# Density matters: Carbon Neutral Potential

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# 1. ABSTRACT

Today, the World is facing the most important environmental challenge in the whole of humanity: Climate change. It is known that, this it is mainly driven by carbon emissions and with the building sector contributing to up to 40% of the total emissions. In this regard, some of the main questions raised by people at Transsolar are: where are we and what could we do more than what we are already doing to limit global warming? This results to discussions around the topic of Carbon Neutrality during the project days, trying to find a uniform approach to address Carbon Neutrality in projects and how to communicate its meaning to clients.

Looking around to the rest of the world, different approaches and definitions of Carbon Neutrality already existing were compared. In the search to come out with our own definition and framework, it was thought that maybe a definition is not needed, but instead defining what is the potential for Carbon Neutrality is important, and as well as how to communicate this potential to clients.

Therefore, the whole discussion was flipped from Carbon Neutrality onsite definition to Carbon Neutrality onsite potential.

To understand Carbon Neutrality onsite Potential, the focus was put on how much–a building can do to be "Carbon Neutral" onsite. From a similar perspective, one of the most relevant question raised was:

“*what is the density(height) of a low energy building to be Carbon Neutral onsite based on a certain program (residential, school, office etc.), in a certain climate and considering what carbon balance (operational energy, plug loads, embodied carbon)?*”

Here starts the sensitivity analysis, trying to answer these questions for different climate zones in the World. The main takeaways from the sensitivity analysis are summarized in the following points:

- To achieve Carbon Neutrality onsite, the height of the building will vary based on the carbon balance (operational energy, plug loads, materials) and climate.
- If embodied carbon of materials is included in the carbon balance, there is only a slight difference in number of floors between wood and concrete construction for some climates (such as Stuttgart) compared to the others such as Pune.
- The orientation of the building offers an extra advantage (height of building) in climate with high solar radiation (closer to the equator).

To keep the bigger picture in mind, the question about the impact of buildings on climate change is still to be addressed. However, this study provides some insights to understand the potentials and limitations of achieving Carbon Neutrality onsite in different parts of the World.

# 2. INTRODUCTION

Diving into the topic of Carbon Neutrality in buildings started with a literature review of what other institutions and organizations are currently during in this topic. The goal is to understand how Carbon Neutrality is defined by other institutions, looking at what do they include in the carbon balance and where is Transsolar in this topic.

Figure 1 depicts an overview of the individual approaches from the main institutions identified, focusing on how Carbon Neutrality is defined based on the ingredients of the carbon balance such as operational energy, plug loads, materials, water and transportation.

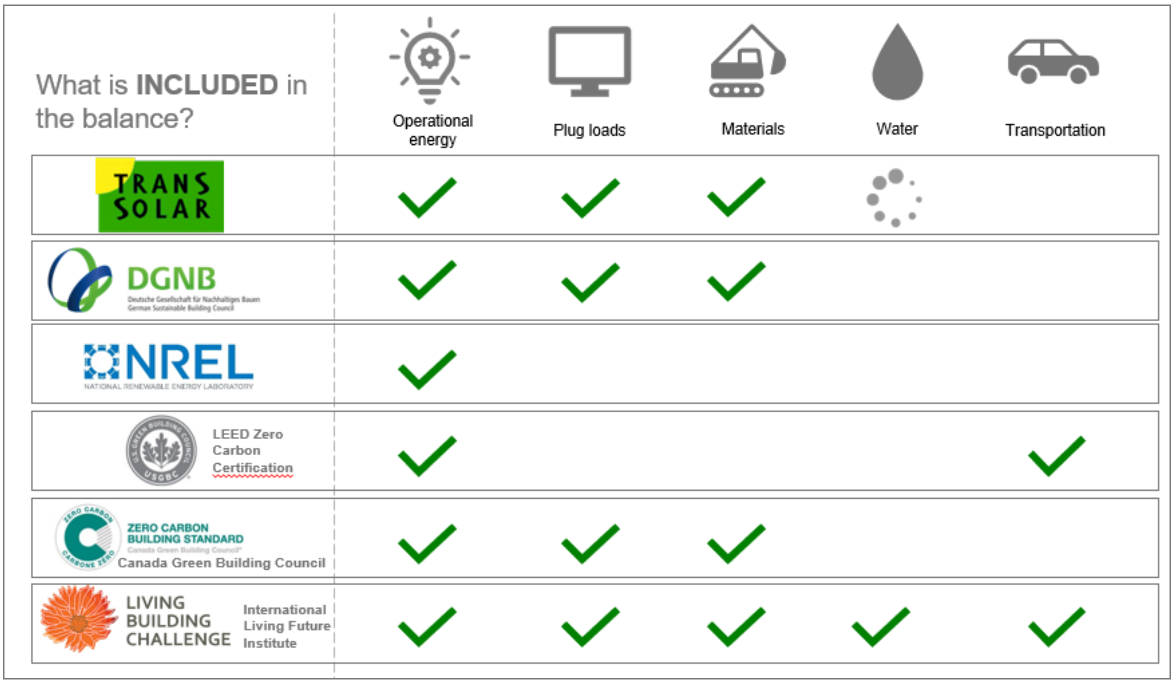


*Figure 1: Summary of Carbon Neutrality definition*

The institutions listed above constitute part of the main actors in the topic of Carbon Neutrality in Buildings and they provide comprehensive definitions and descriptions of their approach to the topic. For most of them, the definition and target for Carbon Neutrality is addressed in their certifications such the LEED Zero Carbon cortication from the US Green Building Council (USGBC), Zero Carbon Building standard from Canada Green Building Council (CGBC), the Climate Positive award from German Sustainable Building Council (DGNB) etc. Today, it can be seen through the work of Transsolar that embodied carbon of materials should be included in the definition of Carbon Neutrality. Also, discussions about water management are becoming important.

# 3. METHODOLOGY

The potential and limitations of achieving Carbon Neutrality onsite in different parts of the World is evaluated by carrying out some sensitivity studies. Sensitivity analyses are performed to assess the maximum "*Height*" of a building to be Carbon Neutral onsite based on three different parameters:

- Building program;
- Climate;
- Carbon balance.

