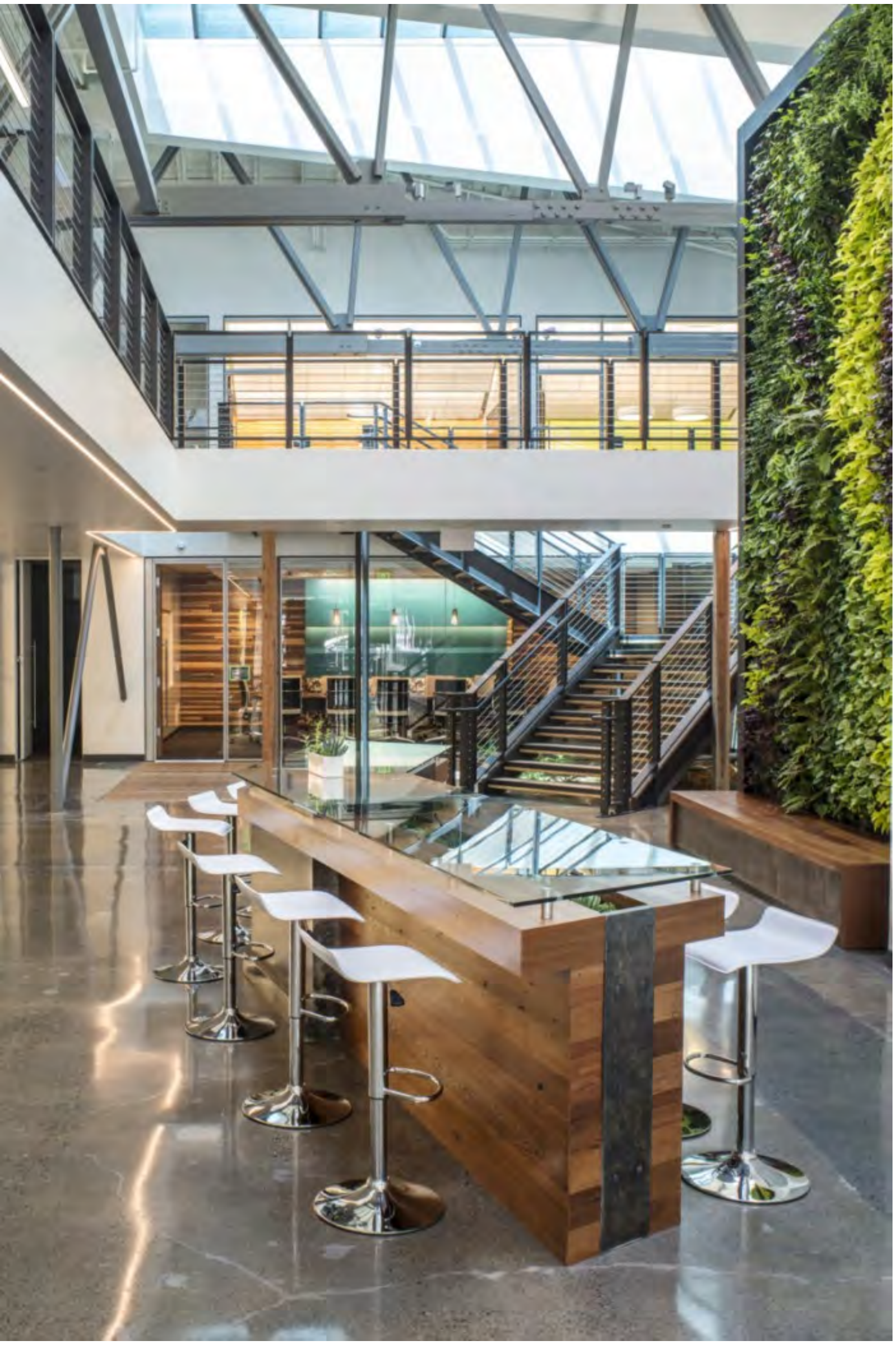

The Total Carbon Study

Case Study of DPR Construction San Francisco Office Building – Net Positive Existing Building Reuse

A Focus on Manufacturing Stage Embodied Carbon via Tally – LCA Revit Plug In

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Why do we care about Embodied Carbon?

The building industry's full range of impacts on the environment — including product manufacturing, site preparation, construction activity, and building occupancy and operations — accounts for 40% of natural resources consumption, 40% of total primary energy consumption, 15% of the world's fresh water resources, 25% of all waste generation, and **40-50% of greenhouse gas emissions**.[1 2]

We have just a few decades to stabilize and then phase out greenhouse gas (GHG) emissions to avoid irreversible climate change.[3] All carbon reduction strategies need to be evaluated on their potential for reduction in the near term. There is a time value to carbon savings that we must take into account.

The current "gold standard" for reducing emissions from buildings is to build new, net zero energy buildings – focusing on eliminating emissions associated with the operations phase. While this is an important strategy to reduce GHG emissions in the built environment, it does not address the two other major sources of building emissions from:

- Embodied, upstream supply chain from building materials,
- Operating emissions from existing buildings

In the United States, we are currently building about 6 billion square feet of new construction every year. Operating that 6 billion square feet releases 25 million metric tons of carbon emissions/year,[4] but the embodied emissions from building that 6 billion square feet has a carbon lifecycle cost of 150 million metric tons, from resource extraction and material production through construction,[5] equating to a carbon footprint of six years of building operations—before emissions for operations start.

An even larger source of emissions results from the operating emissions from the 300+ billion square feet of buildings we already have. Emissions from existing building operations are about 2.2 billion metric tons/year. [6]

So for new buildings it is critical to focus of reducing embodied emissions and for existing buildings we need to focus on reducing operating emissions. Looking at the total carbon footprint of a building that includes reuse plus net positive elements could represent a significant change in building valuation and policy.

About The Total Carbon Study

The 'Total Carbon Study' of the DPR San Francisco Office was initiated by a group of embodied carbon and Life Cycle Assessment experts interested in making a quantitative case comparing embodied carbon of materials, operational carbon from operations, and the total carbon footprint of the building over 30 years. Specifically, this study:

- Signals the need for changes in climate action policy that prioritize deconstruction and reuse over demolition.
- Quantifies saved/avoided carbon attributed to retrofitting an existing building compared to building a new similar structure.
- Demonstrates nearly 70% reduction in the embodied carbon associated with building material supply chain between a new construction and significantly reused existing building structure.
- Quantifies the saved/avoided carbon from converting an average, two story office building into a net positive building. Net Positive buildings generate more energy than they consume on an annual basis.[7]
- Reuse to the maximum amount possible, and renovate to be net positive whenever conditions allow. Please join us in exploring this hypothesis further. Add to our case studies and help us to fill the gaps in the research!

[1] Estimates of this sector's raw materials usage varies between 24% and 40%. In Worldwatch Institute Paper 124, A Building Revolution: How Ecology and Health Concerns are Transforming Construction (1995), Lenssen and Roodman state that "40% of the world's materials and energy is used by buildings." (http://www.worldwatch.org/node/866). According to a 2011 estimate, "approximately 24% of global raw materials are consumed by the (building and construction) industry."
[2] Architecture 2030
[3] National Climate Assessment Report (2014) and the Intergovernmental Panel on Climate Change, fifth Assessment Report (2015), Architecture 2030
[4] Operating emissions for efficient, code compliant buildings assumes 7.5lbs/sf.-residential. 15lbs/sf. –commercial
[5] Embodied emissions conservative assumption: 50lbs.sf-residential, 75 lbs/sf-commercial
[6] Energy Information Administration – CBECS database (2012) and RECS database (2009)
[7] https://living-future.org/net-zero/requirements

