10 Year Carbon Impact Analysis

Tempe Micro Estates

Project Summary

Tempe Micro Estates is an innovative community featuring thirteen 600 square foot homes in the heart of Tempe. The Estates are conveniently located near bike routes, light rail and the future Tempe Streetcar, as well as employment, shopping, healthcare, and entertainment. The Estates are designed as an 'intentional neighborhood' where residents share the desire to have more of a sense of community with their neighbors. Each home is small and private, but the sense of community around them is big. Together, residents share the gardening areas and orchard trees, enjoy the common house and outdoor spaces as areas for neighbors to gather and visit. Cars are left at the edge of the community, with the courtyard kept exclusively for people. These elements all improve quality of life while reducing carbon impact.

The project balances the affordability with sustainability, taking a number of steps to balance both. Homeowners share a 900-square foot community room near the front of the property providing a place to gather, do laundry, share meals, relax, and interact with neighbors and friends. Each home faces out on a central courtyard, which features Sonoran Desert-friendly landscape design, emphasizing shade, native and edible plants, and space for each resident to manage their own on-site kitchen garden, allowing residents to supplement their diet with fresh, local, and healthy foods. All homes are part of a Community Land Trust, providing resident-owned homes on community-owned land, in order to permanently preserve affordability.

Carbon Impact Analysis

The thirteen 600 square-foot homes already significantly reduce their carbon impact over typical single-family home options simply by being small.

This report is an analysis of the 10-year net carbon impact of the building materials related to performance measures (insulation and air sealing). We focus on these materials because they have the largest carbon impact that is easy to change during design or construction. Also, many well intentioned projects will add R-value in an attempt to reduce carbon emissions while actually building in more carbon damage due to the high embodied carbon of materials like foam insulation.

