## BIBM Research and Position Paper on

# Embodied vs Operational Carbon Emissions

## Abstract

This paper introduces the topic of embodied and operational carbon, as well as the relationship between the two. Furthermore, this paper **challenges the idea that as operational carbon emissions decrease in the share of total carbon due to technologies, this will increase the ratio of embodied carbon emissions**. Instead, this paper demonstrates that either technology existing to lower operational carbon emissions will also decrease the embodied carbon emissions as the side effect, or other technologies are available to lower embodied carbon emissions. In the end, this paper advocates for the **total carbon approach** in which both embodied and operational carbon are targeted when lowering carbon emissions.

## Introduction

Reducing the environmental burden of buildings and infrastructures throughout their whole life cycle is key in order to achieve the sustainability transition. Specifically, reducing the carbon emissions in the construction ecosystem is increasingly getting attention, as the built environment in general plays a huge role in global carbon emissions contributing nearly 40% of global greenhouse gas emissions, the equivalent to 14 gigatons every year.[1] In that sense, the construction industry should proactively respond to today's challenges and trends by decarbonizing as it is being supported by the policy as well. In order to respond appropriately, an extensive understanding of the embodied and operational carbon emissions in construction is needed. With the motivation to contribute to this field, this research paper will portray the relationship between embodied and operational carbon emissions. While doing that, it will suggest that with peculiar decarbonisation attempts in embodied emissions, there will also be a decrease observed in itself. This predominantly contrasts with the perception of the studies showing that the ratio between embodied and operational carbon will not change much, so then the current assumption of embodied emissions will overtake the operational ones is challenged. Finally, depending on those positions, we as BIBM support the consideration of total (embodied + operational) emissions altogether in the decarbonisation of the industry.

[1] CharlotteCameron. "Reducing Carbon Emissions in Construction." Planet Mark, October 18, 2022. https://www.planetmark.com/reducing-carbon-emissions-in-construction-embodied-carbon-vs-operational-carbon/.

## What are embodied and operational carbon?

Embodied and operational carbon are two components in measuring total carbon emissions. Embodied carbon is all the carbon emitted in the production of the building that is a result of distinct rather than ongoing processes. It mainly refers to the emissions arising from the manufacturing, transportation, installation, maintenance, and disposal of building materials. On the other hand, operational carbon is the carbon released from the ongoing operation of the building use. Sources include lighting, power, heating, ventilation, air conditioning, and other infrastructure such as lifts and automatic doors.[2] So far, much attention in terms of decarbonization has been given only to improving operational carbon by improving building insulation and installing sustainable lighting, rather than improving the embodied carbon emissions due to the difficulty. However, enhancements in the two aspects altogether play a key role in eliminating carbon emissions as the environmental impact caused by construction can be resulting either from embodied carbon or operational carbon, or both.

## Achieving net-zero by enhancements in embodied carbon emissions

With increased energy performances of buildings at the use phase, energy consumption and environmental impacts associated with the construction and demolition phases play a more important role. However, developing net zero carbon assets requires driving down embodied carbon to an absolute minimum along with operational carbon as well. Embodied carbon can be reduced during the initial design and planning stages of the building or infrastructure, yet it cannot be removed from an existing construction work. This means that any reduction is only achieved by thoughtful initial design and specifying construction products and materials that are more locally available, extracted, manufactured, and delivered via low-carbon means.[3] Reusing buildings and materials, using low-carbon concrete mixes, using less carbon-intensive materials, and using fewer finishings are possible actions that could possibly be taken in order to decrease the environmental impact of embodied carbon.[4]

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[2] Engel, John. "Embodied Carbon vs Operational Carbon: What's the Difference, and Why Does It Matter?" Renewable Energy World, October 12, 2021. https://www.renewableenergyworld.com/energy-efficiency/embodied-carbon-vs-operational-carbon-whats-the-difference-and-why-does-it-matter/#gref.

[3] Engel, John. "Embodied Carbon vs Operational Carbon: What's the Difference, and Why Does It Matter?" Renewable Energy World, October 12, 2021. https://www.renewableenergyworld.com/energy-efficiency/embodied-carbon-vs-operational-carbon-whats-the-difference-and-why-does-it-matter/#gref.

