Michigan Baseline Housing Study

May 25, 2021

Presented to:

Joseph Forcillo
Director of Evaluation,
Measurement & Verification
Clean Energy Products
Consumers Energy
One Energy Plaza
Jackson, MI 49201

Jason Kupser
Manager, Evaluation,
Measurement & Verification
Energy Efficiency
DTE Energy
One Energy Plaza
Detroit, MI 48226

Presented by:
Cadmus
2490 Junction Place, Suite
400
Boulder, CO 80301

Acknowledgements

This report is a deliverable submitted to Consumers Energy and DTE Energy as part of a multiyear, independent calibration research study to analyze the baseline energy conditions in Michigan homes. The results of this study will be used to improve the energy efficiency programs across the state of Michigan and update the Michigan Energy Measures Database. Cadmus led this research with the support of multiple entities, including Apex Analytics and Guidehouse. The Cadmus team would like to acknowledge their invaluable contributions and support to complete this work. Additionally, Cadmus would like the acknowledge and thank, BuildingMetrics, ClearResult, Morgan Marketing Partners and the EWR Collaborative members for providing valuable feedback throughout the development of the project and supporting the objectives of this study.

Prepared by:

Amy Ellsworth, Principal, Cadmus

Shannon Donohue, Associate, Cadmus

Emily Miller, Senior Associate, Cadmus

Steve Cofer, Principal, Cadmus

Prepared for:

Joseph Forcillo, Director of Evaluation, Measurement and Verification, Clean Energy Products, Consumers Energy

Jason Kupser, Manager, Evaluation, Measurement & Verification, Energy Efficiency, DTE Energy

Table of Contents

Tables

Figures

Executive Summary

Consumers Energy and DTE Energy contracted with an independent evaluation team led by Cadmus to assess the characteristics of the Michigan residential building stock and the impacts of this study on various home parameters in the *Michigan Energy Measures Database* (MEMD). The baseline housing study is a broad study of the lower peninsula of Michigan that characterizes the building stock within two climate zones (5 and 6)[1] and two housing types: single family homes[2] and multifamily buildings. This report presents findings based on data collected from 195 completed site visits. The Cadmus team weighted the results to ensure that building observations were weighted proportionally to the segments of the population represented in the sample. In-home observation and data collection began in July of 2019 and ran through the fall of 2020. The study was temporarily halted in March through August of 2020 due to the COVID-19 pandemic.

The primary objective of the study is to characterize the existing residential building stock within Consumers Energy and DTE Energy service territory, which makes up approximately 98%[3] of the state's population of households, from a representative sample of homes. The Cadmus team designed the study to account for regional differences, such as climate, housing type, homeownership, and household income levels. The characterization includes the principle characteristics of homes (e.g., square footage, insulation levels, and heating systems), their occupants (e.g., household size and income levels), and the end-use equipment (e.g., lighting and appliances) that together define residential energy usage. This study was in part developed to support the Michigan Public Service Commissions (MPSC) maintenance of the state's energy efficiency database (known as the Michigan Energy Measures Database or MEMD).

This document is organized to outline the needs of key stakeholders in the MEMD update process:

- *Summary of Key Findings, Conclusions, and Recommendations,* outlines key findings and recommendations for stakeholders.
- *Study Overview,* outlines the background and objectives of this study.

---

[1] International Code Council (ICC) defined climate zones used in building construction standards. The upper peninsula of Michigan was not included in this study as there are no customers served by these utilities. Upper peninsula homes are being studied in a separate study funded by the Michigan Public Service Commission (MPSC).

[2] Single-family homes include site-built and modular homes on a permanent foundation. Manufactured homes were excluded from this study during the scoping process. DTE Energy finalized a pilot study in June of 2019 of 83 manufactured homes. [The 2018/19 Manufactured Homes Pilot, DTE Energy]

[3] Combined Consumers Energy and DTE Energy serve approximately 3,793,405 addresses in Michigan, according to the American Community Survey 5-year estimates from 2016 Michigan has approximately 3,860,394 occupied housing units.

- Detailed Findings: Mechanical Systems*,* outlines study findings related to mechanical equipment found in Michigan homes.
- *Detailed Findings: Building Construction and Envelope,* outlines study findings related to construction characteristics, size of dwellings, and insulation.
- *Detailed Recommendations: Key Datapoint Updates* outlines significant differences to the MEMD, warranting updates. In this section the team provides recommended values to be incorporated into the MEMD.
- Study Overview,
- *Summary of Methodologies*, outlines the methods and processes the team used to identify participants in the study, visit their homes and gather data relevant to the objectives of the study. This section also covers how data was managed, reviewed and processed.
- Four Appendices are included at the end of this document outlining;
  - The survey used to recruit customers**;** *Appendix A. Customer Recruitment Survey*
  - The certification letter customers received upon recruitment*; Appendix B.* Certification Letter
  - Details of the types of data collected onsite through the teams tablet-based tool*; Appendix C. Datapoints Collected*
  - Details the methodology used to process field collected data related to home insulation levels; Appendix D*. Thermal Transmittance Calculations*

Summary of Key Findings, Conclusions, and Recommendations

This section presents the Cadmus team's key research findings, conclusions, and recommendations associated with our research objectives. The detailed findings chapters of this report provide further explanation and the context for our conclusions and recommendations. These recommendations are tailored for natural gas and electric service providers in Michigan, members of Energy Waste Reduction (EWR) Collaborative, MEMD Technical Subcommittee, the Technical Subcommittee Chair and the MEMD Developers (Morgan Marketing Partners, MMP). Findings outlined in *Detailed Recommendations: Key Datapoint Updates,* provide further details on the specific parameters and values we are recommending to be updated. These updates reference the weather sensitive documentation[4] provided each year with the MEMD.

[4] Michigan Statewide Energy Savings Database Weather Sensitive Retrofit Measures for Residential and Commercial Buildings, BuildingMetrics Incorporated, Updated October 15, 2020

Executive Summary

To assist various stakeholders in prioritizing the actions needed to address these recommendations, the Cadmus team organized each recommendation by topic and prioritized them based on the following definitions.

- ***High Priority:*** The study revealed compelling and conclusive data that is likely to have an impact on MEMD modeling and energy savings calculated for weather sensitive measures
- ***Medium Priority:*** The team estimates that implementing this recommendation would improve the quality and results of the MEMD but is based on compelling evidence and observations outside the formal experimental design of this study.
- ***Low Priority:*** Considerations for future improvement of the MEMD and weather-sensitive measures development process.

CONCLUSION 1: In general, the year a home was constructed (i.e., its vintage) had the strongest correlation with that home's efficiency and levels of insulation; additionally, the vintage bins defined in the MEMD could be better aligned with the efficiency levels of Michigan Lower Peninsula homes.

The team explored homeownership type (homeowners versus renters) and household income (greater than or less than $40,000/year) as variables correlating to overall home efficiency and envelope insulation levels, but found that – in aggregate – the year in which sampled homes were constructed had the greatest impact on their insulation levels. There were certain areas where household income and homeownership type correlated with building characteristics, specifically for heating and cooling system efficiencies; however, these results were localized and not consistent across home types or climate zones.

The current vintages used in the MEMD are not explicitly defined in MEMD documentation and have room for subjective interpretation making direct comparisons difficult. However, the commonly accepted years of construction consisting of old, existing, and new are pre-1978, 1980 to 2005 and post-2005. The team found prevailing codes and standards, and trends in the sample population indicated differences in the population starting in 1979, with additional trends between 1980 and 1997 and after 1998. The current energy code[5] went into effect in 2015 with specific requirements that relate to newly built homes. From the housing data and reviewing the state codes over time, adding an additional vintage and redefining the existing vintages would better characterize single-family and multifamily homes.

RECOMMENDATIONS

High Priority: The MEMD developers should update the definitions of home vintage in the MEMD to align with specific years of construction and the prevailing codes and typical home characteristics corresponding to homes built during that time period. To account for changes to codes and standards, a new construction vintage bin should be established. These new vintage bins should include homes built before 1979, between 1979 and 2015, and beyond 2016. The building characteristics of vintages through 2015 represent homes included in this study while homes built after 2016 represent a newly constructed home, built to code. Specific recommended parameters and the data used to define these vintages are outlined in *Detailed Recommendations: Key Datapoint Updates; Home Vintages*.

Medium Priority: Based on the study findings that home vintage was predictive of home efficiency, the MEMD Developers and the MEMD Technical Subcommittee should review the MEMD vintages annually to assess the need for additional tiers due to code and standard changes. Changes requiring periodic updates include federal standard changes to update HVAC efficiencies and state building code changes requiring updates to the building envelope characteristics. New codes and

[5] Michigan Energy Code adopted October 9, 2015, based on the International Energy Conservation Code 2015 edition,

standards adopted in Michigan should initiate a discussion if the characteristics of newly constructed homes should be set at code or another standard based on quantitative research.

CONCLUSION 2: Michigan homes are exceptionally variable, which limits the ability for deemed measures to accurately represent savings for all types of home energy usage characteristics associated with efficiency upgrades.

The current MEMD measures are developed assuming an average home with insulation upgraded to a higher standard. This method implicitly assumes all homeowners are equally likely to upgrade the insulation in their home. Our findings indicate homes are similar based on their vintage but not identical. Accounting for the variability in the population of homes would both increase the precision of the energy savings estimates and allow the users of the MEMD to target homes that would benefit the most from insulation upgrades. This variability can be accounted for by including measure baseline characteristics that represent more types of homes.

While homes of similar vintages may have been built to similar standards, some homeowners make changes and upgrades to their homes over time. Homes may also deteriorate or undergo additions or major renovations significantly affecting their energy consumption characteristics and the corresponding energy savings available from further upgrading the home. Of the dwellings visited in the study, 66% of basements and crawlspaces, 15% of above grade walls[6], and 2% of attics were un-insulated. Even relatively new homes would benefit from insulation measures where the existing insulation had failed (e.g., fell down, improperly secured to the insulating surface), degraded (e.g., settled and compressed attic and wall insulation, rotted from moisture, missing areas of insulation), or been damaged (e.g., physical damage, environmental damage).

RECOMMENDATIONS

High Priority: The MEMD Developers should update the baseline and measure characteristics for single-family and multifamily envelope insulation measures to better represent baseline home characteristics. A new construction baseline should also be included in the MEMD to allow builders to apply prescriptive upgrades to newly constructed homes. Detailed recommendations for changes to insulation measures are provided in *Detailed Recommendations: Key Datapoint Updates Insulation Measure Characteristics*. The measures upgrades are based on observed home characteristics and common upgrades.

