Life Cycle Assessment of Buildings: *A Simple Example*

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A Simple Example

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Project Team

Kathrina Simonen
Monica Huang
Barbara X. Rodriguez
Lindsay Todaro

Graphics Team

Mazohra Thami
Thipok Cholsaipant
Meghan Lewis

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Introduction

This document presents a simple example of the steps in *Life Cycle Assessment of Buildings: A Practice Guide* (referred to as the Practice Guide in this document). A small gingerbread house is used instead of a real-life building for the sake of simplicity, and also to focus attention on the process instead of the material results. All of the numbers for this example have no basis in reality, including the environmental impacts calculated in the later steps.

Some pages have a box (example shown at the right) that discusses the checkpoint steps from Figure 5 of the Practice Guide.

Checkpoint:

Step 1: Define Goal and Scope

For Step 1, the goal and scope of the assessment are presented in Table 1 and Table 2, respectively. The parameters are organized hierarchically according to the *LCA Taxonomy* in the **Online Resources**. In the taxonomy, some parameters do not have lower-level categories, and are indicated here by “N/A”. Note that the taxonomy structure shown here may not reflect the latest version of the taxonomy in the Online Resources. The details for the gingerbread house example are indicated in red text. Some non-critical entries are left blank in this example.

Table 1. Goal description per the LCA taxonomy.

Parameter, Category Level 1	Parameter, Category Level 2	Parameter, Category Level 3	Parameter, Category Level 4	Parameter, Category Level 5	Parameter Field
1. Goal and scope	Goal	Assessment goal	Intended application	N/A	To demonstrate the basic steps of performing an LCA of a building in accordance with the steps outlined in this Practice Guide.
		Background information on assessment	Client for assessment or intended audience	N/A	Building designers or others in the building industry who are learning how to perform an LCA for the first time.
			Name and qualification of assessor	N/A	
			Organization of assessor	N/A	
			Project phase at time of LCA assessment	N/A	Final design
			Year of LCA assessment	N/A	
			Source(s) of environmental impact data	N/A	Environmental impact data for materials were fabricated for the purposes of this study. Energy impacts were estimated from www.EnergyUseCalculator.com and US EPA eGrid data.

Table 2. Scope description per the LCA taxonomy.

Parameter, Category Level 1	Parameter, Category Level 2	Parameter, Category Level 3	Parameter, Category Level 4	Parameter, Category Level 5	Parameter Field
1. Goal and scope	Scope	Functional equivalent	Area characteristics	Building footprint area [in^2]	12.5
				Total gross floor area (GFA) [in^2]	25
			Building model	Building occupancy type and pattern of use	Occupancy type: High hazard (Group H) per the International Building Code.
				Building use type(s)	11-13 21 Military Facility (per OmniClass Table 11)
				Daylight simulation performed	No
				Design life expectancy	1 year
				Design number of building occupants	0
				HVAC design optimization performed	No
				Natural ventilation simulation performed	No
				Parking lot type and size	No parking lot
				Relevant technical and functional requirements	Must conform to the International Gingerbread House Building Code.
				Required service life (ReqSL) [days]	30
				Structural type	Gingerbread
			Geographic and site characteristics	Climate zone	4C (per IECC)
				Landscaping description	Skittles arranged at 1 inch on center around perimeter of building
				Location - address	
				Location - city	Seattle
				Location - country	United States
				Location - state/province	Washington
				Natural hazard area description	The gingerbread house is not located in a flood zone, but it is at risk for earthquakes, volcano eruptions, and tsunamis.
				Seismic zone description	Using the USGS Seismic Design Maps, with ASCE 7 (2010), Site Class D, Risk Category II, and the geographic coordinates of Seattle, the ground motion values are: S_S = 1.527 g, S_{MS} = 1.527 g, S_{DS} = 1.018 g, S_1 = 0.574 g, S_{M1} = 0.860 g, S_{D1} = 0.574 g
				Soil type	Site Class D
			Height characteristics	Average ceiling height [in]	4.84
				Building total height [in]	9.68
				Number of stories above grade	2
				Number of stories below grade	0

Table 2 (cont.). Scope description.

