned here in the problem sheet: 40 kWh/ton is the process of concrete, and that much amount of energy is required for the processing. So, directly I can multiply this by 2040. So, the 80,000 kWh is my total amount of energy required for this processing or whatever. Construction processing. So, now, I can add these three arithmetically: the first one is the material embodied energy, the second one is the transportation energy, and the third one is the process of the construction energy.

So, I can find out by adding all those three numbers, and this is the 5, I think it is 583,000. 250 kWh is the total embodied energy of the material. But please remember that this is for the initial construction of those pavement concrete pavements; we require some maintenance for that every 5 years down the line. So, the same paper also provided the embodied energy. For recurring purposes.

So, it has the renovation energy: manufacturing renovation, transportation renovation, and construction renovation. So, a building will have a lifespan, and the lifespan will have some kind of repair, retrofit, or something like that. So, we have to take that also into account. So, in that particular paper, this particular formula is also given. So, you see the first part of the formula remains the same as the initial embodied energy formula material energy, but it has been multiplied by the life of the building divided by the lifespan of the building -1.

$$E_{Manuf-renov} = \sum_{i=1}^{n} m_i \left(1 + \frac{w_i}{100}\right) \times M_i \times \left(\frac{\text{Life Span of a building}}{\text{Life span of material } i} - 1\right)$$

Suppose the life of the building is, say, 80 years. And the life of that particular material—say, concrete, a door, or maybe some kind of flooring—may have 10 years of life. I think it has also been described here that there are two types of life—I have not mentioned it, but there may be two types: one is called the life from a strength perspective. After 10 years, the strength of the flooring may vanish or reduce. Or maybe it is so low that it becomes dangerous, especially if that particular material is a structural component. So, we have to replace it.

So, it is a technical life, you may say, and there is another life called the aesthetic life, which may apply to paint and such. It may not have the same technical life that could trigger danger or a life threat, but it may pass through its aesthetic life. So, let us suppose for this particular case: a building with an 80-year lifespan and flooring with a life of 10 years. So, in this equation, the last part—the bracketed part—is the lifespan of the building (80 years) and the lifespan of the material (the flooring is 10 years), minus 1. Why is this minus 1?

This is actually (8 – 1) = 7. You see, you require 8 changes. Out of these 8 operations, the first one is already included in the initial embodied energy. So, that is why it is always going to be minus 1, because the initial embodied energy accounts for the flooring. Within the span of 80 years, you have to change that flooring—or whatever has a lifespan of 10 years—7 times over the building's life of 80 years or so. So, based on that, the lifespan of the building divided by the lifespan of the material, minus 1, has been taken into account. In that particular paper, another table provides some lifespans in years.

Suppose if you see the parkway floating, it has a 50-year lifespan. Suppose the water pipes and electrical wires also have 50 years. So, the painting and the wallpapering have almost like 10 years or so, maybe in our country it may be a little less because of the dust, humidity, and other issues. So, like that, we can have different ways to look into it, but the formula goes like this. Next is again the transportation renovation kind of scenario; the same formula is again added with this DE and PC.

Here, 20 km is assumed to be added extra because some material can be scrapped and then sent to the disposal site, which may be assumed to be 20 km away from the site. But there may be some material we may not actually send to the disposal area. We may actually use it for some other purpose or maybe dump it in very nearby areas or so. So, that is also taken. So, it is comprehensively taken that extra 20 km for waste disposal in this formula.

And the construction renovation is also the same; some action has to be taken at the time of renovations. And for the actions to be taken, you require some footprint of the energy. So, the same problem we will continue here. So, let us suppose an amount of 20 tons of concrete is used for the periodic renovation of those pavements, considering 10% of the waste. The lifespan of the pavement is 50 years, and the lifespan of the material is 5 years.

So, the thing is that after 5 years. I am not going to change whole 2000 pavement, but 20 tons of pavement may be 1 % of the there will be some kind of a repair or damage maybe we can find and those 20 tons of ah the concrete has to be brought into or manufactured or whatever I mean have to actually construct. The ingredients are exported from 25 km sorry imported from 25 km. Find the recurring embodied energy using those formulas or so. So, now my m is 20.

It is reduced to 20, this is 10 % of the wastage is there and 210 is the material embodied energy which per ton. So, the to manufacture that on because here also you have to manufacture, but the amount is less amount is not equal to your initial embodied energies or initial requirement or so, at least for this pavement may be for flooring you may require to have whole flooring has to be changed. So, in this case of flooring in case of painting it is a It is the overall kind of a change, but some repair in the wall maybe some structural repair you may not have to change whole lot of structural systems of the material.

So, that there are differences. Here in concrete pavement, I am assuming that the after 5 years 20 tons are going to be used as the repair also. This 50 by 5 is nothing but the 50 years is the life of this pavement and the 5 years is the periodic interval I am going to repair it minus 1. So, that means, this 41,580 kWh is the manufacture renovation energy required for this particular for this particular process.

You need to transport this is the same equation has been further modified with the as it is proposed by this particular paper. And it was found as 6682.5 kWh is the requirement of the transportation energy. Similarly, the process energy is going to be the something like this. Now, one point I want to mention over here. Here we have to take the the process is 9 times because there are 9 times, we are going to do it.

So, it is 20 into 9 that is 180 tons of the concrete has to be required for those 9 times ah renovations work. So, your total energy required for the process is your almost about 7200 kilo hour or so. And, because if you see this 9 comes from this, this is your 9. This is your 9, 50 by 5 minus this is your 9, 10 minus 1 is your 9. So, 9 times I am doing the thing repeating, but in this particular formula this 9 is missing.

So, I have incorporated that in this particular formula. So, actually 20 tons 9 times 120, 180 tons of the work. So, finally, the embodied energy recurring I think there is a small mistake this is should be typological this should be R. Embodied energy recurring will be your 55462.5 kWh So, if I go to the next so, this is going to be the end of this lecture, but if I go to little earlier. So, what I feel is what I got here is the almost 583250.

Is the initial embodied energy 5 lakh? Please remember 583,000, and here it is what I am getting is that it is 55,462. Of course, it is because of the 20. And there it was much higher, 2,000 ton. So, of course, the initial embodied energy will be much higher with respect to the recurring one.

So, we will carry forward this particular calculation of recurring and initial embodied energy in the next 2 lectures, which is lecture number 28 will again see how these 2 will be actually linked with the operational energies also. So, we will see that. What we discussed over here is the building life cycle components, and we have seen what are the fundamental evaluation methods of the initial and the recurring embodied energy. So, I will go back to the reference section again.

So, all the papers which I have referred here are mentioned. Those Asif's paper, Ramesh's paper, and Dilbert's paper, and we can actually go through these, and you can have more knowledge on the embodied energy calculations and that mapping. Thank you very much.