High Priority: Natural gas and electric service providers should document baseline insulation levels in homes receiving insulation upgrades that are relevant to the upgrade (e.g., existing wall insulation levels prior to the measure upgrade). This data should be gathered as a standard part of

[6]Above grade walls are referring to wood framed and masonry exterior walls of the dwelling.

the application process and would be used to determine energy and demand savings associated with insulation upgrades. Collecting this data along with the aforementioned MEMD updates would allow utilities to capture unrealized savings and identify measure opportunities.

CONCLUSION 3: Individual room cooling systems are used in a significant number of both single-family and multifamily dwellings, but these conditions are not represented in MEMD savings calculations.

The MEMD currently assumes that central cooling systems are the only type of cooling used in single-family homes, while this study that found approximately 20% of single-family dwellings visited used room or window air conditioners (primarily window air conditioners) as their only source for mechanical cooling. Many homes had multiple room cooling systems, averaging more than two systems that serve approximately 2/3 of the dwelling area. The MEMD excludes all cooling energy savings in homes with room cooling systems when insulation is added. Adding room cooling as an HVAC option would allow those customers to be targeted with weather dependent measures that save cooling energy such as insulation measures, air sealing and high efficiency heat pumps. .

Additionally, the MEMD assumes package terminal air conditioners and heat pumps are the primary room cooling options for multifamily homes. Cadmus found other room cooling systems include window air conditioners (22% of homes) to be more common in the population than package terminal system (2% of homes). Package terminal air conditioners operate in very similar way to as other room cooling systems and could be combined into one category.

RECOMMENDATIONS

High Priority: The MEMD Developers should include window and room cooling options among the HVAC types used in developing weather sensitive measure savings. We outline our proposed HVAC system types and proposed efficiency updates in *Detailed Recommendations: Key Datapoint Updates, HVAC Systems*. These updates add two new categories for single-family HVAC systems, including adding room cooling for homes with either electric or gas heating. Multifamily package terminal systems should be updated to include room cooling or package terminal cooling.

High Priority: Natural gas and electric service providers should document the presence of room cooling systems used in homes receiving weather sensitive measures. This data should be gathered as a standard part of the application process and would be used to determine energy and demand savings associated with these types of cooling systems. Collecting this data along with the aforementioned MEMD updates would allow utilities to capture unrealized savings and identify measure opportunities.

CONCLUSION 4: The home characteristics used for weather sensitive measures are outdated; updating the dwelling characteristics in the MEMD will ensure energy saving estimates more accurately represent homes in the Michigan Lower Peninsula.

The standard dwelling features used by the MEMD have a significant impact on calculated energy savings for all weather sensitive measures. The current home characteristics used in weather sensitive measures were derived from a 2004 study of housing characteristics in California and are different to homes visited in this study.

Across all vintages, ceilings and attics were found to have similar or more insulation than the current MEMD assumptions. The MEMD assumed R-11 ceiling insulation in older homes where we found homes averaged R-19 insulation. We found windows to be more efficient than the assumptions in the MEMD, which assumed all windows in older homes were single paned. Conversely, walls were found to have less insulation than assumed: the current MEMD assumes between R-7 and R-11 in existing walls depending on vintage, while the team founds between R-5 and R-10 were the average values.

While more data will be available in the summer of 2021 when the findings from the furnace metering portion of this study will be analyzed, Cadmus used customer reported temperature setpoints (based on interviews) and the data collected during field visits to estimate thermostat settings among the study population. The team found significant differences between how customers operated their thermostats and the assumptions in the MEMD. The MEMD assumes that single-family customers set their thermostat to 70°F with a setback to 60°F[7] to heat their homes. Customers' reported thermostats settings and schedules indicate a similar setpoint of 69°F but a very moderate setback to 67°F is more common. When cooling their homes, customers also indicated a 72°F cooling setpoint with a setback to 74°F, this contrasts to the 75°F setpoint with an 80°F setback assumed by the current MEMD.

Updating these characteristics to align with the findings of the baseline housing study would increase the accuracy of energy savings estimates in the weather sensitive MEMD based on conditions in Michigan homes.

RECOMMENDATIONS

High Priority: The MEMD Developers should update the insulation levels used in single-family and multifamily homes. The specific values we recommend be updated are outlined in the findings *Detailed Recommendations: Key Datapoint Updates; Home Insulation*.

Medium Priority: The MEMD Developers should update the thermostat settings used in single-family and multifamily homes. The specific values we recommend be updated are outlined in the findings Detailed Recommendations: Key Datapoint Updates; Thermostat Setpoints. While further

[7] Setback length of time is unspecified in the current MEMD.

refinement of these data is expected based on the results of the furnace metering study, the recommended estimates would better align the current MEMD with customer behavior.

Study Overview

The Michigan residential housing baseline study was conducted over two phases. Phase I, conducted in 2017, was used to assess if a larger statewide study was warranted and test study methods, such as recruitment, data collection, and customers receptiveness to site visits. As part of Phase I, the Cadmus team reviewed existing program documentation including program tracking data and audit reports to assess the alignment of MEMD vintage parameters with actual participant home data. In nearly all the cases, the Cadmus team found that participant data did not align well with the MEMD. That conclusion triggered Phase II of the study.

For Phase II, the Cadmus team collected primary field data from Michigan homes in Consumers Energy and DTE Energy service territories to support updated input parameters for measure savings estimates in the Michigan Energy Measures Database (MEMD).[8] During the Phase II scoping process, stakeholders agreed that the study should reflect a broader focus on various baseline parameters, rather than just home vintage, and helped establish the following research objectives.

This report addresses several research objectives:

Characterize envelope and equipment efficiency levels in Michigan homes while controlling for key parameters of interest including home vintage, household income and home ownership; as well as provide representative results across the two climate zones of the lower peninsula and major dwelling types including single-family and multifamily homes.

Compare study findings to the existing vintage schema used in the MEMD and propose updates or alternative scenarios as appropriate.

Identify gaps in data collection necessary to verify and calculate energy savings within the recommended revisions to the MEMD schema and to inform future MEMD updates and program planning. Recommend data that should be captured by EWR implementation teams.

8 The original statement of work proposed a study of the upper peninsula of Michigan. This study was not approved; however, an upper peninsula study was commissioned by the MPSC to be conducted by CLEAResult. The team has coordinated with the CLEAResult team discussing reporting results and data formatting. The results of the upper peninsula study are expected to be published soon.

Detailed Findings: Mechanical Systems

The Cadmus team visually assessed mechanical systems during the site visits. Mechanical systems included space heating and cooling and water heating equipment. We classified the type of each major piece of equipment and gathered available nameplate information. In some cases, the nameplate information had faded or was otherwise unreadable, resulting in missing equipment details. In these cases, we estimated the missing details based on the equipment age or based on related systems.[9] The team gathered the energy efficiency of mechanical equipment from the equipment nameplate or from manufacturer data, or we estimated this detail based on vintage.

Heating Types

We classified each heating system as primary or secondary, where primary systems were built into the structure and controlled by a thermostat and secondary systems were typically used by the homeowner in the same space as a primary system.

Ducted furnaces were the most common heating system across home types and climate zones. Table 1 shows the percentage of heating systems found by system type.

Table 1. Heating Types (excluding heat pumps) by Home Type and Climate Zone

Climate Zone	Heating System Type	Single-Family		Multifamily	
		n	Percentage of Systems	n	Percentage of Systems
Climate Zone 5	Ducted Furnace	47	60.26%	41	53.25%
	Space Heater	12	15.38%	14	18.18%
	Electric Baseboard	6	7.69%	5	6.49%
	Fireplace	5	6.41%	7	9.09%
	Other	2	2.56%	0	0.00%
	Boiler (Water)	3	3.85%	0	0.00%
	Wood Stove	1	1.28%	0	0.00%
	Common Boiler	0	0.00%	7	9.09%
	Wall Furnace	0	0.00%	3	3.90%
	Boiler (Steam)	2	2.56%	0	0.00%
	Furnace - Gravity	0	0.00%	0	0.00%
	Combi Boiler	0	0.00%	0	0.00%
Climate Zone 6	Ducted Furnace	37	42.53%	28	37.33%
	Space Heater	11	12.64%	10	13.33%
	Electric Baseboard	10	11.49%	20	26.67%
	Fireplace	11	12.64%	6	8.00%
	Other	7	8.05%	1	1.33%
	Boiler (Water)	2	2.30%	4	5.33%
	Wood Stove	6	6.90%	1	1.33%
	Common Boiler	0	0.00%	3	4.00%

9 To estimate the capacity of cooling systems with missing nameplate information, the Cadmus team used the rated capacity of the coil on the indoor component of the split cooling system.

Climate Zone	Heating System Type	Single-Family		Multifamily	
		n	Percentage of Systems	n	Percentage of Systems
	Wall Furnace	2	2.30%	1	1.33%
	Boiler (Steam)	0	0.00%	0	0.00%
	Furnace - Gravity	1	1.15%	0	0.00%
	Combi Boiler	0	0.00%	1	1.33%

Note: The Cadmus team weighted these values based on the sample strata.

Among primary heating systems, ducted furnaces and electric baseboard heating systems were the most common. Homes with electric baseboard heating were likely to have multiple heating systems, averaging more than two baseboard heating systems per dwelling. Portable space heating and fireplaces were common sources of secondary heating. Table 2 shows the percentage of primary and secondary systems by heating system type.

Table 2. Heating Types (excluding heat pumps) for Primary and Secondary Heating

Heating System Type	Primary		Secondary	
	n	Percentage of Systems	n	Percentage of Systems
Ducted Furnace	149	74.4%	4	5.2%
Portable Space Heater	9	3.7%	38	54.5%
Boiler (Water)	32	8.6%	9	7.1%
Fireplace	3	1.7%	26	27.1%
Other	5	2.7%	5	2.7%
Wood Stove	9	3.9%	0	0.0%
Electric Baseboard	4	1.7%	4	1.7%
Boiler (Steam)	4	0.9%	2	1.7%
Furnace - Gravity	2	2.3%	0	0.0%
Wall Furnace	1	0.2%	0	0.0%
Combination Boiler	1	0.0%	0	0.0%

Note: The Cadmus team weighted these values based on the sample strata.

Heat pumps were uncommon, with only three homes using geothermal heat pumps, two homes using ductless mini-split heat pumps, and one home using a package terminal heat pump. These heat pumps were relatively new, with the oldest system manufactured in 2006. Table 3 shows the observed installations of heat pump systems in single-family and multifamily homes in climate zone 5 and climate zone 6.

Table 3. Heat Pump Types Installed

Climate Zone	Single-Family	Multifamily
Southern – Climate Zone 5	1 geothermal heat pump	2 ductless mini-split heat pumps 1 geothermal heat pump 1 package terminal heat pump
Northern – Climate Zone 6	1 geothermal heat pump	none

Heating Efficiency

Single-family homes more commonly had higher-efficiency fuel-fired heating systems than multifamily homes. Standard efficiency non-condensing (low efficiency) heating systems are still very common in multifamily homes, which have lower efficiency. There was no significant difference in heating efficiency between climate zone 5 and climate zone 6, as shown in Table 4.