Parameter, Category Level 1	Parameter, Category Level 2	Parameter, Category Level 3	Parameter, Category Level 4	Parameter, Category Level 5	Parameter Field
1. Goal and scope (cont.)	Scope (cont.)	Project information	BIM model available	N/A	
			Building architect name, engineer, and/or contractor	N/A	
			Building owner, developer, and/or manager	N/A	
			Project construction cost	N/A	$5.00 USD
			Project name	N/A	The Gingerbread House LCA Prototype Building
			Rating achieved	N/A	
			Rating scheme	N/A	
			Year of building commission	N/A	
			Year of construction	N/A	
			Year of occupancy	N/A	
			Year of refurbishment	N/A	Not applicable (no refurbishment anticipated)
		Reference study period [days]	N/A	N/A	30
		System boundary*	Building scope	N/A	The building scope includes all applicable components from the reporting template in the Technical Guidance of the **Online Resources**, summarized as follows: • Substructure: Slabs-On-Grade • Superstructure: Floor Construction • Exterior Enclosure: Exterior Walls • Sitework: Site Improvements
			Life cycle modules included	N/A	Includes cycle modules A1 – C4. Module D is not included. Note that while modules B1 - B7 are considered in the assessment, only B4 (Replacement) was assessed to have an impact, and the remaining modules were determined to have no impact (see Table 4).
			Environmental impact categories assessed	N/A	Global warming potential

			Specific exclusions	N/A	This assessment excludes:
					• Impact of manufacturing supporting machines and products, such as:
					  • Vehicles used for transportation
					  • Ovens used for baking
					  • Lighting needed to assemble the gingerbread house
					  • Kitchen utensils
					• Feeding, housing, and transportation of construction labor
					• Impact of ingredient packaging, including disposal
					• Energy impacts of installing material replacements (assume that baking is not needed for replacing materials)
					• Energy impact of supplying washing water

* Due to space constraints, the system boundary is not described in detail per the LCA taxonomy guidelines here. Instead, a summary of the key components are shown.

Step 2: Collect Inventory

The inventory collection involves defining the materials used in the building and relevant scenarios. Table 3 lists material information about the gingerbread house, and Table 4 describes the scenarios for the materials, including assumptions regarding transportation, energy, water, and end-of-life. The materials were categorized by building component (per the Omniclass system) to facilitate later analysis.

Table 3. List of materials and relevant information.

Material name	Units	Material quantity	Life span [days]	Applicable life cycle stages (see Table 4 for more information)	Building component category (OmniClass Level 1)	Building component (OmniClass name)
Dark Chocolate	oz	6	10	A1 - A5, B4, C1 - C4	Substructure	Slabs-On-Grade
Icing	lb	0.5	10	A1 - A5, B4, C1 - C4	Substructure	Foundations
Cardboard (1/4”)	in^2	100	3000	A1 - A5, C1 - C4	Substructure	Foundations
Gingerbread*	cups	2.5	10	A1 - A5, B4, C1 - C4	Exterior Enclosure	Exterior Walls
Icing	lb	1	10	A1 - A5, B4, C1 - C4	Superstructure	Floor Construction
Candy Canes	each	6	15	A1 - A5, B4, C1 - C4	Site Work	Site Improvements
Licorice	each	4	15	A1 - A5, B4, C1 - C4	Site Work	Site Improvements
Skittles	each	8	15	A1 - A5, B4, C1 - C4	Site Work	Site Improvements

*To avoid a long list of ingredients, we will assume that the gingerbread dough is pre-made (store-bought).

Checkpoint: *Can you find all the necessary LCA and building data?*

Yes, we were able to produce the data that we needed for the inventory. However, if we hadn’t been able find enough information about certain materials or if we were not able to describe the scenarios in sufficient detail, we would have had to go back to Step 1 and revise the goal and/or scope to reflect this. For example, if we had not been able to determine the replacement rate of chocolate, we would have had to revise the scope information in Step 2. Under ‘Life cycle modules included’ in Table 2, we would note that “Module B4, Replacement, for chocolate is not included in this analysis due to lack of available information about chocolate replacement rates in gingerbread houses.”