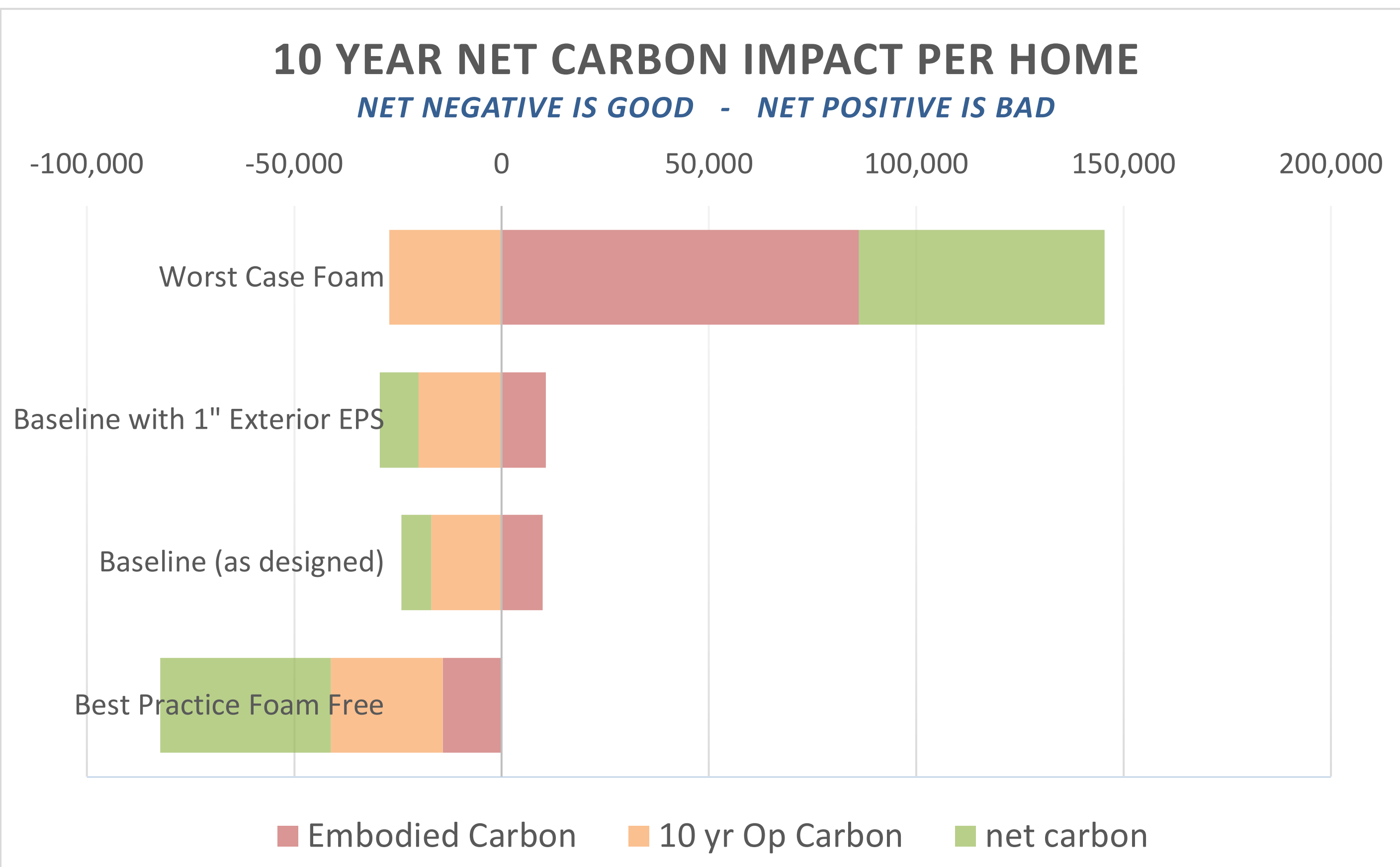
The impact for this project is calculated by taking the upfront "embodied carbon" of performance measures and subtracting 10 years of operational carbon savings when compared to a reference design. It is important to note that energy modeling can sometimes have a challenge conforming to a given climate with certain materials. Lightweight foam in a climate with large daily temperature swings is one extreme example of this issue, explained by thermal diffusivity. When only lightweight materials are present we may make adjustments to the energy modeling, depending on the methodology used, to match expected real world performance.

We are pleased to report that this project is on track for doing good on the carbon front. Read on to learn more.

Analysis Summary

- Roof: 439 square-fee (sf) of R-44 with R-37 fiberglass batts and R-7 spray foam
- Walls: 1,529 sf of R-19 with fiberglass batts in 2x6 stud bays at 16 inches-on-center
    - Potential for 1-inch continuous expanded polystyrene (EPS) exterior insulation behind the stucco finish
    - A key question to address is: how would 1-inch continuous EPS exterior insulation affect energy consumption and the upfront embodied carbon?
- Floor: the "baseline" scenario, or the as-designed scenario, has 433 sf of uninsulated slab
    - The "high performance" scenario uses R-20 slab perimeter insulation
- The all-electric homes will consume:
    - 5,400 kWh/year for the baseline scenario
    - 5,100 kWh/year for the baseline with the exterior EPS continuous insulation
    - 4,200 kWh/year for higher performance homes using either high-carbon foam ("worst practice foam") or a low-carbon system such as the Pro Clima Intello Plus Membrane System ("best practice foam free").
- Connected to APS Utility, which has roughly 0.81 lbsCO^2/kWh on average (see Appendix 3 for calculation)
- There will also be 5 kW of on-site solar dedicated to offsetting the energy consumed by common area loads such as exterior lighting.

Performance Measures 10 Year Net Carbon Impact Analysis



Recommendations

There are significant net carbon savings to be generated from the insulation and airtightness performance measures included in the Baseline Scenario. In addition, adding 1-inch exterior EPS behind the stucco finish will result in slightly higher net carbon savings despite the incremental upfront embodied carbon impact of EPS foam. This would not be the case if using extruded polystyrene (XPS) exterior insulation since it has roughly ten times the embodied carbon of EPS.