The density (height) of the building was considered as the unit of measure to provide the same basis of assumption for balancing electricity consumption due to operational energy and plug loads and offsetting the embodied carbon of materials using onsite renewable energy generation.

## 3.1. Case Study

A residential building with two types of construction (wood or concrete) is considered for the analysis. Two different building orientations (Module A and Module B) is considered for each construction type: Module A with south and north facing apartments and Module B with East and West facing apartments. These modules are assumed to be typical floors (no ground floor and roof floor) for a better representation of the entire building profile for energy consumption and embodied carbon of material.

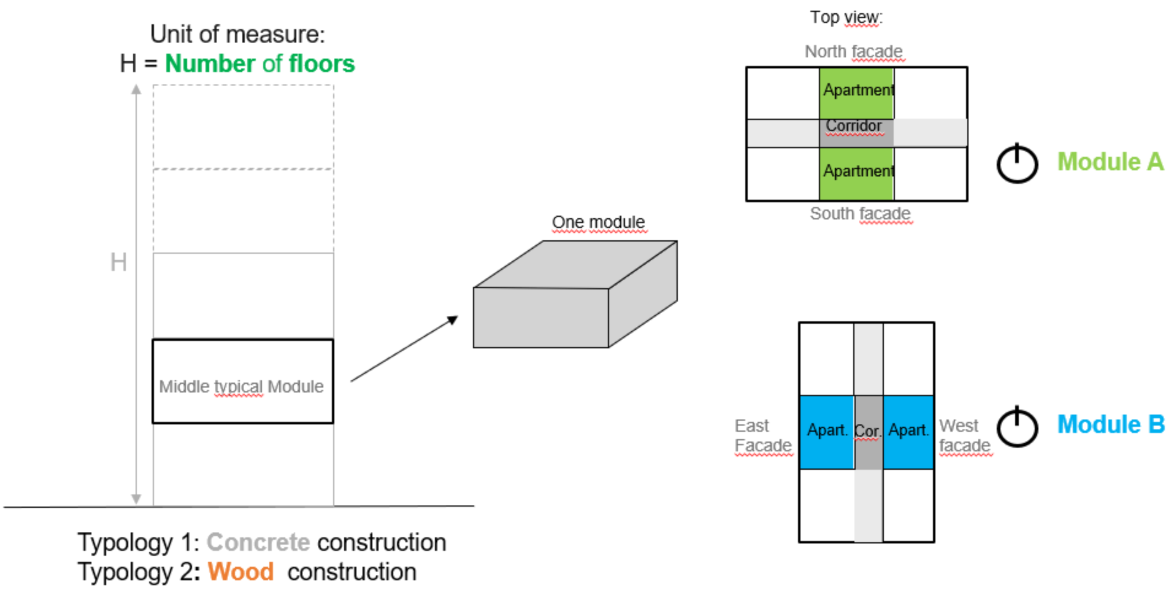


*Figure 2 : case study of building geometry*

For the residential building, different climate zones (such as temperate, hot and dry, warm and humid, composite, moderate climate etc.) were considered in the analysis to provide an overview of what can be achieved onsite that can be used as rule of thumb for similar climates all over the world.

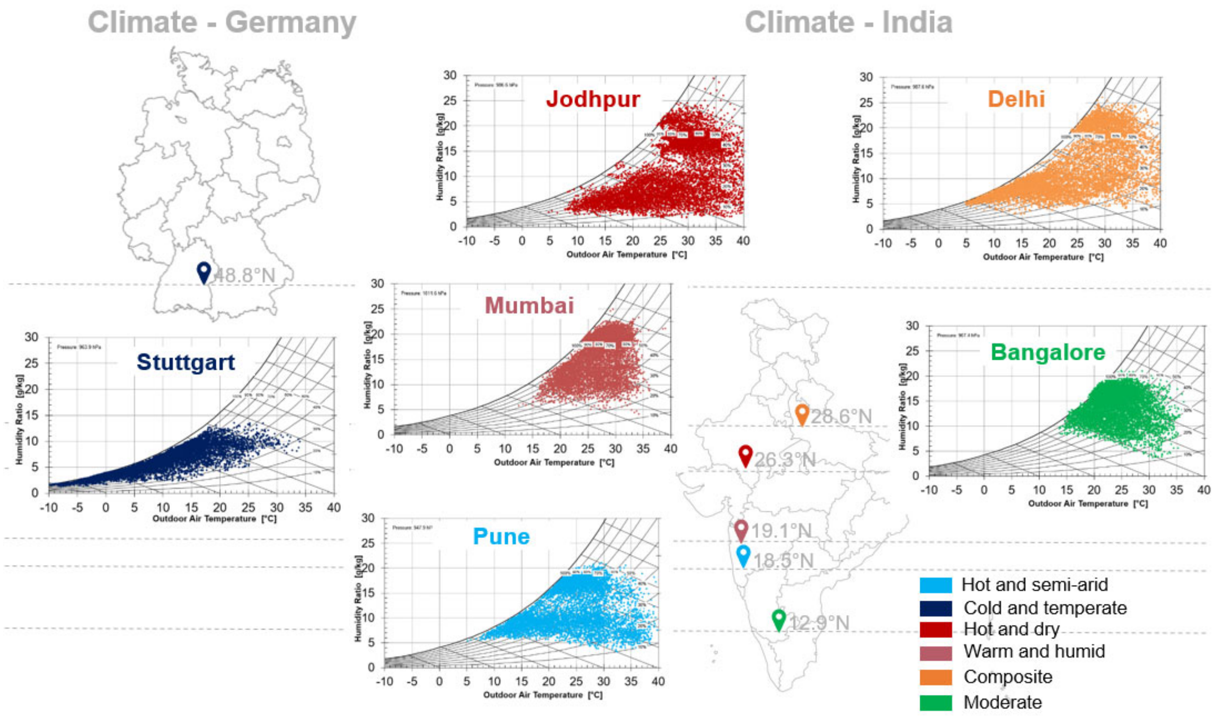


*Figure 3: Psychometric chart of the studied cities*

This study can be applied to other locations with similar climates and solar radiation as shown in Figure 4.

