Carbon Payback Scenario Analysis

Submitted to:
North American Insulation Manufacturers Association

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Executive Summary

ICF carried out an energy and carbon modelling study [1] to analyze the potential use-phase emission reductions realized through the installation of building envelope insulation for residential and commercial new construction. The study focused on one residential prototype: single-family detached home, and six commercial prototypes: midrise apartment building, medium office, retail strip mall, primary school, secondary school, and warehouse.

The analysis included in this report is a follow-on study to the use-phase GHG savings study "Impact of Building Envelope Thermal Insulation on Use-Phase Emissions" [1] that ICF delivered to Insulation Industry stakeholders on May 5th, 2024.

This report presents the analysis framework used to evaluate the carbon payback period for insulation materials identified by the North American Insulation Manufacturers Association (NAIMA). This analysis helps in identifying the time required for the GHG emission savings to exceed the embodied carbon in the insulation. To do so, the carbon emission savings in 2024 and 2025 that were evaluated in the previous study [1] were utilized in the calculation of the carbon payback period. Two scenarios were explored in previous study [1] to predict the impact of thermal insulation in cases with different proliferation of heat pump heating systems:

- Scenario 1: A scenario that assumes that a uniform distribution of existing heating systems (i.e., electric resistance, natural gas furnace, oil furnace and heat pump).
- Scenario 2: A scenario that assumes 100% heat pump heating systems.

In order to calculate carbon payback period, ICF extracted the embodied carbon data from various literature sources for a suite of insulation materials identified by NAIMA. The materials were divided into cavity and continuous insulation and different insulation types such as batts, loose fill, spray foam, boards and foams. The embodied carbon data extracted were the industry averages and only alternative manufacturer-specific values were extracted for those materials that did not have an industry-wide Environmental Product Declaration (EPD).

The key takeaways from this study can be summarized as follows:

Carbon payback for insulation measured in weeks and months, not years. The average carbon payback period for whole building insulation of residential and commercial prototypes was found to be generally under a year for all investigated insulation materials. Some products exceed one year, but only in warm, cooling-dominated climates. It is observed that the average carbon payback periods are higher in plastic insulation materials compared to organic insulation materials due to the relatively large embodied carbon associated with the processing stage of material production.

More insulation leads to more emission reductions over the lifetime of building. This evaluation study of carbon payback period helps in establishing the relationship between the emissions associated with the production of each insulation material and the emissions avoided each year due to the application of the insulation to the building envelope.

1 Introduction

ICF was tasked by North American Manufacturers Association (NAIMA) to evaluate the carbon payback from the application of various types of insulation materials to residential and commercial building envelopes in their carbon impact study. This analysis is a follow-on project to the use-phase GHG savings study "Impact of Building Envelope Thermal Insulation on Use-Phase Emissions" [1] that ICF delivered to Insulation Industry stakeholders on May 5th, 2024.

This report presents the analysis framework used to evaluate the carbon payback period for a suite of insulation materials identified by NAIMA. This analysis helps in identifying the duration it takes for the GHG emission savings to exceed the embodied carbon in the insulation.

The proposed analysis utilized the results from the previous study by adding the effect of upstream energy expenditure and embedded carbon in the manufacturing and application processes of the insulation material.

2 Organization of the Report

The report contains the following remaining sections, beginning with an explanation of the study methodology and data inputs, and progressing through a presentation of the results and key conclusions.

- Methodology
- Results and Discussion
- Conclusions and Key Takeaways

3 Methodology

The study proceeded in the following steps:

3.1 Data Gathering

The previous study [1] analyzed the potential use-phase emission reductions realized through the installation of building envelope insulation for residential and commercial new construction. The study involved one prototype from the residential sector: single-family detached home, and six prototypes from the commercial sector: midrise apartment, medium office, retail strip mall, primary school, secondary school, and warehouse. The study investigated the lifecycle energy and carbon impact of applying building envelope thermal insulation to the seven prototypes in 16 climate zones: 1A, 2A, 2B, 3A, 3B, 3C, 4A, 4B, 4C, 5A, 5B, 5C, 6A, 6B, 7, and 8.

For the residential prototype, the impact of insulation in exterior wall, attic floor and foundation walls were analyzed. For the commercial prototypes, the impact of insulation in exterior wall, roof and slab perimeter was analyzed. The range of lifetime carbon emissions per functional unit of insulation materials were reported for the different climate zones. The functional unit (FU) is defined herein as 1 m^2 of insulation with a thickness corresponding to RSI-1.0. The lifetime of the insulation materials was assumed to be 75 years, commencing in 2024.

To calculate the lifetime carbon emissions, the site energy savings from the simulation results were converted into source energy savings using source-site conversion ratios reported in literature for the different fuel types. The total annual source energy savings were then used to evaluate the annual GHG savings attributable to the insulation applied in the different scenarios. For this, the emission rates of natural gas and fuel oil were obtained from the Environmental Protection Agency database. For GHG emission rates attributed to electricity generation, the emission rates provided by NREL's 2023 Cambium database were utilized. The US national average emission rates were chosen as a representation of emissions from the electricity generation. Three scenarios were selected from the Cambium database to reflect the projected impact of renewable energy (RE) costs on future emission rates: Low RE Costs, Medium RE Costs, and High RE Costs. This report presents the results for the Medium RE Costs scenario only.

Two scenarios were explored in previous study [1] to predict the impact of thermal insulation in cases with different proliferation of heat pump heating systems:

- Scenario 1: A scenario that assumes that a uniform distribution of existing heating systems (i.e., electric resistance, natural gas furnace, oil furnace and heat pump).
- Scenario 2: A scenario that assumes 100% heat pump heating systems.

This study focused on calculating the carbon payback period for various insulation materials identified by NAIMA. As such, the carbon emission savings in the first few years of the analysis period were considered in the calculation of the carbon payback. Table 1 and Table 2 display the average emission savings per FU in years 2024 through 2027 for the residential prototype under Scenarios 1 and 2, respectively. Table 3 and Table 4 display the average emission savings per FU in years 2024 and 2025 for the commercial prototypes under Scenarios 1 and 2, respectively.