Using spray foam and XPS to increase energy efficiency is the worst-case embodied carbon scenario. This has an extremely high net carbon impact over ten years (see Appendix 4 for details on embodied carbon of insulation materials). This is also the scenario with highest health, comfort, and moisture failure risks.

It is worth noting that there are minor health, comfort, and durability risks from the Baseline Scenario. For example, the use of vapor closed insulation and reservoir cladding materials typically increases moisture accumulation, which can often lead to mold/rot. In addition, there are some toxicity with fiberglass and major toxicity concerns with spray foam insulation. Comfort also may not be ideal due to higher radiant temperatures of interior finishes from thermal bridging and convective airflow within the insulated spaces. However, the Baseline Scenario is significantly lower failure risk than the Worst Practice Foam Scenario.

The Best Practice Foam-Free Scenario creates the deepest levels of net carbon savings while maximizing health, comfort, and efficiency along with minimizing moisture failure risks. It could be worth exploring this option, but costs are likely prohibitive.

Due to budget constraints, the only upgrade we recommend is adding the Pro Clima Intello Plus membrane system in the roof and wall systems in addition to the current baseline scenario assumptions. This will dramatically reduce the risk of rot and mold failures while increasing the thermal performance, which translates to deeper efficiency and occupant comfort levels. These improvements are mainly accomplished by eliminating airflow between the conditioned space and the insulation cavities. If the budget doesn't allow using the Intello Plus system to cover all insulation, it is most critical to install Intello Plus in the roof assembly. *Note: there are other products besides Intello to achieve an interior airtightness layer, however, this is our favorite product due to being Red List Free, LBC Declare Label, Passive House certified, best-in-class for moisture management, and proven in tens of thousands of real-world applications. In addition, the Intello Plus Membrane System would provide Pro Clima's ten-year labor and materials warranty, which is effectively the best insurance policy for moisture failures.*

Please see following pages for Appendices

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Appendix 1. Embodied Carbon Details (please zoom to 200% to see details)

EMBODIED CARBON ANALYSIS FOR TEMPE MICRO ESTATES

	Effective R-value	Thickness (ft)	Coverage Area (sf)	Cubic Feet	EC per Cubic Foot (lbs)	Embodied Carbon (EC) (lbs)
High Performance with High Risk Unhealthy Materials						
ROOF - R-44 Spray foam (9" thickness) - *no interior air barrier*	22.00	0.75	439	329.25	98.44	32,410.55
WALLS - R-5 XPS exterior insulation below stucco (1" thickness)	5.00	0.08	1,529	127.42	23.07	2,940.01
WALLS - R-19 Spray foam (4" thickness) - *no interior air barrier*	9.50	0.33	1,529	509.67	98.44	50,170.31
FLOOR - R-10 XPS perimeter insulation (2" thickness)	10.00	0.17	180	30.00	23.07	692.22
					Total Upfront (lbsCO2)	**86,213.09**
					Carbon Payback (years)	**31.93**

	Effective R-value	Thickness (ft)	Coverage Area (sf)	Cubic Feet	EC per Cubic Foot (lbs)	Embodied Carbon (EC) (lbs)
New Construction with Less Bad Materials and Mid-Level Performance (WITH EPS EXTERIOR)						
ROOF - R-37 Fiberglass batts (10" thickness) - *no interior air barrier*	22.00	0.83	439	365.83	2.48	906.42
ROOF - R-7 Spray Foam Insulation (2" thickness for unvented code) - *no interior air barrier*	5.00	0.17	439	73.17	98.44	7,202.34
WALLS - R-4 EPS exterior insulation below stucco (1" thickness) - *no exterior air barrier*	4.00	0.08	1,529	127.42	5.36	682.59
WALLS - R-19 Fiberglass batts (5.5" thickness) - *no interior air barrier*	9.50	0.46	1,529	700.79	2.48	1,736.34
FLOOR - R-8 EPS perimeter insulation (2" thickness)	8.00	0.17	180	30.00	5.36	160.71
					Total Upfront (lbsCO2)	**10,688.40**
					Carbon Payback (years)	**5.34**