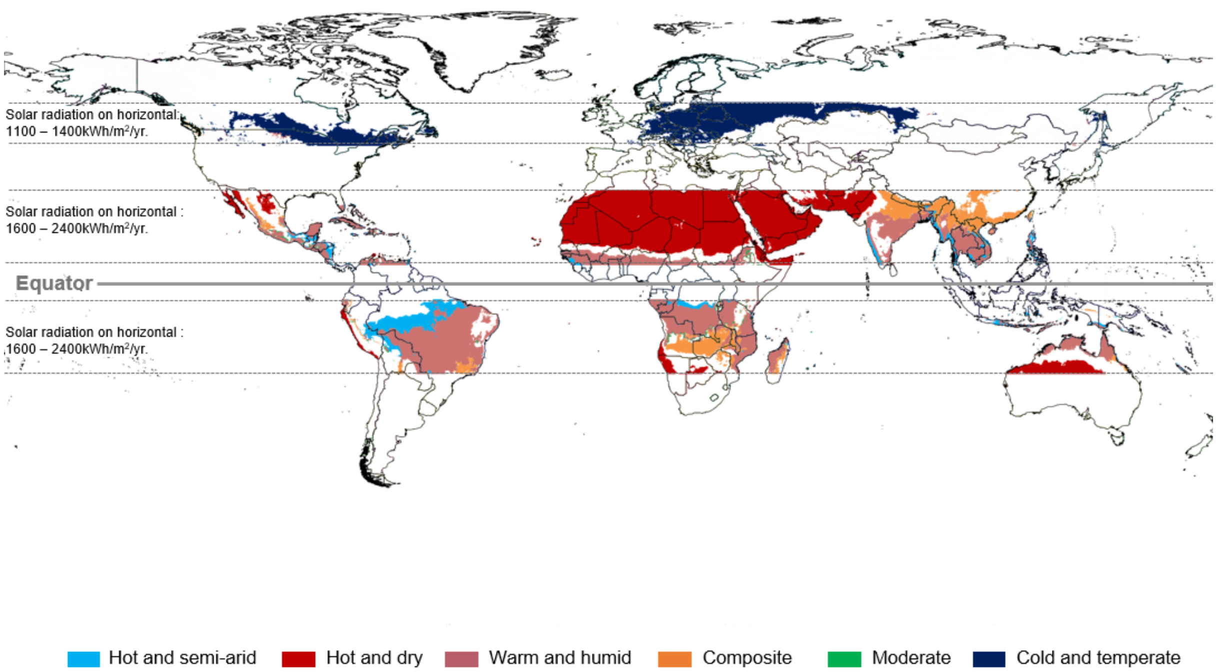


*Figure 4: Climate zone – case study*

Table 1 summarizes the amount of solar radiation in the different locations on a horizontal roof and on vertical facades. This represents potential for electricity generation using PV on roof and on the facades.

*Table 1: Solar Radiation in the different climates*

| | SOLAR RADIATION kWh/m².a | | | | |
|---|---|---|---|---|---|
| **Location** | **Horizontal** | **North** | **South** | **East** | **West** |
| Stuttgart | 1162 | 384 | 996 | 775 | 780 |
| Pune | 2294 | 586 | 1157 | 1256 | 1239 |
| Jodhpur | 1978 | 474 | 1283 | 1036 | 1032 |
| Bangalore | 1849 | 586 | 935 | 990 | 982 |
| Mumbai | 1830 | 512 | 1046 | 873 | 893 |
| Delhi | 1767 | 460 | 1157 | 918 | 912 |

It can be noted from the table above that the locations closer to the equator receive higher radiation on the east and west façade compared to the south façade.

## 3.2. Boundary Conditions

### 3.2.1. Operational energy and Plug loads

For the balance of operational energy and plug loads, a shoebox thermal model of module A and B was simulated using TRNSYS18. The same thermal performance was considered for wood and concrete construction. It is assumed a full electric system with heat pump for heating, cooling and electricity. There are operable windows (with 2.5m$^2$ effective opening area) to allow for natural ventilation when indoor temperature is above 25°C. Night flushing (with 0.5m$^2$ effective opening area) is possible when outdoor temperature is above 15°C and indoor temperature above 22°C. Mechanical ventilation is used for dehumidification and to provide minimum fresh air when natural ventilation is not possible. The details of the boundary conditions are summarized in Figure 5.