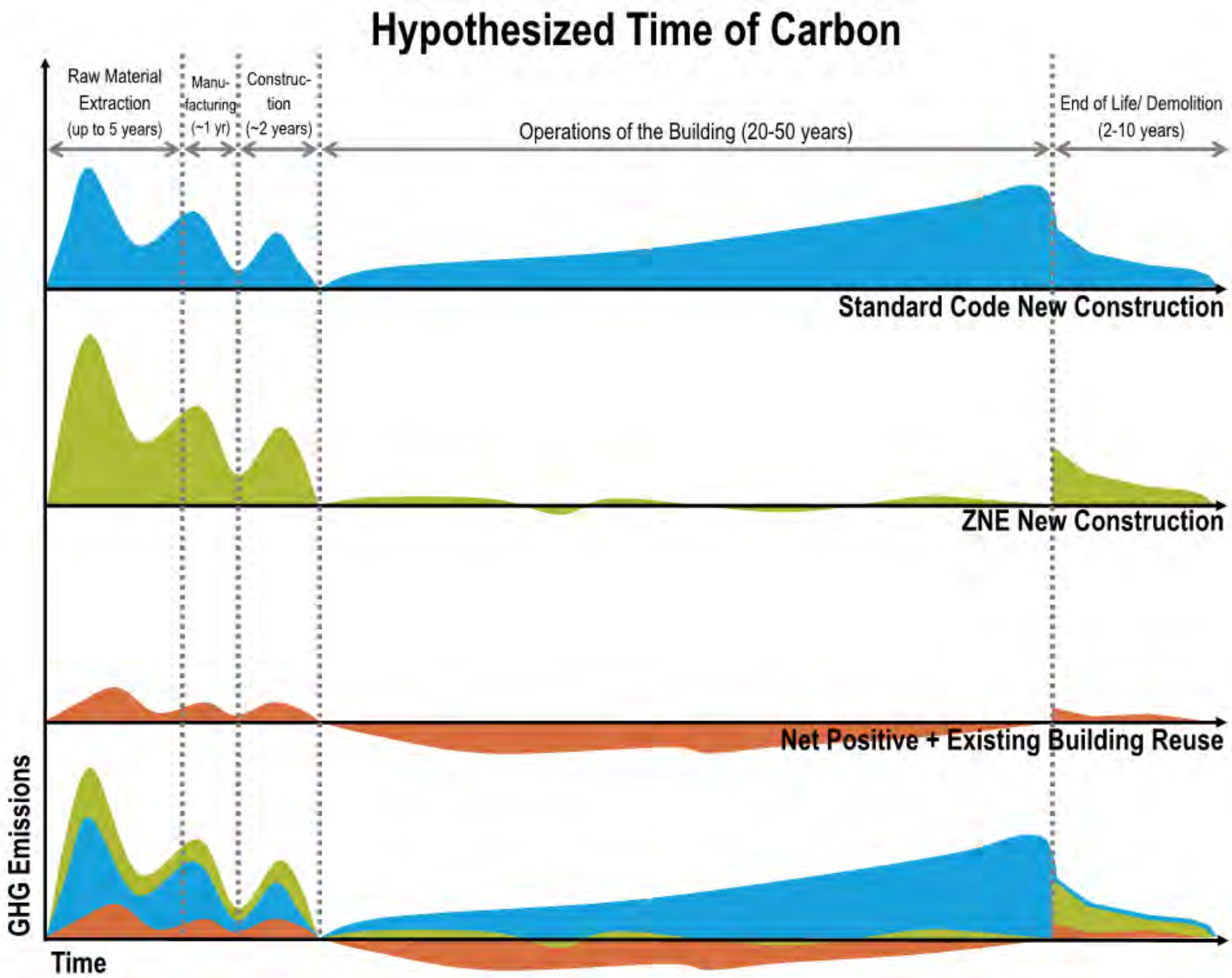


Figure 1. Rough order of magnitude evaluation in the Total GHG emissions released over time (Cradle to Gate) related to buildings - comparing Standard code-compliant new construction, Zero Net Energy (ZNE) new construction, vs. Net Positive existing building reuse.

Parameters

'Carbon' refers to the full spectrum of greenhouse gases as required for EPA GHG reporting, by converting all such emissions into their carbon equivalency noted as CO_{2e}.[8] Through additional case studies, this research effort hopes to piece together chapters that cover each aspect of carbon in the life cycle of buildings; creating an evolving analysis that will build over time. Phase 1 of this study is focused on office buildings that can achieve ZNE or Net Positive performance metrics. The results found herein are based on a single building in San Francisco.

Calculating the total carbon emissions involves evaluating the embodied carbon emissions that went into upgrading the existing building to ZNE or Net Positive standards, the avoided emissions from not building a new building, and the operating emissions of this building compared to a standard code-compliant office building's operating emissions. The term "Total

[8] EPA GHG reporting tracks the following GHG Emissions: Carbon Dioxide, Methane, Nitrous Oxide, Hydrofluorocarbon gases, Perfluorocarbon gases, and Sulfur Hexafluoride. Each greenhouse gas its own global warming potential (GWP) which is translated into carbon equivalency (CO_{2e}).

Carbon" in this study covers the scope I, 2 and 3 emissions as defined World Resource Institute's (WRI) supply chain greenhouse gas protocol for evaluating carbon.

Scope Definitions of Carbon Emissions of a Building refer to the following:

- Scope 1 – Direct emissions during building operations – emissions generated onsite i.e. natural gas for heating, domestic hot water (DHW), gas ranges, etc. Scope 1 emissions are measured per gas utility bills. Fleet Vehicle emissions are also part of Scope 1 emissions - which were assumed to be the same for a remodeled building or a new building, and were not addressed in this study.
- Scope 2 -- Indirect emissions that happen as a result of building operations. Typically, these emissions are associated with electricity usage/power generation coming from beyond the building site, the majority of which is from the electricity provided from the energy grid in the case of buildings. However, these emissions are only created when there is demand placed on the power grid, such as from buildings and their systems that use energy. These Scope 2 emissions are measured per electric utility bills. The emissions associated with grid supplied electricity is accounted for in the greenhouse gas emissions factor published and verified by the utility annually.
- Scope 3 – Indirect Supply Chain emissions. Supply chain emissions refer to both upstream and downstream emissions. Upstream supply chain emissions are associated with the energy and emissions associated with extraction, manufacturing and transportation of the materials, as well as construction phase to build the final product, i.e. a building. Downstream supply chain emissions are associated with the energy and emissions generated through demolition and end of life processes.

What makes Scope 3 different than scope 2 is a lower degree of attribution accuracy for the emissions. For Scope 3 emissions, it is often difficult to prove that an action taken within a building project will have a direct effect on emissions generation somewhere else for which they are not already being claimed. In other words, other parts of the supply chain could already be accounting for some or all of these emissions (leading to possible double-counting).

The Total Carbon Study places a strong focus on breaking down the metrics of the Scope 3 upstream supply chain emissions generated by extraction and manufacturing process of creating new materials vs. material reuse – referred to as 'Embodied Carbon. Scope 3 emissions associated with the materials reused play a major role in the total carbon reduction for the project. Note that the Scope 3 upstream emissions associated directly with the construction process (i.e. excavation, civil work, demolition, construction equipment, etc.) have not been included in this study, but including them will make the case for existing building reuse even stronger.

Another factor that supports including Scope 3 emissions in a total carbon analysis is the importance of time as a factor in climate change. While significant effort has gone into scientific studies that look at the carbon equivalents of various emission gasses, sources, and scopes, ***when*** they occur has not yet been included in the calculation. Yet the authors posit that GHG emissions avoided upstream by the reuse of building materials are more effective in the short term than energy efficiency measures that may take years to realize.

The goal of this report is to compare embodied carbon emissions between a newly constructed building and an existing building retrofit project. Therefore, this study focuses only on the global warming potential (GWP) output metric of the LCA dataset and focuses on the manufacturing stage of the materials life cycle, because the manufacturing stage is where the difference between new buildings and material reuse shows up – by eliminating the need for extracting more raw resources and manufacturing new products. We assumed maintenance and end-of-life were essentially the same for a new building and remodeled existing building.

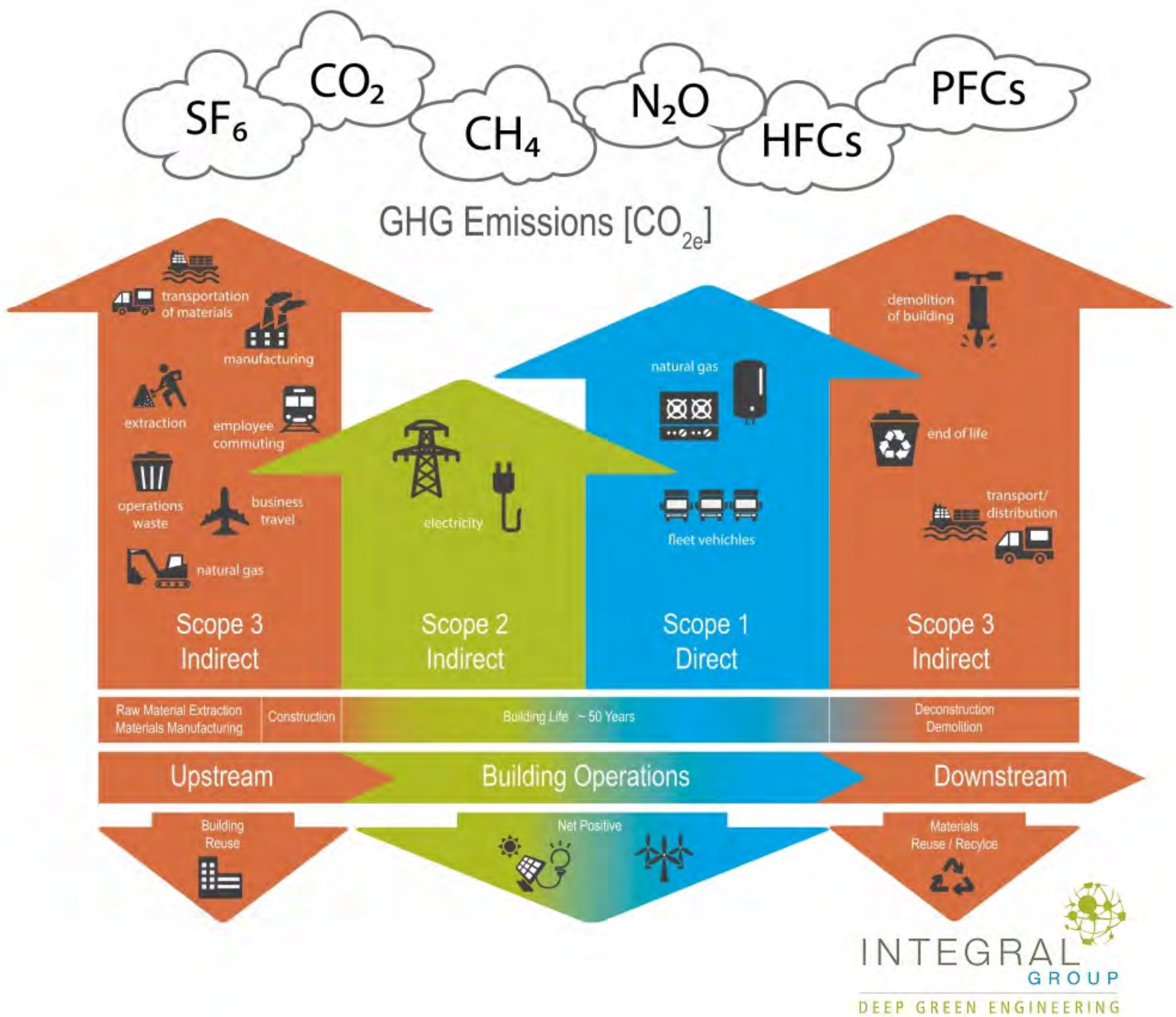


Figure 2. Based on World Resource Institute (WRI) protocols for evaluating carbon/GHG emissions of a Building from Cradle to Gate - divided into 3 scopes: Scope 1 Direct Operation Emissions, Scope 2 Indirect Operation Emissions, and Scope 3 Indirect Supply Chain Emissions.