[4] "Embodied Carbon: What It Is and How to Tackle It." RPS. Accessed July 10, 2023. https://www.rpsgroup.com/services/environment/sustainability-and-climate-resilience/expertise/what-is-embodied-carbon/.

## Scientific studies on the relationship between embodied and operational carbon

The relationship between embodied and operational carbon emissions has been investigated by different studies dealing with different focuses in the construction work.

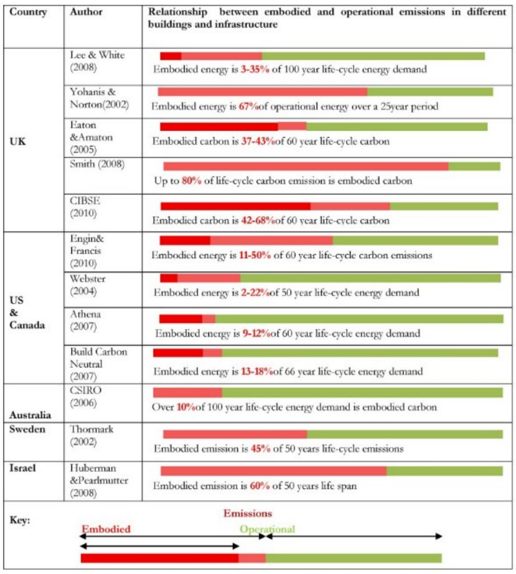

Fig. 3. Variation of embodied emissions versus operational emissions in different buildings and infrastructure.

Several studies on the relationship between embodied and operational carbon. All of them have different methodology measuring different variables, and no future prospect has been found ahead of 2023. Source; Ibn-Mohammed et al.

Some studies demonstrate the improvements in operational carbon increasing the percentage of embodied carbon in total carbon emissions. Röck et al. study more than 650 building lifecycle carbon emissions and show a decline in the total carbon emissions mostly due to operational improvements, while at the same time showing an increase in embodied emissions in the percentage.[5] Similarly, Persson claims by adding wall and/or roof insulation, or improving the windows' U-value, the operational carbon is reduced, while the embodied carbon increases.[6] Thus, Venkatraj et al. point out the increase in embodied carbon associated with different operational energy reduction measures.[7] Chastas et al. analyze 90 case studies in terms of the embodied energy of buildings and the study covers various building types. The results indicate operational emissions constituted a larger portion of the life cycle energy in the past, while now embodied emissions increased with the transition to more energy efficient buildings.[8] Another research argues that the share of embodied carbon is increasing with the emerging trend towards energy efficiency through measures like low/zero carbon building designs and renewable energies.[9]

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[5] M. Röck, M.R.M. Saade, M. Balouktsi, F.N. Rasmussen, H. Birgisdottir, R. Frischknecht, G. Habert, T. Lützkendorf, A. Passer, Embodied ghg emissions of buildings – the hidden challenge for effective climate change mitigation, Appl. Energy 258 (2020), https://doi.org/10.1016/j.apenergy.2019.114107

[6] Persson, Linnea. "A Comparison between Embodied and Operational Carbon in a Building Envelope from a Life Cycle Perspective," 2022.

[7] V. Venkatraj, M.K. Dixit, W. Yan, S. Lavy, Evaluating the impact of operating energy reduction measures on embodied energy, Energy Build. 226 (2020), https://doi.org/10.1016/j.enbuild.2020.110340

[8] Chastas, Panagiotis, Theodoros Theodosiou, and Dimitrios Bikas. "Embodied Energy in Residential Buildings-towards the Nearly Zero Energy Building: A Literature Review." Building and Environment 105 (2016): 267–82. https://doi.org/10.1016/j.buildenv.2016.05.040.

[9] Malmqvist, Tove, Marie Nehasilova, Alice Moncaster, Harpa Birgisdottir, Freja Nygaard Rasmussen, Aoife Houlihan Wiberg, and José Potting. "Design and Construction Strategies for Reducing Embodied Impacts from Buildings – Case Study Analysis." Energy and Buildings 166 (2018): 35–47. https://doi.org/10.1016/j.enbuild.2018.01.033.

