BUILDING ENERGY SYSTEMS AND AUDITING

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Lecture27

Lecture 27: Embodied Energy Calculation

Welcome to the course on building energy systems and auditing. We are in module number 6. We are discussing life cycle analysis and the energy audit. In lecture number 27, we will discuss today the embodied energy calculation. So, we will demonstrate the step-by-step method of calculating the embodied energy of a building.

And in the last lecture, we understood the initial and the recurring embodied energy. By a method where we have taken the transportation component, the manufacturing component, and also the construction component separately. In another paper which I have mentioned here, Ramesh, Prakash, and Sutla's paper, they have also proposed another very simple way of calculating the embodied energy, a very simple mathematical model where they have described it as the embodied energy I, which is the sum of the ith material. The initial embodied energy they are talking about is nothing but the summation of two factors: small mi multiplied by capital Mi.

They are the quantity of the building materials and the energy content of the material, which we understand, and then there is the addition of the energy used for transporting the material to the construction site. They have also proposed the R, the EER. EER is the material embodied energy, but that is a recurring one where they have used almost the same formula. And they have two parts of the equation: in the first part, the material quantity, which is the mi, and the embodied energy density, capital Mi, is multiplied with another factor, multiplication Lb by Lmi, which they have stated as Lb being the lifespan of the building and Lmi being the lifespan of the material i minus 1. So, it is very similar to what we discussed in the last class. Or the last lecture.

So, in a slightly simplified manner, Ramesh, Prakash, and Shukla have suggested that. Now, in embedded energy, what we understand is that we actually deal with a lot of materials in the building. In different parts of the building's structural section, we use concrete, steel, and sometimes bricks, plastering, timber, plastics, and various metals. So, based on that huge set of materials, the NVC 2016 has proposed some classifications. It is under clause number 9.1.4a.

There, they have given a three or four-segment version of embodied energy. The first segment is for aluminum, stainless steel, plastic, copper, and zinc. If you see, they are very heavy in terms of embodied footprint. They have almost more than 50 gJ/ton. So, this is the range: 50 gJ/ton.

So, those are very high. So, we will try to reduce their use in construction. Within the 5 to 50 gJ/ton range, we may say. Mostly, we list the embodied energy of materials in mJ/ton, but sometimes it may go very high for aluminum and steel as well. If you see in the right-side graph, if you compare it with concrete or wood.

These are too high. This aluminum, copper, plastics are too high. Even glass is also too high. So, sometimes they may be, I mean, talked about in terms of gJ. So, in the case of materials like cement, then again steel—not stainless steel, but reinforced mild steel or so. Glass, bitumen, some solvents, cardboard, and papers—these have a little bit less but are also categorized as very high-energy materials, 5 to 15. But out of this slot, steel and cement are high.

I mean high in the sense that we require them in high quantities in our construction. So, you may say that if cement and steel are so high, why is concrete so low? Because concrete is made of steel, cement, stone, aggregates, stone chips, and sand. It is something like one is to two, maybe two is to four. So, one proportion is cement, two is sand, and four is the coarse aggregate. So, definitely, a lion's share of the material will be sand and coarse aggregate, whose embodied energy is very, very less compared to steel and cement. Steel will also be required very less, maybe less than 1% or so in the case of a beam.

In the case of a column, it is less than 4%. So, that is why, even though steel—I am talking about reinforced steel—and cement have a very high, significantly high amount of embodied energy, ranging between 5 to 50 gJ/ton. But you see, the low energy—less than 1—is your sand, aggregate, fly ash, stabilized mud blocks, straw bale, bamboo, stones, and all. So, that is why, if you mix it, in-situ concrete comes under the medium energy, within the 1 to 5 range. So, bricks, timber, particle board, medium-density fiberboard, MDF boards, insulations, and in-situ concrete are in the medium range, 1 to 5 gJ/ton.