The Cadmus team also analyzed heating efficiency by home vintage, household income, and homeownership type, and system type, but did not find any consistent correlations.

Table 4. Percentage Efficiency of Fuel-Fired Heating Systems

Climate Zone	Single-Family			Multifamily		
	Mean	Error Bound	n	Mean	Error Bound	n
Southern – Climate Zone 5	**86.2%**	1.6	52	**82.0%**	1.5	36
Northern – Climate Zone 6	**88.8%**	2.0	35	**80.1%**	4.4	34
Lower Peninsula Average/Total	**86.4%**	**1.5**	**87**	**81.9%**	**1.4**	**70**

Note: The Cadmus team weighted these values based on the sample strata. Bolded values are significantly different.

Central Cooling Systems

Standard efficiency cooling systems[10] are common across the Lower Peninsula, with 95% of the central cooling systems we inspected at or below the current federal standard of 13 Seasonal Energy Efficiency Ratio (SEER). The Cadmus team found no significant difference in central cooling efficiency by climate zone or by home type (single-family versus multifamily). The team also analyzed central cooling efficiency by home vintage, household income, and homeownership type, but did not find any consistent correlations.

Table 5 shows the Seasonal Energy Efficiency Ratio (SEER) of central air conditioners for single-family and multifamily homes in climate zone 5 and climate zone 6.

---

[10] The federal standard efficiency for central cooling systems has increased over time from 10 SEER to 13 SEER in 2006.

Table 5. Efficiency (SEER) of Central Air Conditioners

Climate Zone	Single-Family			Multifamily		
	Mean	Error Bound	n	Mean	Error Bound	n
Southern – Climate Zone 5	11.3	0.6	36	10.9	0.6	31
Northern – Climate Zone 6	11.4	0.7	23	10.4	0.6	21
Lower Peninsula Average/Total	**11.3**	**0.6**	**59**	**10.9**	**0.5**	**52**

Note: The Cadmus team weighted these SEER values based on the sample strata.

Room Cooling Systems

A significant number of dwellings in the Lower Peninsula use room cooling systems, which consisted of window air conditioners (22%), package terminal air conditioners (2%), and portable air conditioners (1%) across all climate zones. Of the multifamily homes we visited, 30% in climate zone 5 and 28% in climate zone 6 used room cooling as their only cooling source, compared to 20% of single-family homes in climate zone 5 and climate zone 6.

Room cooling system efficiency was consistent across strata. Multifamily homes in climate zone 6 show slightly lower efficiency, but this result was not statistically significant.

Table 6 shows the Energy Efficiency Ratio (EER) of room cooling systems for single-family and multifamily homes in climate zone 5 and climate zone 6.

Table 6. Efficiency of Room Cooling Systems

Climate Zone	Single-Family			Multifamily		
	Mean	Error Bound	n	Mean	Error Bound	n
Southern – Climate Zone 5	10.5	0.3	26	10.4	0.6	19
Northern – Climate Zone 6	10.4	0.3	15	9.4	0.9	12
Lower Peninsula Average/Total	**10.5**	**0.2**	**41**	**10.4**	**0.6**	**31**

Note: The Cadmus team weighted these EER values based on sample strata.

Distribution Systems

Distribution systems consisted of central forced air, hydronic (hot water), and steam systems. Most distribution systems were in the conditioned space of both the single-family and multifamily homes. Table 7 shows the percentage of distribution systems located in unconditioned spaces at single-family and multifamily homes.

Table 7. Percentage of Distribution Systems in Unconditioned Space

Distribution System Type	Single-Family			Multifamily		
	Mean	Error Bound	n	Mean	Error Bound	n
Central Forced Air	26.2%	8.9%	85	29.2%	10.0%	70
Hydronic	11.7%	11.9%	5	0.0%	0.0%	7
Steam	36.5%	22.1%	2	0.0%	0%	1

Note: The Cadmus team weighted these values based on sample strata. Percentages will not sum to 100%.

Less than half the square-footage area for distribution systems located in unconditioned spaces was insulated. The uninsulated areas led to thermal losses through the walls of the duct system. Central forced air distribution systems were generally less insulated in multifamily homes compared to single-family homes. Table 8 shows the percentage of insulated area for distribution systems in unconditioned spaces.

Table 8. Percentage of Distribution Systems Insulated in Unconditioned Space

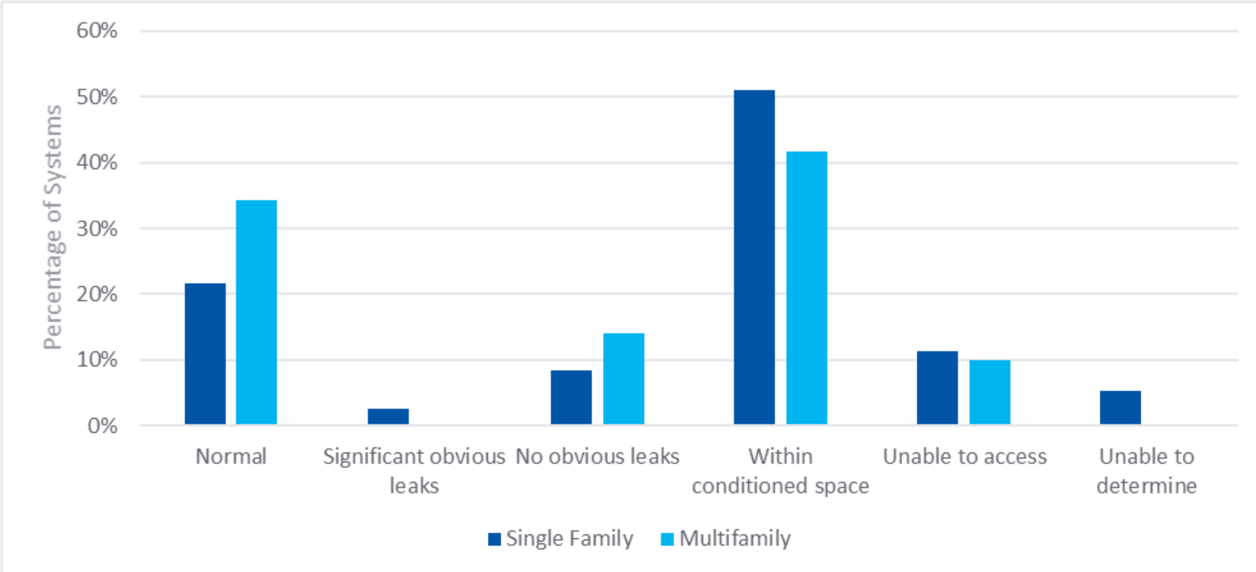
Distribution System Type	Single-Family			Multifamily		
	Mean	Error Bound	n	Mean	Error Bound	n
Central Forced Air	40.0%	11.1%	85	17.7%	9.4%	70
Hydronic	4.6%	10.9%	5	N/A*	N/A*	7
Steam	45.0%	284.1%	2	N/A*	N/A*	1

Note: The Cadmus team weighted these values based on sample strata. Percentages will not sum to 100%
*Distribution systems entirely within the conditioned space of the dwelling do not have applicable insulation on the distribution system since the losses are recovered by the home.

The Cadmus team qualitatively assessed the air leakage in central forced air duct systems. The relative construction of duct systems and the presence of duct sealing materials are described below.

The team ignored duct leakage in conditioned spaces for our assessment since this leakage does not result in heat losses by the duct system. Figure 1 shows the percentage of duct systems in each qualitative assessment category. *Normal* duct leakage characterizes duct systems with typical build quality where mechanical joints are connected but small gaps exist from the connections. Duct systems with *no obvious leaks* were characterized by tight fitting connections and no gap observed in the duct work. Duct systems with significant obvious leaks were characterized as damaged or had poorly fitting joints resulting in significant airflow.

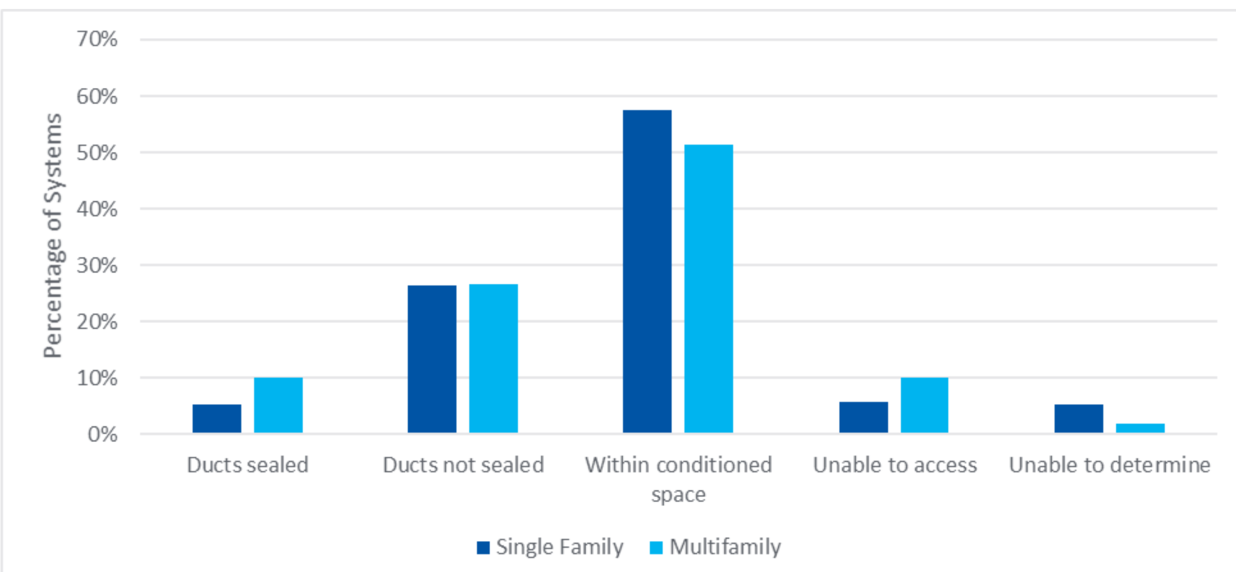
Figure 1. Qualitative Leakage of Central Forced Air Distribution



Note: The Cadmus team weighted these values based on sample strata. Distribution systems entirely within the conditioned space of the dwelling were assumed to not have detrimental impacts from duct leakage.

Air ducts typically have many mechanical joints where relatively small gaps can results in significant air leakage. Few distribution systems were sealed to prevent leakage from the joints. Figure 2 shows the percentage of distribution systems in unconditioned spaces that had been sealed.

