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North America

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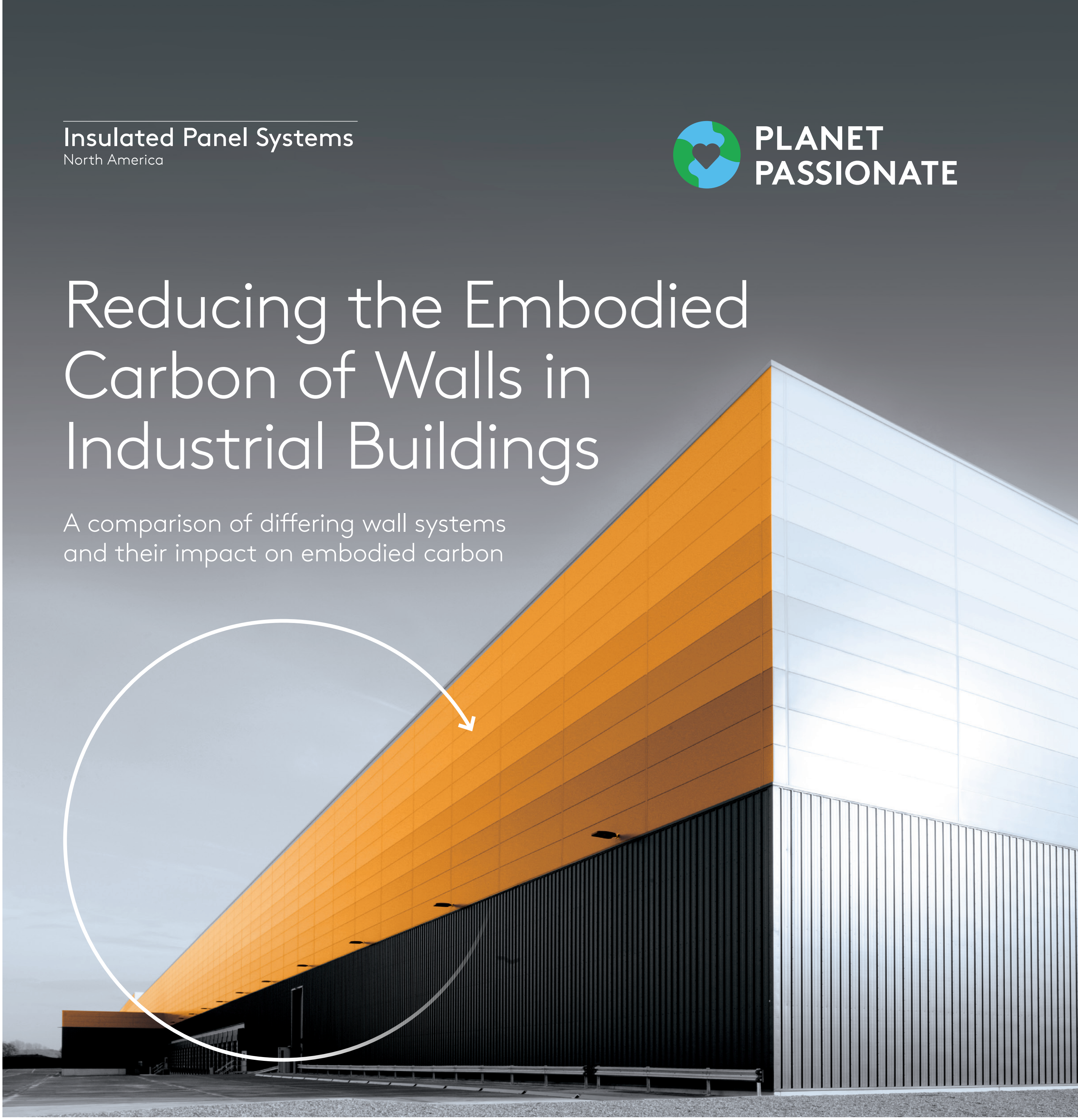


Reducing the Embodied Carbon of Walls in Industrial Buildings

A comparison of differing wall systems and their impact on embodied carbon

Kingspan®

> “For teams seeking to reduce the embodied carbon of their industrial building to the highest degree possible, Kingspan QuadCore® is an effective solution, particularly if the carbon reduction strategies have already been applied to the concrete mix design of the building foundation and floor slab.”

KieranTimberlake, “Kingspan: Life Cycle Assessment of Industrial Claddings Report”, June 7, 2020.

Contents

Introduction

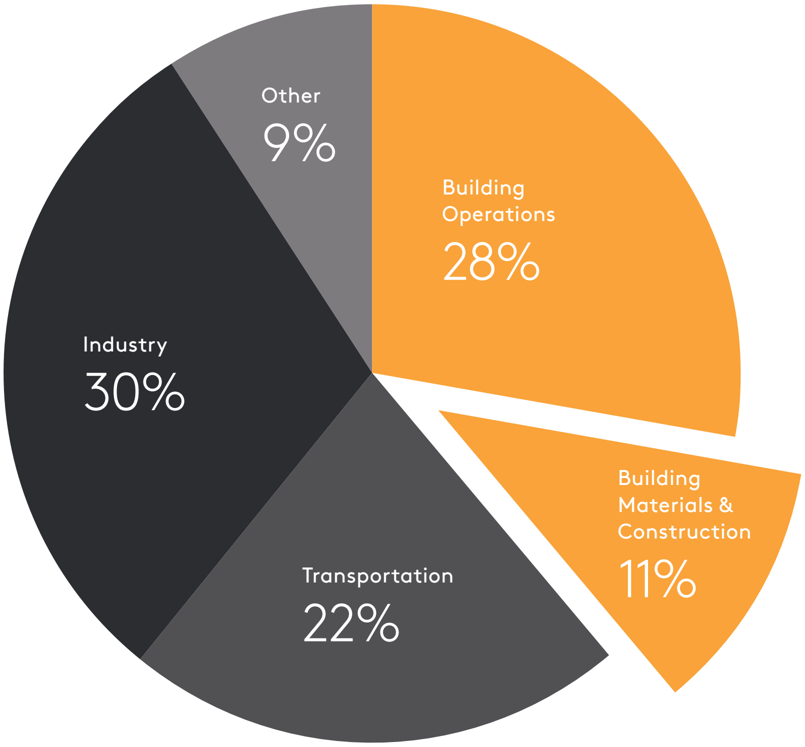
Embodied Carbon: A Locked-in Carbon Cost

According to Architecture 2030, the building sector accounts for 39% of global greenhouse gas (GHG) emissions – 28% of that is from building operations, while the remaining 11% is specifically from building materials and construction[1].

While energy use associated with building operations can be reduced over time with measures such as energy efficiency retrofits, shifts towards renewable energy procurement, and on-site renewable energy installations, embodied carbon from building materials and construction are unchangeable once a building is constructed.

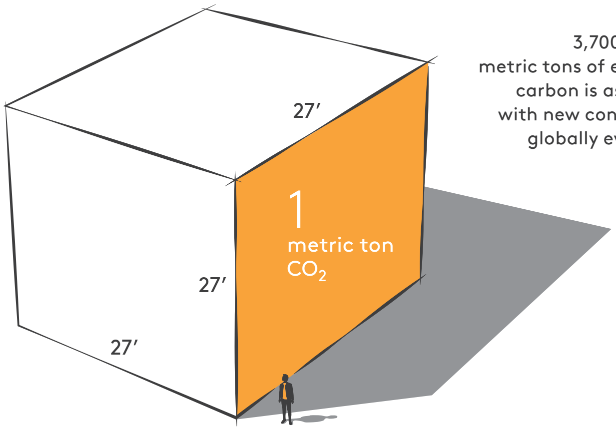
The 11% of GHG accounted for by building materials and construction represents this one-off fixed carbon cost as the embodied carbon which is locked into buildings once they are built. It is estimated that the embodied carbon associated with the annual construction of 66 billion square feet of new buildings globally is a staggering 3.7 billion metric tons[1] - that's more than 11,000 Empire State Buildings every year[2].

This locked-in nature of embodied carbon means that the opportunity for architects and building owners to reduce the carbon footprint of a building, as it relates to building materials, therefore, is limited to the design and procurement phases of a project. This clearly underscores the critical importance of thoughtful material selection and detailed specifications at the outset.



Source: Architecture 2030

The locked-in nature of embodied carbon underscores the critical importance of thoughtful material selection and detailed specifications at the outset.



3,700,000,000 metric tons of embodied carbon is associated with new construction globally every year.

Executive Summary

This paper compares four different wall assemblies applied to the same building design, a typical warehouse structure, to demonstrate and quantify the embodied environmental impacts of material selection, calculated using whole-building life cycle assessment (LCA).

To conduct this study, Kingspan engaged architectural planning and research firm KieranTimberlake, creators of the Tally® LCA software used in the analysis.

The four wall systems compared were a Kingspan insulated metal panel (IMP) system insulated with a QuadCore® insulation core, an IMP insulated with mineral fiber, insulated concrete, and tilt-up concrete. Each building design shares several common elements across the four buildings but varies per the requirements of each wall system in areas such as structural members and associated foundations.

While the shared elements accounted for the vast majority of the mass of the buildings, the primary aim of this study was to compare wall envelopes and quantify the environmental impacts of wall system selection.

The LCAs revealed that the wall system using Kingspan IMPs insulated with QuadCore® had the lowest embodied carbon levels, represented as global warming potential (GWP), out of all the systems compared – 28% lower than both the insulated concrete and tilt-up concrete walls, which had the highest levels of embodied carbon.

Furthermore, the Kingspan QuadCore® IMP wall also had the lowest impact on smog formation – 19% lower than the highest impact design which used tilt-up concrete wall, again followed closely by the insulated concrete wall.

In terms of acidification, the mineral fiber IMP wall had the highest impact, with insulated concrete wall having the lowest impact – 34% lower than the mineral fiber IMP wall.

The impact on ozone depletion of all four wall systems was miniscule, with the highest impact at only 0.08 kg CFC-11 equivalent, which was the mineral fiber IMP wall.

In assessing non-renewable energy demand, the mineral fiber IMP wall had the highest impact, with the Kingspan QuadCore® IMP wall using 13% less non-renewable energy.

In the category of eutrophication, all four wall systems were very close with only a 14 kg Nitrogen-equivalent (Neq) difference from the lowest to the highest impacts – the tilt-up concrete wall having the lowest impact at 173 kg Neq, and the Kingspan QuadCore® IMP wall system at 188 kg Neq.

The study reveals that for design teams and building owners seeking to reduce the embodied carbon of building envelopes in industrial buildings to the highest degree possible, Kingspan QuadCore® IMPs are an effective solution.

The Kingspan QuadCore® IMP wall system had 28% lower embodied carbon than both insulated concrete and tilt-up concrete. This is equivalent to saving the CO_2 emissions from burning 149 tons of coal, or the Greenhouse gas emissions from driving the average car 671,270 miles (27 times around the Earth)[3].

CO_2

28%
lower embodied carbon

149
tons of coal

671,720
miles driven

Background

Purpose of Assessment

This assessment compares the environmental performance of four warehouse building envelope options using a series of whole-building life cycle assessments (LCAs). The purpose of the study is to understand the embodied environmental impact, in particular embodied carbon, of a building constructed using Kingspan products compared to the same building constructed with normative materials.

This LCA specifically compares the ecological impacts of an industrial building constructed using the Kingspan QuadCore® insulated metal panel (IMP) relative to buildings constructed using mineral fiber IMPs, insulated concrete, and tilt-up concrete. The LCA methodology used in this study accounts for the environmental impacts associated with the inputs from and emissions to the environment that result from the manufacturing, maintenance, and disposal of products and materials found in each of the buildings.

The assessment has been conducted according to a North American interpretation of the guidelines provided by European Standard EN 15978:2011, Sustainability of construction works – Assessment of environmental performance of buildings[4].

Scope and System Boundary

The study examines four variations of a 150,000-square-foot warehouse in Philadelphia, PA, to determine the environmental impacts of structure, envelope, and interior assemblies over a 60-year building life. The analysis accounts for the full cradle-to-grave life cycle of the whole building for each of the four options studied across all life cycle stages. The stages include material manufacturing, maintenance and replacement, and eventual end of life.

