03 February 2021

Tracking the Greenhouse Gas Impacts of Your Energy Efficiency Measures:

New Tools & Lessons Learned for Designers and Contractors

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Efficiency Vermont

Overview

EVT R&D program background / context / intro to 3 projects (Daniel)

Project 1: Insulation and new construction (Brian)

Project 2: Insulation and weatherization (Megan, Jacob)

Project 3: Life cycle impacts of heat pumps to offset fossil fuels (Daniel)

Discussion

R&D Allows EVT to:

- Create space for innovation that would not otherwise achieve investment
- Drive evolution of Efficiency Vermont's services to better help ratepayers
- Focus staff and resources to strategic areas that need investment

Efficiency Vermont

Project 1: Embodied Carbon in Residential New Construction

Brian Just

Efficiency Vermont

Project aims

1. Quantify GWP (in terms of CO_2e) for insulation materials
2. Use that to identify high-priority substitutions
3. Figure out how to motivate changes to current practice on residential new construction projects
4. Get feedback from contractors on the logistics / ease of material substitutions
5. Explore benefits beyond carbon, such as potential health impacts on installers and residents

Global Warming Potential (GWP)

R-20 is not the same as R-20

The carbon impacts of R-20 of cellulose

are **much different** than R-20 of XPS

which is **much different** than R-20 of EPS, spray foam, mineral wool, fiberglass, etc.

We measure this difference using GWP,

A **number which is precisely measured/calculated by standardized rules**

and accounts for the impacts of all the raw materials that go into the **creation and use** of insulation (or other materials)

It's measured in kg CO_2e

Life cycle stages

Module	A1-A3			A4-A5		B1-B7							C1-C4				D
Life cycle stages	Product stage			Construction process stage		Use stage							End-of-life stage				Benefits and loads beyond the system boundary stage
Processes	Raw material supply	Transport	Manufacturing	Transport	Construction - installation proces	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction / demolition	Transport	Waste processing	Disposal	Reuse, recovery, and recycling potential
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D

Cradle to gate

Cradle to site

Cradle to grave

Assemblies investigated

- Sub-slab
- Foundation / frost wall, interior
- Foundation / frost wall, exterior
- Above grade wall, cavity
- Above grade wall, continuous
- Joists
- Flat attic
- Sloped ceiling, cavity
- Sloped ceiling, continuous

…which led to specific investigation of:

- Cellular glass, aggregate
- Cellulose, blown / loosefill and densepack
- Expanded polystyrene (EPS); Types I, II, IX, and VIII
- Fiberglass; batt, blown/loosefill, blown/spray, and board
- HempCrete, block
- Mineral wool; batt, blown, and board
- Phenolic foam, board
- Polyisocyanurate, board
- Spray polyurethane foam (SPF); 2K-LP, closed cell, open cell, roofing; hydrofluorocarbon (HFC), hydrofluoroolefin (HFO), water-blown
- Straw, panel
- Wood fiber, batt and board
- Extruded polystyrene (XPS); 15, 25, 40, 60, and 100 psi

Environmental Product Declarations (EPDs)

Details on Life Cycle Assessment (LCA)

Valid for 5 years

Generally, 10-20 pages of information

Quantify impacts on

- **Global warming potential**
- Ozone depletion potential
- Water use
- And much more…

Analyzed roughly 200, including 79 unique records

NSF

Certified Environmental Product Declaration

www.nsf.org

ENVIRONMENTAL PRODUCT DECLARATION

Owner of the Declaration	**BASF Corporation**
EPD Program Operator	NSF Certification LLC
PCR Program Operator	UL Environment
Declaration number	EPD10327
Issue date	February 14, 2020
Period of Validity	5 years

3.1 Declared Unit

The declared unit calculated in the LCA is in conformance with EN 15804 and the relevant sub-category PCR (Part B) for Building Envelope Thermal Insulation and is defined as 1 m^2 of installed Neopor® Plus (GPS) Type I insulation board with a thickness that gives an average thermal resistance (RSI) of 1 m^2*K/W (5.68 ft^2*hr.*F/BTU per inch) with a building service life of 75 years (packaging included). Relative to this declared unit, the mass of the described insulation board is 0.433 kg (0.98 lbs.).

Conversion factors are listed in the table below to convert the declared unit to 1 kg and 1 m^3 of material.

Name	Value	Unit
Declared Unit	0.98 (0.43)	lbs. (kgs.)
Declared Unit	1.21 (0.0307)	ins. (m)
Gross density	0.9	lbs./ft^3
Conversion factor to 1 m^3	32.6	-
Conversion factor to 1 kg	2.3	-

3.2 System boundary

Type of EPD: Cradle-to-gate (installation) - with options (end-of-life).

The modules considered in the Life Cycle Assessment are:

- A1: Raw materials supply
- A2: Transport to manufacturer
- A3: Manufacturing
- A4: Transport to construction site
- A5: Assembly
- C1: Demolition
- C2: Transport to waste treatment
- C3: Waste processing
- C4: Disposal
- D: Reuse, recovery or recycling potential

LCA data for 2 different materials

Results of the LCA – ENVIRONMENTAL IMPACT (TRACI)										
TRACI 2.1		Raw material supply	Transport	Manufacturing	Transport	Construction – Installation	Demolition	Transport	Disposal	Benefits and Loads beyond system boundary
Parameter	Unit	A1	A2	A3	A4	A5	C1	C2	C3/C4	D
GWP	[kg CO_2-eq.]	1.17E+00	1.11E-01	4.63E-01	7.97E-02	6.21E-03	0.00E+00	2.24E-02	1.94E-02	-6.66E-04

Cradle to gate

TRACI v2.1	A1-A3	A4	A5	B1	C2	C4	D
GWP 100 [kg CO_2 eq]	3.83E+00	1.62E-01	5.10E+00	1.04E+01	4.49E-03	6.96E+00	-2.33E-04
GWP 100, IPCC AR5 [kg	3.88E+00	1.62E-01	4.35E+00	8.63E+00	4.50E-03	5.81E+00	-2.33E-04

Cradle to gate

Assembly

Use

Average GWP, by material

Material	Form or variant	R-/"	GWP average, kgCO2e [A1+A2+A3] per 1m² RSI-1	GWP* average, kgCO2e [w/A5+B1] per 1m² RSI-1	GWP* includes
Cellular glass	Aggregate	1.49	3.93	3.93	A5
Cellulose	Blown/loosefill, 1.29 pcf	3.38	0.49	-0.83	A5, carbon
Cellulose	Densepack, 3.55 pcf	3.56	1.27	-2.16	A5, carbon
Expanded polystyrene (EPS)	Board, unfaced Type IX-25psi, graph.	4.70	3.47	3.49	A5
Fiberglass	Batt, unfaced, recycled content	3.64	0.67	0.68	A5
Fiberglass	Blown/loosefill	2.68	1.29	1.30	A5
Fiberglass	Blown/spray	4.00	1.61	1.64	A5
HempCrete	Block	2.14	-7.05	-5.67	A5, B1, carbon
Mineral wool	Batt, unfaced	4.24	3.11	3.25	A5 (1 EPD)
Mineral wool	Board, unfaced, "heavy" density	4.00	4.06	4.06	A5, B1
Phenolic foam	Board, glass tissue faced	7.21	1.54	1.54	Not given
Polyisocyanurate	Board, foil faced	6.53	2.32	2.32	Not given
Spray polyurethane foam	Spray, closed cell HFC	6.60	3.31	14.86	A5, B1
Spray polyurethane foam	Spray, closed cell HFO	6.60	3.47	4.00	A5, B1
Spray polyurethane foam	Spray, open cell	4.05	1.42	1.59	A5, B1
Straw	Panel	2.92	-10.95	-10.88	A5, B1, carbon
Wood fiber	Board, unfaced	3.47	-7.13	-7.13	Carbon
Extruded polystyrene (XPS)	Board, 25psi	5.00	20.17	46.51	A5, B1