Figure 2. Percentage of Distribution Systems in Unconditioned Spaces with Sealing Materials



Note: The Cadmus team weighted these values based on sample strata. Distribution systems entirely within the conditioned space of the dwelling were assumed to not have detrimental impacts from duct leakage.

Heating and Cooling Capacities

The team calculated heating and cooling capacities installed in homes as a function of the area of the dwelling served by the system. Multifamily homes with central cooling had significantly more cooling capacity installed than single family homes. Multifamily dwellings with both electric and fuel heating had significantly more heating capacity installed. While the reason for this difference is not known multifamily dwellings were significantly smaller than single family dwellings.

Dwellings in Climate Zone 5 had significantly more central cooling capacity installed and surprisingly more heating capacity installed. Due to the warmer climate in climate zone 5 dwellings were expected to have less heating capacity.

Table 9 through Table 12 show the installed capacity of cooling and heating systems installed in dwellings per square foot of conditioned area served for single family and multi-family homes by climate zone and system type.

Table 9. Cooling BTU/hr Capacity Per Square Foot of Conditioned Area for Single-Family and Multifamily Dwellings

	Single Family			Multifamily		
Cooling System Type	Mean	EB	n	Mean	EB	n
Central AC	**13.6**	1.5	57	**23.1**	2.7	52
Window AC	27.6	5.8	37	20.6	5.5	25
PTAC	69.4	-	1	25.2	16.5	2
Other	-	-	-	32.0	-	1

Note: Values are weighted and in the units BTU/hr/sq-ft. Bold values indicate significant differences.

Table 10. Cooling BTU/hr Capacity Per Square Foot of Conditioned Area for Climate Zone 5 and Climate Zone 6

	Climate Zone 5			Climate Zone 6		
Cooling System Type	Mean	EB	n	Mean	EB	n
Central AC	**15.9**	1.4	65	**13.3**	1.2	44
Window AC	27.2	5.2	40	16.3	6.1	22
PTAC	25.2	16.5	2	69.4	-	1
Other	-	-	-	32.0	-	1

Note: Values are weighted and in the units BTU/hr/sq-ft. Bold values indicate significant differences.

Table 11.Heating BTU/hr Capacity Per Square Foot of Conditioned Area for Single-Family and Multifamily Dwellings

	Single Family			Multifamily		
Heating Fuel Type	Mean	EB	n	Mean	EB	n

Electric	**19.9**	0.4	11	**58.8**	32.6	17
Fuel	**44.1**	4.2	83	**66.8**	7.5	73

Note: Values are weighted and in the units BTU/hr/sq-ft. Bold values indicate significant differences.

Table 12. Heating BTU/hr Capacity Per Square Foot of Conditioned Area for Climate Zone 5 and Climate Zone 6

Heating Fuel Type	Zone 5			Zone 6		
	Mean	EB	n	Mean	EB	n
Electric	29.0	8.0	15	25.9	6.3	13
Fuel	**49.4**	4.0	90	**40.0**	3.7	66

Note: Values are weighted and in the units BTU/hr/sq-ft. Bold values indicate significant differences.

Domestic Hot Water

Most water heating systems at the sites we visited were storage tank water heaters. Water heating systems that served multiple dwellings were relatively common, representing 28% (n=29) of the multifamily units visited. Table 13 shows the quantities of each water heating system type in the sample population, and whether each system served a single dwelling or multiple dwellings.

Table 13.Water Heating Systems by Type

	Served One Dwelling	Served Multiple Dwellings
Storage tank water heater	142	19
Boiler with tank	13	2
Instantaneous	9	0
Heat pump water heater	1	0
Combination boiler	1	0
Unable to access	1	10
Total	**167**	**31**

Note: The values in this table are unweighted.

Tank sizes for water heaters ranged from 30 gallons to 80 gallons, with a mean of less than 44 gallons across all strata. Table 14 shows the average water heater tank size in gallons for single-family and multifamily homes by climate zone.

Table 14. Storage Water Heater Size in Nominal Gallons

Climate Zone	Single-Family	Multifamily
Southern – Climate Zone 5	43.5	41.5
Northern – Climate Zone 6	42.1	39.2

Note: The values in this table are unweighted.

The energy-efficiency values for water heating systems are typically expressed as the efficiency factor or the uniform efficiency factor. Historically, these efficiency values were not displayed on water heating system nameplates and documentation for older water heaters was rarely available. However, Energy Guide labeling has been required on new water heaters since 1979. These labels typically express the energy usage of a water heater in therms per year, kilowatt-hours per year, or dollars per year.

Energy Guide label data was not significantly different across home vintage, climate zone, or home type. Electric water heaters consume approximately 4,800 kWh per year and natural gas water heaters consume approximately 250 therms per year. Table 15 details the available Energy Guide label data by the type of unit shown on the label for single-family versus multifamily homes.

Table 15. Water Heater Energy Guide Label Consumption by Home Type

Energy Guide Label Type	Single-Family			Multifamily		
	Mean	Error Bound	n	Mean	Error Bound	n
Dollars per year	269.3	28.4	26	287.0	27.7	15
Kilowatt-hours per year	4,834.5	84.7	12	4,819.8	70.3	10
Therms per year	247.1	7.5	35	250.4	5.9	41

Detailed Findings: Building Construction and Envelope

The Cadmus team extensively measured each home in the sample to determine square footage and construction characteristics. We summarized the construction characteristics as the effective insulating qualities of the dwelling including insulation, the construction materials, and environmental factors. These effective insulating qualities are the thermal transmittance of each area, represented as U-factors. Lower U-factors represent a more efficient area, with a theoretical minimum U-factor of 0.0 representing a perfectly insulated area. Details on the calculations we used to determine dwelling U-factors are shown in *Appendix D*.

Dwelling Size

The conditioned floor area of a home is important for estimating the energy usage of that home. The conditioned floor area of a home must meet several characteristics:

- It is served by the home heating system
- It maintains a temperature close to the home thermostat setpoint
- It is within the thermal boundary of the home

Basements are often difficult to classify as being conditioned or unconditioned, as they may meet one or two but not all three of these characteristics. The Cadmus team used professional judgement to classify spaces that did not meet all the requirements of a conditioned space.

The size of conditioned areas in multifamily homes are significantly smaller than those in single-family homes. There were not significant differences in the size of conditioned areas between the Lower Peninsula climate zones. Table 16 details the conditioned floor area of the dwellings by home type.

Table 16. Conditioned Floor Area in Square Feet

Climate Zone	Single-Family			Multifamily		
	Mean	Error Bound	n	Mean	Error Bound	n
Southern – Climate Zone 5	2,392.9	248.5	52	1,136.8	167.9	53
Northern – Climate Zone 6	2,406.0	233.4	41	1,065.1	121.4	49
Lower Peninsula Average/Total	**2,394.3**	**221.7**	**93**	**1,133.2**	**158.3**	**102**

Note: The Cadmus team weighted the conditioned floor areas shown in the table.

The Cadmus team also measured the square footage of unconditioned floor areas at each home. We considered unconditioned areas as those that did not meet the definition of conditioned floor area (outlined above) but are protected from outside weather conditions. This typically included basements, storage areas, and open attic areas. Table 17 details the unconditioned floor area of the dwellings by home type and climate zone.

Table 17. Unconditioned Floor Area in Square Feet

Climate Zone	Single-Family			Multifamily		
	Mean	Error Bound	n	Mean	Error Bound	n
Southern – Climate Zone 5	350.5	101.5	52	143.2	72.9	53
Northern – Climate Zone 6	415.1	116.4	41	125.1	54.8	49
Lower Peninsula Average/Total	**357.4**	**90.8**	**93**	**142.3**	**51.7**	**102**

Note: The Cadmus team weighted the unconditioned floor areas shown in the table.

Number of Floors

Single-family homes averaged 1.6 floors, while multifamily homes averaged slightly lower, at 1.3 floors. Multifamily dwellings within a larger building averaged slightly more floors per home, at 2.2. Table 18 shows details of the number of above-grade floors by home type and climate zone.

Table 18. Number of Above-Grade Floors

Climate Zone	Single-Family Homes			Multifamily Homes			Multifamily Buildings		
	Mean	Error Bound	n	Mean	Error Bound	n	Mean	Error Bound	n
Southern – Climate Zone 5	1.6	0.1	52	1.3	0.1	53	2.2	0.2	51
Northern – Climate Zone 6	1.5	0.1	41	1.3	0.1	49	1.9	0.2	48
Lower Peninsula Average/Total	**1.6**	**0.1**	**93**	**1.3**	**0.1**	**102**	**2.2**	**0.2**	**99**

Note: The Cadmus team weighted the number of floors shown in this table.

Construction U-factors

The Cadmus team analyzed home construction U-factors for various areas of the homes by home type, controlling for climate zone. Enclosed ceiling areas had the only U-factor that was significantly different between single-family and multifamily homes. Enclosed ceiling areas in multifamily homes were often flat roofs that were 12- to 18-inches thick and had significant room for insulation, while enclosed areas in single-family homes typically consisted of vaulted ceilings 6- to 12-inches thick. Table 19 shows effective U-factors by home area and home type.

Table 19. Effective U-factors of Single-Family and Multifamily Homes

Home Area	Single-Family			Multifamily		
	Mean	Error Bound	n	Mean	Error Bound	n
Open attics	0.044	0.004	117	0.047	0.006	72
Enclosed ceilings	**0.057**	0.005	47	**0.038**	0.007	19
Doors	0.676	0.039	249	0.716	0.055	132
Framed floors	0.202	0.020	75	0.216	0.020	56
Foundation walls	0.273	0.016	234	0.284	0.022	82
Rim band joists	0.087	0.003	220	0.094	0.006	131
Skylights	0.380	0.000	62	0.385	0.006	78
Above-grade walls	0.101	0.008	295	0.116	0.013	171
Windows	0.463	0.012	1211	0.493	0.018	522

Note: The Cadmus team weighted each area shown in the table. Bold values indicate significant differences.

U-factors also had a few significant differences by climate zone. Homes in climate zone 6 had slightly higher skylight U-factors and lower wall U-factors than homes in climate zone 5. No other U-factor characteristics had significant differences. Table 20 shows effective U-factors by home area and climate zone.

Table 20. Effective U-factors of Northern and Southern Climate Zone Homes

Home Area	Southern – Climate Zone 5			Northern – Climate Zone 6		
	Mean	Error Bound	n	Mean	Error Bound	n
Open Attics	0.044	0.004	90	0.050	0.005	99
Enclosed ceiling	0.053	0.005	38	0.046	0.005	28
Doors	0.680	0.035	193	0.738	0.035	188
Framed floors	0.205	0.017	68	0.211	0.016	63
Foundation wall	0.276	0.015	171	0.277	0.024	145
Rim band joists	0.088	0.003	189	0.097	0.007	162
Skylights	**0.380**	0.000	71	**0.394**	0.002	69
Above-grade walls	**0.109**	0.008	258	**0.066**	0.004	208
Window	0.471	0.011	956	0.462	0.012	777

Note: The Cadmus team weighted each area shown in the table. Bold values indicate significant differences.