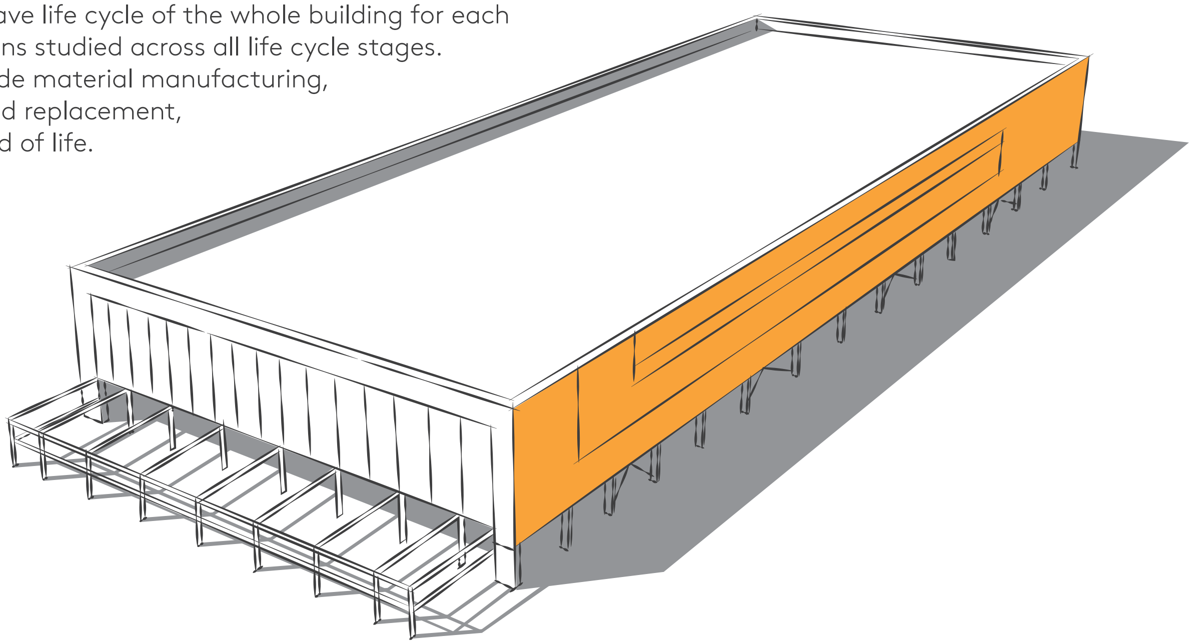


Figure 1. The study considers four wall envelope options for this typical industrial warehouse.

Each option meets the performance criteria defined by the International Building Code[5]. Equivalent energy performance is proxied by maintaining a wall R-value of 20, as required for climate zone 4A.

All buildings meet structural requirements for typical Philadelphia conditions, with structural modifications per option to support the envelope as well as regionally appropriate loads for snow and wind.

Architectural products and assemblies include all materials required for the product's manufacturing and use, such as hardware, sealants, adhesives, coatings, and finishing. Material quantities are included up to a 1% cut-off factor by mass, except for cases known to have high environmental impacts at low levels, where a 1% cut-off is implemented by environmental impact.

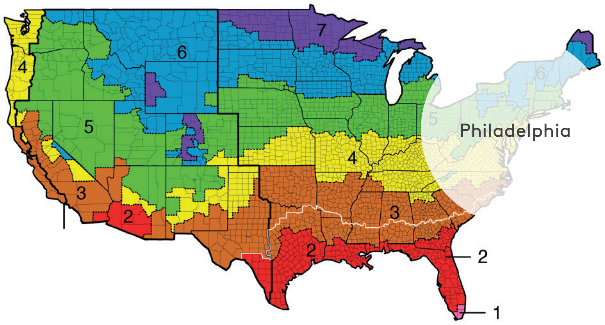


Figure 2. US Climate zone map; Philadelphia is in Climate Zone 4A per the International Building Code, 2018.

Shared vs. Unique Building Components

To compare the impacts of the wall envelopes specifically, it was important to identify which building components were common throughout each of the four designs and which were unique to each wall system. This enabled the analysis to isolate the outcomes for each building to the wall assemblies, allowing for appropriate side-by-side comparisons.

The shared components of each of the four buildings include:

- Roof assembly comprising polyisocyanurate (PIR) insulation, sheathing board, and TPO membrane
- Interior structure of steel columns, trusses, and joists supporting a steel roof deck
- Floor slab of unfinished concrete on grade
- Overhead coiling doors, several aluminum-framed windows, and egress doors as required by building code
- Foundation system including continuous concrete foundation wall and concrete wall footing

Unique to each building variation is an envelope assembly which includes:

- A full wall assembly and any related support structures as required
- Supplementary foundations such as column footings, additional edge foundations, and exterior wall support as required

The analysis in this paper focuses on the comparison of the impacts of the unique components for each building.

	Kingspan QuadCore® IMP	Mineral Fiber IMP	Insulated Concrete	Tilt-up Concrete
Wall Assembly	Unique	Unique	Unique	Unique
Vertical Structure	Unique		Unique	
Foundations	Unique		Unique	
Doors and Windows	Shared			
Roofing	Shared			
Floor Slab	Shared			

Table 1. Building components are held constant or changed to maintain equity across options.

Wall Assemblies

Kingspan IMP insulated with QuadCore®

The Kingspan QuadCore® IMP assembly uses a 2½-inch thick, 24-inch wide Kingspan KS panel. Steel girts provide the secondary structure for hanging the panels between the W-section columns and beams supporting the joists for the roof. Additional concrete footings with embedded steel plates support the steel perimeter columns.

Figure 3. Kingspan KS panel insulated with QuadCore®

Exterior Wall

1. 2½ in. Kingspan QuadCore® insulated metal panel (22 ga steel sheet, PVDF coating, hybrid polyisocyanurate fill, Zincalume coating, modified polyester coating)
2. Stainless steel fasteners and clips
3. White butyl caulk
4. 6x6x⅜ in. HSS steel in braced frame to support panels
5. 6x6x5⁄16 in. HSS steel framing around openings (not shown)
6. 8x8x⅜ in. HSS steel in non-braced frame to support panels
7. 10x10x⅜ in. HSS steel in braced frame to support panels
8. 14x14x⅝ in. HSS steel perimeter columns
9. W24x55 W-flange to support roof joists
10. Steel plate column attachment

Foundation

11. 22x22x1½ in. steel embed plate for non-braced frame columns (not shown)
12. 24x24x2½ in. steel embed plate for braced frame columns
13. 2x2 ft. concrete pier at exterior columns
14. 4x4x1½ ft. concrete footing for non-braced frame columns (not shown)
15. 8x8x2½ ft. Concrete footing for braced frame columns
16. 12 in. concrete footing wall
17. Steel reinforcing rod (rebar)

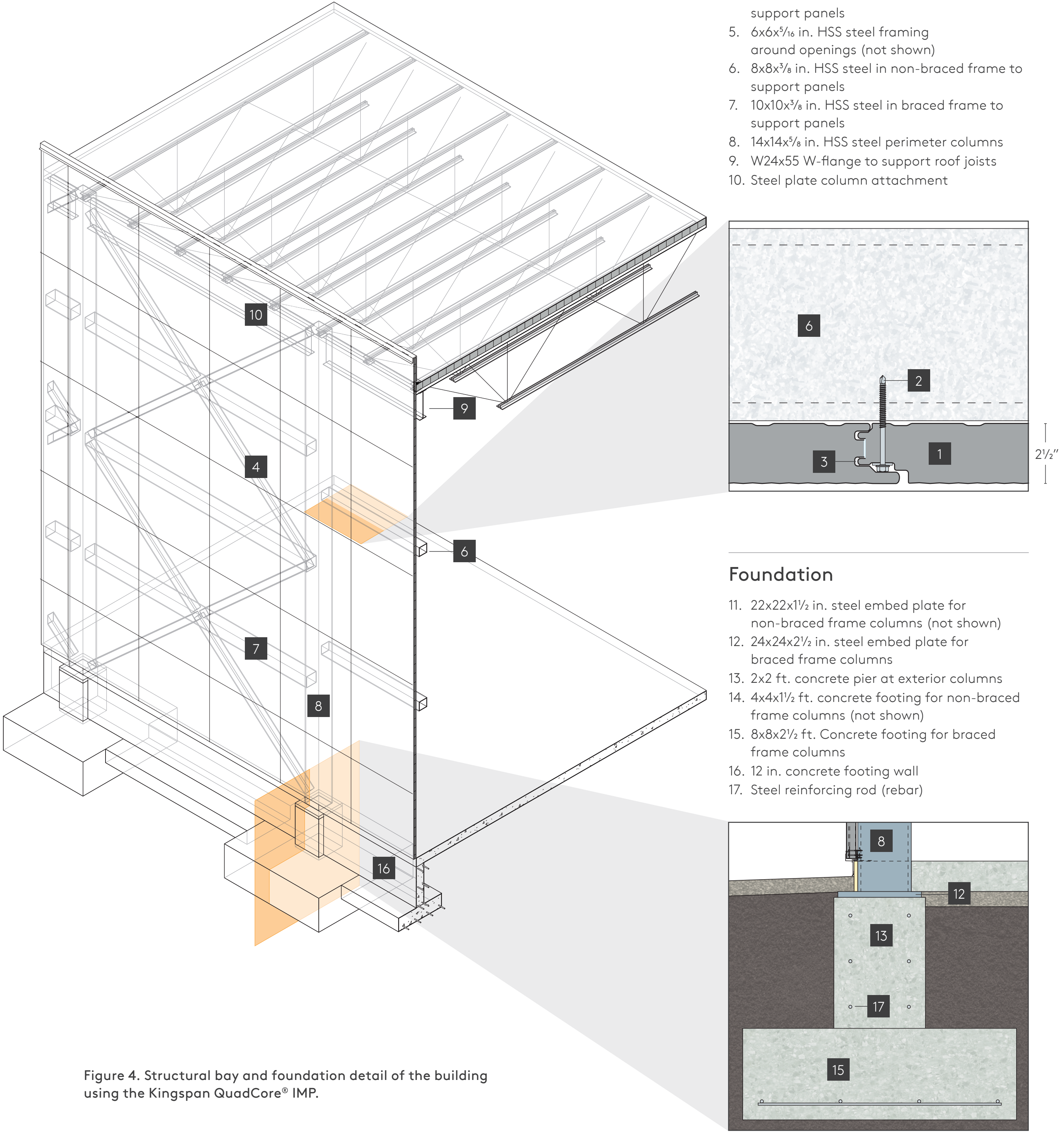


Figure 4. Structural bay and foundation detail of the building using the Kingspan QuadCore® IMP.

Wall Assemblies

Mineral Fiber IMP

This IMP envelope option is based on a 5-inch thick, 42-inch wide standard fluoropolymer-coated panel made of G-90 galvanized steel wrapped around a high-density rigid mineral fiber core. The panel requires a perimeter steel structure of columns, beams, and girts as well as perimeter concrete footings. This added structure is identical to the structural design supporting the Kingspan QuadCore® panels.

