The Climate Impact of Retrofits: Embodied and Operational Emissions in Weatherization

Megan Nedzinski (Vermont Integrated Architecture)
Jacob Racusin (New Frameworks)

Curated by Dave Boettcher (Abode) and Asher Greenberg (Steveworks)

Northeast Sustainable Energy Association (NESEA)
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Research & Development provides Efficiency Vermont an opportunity for staff and partners to pursue innovation and drive the evolution of the energy efficiency utility’s programs and services.
Overview

1. 2020 Study: Embodied Carbon in Residential Retrofits

2. 2021 Study: Embodied and Operational Emissions in Weatherization

3. Conclusions
Learning Objectives

1. Define and differentiate between embodied and operational carbon emissions

2. Quantify the relative scales of embodied and operational carbon emissions in residential weatherization

3. Analyze the time frame in which embodied and operational carbon emissions occur in residential weatherization, and how this applies to developing retrofit strategies

4. Identify different approaches for a variety of specific retrofit measures, and their relative impact on embodied and operational carbon emissions
Intro and Purpose

The authors sought to fill a gap in the growing body embodied carbon emissions analysis work by studying the contribution of weatherization materials, specifically in Vermont.

Quantify the embodied carbon associated with residential retrofit projects.

Understand if and how weatherization work, including material choices have changed over time.

Aid in decision-making for future weatherization scope and material selections from a climate impact perspective.

2020 Study: Embodied Carbon in Residential Retrofits

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

Building on 2020 Research Tasks and Findings

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) 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$_2$e (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).
Building on 2020 Research Tasks and Findings

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2020 Findings

#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.

<table>
<thead>
<tr>
<th></th>
<th>Closed Cell SPF</th>
<th>Dense Pack Cellulose</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed Cavity Ceiling</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2012)</td>
<td>24%</td>
<td>57%</td>
<td></td>
</tr>
<tr>
<td>(2016)</td>
<td>48%</td>
<td>38%</td>
<td></td>
</tr>
<tr>
<td>Wood Framed Walls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2012)</td>
<td>29%</td>
<td>42%</td>
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2020 Findings

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<tr>
<th>Insulation Type</th>
<th>2012</th>
<th>2016</th>
</tr>
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<tbody>
<tr>
<td>Attic Open Cavity</td>
<td>77%</td>
<td>76%</td>
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<tr>
<td>Attic Hatch</td>
<td>85%</td>
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<tr>
<td>Wood Framed Wall</td>
<td>42%</td>
<td>48%</td>
</tr>
<tr>
<td>basement (above grade)</td>
<td>88%</td>
<td>82%</td>
</tr>
<tr>
<td>basement (below grade)</td>
<td>74%</td>
<td>8%</td>
</tr>
<tr>
<td>basement (rim joist)</td>
<td></td>
<td>57%</td>
</tr>
<tr>
<td>floor</td>
<td>4%</td>
<td>23%</td>
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</table>

<table>
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<tr>
<th>Insulation Type</th>
<th>2012</th>
<th>2016</th>
</tr>
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<tbody>
<tr>
<td>closed cell spray foam</td>
<td></td>
<td>55%</td>
</tr>
<tr>
<td>Extruded Polyisocyanurate, rigid board</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyisocyanurate, rigid board</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cellulose, loose fill</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cellulose, dense pack</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>23%</td>
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<td>23%</td>
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2020 Findings

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

How are total CO2e emissions changing over time?
- Emissions went down due to fewer projects

How are CO2e emissions changing over time for different applications?
- Becoming more carbon intensive
2020 Findings
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?
Intro and Purpose

Understand the relationship between embodied emissions and operational emissions

Identify the threshold or “tipping point” between material emissions and operational emissions of weatherized homes

Aid in decision-making for weatherization scope and material selections from a climate impact perspective
Definitions, Studied Conditions & Datasets

A “typical Vermont home”

• approximately 2,200 square feet
• two-story
• three-bedroom
• single-family residence

Datasets were used to establish baseline modeling assumptions

• HPwES was primary source of data
• Assumptions were cross-referenced with the Vermont Department of Public Service’s “Vermont Single-Family Existing Homes Overall Report” to confirm as reasonable
<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Baseline</th>
<th>“Common Practice”</th>
<th>“Carbon Smart”</th>
<th>“Carbon Smart” Equivalent-R</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Typical VT home, unweatherized, the “do-nothing” scenario</td>
<td>Derived from 2020 study</td>
<td>Replaced higher embodied carbon materials with lower embodied carbon materials</td>
<td>“Carbon Smart” materials</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ccSPF (HFO)</td>
<td>• Polyiso</td>
<td>• Polyiso</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• DP cellulose</td>
<td>• DP cellulose</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Existing Cavity restrictions / code venting</td>
<td>• No cavity restrictions = equivalent R</td>
</tr>
</tbody>
</table>
Definitions, Studied Conditions & Datasets

Materials – “the type of insulation”
• Cellulose
• Poly-isocyanurate- rigid board
• Spray foam- closed cell (ccSPF [HFO])
  • w/ HFO blowing agent