On the other hand, with the implementation of low carbon and energy technologies, not only operational emissions decrease, but there will also be a decrease in embodied emissions observed. Hacker et al. finds out operational heating and cooling energy needs decrease with increasing thermal mass due to the beneficial effects of fabric energy storage by the inclusion of sustainable embodied carbon technologies.[10] Alvarez et al. finds out an enhancement in decarbonizing embodied carbon will lead to similar enhancement in operational carbon as well particularly in the design of a novel chilled concrete ceiling technology integrated into the structural floor slab.[11] A decarbonized construction model project has a design that addresses decarbonizing embodied and operational emissions at the same time, with integrating low carbon concrete into carbon offsetting and carbon sink systems that has been used in walls, panels, ceilings and heating systems. At the end, this project presents 55% lower total carbon emissions compared to the traditional means of construction. Furthermore, the building 888 Boylston Street has lowered both operational and embodied carbon emissions with its technologically designed solar panels, chilling systems, and roof. Similarly, Golisano Institute for Sustainability building and The Chicago McDonald's Flagship building have the same operation with its low carbon concrete, solar panels and wind turbines while decarbonizing operational and embodied carbon at the same time.[12]

Moreover, Pan et al. advocate the significance of total lifecycle carbon reduction and find out that utilizing low carbon concrete reduces both embodied carbon and operational carbon. On the other hand, changing the thickness of external walls leads to a very limited life cycle carbon reduction and therefore is not seen by Pan et al. as an effective way for achieving sustainable life cycle for buildings. Although 5.55% embodied carbon is reduced by decreasing the 75 mm thickness of external walls in the building, the operational carbon increases by 2.45% per year with this design. As a result, the life cycle carbon increases by 0.99% over a 50-year building life. This demonstrates the importance of comprehensively addressing the trade-off between the embodied and operational carbon for revealing more insights into the life cycle carbon reduction in buildings.[13] Similarly, as a case study, Rivera et al. conduct a parametric study of a high-rise residential building in Toronto Canada, finding great importance in a total carbon approach.

## Discussion

Today, it is assessed that between 20 and 40 percent of energy and carbon emissions are embodied - associated with the one-shot operations during the lifetime of the building, starting from the extraction of raw materials, going through the manufacturing of construction products and the erection of the building, refurbishment operations and final dismantling. The remaining 60 to 80 percent are counted as operational, being linked with the use phase, heating and cooling, but also electricity consumption. At first sight, due to improvements in low operational carbon technologies, one might conclude that the ratio between embodied and operational emissions will be inverted

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[10] Hacker, Jacob N., Tom P. De Saulles, Andrew J. Minson, and Michael J. Holmes. "Embodied and Operational Carbon Dioxide Emissions from Housing: A Case Study on the Effects of Thermal Mass and Climate Change." Energy and Buildings 40, no. 3 (2008): 375–84. https://doi.org/10.1016/j.enbuild.2007.03.005.

[11] Gascón Alvarez, Eduardo, Natasha L. Stamler, Caitlin T. Mueller, and Leslie K. Norford. "Shape Optimization of Chilled Concrete Ceilings – Reduced Embodied Carbon and Enhanced Operational Performance." Building and Environment 221 (2022): 109330. https://doi.org/10.1016/j.buildenv.2022.109330.

[12] Sayigh, Ali. Towards net zero carbon emissions in the building industry. Springer, 2023.

[13] Pan, Wei, Yue Teng, Yefei Bai, Cong Yu, and Jiayi Xu. "A Holistic Framework for Determining the Trade-off between Embodied and Operational Carbon Emissions of High-Rise Residential Buildings." IOP Conference Series: Earth and Environmental Science 1101, no. 2 (2022): 022014. https://doi.org/10.1088/1755-1315/1101/2/022014.