	Effective R-value	Thickness (ft)	Coverage Area (sf)	Cubic Feet	EC per Cubic Foot (lbs)	Embodied Carbon (EC) (lbs)
New Construction with Less Bad Materials and Mid-Level Performance (NO EXTERIOR INSULATION)						
ROOF - Fiberglass batts to R-37 (12" thickness) - *no interior air barrier*	22.00	0.83	439	365.83	2.48	906.42
ROOF - R-7 Spray Foam Insulation (2" thickness for unvented code) - *no interior air barrier*	5.00	0.17	439	73.17	98.44	7,202.34
WALLS - no exterior insulation	0.00	0.00	1,529	0.00	0.00	0.00
WALLS - Fiberglaass batts to R-19 (5.5" thickness) - *no interior air barrier*	9.50	0.46	1,529	700.79	2.48	1,736.34
FLOOR - no perimeter insulation	0.00	0.00	180	0.00	0.00	0.00
					Total Upfront (lbsCO2)	**9,845.10**
					Carbon Payback (years)	**5.79**

High Performance with Best Practice Healthy Durable Carbon Negative Materials						
ROOF (*interior*) - Gutex Thermofiber to R-38 (10" thickness) - *covered by Intello Plus*	38.00	0.83	439	365.83	-8.92	-3,263.13
ROOF (*exterior*) - Gutex Multitherm 80 (3/18" thickness) - *covered by Solitex Mento 1000*	12.00	0.26	439	114.32	-5.85	-668.26
WALLS - Gutex Multitherm 40 (1 9/16" thickness) - *covered by Solitex Mento 1000*	5.80	0.46	1,529	700.79	-5.85	-4,096.41
WALLS - Gutex Thermofiber to R-19 - *covered by Intello Plus*	19.00	0.46	1,529	700.79	-8.92	-6,250.87
FLOOR - Glavel foam glass as insulation and drainage (6" thickness)	10.8	0.17	180	30.00	5.00	150.00
					Total Upfront (lbsCO2)	**-14,128.67**
					Carbon Payback (years)	**-5.23**

Appendix 2. 10 Year Carbon Impact Analysis Details (please zoom to 200% to see details)

WORST PRACTICE FOAM - PER HOME ANALYSIS

Using spray foam and XPS to achieve "high performance", each 670 unit is expected to consume 4,200 kWh/yr
APS has roughly 0.81 lbsCOS/kWh, so each baseline unit will have ~3,400lbs CO2/yr of operational carbon impact
The HERS Reference Home would consume ~7,500 kWh/yr, which is ~6,100 lbsCO2/yr of operational carbon impact
So, the worst practice foam micro estate would create 2,700 lbsCO2/yr operational carbon savings*
Over a ten year period the total "performance measures carbon savings" would be roughly (10 x 2,700 lbsCO2/yr) minus 86,213 lbsCO2 upfront = -59,213 lbsCO2 which still leaves ~22 years to payback upfront carbon

WORST PRACTICE FOAM - COMMUNITY SCALE ANALYSIS

There is 5.0 kW of on-site solar, which should provide roughly 8,760 kWh per year and therefore save ~7,000 lbsCO2/yr
With 13 "high performance" micro estate homes we'd expect about 13 x 4,200 kWh = 54,600 kWh total energy consumption per year
Subtracting the solar generation, we'd expect a net consumption of 47,600 kWh/yr which results in an operational carbon impact of 38,556 lbsCO2/yr
We'd expect operational carbon savings of (13 x 7,500 kWh/yr x 0.81 lbsCO2/kWh) = 78,975 lbsCO2/yr minus 38,556 lbsCO2/yr = **40,419 lbsCO2/yr saved***