…which was transformed into something useful

User Inputs [Ensure that each entry is correct -- or left blank if not needed]										GHG impacts [Do not modify calculations]				
Building assembly [leave unused ones blank]	Insulation - *Base* [status quo material] [use drop-down]	Installed (added) R-value	Cost [optional]	Insulation - *Alternative* [for comparison] [use drop-down]	Installed (added) R-value2	Cost/ Added [optional]	Total area incl. framing [sq ft]	Framing factor [Cont = 0.00] [2x 16oc = 0.23] [2x 24oc = 0.20]	Include in summary?	GWP - *Base* [kg CO2e]	GWP - *Alternative* [kg CO2e]	Apples to Apples?	Incr. cost	GWP savings [kg CO2e]
Foundation_Slab	XPS - Board, 25psi	15	$1,722	EPS - Board, unfaced, Type IX - 25psi, graphite	15	$1,376	1120	0.00	Yes	12781	958	Yes	($346)	11823
Foundation_Slab	XPS - Board, 25psi	15	$1,722	Cellular glass - Aggregate	15	$990	1120	0.00	No	12781	1080	Yes	($732)	11701
Foundation_Ext_Wall	XPS - Board, 25psi	15	$1,083	EPS - Board, unfaced, Type IX - 25psi, graphite	15	$865	704	0.00	Yes	8034	602	Yes	($218)	7431
AGW_Continuous	XPS - Board, 25psi	15	$1,673	Polyiso - Board, foil faced	16	$2,406	1088	0.00	Yes	12416	661	No	$733	11755
Totals	Baseline			Alternative					Totals [kg CO2e]	33230	2221	No	$169	31009
									% reduction					93%
									m.t. CO2e					31.0
									Equivalance to:					
									Miles driven by average passenger vehicle					76,934
									Propane cylinders (18#) burned					1,268
									Pounds of coal burned					34,172
									Tons of waste recycled instead of landfilled					11
									Tree seedlings grown for 10 years					512

Case study #1

1200 sq ft single-family affordable home in Bennington County

Assembly	Plan	Modification
Under slab, R-15	XPS	Cellular glass aggregate
Frost-protected foundation, R-15	XPS	EPS Type IX
Above-grade wall continuous, R-15	XPS	Phenolic foam

Impact ➔
30 metric tons of CO_2e

Case study #2

2600 sq ft quadplex in Chittenden County

Assembly	Plan	Modification
Under slab, R-15	XPS	EPS Type IX
Foundation wall, R-20	XPS	Polyisocyanurate

Impact ➔
52 metric tons of CO_2e

Case study #3

3700 sq ft single-family home in Chittenden County

Assembly	Plan	Modification
Above-grade wall continuous, R-24	XPS	Phenolic foam

Impact →
52 metric tons of CO_2e

Image: https://www.greenbuildingadvisor.com/article/kingspan-kooltherm-phenolic-foam-rigid-insulation

Other benefits from substitutions

Material	GHG impact[a]	Recycled content[b]	Toxic emissions[c]	Notes[d]
Wood fiber	Lowest / best			
Cellulose	Lowest / best			
Fiberglass	Low			Avoid formaldehyde bind
Polyisocyanurate	Low			Chlorinated flame retardant (otherw Toxic manufacturing pro
EPS (expanded polystyrene)	Low			Brominated flame retard
Open cell spray foam	Low			Off-gassing under investigatio Chlorinated flame retard Highly toxic when appli
Phenolic foam	Low		See note	Phenol formaldehyde content, but
Mineral wool	Medium		See note	Choose low-emitting products
Closed-cell spray foam, HFO	Medium			Off-gassing under investigation by EPA Chlorinated flame retardant Highly toxic when applied
Closed-cell spray foam, HFC	Highest / worst			Off-gassing under investigation by EPA Chlorinated flame retardant Highly toxic when applied
XPS (extruded polystyrene)	Highest / worst			Brominated flame retardant (otherwise fairly inert) Toxic manufacturing process

Sources: Efficiency Vermont analysis and *BuildingGreen Guide to Insulation.*

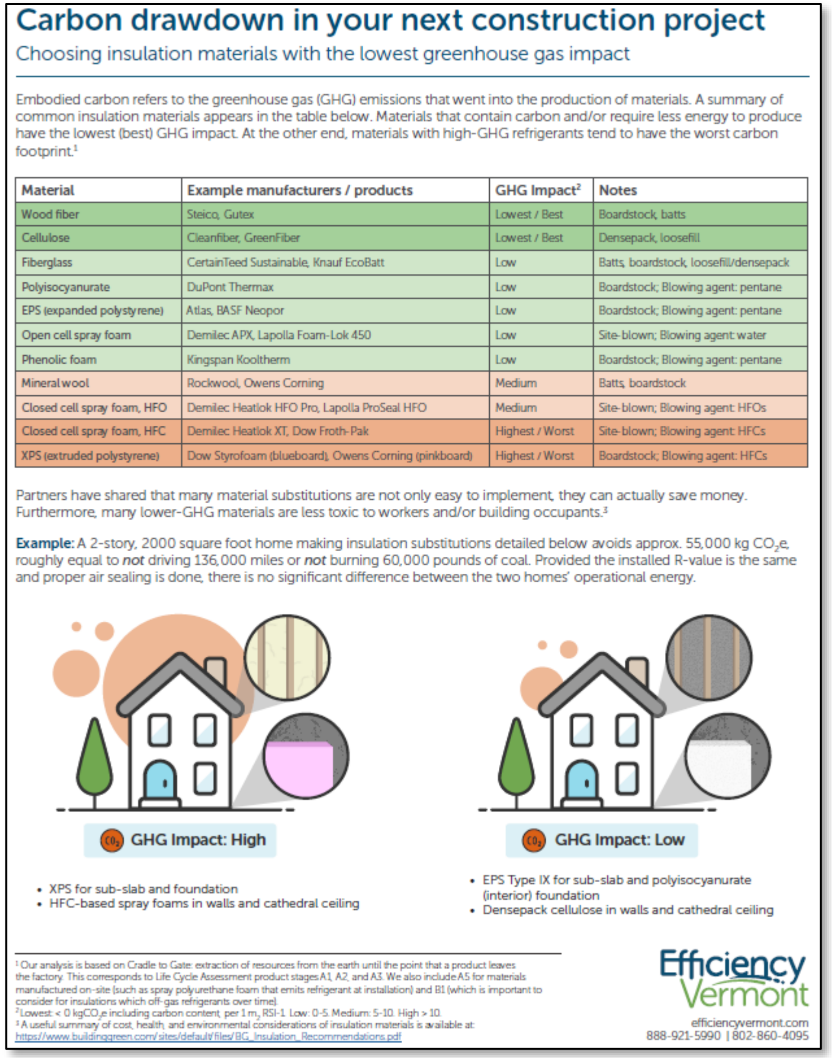
a Lowest: < 0 $kgCO_2e$ including carbon content, per 1 m^2 RSI-1. Low: 0-5. Medium: 5-10. High > 10. Calculations are based on analysis within this report.

b From *BuildingGreen Guide*. Green indicates significant recycled content or renewable material. Red indicates little or no recycled content and fossil fuel-based materials in typical products.

c From *BuildingGreen*. Green indicates relatively low toxic emissions during use from typical products. Red indicates potential high toxic emissions from typical products or during manufacturing or application.

d From *BuildingGreen*, "Environmental Notes" in *Key Environmental and Performance Factors for Insulation Materials* table.