Applications – “the physical space”
• Basement, below grade
• Basement rim joist
• Wood-framed wall
• Closed-cavity ceiling
Definitions, Studied Conditions & Datasets

Datasets -

• Efficiency Vermont Home Performance with ENERGY STAR® (HPwES) program data
  • 2012-2016, installed measures
• Vermont Department of Public Service’s Vermont Single-Family Existing Homes Overall Report
• State of Wisconsin 2020 study “Assessment of Energy and Cost Savings for Homes Treated under Wisconsin’s Home Energy Plus Weatherization Program,”

Dataset application

➢ Established baseline modeling assumptions (available cavities, fenestration, areas, etc.)
➢ Cross-reference data source to confirm calculated cavities and assumptions as reasonable
➢ Energy model calibration
### Definitions, Studied Conditions & Datasets

#### Scenarios

<table>
<thead>
<tr>
<th>Condition</th>
<th>Baseline</th>
<th>Common Practice</th>
<th>Carbon Smart</th>
<th>Carbon Smart – Equivalent-R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundation (8” concrete)</td>
<td>R-3.5</td>
<td>R-19.8</td>
<td>R-19.6</td>
<td>R-19.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3” ccSPF)</td>
<td>(3” polyiso)</td>
<td></td>
</tr>
<tr>
<td>2x10 Rim Joist</td>
<td>R-5.8</td>
<td>R-19.8</td>
<td>R-19.8</td>
<td>R-19.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3” ccSPF)</td>
<td>(5.5” DP cellulose w/ caulking)</td>
<td></td>
</tr>
<tr>
<td>Wood framed Walls (2x4, 16” o.c.), no continuous insulation</td>
<td>R-6.75 nominal R-8.77 effective</td>
<td>R-19.8 nominal R-13.5 effective (3” ccSPF)</td>
<td>R-12.46 nominal R-11.49 effective (3.5” DP cellulose w/ caulking)</td>
<td>R-19.8 nominal R-13.5 effective (5.5” DP cellulose w/ caulking)</td>
</tr>
<tr>
<td>Attic Framing (2x8s @ 16” o.c.)</td>
<td>R-9.9 nominal R-10.5 effective</td>
<td>R-39.4 nominal R-28.57 effective (6” ccSPF)</td>
<td>R-18.7 nominal R-17.86 effective (5.25” DP cellulose, w/ caulking, 2” venting)</td>
<td>R-39.4 nominal R-28.57 effective (11” DP cellulose, w/ caulking, 2” venting)</td>
</tr>
<tr>
<td>Air-infiltration (ACH50)</td>
<td>12</td>
<td>8.4</td>
<td>8.4</td>
<td>8.4</td>
</tr>
</tbody>
</table>
Definitions, Studied Conditions & Datasets

Embodied Carbon – LCA stages included

2020 study by Brian Just of VEIC

Source: Just, “The high greenhouse gas price tag on residential building materials: True life cycle costs (and what can be done about them).”

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<table>
<thead>
<tr>
<th>Material</th>
<th>Example manufacturers / products</th>
<th>GHG Impact</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood fiber</td>
<td>Steico, Gutex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cellulose</td>
<td>Cleanfiber, Greenfiber</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cellulose</td>
<td>DuPont Thermax</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>EPS (expanded polystyrene)</td>
<td>Atlas, BASF Neopor</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Open cell spray foam</td>
<td>Demicel APX, Lapolla Foam-Ico 450</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Phenolic foam</td>
<td>Kingspan Kooltherm</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Mineral wool</td>
<td>Rockwool, Owens Corning</td>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>Closed cell spray foam, HFO</td>
<td>Demicel Heatlok HFO Pro, Lapolla ProSeal HFO</td>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>Closed cell spray foam, HFC</td>
<td>Demicel Heatlok XT, Dow Froth-Pak</td>
<td>Highest/ Worst</td>
<td></td>
</tr>
<tr>
<td>XPS (extruded polystyrene)</td>
<td>Dow Syrofoam (blueboard), Owens Corning (pinkboard)</td>
<td>Highest/ Worst</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Global warming potential (GWP) of insulation material and R-value summary (partial list)

* Averages used in this study are based on 100-year GWP value and appear in highlighted column.

Definitions, Studied Conditions & Datasets

Embodied Carbon – LCA stages included

2021 Research Tasks

1. Calculate the approximate operational carbon savings when a typical existing Vermont home is weatherized using the most commonly adopted HPwES practices.
Approach

1. Calculate the approximate operational carbon savings when a typical existing Vermont home is weatherized using the most commonly adopted HPwES practices.

Typical VT Home
HPwES data + PSD Report

Energy Model
OpenStudio(OS) Parametric Analysis Tool (PAT)

1st Year Operational Energy
kgCO2e

Operational Energy
kg CO₂e (Fuel Oil)
Figure 2: First-year operational kg CO2e emissions—all measures
RESEARCH TASK #1: Operational Savings

Figure 3: First-year operational kg CO$_2$e savings compared to baseline condition—all measures
Figure 4: First-year operational kg CO$_2$e savings by measure compared to baseline condition
2021 Research Tasks

1. Calculate the approximate operational carbon savings when a typical existing Vermont home is weatherized using the most commonly adopted HPwES practices.

