Pathway to Net Zero Carbon Labs

Technical Report

HOK research provides lab owners and developers technical guidance for reducing operational and embodied carbon to meet net zero goals

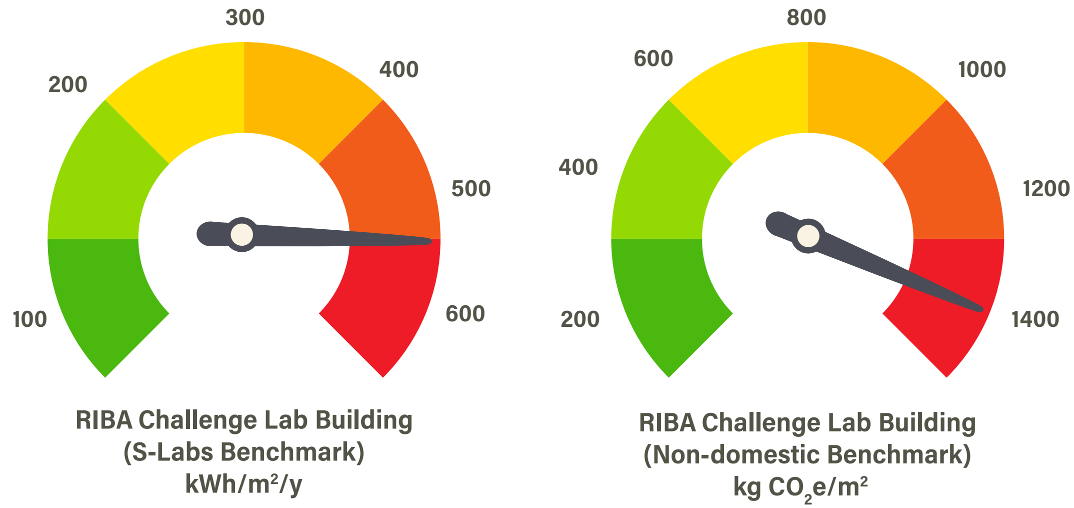
Pathway to Net Zero Carbon Labs

Buildings account for 35-40% of global energy consumption, and few building types consume as much energy as scientific labs. To help lab owners and developers reduce their carbon footprint, HOK's Science + Technology team conducted extensive analysis examining how lab buildings can significantly reduce their carbon dependency and, with the addition of on-site renewables and offsetting, achieve net zero.

The Challenge

The carbon intensity of labs has presented designers with a unique challenge that has increasing urgency to overcome. These highly complex facilities demand far greater ventilation than most building types and are home to energy-intensive equipment that is often in operation 24 hours a day. Labs also need robust structural systems to limit building vibration and support heavy imposed loads. Structural systems, typically comprised of concrete and steel, contain high quantities of embodied carbon, i.e. the global warming emissions expended in the base extraction, manufacturing and transportation of building materials. The cause of this is that labs require far more non-renewable energy to build and operate than most other building types.

Lab Building Energy Consumption Benchmark



Poor performers: The typical lab building requires 589 kWh/m²/y of energy to operate (S-Labs Benchmark) and contains 1400 kgCO_2e/m² of embodied carbon (RIBA 2030 Challenge Non-Domestic Benchmark). Both performance measures place lab buildings at odds with widely accepted sustainability goals.

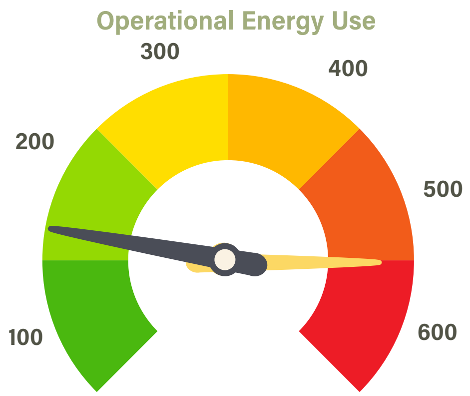
Today, the S-Labs benchmark operational energy use intensity (EUI) for a modern research lab stands at 589 kilowatt hours per square metre annually (kWh/m²/y). By comparison, the annual benchmark energy use for a commercial office building stands at 130 kWh/m²/y, and the benchmark for residential buildings is 120 kWh/m²/y. When it comes to embodied carbon, it's not uncommon for lab buildings to contain twice the construction carbon of other building types.