Table 1: Average Carbon Emission Savings in kg CO_2e per FU for Residential Prototype (Scenario 1)

Year	Climate Zone																
	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8	Average
2024	3.6	4.6	6.7	6.6	6.4	5.5	8.0	7.4	7.1	10.2	9.6	7.8	12.9	11.6	14.5	17.4	8.7
2025	3.4	4.4	6.3	6.3	6.1	5.3	7.7	7.1	6.8	9.7	9.2	7.5	12.3	11.1	13.8	16.6	8.4
2026	3.2	4.1	6.0	6.0	5.8	5.0	7.3	6.8	6.5	9.3	8.7	7.2	11.8	10.6	13.2	15.8	8.0
2027	1.9	2.6	3.8	4.1	3.8	3.4	5.1	4.6	4.5	6.4	6.0	5.0	8.1	7.3	9.1	10.9	5.4

Table 2: Average Carbon Emission Savings in kg CO_2e per FU for Residential Prototype (Scenario 2)

Year	Climate Zone																
	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8	Average
2024	3.3	3.8	5.4	5.6	5.1	3.9	7.6	6.2	5.6	11.1	9.5	6.6	15.0	12.2	17.5	22.2	8.8
2025	3.1	3.6	5.1	5.3	4.8	3.7	7.2	5.9	5.3	10.4	9.0	6.2	14.2	11.5	16.5	21.2	8.3
2026	2.9	3.3	4.8	5.0	4.5	3.5	6.7	5.5	5.0	9.8	8.4	5.8	13.3	10.8	15.4	20.1	7.8
2027	1.6	1.9	2.7	2.8	2.5	1.9	3.7	3.1	2.8	5.5	4.7	3.2	7.4	6.0	8.6	13.2	4.5

Table 3: Average Carbon Emission Savings in kg CO_2e per FU for Commercial Prototypes (Scenario 1)

Year	Climate Zone																
	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8	Average
2024	15.0	13.5	17.3	16.1	16.7	9.5	17.5	18.5	13.5	18.6	20.0	13.5	21.5	20.7	20.7	22.8	17.2
2025	14.1	12.8	16.5	15.4	15.9	9.1	16.9	17.7	13.0	18.0	19.3	13.0	20.8	20.0	20.1	22.3	16.6

Table 4: Average Carbon Emission Savings in kg CO_2e per FU for Commercial Prototypes (Scenario 2)

Year	Climate Zone																
	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8	Average
2024	14.7	13.2	17.0	15.3	16.2	9.2	16.5	17.8	12.6	17.5	19.1	12.5	20.2	19.6	19.3	21.3	16.4
2025	13.9	12.4	16.0	14.4	15.2	8.7	15.6	16.7	11.9	16.4	18.0	11.8	19.0	18.4	18.2	20.3	15.4

ICF extracted the embodied carbon data from various literature sources for a suite of insulation materials identified by NAIMA. The materials were divided into cavity and continuous insulation and different insulation types such as batts, loose fill, spray foam, boards, and spray-applied foams. Environmental Product Declaration (EPD) databases presenting industry average values for embodied carbon were prioritized. For insulation materials with no available industry-average data, manufacturer-specific EPD values were obtained.

Table 5 displays the embodied carbon values per FU for the various insulation materials considered in the present analysis.

Table 5 : Embodied Carbon Per FU of Insulation Materials

Insulation Type	Insulation Material	Embodied Carbon (kg CO_2e per FU)	Source
Cavity	Cellulose Loose Fill – Industry Average	0.61	[2]
	Fiber Glass Loose Fill – Industry Average	1.07	[3]
	Fiber Glass (Unfaced) Batts – Industry Average	1.08	[4]
	HFC (Open Cell) Spray Foam – Industry Average	1.68	[5]
	HFO (Open Cell) Spray Foam – Industry Average	1.68	[6]
	Mineral Wool Loose Fill – Industry Average	2.07	[7]
	Sheep's Wool Batts – Havelock Sheep's Wool	3.11	[8]
	HFO (Closed Cell) Spray Foam – Industry Average	4.21	[6]
	Mineral Wool (light board) Batt – Industry Average	4.22	[9]
	HFC (Closed Cell) Spray Foam – Industry Average	11.07	[5]
	Cellulose Batts – Industry Average	N/A*	
	Wood Fiber Batts – Industry Average	N/A*	
	Wood Fiber Loose Fill – Industry Average	N/A*	
Continuous	Phenolic Foam – Kingspan Kooltherm K12	1.62	[10]
	Polyisocyanurate – Roof Foam– Industry Average	2.30	[11]
	EPS Board – Industry Average	2.80	[12]
	Polyisocyanurate – Wall Foam – Industry Average	4.29	[13]
	XPS Board – Dupont Styrofoam ST-100	5.08	[14]
	Mineral Wool (heavy density) Board – Industry Average	7.97	[15]
	Wood Fiber Board – Industry Average	N/A*	

* N/A: No data available in the literature.

3.2 Carbon Payback Period Calculation

The carbon payback period in months was evaluated by aggregating the monthly emission savings up to the point in time when the cumulative savings are equal to the total embodied carbon in the envelope insulation (illustrated in Figure 1). The annual emission savings are assumed to be uniformly distributed over the months of the respective years.