Phase 1: Case Study of DPR Construction San Francisco Office Building - Focus on Manufacturing Stage Embodied Carbon

In 2014, DPR Construction moved their San Francisco office into an existing two-story 24,000 square foot office building at 945 Front Street in San Francisco. They set out to build a LEED Platinum project and get a Net Zero Energy (NZE) Building certification from the International Living Future Institute. This is an ambitious goal not only because zero net energy buildings are still a rarity, but also because they wanted to do it on a traditional budget for a Class A+ office space. Although DPR chose to retrofit an existing building to net zero energy standards rather than build a new building and were aware of the positive benefit of reuse, they hadn't calculated the embodied carbon avoided or saved from building materials reuse.

A successful ZNE office building requires a very efficient building powered by non-fossil fuels. Achieving this in an existing building can be challenging due to existing constraints. This existing two-story building was surrounded by taller buildings on three sides and only had windows on one side, which is an historic aluminum storefront that could not be altered or upgraded. The project reused the building foundations, shell and existing window wall, remodeled and replaced interior finishes, and upgraded and replaced the building mechanical, electrical and plumbing systems. They were able to meet and exceed their NZE goal by adding insulation to the roof; adding vertical skylights by Solatube to increase daylight, and installing View® Dynamic Glass (electro-chromatic tinting glass) in the skylights; reducing energy loads and plug loads, ultra-efficient lighting and HVAC systems; and powering it all with rooftop photovoltaic and solar thermal systems. For a full description of MEP systems and efficiency measures see Appendix A. Description of the existing structural system can be found in Appendix B.

Figure 3. Entrance to DPR SF Office, 945 Front Street. Photo courtesy of DPR Construction.

The entire project was completed in 5 months including research, design, permitting and construction. The design team was led by DPR Construction, FME Architecture & Design, EBS as the LEED consultant, and Integral Group as the MEP Engineers & ILFI Net Zero Energy consultant. The project included collaboration from more than 50 sub-contractors and material suppliers.

Total Carbon Profile Comparisons:

Case Study projects are compared to 'Traditional' projects of the same size (GSF), and of the same usage (office). Scope 1 and Scope 2 metrics for the baseline traditional building, which is an average EUI of 60 per the CBECS [9] database – where approximately 20% of the EUI is dedicated toward Scope 1 direct emissions (natural gas usage), and 80% toward Scope 2 indirect emissions (electricity bill). Energy sources conversions to CO_{2e} emissions were calculated from current PG&E Grid

[9] Commercial Buildings Energy Consumption Survey

mix over the last 50 years. Note that Fleet vehicle and transportation emissions have not been incorporated into this case study.

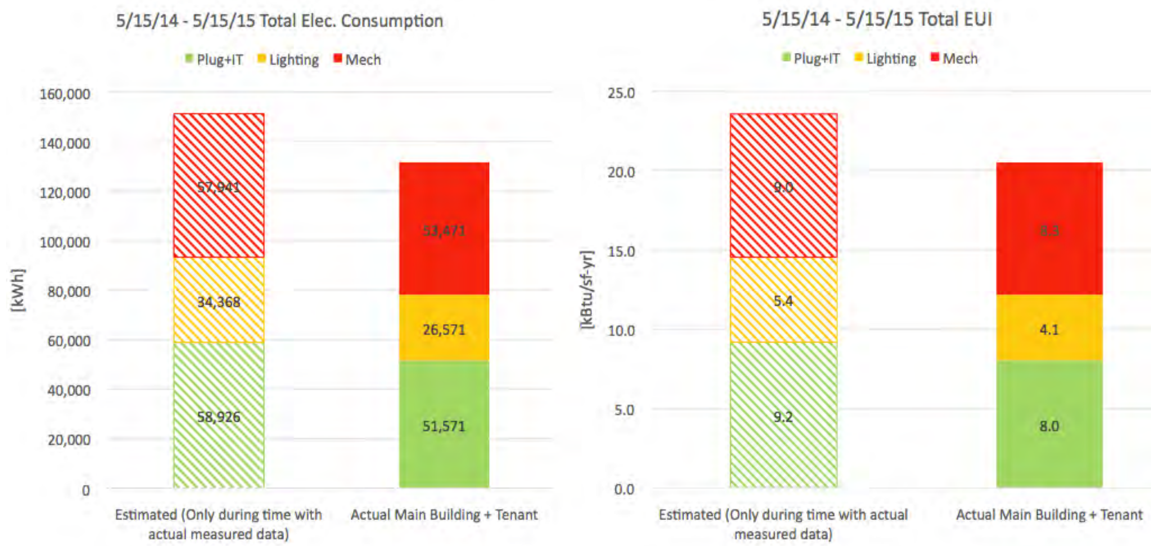


Figure 4. First year operations performance at 945 Front Street comparing Total Electric Consumption vs. Total EUI profiles per typical high load categories of Mechanical, Lighting, and Plugloads/IT.

Figure 5. Ted van der Linden, Sustainability Director at DPR Construction, inspecting the PV array on the roof of their newly renovated San Francisco headquarters building. The building has submitted its LEED v4 Platinum certification to the U.S. Green Building Council as well as Net Positive Certified from the International Living Future Institute.

After a year in their new space the building is currently producing 20% more power than it consumes on site, making it not just NZE performance but Net Positive. The project had a target Energy Use Intensity (EUI) of 24 kBTU/sf/yr, and after one year of operations it performed at an EUI of 20.3, significantly lower than an average office building. Emissions for the DPR building without PV's would be about 20 tons/year. With the PV's it is operating at a net positive rate of 5.84 tons/year.

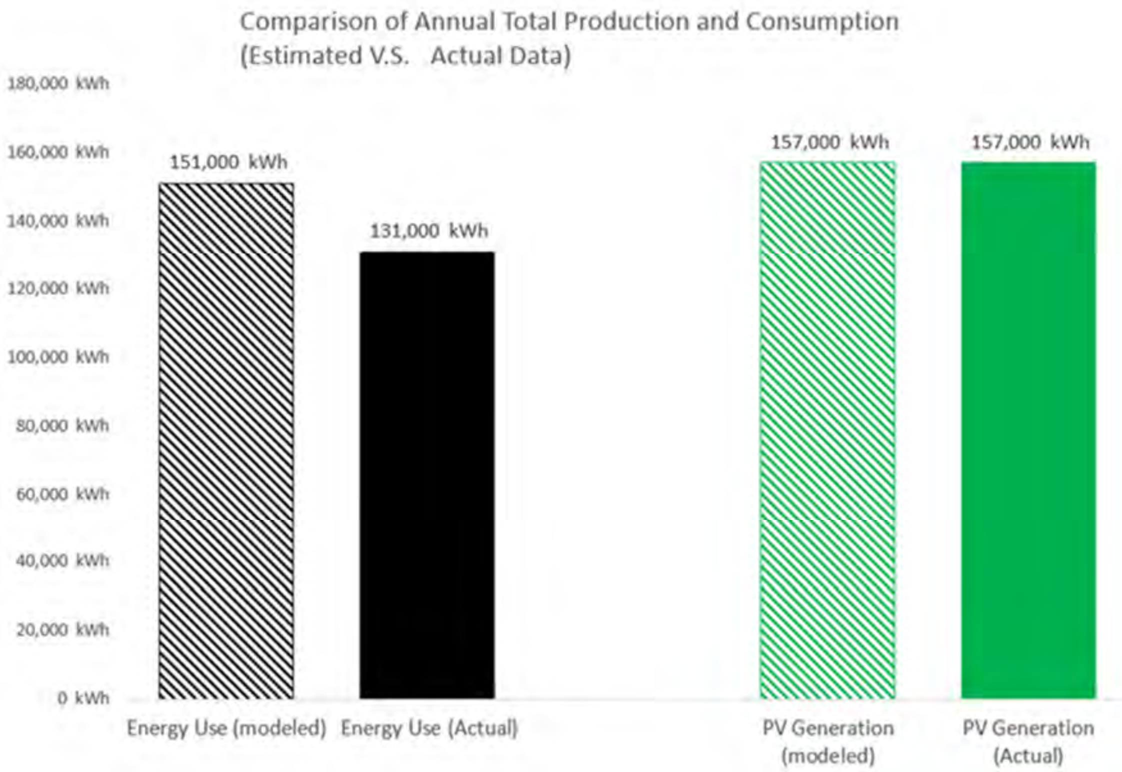


Figure 6. Year 1 comparison of Energy Use and PV production estimated (modeled) vs. Actual.