2. Calculate the carbon impact (operational and embodied emissions) for the first year of implementation when a typical Vermont home is weatherized:
   - Using the most commonly adopted HPwES practices (“Common Practice”).
   - Using low-carbon approaches with HPwES practices (“Carbon Smart”).
Calculate the carbon impact (operational and embodied emissions) for the first year of implementation when a typical Vermont home is weatherized:

EPD calculator
Brian Just/VEIC (2020)

Typical VT Home
HPwES data + PSD Report

1st Year Carbon Impact (Embodied and Operational)
kgCO2e
Figure 5: First-year kg CO₂e emissions (operational and embodied)—all measures
RESEARCH TASK #2: First Year emissions – by measure

Figure 6: First-year kg CO2e emissions (operational and embodied) by measure
2021 Research Tasks

1. Calculate the approximate operational carbon savings when a typical existing Vermont home is weatherized using the most commonly adopted HPwES practices.

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3. Calculate the time period required to equalize the up-front embodied carbon emissions for specific installed weatherization practices with the estimated operational carbon emissions avoided:
   - Using the most commonly adopted HPwES practices (“Common Practice”).
   - Using low-carbon approaches with HPwES practices (“Carbon Smart”).
Approach

Calculate the time period required to equalize the up-front embodied carbon emissions for specific installed weatherization practices with the estimated operational carbon emissions avoided:

1st Year Carbon Impact (Embodied and Operational) [kgCO2e]

Annual Operational Energy for 10 years [kgCO2e]

Time Period to equalize embodied [kgCO2e]
RESEARCH TASK #3: Time period to equalize embodied CO2e emissions

Figure 7: kg CO2e emissions (operational and embodied) over time – all measures
Carbon Smart approaches have lower net emissions than the Common Practice in the first year; lower net emissions than the Baseline.

Figure 7: kg CO2e emissions (operational and embodied) over time – all measures
Common Practice approach results in net carbon emissions reduction by the second year compared with Baseline.

Figure 7: kg CO₂e emissions (operational and embodied) over time – all measures
Common Practice and Carbon Smart emissions are equivalent after ~10 years.
The Carbon Smart (Equivalent-R) scenario has a more favorable carbon impact indefinitely.

Figure 7: kg CO2e emissions (operational and embodied) over time – all measures.
Figure 7: kg CO2e emissions (operational and embodied) over time – all measures
RESEARCH TASK #3: Conclusions

Figure 7: kg CO2e emissions (operational and embodied) over time – all measures

Common Practice materials release a plume of emissions at the beginning of the project; *emissions reduced immediately are of greater benefit than an equivalent reduction in the future.*
RESEARCH TASK #3: Conclusions

Weatherizing buildings using any studied approach yields critical short-term emission reductions.

Figure 7: kg CO2e emissions (operational and embodied) over time – all measures
Both first-year impacts and impacts over time are important to evaluate.

*Figure 7: kg CO2e emissions (operational and embodied) over time – all measures*
The Carbon Smart (Equivalent-R) is the most favorable approach notwithstanding constraints of existing home building assemblies.
Conclusions

Weatherizing 36 homes = saved emissions of 1 million pounds of coal

“Common Practice” and “Carbon Smart” strategies offers a pathway to significant CO2e reductions within a decade when compared to the Baseline Scenario.

Conclusions

Weatherizing **36 homes** =

“Common Practice” and “Carbon Smart” strategies offers a pathway to significant CO2e reductions within a decade when compared to the Baseline.

Conclusions

“Carbon Smart” strategy offers a pathway to significant CO2e reductions in the short-term when compared to the Baseline.

Figure 5: First-year kg CO2e emissions (operational and embodied)—all measures
Conclusions

Weatherizing **27 homes** = saved emissions of **1 million pounds of coal**

“Carbon Smart” (Equivalent-R) is the most favorable approach, notwithstanding constraints of existing assemblies.

Conclusions

Weatherizing 27 homes =

“Carbon Smart” (Equivalent-R) is the most favorable approach, notwithstanding constraints of existing assemblies.

Nearly 8x annually

or

Nearly 200,000 miles annually

Conclusions

“Carbon Smart” (Equivalent-R) is the most favorable approach, notwithstanding constraints of existing assemblies.

“Carbon Smart” (Equivalent-R) is the most favorable approach, notwithstanding constraints of existing assemblies.

50% REDUCTION OVER BASELINE

Figure 5: First-year kg CO2e emissions (operational and embodied)—all measures
First year emissions reductions are critically important when considered with the embodied carbon emissions avoided due to building reuse.

It is urgent that we weatherize existing buildings in the shortest time possible to avoid irreversible climate change.

Conclusions

Figure 5: First-year kg CO2e emissions (operational and embodied)—all measures
THANK YOU!

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Questions / Discussion?

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