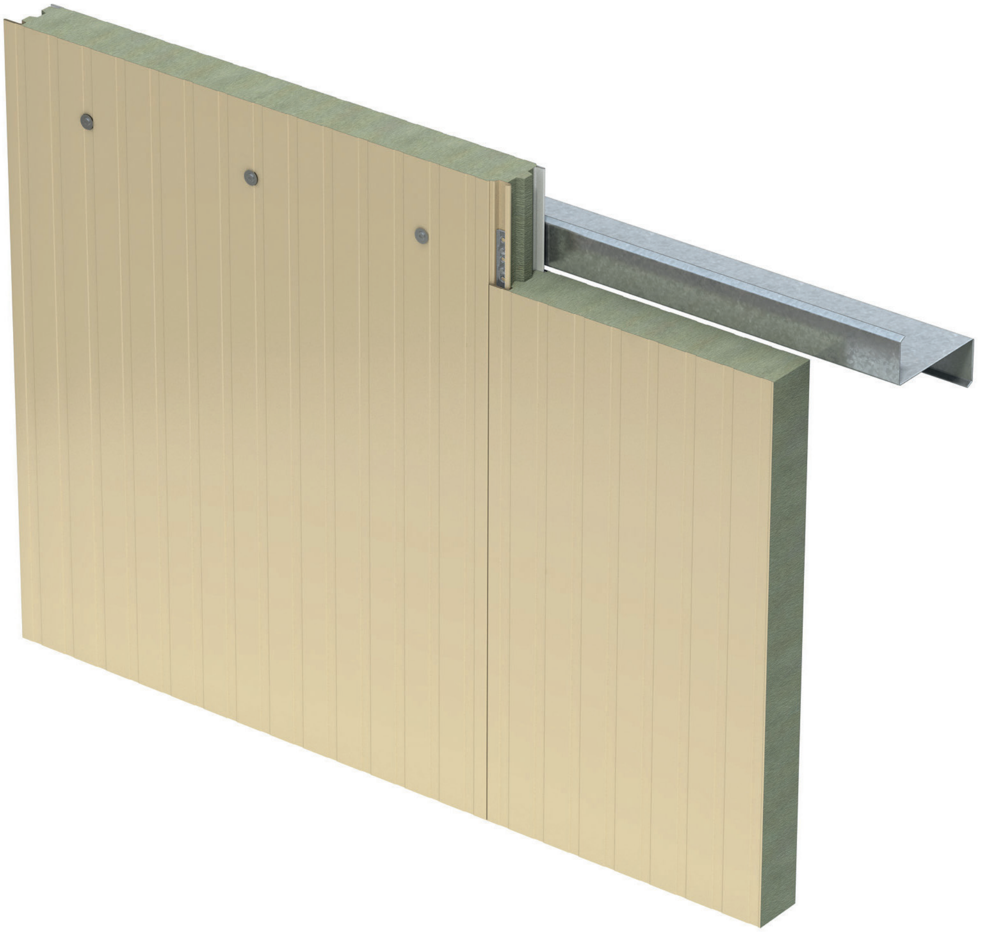
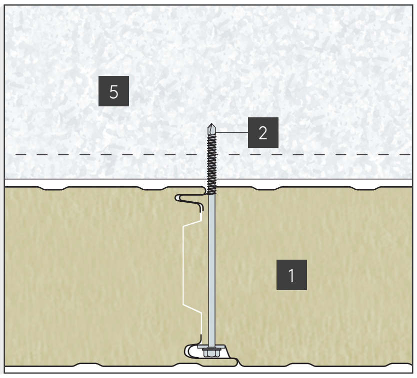


Figure 5. Insulated metal panel with a mineral fiber core.

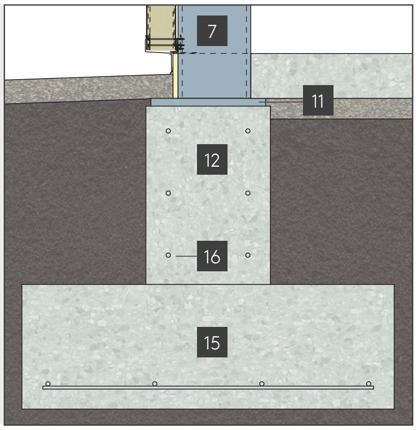
Exterior Wall

1. 5 in. metal-clad mineral wool panel (26 ga steel sheet, 4¾ in. high-density mineral wool board, polyurethane adhesive, G-90 galvanized coating, fluoropolymer coating)
2. Galvanized fasteners and clips
3. 6x6x⅜ in. HSS steel in braced frame to support panels
4. 6x6x⁵⁄₁₆ in. HSS steel framing around openings (not shown)
5. 8x8x⅜ in. HSS steel in non-braced frame to support panels
6. 10x10x⅜ in. HSS steel in braced frame to support panels
7. 14x14x⅝ in. HSS steel perimeter columns
8. W24x55 W-flange to support roof joists
9. Steel plate column attachment



Foundation

10. 22x22x1½ in. steel embed plate for non braced frame columns (not shown)
11. 24x24x2½ in. steel embed plate for braced frame columns
12. 2x2 ft. concrete pier at exterior columns
13. 4x4x1½ ft. concrete footing for non-braced frame columns (not shown)
14. 8x8x2½ ft. Concrete footing for braced frame columns
15. 12 in. concrete footing wall
16. Steel reinforcing rod (rebar)



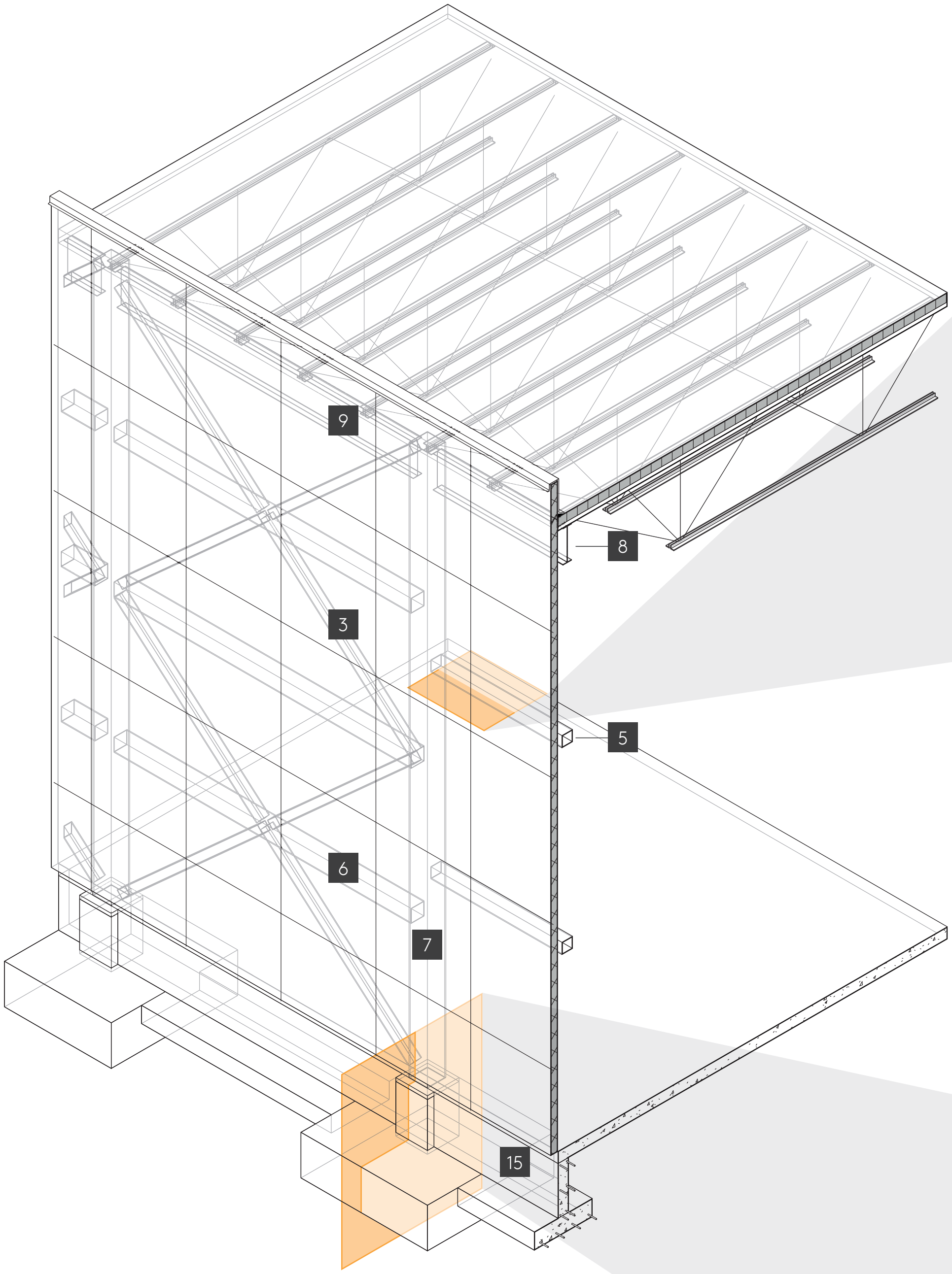


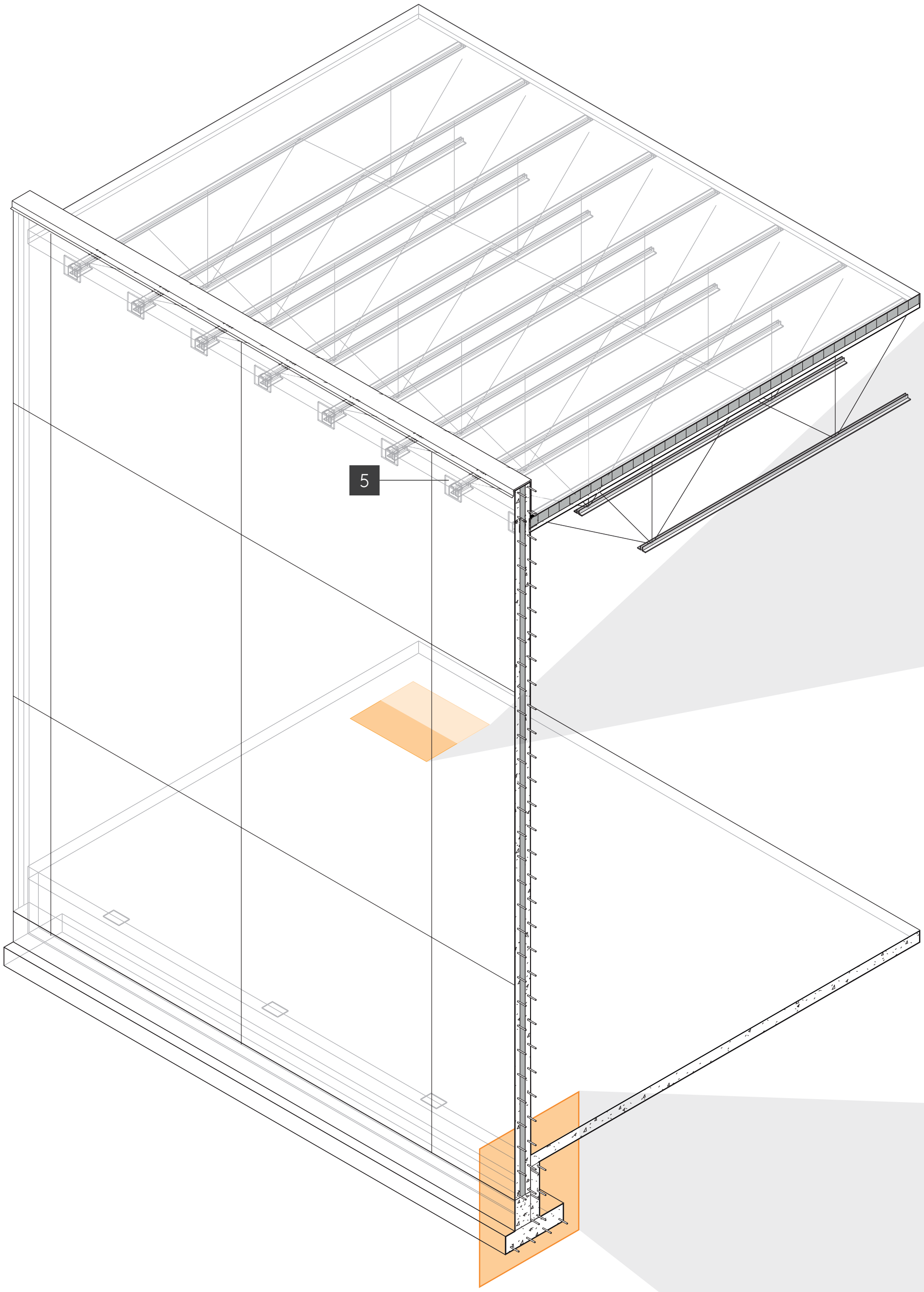
Figure 6. Structural bay and foundation detail of the building using the mineral fiber IMP.

Wall Assemblies

Insulated Concrete

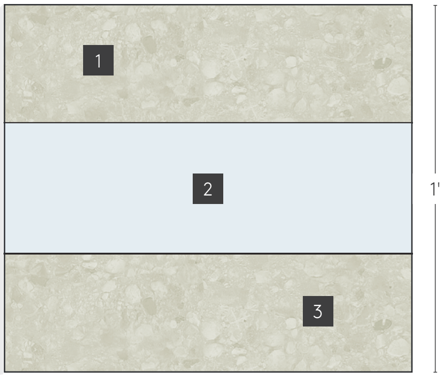
The insulated concrete panels consist of four inches of rigid expanded polystyrene (EPS) foam insulation sandwiched between four-inch layers of reinforced precast concrete. The concrete used in the panels is a typical mix for precast concrete with two-way rebar reinforcement[6]. As the panels provide inherent structural support, this building does not require vertical perimeter steel members. However, the footing wall requires additional continuous concrete reinforcement and substantial embedded steel plates to support the weight of the panels from below grade.