The Scope 3 comparison was found to be a more difficult pursuit than originally hypothesized as the team discovered many details that made a fair analysis challenging. Ideally, the team believes that the fairest analysis would be to compare the actual DPR project to the same building being constructed today with modern construction practices, as the study aims to show the comparison between making a choice to build new versus finding an existing building to retrofit. However, the challenge in this approach would require that an entirely separate Revit model be created to compare what was actually existing in the structure for the case study. As budget was limited for this first round of study, the team decided to use the existing Revit model created by FME and DPR to compare the case study project against the same exact building as if it was built today with the same materials and quantities represented in the model. For example, the existing structural footings and exterior concrete walls likely contained no Secondary Cementious Materials (SCMs) and followed older structural practices that are no longer in use. As a result, the team expects that the mass of concrete used in footings or slabs would likely have been different (smaller) widths and depths that what was initially constructed.

The results of the case study provide a snap shot of how carbon emissions vary per Scope over a 20 year life of the building. Figure 7 shows a 20 year carbon footprint period for all emissions Scope shows a more evenly distributed profile than a 50 year life analysis, and is more likely the lifecycle of the building. On day one when the building is turned on and occupied, all the savings are from embodied carbon. Over 50 years the savings are impressive and are mostly from operational savings as seen in Figure 8.

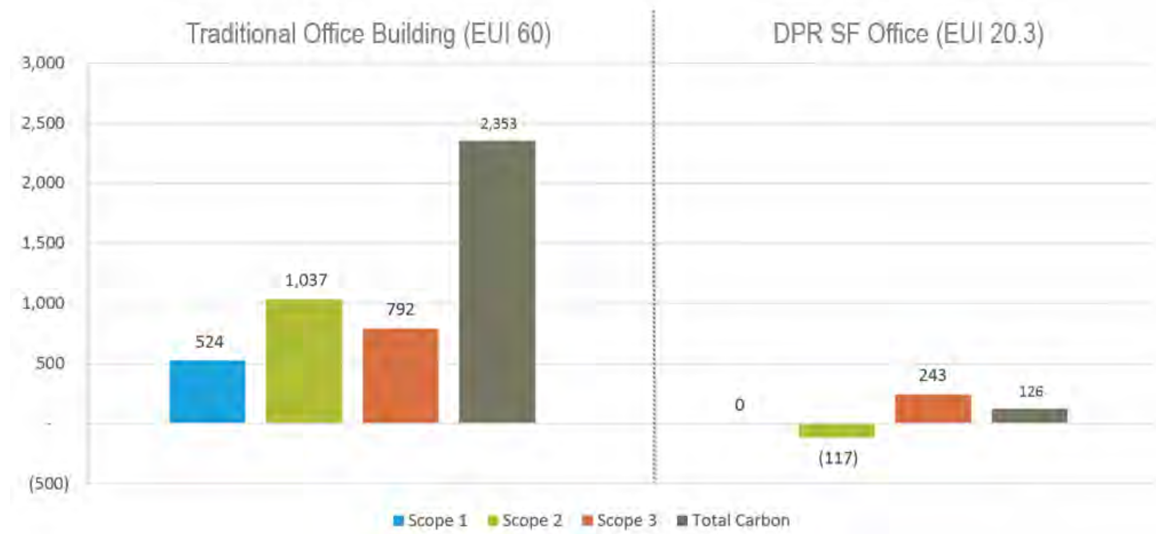


Figure 7. Total Carbon (MTons CO_{2e}) 20 year life Comparison of Traditional Code-Compliant New Construction Office Building vs. the DPR San Francisco Net Positive Existing Building Retrofit Office.

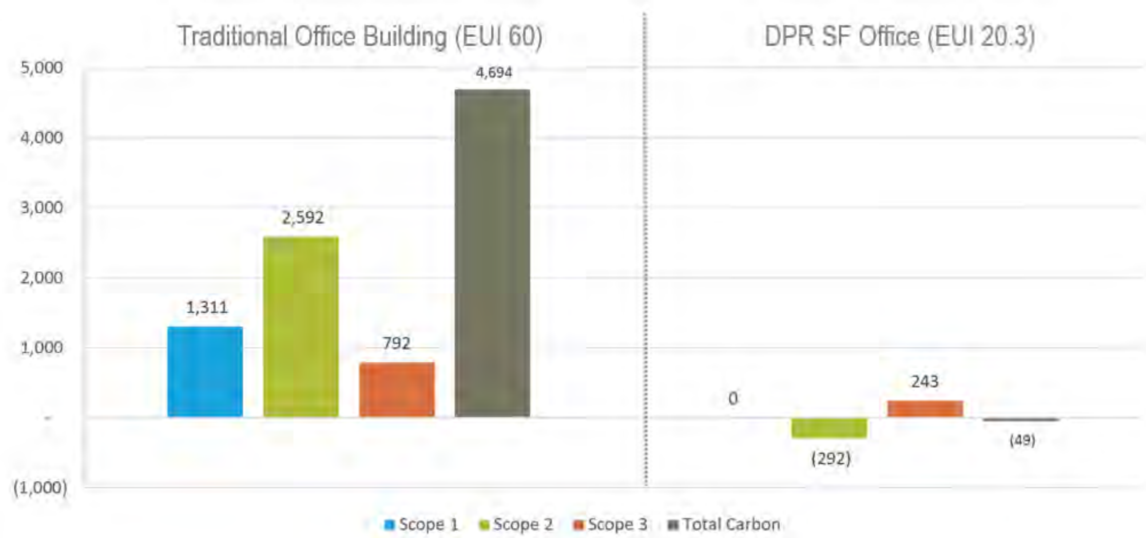


Figure 8. Total Carbon (MTons CO_{2e}) 50 year life Comparison of Traditional Code-Compliant New Construction Office Building vs. the DPR San Francisco Net Positive Existing Building Retrofit Office.

Scope 3 Calculation Methodology

To calculate the embodied carbon footprint for the project, as well as evaluate the avoided emissions from existing building reuse, the study used *Tally*®, http://choosetally.com/overview/ a Revit Plug-in created by Kiernan Timberlake, ThinkStep and Autodesk to execute Life-Cycle Assessments (LCA). Tally quickly pulls material quantities from the Revit model, links to the GaBi database which provides global material information on environmental metrics such as acidification, eutrophication, smog formation, global warming potential, and ozone depletion. The Tally tool generates results over each phase of the life cycle of each building material – the manufacturing stage, the maintenance and repair stage, and the end of life stage. Other LCA software tools exist, but only Tally utilizes a revit model, hence it was used by this team during phase 1 of our research. The authors believe, however, that additional analysis using other software tools would be beneficial for testing the concepts of total carbon analysis. We have identified some next steps in analysis that are included as part of the Conclusion section at the end of this report.

Scope 3 Embodied Carbon Results

The avoided emissions realized before buildings are occupied comes from the reduced embodied emissions from building reuse compared to building new. Per the parameters of the study, avoided emissions to remodel the building were less than one third of what they would have been to build the same building from the ground up, without photovoltaic panels & MEP equipment, which would have the same impact in either scenario. Note again that a new building built today would use different materials and construction methods and we would anticipate the baseline case to have a lower carbon footprint, though the magnitude of the difference is unevaluated.

The materials were broken down into the Tally identified categories which currently includes materials in CSI divisions 3-10. A separate estimate was developed for MEP systems and PV panels[10]. SunPower panels were reported a GWP of 281 kg CO_{2e} per m^2 of module area. PV racks were not included in our calculation. MEP equipment was estimated to be 10% of the total of all building materials per past project research experience[11]. All of these results can be seen in Figure 9 which show the difference between the new and existing materials identified as solid vs. hatched. Existing reused materials include: structural footings, slab on grade concrete, exterior walls, store front curtain wall (historic) windows and mullions. The most surprising result of this study was that the extensive structural upgrades required to hold the additional weight of PV were relatively minor in the total picture and less than hypothesized.

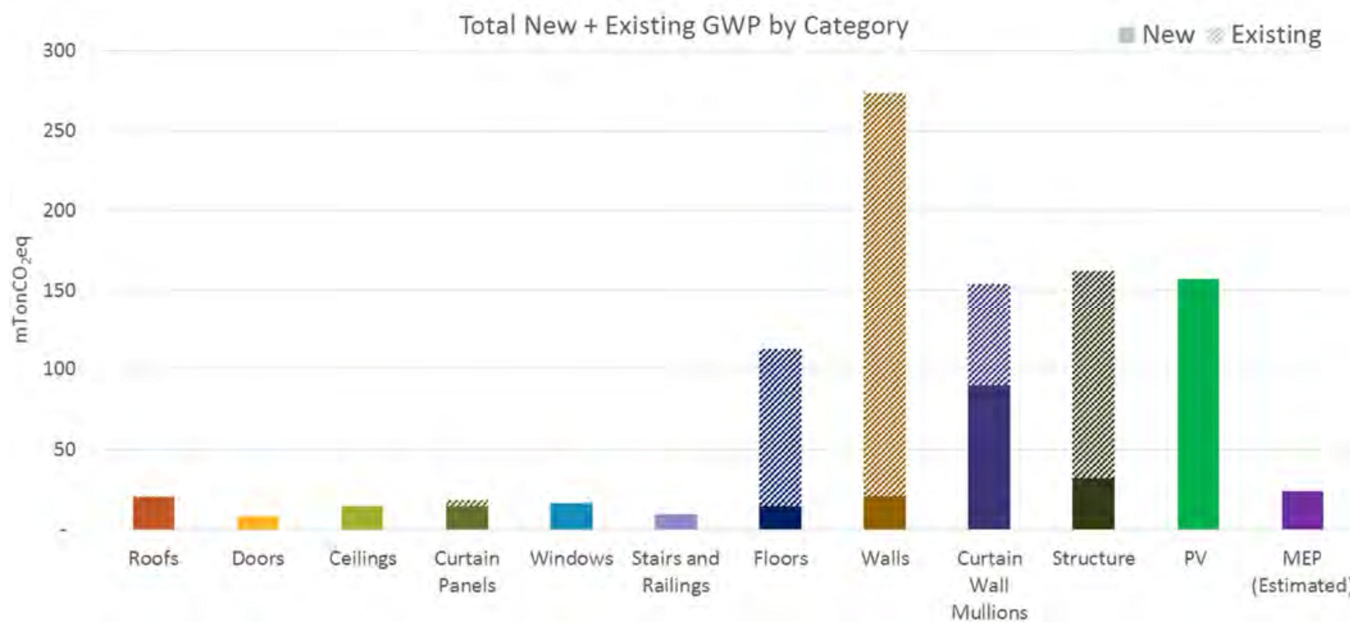


Figure 9. Embodied Carbon of DPR SF Office per material category, highlighting new vs. existing reuse.