However, despite signifcant operational carbon savings, the net carbon impact of the performance measures over 10 years would be *~717,000 lbsCO2 emitted**

Formula: (86,213 lbsCO2 upfront x 13) - (10 x 40,419 lbsCO2/yr) = 1,120,769 lbsCO2 upfront - 404,190 lbsCO2 saved over 10 years = ~717,000 lbsCO2

**compared to the HERS Reference Home*

BASELINE WITH 1" EXTERIOR EPS - PER HOME ANALYSIS

For baseline with 1" Exterior EPS, each 670 unit is expected to consume ~5,100 kWh/yr
APS has roughly 0.81 lbsCOS/kWh, so each baseline unit will have ~4,100 lbsCO2/yr of operational carbon impact
The HERS Reference Home would consume ~7,500 kWh/yr, which is ~6,100 lbsCO2/yr of operational carbon impact
So, the baseline micro estate would create ~2,000 lbsCO2/yr operational carbon savings*
Over a ten year period the total "performance measures carbon savings" would be roughly (10 x 2,000 lbsCO2/yr) minus 10,700 lbsCO2 upfront = 9,300 lbsCO2 saved*

BASELINE WITH 1" EXTERIOR EPS - COMMUNITY SCALE ANALYSIS

There is 5.0 kW of on-site solar, which should provide roughly 8,760 kWh per year and therefore save ~7,000 lbsCO2/yr
With 13 basline with 1" exterior EPS micro estate homes we'd expect about 13 x 5,100 kWh = 66,300 kWh total energy consumption per year
Subtracting the solar generation, we'd expect a net consumption of 57,540 kWh/yr which results in a net carbon impact of ~46,600 lbsCO2/yr
We'd expect operational carbon savings of (13 x 7,500 kWh/yr x 0.81 lbsCO2/kWh) = 78,975 lbsCO2/yr minus 46,600 lbsCO2/yr = **~32,400 lbsCO2/yr saved***

The net carbon impact of the performance measures over 10 years would be *~185,000 lbsCO2 saved**

Formula: (10,700 lbsCO2 upfront x 13) - (10 x 32,400 lbsCO2/yr) = 139,100 lbsCO2 upfront - 324,000 lbsCO2 saved over 10 years = -185,000 lbsCO2

**compared to the HERS Reference Home*

BASELINE - PER HOME ANALYSIS

As designed (baseline), each 670 unit is expected to consume ~5,400 kWh/yr
APS has roughly 0.81 lbsCOS/kWh, so each baseline unit will have ~4,400 lbsCO2/yr of operational carbon impact
The HERS Reference Home would consume ~7,500 kWh/yr, which is ~6,100 lbsCO2/yr of operational carbon impact
So, the baseline micro estate would create ~1,700 lbsCO2/yr operational carbon savings*
Over a ten year period the total "performance measures carbon savings" would be roughly (10 x 1,700lbsCO2/yr) minus 9,845 lbsCO2 upfront = 7,155 lbsCO2 saved*

BASELINE - COMMUNITY SCALE ANALYSIS

There is 5.0 kW of on-site solar, which should provide roughly 8,760 kWh per year and therefore save ~7,000 lbsCO2/yr
With 13 baseline micro estate homes we'd expect about 13 x 5,400 kWh = 70,200 kWh total energy consumption per year
Subtracting the solar generation, we'd expect a net consumption of 63,200 kWh/yr which results in a net carbon impact of ~51,000 lbsCO2/yr
We'd expect operational carbon savings of (13 x 7,500 kWh/yr x 0.81 lbsCO2/kWh) = 78,975 lbsCO2/yr minus 51,000 lbsCO2/yr = **~28,000 lbsCO2/yr saved***

The net carbon impact of the performance measures over 10 years would be *~152,000 lbsCO2 saved**