Table 4. Scenario descriptions for materials by life cycle stage.

Life Cycle Module	Material Scenarios*						
	Dark Chocolate	Gingerbread	Icing	Candy Canes	Licorice	Skittles	Cardboard (1/4")
A4: Transport	Transport materials from grocery store to kitchen[1]. Assume that the mode of transportation is car and distance traveled is 5 miles.						
A5: Construction installation	1. Bake gingerbread for 15 min @ 350 degrees F in an electric oven with 15 min of preheating. Assume that oven is at average efficiency and electricity is based on US EPA eGrid region NWPP. 2. Assemble gingerbread house with remaining ingredients by hand on cardboard. No additional energy beyond human labor is needed (no fuel, electricity, or water is consumed during assembly). 3. Waste: Plastic and other non-recyclable packaging that originally contained the ingredients (materials) is disposed in the trash bin. 4. Water use: Assume that 1 gallon of domestic, unheated water is used to clean the mixing and baking equipment post-assembly.						
B1: Use	Aromas of gingerbread, chocolate, and sugar in general will be emitted into surrounding environment. Assume that these aromas have a negligible environmental impact. Assume that cardboard has a negligible environmental impact during use. Occasional dusting may be required, but environmental impact of dusting is ignored due to lack of data and method to report.						
B2: Maintenance	Occasional dusting may be required, but environmental impact of dusting is ignored due to lack of data and method to report.						
B3: Repair	Repair is not anticipated.						
B4: Replacement	Chocolate replaced 2 times.	Gingerbread replaced 2 times.	Icing replaced 2 times.	Candy canes replaced 1 time.	Licorice replaced 1 time.	Skittles replaced 1 time.	No replacement needed for cardboard.
B5: Refurbishment	Refurbishment is not anticipated.						
B6: Operational energy use	No energy requirements – this is a passive house.						
B7: Operational water use	No water requirements – gingerbread occupant does not require water-based amenities.						
C1: Deconstruction, demolition	The gingerbread house will be disposed of in its entirety in the composting bin, which will be taken to the local composting facility.						The cardboard will be disposed of in the recycling bin.
C2: Transport	Transportation to the composting facility will be performed by a collection truck over a distance of 20 miles.						Cardboard will be taken by collection truck to the recycling facility, over a distance of 10 miles.
C3: Waste processing	The remains of the gingerbread house will be taken directly to the composting facility.						Cardboard will be sorted, shredded, pulped, filtered, de-inked, then finished for re-use.
C4: Disposal	At the composting facility, the remains of the gingerbread house will join the composting feedstock, which will be allowed to mature under ideal conditions.						Not applicable (final product will be used to make new cardboard).

*The scenario descriptions are all based on common recipes for gingerbread house-making. Description of end-of-life composting processes are based on general information from the EPA. Description of end-of-life cardboard recycling processes are based on information from Conserve Energy Future.

[1]Assume that the grocery store is the "factory," though in reality the factories are meant to be the buildings in which the materials (ingredients) were made.

Step 3: Perform Impact Assessment

If you are using a software tool to help you perform your LCA, it is unlikely that you will need to go into as much detail as this step illustrates. This step demonstrates the basic principles of performing an impact assessment calculation, starting with the environmental impact factors (LCA source data), determining replacement rates of certain materials, then performing the mathematical computations.

Step 3.1 Gather environmental impact factors (LCA source data)

Before performing the calculations, we must first obtain the environmental impact factors for each material collected in Step 2. The environmental impact factors used for this gingerbread house example are shown in Table 5 (these values were fabricated for this example).

Due to space constraints, this example groups the impact factors by life cycle stages, and considers global warming potential (GWP) as the only environmental impact measure. However, in a comprehensive LCA, you would separate the factors by life cycle module (A1, A2, A3, etc.), and would likely consider additional impact categories in addition to GWP.