The largest embodied carbon savings from reuse (hatched) came from the structure – concrete footings and steel pilings, followed by the aluminum frame window wall and the concrete walls. The largest additional embodied emissions came from the 118 kW photovoltaic system on the roof and the new aluminum interior partitions, included in the Curtain Wall mullions. Other contributing categories include the roof, structural upgrades and new MEP systems. Interior finishes were mostly replaced and are assumed to be approximately the same as for a new building.

The majority of the embodied carbon savings are attributed to the manufacturing phase. The outputs from *Tally* provide raw data that breaks down every material by each phase: Manufacturing, Maintenance/replacement, and End of Life, as seen in

[10] https://www.bnl.gov/pv/files/pdf/242_27EUPVS_Fthenakis_SunPower_6CV.4.14.pdf

[11] 1996 study by Cole and Kernana put services at 25%. Past project research by Siegel & Strain found: Orinda City Hall – 8%, Portola Valley Town Center 7.3%, Yountville Community Center 9%

Figure 10. Since the materials were existing and being reused, and not needing to be remanufactured or replaced with virgin materials, the GWP value from reused materials was removed.

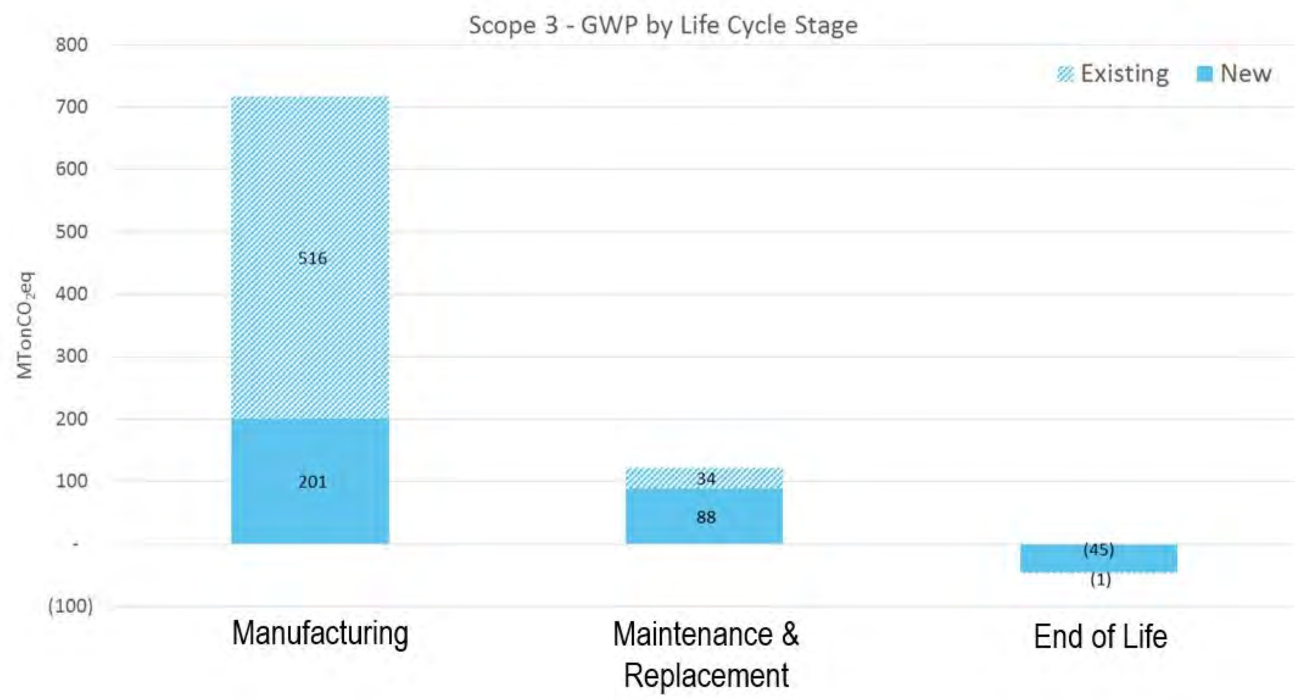


Figure 10. Embodied Carbon results broken down by Life Cycle Stage.

Total embodied carbon savings from reusing significant portions of the DPR building resulted in a **69% reduction** in Scope 3 GHG emissions. This includes embodied emissions from extraction, manufacturing, transportation, maintenance, repairs, and end of life phases. However this savings result does not include the PV and MEP embodied carbon numbers as they were not outputs from the Tally data set.

Manufacturing Phase

Removing the PV + MEP estimates, the manufacturing phase only embodied carbon per category is presented in Figure 13 below. The luargest Scope 3 carbon savings came from the existing structural framing, exterior walls, slab on grade concrete floors, and storefront windows. The largest added carbon contributors (new) can be attributed to curtain wall mullions and additional structural steel bracing to support the new PV system.

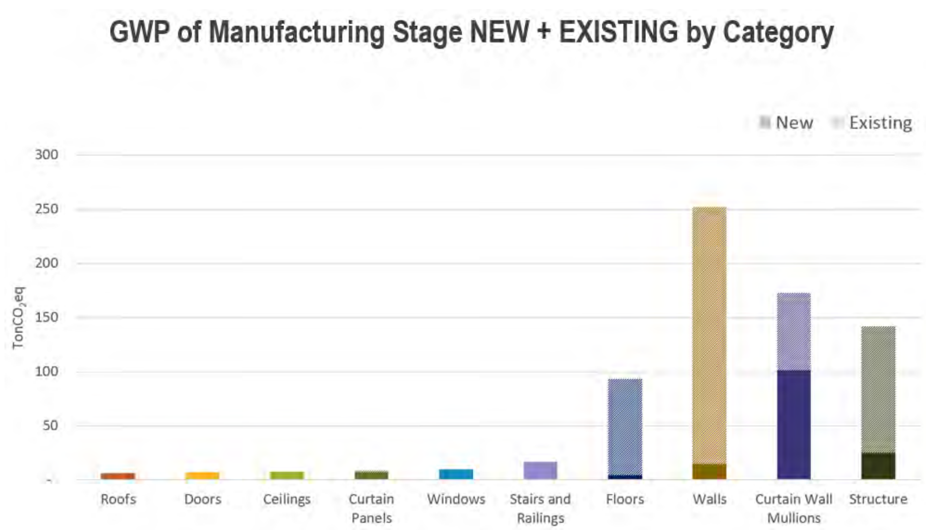


Figure 11. Manufacturing Phase Scope 3 Emissions

Maintenance/Replacement Phase

Looking deeper into the Maintenance/Replacement Stage, carbon savings was predominately seen attributed to the curtain wall category – associated with the historic storefront window. The largest carbon contributor (new) is associated with the curtain wall mullions – specifically the aluminum materials of the assembly. Note that Tally assumes replacement of mullions at 50 years, however, these are part of the registered historic façade. We deleted emissions from the manufacturing phase for this material, but further considerations need to be made on how to handle replacement of this material.

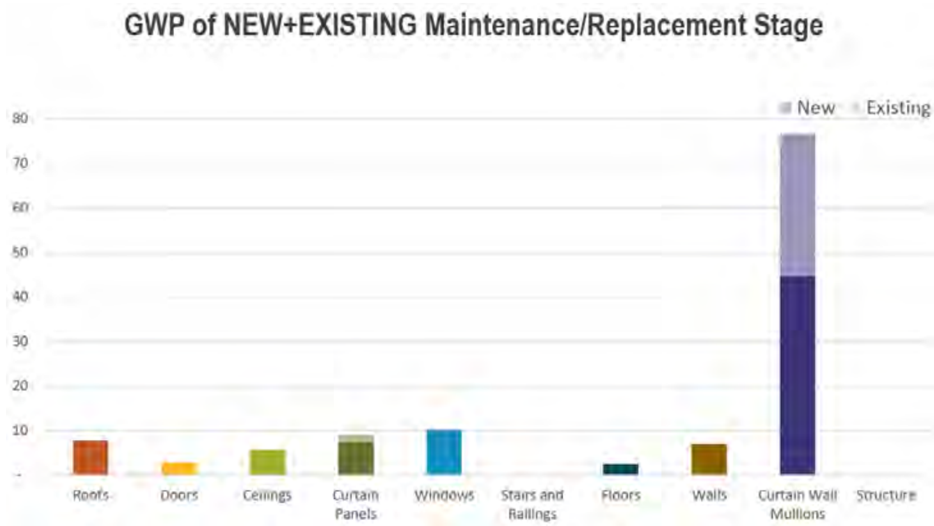


Figure 12. Maintenance/ Replacement Phase Scope 3 Emissions

End of Life Phase

The End of Life phase has not been the focus of this chapter of the study. However, the Total Carbon Study does have goals to look deeper into End of Life phase in future phases. Per the DPR project, a payback in carbon was recognized to be associated with curtain wall mullions because it's assumed that the aluminum is highly recyclable. Other material groups that saw carbon payback at end of life include: Stairs & railings, Windows, and doors.