So, we can actually take those data from a wonderful publication made by the Earth Institute Auroville. And they have listed down the various material and that is predominantly used in the Indian construction industry. and also, they have the end of this particular booklet. They have also mentioned that how they have calculated, what is the calculation method or so. I sincerely request you all to please go through that.

I will provide this particular material in our forum. It is available freely in the internet also. I mean you can download also. But I will provide you and I will request you to please go through this particular material to try to understand the what is the energy footprint and the carbon footprint is also given the carbon footprint see it is the how much. kg of $CO2/m^3$ of that material which is listed in the column number 1 is also mentioned and also it is mentioned about the energy quantities in the mJ/m^3.

It is mJ/m^3, it is also mJ/m^3 unit and based on some different criteria they have selected that one in a different criteria in the sense if you see the unit it is little different because this is first one is the mJ/m^2 which is based on some the area and this is mJ/m^3 which is based on some volume. So, we have to we can use this data. So, as I told in this particular lecture, we have to see the how to calculate what is the step-by-step procedure. So, I have taken a very simple floor plan of a Dwelling, which is yes, this type of one of the dwelling or one of our faculty accommodations in our IIT Kharagpur campus.

So, it is a very simple dwelling. We have two bedrooms, one dining area, and some living space with a toilet. So, those dimensions and everything are given in the figure. So, what will I do? I will calculate the energy footprint of this building, except the central part.

I will only do this for the housing part. So, I will take from grid A to grid D and grid E to grid H. Between grid D and E, there is a staircase. I am not going to include that in my calculation because it will take a bit longer. So, I want to give you a glimpse of how this calculation will happen. So, I need some data.

So, I need material data. I need the sectional view. It has 3 floors—ground plus 2—and there are 6 total apartments, with 2 apartments on each floor. It has a 1.2-meter by 1.2-meter pad foundation with a 300 mm thickness. It has 300 by 300 mm columns throughout with 1.5 % steel. I have mentioned here—if you see in the section—the footing has 1 % steel. We also have a PCC slab, 120 mm thick, as the base slab.

It has a 300 by 350 plinth beam. It has a 250 mm brickwork. It has floor beams of 300 by 500. So, those are there in those particular calculations, and there is a 150 mm thick RCC slab also provided over there. So, I have calculated in my own way; there may be some small errors because I have gone through this particular thing and estimated the total energy required.

So, the error may involve detailed calculations with the way we do the estimation and costing, like the central line method or so. So, I have not gone into that much detail, as you can always do, but I want to give you a glimpse of how estimation can be done. So, there may be some slight variation between the exact estimate and my estimate. So, there are three floors. The total number of apartment floors is two, as we have seen.

We have plain cement concrete. I will estimate that. I will estimate the concrete. I will estimate the reinforcement also because all the percentages are given. I will also estimate the country brickwork.

These mJ/m^3 values I have taken from the Auroville data, and these are the applications. So, this is only for the subfloor on the ground. This RCC and reinforcement is applied in the RCC of footing, column, plinth, floor beams, and slab. And the wall is also there—I mean, bricks are used for the wall. So, I am not going to calculate for the floor finish or maybe the windows, doors, painting, and all; just these rough calculations I am going to perform.

So, one by one, I have performed that. So, first, I found out the volume of the footing: 1.2 by 1.2 by 0.3, and then 1% of the steel. So, every time I did that, I first found out the overall volume, and then the percentage of steel gave me how much steel there was. Then I deducted that from the whole volume and got the volume of the concrete. So, similarly, I did it for the RCC column: total length, then I deducted the beam size and all, then the total length of the column, and then I calculated the volume of each column, the steel, and the concrete. And similarly, I did it for the estimation of the RCC plinth beam and the RCC roof beam.