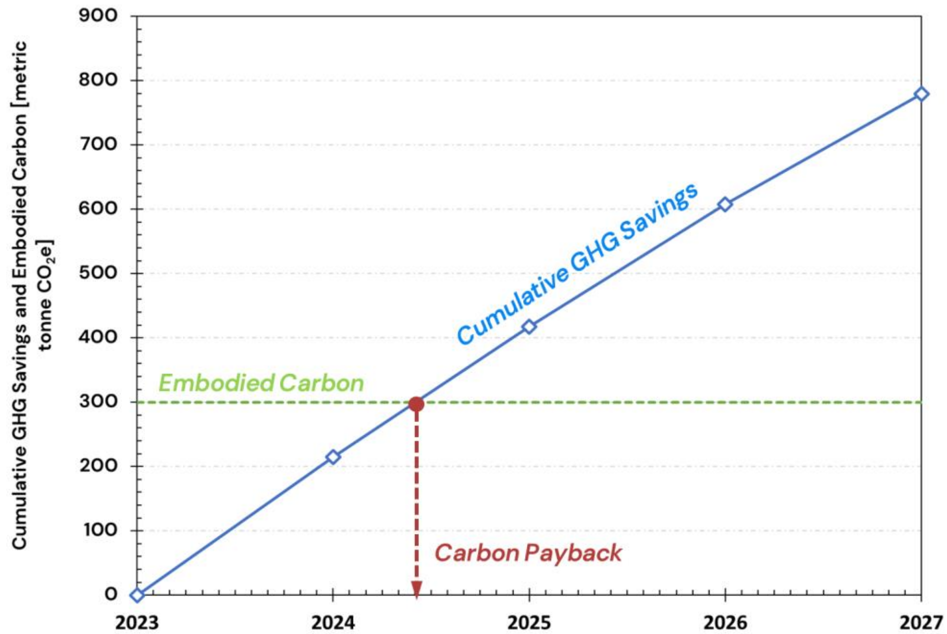

Figure 1: Illustration of the calculation method for carbon payback period

4 Results and Discussion

This section discusses the carbon payback period results for the residential and commercial prototypes under Scenarios 1 and 2.

4.1 Residential Prototype: Single-family Detached Home

4.1.1 Scenario 1: Uniform Distribution of Existing Heating Systems

This scenario assumes an equal distribution of the four heating system types as discussed in our previous study [1]. Figure 2 and Table 6 show the average carbon payback period for single-family home prototype. It is observed that the payback period drops from climate CZ1A to CZ8, as larger first year savings are realized in CZ8 due to the pronounced impact of insulation on reducing the heating load. The average carbon payback period is seen to be under a year for the vast majority of simulated cases. The exceptions are limited to cases with large embodied carbon insulation materials and/or cooling dominant climates where the impact of insulation on emission savings is minimal. Clear examples for these exceptions are closed-cell HFC in climate zones 1 to 5 and heavy-density mineral wool application in climate zones 1A and 2A. Closed-cell HFC has the highest embodied carbon followed by heavy-density mineral wool board. The range of average carbon payback period across all materials and climate zones is between 1.5 weeks to 41 months.

4.1.2 Scenario 2: 100% Heat Pump Systems

This scenario assumes that the residential prototype is heated using a heat pump system. Figure 3 and Table 7 show the average carbon payback period for single-family home prototype. It is observed that the carbon payback is generally longer for Scenario 2 compared to Scenario 1. This is primarily attributed to the lower emission savings in Scenario 2 due to the larger efficiency of heat pumps relative to fossil-based heating systems. Table 7 summarizes the carbon payback period values in months for whole home insulation. The range of average carbon payback period (months) across all materials and climate zones is from 1.5 weeks to 48 months.

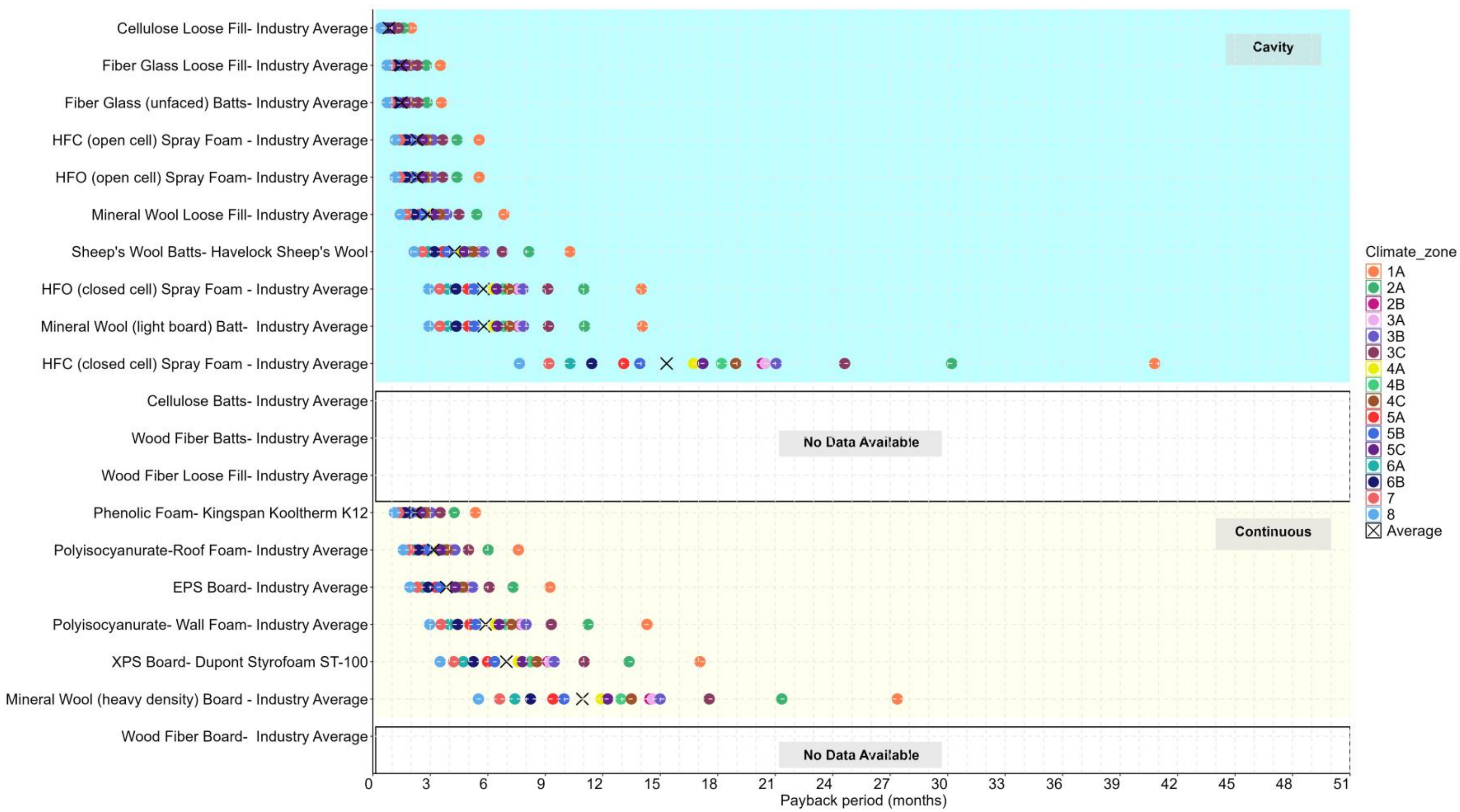

Figure 2: Average Carbon Payback Period for Residential Prototype (Scenario 1)