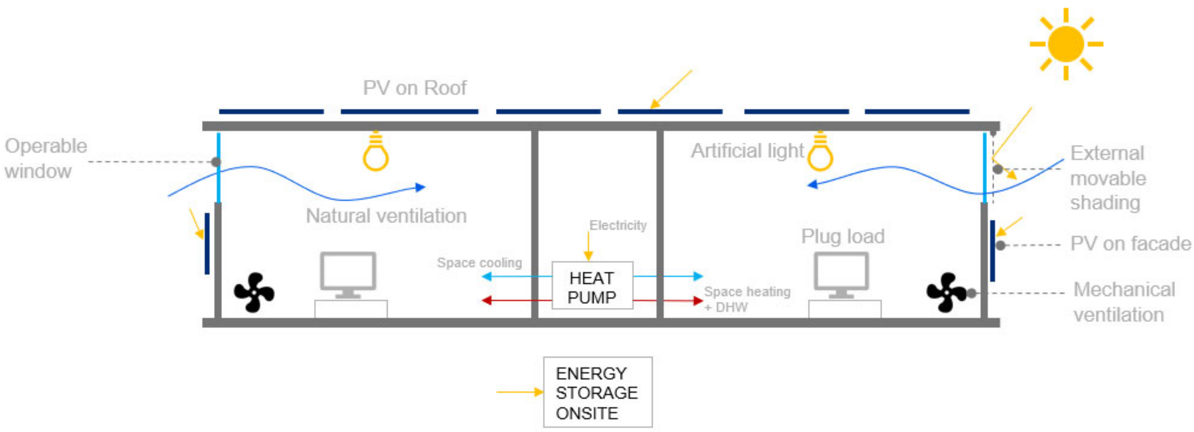


*Figure 5: Boundary conditions for Operational Energy and Plug loads*

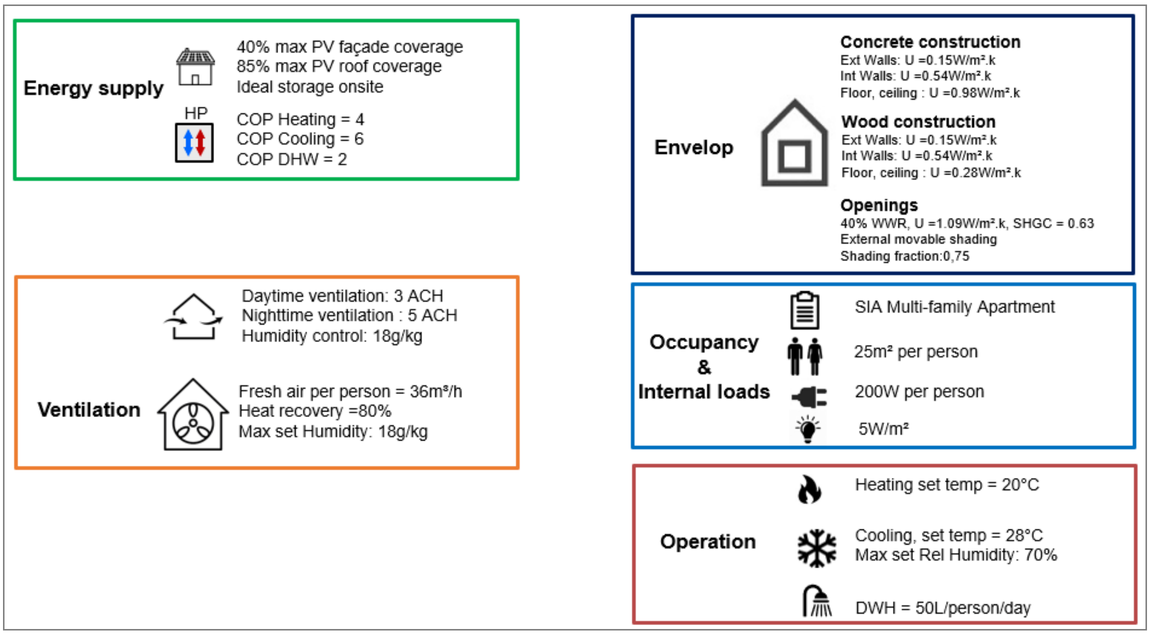


*Figure 6: Boundary conditions for energy simulation*

Table 1 summarizes the site electricity demand for concrete and wood construction in the different climates

*Table 2: Site Electricity demand*

| Climate zone | Operational Energy kWh/m².a | | Operational Energy and Plug loads kWh/m².a | |
|---|---|---|---|---|
| **City** | **Concrete** | **Wood** | **Concrete** | **Wood** |
| Stuttgart | 33 | 33 | 46 | 46 |
| Pune | 29 | 30 | 49 | 48 |
| Jodhpur | 31 | 32 | 49 | 49 |
| Bangalore | 27 | 28 | 45 | 46 |
| Mumbai | 34 | 34 | 52 | 52 |
| Delhi | 32 | 32 | 49 | 50 |

### 3.2.2. Embodied carbon of materials

For the material balance, a Carbon Neutrality target of 30 years was considered as a reasonable timeline to offset embodied carbon assuming that by 2050, the World will be climate neutral according to the Paris Agreement. To include embodied carbon of materials in the balance, Life cycle analysis (LCA) calculations are performed considering only the production phase (see Figure 5). This is to establish the same basis of assumptions between the different databases used: The german database (Oekobaudat) and the indian database (Report from the International Finance Corporation).

Including embodied carbon of materials in the balance, the evaluation of the Height (only metric) of a building considers the following assumption:

- The total embodied carbon of materials obtained from the LCA is converted to electricity equivalent that should be offset every year using the current carbon emissions footprint of the grid (see Figure 5).

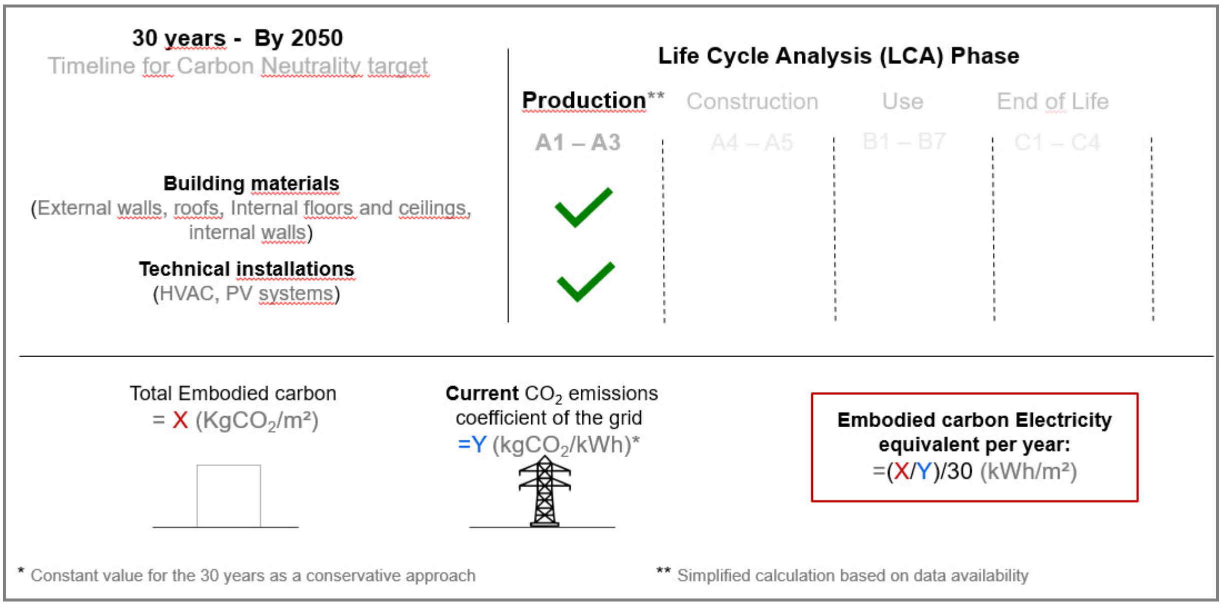


*Figure 7: Assumptions for LCA calculation*

Table 3 shows the results of the embodied carbon of materials obtain from the LCA calculations for both concrete and wood constrution in the different climates. The german database (Oekobaudat) and the indian database (Report from the International Finance Corporation) is used to perform the LCA calculations. The end of life or renewable energy potential of wood constrution is not considered in the calculations. The embodied carbon of materials for the other climates in India are assumed similar to Pune, since the emissions due to transporation in phase A4 are not considered. Base on the current emissions of the grid and assuming a constant value for the next 30 years (0.5$KgCO_2$/kWh for Germany and 0.7$KgCO_2$/kWh for India), the electricity equivalent to be offset every year is also calculated as shown in Table 3.