Table 5. Environmental impact factors of materials. Note that these factors were fabricated for this example and have no basis in reality.

Material	Units	Global warming potential [g CO2e/unit of material]			
		Production stage (A1-A3)	Construction stage (A4-A5)	Use stage (B1-B7)	End-of-life stage (C1-C4)
Dark chocolate	oz	16	1	0	3
Milk chocolate	oz	20	4	0	7
Cardboard, 1/4"	in2	0.5	0	0	0.5
Icing (foundation)	lbs	6	8	0	3
Gingerbread	cup	10	3	0	4
Icing (floor construction)	lbs	6	8	0	3
Candy canes	each	7	6	0	9
Licorice	each	4	2	0	9
Skittles	each	8	1	0	7

Step 3.2 Determine replacement requirements

The next step is to consider how some materials will have to be replaced over the required service life (and RSP) of 30 days, due to their shorter life spans. The effects of this replacement are considered under module B4: Replacement, which is within the Use stage. We will assume that no baking is required to install replacement material.

Here is an example of how to calculate the number of replacements required for the Use stage:

> *6 oz of dark chocolate is required for the slab-on-grade. The life span of dark chocolate is 10 days. After the initial installation, the chocolate will have be replaced two times over the 30-day required service life of the gingerbread house LCA.*

> Number of replacements required
> = (30 days) / (10 day life span) – 1 instance for initial installation
> = 3 – 1
> = 2 replacements

> Total quantity of chocolate to be replaced = (6 oz) * (2 replacements) = 12 oz

Table 6 presents the number of replacements and quantities needed for all materials in the use stage.

Table 6. Number of replacements and material quantities needed for the Use stage calculations.

Material	Units	Material quantity at installation [units from the Units column]	Life span [days]	Number of replacements needed	Material quantities for use stage [units from the Units column]
Dark chocolate	oz	6	10	2	12
Icing (foundation)	lbs	0.5	10	2	1
Cardboard, 1/4"	in^2	100	3000	0	0
Gingerbread	cup	2.5	10	2	5
Icing (floor construction)	lbs	1	10	2	2
Candy canes	each	6	15	1	6
Licorice	each	4	15	1	4
Skittles	each	8	15	1	8

Step 3.3 Calculate material impacts

Now we can apply the environmental impact factors from Table 4 to the material quantities. Note that in order to comply with the modularity principle (which states that the impact of a process shall be assigned to the life cycle stage that it influences), the Use stage will need to include the production and construction stage impacts of the replacements as well as the end-of-life stage impacts from the initial installation.

An example calculation for dark chocolate is shown as follows:

GWP of production stage = (6 oz) * (16 g CO2e/oz) = **96** g CO2e

GWP of construction stage = (6 oz) * (3 g CO2e/oz) = **18** g CO2e

GWP of use stage = (12 oz) * [(16 g CO2e from product stage + 3 g CO2e from construction stage + 3 g CO2e from end-of-life stage)/ oz]

= (12) * (16 + 3 + 3) = **264** g CO2e

GWP of end-of-life stage = (6 oz) * (3 g CO2e/oz) = **18** g CO2e

The final global warming potential results for all materials and life cycle stages are shown in Table 7, with the results from above indicated in bold red text.

Table 7. Global warming potential results by life cycle stage.

Material	Global warming potential [g CO2e]			
	Production stage (A1-A3)	Construction stage (A4-A5)	Use stage (B1-B7)	End-of-life stage (C1-C4)
Dark chocolate	**96**	**18**	**264**	**18**
Icing (foundations)	3	4	17	1.5
Cardboard, 1/4"	50	0	0	50
Gingerbread	25	7.5	85	10
Icing (floor construction)	6	8	34	3
Candy canes	42	36	132	54
Licorice	16	8	60	36
Skittles	64	8	128	56

Step 3.4 Estimate construction impacts

After calculating the material impacts in the previous steps, the next step is to calculate the energy impacts due to construction (module A5: Construction Installation) as a result of baking.