Table 6: Average Carbon Payback Period for Residential Prototype (Scenario 1)

Insulation Material	Embodied Carbon (kg CO_2e per FU)	Carbon Payback Period (Months)																
		1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8	All
Cellulose Loose Fill	**0.61**	2.0	1.6	1.1	1.1	1.1	1.3	0.9	1.0	1.0	0.7	0.8	0.9	0.6	0.6	0.5	0.4	0.8
Fiber glass Loose Fill	**1.07**	3.5	2.8	1.9	1.9	2.0	2.3	1.6	1.7	1.8	1.3	1.3	1.6	1.0	1.1	0.9	0.7	1.5
Fiber glass (unfaced) Batts	**1.08**	3.6	2.8	1.9	2.0	2.0	2.3	1.6	1.8	1.8	1.3	1.4	1.7	1.0	1.1	0.9	0.7	1.5
HFC (open cell) Spray Foam	**1.68**	5.5	4.4	3.0	3.0	3.1	3.6	2.5	2.7	2.8	2.0	2.1	2.6	1.6	1.7	1.4	1.2	2.3
HFO (open cell) Spray Foam	**1.68**	5.5	4.4	3.0	3.0	3.1	3.6	2.5	2.7	2.8	2.0	2.1	2.6	1.6	1.7	1.4	1.2	2.3
Mineral wool Loose Fill	**2.07**	6.8	5.4	3.7	3.8	3.9	4.5	3.1	3.4	3.5	2.4	2.6	3.2	1.9	2.1	1.7	1.4	2.8
Sheep's Wool Batts	**3.11**	10.3	8.1	5.6	5.6	5.8	6.8	4.6	5.0	5.2	3.7	3.9	4.8	2.9	3.2	2.6	2.2	4.3
HFO (closed cell) Spray Foam	**4.21**	14.0	11.0	7.6	7.6	7.8	9.1	6.3	6.8	7.1	5.0	5.3	6.5	3.9	4.3	3.5	2.9	5.8
Mineral Wool (light board) Batt	**4.22**	14.1	11.1	7.6	7.7	7.9	9.2	6.3	6.8	7.1	5.0	5.3	6.5	3.9	4.4	3.5	2.9	5.8
HFC (closed cell) Spray Foam	**11.07**	40.8	30.2	20.3	20.5	21.0	24.6	16.7	18.2	18.9	13.1	13.9	17.2	10.3	11.4	9.2	7.7	15.3
Cellulose Batts	**N/A**	N/A																
Wood Fiber Batts	**N/A**																	
Wood Fiber Loose Fill	**N/A**																	
Phenolic Foam	**1.62**	5.4	4.2	2.9	2.9	3.0	3.5	2.4	2.6	2.7	1.9	2.0	2.5	1.5	1.7	1.3	1.1	2.2
Polyisocyanurate-Roof Foam	**2.30**	7.6	6.0	4.1	4.2	4.3	5.0	3.4	3.7	3.9	2.7	2.9	3.5	2.1	2.4	1.9	1.6	3.2
EPS Board	**2.80**	9.2	7.3	5.0	5.1	5.2	6.1	4.2	4.5	4.7	3.3	3.5	4.3	2.6	2.9	2.3	1.9	3.8
Polyisocyanurate- Wall Foam	**4.29**	14.3	11.2	7.7	7.8	8.0	9.3	6.4	6.9	7.2	5.1	5.4	6.6	4.0	4.4	3.6	3.0	5.9
XPS Board	**5.08**	17.1	13.4	9.1	9.2	9.5	11.0	7.6	8.2	8.6	6.0	6.4	7.8	4.7	5.2	4.2	3.5	7.0
Mineral Wool (heavy density) Board	**7.97**	27.4	21.3	14.5	14.6	15.0	17.6	11.9	12.9	13.5	9.4	10.0	12.3	7.4	8.2	6.6	5.5	10.9
Wood Fiber Board	**N/A**	N/A																