Figure 7. Insulated concrete wall with EPS core.



Exterior Wall

1. 4 in. precast structural concrete (admixture, coarse aggregate, expanded slag, fly ash, Portland cement, sand, rebar)
2. 4 in. Expanded polystyrene (EPS) board
3. 4 in. precast structural concrete (admixture, coarse aggregate, expanded slag, fly ash, Portland cement, sand, rebar)
4. Steel reinforcing rod (rebar)
5. 12x12x¾ in. Steel embed plate



Foundation

6. 12x½ in. steel shelf
7. ½x12 in. Steel embed plate
8. 4 in. continuous concrete footing neck
9. 12 in. continuous concrete footing wall
10. 3x1 ft. continuous concrete footing
11. Steel reinforcing rod (rebar)

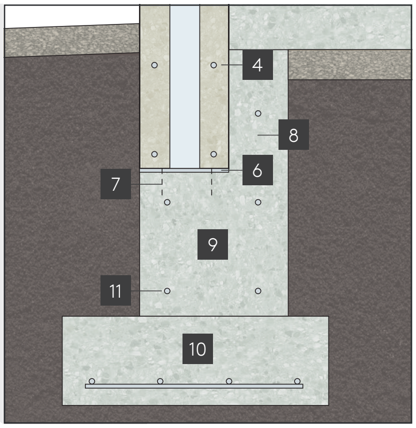


Figure 8. Structural bay and foundation detail of the building using insulated concrete.

Wall Assemblies

Tilt-Up Concrete

The primary material in the tilt-up concrete construction is the nine-inch thick tilt-up reinforced concrete panel. The concrete mix matches the typical mix for a 5ksi panel in the Philadelphia region and uses a mixture of slag and fly ash to replace some of the cement to reduce embodied greenhouse gas emissions[7]. As the panels do not provide sufficient thermal insulation on their own, metal studs with fiberglass batt insulation and an interior layer of gypsum board are required to maintain an equivalent function with the other buildings. The foundation structure for the tilt-up concrete variation is the same as the foundations in the insulated concrete construction.

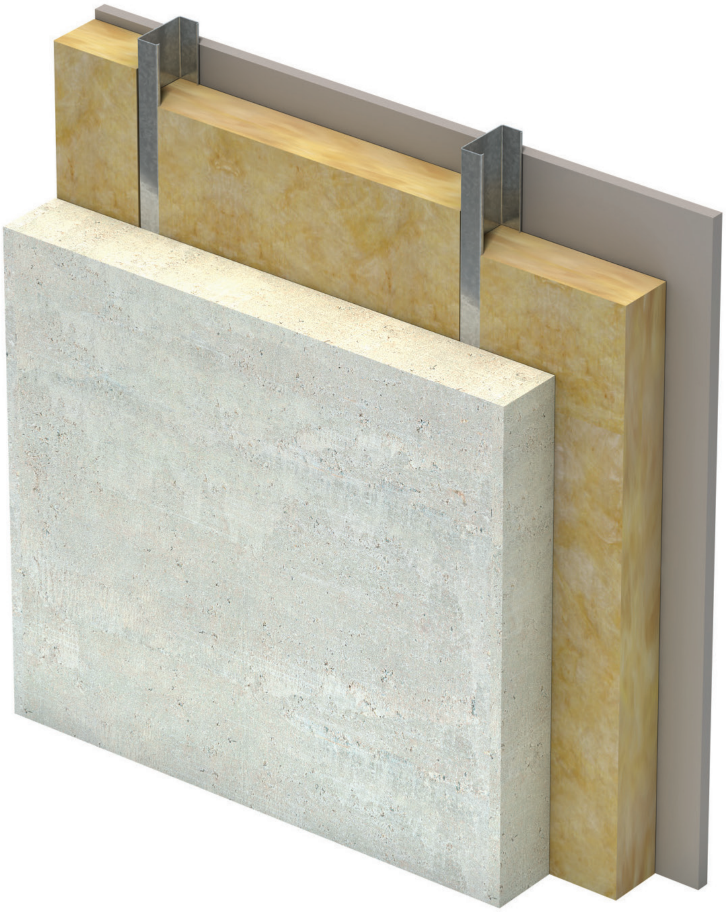
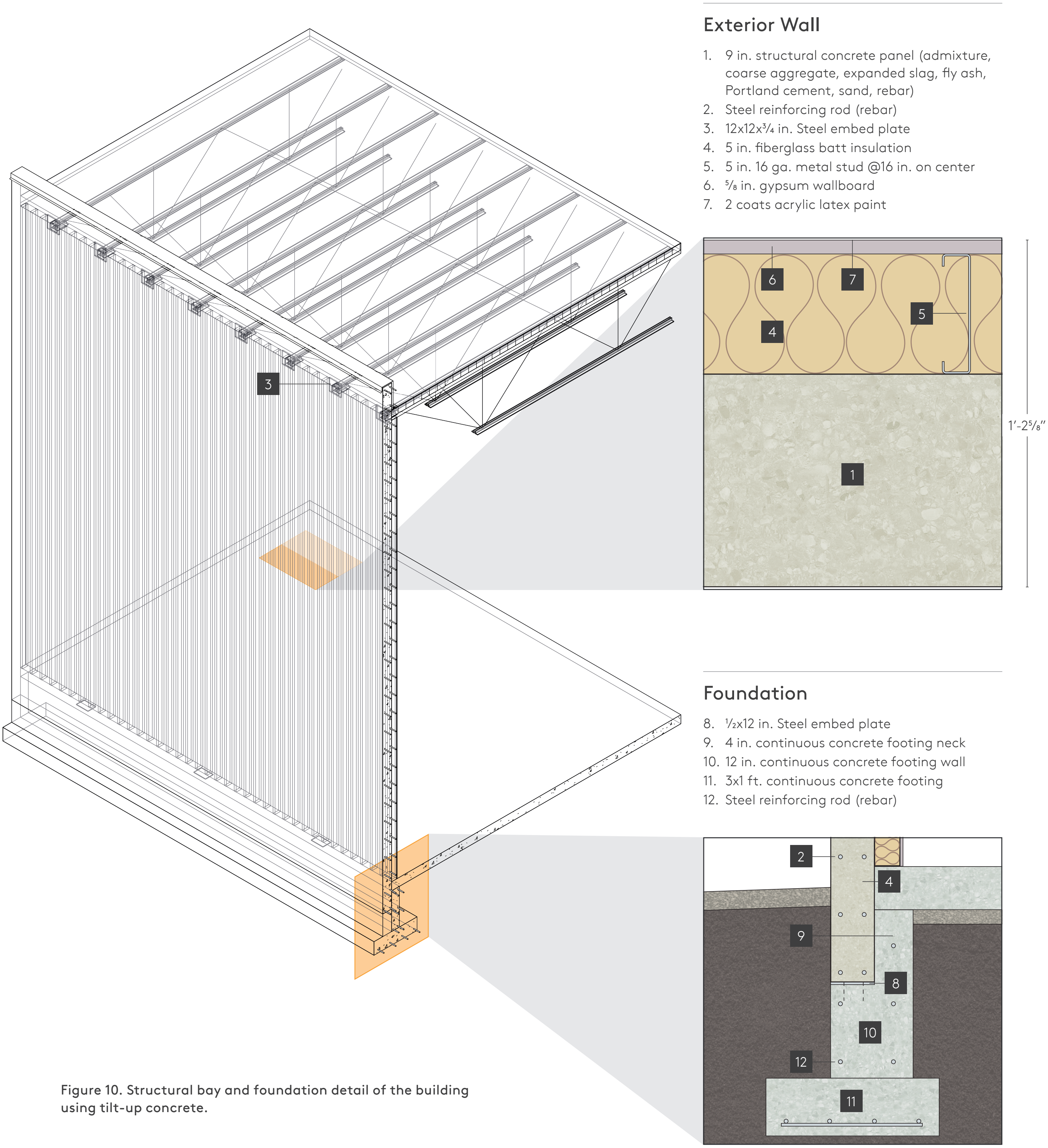


Figure 9. Tilt-up concrete wall assembly with fiberglass batt insulation and internal lining.



Exterior Wall

1. 9 in. structural concrete panel (admixture, coarse aggregate, expanded slag, fly ash, Portland cement, sand, rebar)
2. Steel reinforcing rod (rebar)
3. 12x12x¾ in. Steel embed plate
4. 5 in. fiberglass batt insulation
5. 5 in. 16 ga. metal stud @16 in. on center
6. ⅝ in. gypsum wallboard
7. 2 coats acrylic latex paint

Foundation

8. ½x12 in. Steel embed plate
9. 4 in. continuous concrete footing neck
10. 12 in. continuous concrete footing wall
11. 3x1 ft. continuous concrete footing
12. Steel reinforcing rod (rebar)

Figure 10. Structural bay and foundation detail of the building using tilt-up concrete.

Methodology: Life Cycle Assessment (LCA)

To conduct this comparison study, Kingspan engaged architectural planning and research firm KieranTimberlake, creators of the Tally LCA software used in the analysis.

Each industrial building was designed to create a 600-foot by 250-foot interior space with minimal columns in order to maximize usable clear floor area. As the buildings are situated in Philadelphia, all cast-in-place concrete is assumed to match regional baseline concrete mixes provided by the National Ready Mixed Concrete Association[8]. Tally, which is a Revit-integrated LCA tool, provided accurate material take-off calculations from the Revit geometry to generate a complete bill of materials.

Tally generated the figures for potential environmental impacts and resource demand over the full building life cycle based on the TRACI 2.1 Characterization Scheme, including Global Warming, Acidification, Eutrophication, Smog Formation, Ozone Depletion, and Non-Renewable Energy Demand[9].

Although a characterization scheme translates all emissions and fuel use associated with the assessment into quantities of categorized environmental impact, the degree of resulting environmental harm depends on the regional ecosystem conditions and the location in which emissions occur. Therefore, effects are reported as potential to harm in kilograms of equal relative contribution (eq) of an emission commonly associated with that form of environmental impact, rather than as absolute measures of ecological harm.

Results

Global Warming Potential

In this comparison of embodied carbon, measured as global warming potential, the LCA revealed that the Kingspan QuadCore® IMP had the lowest levels out of all the wall assemblies – 28% lower than both the insulated concrete wall and tilt-up concrete wall, which had the highest levels of embodied carbon.

The cement content in the precast panels and the tilt-up concrete creates the high greenhouse gas contributions for those options. For the two IMP options, the most significant contributor is the metal structure at the perimeter. The fluoropolymer coating on the mineral fiber IMP also drives up the global warming contribution of that option.

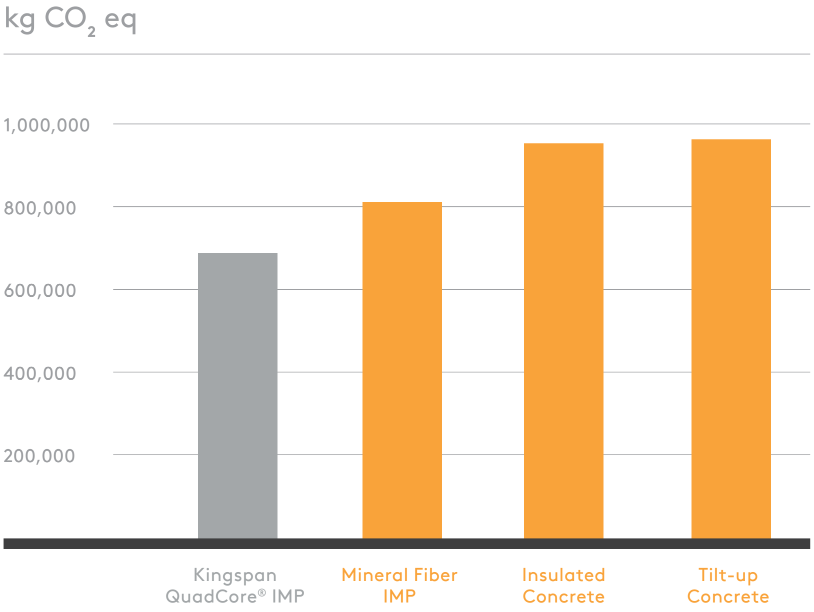


Figure 11. Embodied carbon, measured as global warming potential.