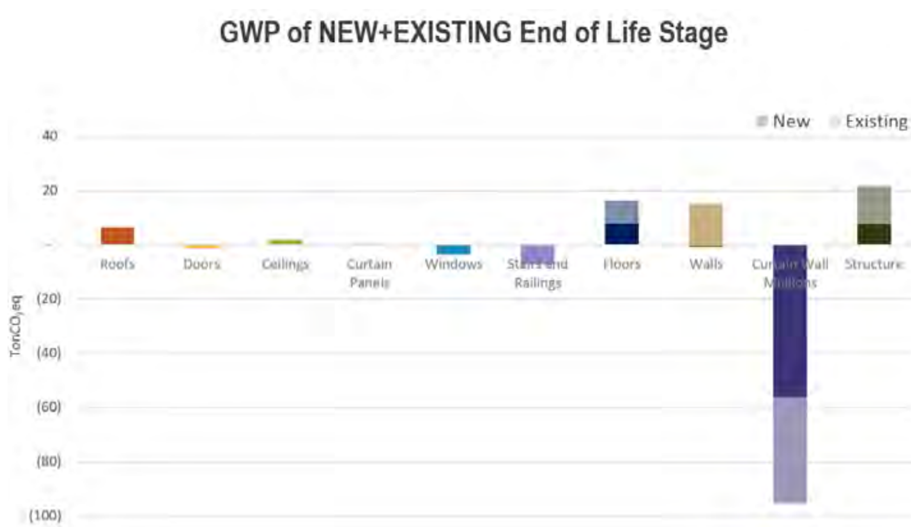


Figure 13. End of Life Phase Scope 3 Emissions

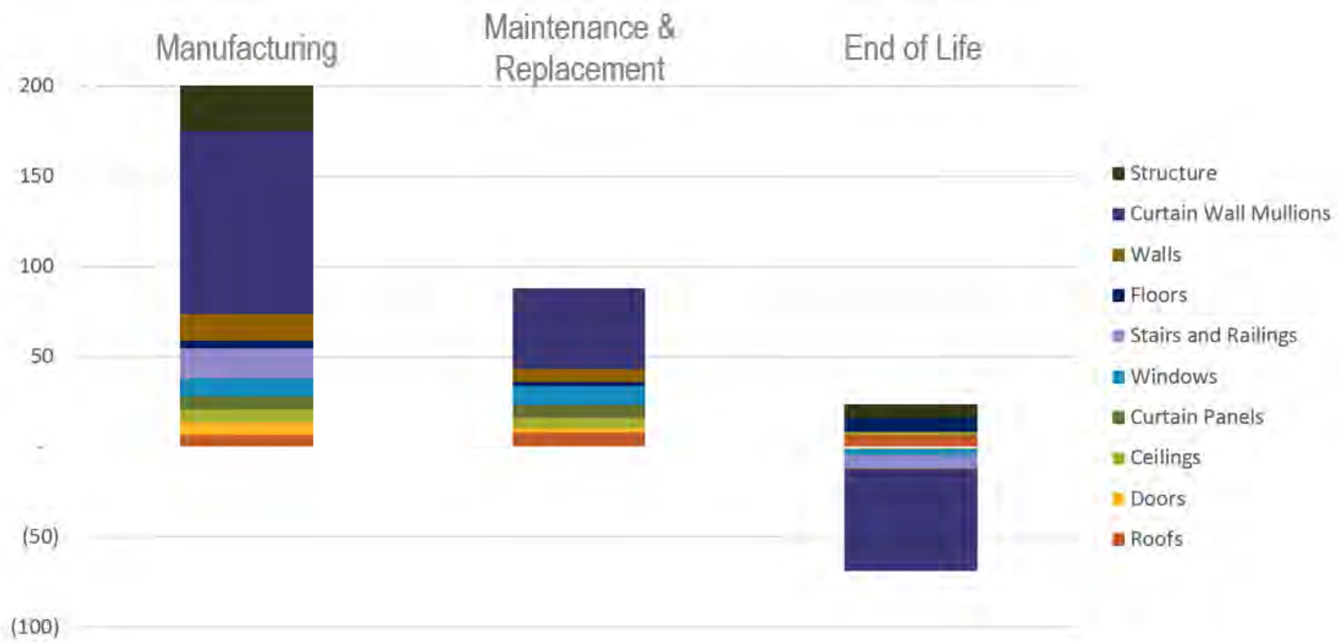


Figure 14. Total Scope 3 embodied carbon emissions (MTons CO_{2e}) per Life Cycle Stage by Material Category

In Figure 14, materials have been sorted by category and phase. This includes GHG emissions associated with the new materials only from the Tally data set (not including PV and MEP). This graphic provides an understanding that curtain wall mullions have the largest impact to embodied carbon, however also provide the most avoided carbon at end of life due to ability to recycle the material. This result led our team to question more specifically an understanding about material type (i.e. aluminum) and mass of materials. Is there a direct correlation between material mass and embodied carbon?

Mass of Materials by Category

The Tally output table provides us with many usable and interesting metrics, including material density, volumes, and mass. We hypothesized that the weight of materials tends to have a direct correlation to embodied carbon emissions and that some materials may be more carbon intensive than others where mass is not as directly correlated. Figure 15 provides the evaluation of mass by material category. The floors, walls and structure are mostly concrete and the mass chart makes it clear how much concrete dwarfs other building materials. Considering that the aluminum curtain wall mullions mass is quite low, it is clear that there are two ways to achieve significant embodied carbon savings:

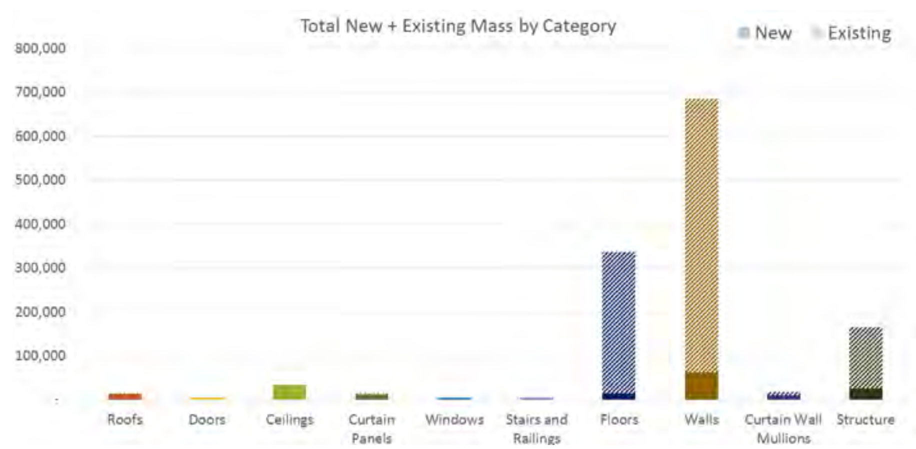


Figure 15. Mass of Materials per category in kg.

- reuse high volume, high mass materials - typically structural materials; and
- reuse energy intensive materials such as the aluminum curtain wall.

Final Take Away

The DPR SF Office case study project has provided an initial look into the total carbon story, and many questions have resulted. The following is a list of key findings and resulting questions or areas for future study:

- Reuse to the maximum amount possible, and renovate to be net positive whenever conditions allow.
- Evaluating carbon emissions over a 20 year time span rather than a typically evaluated 50 year life span better demonstrates the effectiveness of reuse coupled with ZNE performance at reducing CO_{2e} emissions in the near term.
- The largest savings came from reuse of high mass materials – concrete structure, and energy intensive materials – aluminum curtain wall.
- A nearly 70% reduction in Scope 3 embodied carbon by reusing existing building (while still investing in structural upgrades to support solar PV to meet Net Zero Energy targets) was surprising and really drives home the importance of the 'Time value of Carbon.'
- Carbon emissions associated with construction phase activities – equipment, electricity use, etc. - is still a big unknown, and of interest to the team for future studies.
- Carbon emissions associated with transportation of employees either through fleet vehicles or employee Vehicle Miles Travelled for typical commute have not been included in the study and may be a significant element in the total carbon footprint.
- The Total Carbon Study team hopes to execute a future research paper that will study an existing building reuse project and compare it to demolition and modern day new building construction practices. Additional analysis using other LCA software tools and additional building types could also provide interesting results.

Conclusions & Next Steps

This study represents a deep dive on an individual project that incorporated both reuse and net positive energy design strategies to achieve a highly sustainable building. By looking at the total carbon profile of the DPR SF office and comparing it to a conventional new building, this study provides insight into the magnitude of carbon savings that can occur from a building that reuses major structural elements and generates more energy than it consumes in operation. The results of our investigation are compelling: a net positive renovation of a mostly existing structure/shell can be a carbon sequestering building over time. Importantly, the impacts are most significantly reduced in the immediate/short term because of the reuse of building components, which should be weighted heavier than the energy generation or energy efficiency that accumulate after the building is occupied.