Customer-facing reference



Carbon drawdown in your next construction project

Choosing insulation materials with the lowest greenhouse gas impact

Embodied carbon refers to the greenhouse gas (GHG) emissions that went into the production of materials. A summary of common insulation materials appears in the table below. Materials that contain carbon and/or require less energy to produce have the lowest (best) GHG impact. At the other end, materials with high-GHG refrigerants tend to have the worst carbon footprint.[1]

Material	Example manufacturers / products	GHG Impact[2]	Notes
Wood fiber	Steico, Gutex	Lowest / Best	Boardstock, batts
Cellulose	Cleanfiber, GreenFiber	Lowest / Best	Densepack, loosefill
Fiberglass	CertainTeed Sustainable, Knauf EcoBatt	Low	Batts, boardstock, loosefill/densepack
Polyisocyanurate	DuPont Thermax	Low	Boardstock; Blowing agent: pentane
EPS (expanded polystyrene)	Atlas, BASF Neopor	Low	Boardstock; Blowing agent: pentane
Open cell spray foam	Demilec APX, Lapolla Foam-Lok 450	Low	Site-blown; Blowing agent: water
Phenolic foam	Kingspan Kooltherm	Low	Boardstock; Blowing agent: pentane
Mineral wool	Rockwool, Owens Corning	Medium	Batts, boardstock
Closed cell spray foam, HFO	Demilec Heatlok HFO Pro, Lapolla ProSeal HFO	Medium	Site-blown; Blowing agent: HFOs
Closed cell spray foam, HFC	Demilec Heatlok XT, Dow Froth-Pak	Highest / Worst	Site-blown; Blowing agent: HFCs
XPS (extruded polystyrene)	Dow Styrofoam (blueboard), Owens Corning (pinkboard)	Highest / Worst	Boardstock; Blowing agent: HFCs

Partners have shared that many material substitutions are not only easy to implement, they can actually save money. Furthermore, many lower-GHG materials are less toxic to workers and/or building occupants.[3]

Example: A 2-story, 2000 square foot home making insulation substitutions detailed below avoids approx. 55,000 kg CO_2e, roughly equal to *not* driving 136,000 miles or *not* burning 60,000 pounds of coal. Provided the installed R-value is the same and proper air sealing is done, there is no significant difference between the two homes' operational energy.

- XPS for sub-slab and foundation
- HFC-based spray foams in walls and cathedral ceiling

- EPS Type IX for sub-slab and polyisocyanurate (interior) foundation
- Densepack cellulose in walls and cathedral ceiling

[1] Our analysis is based on Cradle to Gate: extraction of resources from the earth until the point that a product leaves the factory. This corresponds to Life Cycle Assessment product stages A1, A2, and A3. We also include A5 for materials manufactured on-site (such as spray polyurethane foam that emits refrigerant at installation) and B1 (which is important to consider for insulations which off-gas refrigerants over time).
[2] Lowest: < 0 kgCO_2e including carbon content, per 1 m_2 RSI-1. Low: 0-5. Medium: 5-10. High > 10.
[3] A useful summary of cost, health, and environmental considerations of insulation materials is available at: https://www.buildinggreen.com/sites/default/files/BG_Insulation_Recommendations.pdf

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efficiencyvermont.com
888-921-5990 | 802-860-4095

Material	Example manufacturers / products	GHG Impact[2]
Wood fiber	Steico, Gutex	Lowest / Best
Cellulose	Cleanfiber, GreenFiber	Lowest / Best
Fiberglass	CertainTeed Sustainable, Knauf EcoBatt	Low
Polyisocyanurate	DuPont Thermax	Low
EPS (expanded polystyrene)	Atlas, BASF Neopor	Low
Open cell spray foam	Demilec APX, Lapolla Foam-Lok 450	Low
Phenolic foam	Kingspan Kooltherm	Low
Mineral wool	Rockwool, Owens Corning	Medium
Closed cell spray foam, HFO	Demilec Heatlok HFO Pro, Lapolla ProSeal HFO	Medium
Closed cell spray foam, HFC	Demilec Heatlok XT, Dow Froth-Pak	Highest / Worst
XPS (extruded polystyrene)	Dow Styrofoam (blueboard), Owens Corning (pinkboard)	Highest / Worst

https://www.efficiencyvermont.com/Media/Default/docs/printable-resources/GeneralInfoForHomes/EVT-Home-Insulation-GHG-OnePager.pdf

Future work

- Share feedback on the logistics / ease of material substitutions
- Share added or avoided costs
- Learn whether pilot builders continue with low-GWP materials in future
- Share information with contractors and homeowners on the co-benefits

Project 2: Embodied Carbon in Residential Retrofits

Megan Nedzinski - Vermont Integrated Architecture
Jacob Deva Racusin - New Frameworks
Chris Gordon, Brian Just, Matt Sharpe, and Mike Fink - Efficiency Vermont

Efficiency Vermont

VERMONT INTEGRATED ARCHITECTURE, PC

New Frameworks

Introduction & Purpose

The Why?

Weatherization insulation material decisions

- Cost, availability, durability, ease of use
- Global environmental impacts?

Understand what work is being done

Realize where and what opportunities exist

Share findings to inform and streamline the process

- Use a single point of comparison - embodied carbon

Research Tasks

1 Determine and illustrate the density of HPwES projects in Vermont by geographic location.

2 Determine the types of insulation materials used in specific residential building assemblies (walls, attics, band joist, foundation walls, etc.) and if/how these choices have changed over time.

3 Characterize the embodied carbon emissions by application type to understand:

a) which types contribute most to CO_2e (carbon dioxide equivalent) emissions

b) which applications are the most carbon intensive

4 Illustrate the evolution of HPwES installations and the associated embodied carbon emissions over time (by material and application).

Methods, Dataset, and Definitions

Dataset sorted to remove null entries and user input errors

Base data is 2012-2016, installed measures

Embodied Carbon Emissions – LCA stages A1-A3 Product Stage, and A5

- A1 - Raw material supply
- A2 – Transport
- A3 – Manufacturing
- A5 - Construction Installation process, where applicable
- B1 – Use, where applicable

Methods, Dataset, and Definitions

Materials – *"the type of insulation"*
- Cellulose, dense pack
- Cellulose, loose fill
- Expanded polystyrene- rigid board
- Extruded polystyrene- rigid board
- Fiberglass batts
- Fiberglass- loose fill
- Poly-isocyanurate- rigid board
- Spray foam- closed cell
- Spray foam- open cell

Applications – "the physical space"
- Attic Hatch
- Attic, open cavity
- Basement, above grade
- Basement, below grade
- Basement rim joist
- Closed-cavity ceiling
- Floor
- Wood-framed wall