The year of a home's construction significantly impacted the observed U-factors. Homes built in 1998 or later had significantly lower U-factors in attics, enclosed ceilings, foundation walls, above-grade walls, and windows than homes built prior to 1979. Homes built in 1998 or later also had significantly lower U-factors in attics, foundation walls, and windows than homes built between 1979 and 1997.

Homes built prior to 1979 had the highest U-factors among all analyzed areas except attic insulation and skylights, indicating that these homes are the least insulated. Homes built after 1998 had the lowest U-factors for every area except doors, floors, and skylights. However, there were no significant differences in U-factors for doors and framed floors across all vintages. Table 21 shows effective U-factors by home area and vintage.

Table 21. Effective U-factors by Home Area and Vintage

Home Area	Pre-1979			1979-1997			1998-2019		
	Mean	Error Bound	n	Mean	Error Bound	n	Mean	Error Bound	n
Open attics	**0.047**	0.002	101	**0.055**	0.007	38	**0.034**	0.002	44
Enclosed ceilings	**0.055**	0.004	34	0.046	0.006	15	**0.043**	0.005	16
Doors	0.715	0.026	192	0.658	0.045	80	0.705	0.039	101
Framed floors	0.211	0.011	70	0.200	0.022	26	0.227	0.007	33
Foundation walls	**0.320**	0.016	167	**0.248**	0.013	70	**0.206**	0.010	77
Rim band joists	**0.094**	0.003	187	0.093	0.007	74	**0.085**	0.005	85
Skylights	**0.396**	0.006	72	**0.419**	0.012	33	**0.420**	0.016	32
Above-grade walls	**0.113**	0.007	215	**0.077**	0.007	97	**0.076**	0.005	146
Windows	**0.516**	0.010	912	**0.428**	0.012	324	**0.399**	0.006	469

Note: The values in this table are unweighted. Bold values indicate significant differences.

Detailed Recommendations: Key Datapoint Updates

The MEMD Overview and Maintenance Process Manual outlines the standard update process to submit new measures, update existing measures and calibrate energy savings. However, the manual focuses on non-weather sensitive measures when the entire scope of the measure update can be outlined in a single whitepaper update. Weather sensitive measures require coordination with multiple parties to propose and execute updates. Further refining the steps in the process and parties involved would be helpful for all EWR Collaborative members.

The MEMD uses sets of DOE-2.2[11] energy models to develop energy-savings estimates for weather-dependent measures. These energy models characterize a home based on vintage, HVAC system types, and location. Using the field data collected (presented in previous sections of this report), the Cadmus team created several recommendations for updating the MEMD energy models and measure calculations used to develop energy savings. This chapter outlines our recommended updates by home characteristic.

Measures are modeled using a baseline and efficient energy model. The energy savings for a measure is the decrease in energy usage from the baseline to the efficient models. For each measure, the baseline and efficient conditions of the measure are varied while keeping all other characteristics of the home constant. The home characteristics kept constant are general characteristics of the home that represent a large population of homes, while the measure baselines are specific to the measure. For example when a high efficiency air conditioner is modeled, the baseline for the measure is the federal standard efficiency. However when windows are upgraded in a home with central air conditioning, the efficiency of the air conditioner is best represented as the general efficiency of central air conditioners.

Home Vintages

The MEMD defines home vintage based on the year energy codes were introduced and adopted and on code updates over time, which characterize a home's energy efficiency. The current MEMD vintages are as defined as;

1. **Old**, poorly insulated building constructed prior to the introduction of building codes. This vintage is referred to as the "old" vintage
2. **Existing**, average insulated building conforming to 1980 and 1990s era building codes. This vintage is referred to as the "average" vintage.
3. **New,** Recent construction conforming to the Michigan State Uniform Energy Code. This vintage is referred to as the "new" vintage.

For this Phase II study, the Cadmus team recommends further refining the MEMD vintage bins into specific age ranges and updating the new construction vintage that can evolve to account for future changes to building codes and equipment standards. Table 22 shows an outline of three vintage bin

[11] DOE-2.2 is an hourly energy simulation engine developed by the U.S. Department of Energy that supports calculations of building energy usage.

ranges and their corresponding home characteristics we recommend adopting into the MEMD. Due to construction schedules, it typically takes between one and two years for the new homes market to fully align with new building codes. The team selected these vintages based on energy code changes in Michigan, the housing population we observed, and trends in the data we collected.

Table 22. Recommended Vintages and Home Characteristics for MEMD Updates

Vintage Range	Code Considerations	Housing Population	Data Trends
Pre 1979	Prior to 1977, there was no adopted building code in Michigan.	Approximately half the homes in the study were built before 1979.	In the late 1970s the insulation levels of the least-efficient homes started to increase.
1979-2015	In 1977, the state adopted its first energy code, changing how buildings are constructed in the state. In early 1996, Michigan SB719 repealed the adoption of the newer 1993 Michigan Energy Code, delaying energy code advancements.	Approximately one-half of homes in the study were built between 1979 and 2015.	The trend of increasing efficiency levels of the least-efficient homes began to level off through the late 90's, however the most efficient homes still show increasing energy efficiency. Homes built into the 2000's and after show moderate increases in overall insulation
New Construction (2016-Current)	In February 2016 the current code (International Energy Conservation Code 2015) went into effect. As new building codes are adopted in Michigan, this vintage bin should be updated to reflect the current standard.	Over time, the efficiency of new construction will shift as new codes are adopted.	Field data indicates that newer homes are much more efficient and should be accounted for accordingly.

Weather Locations

The MEMD uses seven weather locations in Michigan, which are appropriate and broad enough to reasonably cover the state. The team did not find significant differences in construction characteristics between homes built in climate zone 5 and those built in climate zone 6; however, the mechanical systems in each zone do have significant differences. Additionally, the newest code, International Energy Conservation Code 2015, requires more stringent insulation levels in climate zone 6. The MEMD should preserve the current weather locations with distinct home characteristics.

HVAC Systems

Room cooling systems, including window air conditioners, were common in both single-family and multifamily homes. We recommend that the MEMD add window air conditioning as an available HVAC type for energy simulations.

Electric furnaces (n=2) were significantly less common than electric baseboard heating (n=12). We recommend that the MEMD replace the current electric furnace option with electric baseboard heating and rename the option to encompass all electric resistance heating systems as these systems operate at similar efficiencies.

Additionally we did not find significant differences in installed efficiencies between natural gas fueled heating systems. To simplify the data collecting and reduce the number of prototypes we recommend modeling a natural gas furnace as the primary heating type for centrally heated natural gas homes.

Table 23 details our recommended updates to heating and cooling types for single-family and low-rise multifamily homes. The MEMD should use these recommended characteristics in both climate zone 5 and climate zone 6 for all measures except HVAC replacements, which use measure-specific baseline values.

Table 23. Recommended MEMD General HVAC Characteristics for Single-Family and Multifamily Low Rise Homes

Home Type	HVAC Type	Heating Efficiency	Cooling Efficiency
Single-Family	Central split-system AC with natural gas heating	**86% AFUE**	**11.3 SEER** (NC=13 SEER)
	Central split-system heat pump	8.2 HSPF	**11.3 SEER** (NC=14 SEER)
	Central split-system dual-fuel heat pump	**86% AFUE** and 8.2 HSPF	**11.3 SEER** (NC=14 SEER)
	Electric resistance heating with room cooling	100% efficient	**10.5 EER (NC=10.9 CEER)**
	Electric resistance heating only	100% efficient	N/A
	Natural gas heating only	**86% AFUE**	N/A
	Natural gas heating with room cooling	**86% AFUE**	**10.5 EER** (**NC=10.9 CEER**)
Multifamily (low rise)	Central split-system AC with natural gas heat	**82% AFUE**	**10.9 SEER** (NC=13 SEER)
	Central split-system AC with electric resistance heat	100% efficient	**10.9 SEER** (NC=13 SEER)
	Split-system heat pump	8.2 HSPF	**11.3 SEER** (NC=14 SEER)
	Packaged terminal heat pump	7.4 HSPF	7.1 EER (**NC=10.9 CEER**)
	Packaged terminal air conditioner or room air conditioner with electric resistance heating	100% efficient	**10.5 EER (NC=10.9 CEER)**
	Electric baseboard only	100% efficient	N/A
	Natural gas heating only	**82% AFUE**	N/A
	Natural gas heating with room cooling	**82% AFUE**	**10.5 EER (NC=10.9 CEER)**

Notes: AC stands for air conditioner and NC stands for new construction. Where the efficiency of the existing systems was less efficient than current federal standards, the MEMD should use federal standard efficiency levels for new construction scenarios. Most existing room cooling systems were rated in EER while the newest federal standard rates those system in CEER based on a newer test procedure. Bolded values indicate a difference from current MEMD values. SEER may be converted to EER using the follow equation, $EER=(-0.02*SEER^2)+(1.12*SEER)$. [From: Wassmer, M. (2003), "A Component Based Model for Residential Air Conditioner and Heat Pump Energy Calculations," Master's Thesis, University of Colorado at Boulder]

Thermostat Setpoints

The current thermostat setting used by the MEMD assume a 70F setpoint for heating with a setback temperature to 60F in single-family and 67F in multifamily homes and a 75F cooling setpoint with a setback to 80F in single-family and 78F in multifamily homes. Typically, few customers reported using heating and cooling setback with 23% of single family homes 12% of multifamily homes reporting they typically schedule their thermostat. Of thermostat setting viewed in the field an average heating setback of 2.6F and a cooling setback of 1.6F was observed.

Due to the ongoing metering study, full indoor temperature data was not available for the Cadmus team to calibrate thermostat setpoints. In the interim, we recommend that the MEMD use thermostat setpoints from customer interviews and thermostat settings observed in the field. The setpoints and setback temperatures we observed were significantly less stringent than those currently used in the MEMD.

Table 24 details our recommended general setpoints and corresponding times for those setpoints. These setpoints are derived from observed thermostat setting at the time of the site visit and a limited sample of thermostat loggers. The MEMD should use these recommended setpoints as standard for all measures except thermostat setback measures until they can be further refined based on additional collected meter data.