*Table 3: Embodied Carbon of materials*

| Climate zone | Embodied carbon $KgCO_2/m^2$ | | Electricity Equivalent to offset Embodied Carbon $kWh/m^2.a$ | |
|---|---|---|---|---|
| **City** | **Concrete** | **Wood** | **Concrete** | **Wood** |
| Stuttgart | 552 | 233 | 35 | 14 |
| Pune | 610 | 226 | 29 | 11 |

# 4. SENSITIVITY ANALYSIS

A sensitivity study was performed considering three different scenarios including:

- Case A - operational energy;
- Case B - operational energy and plug loads;
- Case C - operational energy, plug loads and embodied carbon.

This provides a portfolio of what can be achieved onsite with case A being the minimum target as sometimes due to limitations onsite, it is not possible to achieve case B or C. The approach for the sensitivity is summarized in Figure 7.

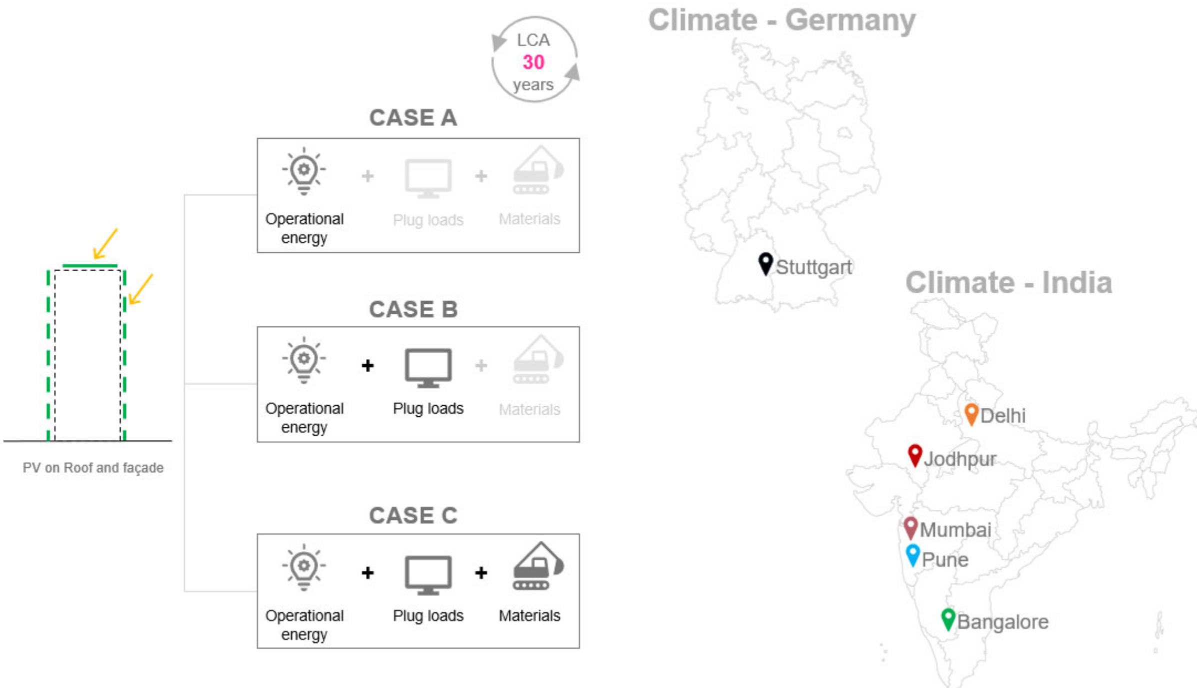


*Figure 8: Sensitivity study for simulated climates*

The total number of floors is calculated by balancing the total electricity consumption (or electricity equivalent for case of embodied carbon) for each scenario with the total electricity onsite production from the PV panels on the roof and facade.

Shown in Figure 6 is a summary of the total number of floors that can be built in Stuttgart based on different scenarios:

- With PV on roof only, 4 floors can be built considering only operational energy.
- There is a variation in number of floors between module A and B considering PV on roof and façade for both cases of including operational energy only and operational energy and plug loads. This mainly due to the higher solar radiation in both the west and east façade compared to the south facade
- If embodied carbon of materials is included, there is only a slight difference in number of floors between wood and concrete construction, roughly a difference of

one floor. Embodied carbon electricity equivalent contributes to roughly 20% and 40% of total electricity consumption for wood and concrete construction respectively.