Formula: (9,845 lbsCO2 upfront x 13) - (10 x 28,000 lbsCO2/yr) = 128,000 lbsCO2 upfront - 280,000 lbsCO2 saved over 10 years = -152,000 lbsCO2

**compared to the HERS Reference Home*

BEST PRACTICE LOW CARBON - PER HOME ANALYSIS

Using woodfiber insulation and Red List Free airtigtness to achieve "high performance", each 670 unit is expected to consume 4,200 kWh/yr
APS has roughly 0.81 lbsCOS/kWh, so each baseline unit will have ~3,400lbs CO2/yr of operational carbon impact
The HERS Reference Home would consume ~7,500 kWh/yr, which is ~6,100 lbsCO2/yr of operational carbon impact
So, the best practice foam micro estate would create 2,700 lbsCO2/yr operational carbon savings*
Over a ten year period the total "performance measures carbon savings" would be roughly (10 x 2,700 lbsCO2/yr) minus -14,128 lbsCO2 upfront = 41,128 lbsCO2 saved*

BEST PRACTICE LOW CARBON - COMMUNITY SCALE ANALYSIS

There is 5.0 kW of on-site solar, which should provide roughly 8,760 kWh per year and therefore save ~7,000 lbsCO2/yr
With 13 "high performance" micro estate homes we'd expect about 13 x 4,200 kWh = 54,600 kWh total energy consumption per year
Subtracting the solar generation, we'd expect a net consumption of 47,600 kWh/yr which results in an operational carbon impact of 38,556 lbsCO2/yr
We'd expect operational carbon savings of (13 x 7,500 kWh/yr x 0.81 lbsCO2/kWh) = 78,975 lbsCO2/yr minus 38,556 lbsCO2/yr = **40,419 lbsCO2/yr saved***

The net carbon impact of the performance measures over 10 years would be *~588,000 lbsCO2 saved**

Formula: (-14,128 lbsCO2 upfront x 13) - (10 x 40,419 lbsCO2/yr) = -184,000 lbsCO2 upfront - 404,190 lbsCO2 saved over 10 years = 588,000 lbsCO2 saved

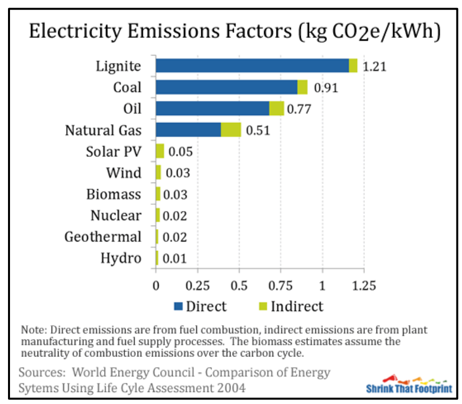
**compared to the HERS Reference Home*

Appendix 3. APS Power Mix

- APS announced plans to fully decarbonize their grid by 2050 and be 65% "clean" with 45% renewables by 2030
- However, there is a report showing they expect the below energy mix by 2021:
    - 13% renewable energy
    - 15% demand side management (counted as renewables in our analysis)
    - 22% nuclear
    - 32% natural gas
    - 18% coal (includes the 3% purchased power)
- APS Energy Mix Report
    - In case the hyperlink doesn't work, this is the URL: https://www.aps.com/-/media/APS/APSCOM-PDFs/About/Our-Company/Doing-business-with-us/Resource-Planning-and-Management/2017IntegratedResourcePlan.ashx

Regional Carbon Impact by Grid Mix

Fuel Source Carbon Intensity*	***lbsCO²/kWh***
Coal	2.21
Oil	1.76
Natural Gas	1.13
Nuclear	0.15
Renewables (less than)	0.06



This chart is simply to show another source of information about this subject, but the numbers above are global averages, which are lower than the US averages.