Note: This technical paper is a companion document to our executive summary, which provides a broader overview.

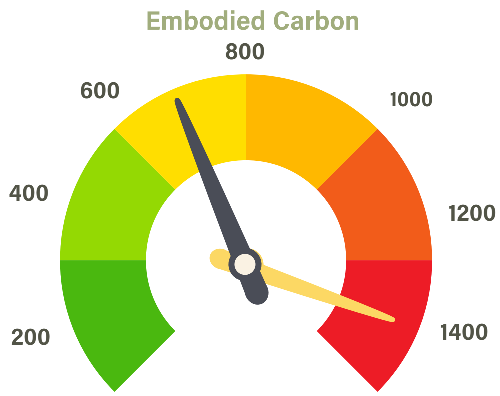
The Goal

Given the imminent threat of climate change, can labs be built and operated in a manner that is significantly less harmful to the environment? Particularly, can lab buildings achieve net zero status by 2030 as set out by the design challenges of both the Royal Institute of British Architects (RIBA) and the American Institute of Architects (AIA)? Those are the key questions of HOK's analysis.

Lab Building Energy Consumption 2030



RIBA Challenge Lab Building (75% reduction) kwh/m²/y



RIBA Challenge Lab Building (50% reduction) kg CO_2e/m^2

Dial it down: To meet the guidelines of the RIBA 2030 Challenge, lab buildings would need to reduce their operational consumption by 75% (to 147 kWh/m²/y) and embodied carbon by 50% (to 700 $kgCO_2e/m^2$).

Using the RIBA 2030 Challenge as a target, HOK explored how lab buildings could reduce their operational energy use by 75% from 589 kWh to 147 kWh/m²/y and embodied carbon 50% from 1400 $kgCO_2e/$ m2 to 700 $kgCO_2e/m^2$ or lower.

Analysis and Results

Operational Energy Analysis

Net Zero Lab Case Studies - Building Layout

Top: The floorplate for a typical linear-style lab building.
Bottom: The floorplate for a lab in a tower-type building.

Methodology

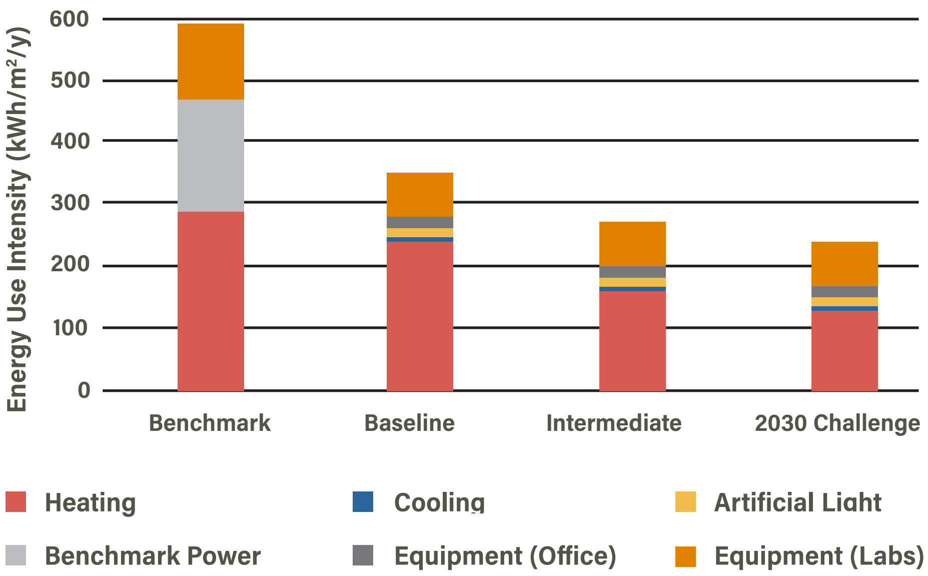
For this paper, HOK analysed two different lab building forms – a compact and vertical lab akin to those found in city centres and a linear lab more typical of suburban settings. These lab types were modelled to assess how they perform under the following three design performance approaches:

1. **Baseline Practice:** This approach incorporates performance specifications greater than current building regulations while using products that are still commercially competitive, for example high performance double glazing. This approach also assumes an average ventilation rate of 6 air changes per hour (ACH).

2. **Intermediate Practice:** This approach improves upon the Baseline practice by increasing performance specification to the next commercially available level, for example using high performance double glazing with a krypton filled cavity. This approach assumes a ventilation rate of 5 ACH.

3. **2030 Net Zero Practice:** This approach uses back-stop performance specification to achieve net zero certification. For example, where the intermediate approach would use double glazing with krypton cavities, 2030 Net Zero would use triple glazing. Ventilation rates under this approach would be kept to 4 ACH.

Operational Carbon Reductions



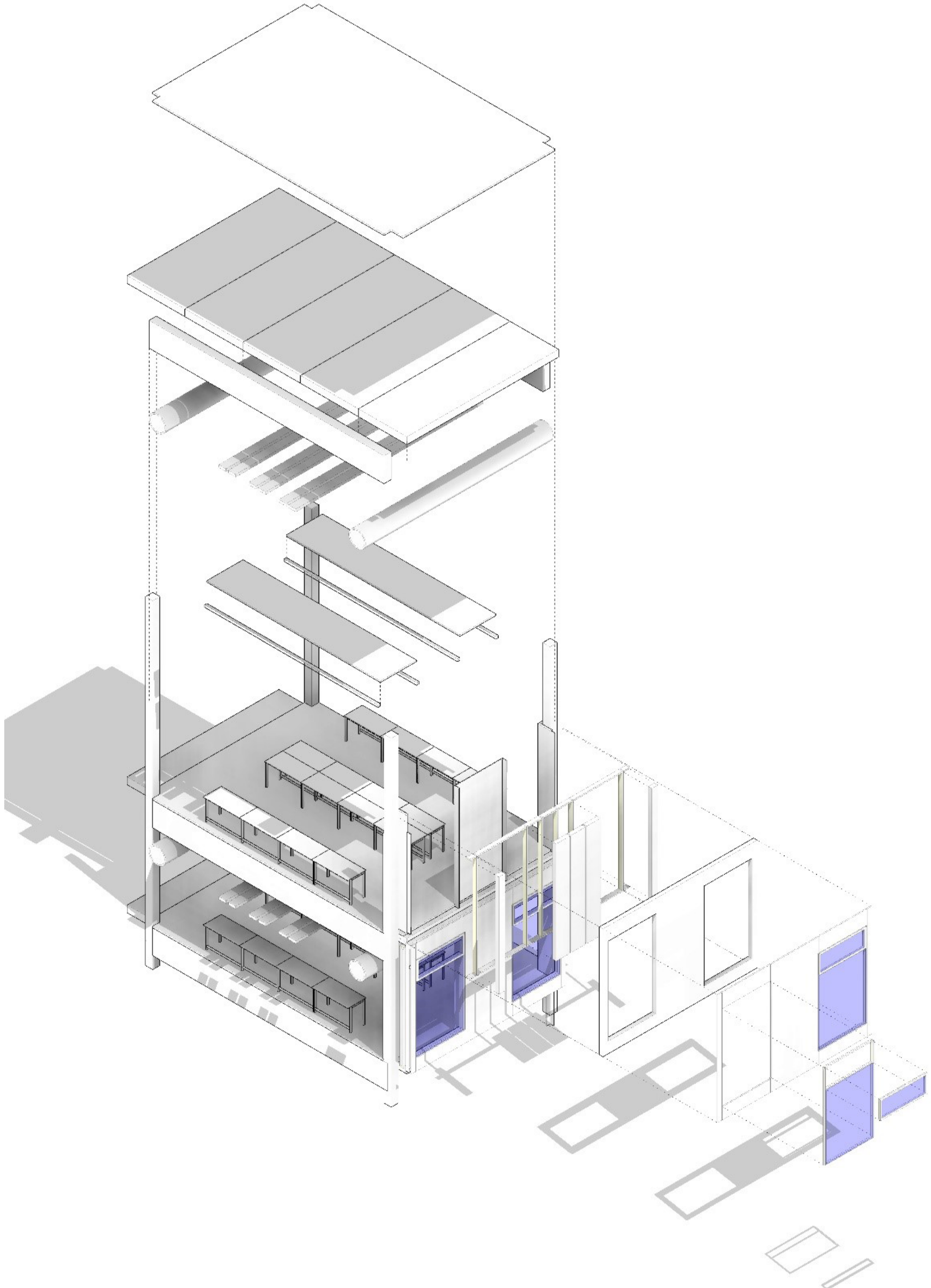
The research team used advanced design and environmental modelling tools, including Grasshopper, Energy+, Ladybug, Honeybee and Octopus) to test bundles of low carbon strategies and determine the optimum combination to achieve the RIBA Climate Challenge 75% reduction in operational energy and 50% reduction embodied carbon emissions against relevant benchmarks.