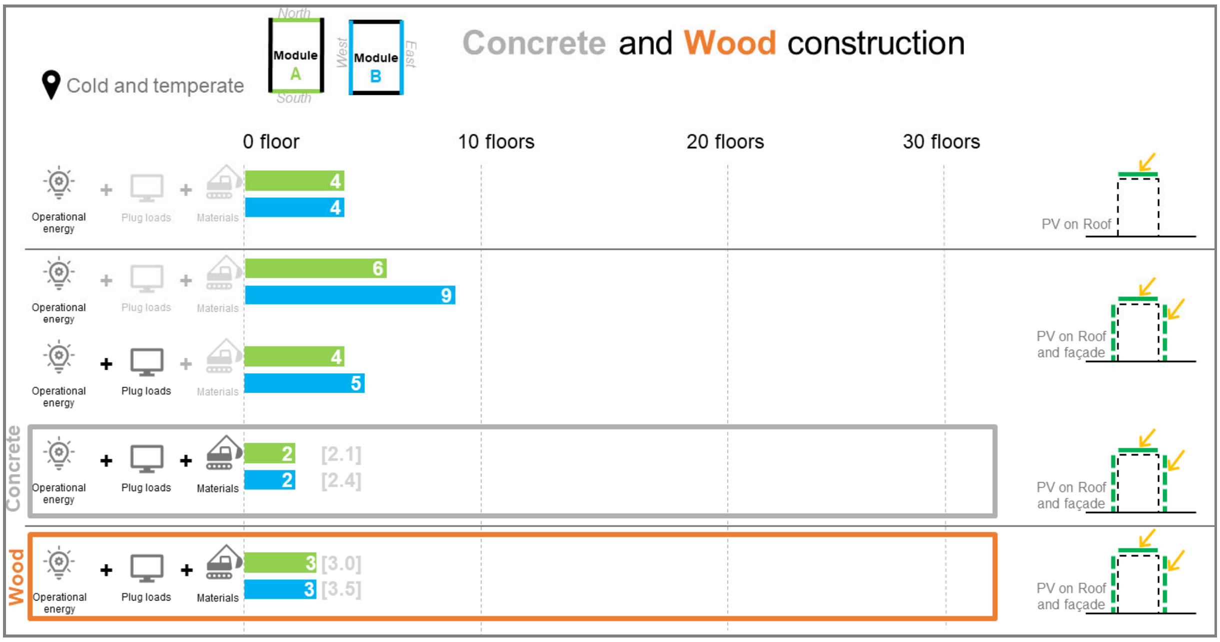


*Figure 9: Number of floors in cold and temperate climate. Case study of Stuttgart*

For the case of Pune (see figure 7), there is a bigger variation in number of floors between module A and B when considering PV on roof and façade for both cases of including operational energy only and operational energy and plug loads.

There is also a significant difference in number of floors between wood and concrete construction. This mainly due to the high solar radiation in both the west and east façade.

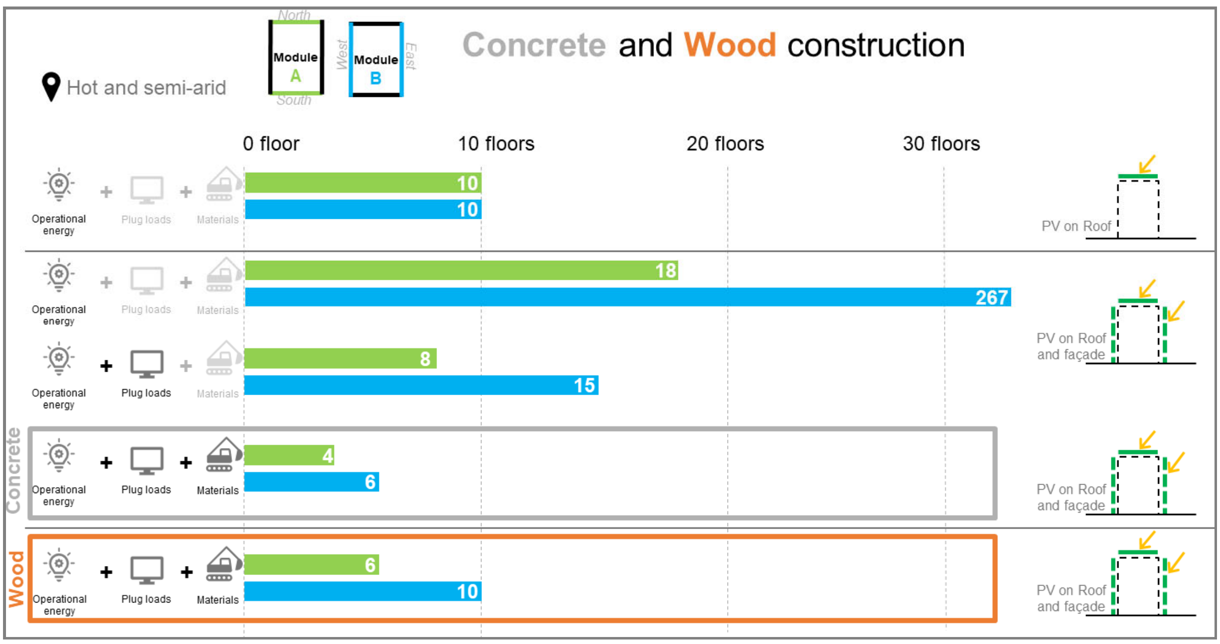


*Figure 10: Number of floors in Hot and semi-arid climate. Case study of Pune*

Similar studies were done for the other climates and summarized in Table 4 and 5. This provides a summary of the number of floors that can be built for concrete and wood construction respectively considering the different scenarios in the investigated climates.

*Table 4: Summary of number of floors for concrete construction*

| Carbon Balance | PV Coverage | Cold and temperate | | Hot and semi-arid | | Moderate | | Warm and humid | | Composite | | Hot and dry | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Module A | Module B | Module A | Module B | Module A | Module B | Module A | Module B | Module A | Module B | Module A | Module B |
| Operation | Roof | **4.4** | **4.4** | **9.9** | **9.9** | **8.6** | **8.6** | **6.9** | **6.8** | **7.1** | **7.1** | **8.2** | **8.0** |
| | roof & Facade | **6.8** | **9.6** | **18.1** | **266.7** | **14.2** | **49.2** | **10.7** | **16.8** | **12.3** | **20.5** | **15.6** | **33.0** |
| Operation& plugload | Roof | **3.2** | **3.2** | **6.2** | **6.2** | **5.2** | **5.2** | **4.5** | **4.5** | **4.6** | **4.5** | **5.2** | **5.1** |
| | Roof&facade | **4.3** | **5.3** | **8.6** | **15.4** | **6.8** | **10.4** | **5.9** | **7.3** | **6.3** | **7.9** | **7.4** | **9.9** |
| Operation& plugload & Embodied carbon | Roof | **1.8** | **1.8** | **3.8** | **3.8** | **3.2** | **3.2** | **2.9** | **2.9** | **2.9** | **2.9** | **3.2** | **3.2** |
| | Roof&Facade | **2.1** | **2.4** | **4.6** | **6.1** | **3.7** | **4.6** | **3.4** | **3.8** | **3.5** | **3.9** | **4.0** | **4.6** |