Smog Formation Potential

The impacts of smog formation have the same drivers as the impacts of global warming, and here the Kingspan QuadCore® IMP wall again had the lowest impact – 19% lower than the highest impact design which used the tilt-up concrete wall, again followed closely by the insulated concrete wall.

For the two concrete options, the primary driver is the cement. For the IMP options, the most considerable contributions are from the HSS steel support structure and metal in each panel. The difference in performance between the IMP options is due to the contributions of the fluoropolymer coating on the mineral fiber IMP.

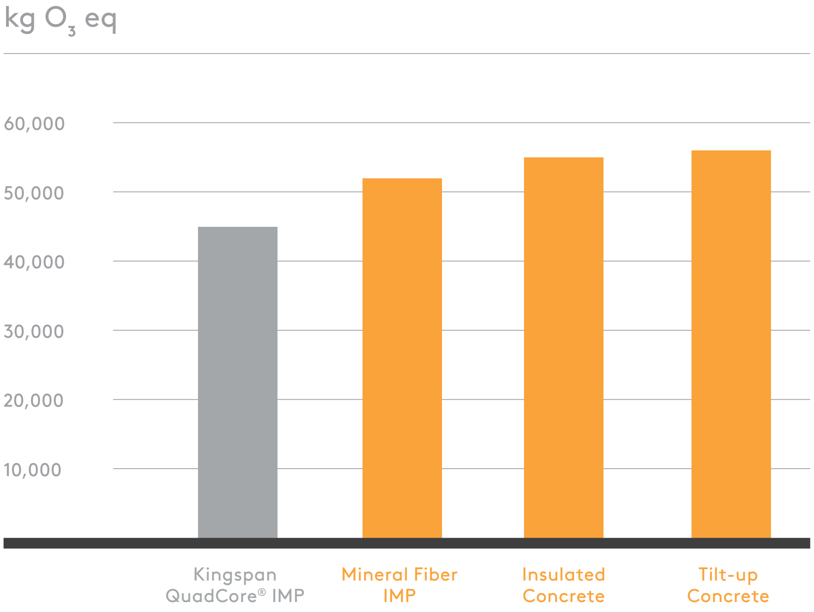


Figure 12. Smog formation comparison.

Results

Acidification Potential

Comparing only the components that change between buildings, the mineral fiber IMP contributes the most to acidification, while insulated concrete contributes the least, with 34% lower levels than the mineral fiber IMP.

The quantity of steel used in each option correlates strongly with the performance in this category. In the mineral fiber IMP, the heavy galvanization and fluoropolymer finish further drive up the impacts.

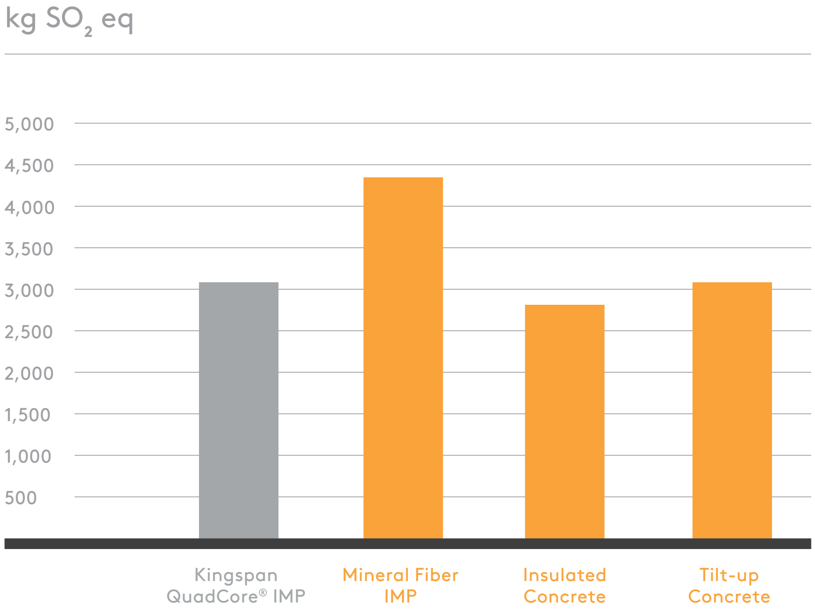


Figure 13. Acidification comparison.

Eutrophication Potential

In the category of eutrophication, all four wall systems were very close with only a 14 kg Nitrogen equivalent (N eq) difference from the lowest to the highest impacts – the tilt-up concrete wall having the lowest impact at 173 kg N eq, and the Kingspan QuadCore® IMP wall system at 188 kg N eq.

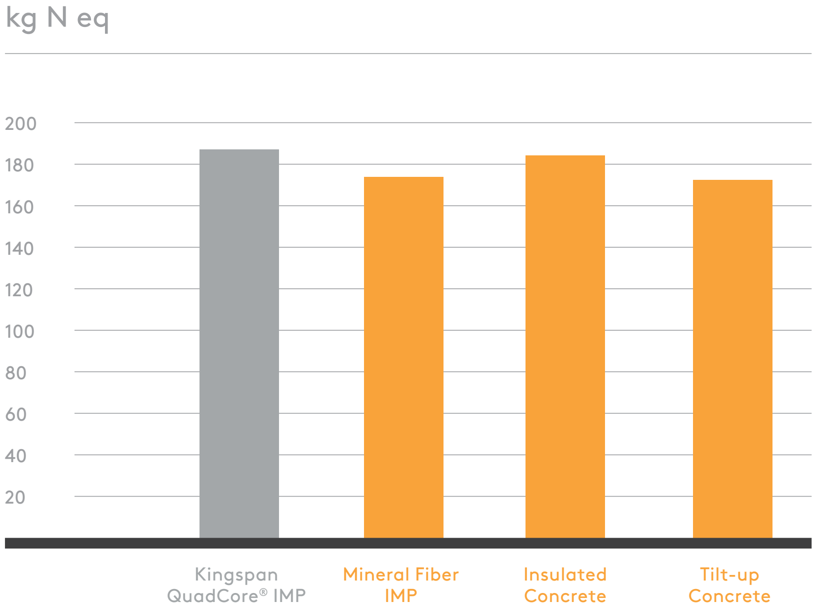


Figure 14. Eutrophication comparison.

Ozone Depletion Potential

With only a 0.08 kg CFC-11 equivalent (CFC-11 eq) difference between the highest impact wall and the lowest impact wall, these impacts are relatively insignificant across all options.

The difference in impact of the mineral fiber IMP is a result of the fluoropolymer coating used in that option. Negative values for insulated concrete this category result from the recycling credits at the end of life associated with the rebar in the concrete, which offset the impacts that would have come with the avoided primary material.

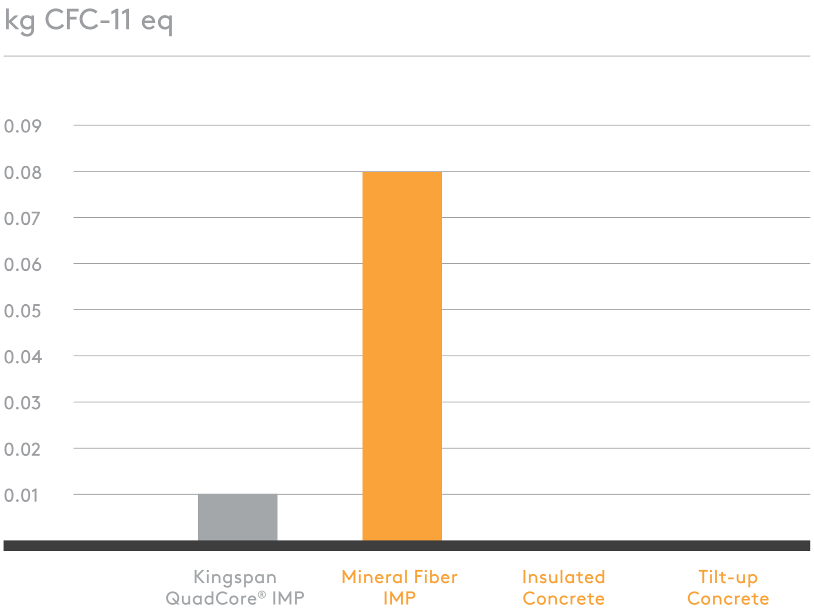


Figure 14. Ozone depletion comparison.

Non-renewable Energy Demand

In assessing non-renewable energy demand, the mineral fiber IMP wall had the highest impact, with the Kingspan QuadCore® IMP wall using 13% less non-renewable energy.

The primary driver of impact for the mineral fiber IMP option is the fluoropolymer coating and the power sources used for manufacturing. The insulated concrete option uses the fewest fossil fuels.

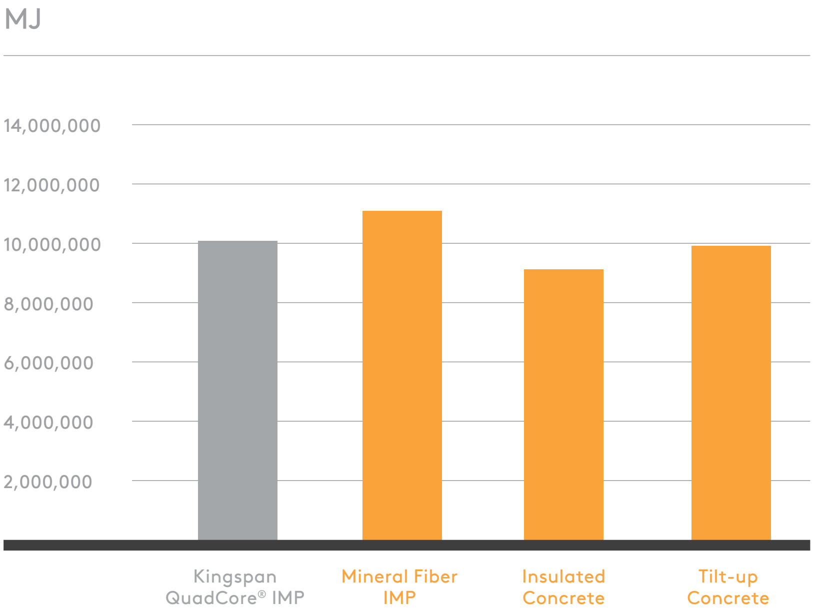


Figure 16. Non-renewable energy demand comparison.

Conclusion

Due to the locked-in nature of embodied carbon, the effort to reduce the carbon footprint of a building, as it relates to building materials, must be considered in the design and procurement phase of a project.

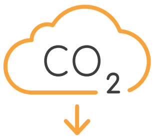
This research conducted by KieranTimberlake highlights the importance of thoughtful material selection at the outset.

The results demonstrate that when it comes to material selection for wall envelopes, using Kingspan QuadCore® IMPs for industrial type buildings can reduce the embodied carbon impact of the building compared to conventional systems such as insulated concrete, tilt-up concrete and mineral fiber IMPs. For the building design and boundaries of this study, the LCA analysis revealed that the Kingspan QuadCore® IMPs reduced embodied carbon of the wall envelope by 28% compared to both insulated concrete and tilt-up concrete wall systems.

Future opportunities exist to reduce the embodied carbon in Kingspan QuadCore® IMPs even further through a substantial change in the fuel source mix for manufacturing. The Kingspan QuadCore® product EPD (2019) used in this research describes the current manufacturing fuel sources as natural gas, the Upstate New York electricity grid, and liquified petroleum gas. A substantial change in fuel sources to renewables for manufacturing could improve the Kingspan QuadCore® panel performance in all environmental impact categories, as a direct correlation exists between non-renewable energy demand and environmental impacts, especially global warming, acidification, and smog formation.

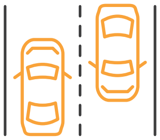
These improvement measures are currently underway as part of Kingspan's Planet Passionate program and will be formally reflected in an updated EPD for Kingspan QuadCore® in the near future.