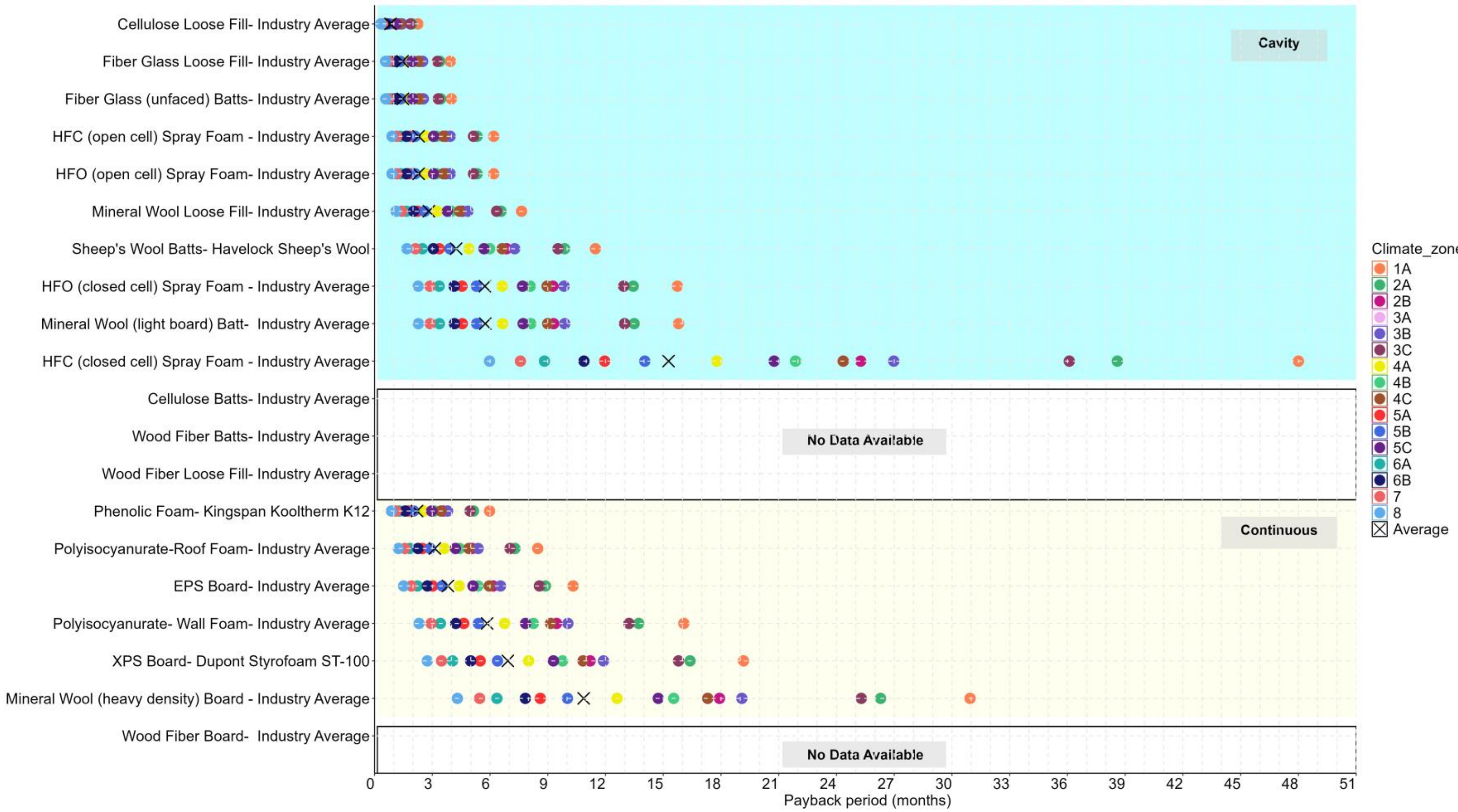

Figure 3: Average Carbon Payback Period for Residential Prototype (Scenario 2)

Table 7: Average Carbon Payback Period for Residential Prototype (Scenario 2)

Insulation Material	Embodied Carbon (kg CO_2e per FU)	Carbon Payback Period (Months)																
		1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8	All
Cellulose Loose Fill	**0.61**	2.3	1.9	1.3	1.3	1.4	1.9	1.0	1.2	1.3	0.7	0.8	1.1	0.5	0.6	0.4	0.3	0.8
Fiber glass Loose Fill	**1.07**	3.9	3.4	2.4	2.3	2.5	3.3	1.7	2.1	2.3	1.2	1.3	2.0	0.9	1.0	0.7	0.6	1.5
Fiber glass (unfaced) Batts	**1.08**	4.0	3.4	2.4	2.3	2.5	3.3	1.7	2.1	2.3	1.2	1.4	2.0	0.9	1.1	0.7	0.6	1.5
HFC (open cell) Spray Foam	**1.68**	6.2	5.3	3.7	3.6	3.9	5.1	2.6	3.2	3.6	1.8	2.1	3.1	1.3	1.6	1.1	0.9	2.3
HFO (open cell) Spray Foam	**1.68**	6.2	5.3	3.7	3.6	3.9	5.1	2.6	3.2	3.6	1.8	2.1	3.1	1.3	1.6	1.1	0.9	2.3
Mineral wool Loose Fill	**2.07**	7.6	6.6	4.6	4.4	4.8	6.3	3.3	4.0	4.4	2.2	2.6	3.8	1.7	2.0	1.4	1.1	2.8
Sheep's Wool Batts	**3.11**	11.5	9.9	6.9	6.6	7.3	9.5	4.9	6.0	6.6	3.4	3.9	5.7	2.5	3.1	2.1	1.7	4.2
HFO (closed cell) Spray Foam	**4.21**	15.7	13.4	9.3	9.0	9.8	12.9	6.6	8.1	9.0	4.5	5.3	7.7	3.4	4.1	2.9	2.3	5.7
Mineral Wool (light board) Batt	**4.22**	15.8	13.5	9.3	9.0	9.9	13.0	6.7	8.1	9.0	4.6	5.3	7.7	3.4	4.1	2.9	2.3	5.8
HFC (closed cell) Spray Foam	**11.07**	48.0	38.6	25.3	24.3	27.0	36.1	17.8	21.9	24.4	12.0	14.0	20.8	8.8	10.9	7.6	6.0	15.3
Cellulose Batts	**N/A**	N/A																
Wood Fiber Batts	**N/A**																	
Wood Fiber Loose Fill	**N/A**																	
Phenolic Foam	**1.62**	6.0	5.1	3.6	3.5	3.8	5.0	2.6	3.1	3.5	1.8	2.0	3.0	1.3	1.6	1.1	0.9	2.2
Polyisocyanurate-Roof Foam	**2.30**	8.5	7.3	5.1	4.9	5.4	7.0	3.6	4.4	4.9	2.5	2.9	4.2	1.8	2.3	1.6	1.2	3.1
EPS Board	**2.80**	10.3	8.9	6.2	6.0	6.5	8.6	4.4	5.4	6.0	3.0	3.5	5.1	2.2	2.7	1.9	1.5	3.8
Polyisocyanurate- Wall Foam	**4.29**	16.1	13.7	9.5	9.1	10.0	13.2	6.8	8.3	9.1	4.6	5.4	7.8	3.4	4.2	2.9	2.3	5.8
XPS Board	**5.08**	19.2	16.4	11.2	10.8	11.9	15.8	8.0	9.8	10.8	5.5	6.4	9.3	4.1	5.0	3.5	2.7	6.9
Mineral Wool (heavy density) Board	**7.97**	30.9	26.3	17.9	17.3	19.1	25.3	12.6	15.5	17.3	8.6	10.0	14.7	6.4	7.8	5.5	4.3	10.9
Wood Fiber Board	**N/A**	N/A																

4.2 Commercial Prototypes

Similar figures were developed for the commercial prototypes in different climate zones.