Somewhat surprisingly, the modelling revealed statistically little difference between the linear and vertical lab types when it came to operational energy. (The vertical lab performed 1% better than the linear lab.) This commonality between the two lab types is largely due to ventilation, which is the main driver of energy loss for lab buildings regardless of their height or massing. Given the similarity of vertical and linear labs, we have presented one set of results below for a linear lab.

Results

Our findings revealed the 2030 Net Zero practice reduced energy consumption the most — by 60% through a combination of improvements to air tightness, insulation, glazing performance, shading and, most importantly, lowering the number of average air changes to 4 per hour. These adjustments to the 2030 Net Zero specification would bring energy consumption from the grid down to the targeted goal of 235 kWh/m^2/y before on-site renewables and offsetting.

The energy modelling undertaken assumed an on-site energy provision through renewables, such as photovoltaics and ground source heat pumps (GSHP), that would reduce grid demand by 15% to 147 kWh/m^2/y. An additional 25% reduction in energy would have to come from certified offsetting programmes — a necessary requirement until the energy grid itself is decarbonised.



Discussion

Unregulated energy use of equipment, small power, and special lab processes were not included in this study. Instead we used 90kWh/m^2 as a representative value based on the actual energy performance of a low-energy laboratory in England.

The next stage in our research will be to investigate what combination of renewables would be required to achieve our 75% reduction target. Using current technologies, a 75% reduction in operational energy would require a fully electric building with ground source heat pumps and a significant amount of solar PV. This might be possible in low rise buildings with large roof areas but would be challenging in tall buildings in dense urban locations, which would likely require offsetting.

Embodied Carbon Analysis

In conjunction with our energy reduction studies, HOK examined three construction approaches to determine which offered the lowest embodied (construction) carbon.