I am assuming that wherever there is a plinth beam, there is also a floor beam connecting pillar to pillar or column to column. So, I have taken the way we do our estimation grid lines. So, grid A1—how much is the length? 3.5 plus 2.5 plus 300 is the half and half of the length of this brickwork or so. So, like that, grid 2 has 3 segments of the wall, which is why it is 3; grid 3 is also having 3.

So, again, the other directions A, B, C, and D—those four grids are there. So, I have calculated all the grid lengths and added them up. So, the total length becomes 76.2 meters for both, and the differential—the area of the cross-section of the floor beams and the other plane beams—are taken. So, as it is of the So, the depth of the beam is 500, keeping that 150 mm thick for the slab.

So, I have deducted that one and finally, with the percentage of steel, I have calculated. So, this is not—my intention is not to teach you the estimation. That may be a little bit of a calculation error, I must say. It may be an error because I have not taken the centerline method or the other method. So, similarly, I have found out the RCC slab and also the PCC on the ground floor, which I have estimated from the AutoCAD file itself. So, from the AutoCAD file, I will use the area formula or the area command, and then I have got those values. And for the PCC, I have taken the internal floors because I know here there will

And for the RCC slabs, I have taken the whole perimeter boundary. So, that is, it is a little bit more. So, like that, and finally, I have calculated the wall. In a similar way, the grids—this is grid 1 and 1, 2, meaning the grid in between 1 and 2—that means this is called 1, 2 because this is in between this D2, this wall, this toilet wall, or whatever. No, it is a kitchen wall.

this is the grid D2. Similarly, there is a 2 3 also that is this one, this is 2 3. Similarly, there is a is AB, this is AB. Like that the way we do in our estimation the date but this is for the 250 wall thickness brickwork and I have deducted the door and window from that because we have to deduct that one that is going to be a good volume. So, the net volume of the 250 wall is something like 19.145 m^3.

So, that also has been done then in next I have calculated the internal partition wall. So, internal partition wall supposes if I go back. This 1 2 this grid 1 2 does not have any 250 wall. So, that is why this length is blank this length is blank. Even the 2 3 and 3 2 3 is this 2 3 is this and 3 3 is this.

So, it has all internal wall. So, that is why it does not have any 250. So, this is blank. a b and b a b is this yes this is a b and b b is this this one is b b these are also blank because this does not have any 250. So, like that

the where are there are in which grid the what is the length of the brickwork that I have taken and another thing I must tell you suppose if you take the grid number 1. So, I will just erase it then grid number 1 it is why it is 3200 and 2200. say this the brick work will be from here to here right here to here so this is 3500 3500 is the entire length from the center line of the so this is of estimation actually so let us still just try to understand the thing so this is my column this is my column this is 3500 column to column center line of the column to column so this this is my brick So that means this will be 3500 minus 150 here and another set it is 150 minus 3500 minus 300. So that means it is 3200.

That is why it is 3200 for the first one. The second one is what? This one. This one is 2500. The grid to grid and then again, I have to deduct 300.

So, it is 2200. Okay. So that is why. So, like that there is little... changes in length.

So, I have just calculated the split length between the columns. So, that may be what we need to understand. And then the total volume I have multiplied with the height and with the thickness. You may ask why the height is 2.5 meters or so, because if you go back to the section. So, this is your 3 meters till here, and this is your This is your 350 from the soffit of the slab, but this is your 500.

So, the height of this is 2500 for the wall. So, for all three. So, that is why the height is 2500. 2500 is the height; this is the thickness. So, I have converted everything to meters, and then this is the volume.

And then there is one number of W in the first grid. This is one number of W, and nothing is there. So, there is a reduction of this much. So, finally, this much. So, like that, I did it for all. Similarly, the 250 wall is also calculated.

See, in the grid 1, there is no 250 wall because this is the perimeter wall. So, similarly, grid A will also not have. The grid number 4 also will not have because this is all perimeter. This is grid number 4, then D, then A this will not going to have even C will not going to have because there is no partition as such.