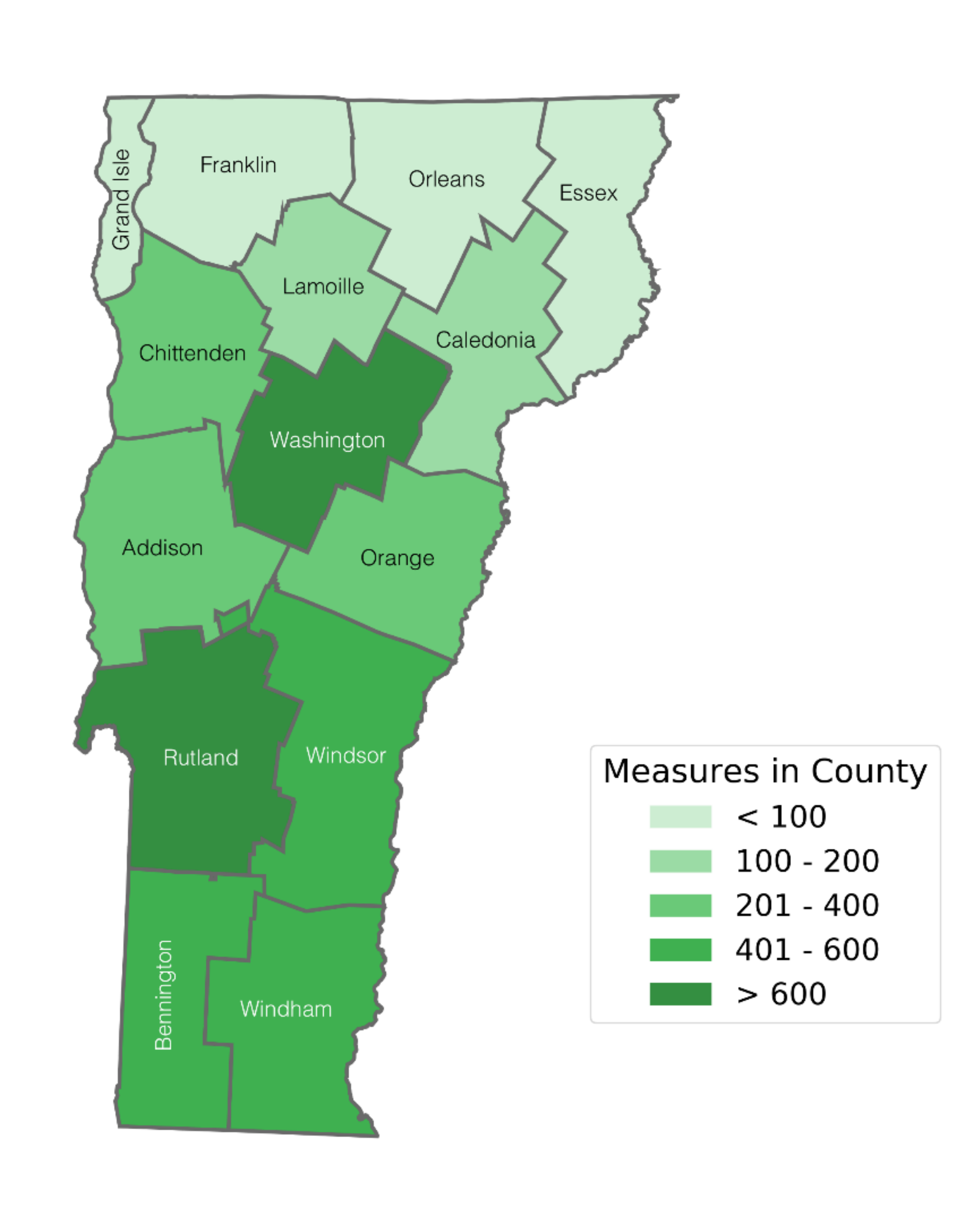
R-value and Improved R-value

Practices and measures – "what insulation is installed where"
- Installed insulation materials at defined thicknesses (in units of inches added) for each physical space, with an indication of the net square feet treated).

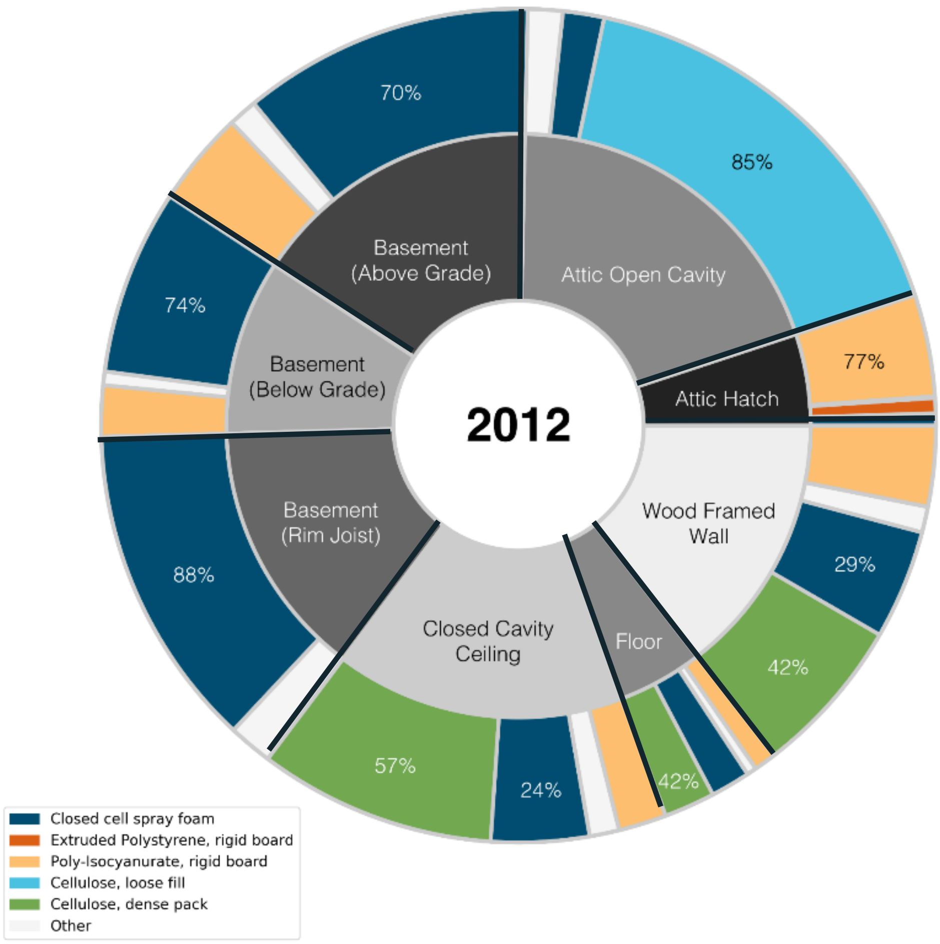
1: Relative density of completed HPwES measures by county

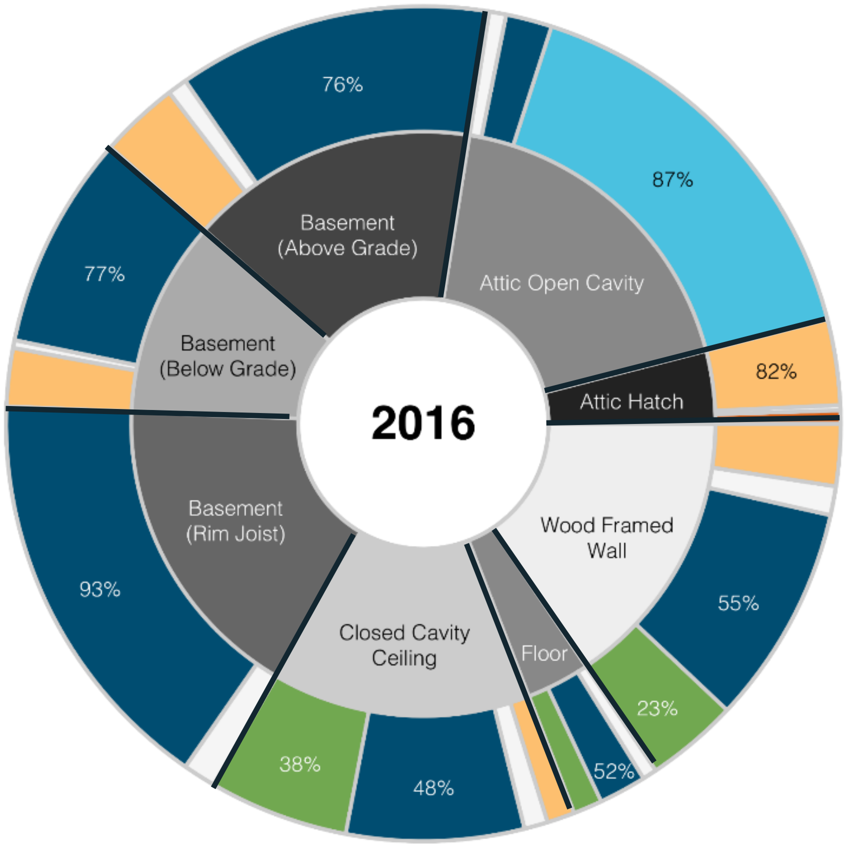
- Concentration by total count
- Installed measures only from 2012-2016

Figure 1: Relative density of completed HPwES measures by county.