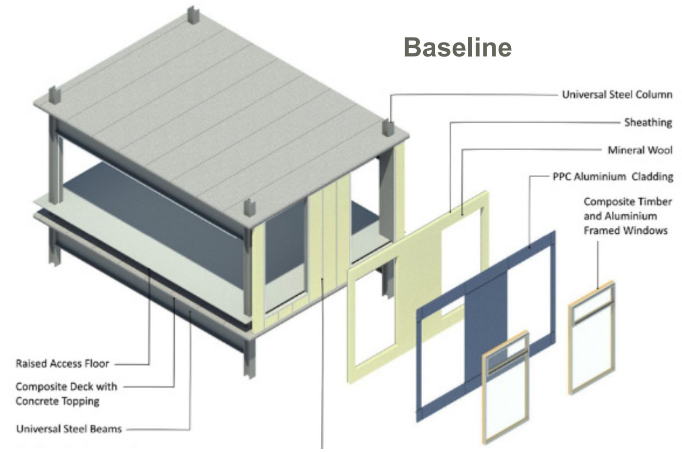
Methodology

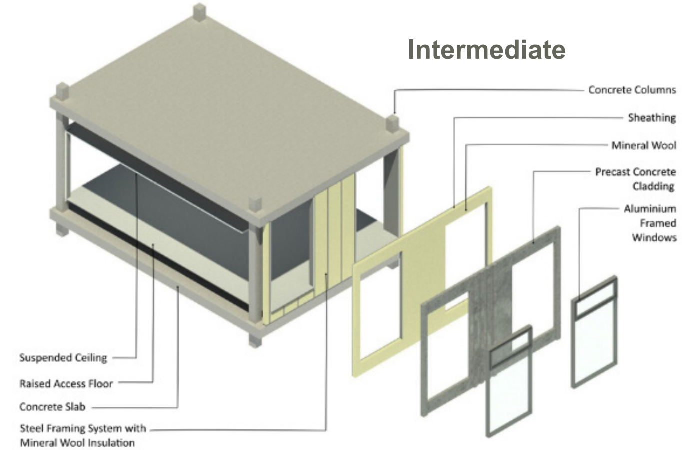
All three construction options studied include measures for reducing embodied carbon, beginning with the current Baseline standard and progressing to the more rigorous measures of the 2030 Net Zero.

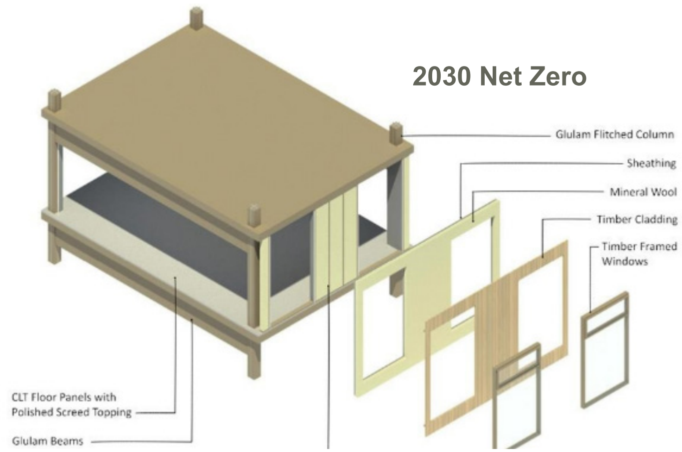
Baseline Practice: This design would feature a steel and pre-cast concrete structural system with low carbon concrete. The façade for this approach would use a PPC aluminium panel system with composite timber and aluminium framed fenestration. The fit out would include limited suspended ceilings, limited raised floors, screed and resin flooring, aluminium glazed partitions and paintings and coatings with low or no off-gassing.

Intermediate Practice: This design approach would incorporate a low carbon concrete structural system and use a pre-cast concrete unitised façade system with PPC aluminium fenestration. Fit out would include suspended ceilings, raised floors, aluminium glazed partitions and industry standard paints and coatings.

2030 Net Zero Practice: This design would use a mass timber structural system with screed topping, a timber cladding system and full timber framed fenestration. Fit out would have no suspended ceilings or raised floors (the screed floor will be exposed with a polished finish).