	lbsCO²/kWh	***Renewables***	***Coal***	***Nat. Gas***	***Nuclear***	***TOTAL***
Seattle (SCL) 2017	**0.12**	94%	1%	4%	1%	100%
Portland (PGE) 2017	**0.90**	34%	15%	48%	3%	100%
NorCal (PG&E) 2017	**0.34**	51%	2%	20%	27%	100%
SoCal (SCE) 2017	**0.61**	50%	10%	30%	10%	100%
Tucson (TEP) 2017	**1.78**	8%	70%	20%	2%	100%
Phoenix (APS) 2021	**0.81**	28%	18%	32%	22%	100%
Saskatoon L&P 2017	**1.40**	20%	45%	35%	0%	100%
BC Hydro 2017	**0.17**	90%	0%	10%	0%	100%

**data derived from Energy Information Administration research and summarized in this chart. Please see this website if you'd like to dig into the info.*

Appendix 4. Embodied Carbon Data

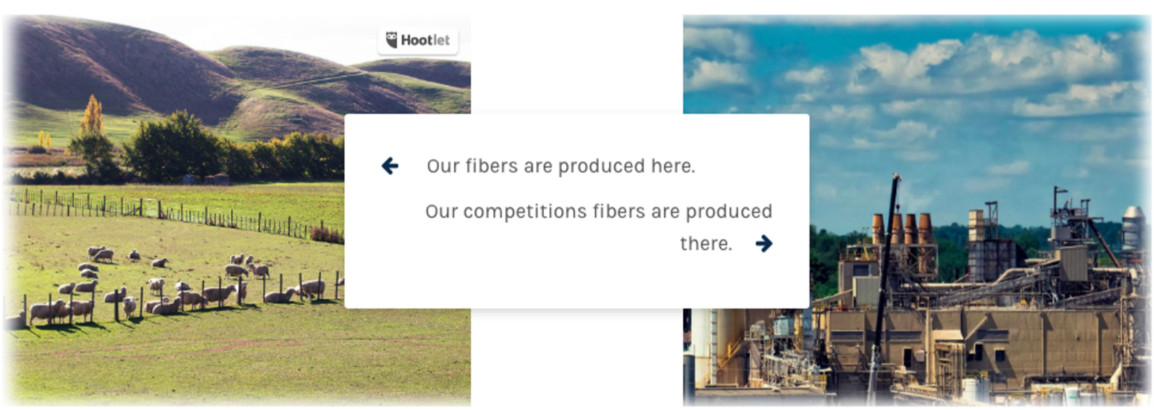
EMBODIED CARBON FOR INSULATION MATERIALS*	
lbs CO^2 per cubic foot	
Gutex Thermofiber	**-8.9**
Gutex Multitherm	**-5.8**
Dense-pack cellullose	**-5.0**
Havelock Wool	**-2.9**
Fiberglass	**2.5**
Mineral Wool	**2.7**
EPS Foam Board	**5.4**
XPS Foam Board	**23.1**
Closed Cell Spray Foam	**98.4**

**Based upon 3rd party Environmental Product Declarations (EPDs) reported by Architecture 2030 through their Carbon Smart Materials Palette: https://materialspalette.org/insulation/*

Many people ask how some insulation options can be carbon storing.

Simply put, upfront embodied carbon is a measurement of the net carbon impact of the discovery, harvesting, processing, and manufacturing stages of producing a product. For woodfiber, cork, and wool insulation the trees and sheep sequester carbon into their wood or wool as the trees and sheep grow. Then after subtracting all the carbon impact to manufacture the final product, there is still a net carbon savings in the material itself. This is in opposition to the lifecycle of fiberglass, mineral wool, and foam insulations that do not store carbon before the process begins and then consume a massive amount of energy to create the chemicals, process the fossil fuels, and superheat the materials to become fibers.

The image below, provided by Havelock Wool, is the best visual summary to date.