Table 24. Recommended MEMD General Thermostat Setpoints for Residential Homes

Setpoint Type	Setpoint	Time Frame
Heating setpoints	69°F	5 p.m. to 10 p.m.
	67°F	10 p.m. to 6 a.m.
	68°F	6 a.m. to 5 p.m.
Cooling setpoints	72°F	4 a.m. to 12 p.m.
	74°F	12 p.m. to 4 a.m.

Home Insulation

Cadmus observed several significant differences between home insulation characteristics and current MEMD assumptions. Attic and ceiling insulation values in older homes were significantly higher than MEMD assumptions, while wall insulation values were noticeably lower than current MEMD assumptions. Table 25 details our recommended nominal insulation values[12] by home area and climate zone. These parameters are informational used in for single-family and low rise multifamily (less than 4 floors) energy simulations. The MEMD should use these general values for all measures except insulation measures, which use measure-specific values. The team provides measure specific baseline recommendations below in *Insulation Measure Characteristics.*

[12]Nominal insulation values represent a home intentional insulation amount that excludes the insulating values of structural and decorative components of the home.

Table 25. Recommended MEMD General Insulation Characteristics by Climate Zone (R-Values)

Characteristic	Southern – Climate Zone 5			Northern – Climate Zone 6		
	Pre-1979	1979-2015	2016 - Current	Pre-1979	1979-2015	2016 - Current
Window U-factor	0.52	0.41	0.32	0.52	0.41	0.32
Skylight U-factor	0.40	0.42	0.55	0.40	0.42	0.55
Attic R-value	19	31	38	19	31	49
Enclosed ceiling R-value	17	23	38	17	23	49
Wood-framed wall R-value	5	10	20	5	10	20
Mass wall R-value	5	11	13	5	11	19
Floor R-value	1	1	30	1	1	30
Basement wall R-value	Unins.	5	10	Unins.	5	15
Slab R-value	Unins.	5, 2 foot	10, 2 foot	Unins.	5, 2 foot	10, 4 foot
Crawlspace wall R-value	3	10	15	3	10	15

Nominal insulation values can be interpreted in various ways due to the nature of building construction. Construction assumptions are an important consideration in developing an updated MEMD energy model. Table 26 details the construction characteristics that are assumed in MEMD nominal U-factors and R-values.

Table 26. Construction Characteristics Assumed with Nominal U-Factors and R-Values

Characteristic	Construction Assumptions
Window U-factor	Assuming window types detailed in *Appendix D*
Skylight U-factor	Assuming skylight types detailed in *Appendix D*
Ceiling with attic R-value	Assuming a 3/12 pitch roof with hip and valley construction and 2x4 chord rafters (insulation over 2.25-inches deep does not fully insulate out to the roof eve with 5/8-inch wallboard on the ceiling)
Enclosed ceiling R-value	Assuming a 6-inch thick rafter with cavity insulation fully filling the enclosed space, with 1/2-inch plywood sheathing, asphalt shingles, and 5/8-inch wallboard
Wood-framed wall R-value	Assuming a 2x4 wood-framed wall with cavity insulation of the nominal value with 1/2-inch sheathing, 1/2-inch wallboard, 1/2-inch wood siding, and cavity insulation of the nominal value
Mass wall R-value	Assuming a 6-inch thick masonry wall with a 2x4 furred interior wall and cavity insulation of the nominal value
Floor R-value	Assuming 2x8 floor joists with hardwood flooring, 1/2-inch plywood subfloor, and cavity insulation that fully contacts the floor surface
Basement wall R-value	Assuming a 6-inch thick, furred masonry foundation wall with 1/2-inch wallboard and an uninsulated interior wall with bare concrete
Slab R-value	Assuming continuous vertical slab edge insulation on the home exterior down to the specified depth
Crawlspace wall R-value	Assuming a 6-inch thick, furred masonry foundation wall with 1/2-inch wallboard and an uninsulated interior wall with bare concrete

Table 27 details the equivalent U-factors we used to develop the nominal R-values presented above. The U-factor represents the effective efficiency of a component and were calculated from field data. Additional details on these calculations can be found in *Appendix D*. Cadmus recommends the MEMD developers utilize the equivalent u-factors in modeling general home characteristics as these values represent the total insulating characteristics of homes including structural and decorative components of a home.

Table 27. Recommended MEMD General Equivalent U-Factors by Climate Zone

Characteristic	Southern – Climate Zone 5			Northern – Climate Zone 6		
	Pre-1979	1979-2015	2016 - Current	Pre-1979	1979-2015	2016 - Current
Window U-factor	0.52	0.41	0.32	0.52	0.41	0.32
Skylight U-factor	0.40	0.42	0.55	0.40	0.42	0.55
Attic U-factor	0.051	0.044	0.030	0.051	0.044	0.026
Enclosed ceiling U-factor	0.055	0.044	0.030	0.055	0.044	0.026
Wood-framed wall U-factor	0.113	0.076	0.057	0.113	0.076	0.057
Mass wall U-factor	0.113	0.076	0.082	0.113	0.076	0.060
Floor U-factor	0.211	0.215	0.033	0.211	0.215	0.033
Basement wall U-factor	0.320	0.226	0.059	0.320	0.226	0.050
Crawlspace wall U-factor	0.320	0.226	0.055	0.320	0.226	0.055

Insulation Measure Characteristics

The current MEMD assumes typical baseline characteristics for insulation measures to determine energy and demand savings for weather-sensitive measures. However, this method assumes that an average cross section of the population upgrades their home insulation. Yet customers who have the lowest amounts of insulation have the most to gain from insulation upgrades. These customers are more likely to seek insulation upgrades due to their homes' performance.

Homes typically either had or did not have wall cavity insulation installed. Wall insulation has a significant impact on energy usage, where as little as R-5 insulation can more than double the effectiveness[13] of the wall assembly and make a significant impact on energy usage and calculated energy savings. We observed similarly large variations in insulation amounts in other areas including floors, foundations, and ceilings. The team recommends several updates to the MEMD insulation measures' baseline and efficient characteristics.

Table 28 through Table 31 show the teams recommended measure scenarios including the description of the baseline and efficient conditions relevant to the scenario. Scenario are included for unknown insulation where the existing condition is not known. Measures where the baseline case should reflect current Michigan energy code are only applicable to new construction. Also, the energy code varies by climate zone for certain measures. These scenarios are applicable to both single-family and low rise multifamily.

[13] An uninsulated wall has an effective R-value of approximately R-4 and adding R-5 to the wall cavity increases the effective insulation level to nearly R-9. This assumes infiltration has a negatable impact on insulation efficacy.

Table 28. Wall Insulation Recommended Measure Scenarios

Measure	Baseline Case	Efficient Case	Applicable Vintages and Climate Zones
Insulate existing wall of unknown condition with R-10	Existing R-5 wall	Add continuous insulation of R-10 or better to the interior or exterior of the wall	Pre 1979 Vintage / CZ5&CZ6
	Existing R-10 wall	Add continuous insulation of R-10 or better to the interior or exterior of the wall	1979-2015 Vintage/ CZ5&CZ6
Insulate existing uninsulated 2X4 wall cavity	Existing uninsulated 2X4 wall	Filled wall cavity with insulating materials of at least R2 per inch	All Existing Vintages / CZ5&CZ6
Insulate existing uninsulated 2X4 Wall with R10 continuous insulation		Add continuous insulation of R-10 or better to the interior or exterior of the wall	
Insulate existing masonry wall with R10 insulation	Existing masonry wall without interior or exterior insulation		
Insulate standard 2X4 Wall with an additional R5 of continuous insulation	Existing 2X4 wall with standard R-11 cavity insulation	Add continuous insulation of R-5 or better to the interior or exterior of the wall	
Insulate standard 2X4 Wall with R10 continuous insulation		Add continuous insulation of R-10 or better to the interior or exterior of the wall	
Insulate new 2X6 Wall with R5 continuous insulation	Code R-20 Insulation	Add continuous insulation of R-5 or better to the interior or exterior of the wall	New Construction / CZ5&CZ6
Insulate new 2X6 Wall with R10 continuous insulation		Add continuous insulation of R-10 or better to the interior or exterior of the wall	

Note: These scenarios assume the same construction characteristics outlined in Table 27

Table 29. Ceiling Insulation Recommended Measure Scenarios

Measure	Baseline Case	Efficient Case	Applicable Vintages and Climate Zones
Insulate unknown ceiling or attic to R-30	R-19 attic insulation	Insulate to R-30	Pre 1979 Vintage / CZ5&CZ6
Insulate unknown ceiling or attic to R-38		Insulate to R-38	
Insulate unknown ceiling or attic to R-49		Insulate to R-49	
Insulate unknown ceiling or attic to R-60		Insulate to R-60	
Insulate unknown ceiling or attic to R-38	R-31 attic insulation	Insulate to R-38	1979-2015 Vintage / CZ5&CZ6
Insulate unknown ceiling or attic to R-49		Insulate to R-49	
Insulate unknown ceiling or attic to R-60		Insulate to R-60	
Insulate uninsulated ceiling or attic to R-30	Existing uninsulated roof or ceiling	Insulate to R-30	All Existing / CZ5&CZ6
Insulate uninsulated ceiling or attic to R-38		Insulate to R-38	
Insulate uninsulated ceiling or attic to R-49		Insulate to R-49	
Insulate uninsulated ceiling or attic to R-60		Insulate to R-60	
Insulate R-11 ceiling or attic to R-30	Existing R-11 insulation	Insulate to R-30	
Insulate R-11 ceiling or attic to R-38		Insulate to R-38	
Insulate R-11 ceiling or attic to R-49		Insulate to R-49	
Insulate R-11 ceiling or attic to R-60		Insulate to R-60	
Insulate R-19 ceiling or attic to R-30	Existing R-19 insulation	Insulate to R-30	
Insulate R-19 ceiling or attic to R-38		Insulate to R-38	
Insulate R-19 ceiling or attic to R-49		Insulate to R-49	
Insulate R-19 ceiling or attic to R-60		Insulate to R-60	
Insulate new ceiling or attic to R-49	Code R-38 insulation	Insulate to R-49	New Construction / CZ5
Insulate new ceiling or attic to R-60	Code R-49 insulation	Insulate to R-60	New Construction / CZ6

Note: These scenarios assume the same construction characteristics outlined in Table 27

Table 30. Floor Insulation Recommended Measure Scenarios

Measure	Baseline Case	Efficient Case	Applicable Vintages and Climate Zones
Insulate unknown floor to R-30	Existing R-1 floor	Insulate to R-30	All Existing / CZ5&CZ6
Insulate unknown floor to R-38	Existing R-1 floor	Insulate to R-38	
Insulate uninsulated floor to R-30	Existing uninsulated floor	Insulate to R-30	
Insulate R-11 floor to R-30	Existing R-11 floor		
Insulate R-19 floor to R-30	Existing R-19 floor		
Insulate new R-30 floor to R-38	Code R-30 floor	Insulate to R-38	New Construction / CZ5&CZ6