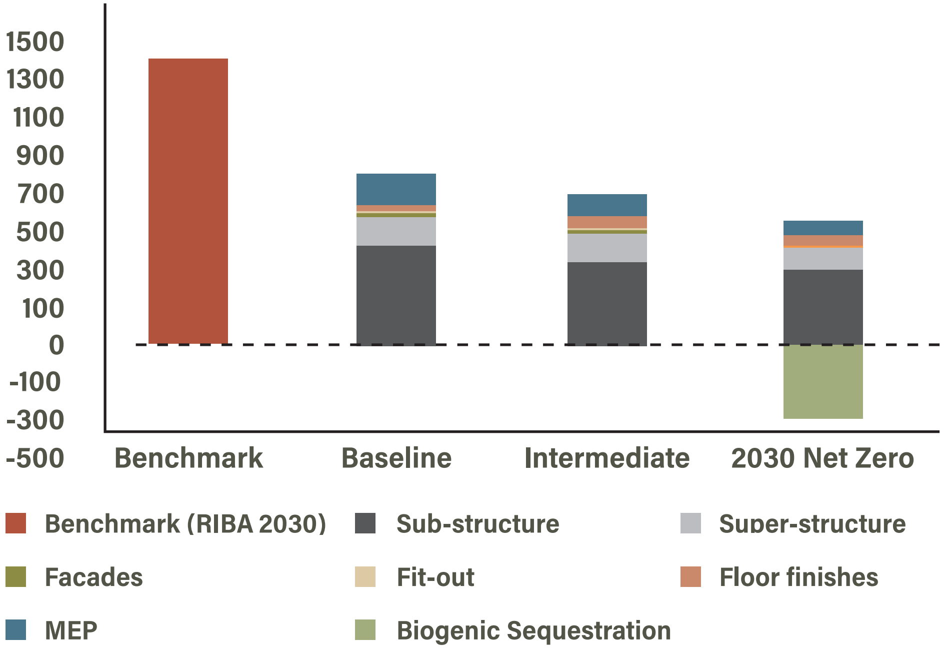




Results

A detailed product specification was created for each option and imported into the open source One-Click LCA tool. The results have been broken into key construction systems and are outlined below.

Embodied Carbon Analysis



HOK's analysis indicates that the timber-based approach was most effective at reducing embodied carbon.

While all three approaches reduced embodied carbon, the 2030 Net Zero option had the lowest embodied carbon at 547 $kgCO_2e/m^2$, falling within RIBA's 2030 Challenge target. If we included the carbon sequestration of the timber (the amount of carbon absorbed from the environment and stored during the growing of the trees) the embodied carbon would drop even further to around 141 $kgCO_2e/m^2$ — a 90% reduction from the benchmark.

Structure

- As expected, the largest embodied carbon for all options is linked to sub-structure, followed by the steel super structure.
- The mass timber 2030 Net Zero option had the lowest embodied carbon structural emissions of 362kgCO_2/m^2 before sequestration and -44kgCO_2/m^2 including biogenic sequestration.

Façade

- The highest façade emissions were related to the Baseline option which used an SFS system and aluminium cladding (94kgCO_2/m^2). This was surprising since we had assumed the lightweight systems combined with a composite timber and aluminium window system would be lower than the precast Intermediate option.
- Due to its larger surface area to volume ratio, the linear lab type was marginally worse than the more compact and vertical form.
- The insulated pre-cast panel façade with aluminium curtain walling was two-thirds less than the Intermediate option with an embodied carbon emission of 30kgCO_2/m^2.
- The predominately timber cladding system and windows, as expected, had a significant impact on the embodied carbon with just 7kgCO2/m2 or a 93% reduction from the typical cladding specification of many buildings.
- The fire implications of timber are fully appreciated and requires further investigation with building insurance companies in the light of Grenfell tragedy in the UK.