2: Types of insulation used in specific retrofit assemblies

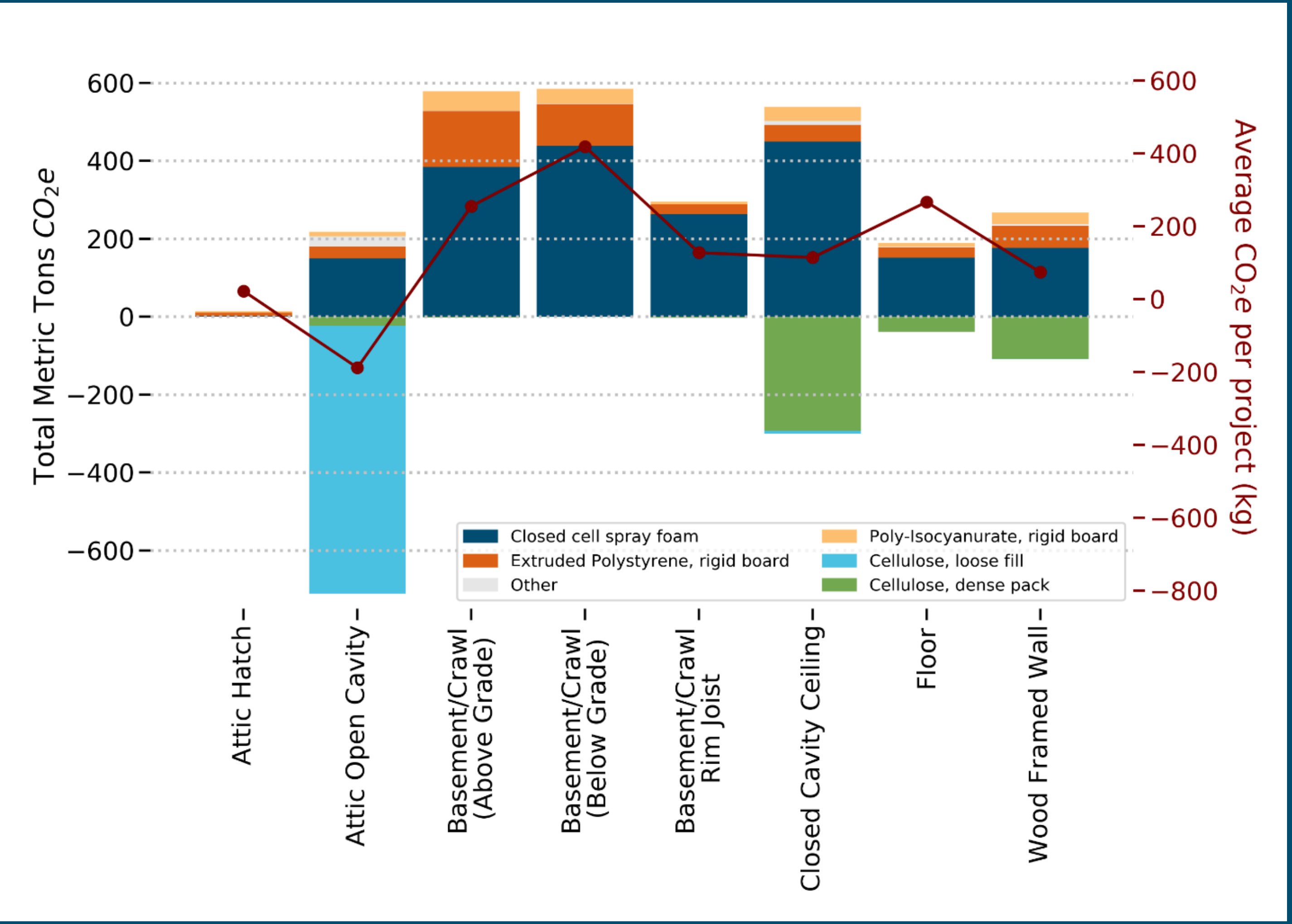




- *Assemblies receiving insulation remained fairly constant*
- *Insulation type used remained largely unchanged*
- *Closed cavity ceilings and wood framed walls, however, showed a proportional increase in the use of closed cell spray foam.*

Closed Cavity Ceiling (2012)	Closed Cell SPF	24%	Dense Pack Cellulose	57%
Closed Cavity Ceiling (2016)	Closed Cell SPF	48%	Dense Pack Cellulose	38%
Wood Framed Walls (2012)	Closed Cell SPF	29%	Dense Pack Cellulose	42%
Wood Framed Walls (2016)	Closed Cell SPF	55%	Dense Pack Cellulose	23%

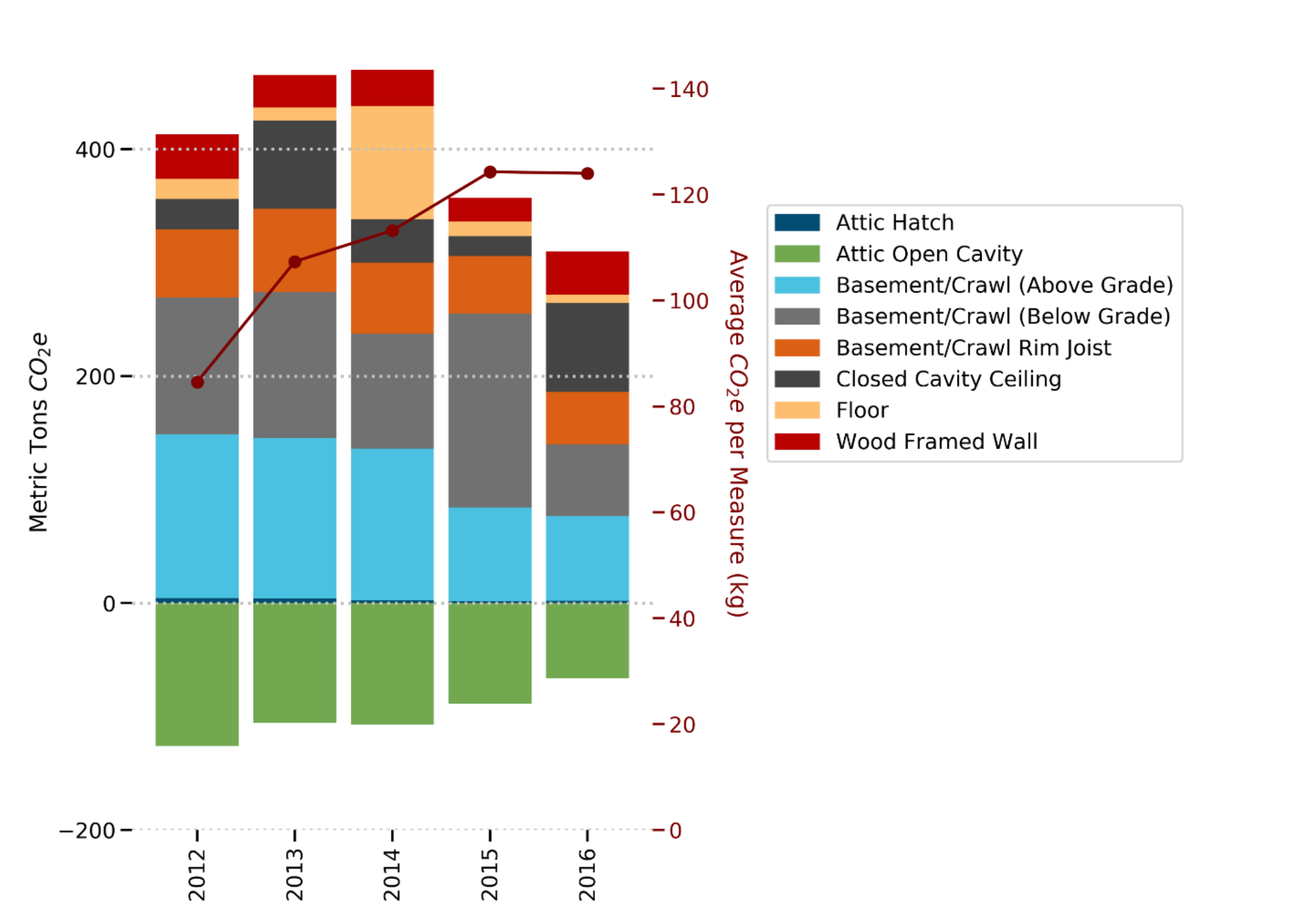
3. Embodied carbon emissions by application type, per material:



Which applications contribute most to CO2e emissions?

Which applications are the most carbon intensive?