A host of implications can cascade from the findings in this study. If the results of this study are found to be consistent among more buildings and building types, then it holds key information for how redevelopment can occur. The results can inform better existing building reuse design decisions, illustrate ways of updating LCA modeling tools, and could signal changes in climate action policy that prioritize deconstruction and reuse over demolition. Looking at the total carbon footprint of a building that includes reuse plus net positive elements could represent a significant change in building valuation and policy.

Though the study is compelling, it represents only a single example using one LCA software dataset. Further case studies of additional buildings and building types are needed to test the concepts of reuse and net positive design. Other whole building LCA tools should also be cross-compared with the LCA software tool used in this study to see if any themes emerge that support our findings, or point to greater areas of analysis where results diverge. Outcomes from conducting additional analysis could be useful tools like design phases rules-of-thumb for use in determining when reuse makes the most sense versus when to demolish and build new. Further analysis could also pinpoint redevelopment activities or zones that tend to be best positioned to make use of total carbon synergies in city or regional Climate Action Plans. Finally, additional building analysis can be used to inform LCA software packages on how to account for reuse more consistently, and can also provide recommendations to green labels like the LEED Rating System about how to most accurately account for reuse in whole building LCA.

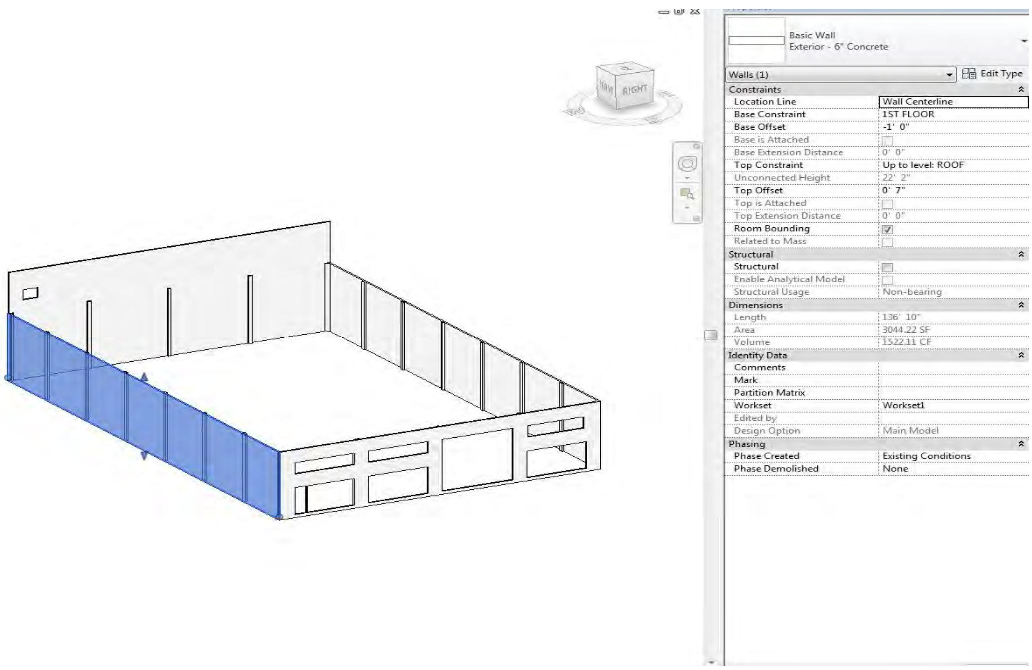
Please join us in continuing this important research. Contact Megan White, Integral Group, mwhite@integralgroup.com 510-663-2070, for more information on the partnership.

Side Bar: the Tools – Revit & Tally

After evaluating multiple LCA tool options, the team chose to use Tally as the tool for the first chapter of this study based on the project having a complete Revit model and reducing the time needed to execute material take-offs. Additionally, Tally provides a very robust excel spreadsheet output with a large variety of metrics for deep analysis; in particular it breaks out GWP by phase. There is a desire to follow up with a future study to compare the results of a project between two separate tools, such as Tally vs. Athena, with a focus on resulting differences.

As is always the case with any new tool, many valuable lessons were learned that can be implemented for future studies. Here are a few lessons from the DPR SF Office case study:

1. Existing Wall Metrics



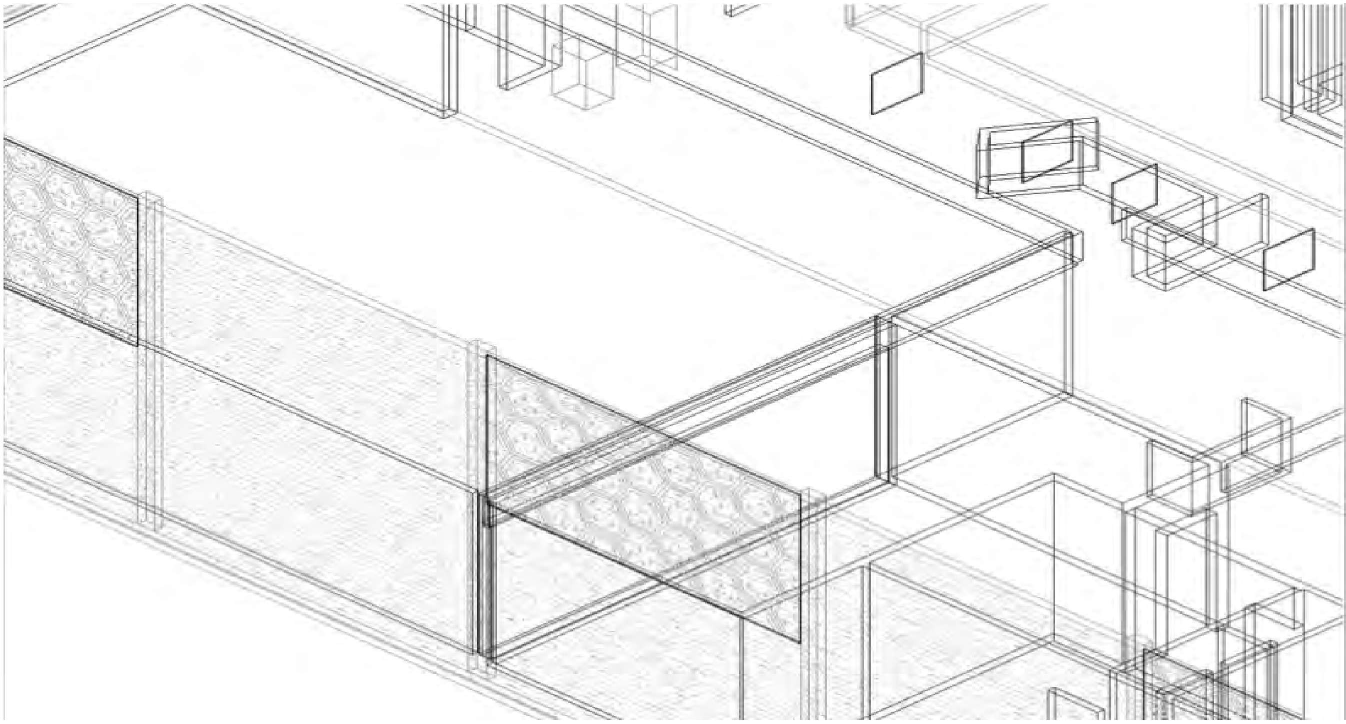
The Revit model defined all existing exterior walls as 6” concrete, which alarmed the team that this is not structurally feasible. A site visit revealed that only the front and back exterior walls were 6” thick while the side walls were actually 14” thick. Therefore the team had two options, (a) adjust the wall thickness in the Revit model, or (b) adjust the volume takeoff of the existing material in the excel table and calculate the tons of CO_{2e} after exporting the results from Tally. We chose to execute option (b) to create a more accurate carbon calculation. A key take-way was that models are not always accurate, especially when looking at existing building structures where original as-built drawings may not exist.

Lesson Learned: Confirm all metrics, especially the large carbon culprits.

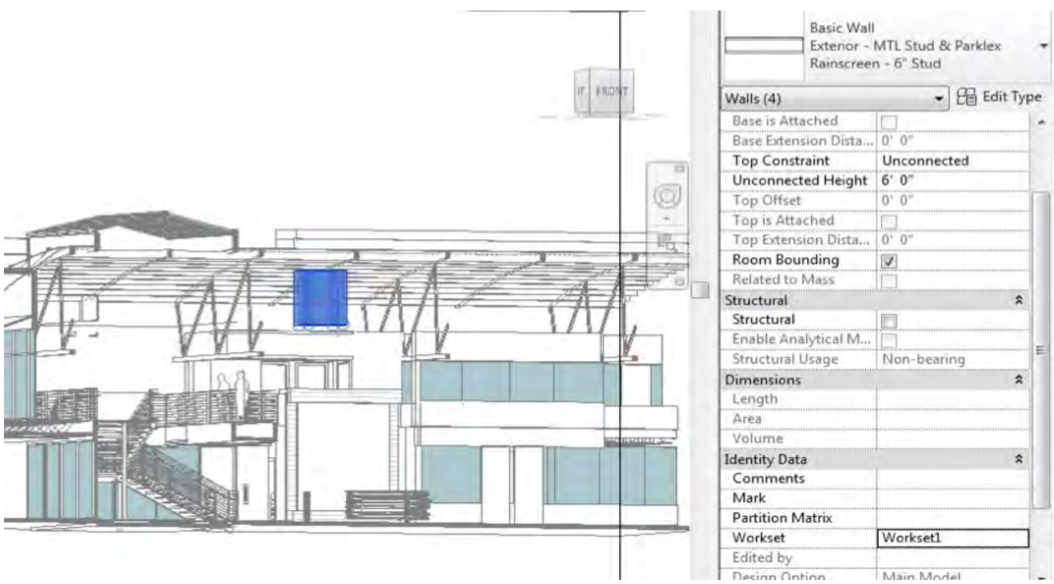
2. Hexagonal “Furring”

Objects in the Revit model are given names by either the Architect or Contractor. We have found that many times the two stakeholders identify materials in different ways and create some unique nomenclature that is hard to match up with Tally materials. In this case, a material was identified as “FME Hexagonal Furring” – and on first pass was originally linked in Tally to Metal Furring Channels, because the key term searched was ‘furring.” Upon first QA/QC, we saw that this material was shown to have been 8.9 million kg of CO_{2e} emissions. When the ‘furring’ material was identified in the BIM model – we quickly realized these were not metal furring channels but actually the acoustical felt panels on second floor. Once updated, the new GWP value was only 309 kg of CO_{2e}.