The 28% savings in embodied carbon by using Kingspan QuadCore® IMPs compared to the concrete wall systems is equivalent to the CO_2 emissions from burning 149 tons of coal, or the Greenhouse gas emissions from driving the average car 671,270 miles (27 times around the Earth).[4]



28%
lower embodied carbon

149
tons of coal



671,720
miles driven

To reduce the embodied carbon of building envelopes, Kingspan QuadCore® IMPs should be considered the product of choice compared to conventional wall systems such as concrete or mineral fiber IMPs.

Projects

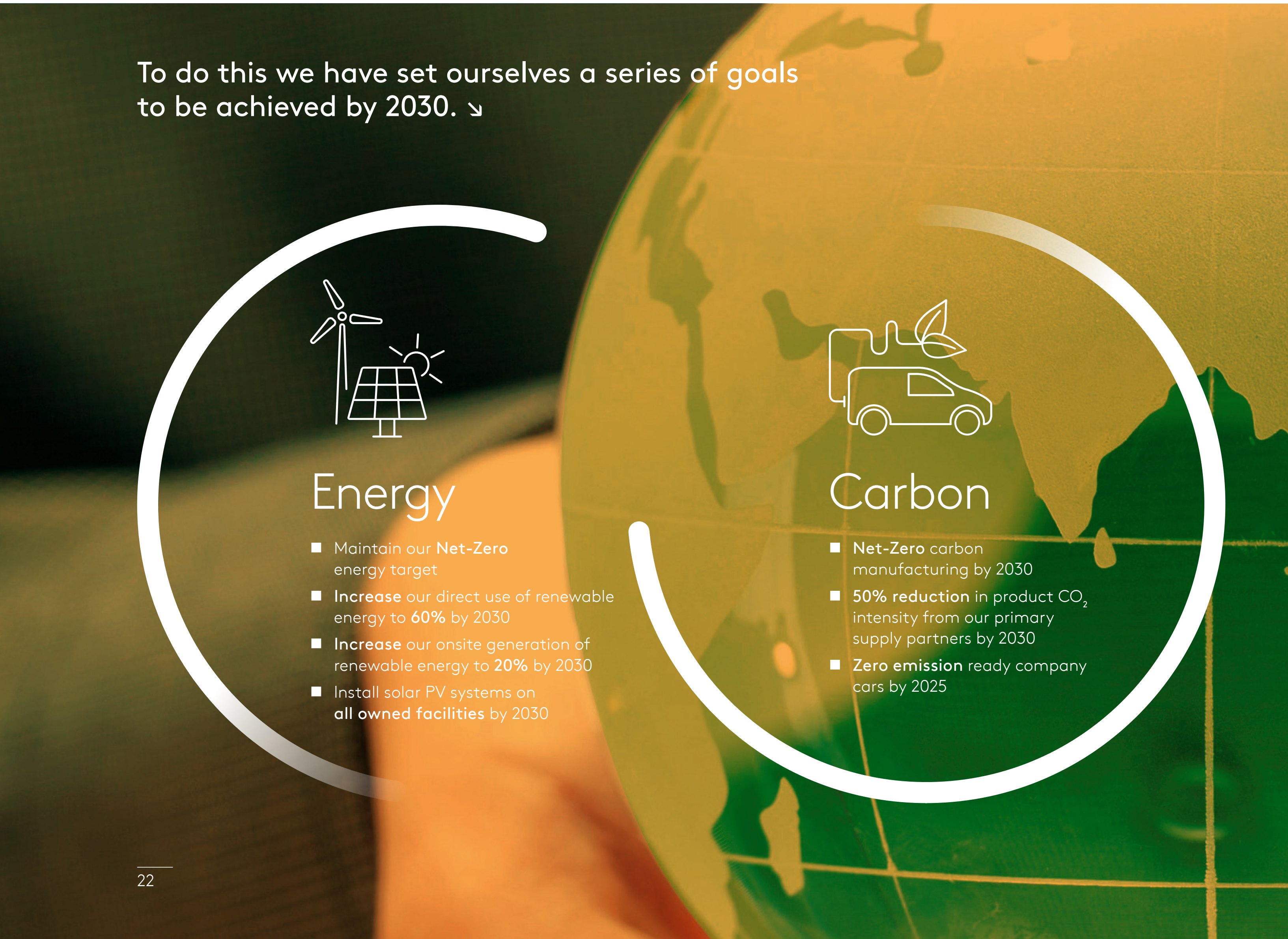
Lower embodied carbon

Independent sustainability certification

Building rating system credits

Our 2030 Global Commitments

At Kingspan, we want to play our part. We believe advanced materials, building systems and digital technologies hold the key to addressing these issues. With our Planet Passionate global sustainability program, we are confident that together we can move to a clean energy future, manage the earth's resources more sustainably and protect our natural environment.



To do this we have set ourselves a series of goals to be achieved by 2030. ↘

Energy

- Maintain our **Net-Zero** energy target
- **Increase** our direct use of renewable energy to **60%** by 2030
- **Increase** our onsite generation of renewable energy to **20%** by 2030
- Install solar PV systems on **all owned facilities** by 2030

Carbon

- **Net-Zero** carbon manufacturing by 2030
- **50% reduction** in product CO_2 intensity from our primary supply partners by 2030
- **Zero emission** ready company cars by 2025

Planet Passionate Program to Further Drive Down Embodied Carbon

Planet Passionate is Kingspan's ambitious 10-year global sustainability program that aims to impact three big global issues – climate change, circularity, and protection of our natural world.

In addressing these issues, Kingspan has set targets in the areas of energy, carbon, circularity, and water, which are also aimed at making significant advances in the sustainability of both our business operations and our products.

Some of the targets that will specifically the impact embodied carbon of our products include:

- Increasing the use of direct renewable energy to 60% by 2030
- Increasing our on-site renewable energy generation to 20% by 2030
- Reducing the product CO_2 intensity from our primary supply partners by 50% by 2030
- All QuadCore® to use upcycled PET by 2025

PLANET PASSIONATE

Through Planet Passionate, we are playing our part by driving energy and carbon out of our business operations and supply chain, as well as increasing our recycling of rainwater and waste, while also accelerating our participation in the circular economy.

For more details on the program and the full list of targets, please visit **www.kingspan.com/planetpassionate**.

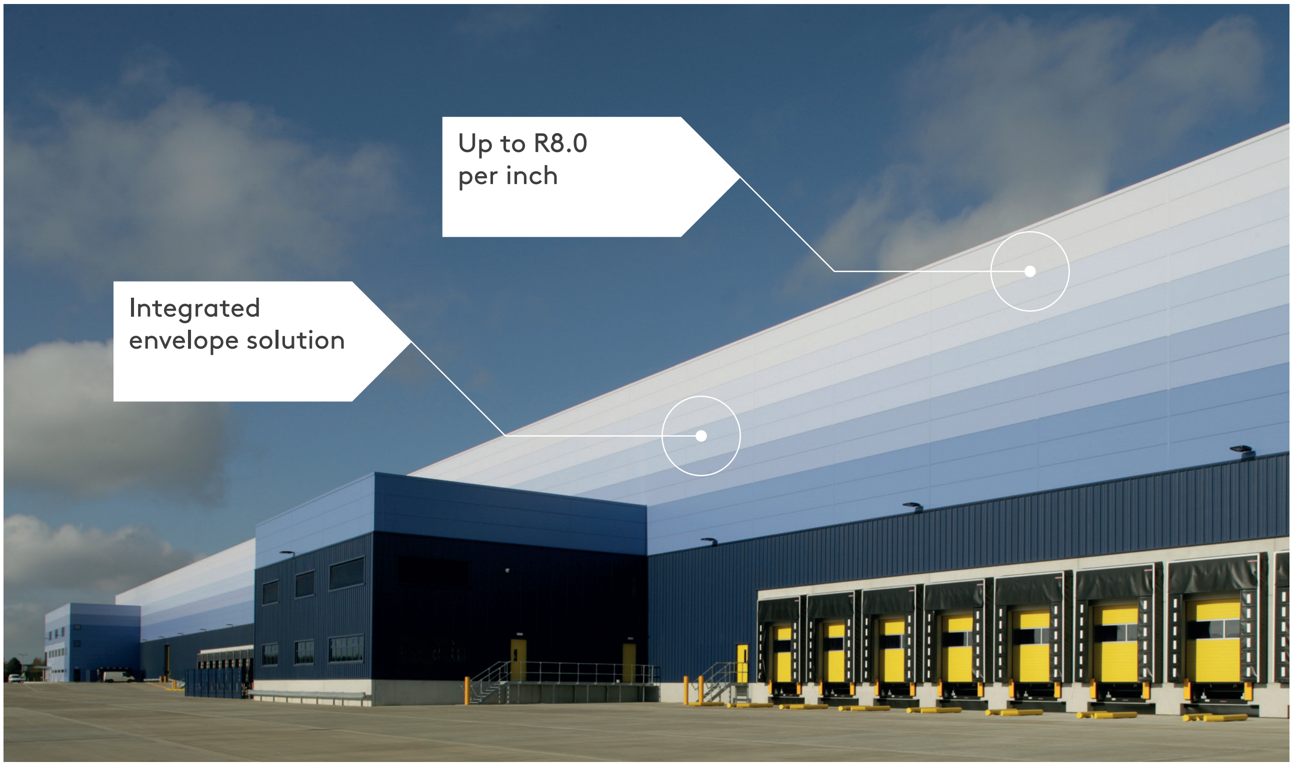
Circularity

- **1 billion** PET bottles upcycled into our manufacturing processes by 2025
- **All QuadCore®** insulation to utilise upcycled PET by 2025
- **Zero company waste** to landfill by 2030

Water

- **5 active** ocean clean-up projects by 2025
- **100 million** liters of rainwater harvested by 2030

Projects



Up to R8.0 per inch

Integrated envelope solution

FIRE*safe*™

Space saving

Appendix

Environmental Impact Categories

A characterization scheme translates all emissions and fuel use associated with the reference flow into quantities of categorized environmental impact.

As the degree that the emissions will result in environmental harm depends on regional ecosystem conditions and the location in which they occur, the results are reported as impact potential. Potential impacts are reported in kilograms of equivalent relative contribution (eq) of an emission commonly associated with that form of environmental impact (e.g. kg CO_2eq).

The following list provides a description of environmental impact categories reported according to the TRACI 2.1 characterization scheme, the environmental impact model developed by the US EPA to quantify environmental impact risk associated with emissions to the environment in the United States. TRACI is the standard environmental impact reporting format for LCA in North America.

Impacts associated with land use change and fresh water depletion are not included in TRACI 2.1. For more information on TRACI 2.1, reference Bare 2010[10], Bare 2012, and Guinée 2001[11].

Global Warming Potential (kg CO_2eq)

A measure of greenhouse gas emissions, such as carbon dioxide and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, increasing the natural greenhouse effect. This may, in turn, have adverse impacts on ecosystem health, human health, and material welfare.

Smog Formation Potential (SFP) (kg O_3eq)

A measure of ground level ozone, caused by various chemical reactions between nitrogen oxides (NOx) and volatile organic compounds (VOCs) in sunlight. Human health effects can result in a variety of respiratory issues, including increasing symptoms of bronchitis, asthma, and emphysema. Permanent lung damage may result from prolonged exposure to ozone. Ecological impacts include damage to various ecosystems and crop damage.

Acidification Potential (kg SO_2eq)

A measure of emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule's capacity to increase the hydrogen ion (H+) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline, and the deterioration of building materials.

Eutrophication Potential (kg Neq)

A measure of the impacts of excessively high levels of macronutrients, the most important of which are nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In aquatic ecosystems, increased biomass production may lead to depressed oxygen levels caused by the additional consumption of oxygen in biomass decomposition.

Ozone Depletion Potential (kg CFC-11eq)

A measure of air emissions that contribute to the depletion of the stratospheric ozone layer. Depletion of the ozone leads to higher levels of UVB ultraviolet rays reaching the earth's surface with detrimental effects on humans and plants. As these impacts tend to be very small, ODP impacts can be difficult to calculate and are prone to a larger margin of error than the other impact categories.

Non-Renewable Energy Demand (MJ)

A measure of the energy extracted from non-renewable resources (e.g. petroleum, natural gas, etc.) contributing to the Primary Energy Demand. Non-renewable resources are those that cannot be regenerated within a human time scale. Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account when calculating this result.

Contribution Assessment by Material

Kingspan QuadCore® IMP

Table 2. Data visually reformatted from Tally results export.