*Table 5: Summary of number of floors for wood construction*

| Carbon Balance | PV Coverage | Cold and temperate | | Hot and semi-arid | | Moderate | | Warm and humid | | Composite | | Hot and dry | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Module A | Module B | Module A | Module B | Module A | Module B | Module A | Module B | Module A | Module B | Module A | Module B |
| Operation | Roof | **4.4** | **4.4** | **9.8** | **9.8** | **8.6** | **8.5** | **6.8** | **6.7** | **7.1** | **7.0** | **8.1** | **7.9** |
| | roof & Facade | **6.8** | **9.5** | **17.7** | **212.4** | **14.0** | **46.4** | **10.5** | **16.1** | **12.1** | **19.7** | **15.2** | **30.8** |
| Operation& plugload | Roof | **3.2** | **3.2** | **6.1** | **6.1** | **5.2** | **5.2** | **4.5** | **4.4** | **4.5** | **4.5** | **5.1** | **5.1** |
| | Roof&facade | **4.3** | **5.3** | **8.5** | **15.2** | **6.8** | **10.3** | **5.8** | **7.2** | **6.2** | **7.8** | **7.3** | **9.7** |
| Operation& plugload & Embodied carbon | Roof | **2.5** | **2.5** | **5.0** | **5.0** | **4.2** | **4.2** | **3.7** | **3.7** | **3.7** | **3.7** | **4.2** | **4.2** |
| | Roof&Facade | **3.0** | **3.5** | **6.4** | **9.9** | **5.1** | **7.1** | **4.5** | **5.5** | **4.8** | **5.7** | **5.5** | **6.9** |

## 5. CONCLUSION

The main conclusions from this study are summarized in the following points:

- To achieve Carbon Neutrality onsite, the height of the building will vary based on the carbon balance (operational energy, plug loads, materials), building program and climate.
- If embodied carbon of materials is included in the carbon balance, there is only a slight difference in number of floors between wood and concrete construction for some climates (such as Stuttgart) compared to the others such as Pune and Bangalore.
- The orientation of the building offers an extra advantage (height of building) in locations (closer to the equator) with high solar radiation on the east and west facade.