possibly with 60 to 80 emissions being embodied and the remaining 20 to 40 emissions being operational. Indeed, Erlandsson et al. claim that the climate impact caused by the operational stage is decreasing as is its share of a building's total climate impact.[14] However, this hypothesis does not consider the overall decarbonization trends of the energy and construction sector. Currently, there is an increasing focus on the reduction of embodied emissions either through the optimisation of building fabric to reduce material use or through the specification of materials with a lower embodied emission to reduce the amount of emissions embodied in buildings.[15] As proven in the later part of the literature review, there are technologies and cases concluding that low energy and carbon technologies will impact embodied emissions positively in addition to operational. This prompts a critical review of the relationship between embodied and operational emissions over the life cycle of buildings and demonstrating the increasing proportion of embodied emissions that is one consequence of efforts to decrease operational emissions.[16] Combined with the existing low operational carbon emission technologies, decarbonization in embodied emissions lowers the overall life cycle emissions. This suggests that the performance of buildings should be calibrated in terms of both embodied and operating emissions by accounting for emissions from cradle-to-grave.[17] From the business aspect, lower embodied emissions save emissions during the use phase for a total positive balance as it provides an easy comparison with insulation.

At the end, the overall objective should be lowering the total carbon emissions; embodied summed with operational. The environmental impacts of buildings go beyond the operational phase, and the portion of impacts related to the embodied energy of the building receives significance. Achieving net zero carbon in buildings means having a net balance of zero carbon emissions throughout the whole life cycle, from the extraction of raw materials, through manufacturing and transport, during the use phase and at the end-of-life. So, it is equally important to assess and improve both the embodied and operational carbon in construction across the structure's lifetime. In addition to energy efficiency and decarbonization in operational carbon emissions, such will also take place in the construction and demolition phases including materials, products and operations.

## Conclusion

This paper demonstrates the relationship between embodied and operational carbon emissions and brings a new perspective to the current understanding and expectations of the relationship among the two. In this way, with new decarbonization technologies, embodied carbon will decrease in its share of total emissions, and even in some cases it goes hand in hand with the decrease in operational emissions. Therefore, in future, the ratio between embodied and operational emissions could possibly remain almost the same as today with a decline in both ratios. Although embodied carbon may be a

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[14] Erlandsson, M., Petersson, D., and Jönsson, J.A. ''Referensbyggnaden Blå Jungfrun med träbaserade element med lättbalkar och cellulosaisolering – en klimatdeklaration för hela byggnaden och livscykeln.'' IVL Svenska Miljöinstitutet, Nr C 558. (2020) https://www.ivl.se/download/18.7342a03f17582337c284e94/1606374481222/C558.pdf

[15] Ibn-Mohammed, T., R. Greenough, S. Taylor, L. Ozawa-Meida, and A. Acquaye. "Operational vs. Embodied Emissions in Buildings—a Review of Current Trends." Energy and Buildings 66 (2013): 232–45. https://doi.org/10.1016/j.enbuild.2013.07.026.

[16] Ibn-Mohammed, T., R. Greenough, S. Taylor, L. Ozawa-Meida, and A. Acquaye. "Operational vs. Embodied Emissions in Buildings—a Review of Current Trends." Energy and Buildings 66 (2013): 232–45. https://doi.org/10.1016/j.enbuild.2013.07.026.

[17] Ibn-Mohammed, T., R. Greenough, S. Taylor, L. Ozawa-Meida, and A. Acquaye. "Operational vs. Embodied Emissions in Buildings—a Review of Current Trends." Energy and Buildings 66 (2013): 232–45. https://doi.org/10.1016/j.enbuild.2013.07.026.

new challenge for the sector, businesses, researchers and organisations have been working on this topic for over a decade.[18] These attempts succeeds by preventing - avoid embodied carbon from the outset by considering alternative strategies to deliver the desired function;  reducing and optimizing – evaluate each design choice in terms of the upfront carbon reductions and as part of a whole lifecycle approach; planning for the future – take steps to avoid future embodied carbon during and at end of life;  and offsetting – as a last resort, offset residual embodied carbon emissions within the project organizational boundary where possible or if necessary through verified offset schemes.[19] In that sense, we as BIBM expect all the stakeholders and policymakers to communicate and collaborate for having a common methodology, legislation, and mindset for decarbonizing construction. At the end, long term performance of concrete and precast concrete as a building material will also contribute to reducing the total carbon emissions of the built environment.

[18] World Green Building Council. Bringing Embodied Carbon Upfront Coordinated Action for the Building and Construction Sector to Tackle Embodied Carbon, n.d.

[19] World Green Building Council. Bringing Embodied Carbon Upfront Coordinated Action for the Building and Construction Sector to Tackle Embodied Carbon, n.d.