In Step 2, we had assumed in the scenarios that the gingerbread would be baked at 350 degrees F in an average efficiency oven using electricity from the NWPP subregion of eGrid. Preheating the oven would require 15 minutes, and baking would require an additional 15 minutes. The average modern oven is assumed to consume 2400 watts (W) at medium-high heat[1]. The greenhouse gas emission rate for the NWPP subregion is 913.4 lb CO_2e/MWh. Thus, the calculation for obtaining the total GHGs or global warming potential produced as a result of using the oven for 30 minutes or 0.5 hours (h) is:

$$\text{GWP impact of baking} = (0.5)(2400W)\left(\frac{913.4\ lb}{MWh}\right)\left(\frac{1\ MWh}{10^6 Wh}\right)\left(\frac{1\ kg}{2.2 lb}\right)\left(\frac{10^3\ g}{1\ kg}\right)$$

$$= 498\ g\ CO_2\ e$$

This impact will be added to the Construction stage impacts.

Checkpoint: *Are you able to calculate the LCA impacts?*

Yes, we were able to calculate the LCA impacts using a spreadsheet, but if we were using a software tool that was unable to complete this step (due to lack of appropriate material data, or even technical problems), then we would have to consider another tool. In that case, we would go back to Step 1, note the new software or data under *Goal > Background information on assessment > Source(s) of environmental impact data*, check Step 2 if necessary, then re-perform Step 3.

[1] EnergyUse Calculator, "Electricity usage of an Oven." http://energyusecalculator.com/electricity_oven.htm

[2] US EPA, "eGRID 2014 Summary Tables," 2014. https://www.epa.gov/energy/egrid-2014-summary-tables

Step 4: Interpret Results

Step 4.1 Visualize results

After an initial overview of the LCA results (Table 7), a good first step is to visualize the results by breaking down the environmental impacts by building component, material type, and/or life cycle stage.

Figure 1 presents a simple overview of the global warming potential results of the materials by life cycle stage subdivided by building component category and color-coded by material contribution.

Figure 2 presents a simplified version of Figure 1, but with energy consumption included to compare with the total material impacts by life cycle stage. Note that there are no impacts in the Use stage, but a real building would be expected to produce energy impacts as well as water impacts over the building lifetime.

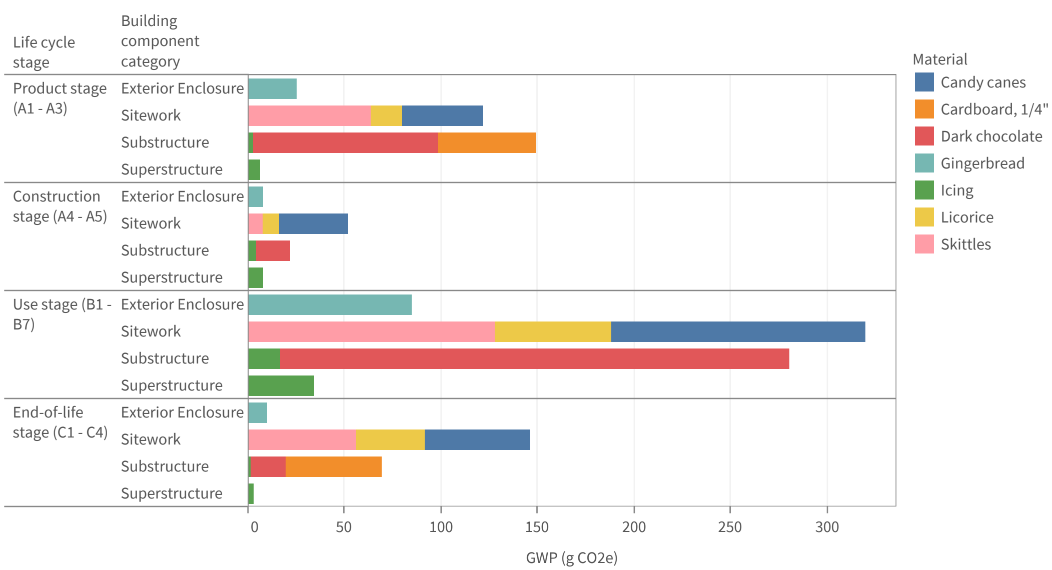

Figure 1. Gingerbread house example. Global warming potential (GWP) results by life cycle stage and building component category.