	Acidification (kg SO$_2$ eq)	Eutrophication (kg N eq)	Global Warming (kg CO$_2$ eq)	Ozone Depletion (CFC-11 eq)
03 – Concrete				
Admixture	0.36	0.04	210.52	0.00000
Coarse aggregate	23.26	1.34	4,257.56	0.00000
Expanded slag	2.53	0.12	344.84	0.00000
Fly ash	4.86	0.40	2,036.31	0.00000
Portland cement	194.30	15.14	86,463.15	0.00000
Sand	28.75	1.64	9,360.66	0.00000
Steel reinforcing rod (rebar)	70.44	2.08	13,830.57	(0.00005)
Water	3.64	0.20	777.52	0.00000
05 – Metals				
Cold formed structural steel	1,548.63	73.94	240,682.82	0.00916
Hot rolled structural steel	220.70	5.13	43,715.72	(0.00002)
Steel plate	126.90	5.96	25,184.68	0.00061
07 – Thermal and Moisture Protection				
Stainless steel fasteners	230.60	38.10	11,294.12	0.00166
Kingspan QuadCore® insulated metal panel	707.73	43.47	247,777.85	0.00018
TOTAL	**3,162.70**	**187.55**	**685,936.32**	**0.01154**

Smog Formation (kg O_3 eq)	Primary Energy Demand (MJ)	Non-Renewable Energy Demand (MJ)	Renewable Energy Demand (MJ)	Mass (kg)
6.43	4,951.87	4,873.45	77.17	64.12
550.06	70,766.25	66,374.22	4,460.86	161,953.90
55.45	5,540.97	5,284.36	260.42	12,588.26
97.97	22,444.75	22,162.13	310.59	8,767.27
4,176.20	613,456.56	560,047.15	53,191.85	83,281.48
711.93	155,541.44	150,984.22	4,524.02	138,914.24
837.97	194,922.55	183,510.77	11,705.97	9,810.77
77.51	12,875.09	12,179.08	709.10	36,864.97
22,039.33	4,045,084.09	3,707,005.22	345,265.50	224,013.61
1,259.60	553,323.72	539,615.21	12,469.48	39,944.49
1,808.19	358,856.98	339,168.90	19,897.17	16,943.23
420.99	224,881.46	179,416.42	46,014.38	4,985.19
13,137.88	4,458,331.02	4,247,553.48	210,784.75	65,164.38
45,179.50	**10,720,976.74**	**10,018,174.60**	**709,671.23**	**803,295.91**

Contribution Assessment by Material

Mineral Fiber IMP

Table 3. Data visually reformatted from Tally results export.

	Acidification (kg SO_2 eq)	Eutrophication (kg N eq)	Global Warming (kg CO_2 eq)	Ozone Depletion (CFC-11 eq)
03 – Concrete				
Admixture	0.36	0.04	210.52	0.00000
Coarse aggregate	23.26	1.33	4,257.56	0.00000
Expanded slag	2.53	0.12	344.85	0.00000
Fly ash	4.85	0.40	2,036.31	0.00000
Portland cement	194.30	15.15	86,463.15	0.00000
Sand	28.75	1.64	9,360.65	0.00000
Steel reinforcing rod (rebar)	70.44	2.08	13,830.57	(0.00005)
Water	3.64	0.20	777.52	0.00000
05 – Metals				
Cold formed structural steel	1,556.45	74.32	241,897.68	0.00920
Hot rolled structural steel	220.70	5.12	43,715.72	(0.00002)
Steel plate	220.70	5.13	43,715.72	-
07 – Thermal and Moisture Protection				
Adhesive, polyurethane	3.93	0.69	1,805.61	-
Fluoropolymer coating, metal stock	590.97	25.38	133,431.86	0.06900
Mineral wool, high density, NAIMA - EPD	1,104.26	20.07	156,509.61	0.00412
Steel sheet	186.38	14.17	27,350.44	0.00200
Zinc coating (galvanized) for steel G90	156.57	8.17	38,877.02	-
TOTAL	**4,368.09**	**174.00**	**804,584.78**	**0.08400**

Smog Formation (kg O_3 eq)	Primary Energy Demand (MJ)	Non-Renewable Energy Demand (MJ)	Renewable Energy Demand (MJ)	Mass (kg)
6.43	4,951.87	4,873.45	77.17	64.12
550.05	70,766.24	66,374.21	4,460.86	161,953.90
55.45	5,540.97	5,284.35	260.41	12,588.27
97.97	22,444.75	22,162.12	310.59	8,767.27
4,176.21	613,456.56	560,047.15	53,191.85	83,281.48
711.93	155,541.44	150,984.22	4,524.02	138,914.24
837.97	194,922.55	183,510.77	11,705.97	9,810.77
77.51	12,875.09	12,179.08	709.10	36,864.97
22,150.57	4,065,501.86	3,725,716.51	347,008.25	225,144.33
1,259.60	553,323.72	539,615.20	12,469.48	39,944.50
1,259.60	553,323.72	539,615.21	12,469.48	39,944.49
89.81	34,849.21	33,271.83	1,529.43	802.76
8,952.24	2,865,186.52	2,725,867.10	136,399.04	7,313.74
5,527.70	1,952,172.40	1,868,364.54	89,042.51	87,556.23
4,542.48	547,440.71	482,888.49	66,500.52	18,570.81
2,527.77	636,425.23	548,935.60	85,932.95	3,118.26
52,823.28	**12,288,722.84**	**11,469,689.83**	**826,591.62**	**874,640.13**

Contribution Assessment by Material

Insulated Concrete

Table 4. Data visually reformatted from Tally results export.

	Acidification (kg SO_2 eq)	Eutrophication (kg N eq)	Global Warming (kg CO_2 eq)	Ozone Depletion (CFC-11 eq)
03 – Concrete				
Admixture	0.30	0.03	175.85	0.00000
Coarse aggregate	9.86	0.57	1,804.76	0.00000
Expanded slag	1.07	0.05	146.27	0.00000
Fly ash	2.06	0.17	863.46	0.00000
Portland cement	82.42	6.43	36,679.07	0.00000
Sand	12.18	0.70	3,965.94	0.00000
Steel reinforcing rod (rebar)	844.86	24.94	165,879.25	(0.00057)
Precast structural concrete, 4001-5000 psi	1,788.06	140.69	686,641.79	0.00000
Water	1.55	0.08	330.23	0.00000
05 – Metals				
Hot rolled structural steel	11.82	0.27	2,341.53	(0.00000)
Steel joist	0.77	0.03	156.46	0.00000
Steel plate	7.08	0.34	1,158.50	0.00004
07 – Thermal and Moisture Protection				
Expanded polystyrene (EPS), board	99.81	9.42	49,294.38	0.00000
TOTAL	**2,861.84**	**183.71**	**949,437.51**	**(0.00053)**

Smog Formation (kg O_3 eq)	Primary Energy Demand (MJ)	Non-Renewable Energy Demand (MJ)	Renewable Energy Demand (MJ)	Mass (kg)
5.37	4,136.28	4,070.78	64.46	53.56
233.17	29,997.42	28,135.66	1,890.93	68,651.36
23.52	2,350.31	2,241.46	110.46	5,339.55
41.54	9,517.32	9,397.47	131.70	3,717.61
1,771.62	260,238.23	237,581.09	22,564.85	35,329.36
301.63	65,900.15	63,969.33	1,916.75	58,855.50
10,050.33	2,337,836.63	2,200,967.47	140,397.56	117,667.18
40,291.83	5,881,552.51	5,439,101.46	443,465.26	2,780,158.18
32.92	5,468.32	5,172.71	301.17	15,657.33
67.47	29,637.45	28,903.19	667.90	2,139.53
6.61	2,185.74	2,080.46	112.23	128.52
100.85	18,733.07	17,254.12	1,491.58	1,049.69
2,522.32	1,403,429.73	1,389,208.08	14,031.18	14,606.07
55,449.16	**10,050,983.15**	**9,428,083.27**	**627,146.01**	**3,103,353.42**

Contribution Assessment by Material

Tilt-up Concrete

Table 5. Data visually reformatted from Tally results export.

	Acidification (kg SO_2 eq)	Eutrophication (kg N eq)	Global Warming (kg CO_2 eq)	Ozone Depletion (CFC-11 eq)
03 – Concrete				
Admixture	0.22	0.02	131.84	0.00000
Coarse aggregate	196.51	11.27	35,965.08	0.00000
Expanded slag	15.31	0.73	2,089.88	0.00000
Fly ash	29.42	2.45	12,342.63	0.00000
Portland cement	1,176.01	91.67	523,337.17	0.00000
Sand	242.95	13.86	79,104.63	0.00000
Steel reinforcing rod (rebar)	903.18	26.66	177,330.36	(0.00061)
Water	26.56	1.44	5,676.00	0.00000
05 – Metals				
Cold formed structural steel	239.79	11.45	37,266.57	0.00142
Hot rolled structural steel	11.82	0.27	2,341.53	(0.00000)
Steel plate	9.49	0.45	1,553.76	0.00005
07 – Thermal and Moisture Protection				
Fiberglass blanket insulation	82.22	4.34	15,896.31	0.00102
09 - Finishes				
Acrylic latex paint	87.94	4.63	23,496.03	0.00000
Gypsum wallboard	62.63	3.95	39,926.38	0.00000
TOTAL	**3,084.05**	**173.21**	**956,458.17**	**0.00188**

Smog Formation (kg O_3 eq)	Primary Energy Demand (MJ)	Non-Renewable Energy Demand (MJ)	Renewable Energy Demand (MJ)	Mass (kg)
4.02	3,101.20	3,052.09	48.33	40.15
4,646.50	597,787.31	560,686.31	37,682.41	1,368,081.49
336.05	33,580.00	32,024.85	1,578.19	76,288.89
593.81	136,043.60	134,330.50	1,882.55	53,140.74
25,277.41	3,713,080.28	3,389,808.10	321,955.33	504,079.42
6,016.35	1,314,443.39	1,275,931.42	38,231.38	1,173,930.91
10,744.13	2,499,223.98	2,352,906.35	150,089.59	125,790.07
565.85	93,989.97	88,909.00	5,176.51	269,119.47
3,412.50	626,328.04	573,980.97	53,459.82	34,685.56
67.47	29,637.45	28,903.19	667.90	2,139.53
135.25	25,124.35	23,140.82	2,000.47	1,407.82
986.52	297,165.53	268,550.86	28,701.14	8,055.33
1,694.55	558,947.94	505,423.85	53,531.78	9,290.44
1,461.76	651,215.07	626,744.60	24,837.58	134,255.43
55,942.16	**10,579,668.12**	**9,864,392.90**	**719,842.98**	**3,760,305.24**

Contribution Assessment by Material

Shared Components

Table 6. Data visually reformatted from Tally results export.