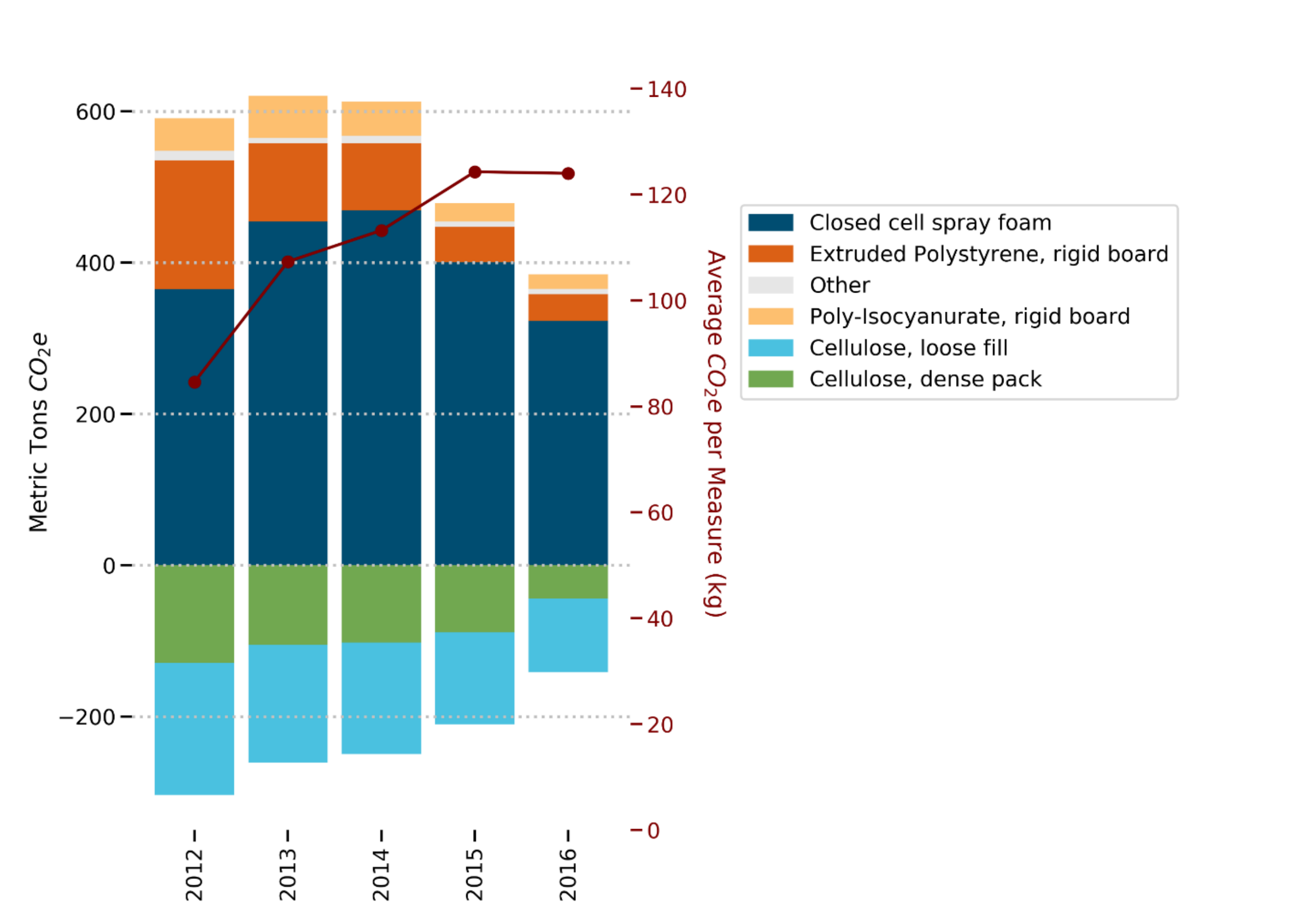
4a. Embodied carbon emissions by application type, over time:



How are CO2e emissions changing over time for different applications?

How are total CO2e emissions changing over time?

4b. Embodied carbon emissions by material type, over time:



How are CO2e emissions changing over time for different materials?

What is the relationship between increasing average emissions and decreasing total emissions?

Recommendation #1:

Convert 90% of the non-cellulose material selection for open attics to **loose-fill cellulose**.

Average annual embodied $CO2_e$ **reduction of 37%**

Recommendation #2:

Convert 50% of XPS and spray polyurethane foam material selection for basement walls (above and below grade) to **polyisocyanurate foam board**.

Average annual embodied $CO2_e$ **reduction of 35%**

Recommendation #3:

Convert 75% of total material selection for basement rim joists to **dense-pack cellulose**.

Average annual embodied $CO2_e$ **reduction of 115%** due to carbon storage benefits of recycled cellulose insulation.

Recommendation #4:

Convert 60% of material selection for closed cavity ceilings to **dense-pack cellulose**.

Average annual embodied $CO2_e$ **reduction of 65%**

Recommendation #5:

Convert 100% of the material selection for wood frame walls to **dense-pack cellulose**.

Average annual embodied $CO2_e$ **reduction of 221%** due to carbon storage benefits of recycled cellulose insulation.

Opportunities for Further Research

- Relationship of Embodied and Operational Emissions in Weatherization in Vermont.
- Greater accounting of Operational Emission Reductions from weatherization improvements.
- Further development of what opportunities exist to reduce embodied emissions through industry and market engagement.

Project 3: Lifecycle Carbon of Heat Pumps

Daniel Jordan

Efficiency Vermont

What are the carbon impacts of electrifying my heating?

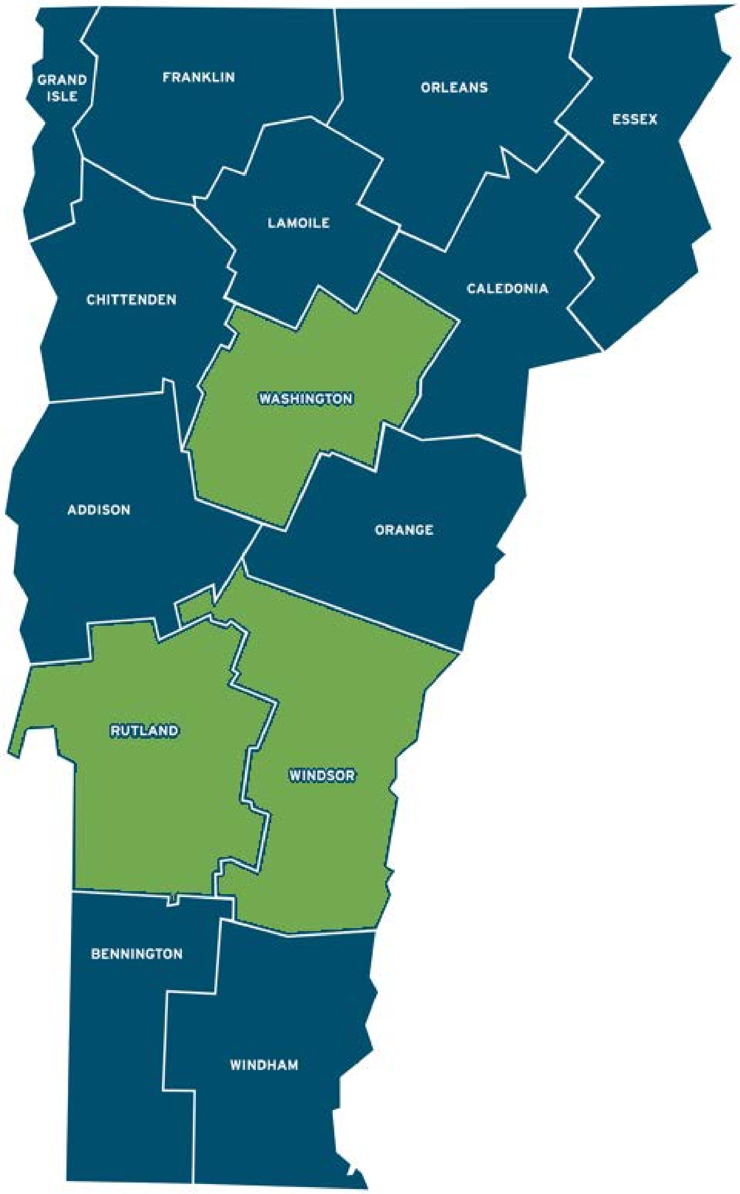
Efficiency Vermont

Study Overview

1. Existing **commercial**, **municipal**, or **industrial** building.

2. Heat pumps to supplement **existing boiler**.

3. Split system, ductless, cold climate heat pumps with **R-410A**.



4 projects

Study Overview

	Heating square feet	Boiler fuel	Heat Pumps: Number of indoor heads	Heat Pumps: Types	Heat Pumps: Nominal capacity (tons)
School	20,100	Oil	30	Single & multi-head	37
Storage	16,900	Oil	10	VRF	12
Plant offices	12,500	Propane	13	VRF & single-head	11
Retail	10,500	Oil	6	Single-head	9

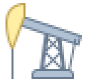
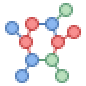
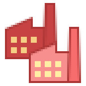
Study Aims
Answers to the following questions:

1. What are the GHG impacts beyond operational efficiency?
   a) Heat pumps offset boiler fuel, but **at what cost**?
   b) What are the **major factors** in determining these impacts?