Appendix 5. Comfort, Health, and Durability Considerations

As we all seek to build higher performing buildings the risk of many failures, such as mold and rot, increase. The easiest way to visualize this is inefficient walls are essentially ovens with large amounts of heat moving through to bake them dry. On the other extreme of performance, Passive Houses have very little heat moving through the assemblies so the potential to let in and trap moisture is exponentially higher. This adds a new level of responsibility to designers and builders to get the details correct. High performance is a new frontier of construction.

Often the only metric used to measure a given insulation material is R-value per inch. While R-value is important, it is only a single piece of the equation, even for efficiency. At a minimum, we need to also consider the thermal capacity of an insulation material and how that will alter its performance in a given climate. In some climates this is a negligible difference, in others it could be a factor of 2-3x for rated R-value versus real world performance. The interaction between resistance (R-value) and thermal capacity can be understood on a basic level through thermal diffusivity. In hot mixed climate zones, this is a critical element to understand for maximizing comfort, efficiency, and carbon savings.

Another important factor is the vapor permeability of a material. This calculates the rate at which moisture will move through a material, given the vapor drive exists to do so. In addition to the rate, materials vary in how much water they will hold and, if their properties will change when saturated. OSB is an example of a material with low permeability, high holding ability but low tolerance for moisture content. Thus OSB has gained it nicknames like "vertical mulch." This isn't to say that you should never use OSB but simply that it can present additional risks. A basic primer on the subject can be found here. It is also critical to understand that airtightness and vapor permeability are completely different things; it is possible to be completely airtight yet vapor permeable.

Airtightness is an often-overlooked, and even more often, poorly modeled aspect of real world performance. Partially this is because most energy modeling software isn't yet powerful enough to calculate the differences. This is also partially because going from "really bad" to "sort of ok" is easy yet getting to "truly good" takes more attention to detail. The industry as a whole hasn't yet embraced the mentality needed to deliver best practice airtightness. The basics to understand are that huge amounts of moisture can get into a wall through quite small air leaks and the smaller the leak the more moisture is left behind. If that wall is highly insulated then there also might not be enough heat moving through to dry out the wall or roof assembly. While not totally accurate the basic points in this video at around 5min are well described.

For further information about any of the above subject, please feel free to contact:

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Austin Trautman

MACRO-GEEK

Austin founded vali homes, llc development company and sustainability consultancy to provide Phoenix with affordable in-fill housing focused on contemporary design with high energy efficiency. Austin wants to live in a world where people flock to increasingly dynamic, comfortable and fulfilling urban centers. As general instigator, he has been lauded by a wide variety of luminaries including Phoenix NPR affiliate, KJZZ; *Inhabitat*; *Residential Architect; Arizona Horizon; American Institute of Architects; Builder Magazine,* and the front page of the *Arizona Republic*.

Austin believes the best solutions are a mix of relentless scientific discovery and improvement guided by what the natural world has already figured out. He draws on widely varied experiences combined with specific knowledge to ensure his next collaboration is his best yet.

Lucas Johnson

BUILDING WHISPERER

Lucas is a building scientist who has worked as a builder, utility program manager, enclosure systems designer, and clean tech venture capital consultant to deliver Zero Net Energy, Passive House, and Living Future projects. His goal is to optimize what he calls "The Five Factors of Good Building": health, comfort, durability, efficiency, and lifecycle carbon impact. Lucas holds a degree in Physicochemical Biology as well as a Master of Environmental Science and a Master of Eco-Entrepreneurship. He is deeply knowledgeable about enclosure systems, moisture dynamics, materials health, net carbon impact analysis, and high-performance best practices.

Lucas has helped deliver thousands of projects including some of the world's greenest, lowest carbon, and most airtight buildings. He feels lucky to work every day to make health, comfort, durability, efficiency and carbon saving accessible to everyone. He loves to share his experience by collaborating with architects, engineers, builders, developers, and homeowners to make their projects more cost-effective, carbon-effective, and enjoyable.