# 6. APPENDIX

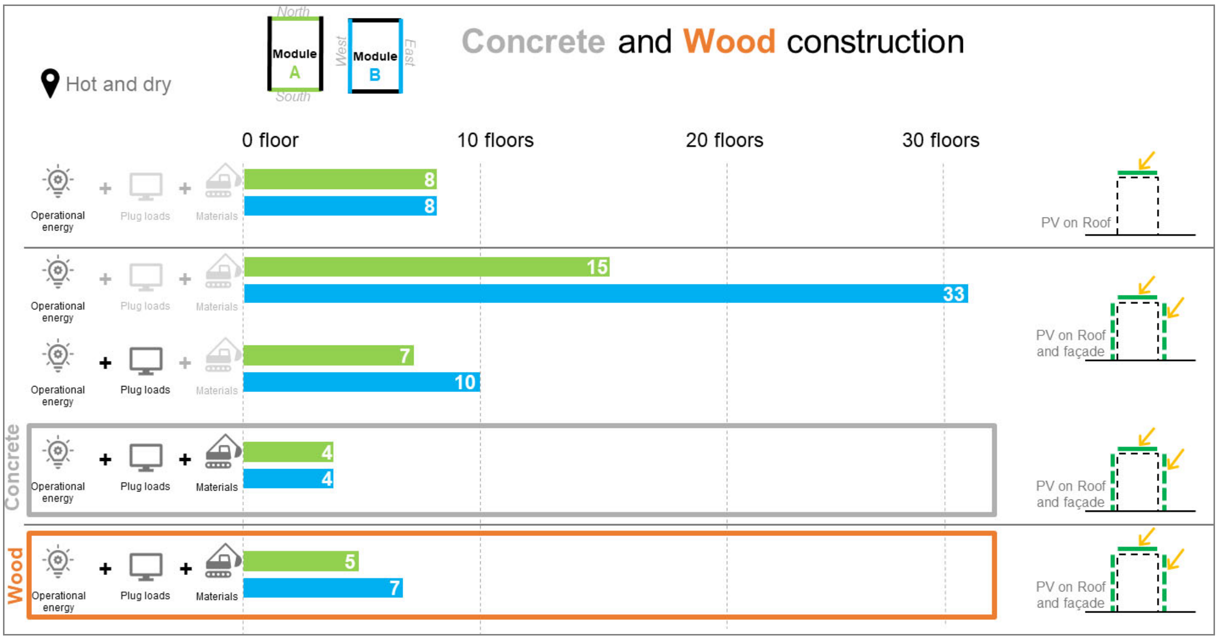


*Figure 11: Number of floors in hot and dry climate. Case study of Jodhpur*

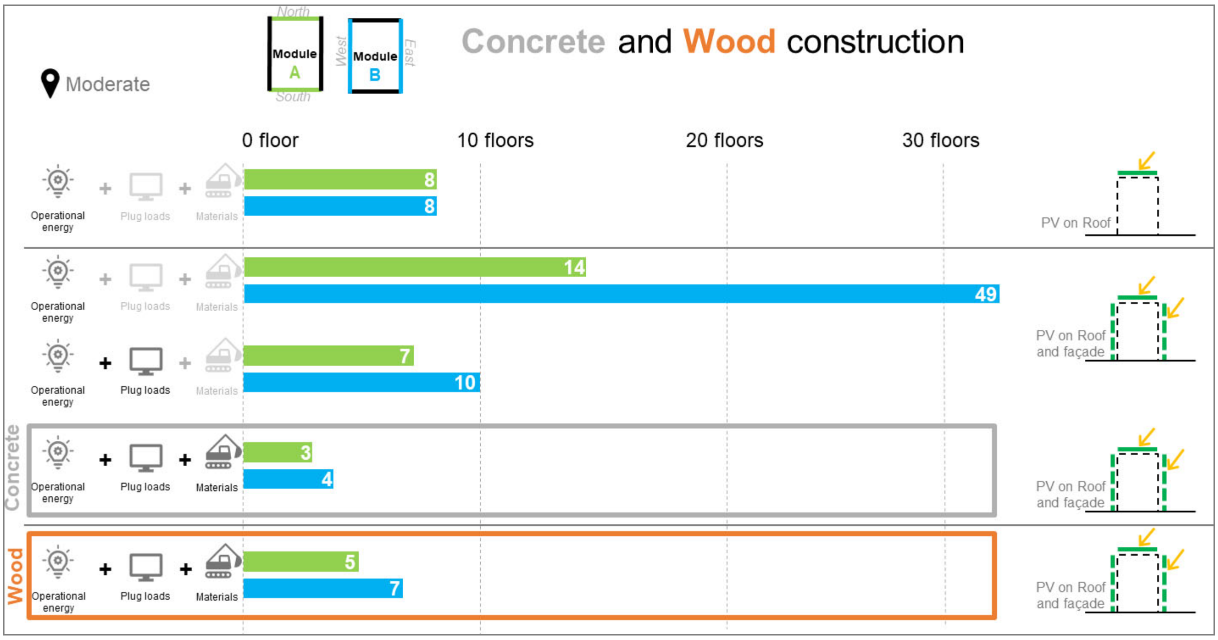


*Figure 12: Number of floors in moderate climate. Case study of Bangalore*

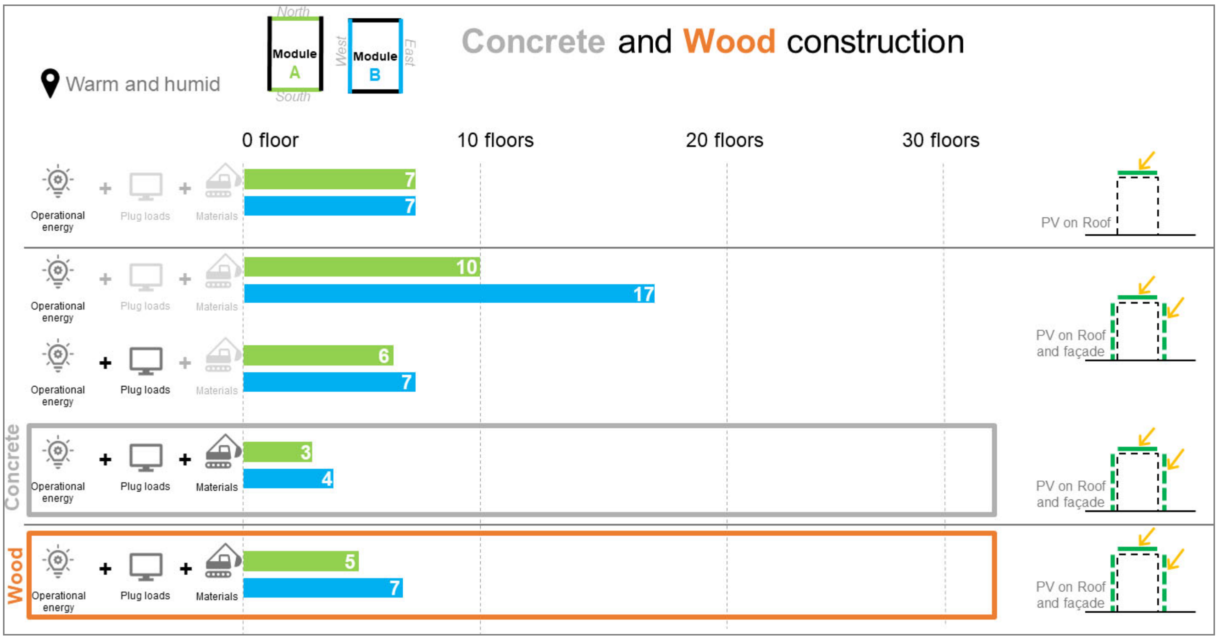


*Figure 13: Number of floors in warm and humid climate. Case study of Mumbai*

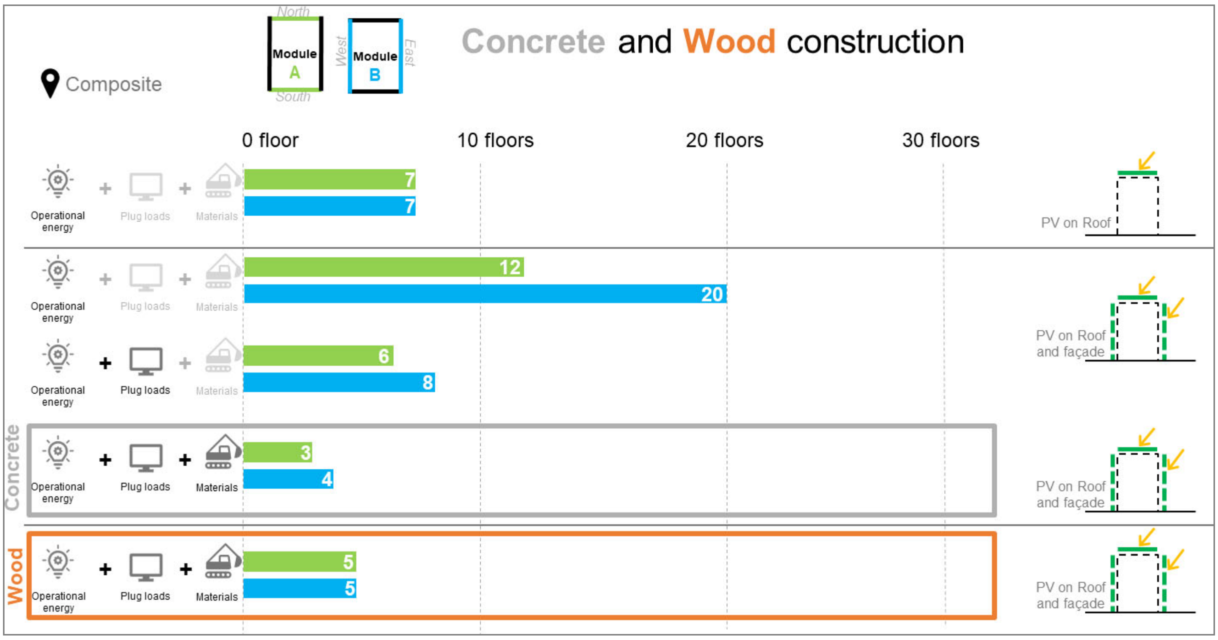


*Figure 14: Number of floors in composite climate. Case study of Delhi*

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