	Acidification (kg SO_2 eq)	Eutrophication (kg N eq)	Global Warming (kg CO_2 eq)	Ozone Depletion (CFC-11 eq)
03 – Concrete				
Admixture	14.70	1.50	8,726.00	0.00000
Coarse aggregate	439.10	25.20	80,368.00	0.00000
Expanded slag	35.20	1.70	4,807.00	0.00000
Fly ash	67.70	5.60	28,389.00	0.00000
Portland cement	2,705.30	210.90	1,203,899.00	0.00000
Sand	542.90	31.00	176,760.00	0.00000
Steel reinforcing rod (rebar)	776.60	22.90	152,485.00	(0.00053)
Water	60.10	3.30	12,837.00	0.00000
05 – Metals				
Coated steel deck	1,824.20	84.95	262,042.00	0.01140
Cold formed structural steel	123.90	5.92	19,255.00	0.00073
Hot rolled structural steel	13.60	0.32	2,703.00	(0.00000)
Powder coating	0.30	0.03	234.00	0.00000
Steel joist	4,766.90	155.06	963,188.00	0.00488
Steel plate	7.40	0.35	1,216.00	0.00004
Zinc coating, G60	1.50	0.07	397.00	(0.00000)
07 - Thermal and Moisture Protection				
Fiberglass mat gypsum sheathing board	402.20	37.10	93,150.00	0.00357
PIR rigid foam insulation	415.10	35.30	108,057.00	0.00422
Polychloroprene (neoprene) adhesive	13.20	1.10	7,233.00	0.00000
TPO membrane	377.50	36.20	139,250.00	0.00000
08 - Openings and Glazing				
Anodized aluminum extrusion	6.30	0.31	1,222.00	0.00000
Door frame, galvanized steel	0.10	0.01	18.00	0.00000
Fasteners, glavanized steel	0.02	0.00	5.00	(0.00000)
Glazing, double IGU (air fill)	26.80	1.16	3,446.00	0.00000
Hardware, aluminum	0.30	0.01	67.00	0.00000
Steel door, galvanized	13.40	0.60	2,473.00	0.00006
Steel door hinge	2.10	1.92	391.00	0.00004
TOTAL	**12,636.00**	**663.00**	**3,272,618.00**	**0.02440**

Smog Formation (kg O_3 eq)	Primary Energy Demand (MJ)	Non-Renewable Energy Demand (MJ)	Renewable Energy Demand (MJ)	Mass (kg)
266.30	205,243.00	201,993.00	3,198.40	2,657.00
10,383.10	1,335,818.00	1,252,912.00	84,205.30	3,057,121.00
772.90	77,238.00	73,661.00	3,630.00	175,474.00
1,365.80	312,910.00	308,969.00	4,330.00	122,227.00
58,148.80	8,541,670.00	7,798,006.00	740,634.70	1,159,598.00
13,443.60	2,937,139.00	2,851,083.00	85,428.50	2,623,162.00
9,238.80	2,149,060.00	2,023,243.00	129,060.70	108,166.00
1,279.70	212,565.00	201,074.00	11,707.00	608,632.00
27,232.30	4,355,441.00	3,979,875.00	366,879.00	212,281.00
1,763.20	323,620.00	296,573.00	27,622.00	17,922.00
77.90	34,212.00	33,365.00	771.00	2,470.00
4.80	4,277.00	3,907.00	362.00	22.00
40,709.10	13,455,795.00	12,807,672.00	690,911.00	791,177.00
105.90	19,663.00	18,111.00	1,566.00	1,102.00
21.70	6,582.00	5,754.00	816.00	31.00
5,292.00	1,703,463.00	1,480,469.00	224,969.00	183,948.00
5,021.00	2,280,344.00	2,226,957.00	50,012.00	42,581.00
5,766.00	216,007.00	208,308.00	7,809.00	2,722.00
6,060.00	3,637,025.00	3,513,808.00	121,953.00	43,200.00
79.80	19,304.00	17,685.00	1,763.00	288.00
1.90	279.00	260.00	19.00	10.00
0.20	66.00	61.00	5.00	1.00
340.70	49,704.00	47,382.00	2,480.00	2,401.00
2.60	1,093.00	901.00	192.00	27.00
208.50	36,657.00	35,044.00	1,633.00	1,137.00
16.10	6,018.00	5,401.00	647.00	50.00
187,603.00	**41,921,193.00**	**39,392,474.00**	**2,562,604.00**	**9,158,407.00**

LCI Data Sources

Table 7.

Data sources used in the the LCA modeling.

Material	LCI Source
Aluminum extrusion, anodized	Aluminum Extruders Council EPD
Coarse aggregate	EU-2B: Gravel 2/32 ts (2017)
Cold-formed structural steel	RNA: Steel finished cold-rolled coil worldsteel (2007); GLO: Steel sheet stamping and bending (5% loss) ts (2017); US: Electricity grid mix ts (2014); US: Lubricants at refinery ts (2014); GLO: Compressed air 7 bar (medium power consumption) ts (2014); GLO: Value of scrap worldsteel (2014)
Galvanized metal doorframe	DE: Aluminium wing frame profile, powder coated (2011); modified with US: Metal roll forming MCA (2010); GLO: Steel sheet stamping and bending (5% loss) ts (2012); RNA: Steel hot dip galvanized worldsteel (2007)
Expanded polystyrene (EPS)	US: EPS-Foam (expanded polystyrene foam (PS 12)) Incl. flame retardant (estimation) ts (2017)
Expanded slag	DE: Slag-tap granulate (EN 15804 A1-A3) ts (2017)
Fasteners, galvanized steel	GLO: Steel wire rod worldsteel (2014); GLO: Steel turning ts (2017); GLO: Electrolytic galvanization ts (2017); GLO: Value of scrap worldsteel (2014)
Fasteners, stainless steel	RER: Stainless steel Quarto plate (304) Eurofer (2010); GLO: Steel turning ts (2017); US: Electricity grid mix ts (2014); RER: Stainless steel flat product (304) – value of scrap Eurofer (2010)
Fiberglass blanket insulation	US: Fiberglass Batt NAIMA (2007)
Fly ash	DE: Fly ash (EN 15804 A1-A3) ts (2017)
Glazing, double insulated	DE: Double glazing unit ts (2017), modified to exclude coating and argon
Hardware, aluminum	RNA: Secondary aluminium ingot AA/ts (2010); DE: Aluminium cast machining ts (2017); DE: Aluminium die-cast part ts (2017); RNA: Primary Aluminium Ingot AA/ts (2010); US: Electricity grid mix ts (2014); US: Thermal energy from natural gas ts (2014)
Hollow steel door, galvanized	DE: Expanded Polystyrene (PS 25) (EN15804 A1-A3) ts (2017); GLO: Steel sheet stamping and bending (5% loss) ts (2017); GLO: Value of scrap worldsteel (2014); US: Electricity grid mix ts (2014); US: Lubricants at refinery ts (2014); GLO: Compressed air 7 bar (medium power consumption) ts (2014); RNA: Steel hot dip galvanized worldsteel (2007)
Hot-rolled structural steel	American Institute of Steel Construction EPD
Insulated metal panel, Kingspan QuadCore®	Kingspan QuadCore® EPD
Mineral wool, high-density	North America Insulation Manufacturers Association EPD
Paint, interior acrylic latex	DE: Application paint emulsion (building, interior, white, wear-resistant) ts (2017)
Portland cement	Portland Cement Association EPD
Powder coating, metal stock	DE: Application top coat powder (aluminium) ts (2017); DE: Coating powder (industry, outside, red) ts (2017)

Sand	US: Silica sand (Excavation and processing) ts (2017)
Material	LCI Source
Steel door hinge	DE: Door hinge – Object hinge - FV S+B PE-EPD (2009); GLO: Value of scrap worldsteel (2014)
Steel joist	Steel Joist Institute EPD
Steel, reinforcing rod	GLO: Steel rebar worldsteel (2014)
Steel, sheet	RNA: Steel finished cold rolled coil worldsteel (2007); GLO: Steel sheet stamping and bending (5% loss) ts (2017); US: Electricity grid mix ts (2014); US: Lubricants at refinery ts (2014); GLO: Compressed air 7 bar (medium power consumption) ts (2014); GLO: Value of scrap worldsteel (2014)
Structural concrete, 4001-5000 psi	US: Portland cement PCA/ts (2014); DE: Pumice gravel (grain size 4/16) (EN 15804 A1-A3) ts (2017); DE: Gravel (Grain size 2/32) (EN 15804 A1-A3) ts (2017); DE: Fly ash (EN 15804 A1-A3) ts (2017); DE: Slag-tap granulate (EN 15804 A1-A3) ts (2017); DE: Expanded clay (EN 15804 A1-A3) ts (2017); DE: Calcium nitrate ts (2017); DE: Sodium ligninsulfonate ts (2017); DE: Sodium naphtalene sulfonate [estimated] ts (2017); US: Sodium hydroxide (caustic soda) mix (100%) ts (2017); US: Colophony (rosin, refined) from CN pine gum rosin ts (2017); US: Tap water from groundwater ts (2017); US: Electricity grid mix ts (2014); US: Natural gas mix ts (2014); US: Diesel mix at filling station (100% fossil) ts (2014); US: Liquefied Petroleum Gas (LPG) (70% propane 30% butane) ts (2014); US: Light fuel oil at refinery ts (2014)
Wallboard, gypsum, natural	DE: Gypsum wallboard (EN 15804 A1-A3) ts (2017)
Water	US: Tap water from groundwater ts (2017)
Zinc coating (galvanized) for steel, G60	GLO: Unit load galvanisation (1 m^2 steel sheet part, electrolytic) ts (2017); GLO: Zinc mix ts (2017)
Zinc coating (galvanized) for steel, G90	GLO: Unit load galvanisation (1 m^2 steel sheet part, electrolytic) ts (2017); GLO: Zinc mix ts (2017)
Polyisocyanurate (PIR) Rigid Foam Insulation	RNA: Polyisocyanurate rigid foam board roof insulation, R=10.2 (A1-A3) ts-EPD (2013)
Polyurethane adhesive	US: Limestone flour (5mm) ts (2017) DE: Polyurethane (copolymer-component) (estimation from TPU adhesive) ts (2017) US: Lime (CaO) calcination ts (2017) US: Methylene diisocyanate (MDI) ts (2017) DE: Stearic acid ts (2017) US: Electricity grid mix ts (2014)
Fluoropolymer coating	US: Coil coating MCA (2010) US: Electricity grid mix ts (2014) US: Thermal energy from natural gas ts (2014)

LCA Tool Assumptions

Tally Tool Assumptions

Tally methodology is consistent with LCA standards ISO 14040-14044, ISO 21930:2017, ISO 21931:2010, EN 15804:2012, and EN 15978:2011.

Tally utilizes a custom designed LCA database that combines material attributes, assembly details, and architectural specifications with environmental impact data resulting from the collaboration between KieranTimberlake and thinkstep. LCA modeling was conducted in GaBi 8.5 using GaBi 2018 databases and in accordance with GaBi databases and modeling principles.

The data used are intended to represent the US and the year 2017. Where representative data were unavailable, proxy data were used. The datasets used, their geographic region, and year of reference are listed for each entry. An effort was made to choose proxy datasets that are technologically consistent with the relevant entry.

Uncertainty in results can stem from both the data used and their application. Data quality is judged by: its measured, calculated, or estimated precision; its completeness, such as unreported emissions; its consistency, or degree of uniformity of the methodology applied on a study serving as a data source; and geographical, temporal, and technological representativeness. The GaBi LCI databases have been used in LCA models worldwide in both industrial and scientific applications. These LCI databases have additionally been used both as internal and critically reviewed and published studies. Uncertainty introduced by the use of proxy data is reduced by using technologically, geographically, and/or temporally similar data. It is the responsibility of the modeler to appropriately apply the predefined material entries to the building under study.

Scenarios Used for Transportation, EOL, Module D, and Replacement Rates

Default transportation values are based on the three-digit material commodity code in the 2012 Commodity Flow Survey by the US Department of Transportation Bureau of Transportation Statistics and the US Department of Commerce where more specific industry-level transportation is not available. All transportation is assumed to be by diesel truck, except where otherwise specified.

Replacement rates for materials are assumed to follow predicted service life from Product Category Rules and published EPDs. When materials are included in a larger single assembly, the service life for the assembly is presumed to correspond to the outermost non-coating layer. Coatings are assumed to have a separate replacement rate from the rest of the assembly.

At end of life, all products are modeled using the avoided burden approach. Specific end-of-life scenarios are detailed for each entry based on the US construction and demolition waste treatment methods and rates in the 2016 WARM Model by the US Environmental Protection Agency except where otherwise specified. Heterogeneous assemblies are modeled using the appropriate methodologies for the component materials. Concrete products are assumed to have a 55% recycling rate into aggregate or general fill material. Remaining concrete is landfilled. Module D accounts for both the credit associated with offsetting the production aggregate and the burden of the grinding energy required for processing. Metal products assume a recycling rate at end of life to determine how much secondary metal can be recovered after subtracting any scrap input into manufacturing to calculate net scrap credits in Module D. The corresponding share of the primary burden is allocated to the subsequent product system using secondary material as an input. All other products are assumed to be sent to landfill, including glass, drywall, insulation, and plastics. Where the landfill contains biodegradable material, the energy recovered from landfill gas utilization is reflected as a credit in Module D.

Environmental Categorization and Data Substitutions

Environmental impacts are calculated according to the TRACI 2.1 characterization scheme for Global Warming Potential, Acidification Potential, Eutrophication Potential, Smog Formation Potential, Ozone Depletion Potential, and Non-Renewable Energy Demand. TRACI is the standard environmental impact reporting format for LCA in North America. Impacts associated with land use change and fresh water depletion are not included in TRACI 2.1. For more information on TRACI 2.1, reference Bare 2010, EPA 2012, and Guinée 2001. Utilization of recycled or reclaimed material is reflected as a credit in Module D.

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