So, like that those are zeros and the thicknesses are less now 225 and the heights are. So, this is something like you know the estimation this is not in our domain not it is our domain, but not in the domain of this energy. energy part, but we need to do this and we need the specification and also the estimation of the material to convert that one into the energy footprint, embodied energy footprint at least. So, it was 6.5 m^3. of the 125 mm the smaller one and the 19.145 is the thicker one, so 250 mm brick wall.

So, now both are added just these are the same table, both are added and I found that I need to have per apartment, 25.65 m^3 of the brickwork. So, I need to have that much. So, now I put all the numbers. So, I have different materials.

See this concrete 1 : 2 : 3 is where? It is from the subfloor per apartment. So, this concrete is for footing per number. So, there are how many footings are there have to count. So, there are 30 such footings, there are 30 such columns.

So, this is per footing, this is per column concrete, per footing steel, per footing per column steel, per plinth beam that is also per apartment. So, like that this is the floor beams and all everything per this is per estimated as per what we have calculated. This is the final one the brickwork 25.65. Now, this one is seeing this footing is there are 30. So, I have multiplied those all number by 30.

Column is also 30. The plinth beam is per apartment. So, that means, I have to multiply with 2 because the plane beam will be only in the ground. So, there are 2 of such set the floor beams will be 6 because there are 3 and there are 3 or maybe you may say there are 2 in each floor there are 3 floors.

Similarly, floor slabs are also 6. There are floor slabs that are also 6 because, per apartment, I have calculated. So, there are 6 such apartments. So, 6 this is 2 for the floor beams, and this is 2 for the subfloor because subfloors are on the ground floor only. And there are six for the brickwork because they are also like that—six sets. So, I have multiplied and put each value in the corresponding.

So, I have four materials actually. Basically, I have concrete, I have RCC of different types of concrete, two types of steel, and brickwork. So, I have all four material estimates for the. The for the building plus this—remember the central part of the D to E grid is not taken into account: the staircase and the central lobby part, the common lobby part. Now, the things are very easy. I have put in those values: 21.45 concrete, which is PCC, then 188.5 something is your concrete of steel.

The steel is 1.3, 153 is a big, and then I just multiplied with the corresponding embodied energy, which I got from this Auroville Earth Institute data bank, and added. So, it is almost like. 16,64,670.9 MJ is the total embodied energy of this particular building. Of course, it is much more. Because the central part is not there, and also a lot of other materials have not been considered, like brick, the floorings, and also you can definitely do it—we can definitely do it. You can definitely add up, and then this value may magnify or so, but this is the whole soul about it. You may say this is the total civil work required—this much amount of mJ.

What I did next was convert the mJ to kilowatt-hours by dividing by 3.6 because 1 kilowatt-hour is 3.6 mJ. The total built-up area I calculated was, of course, not including the central one because I had not calculated that. I calculated the total built-up area of all 6 apartments, which is 586 m^2. So, I tried to estimate the building footprint—the energy footprint of the apartment. So, in mJ, that was converted to gJ/m^2, which comes to around 2.84 gJ/m^2. Whereas, in kilowatt-hour terms, we can say it is 789 kilowatt-hours/m^2, as both values—this value and this value—are divided by this value.

The final slide shows that this particular code also provides the carbon emissions. So, I took the first data point: CO_2 emissions produced an average of 0.098 kg of CO_2/mJ of embodied energy. So, knowing this, I now converted those mJ by multiplying by 0.098. So, it comes to almost 163.1 tons of carbon dioxide equivalent emissions.

Then again, I divided that by the footprint—the total built-up area. So, that gives me the carbon footprint of the building as almost 278 kg/m^2. So, in this particular lecture, some of the initial and recurring energies, along with other computational methods by T. Ramesh et al., were discussed. It also provided guidance on computing the carbon footprint of a building and the energy footprint of a building. Of course, it is the embodied energy footprint and also considers many other factors.

Thank you very much.