2. How do these impacts stack up, roughly?

Emissions by Scope

metric tons CO_2e over 20 years, project averages, heat output equivalence

	direct	electric	embodied
boiler			
heat pumps			

Emissions by Scope

metric tons CO_2e over 20 years, project averages, heat output equivalence

	direct	electric	embodied
boiler			
heat pumps			

Embodied Carbon

Resources and Calculations

1. **Heat pumps:**
   - Manufacturer annual **Material Balance** and **Environmental Impact** reports.

$$\frac{\text{lb } CO_2e}{\text{lb product}} = \frac{\text{production emissions} + \text{RM embodied carbon}}{\text{weight of all products sold}}$$

2. **Piping**
   - Copper LCI: cradle-to-gate + disposal and recycling

3. **Refrigerant**
   - EPA GHG Reporting Program for F-gas. HFC byproducts are released during manufacture.
   - HFC global warming potential (GWP) is **x1000s** CO2e by mass.
   - Manufacturers are taking steps to destroy HFC byproducts before emission.

Install weight (lbs), heat pumps + piping	
school	5,568
retail	1,013
storage	1,901
mfg plant	1,918

Embodied Carbon

Resources and Calculations

Environmental Science & Technology

Energy Efficiency and Greenhouse Gas Emission Intensity of Petroleum Products at U.S. Refineries

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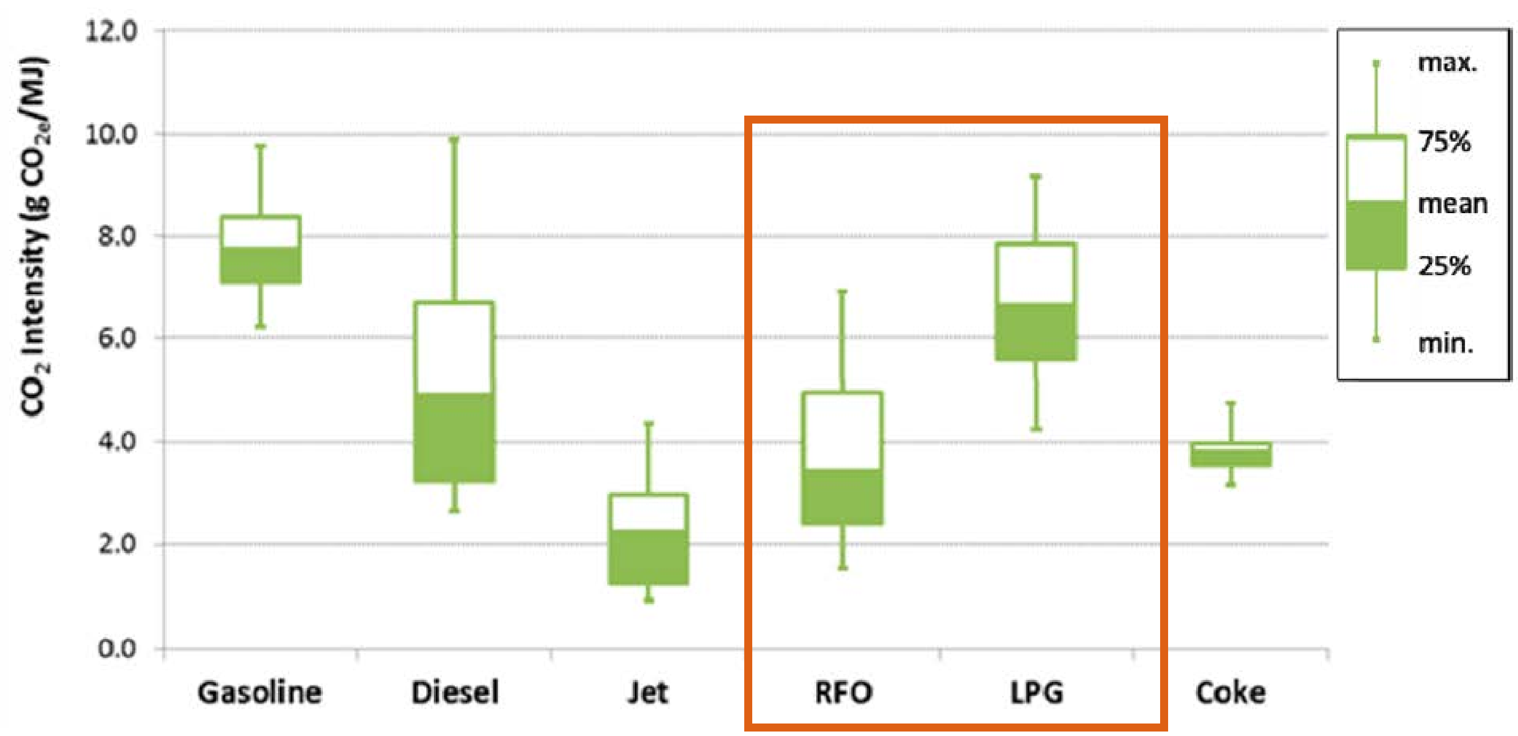
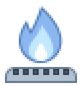
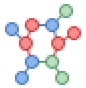


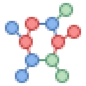
Emissions by Scope

metric tons CO_2e over 20 years, project averages, heat output equivalence

	direct	electric	embodied
boiler			50
heat pumps			9 (fixed)

Emissions by Scope

metric tons CO_2e over 20 years, project averages, heat output equivalence

	direct	electric	embodied
boiler			50
heat pumps			9 (fixed)

Electric Emissions

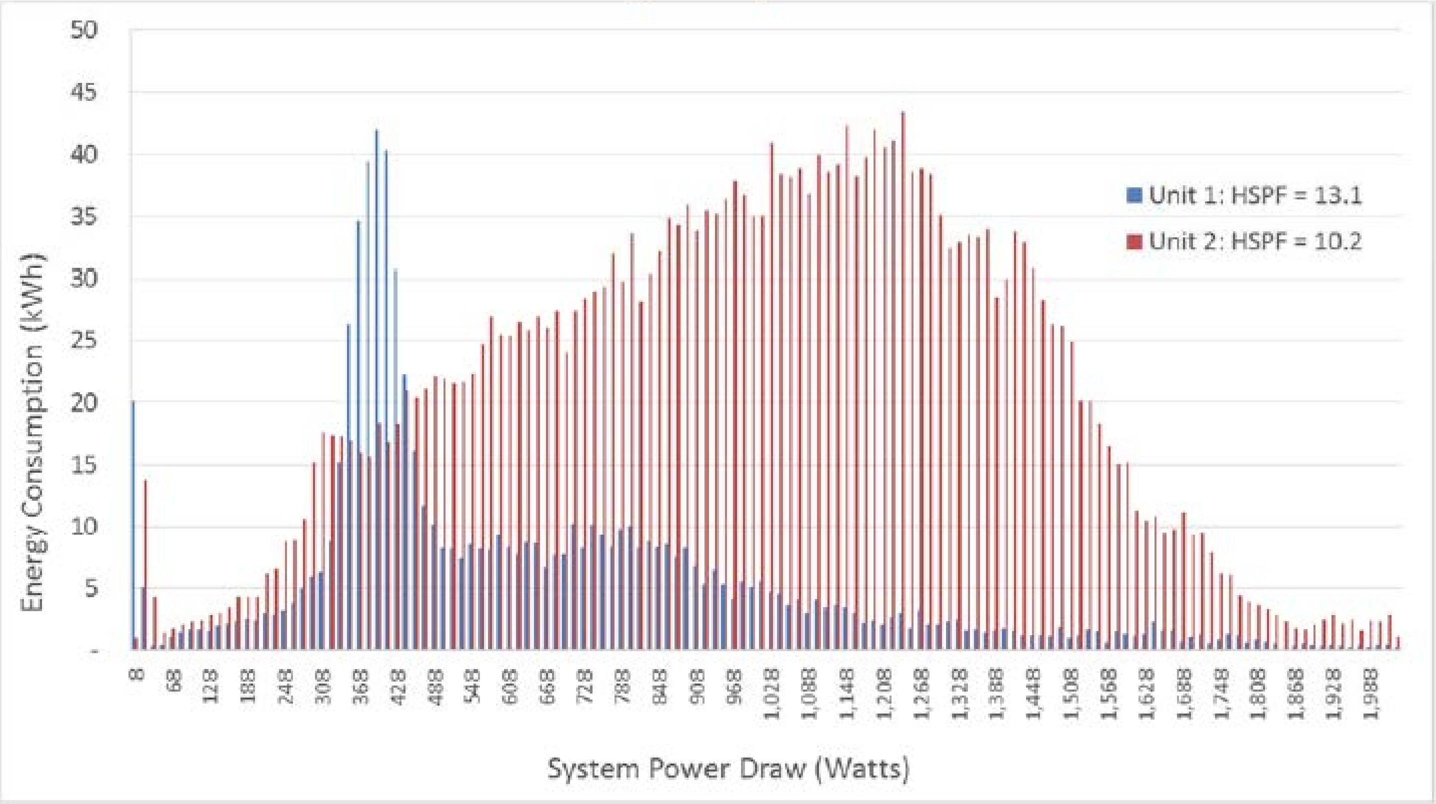
First off: A heat pump is only as good at its install!