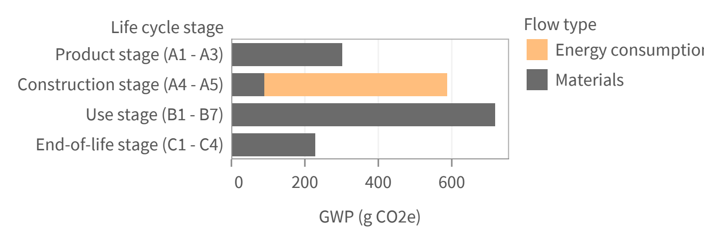

Figure 2. Gingerbread house example. Contribution of materials, water use, and energy consumption to overall GWP of the building.

Step 4.2 Check for errors

Since no other LCAs of gingerbread houses have been published, we can not compare our results to similar studies to check if our results are in the same ballpark. Instead, we must ponder if the results make sense. We can consider the following:

- *If one element in the graphs dominates over the other elements, can you explain why?* In Figure 1, there is no obvious outlier in the results, which is a good sign. The Use stage impacts are greater than that of the other stages, which makes sense because these materials have to be replaced 1 or 2 times during the Use stage (except for Cardboard).

- *Do the contributions from the different elements make sense?* Looking at the material color-coding in Figure 1, we can see that gingerbread appears under Exterior Enclosure, Skittles appears under Sitework, Dark Chocolate appears under Substructure, etc., so it appears that the LCA results correctly reflect the materials assigned to the different building components.

At this point, we don't see indications for errors, so we can move on to the next part of interpretation.

Checkpoint: *Can you find errors in the results?*

We did not find errors or suspicious patterns in the results, but if we did, we would go back to Step 2, check the inventory data, and re-perform Step 3.

Step 4.3 Understand results

To better understand the results, we can perform a sensitivity analysis and uncertainty analysis to see how the variables affect the overall results.

Sensitivity analysis: For example, let's say we want to double the RSP from 30 days to 60 days. Figure 3 compares the results for these two RSPs. From this figure, we can see that the Use stage reflects the increase in RSP as a result of the additional material replacements. To quantify the overall effect, we can say that "Doubling the RSP resulted in a 172% increase in Use stage impacts, or a 67% increase in overall impacts." Since the use stage impacts were already a large portion of the overall impacts, one can conclude that the overall results are sensitive to the choice of reference study period.

Checkpoint: *Do you need to understand the importance of certain variables?*

You can skip this step if the goal of your study does not require you to understand how certain variables affect the LCA results; for example, if you simply need to report the carbon footprint of your building. However, the goal of performing an LCA is often to inform a more environmentally-conscious building design or meet reduction targets. Identifying high-impact variables can help you achieve these goals more easily and efficiently.

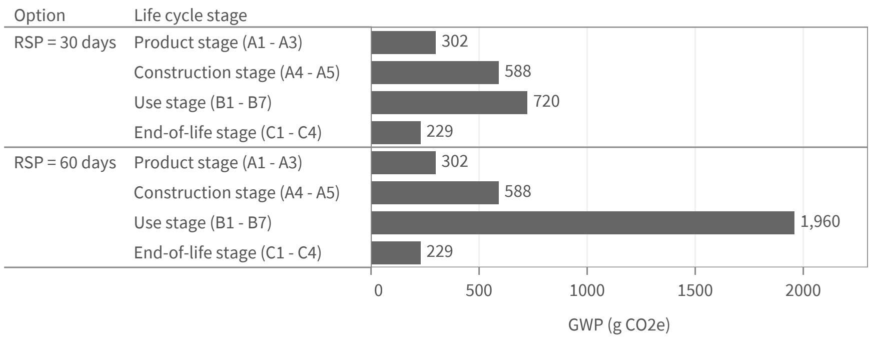

Figure 3. Sensitivity analysis of the effect of doubling the reference study period from RSP = 30 days to RSP = 60 days.