Lesson Learned: Don’t assume names in the Revit Model match perfectly with *Tally* Material options – it sometimes requires looking at each material more directly and confirming with the Architect/Contractor what the specific material is if not clear in the Revit name.



3. UFO – Unidentified Floating Object



When executing the Tally analysis, there was a material from the Revit model that was identified as exterior brick wall. Since we were not aware of any exterior brick wall materials from interviews with DPR, we isolated the material in the Revit model. We found the material highlighted below and questioned if (a) it was existing structure to a roof hatch that was not removed and just not visible, or (b) possibly part of the greenwall watering system due to its location on the project. Either way – this material was showing up as the 2nd largest CO_{2e} emitter due to volume and weight – which also didn't make sense to be able to float in near midair. After reviewing with DPR, the team realized that it was an object dropped into the model by accident and never removed/cleaned up. Therefore, the object and resulting carbon were removed from the analysis.

Lesson Learned: Revit models sometimes have materials dropped in temporarily or accidentally and may not actually exist on the project.

Appendix A - DPR Construction San Francisco Office - Energy Efficiency and MEP System Description

Energy Efficiency

Designing a net positive office building requires aggressive energy efficiency goals. These goals were attained by reducing energy loads through use of efficient HVAC and electrical systems, then by installing photovoltaic and solar thermal systems on the roof to produce more energy than the building consumes. The project had a target EUI of 24 kBTU/sf/yr, and is operating at a projected EUI of 20.3, significantly lower than the average EUI of around 50 for office buildings in California.

The new DPR office has a variable refrigerant flow (VRF) system that enables heat to be transferred from spaces requiring cooling to spaces that require heating, allowing for better zoned thermal control of the building and higher efficiencies. The building also has a dedicated outside air system (DOAS), using 100% outside air, demand controlled ventilation based on CO_{2e} sensors. The DOAS units are equipped with an air-to-air plate heat exchanger, transferring heat from exhaust air to supply air, requiring no additional conditioning at the unit. The system takes advantage of the Bay Area's mild climate, using free air-side economizing for the majority of the year.

Daylighting was maximized in the building through large skylights, an open atrium, and Solatubes in the office areas. The light through two large skylights is controlled with View Dynamic Glass that tints electronically in response to outside light levels. The low watt/sf LED Lighting design is controlled by daylight and occupancy sensors, further reducing energy usage.

A plug load study was performed to identify large energy consumers and inform new equipment purchasing decisions. The design included smart plug strips, 42 CT meters and a building plug load "kill switch". The modeled energy consumption for DPR's office was estimated to be 151,000 kWh/year, however the building is currently on track to use 130,000 kWh during its first year of occupancy, 14% lower than predicted. The 100% electric mechanical system and energy loads are designed to be offset by the 118 kW photovoltaic system. The PV panels were estimated to generate 157,000 kWh and are on track to generate 153,000 kWh, 2.5% below predictions. DPR SF is predicted to be 15% Net Positive Energy at the end of their first year of occupancy - May 2015.

Indoor Air Quality

Occupant comfort is a top priority in this building and indoor air quality plays a major role in that. The DOAS system delivers 30% more ventilation air than required by code and uses MERV 13 filters to filter out contaminants. Increasing the efficiency of filtration, especially for small particles, greatly improves indoor air quality.

Implementing biophilic design aspects in the office was a priority for DPR when designing their new office space. Three living walls were installed in the main lobby. The plants not only improve indoor air quality by absorbing VOCs, but also increase overall wellbeing for people in the space.

Occupant wellbeing is also benefited by enhanced thermal comfort. "Big Ass Fans" were installed to promote airflow within the office, there is natural ventilation at the long perimeter and roof vents can release warm air during summer days. Occupants were given task lights and personal fans, which gives employees control over their environment and increases comfort.

Innovation

The DPR SF Office displays high levels of innovation in its design, as well as in its ongoing commissioning and educational efforts.

Net Positive with Active Systems

A major feat of this project was designing a net positive building that primarily uses active mechanical systems. The building is surrounded on three sides by other buildings, so a passive design with operable windows was not an option. By enhancing the roof insulation and increasing natural daylight in the space from the roof, the mechanical and electrical loads were decreased significantly. Designing the mechanical system to take advantage of the temperate climate through air-side economizing and making the equipment 100% electric allowed the loads to be offset completely from the photovoltaic system.

Solar Thermal

In addition to PV panels, the building uses a solar thermal system with electric backup heating for its domestic hot water. This system eliminates the use of gas for heating hot water and has an estimated energy savings of 3,400 kWh/year, with a ROI of 5 years.

Education / Driving the Market

Beyond energy savings, the DPR Office is raising the bar for the building industry through being an example of how sustainable buildings can be “mainstream” - both efficient and cost-effective. DPR is walking the talk. They are now using this space as a living lab learning center to educate the community about energy efficiency measures. They have a LEED Dynamic Plaque and a Lucid Energy Dashboard in the lobby entryway that lets occupants see the building’s performance. DPR’s new office is intended to attract new clients and retain employees, increasing business profit. They regularly open their doors to host industry events and open houses. This design is not only benefiting DPR, but is also driving the market towards a sustainable future.

Design Delivery

DPR elected to use an integrated Design/Build process for the project delivery. This allowed the project to move quickly, as demanded by TI work, and to be cost effective while still meeting the strict design goals. The process also allowed the installing contractors the liberty to make changes to the layout and identify ductwork that could be reused based on the existing conditions.

Operation and Maintenance

The design of an energy efficient building often inherently assists in the simplicity of the operation and maintenance. In this case, the utilization of a packaged VRF system and the reduction of airflow through low pressure drop design requires fewer and smaller fans. The enhanced controls also reduce run-time on the equipment.

The Honeywell Building Management System (BMS) and Lucid Dashboard work together to track mechanical and electrical systems in addition to the operational energy used within the building. An ongoing Monitoring Based Commissioning (MBCx) plan was created to categorize energy distribution in the building and a trend analysis allows problems with the systems to be identified. This is a great opportunity to explore areas of improvement to further reduce energy usage and to use the data for an educational case study.

Cost Effectiveness

DPR set as a high priority to design a building that is not only sustainable but also cost-effective. They wanted to use their office as a replicable design standard within the industry. This project showcased that energy efficient and renewable systems have reached a nearly cost neutral tipping point. PV prices have dropped to an average of cost of $3.10/watt (installed) in the Bay Area, down from $9-10/watt in 2008. The mechanical cost was $20.70/sq.ft, lower than the national average of $23/sq.ft for office buildings. Overall, the building cost $160/sq.ft and the PV and structural roof upgrades to support the PV cost $40/sq.ft., slightly higher than other projects in the area, but the estimated energy savings per sq. ft. are predicted to bring down the cost to lower than average in the area. Costs were further offset by taking advantage of incentives and rebates, such as the California Savings by Design program.

Environmental Impact

The DPR SF Office positively impacts the environment in several ways. First, the project has a lower construction carbon footprint by being a retrofit of an existing building as compared to new construction. The retrofit meant that less energy was required for deconstruction and that the majority of the structure was reused from the existing building. The building further impacts the environment in a positive way through all-electric systems that are 100% offset with rooftop PV panels, and water efficient fixtures heated by a solar thermal system.

Appendix B - DPR Construction San Francisco Office - Structural System Description

The existing building is a cast-in-place, two story, concrete building. The building was built in 1955 and is located on an area of bay fill.

Existing drawings were not available so the foundation could not be verified. The study team made the following assumptions about the existing foundation after consulting with a structural engineer:
Slab on 4” grade over a grade beam foundations on steel piles.
Grade beams: 18” wide by 30” deep at the perimeter, and 18” x 18” at the interior and a grid of 20’ x 20”.
Steel piles: 8” diameter steel pipe, 25’ deep at 10’ o.c. at the perimeter and 20’ o.c. at the interior slab.

Walls are cast-in-place concrete, and were field measured at 6” for the front and back walls and 14” for the side walls.

The partial second floor is plywood over TJI joists.

Roof is plywood over 2x10 joists over wood bow trusses.

Structural upgrades included replacing a small area of the first floor slab, installing new columns and footings to carry second floor loads, and strengthening the existing wood trusses with hollow steel tubing to carry the added weight of the PV panels.