4.2.1 Scenario 1: Existing Heating Systems

This scenario assumes that the existing natural gas space heating systems prevail in all six commercial prototypes. Figure 4 and Table 8 show the average carbon payback period for the commercial prototypes. It is observed that that the average carbon payback period is under a year for all insulation materials. The range of average carbon payback period across all materials and climate zones is from 1.5 weeks to 14 months.

4.2.2 Scenario 2: 100% Heat Pump Systems

This scenario explores a hypothesized case where all commercial prototypes are heated using heat pumps. Such a scenario was compiled by estimating the heating loads from Scenario 1, then calculating the heat pump electricity consumption assuming a seasonal average COP of 3.3 for all climate zones.

Figure 5 and Table 9 show the average carbon payback period for the commercial prototypes. It is observed that that the average carbon payback period is under a year for all insulation materials. The range of average carbon payback period across all materials and climate zones is from 1.5 weeks to 15 months.

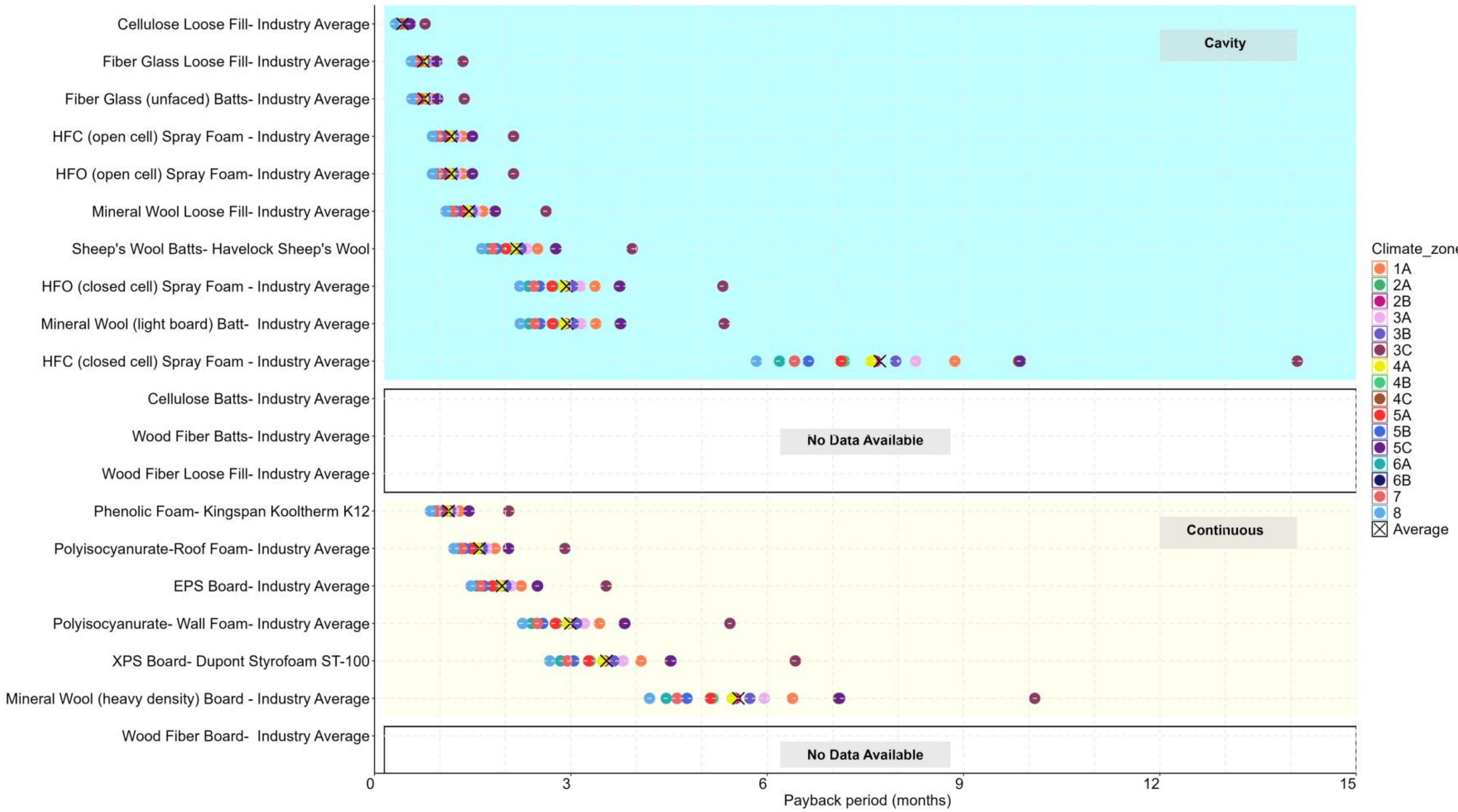

Figure 4: Average Carbon Payback Period for Commercial Prototype (Scenario 1)

Table 8: Average Carbon Payback Period for Commercial Prototype (Scenario 1)