Uncertainty analysis: For example, let's presume that we are uncertain about the cocoa content in the dark chocolate used for the slab-on-grade. We can explore this uncertainty by comparing two options for chocolate: dark chocolate versus milk chocolate. The comparison of the results for these two options is shown in Figure 4. From this figure, we can observe that milk chocolate has slightly higher impacts than dark chocolate in all four life cycle stages, but the difference is not too significant. From this comparison, we can conclude that the overall LCA results are not sensitive to the type of chocolate used for slab-on-grade, but dark chocolate would be the environmentally preferable option.

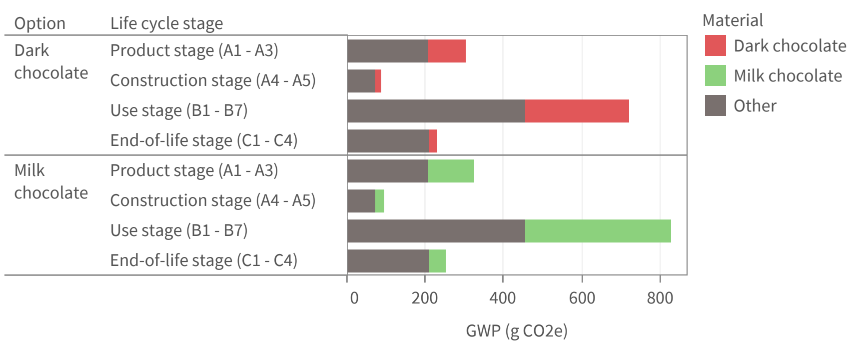

Figure 4. Comparison of two material options for slab-on-grade: dark chocolate vs milk chocolate.

Step 4.4 Develop conclusions

After performing Step 4, we must ask ourselves: Do the results satisfy the goal of the study? From Step 1, the goal of this example was to "demonstrate the basic steps of performing an LCA of a building in accordance with the steps outlined in this Practice Guide." We can conclude that yes, we have accomplished the simple goal of this study, as seen in the example sections for Steps 1, 2, and 3. We can now move on to Step 5.

Checkpoint: *Does your analysis meet the goal and scope of your study?*

The goal of this example was facetious, so it was easily met, but in a real building LCA you may not meet the goal of your study on the first try (for example, meeting a reduction target). You will likely have to either a) change your design update the inventory data in Step 2, or b) revise the goal or scope in Step 1 to reflect changes in your assumptions. This process would have to be repeated until you do meet your stated goal.

Step 5: Report Results

The documentation of information for the gingerbread house example is documented in the previous steps.

For verification (optional), a sample response to the verification process is shown in Table 8.

Table 8. Sample responses to verification process.

Requirement	Response
1. Consistency: Are the system boundaries and scenarios used consistent with the analysis goal and scope?	Yes. The goal of the analysis was to "demonstrate the basic steps of performing an LCA of a building in accordance with the steps outlined in this Practice Guide," which aims to clarify best practices in whole building LCA. The scope of the gingerbread house study included all of these considerations (as much as possible, since the simplicity of the gingerbread house limited the full breadth of information that would normally be present in a real building). Thus, the system boundaries and scenarios reflect the goal and scope of the study.
2. Data: Is the LCA data used representative of the products being evaluated? Was the data developed in conformance with ISO 21930?	No. For the purposes of this example, the LCA data was entirely fabricated for all of the materials in this study and not developed in conformance with ISO 21930. The energy and water use data was based on eGrid, which reflects the geographic region of the study.
3. Scenarios: Are the scenarios representative of practice? Are the scenarios that were used for different products aligned?	The scenarios are fairly representative of typical gingerbread house-making practice. Many of the products/materials underwent the same scenarios, so they are aligned.
4. Completeness: Does the analysis include all relevant components to meet the intentions of the described goal and scope?	Yes.