Note: These scenarios assume the same construction characteristics outlined in Table 27

Table 31. Foundation Insulation Recommended Measure Scenarios

Measure	Baseline Case	Efficient Case	Home Types
Insulate unknown basement wall to R-10	Existing uninsulated basement wall	Insulate to R-10	Pre 1979 Vintage / CZ5&CZ6
	Existing R-5 basement wall		1979-2015 Vintage / CZ5&CZ6
Insulate unknown crawlspace wall to R-10	Existing uninsulated crawlspace wall		Pre 1979 Vintage / CZ5&CZ6
Insulate uninsulated foundation walls to R-10	Existing uninsulated crawlspace		All Existing / CZ5&CZ6
Insulate unknown basement wall to R-20	Existing uninsulated basement wall	Insulate to R-20	Pre 1979 Vintage / CZ5&CZ6
	Existing R-5 basement wall		1979-2015 Vintage / CZ5&CZ6
Insulate unknown crawlspace wall to R-20	Existing uninsulated crawlspace wall		Pre 1979 Vintage / CZ5&CZ6
	Existing R-10 crawlspace wall		1979-2015 Vintage / CZ5&CZ6
Insulate uninsulated foundation walls to R-20	Existing uninsulated crawlspace		All Existing / CZ5&CZ6
Insulate new R-10 basement walls to R-15	New Code R-10 basement walls	Insulate to R-15	New Construction / CZ5
Insulate new R-15 crawlspace walls to R-20	New Code R-15 crawlspace walls	Insulate to R-20	
Insulate new R-15 foundation walls to R-20	New Code R-15 foundation walls		New Construction / CZ6

Note: These scenarios assume the same construction characteristics outlined in Table 27

Summary of Methodologies

The Cadmus team focused research activities for Phase II of the Michigan baseline housing study on conducting sampling, recruiting customers, performing site visits, assessing data quality, and processing data, and weighting the results of our research. This chapter outlines our methodology for each task.

Sampling

Customers of Consumers Energy and DTE Energy represent most households in Michigan, with 89% of Michigan counties (including 68 of 69 counties in the Lower Peninsula) being served by these two utilities. As a result, this joint study provides broad results covering home characteristics across the Lower Peninsula of Michigan.

The team initially requested all residential customer account details from DTE Energy and Consumers Energy to support the sample design process. We then merged these databases using the customer service address and removed duplicate addresses, leaving 3,793,405 residential addresses in the sample population. This population represented most households in the Lower Peninsula of Michigan.[14]

Drawing from the Consumers Energy and DTE Energy residential accounts lists, the Cadmus team pulled representative samples stratified by climate zone 5 and climate zone 6,[15] targeting 102 sites from each climate zone for a total of 204 sites. The Cadmus team further stratified these 204 sites by home type and targeted a total of 92 single-family homes and 112 multifamily homes for inclusion in the study.[16] We divided this Phase II study into a pilot phase (±20 sites) and a main phase (±184 sites).

The Cadmus team also employed target quotas for several parameters during site visit recruiting. We tracked homeownership type and low-income qualification to provide nested quotas, and used

---

14 Per the 2016 American Community Survey five-year estimates, there were 3,735,953 occupied housing units in the Lower Peninsula of Michigan (https://www.census.gov/programs-surveys/acs).

15 This Phase II study was restricted to the Lower Peninsula. The Michigan Upper Peninsula represents roughly 3% of Michigan's housing units, and Consumers Energy and DTE Energy do not have territory in the Upper Peninsula. To capture research findings covering the entire state, the Michigan Public Service Commission contracted with a separate firm to conduct a supplemental study in the Upper Peninsula. Climate zone 7 only occurs in the Upper Peninsula at the far west and east portions of the land mass and represents roughly 2% of Michigan housing units.

16 Other dwelling types represent roughly 5% of Michigan housing units and were excluded from the stratification scheme. For this study, single-family homes include both detached and attached homes and multifamily homes include all low-rise apartment-style dwellings with two or more units.

applicable MEMD weather stations to identify non-nested quotas.[17] We anticipated that recruitment would naturally align with the known distributions of the parameters, so we set criteria during customer recruitment to restrict the overrepresentation of one customer group. If a customer taking the survey represented a strata where enough recruits had already been recruited, the customer was informed their study group was full. The team planned the overall study to achieve ±10% precision at the 90% confidence level for assuming a coefficient of variation (CV) of 0.90 for multifamily homes and 0.80 for single-family homes. We targeted ±20% precision at the 90% confidence level for inference at the strata level. Table 32 presents the sample design for the pilot and main phases of the study, including nested quota targets.

Table 32. Pilot and Main Phase Sample Targets

Climate Zone	Home Type	Homeownership Status	Income <$40,000 Per Year	Target Number	Completed Visits	Percentage of Target
Climate Zone 5	Single-Family	Owned	Yes	15	14	93%
			No	23	30	130%
		Rented	Yes	3	4	133%
			No	5	3	60%
	Multifamily	Owned	Yes	2	7	350%
			No	3	9	300%
		Rented	Yes	20	21	105%
			No	31	16	52%
Climate Zone 6	Single-Family	Owned	Yes	15	17	113%
			No	23	19	83%
		Rented	Yes	3	3	100%
			No	5	2	40%
	Multifamily	Owned	Yes	2	4	200%
			No	3	9	300%
		Rented	Yes	20	22	110%
			No	31	14	45%
Total				**204**	**195**	**96%**

Note: An additional two customers were visited who were not included in the analysis due to incomplete data and conflicts with the customers schedule to revisit the home. One customer did not identify their household income and was not included in the sub-strata analysis.

17 Samples and quotas were informed by the 2016 American Community Survey five-year census data for Michigan. We rounded targets up and set a minimum of two, in conformance with industry best practices. Weather station quotas are not nested since we anticipated that study data would need to be normalized by actual and historical weather measurements, where nesting would add minimal value for the increased precision.

Customer Recruitment

At the start of the COVID-19 pandemic in March 2020, the team cancelled 13 appointments with customers. When we resumed site visits in July 2020, we were only able to reschedule four of those original 13 appointments. Recruitment and scheduling during the summer of 2020 was more problematic than it had been in previous periods, with the customer response rate dropping from 4.4% before 2020 to 3.4% in 2020. Also, fewer customers qualified for the study, dropping from 39% before 2020 to 27% in 2020. The team conducted site visits at 55 customer homes in July through September 2020.

COVID-19 IMPACT

In February 2020 the Cadmus team was on track to complete the study, but the lockdown forced us to halt the data collection. We resumed site visits in August with stringent health and safety protocols in place to collect additional data.

The Cadmus team used a combination of direct mailing, email, and outbound calling to recruit participants for the study. We contacted 29,893 customers via email or postcard mailer, asking them to complete a brief survey to verify their address, provide demographic details relevant to sampling, and give details about their availability for a site visit. The Cadmus team drew the sample for this study from 3,793,405 unique households served by the utilities, representing 80% of all zip codes in the state. Of those contacted, 1,165 customers completed the survey (for a 4% response rate).

We mailed a postcard to each sampled customer and sent them an email that introduced the study, explained the study process and objectives, and asked them to participate. Willing recipients went online and completed a short web survey with some basic pre-screening questions (this survey is available in *Appendix A*). This survey also asked customers about their willingness to participate in a site visit.

Two-thirds of the customers who completed the survey did not qualify for the study for one or more of the following reasons:

- The sample quota was full
- The customer could not answer the key demographic questions
- The customer was unable to accommodate a site visit to their home

The Cadmus team contacted the remaining 389 customers who did qualify for the study to confirm their survey answers and schedule a site visit. Customers were not non-responsive to outreach after completing their survey were contacted over email, followed up with phone calls. Customers were offered timeslots for technicians to visit their homes, and if no timeslot were possible for the customer, they were added to a reserve list and were contacted in cases of canceled appointments.

Of the 389 qualifying customers, the team was able to schedule visits at 197 dwellings. Of the site visits at 197 dwellings, we included details from 195 completed visits in the final analysis results. Typically, two Cadmus team technicians visited each home for two to three hours per visit; however, in some instances, we returned to accommodate a customer's schedule due to the visit length.

29,893	1,165	389
Households Contacted	Households Completed Survey	Households Qualified for a Site Visit

The team offered each customer a standard incentive of $100 for allowing us to conduct a site visit. In January 2020, we offered customers an additional $50 bonus incentive to participate in furnace metering during the site visit. In July 2020, we increased the standard incentive to $200 with an additional $50 for customers with a natural gas furnace.

Site Visit Process

Each site visit was two to three hours in duration. The team began each visit with a short, informal interview to confirm data from the web survey. We also used this interview to gather information about the customer's habits related to operating their heating and cooling systems and to answer their questions about the site visit process.

We began the primary data collection outside by measuring the home and gathering data on the foundation type, exterior insulation, soffit venting, roof type, and home characteristics. Then we collected data inside the home, starting with the attic, by measuring insulation levels and calculating square footage for each area. We collected window details including type, shading, and size. The team typically went into every room to verify window details and assess the evidence of wall insulation: this included the inside of sink cabinets, closets, and other areas where unfinished walls were often exposed.

Then the Cadmus team assessed the crawl space or basement of the home, where mechanical equipment is most often installed. We collected nameplate details and U.S. Department of Energy efficiency labels from all mechanical equipment (space heating and cooling, water heating, and humidifying and dehumidifying equipment, as well as secondary and seasonally installed equipment such as window air conditioners). The team inspected the home distribution system to look for insulation and evidence of sealing materials in unconditioned spaces of the home.

The team also installed an Onset UX-90 indoor temperature and relative humidity logger inside the customer's home near the thermostat on the main floor. Customers were able to decline having the thermostat logger installed at their discretion. They were assured the data collected by the thermostat logger would remain anonymous and would only be reported in aggregate with data from other customers in similar home. These loggers will remain installed for approximately one year. As of March 2021, 53 of the 180 installed loggers have been removed. The remainder are anticipated to be removed by July of 2021.

In January 2020, the team began installing Onset UX90-004 furnace runtime loggers and Verris-Halkeye current transformers in customer's homes with fuel fired furnaces. These loggers were installed on the wiring between the furnace control board and the gas valve on the furnace. The current transformers monitor the signal sent by the control board to the gas valve supplying gas to the burner. All customers in Climate Zone 5 with fuel fired heating equipment were surveyed about their willingness to have their natural gas furnace monitored. The furnace monitoring was not a requirement to participate in the study, however, participating customers were given an additional $50 incentive. These loggers are scheduled to be removed from customer homes by June of 2021.