Insulation Material	Embodied Carbon (kg CO_2e per FU)	Carbon Payback Period (Months)																
		1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8	All
Cellulose Loose Fill	**0.61**	0.5	0.5	0.4	0.5	0.4	0.8	0.4	0.4	0.5	0.4	0.4	0.5	0.3	0.4	0.4	0.3	0.4
Fiber glass Loose Fill	**1.07**	0.9	1.0	0.7	0.8	0.8	1.4	0.7	0.7	0.9	0.7	0.6	1.0	0.6	0.6	0.6	0.6	0.7
Fiber glass (unfaced) Batts	**1.08**	0.9	1.0	0.7	0.8	0.8	1.4	0.7	0.7	1.0	0.7	0.6	1.0	0.6	0.6	0.6	0.6	0.8
HFC (open cell) Spray Foam	**1.68**	1.3	1.5	1.2	1.3	1.2	2.1	1.2	1.1	1.5	1.1	1.0	1.5	0.9	1.0	1.0	0.9	1.2
HFO (open cell) Spray Foam	**1.68**	1.3	1.5	1.2	1.3	1.2	2.1	1.2	1.1	1.5	1.1	1.0	1.5	0.9	1.0	1.0	0.9	1.2
Mineral wool Loose Fill	**2.07**	1.7	1.8	1.4	1.5	1.5	2.6	1.4	1.3	1.8	1.3	1.2	1.8	1.2	1.2	1.2	1.1	1.4
Sheep's Wool Batts	**3.11**	2.5	2.8	2.2	2.3	2.2	3.9	2.1	2.0	2.8	2.0	1.9	2.8	1.7	1.8	1.8	1.6	2.2
HFO (closed cell) Spray Foam	**4.21**	3.4	3.7	2.9	3.1	3.0	5.3	2.9	2.7	3.7	2.7	2.5	3.7	2.4	2.4	2.4	2.2	2.9
Mineral Wool (light board) Batt	**4.22**	3.4	3.8	2.9	3.2	3.0	5.3	2.9	2.7	3.8	2.7	2.5	3.8	2.4	2.4	2.4	2.2	2.9
HFC (closed cell) Spray Foam	**11.07**	8.9	9.9	7.7	8.3	8.0	14.1	7.6	7.2	9.8	7.1	6.6	9.9	6.2	6.4	6.4	5.8	7.7
Cellulose Batts	**N/A**																	
Wood Fiber Batts	**N/A**	N/A																
Wood Fiber Loose Fill	**N/A**																	
Phenolic Foam	**1.62**	1.3	1.4	1.1	1.2	1.2	2.1	1.1	1.1	1.4	1.0	1.0	1.4	0.9	0.9	0.9	0.9	1.1
Polyisocyanurate-Roof Foam	**2.30**	1.8	2.0	1.6	1.7	1.7	2.9	1.6	1.5	2.0	1.5	1.4	2.0	1.3	1.3	1.3	1.2	1.6
EPS Board	**2.80**	2.2	2.5	1.9	2.1	2.0	3.5	1.9	1.8	2.5	1.8	1.7	2.5	1.6	1.6	1.6	1.5	2.0
Polyisocyanurate- Wall Foam	**4.29**	3.4	3.8	3.0	3.2	3.1	5.4	2.9	2.8	3.8	2.8	2.6	3.8	2.4	2.5	2.5	2.3	3.0
XPS Board	**5.08**	4.1	4.5	3.5	3.8	3.7	6.4	3.5	3.3	4.5	3.3	3.0	4.5	2.8	2.9	2.9	2.7	3.5
Mineral Wool (heavy density) Board	**7.97**	6.4	7.1	5.5	6.0	5.7	10.1	5.5	5.2	7.1	5.1	4.8	7.1	4.5	4.6	4.6	4.2	5.6
Wood Fiber Board	**N/A**	N/A																