Internal Fit-out and Finishes

- The Baseline option had the highest combined embodied carbon emissions of 134kgCO_2m^2 which was 43kgCO_2/m^2 higher than the Intermediate option of 91kgCO_2/m^2. This result is primarily linked to the increased use of levelling screed and resin finish (and associated cement usage) in lieu of using a raised floor system with vinyl finish.
- The Net Zero 2030 option had the lowest carbon emissions of 78kgCO_2/m^2 which was 42% less than the highest option. The key reasons for this significant decrease was the use of a polished terrazzo/screed floor finish throughout with no raised floors, limited suspended ceilings, predominately timber fitout products, and the use of organic paints and finishes.

Mechanical, Electrical and Plumbing (MEP)

The embodied carbon research of MEP systems is still in its infancy, and therefore MEP was not a direct part of this study. There are some early studies on this subject, and CIBSE has created a new Technical Memorandum 65 to define a methodology to measure MEP embodied carbon.

We have used a study by Elementa Consulting that suggests the embodied carbon of MEP for commercial offices could be 63kgCO_2/m^2 (best case) to 105kgCO_2/m^2 (medium case). Laboratory buildings typically employ complex MEP systems due to the research process, and therefore we have used the medium case benchmark of 105kgCO_2/m^2 for all the scenarios above. Further work in the next stage of the research is required to establish benchmarks for MEP embodied carbon of lab buildings.

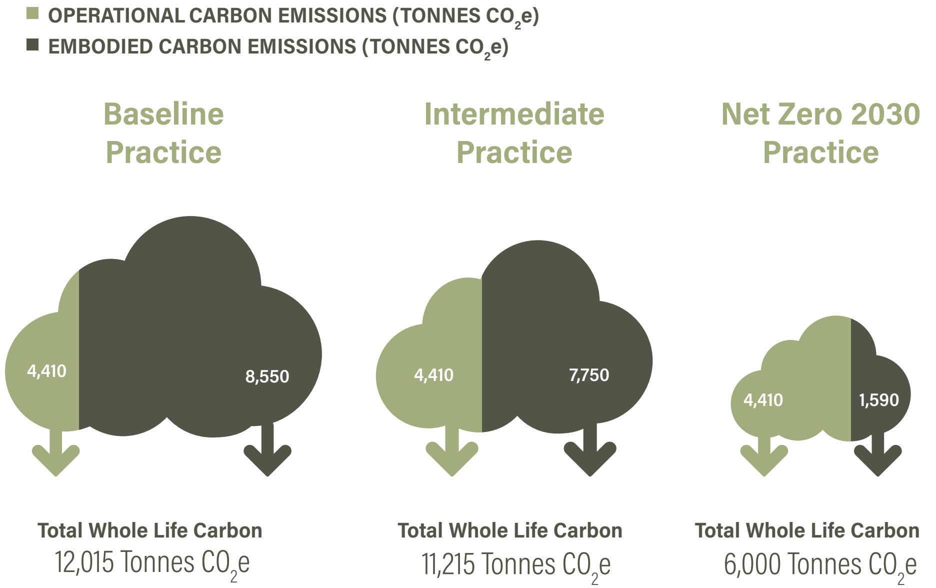
Discussion

In all the options, our structural engineering research partner, AKTII, ensured that the structural specifications used in our analysis achieved a vibration criterion of RF 1 for lab use with a structural bay size of 6.6m by 9.6m. The same sub-structure strategy of mass concrete pads using 50% GGBS was used for all options. However, as is evident in the results of the embodied carbon analysis, sub-structure is linked to building mass i.e. lighter buildings that don't require robust sub-structures would incorporate less embodied carbon.

Conclusion + Considerations

HOK's initial analysis indicates that, while not easy, it is possible to build and operate labs in accordance with the sustainable design goals of the RIBA and AIA 2030 challenges. Altogether, the approaches studied in this analysis can significantly reduce the whole life carbon (operational carbon + embodied carbon building lifespan) of a lab building.