Source:

Walczyk, J., 2017. "Evaluation of Cold Climate Heat Pumps in Vermont."

The Cadmus Group, LLC.

Figure 18. Comparison of Operation of Identical Cold Climate Heat Pumps (MUZ-FH12NA) During Heating Season

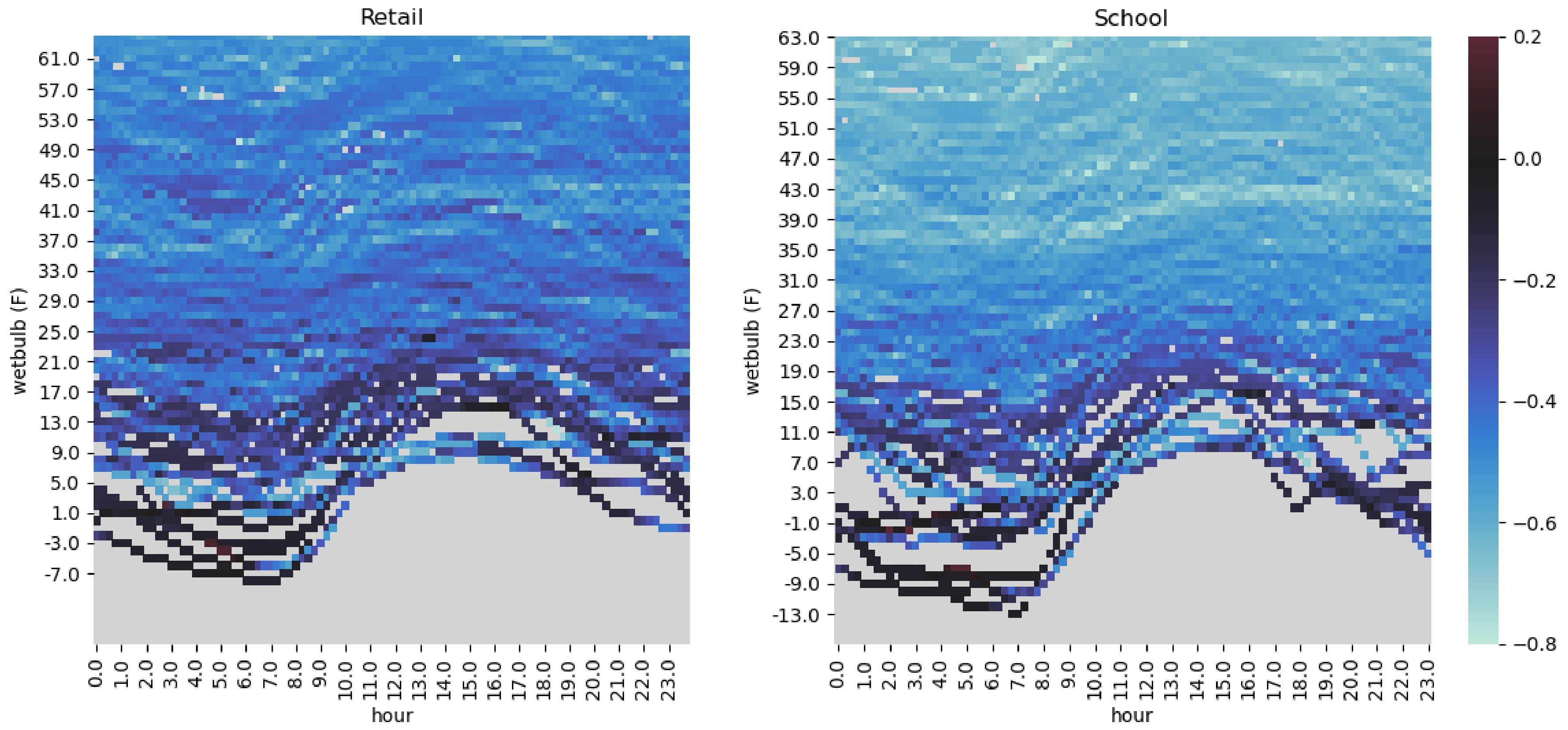


Heat pump operational carbon intensity savings (%)

At a given hour/temp, how much would the fully loaded heat pumps reduce electric source emissions compared to the direct emissions of an on-site #2 oil boiler providing the same heat?

Assumptions:

1. Heat output equivalence.
2. Daily load shape ignored.
3. ISONE marginal fuel mix, 2019-20, 5% line loss.
4. 85% constant boiler combustion efficiency.



Emissions by Scope

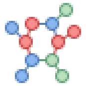
metric tons CO_2e over 20 years, project averages, heat output equivalence

	direct	electric	embodied
boiler		22[1]	50
heat pumps		541[1]	9 (fixed)

1. ISO New England marginal fuel mix, 2019-20 heating season.

Emissions by Scope

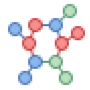
metric tons CO_2e over 20 years, project averages, heat output equivalence

	direct	electric	embodied
boiler		3[1]	50
heat pumps		74[1]	9 (fixed)

1. GMP aggregate fuel mix, 2017-2019 average.

Emissions by Scope

metric tons CO_2e over 20 years, project averages, heat output equivalence

	direct	electric	embodied
boiler		3[1]	50
heat pumps		74[1]	9 (fixed)

1. GMP aggregate fuel mix, 2017-2019 average.

Direct Emissions

Heat Pump Fugitive Emissions Studies

who	when	annual leak estimate	what	details
U.S. DoD United Facilities Criteria	2017	25%	VRF	
CARB	2016	5.3%	residential	
EPA	2014	10%	residential + commercial	refined in 2019
Eunomia, CACR	2013	3.8%	residential + commercial	9% leak at all, median of 42%

Emissions by Scope

metric tons CO_2e over 20 years, project averages, heat output equivalence

	direct	electric	embodied
boiler	930	3[1]	50
heat pumps	82[2]	74[1]	9 (fixed)

1. GMP aggregate fuel mix, 2017-2019 average.
2. 5% annual leak x 20 years.

Emissions by Scope

metric tons CO_2e over 20 years, project averages, heat output equivalence

	direct	electric	embodied
boiler	930	3 [1]	50
heat pumps	410 [2]	74 [1]	9 (fixed)

1. GMP aggregate fuel mix, 2017-2019 average.
2. 25% annual leak x 20 years.

Results

	hp Btu/sf	% fuel reduction	break-even days	lifetime GHG reduction	
				percent	t CO_2e
school	21.9	>95%	37	79%	1,250
retail	8.5	30%	57	40%	324
storage	10.6	65%	205	6%	47
mfg office	9.7	>95%	50	65%	376

Assumptions

1. GMP aggregate fuel mix, 2017-2019 average.
2. Annual leak rates 5- 20% depending on system.

Conclusions & future work

- Heat pump retrofits are a good idea.
  - Embodied carbon of heat pumps: nbd.
- Heat pump **peak coincidence** will continue to stress the grid.
  - Importance of **load management**.
- R410A is a GHG liability. Install/testing can make a **huge** difference.
- Looking for industry partners on GHG impacts of HVAC equipment.

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