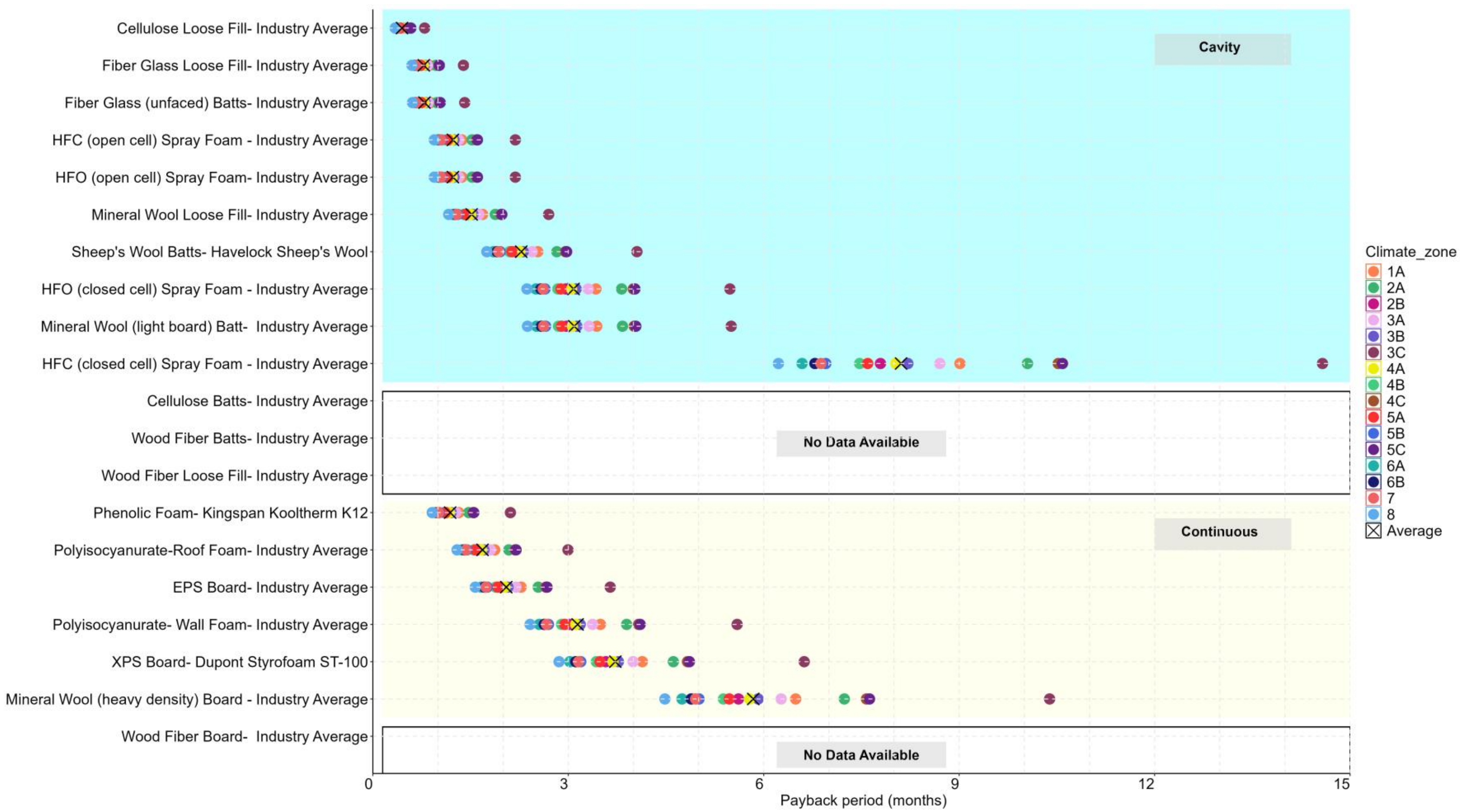

Figure 5: Average Carbon Payback Period for Commercial Prototype (Scenario 2)

Table 9: Average Carbon Payback Period for Commercial Prototype (Scenario 2)

Insulation Material	Embodied Carbon (kg CO_2e per FU)	Carbon Payback Period (Months)																
		1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8	All
Cellulose Loose Fill	**0.61**	0.5	0.6	0.4	0.5	0.5	0.8	0.4	0.4	0.6	0.4	0.4	0.6	0.4	0.4	0.4	0.3	0.4
Fiber glass Loose Fill	**1.07**	0.9	1.0	0.8	0.8	0.8	1.4	0.8	0.7	1.0	0.7	0.7	1.0	0.6	0.7	0.7	0.6	0.8
Fiber glass (unfaced) Batts	**1.08**	0.9	1.0	0.8	0.9	0.8	1.4	0.8	0.7	1.0	0.7	0.7	1.0	0.6	0.7	0.7	0.6	0.8
HFC (open cell) Spray Foam	**1.68**	1.4	1.5	1.2	1.3	1.2	2.2	1.2	1.1	1.6	1.2	1.1	1.6	1.0	1.0	1.0	0.9	1.2
HFO (open cell) Spray Foam	**1.68**	1.4	1.5	1.2	1.3	1.2	2.2	1.2	1.1	1.6	1.2	1.1	1.6	1.0	1.0	1.0	0.9	1.2
Mineral wool Loose Fill	**2.07**	1.7	1.9	1.5	1.6	1.5	2.7	1.5	1.4	2.0	1.4	1.3	2.0	1.2	1.3	1.3	1.2	1.5
Sheep's Wool Batts	**3.11**	2.5	2.8	2.2	2.4	2.3	4.1	2.3	2.1	3.0	2.1	2.0	3.0	1.9	1.9	1.9	1.7	2.3
HFO (closed cell) Spray Foam	**4.21**	3.4	3.8	3.0	3.3	3.1	5.5	3.1	2.8	4.0	2.9	2.6	4.0	2.5	2.6	2.6	2.4	3.1
Mineral Wool (light board) Batt	**4.22**	3.4	3.8	3.0	3.3	3.1	5.5	3.1	2.8	4.0	2.9	2.7	4.0	2.5	2.6	2.6	2.4	3.1
HFC (closed cell) Spray Foam	**11.07**	9.0	10.0	7.8	8.7	8.2	14.6	8.0	7.5	10.5	7.6	7.0	10.6	6.6	6.8	6.9	6.2	8.1
Cellulose Batts	**N/A**	N/A																
Wood Fiber Batts	**N/A**																	
Wood Fiber Loose Fill	**N/A**																	
Phenolic Foam	**1.62**	1.3	1.5	1.1	1.3	1.2	2.1	1.2	1.1	1.5	1.1	1.0	1.5	1.0	1.0	1.0	0.9	1.2
Polyisocyanurate-Roof Foam	**2.30**	1.9	2.1	1.6	1.8	1.7	3.0	1.7	1.6	2.2	1.6	1.4	2.2	1.4	1.4	1.4	1.3	1.7
EPS Board	**2.80**	2.3	2.5	2.0	2.2	2.1	3.6	2.0	1.9	2.7	1.9	1.8	2.7	1.7	1.7	1.7	1.6	2.0
Polyisocyanurate- Wall Foam	**4.29**	3.5	3.9	3.0	3.4	3.2	5.6	3.1	2.9	4.1	2.9	2.7	4.1	2.6	2.6	2.7	2.4	3.1
XPS Board	**5.08**	4.1	4.6	3.6	4.0	3.8	6.6	3.7	3.4	4.8	3.5	3.2	4.9	3.0	3.1	3.2	2.9	3.7
Mineral Wool (heavy density) Board	**7.97**	6.5	7.2	5.6	6.3	5.9	10.4	5.8	5.4	7.6	5.5	5.0	7.6	4.7	4.9	5.0	4.5	5.8
Wood Fiber Board	**N/A**	N/A																

5 Conclusions

The key takeaways from this study can be summarized as follows:

The average carbon payback period for whole building insulation of residential and commercial prototypes was found to be generally under a year for most investigated insulation materials. It is observed that the average carbon payback periods are higher in plastic insulation materials compared to organic insulation materials due to the relatively large embodied carbon associated with the processing stage of material production. The use of closed-cell HFC and heavy-density mineral fiber in the residential prototype resulted in longer payback, approaching four years for cooling dominant climates.

The results show that regardless of the insulation type, insulation is generally an impactful measure that yields significant carbon emission savings over the lifetime of the building compared to other energy efficiency measures. Over the projected 75-year lifespan of the insulation materials, the average emission savings are conservatively estimated to be 7 to 52 times greater than the embodied carbon for the residential prototypes, but this range can reach up to 127 to 944 times, depending on the climate zone and insulation material used. Similarly for the commercial prototypes, the average emission savings are conservatively estimated to be 29 to 110 times greater than the embodied carbon, reaching up to 526 to 1,996 times, depending on the climate zone and insulation material used.

This evaluation study of carbon payback period helps in establishing the relationship between the emissions associated with the production of each insulation material and the emissions avoided each year due to the application of the insulation to the building envelope.

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