Commercial Lab Whole Life Carbon Results



By reducing embodied carbon, labs can 'flip the script' wherein the building of the lab would no longer create a greater carbon footprint than its year-to-year operation. The diagram above show whole life carbon over a 30-year time span on a 10,000m2 building (see notes on the next page for more details on the whole life carbon of each practice.)

In general, while HOK's studies showed little difference between vertical and linear lab buildings in achieving net zero, linear labs do hold one distinct advantage: their expansive roofs allow for more solar panel arrays. It is important to note that our analysis examined new lab buildings, but the most sustainable option is to reuse and adapt existing buildings. This 'retrofit first' principle will save over 500 $kgCO_2e/m^2$ of embodied carbon without the use of limited global timber supply. It is perhaps our best way to achieve net zero carbon for our sector.

HOK is now studying how labs can achieve targeted operational carbon goals while allowing for more than 4 air changes per hour. Additionally HOK research underway includes an analysis of the embodied carbon of lab MEP systems, a renewables feasibility study, and net zero costs and savings compared with business as usual.

We will be publishing the results of these studies in coming months. HOK's London, New York and San Francisco offices contributed to this study.

Notes on whole life carbon analysis

Baseline Practice

Operational Energy Use Intensity Resultant	147kWh/m²/y
Operational Carbon Emissions[1]	15kgCO_2e/m²/y
Operational Carbon Emissions over 30 years	4,410 tCO_2
Embodied Carbon Emissions	8,550 tCO_2
Total Whole Life Carbon Emissions	12,015 tCO_2

Gold Standard Offsetting

129,000 MWh of wind generated power over 30 years[2]

or

60,075 trees within 2,403 Acres over 100 years[3]

Intermediate Practice

Operational Energy Use Intensity Resultant	147kWh/m²/y
Operational Carbon Emissions[1]	15kgCO_2e/m²/y
Operational Carbon Emissions over 30 years	4,410 tCO_2
Embodied Carbon Emissions	7,750 tCO_2
Total Whole Life Carbon Emissions	11,215 tCO_2

Gold Standard Offsetting (note 2)

121,000 MWh of wind generated power over 30 years[2]

or

56,075 trees on 2,243 Acres over 100 years[3]

Net Zero 2030 Practice

Operational Energy Use Intensity Resultant	147kWh/m²/y
Operational Carbon Emissions[1]	15kgCO_2e/m²/y
Operational Carbon Emissions over 30 years	4,410 tCO_2
Embodied Carbon Emissions	1,590 tCO_2
Total Whole Life Carbon Emissions	6,000 tCO_2

Gold Standard Offsetting

15,900 MWh of wind generated power over 30 years[2]

or

30,000 trees within 1,200 Acres over 100 years[3]

Carbon conversion factors for UK grid[1]

The grid intensity has dramatically reduced in the last 10 years from a peak of 0.56 to around 0.2 ‘whole year average’ which is now on a par with gas conversion factor of 0.19 in the UK. The carbon intensity of the UK is predicted to reach 0.1 by 2035 and drop to zero by 2050. Therefore, over the next 30 years the average electricity carbon conversion factor will be around 0.1, which has been used for this study.

To offset the entire 30 years emissions of the three scenarios there are two distinct Gold Standard Offsetting approaches:

Offsite Wind Generators[2]

The most efficient and cost-effective way to generate renewable electricity in the UK at the present time is by offshore wind generation. Using Vattenfall’s Kentish Flats wind farm data.

173,000 MWh/year from a total of 15 turbines

=11,500 MWh/year/turbine

Woodland and Forest Creation[3]

Based on Trees for Life 10,000 Acre Dundreggan Forest, Scotland

250,000 new trees

50,000 tCO_2 absorption trees per 1 tCO_2

Given the likely pressure for woodland creation due to hard to decarbonise sectors such as farming, aviation and some industries. Priority should be made to decarbonise local electrical grids with local renewables.

HOK’s London, New York and San Francisco offices contributed to this study.

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