Data Quality Control and Processing

The team implemented a quality assurance plan to assure the delivery of high-quality products and services to the Michigan utilities and stakeholders. Cadmus' quality assurance steps are intended to ensure that we:

- Provide research and analyses that achieve Consumers Energy's and DTE Energy's research objectives and priorities;
- Deliver the tasks and activities outlined in the Housing Baseline Study Evaluation Work Scope;[18]
- Rely on data collection and analytical methods that are consistent with current industry best practices and are appropriate to achieve the intended objectives of the research;
- Provide valuable feedback to help improve the accuracy of savings calculations in the MEMD;
- Fully document research findings and use logical inferences to draw useful conclusions and actionable recommendations;
- Provide results that are free of analytical errors and based on accurate, unbiased data and assumptions; and
- Produce well organized deliverables that are free of spelling, grammatical, and formatting errors.

Quality assurance was broken out into three key categories including: Quality of Data Collection, Data Handling and Cleansing Personally Identifiable Information (PII), and Analysis Review.

[18] *Housing Baseline Study Evaluation Work Scope*, CADMUS April 17, 2018

- The team ensured the sampling plan and data collection instruments met the project goals.
- The team ensured the customer surveys and recruitment materials were properly formatted and met customer contact guidelines.
- The team ensured the customer recruitment survey was regularly monitored and accurately captured necessarily data.
- The team tested the data collection tool in the field prior to starting data collection.
- The team incorporated automated quality assurance tests into the data collection tool to help field technicians address data quality.
- The team had a second technician review data collected by the site technician to identify inconsistent, missing, or incorrect information.
- The team reviewed compiled datasets to remove erroneous or incorrect data.

QUALITY OF DATA COLLECTION

Ensure data collected was complete, accurate, free of bias and captured all necessary information to complete research objectives.

- The team removed PII according to standards approved by Consumers Energy and DTE Energy from all customer datasets and replaced it with randomly-generated identification numbers.
- The team used standardized data request methods and securely transferred information from Consumers Energy and DTE Energy.
- The team stored customer data on encrypted servers.
- The team maintained records of user access to folders containing PII.

DATA HANDLING AND CLEANSING PII

Implement corporate standard practices and protocols regarding data handling to protect customer data and ensure security.

- The team replicated the analysis code using manual calculations.
- The team used a second party to review and re-run the analysis code.
- The team reviewed all summary data in conjunction with granular datasets to identify outliers.
- The team provided second parties with regular extracts of collected datasets for review.

ANALYSIS REVIEW

Ensured that all analysis was grounded in analytical best practices and leveraged flexible strategies to expedite quantitative and qualitative results.

Weighting Results

The Cadmus team developed weighting criteria for cross-strata and summary results to report data in this study by analyzing customer characteristics including climate zone, home type, ownership, and household income. The sample was chosen to provide 90% confidence at 20% relative precision at the main strata level, including climate zone and home type. Additional sampling at the sub-strata level included home ownership and household income. Home ownership and household income were targeted based on their relative distribution in the population to assure the sample represented the known cross section of households in Michigan.

The team analyzed the study sample at the sub-strata level to determine if the sample was significantly skewed from the population using a chi-squared test. At each strata the chi-squared value was significantly higher than the critical value of 0.05, indicating the sample was not significantly skewed. From this analysis, the team determined that weighting at the sub-strata level was not necessary as the sample was chosen to represent the population at that level.

Table 33 shows the population and sample of customers including distribution of the population and the sample and the results of the chi-squared significance test.

Table 33. Population and Sample Distribution Among Sub-Strata

Home Type	Ownership Type	Household Income	N	n	Distribution of the Population	Distribution of the Sample	X^2 P
Southern - Climate Zone 5							
Single-Family	Owned	<$40,000/year	820,258	14	0.340	0.275	0.998
		≥$40,000/year	1,251,234	30	0.518	0.588	
	Rented	<$40,000/year	135,985	4	0.056	0.078	
		≥$40,000/year	207,433	3	0.086	0.059	
Multifamily	Owner	<$40,000/year	65,972	7	0.081	0.132	0.985
		≥$40,000/year	100,634	9	0.124	0.170	
	Renter	<$40,000/year	255,542	21	0.315	0.396	
		≥$40,000/year	389,807	16	0.480	0.302	
Northern - Climate Zone 6							
Single-Family	Owner	<$40,000/year	100,915	17	0.351	0.415	0.998
		≥$40,000/year	153,937	19	0.536	0.463	
	Renter	<$40,000/year	12,868	3	0.045	0.073	
		≥$40,000/year	19,629	2	0.068	0.049	
Multifamily	Owner	<$40,000/year	2,678	4	0.063	0.082	0.969
		≥$40,000/year	4,085	9	0.096	0.184	
	Renter	<$40,000/year	14,235	22	0.333	0.449	
		≥$40,000/year	21,714	14	0.508	0.286	

Note: N is the population of customers in the lower peninsula of Michigan from the 2015 American Community Survey, n is the sample of customers analyzed in this study. The X^2 P (chi-squared) indicates the significance of the estimate, if the value is less than 0.05, this indicates the substrata has significant difference. With P-value in the 0.90 and above, there is no significant difference between the sample and the population estimates.

Since the sample was not skewed at the sub-strata level, weighting was applied to the main strata categories of home type and climate zone. The largest population were single-family homes in southern Michigan with each sampled home representing 46,441 households. The smallest population were multifamily homes in climate zone 6 with each sampled home representing 872 households. Table 34 shows the sample weights applied in weighted summary data.

Table 34. Weighting Applied

Climate Zone	Home Type	N	n	Weight
Southern - Climate Zone 5	Single-Family	2,414,910	52	46,440.58
	Multifamily	811,955	53	15,319.91
Northern - Climate Zone 6	Single-Family	287,349	41	7,008.51
	Multifamily	42,712	49	871.67

Note: N is the population of customers in the lower peninsula of Michigan from the 2015 American Community Survey, n is the sample of customers analyzed in this study.

Appendix A. Customer Recruitment Survey

Customer List	Climate Zone	Home Type	Strata Sample Size	Ownership Type	Household Income	Survey Limits
Consumers Energy and DTE Energy	Climate Zone 5	Single-Family	46	Owned	<$40,000/year	20
					≥$40,000/year	30
				Rented	<$40,000/year	7
					≥$40,000/year	11
		Multifamily	56	Owned	<$40,000/year	9
					≥$40,000/year	8
				Rented	<$40,000/year	28
					≥$40,000/year	38
	Climate Zone 6	Single-Family	46	Owned	<$40,000/year	20
					≥$40,000/year	30
				Rented	<$40,000/year	7
					≥$40,000/year	11
		Multifamily	56	Owned	<$40,000/year	9
					≥$40,000/year	8
				Rented	<$40,000/year	28
					≥$40,000/year	38

Programming notes:

Mixed mode distribution:

- Email (to those with emails, separated by energy provider; mode field will be blank)
- Contact list fields for email distribution: FirstName, LastName, Email, Service Address/City/State/Zip (piped text), CadmusAccountID, Zone (for quota tracking), optional: energy provider

Email Invitation

From: DTE Energy and Consumers Energy

Subject: Home Energy Study

Dear **[FIRST AND LAST NAME]**,

To offer the best rebates for energy-efficiency improvements we need your help. **[MF FUNDRAISING VERSION:]** If you live in an attached home (an apartment, condo, or townhome), we need your help. **[DTE ENERGY/CONSUMERS ENERGY]** is conducting an important study about home energy performance, which will involve measuring the energy efficiency of our customers' homes. The study will help us to better understand how we can help you save energy.

To do this, **[DTE ENERGY/CONSUMERS ENERGY]** has hired the research firm Cadmus to study energy consumption in our customers' homes. Participation is optional, but highly encouraged. **[GENERIC REMINDER VERSION:]** We contacted you recently and would still like to hear from you! **[MULTIFAMILY**

REMINDER VERSION:] To reach our participation goal, we need at least 15 more responses. Can we count on you? If you have not completed the survey yet, please take five minutes to do so now.

To help protect everyone's health and safety, we have instituted strict protocols to prevent the spread of COVID-19, including asking all staff to wear masks, sanitize surfaces, and avoid coming into contact with you to the extent possible while inside your home.

If you choose to participate and are selected for and complete a visit, you will be compensated for your time with a $200[19] gift card to Meijer or Amazon. If you would like to determine if you are eligible for the study and learn more about participating, go to the website and confirm your service address:

- Follow this link to the Survey: **${L://SURVEYLINK?D=TAKE THE SURVEY}**
- Or copy and paste the URL below into your internet browser: **${L://SURVEYURL}**

Should you qualify, over the next few days a representative from Cadmus may reach out to further discuss your participation in this study.

Thank you in advance for your assistance and time with this important research effort.

Sincerely,

Jason Kupser
DTE Energy

Jenny Sample
Evaluation, Measurement & Verification
Clean Energy Products
Consumers Energy

Introduction

Thank you for your interest!

Consumers Energy and DTE Energy are conducting an important study of homes in Michigan. Cadmus has been contracted to conduct this study. The study results will be used to help design energy-efficiency rebate programs to meet rising energy needs. Consumers Energy and DTE Energy are providing a $200 Meijer or Amazon gift card to participants of this study. Participation involves a 1.5 to two hour visit from a Cadmus engineer. The engineer will conduct a walk-through survey of your home, gathering data about your heating system, cooling system, insulation, and other home features.

To help protect everyone's health and safety, our staff will be following strict protocols to prevent the spread of COVID-19, including wearing masks while inside your home, sanitizing surfaces, and avoiding coming into contact with you to the extent possible while inside your home.

[19] Note: The Cadmus team increased this incentive from $100 to $200 in the summer of 2020.

Please be assured that all data collected as part of this study will be kept strictly confidential and used only for research purposes. All personal information will be removed and the collected data will be aggregated with that of many other residents in your region for analysis. Please note that there may not be enough room in this study to accommodate all interested parties. If your home is qualified to participate in the study, our scheduling team will contact you to either schedule a convenient time for you to participate or inform you that the study is full.

If you are interested in participating in this study, please click the Next button below to complete our brief questionnaire to confirm if your home is eligible for the study. **[PROVIDE LINK LABELED "I AM INTERESTED IN PARTICIPATING" AND CONTINUE TO A1 WHEN CLICKED]**

[NOTE FOR PROGRAMMING, OUR PREFERENCE IS FOR MOST QUESTIONS TO NOT INCLUDE A "DON'T KNOW" OR "PREFER NOT TO ANSWER" OPTION. INSTEAD WE WOULD LIKE A BUTTON BELOW RESPONSE OPTIONS LABELED "NEXT" THAT WILL ALLOW MANY QUESTIONS TO BE SKIPPED. FORCED RESPONSES ARE LABELED WHEN NEEDED]

A. Screener

A1. Would you or someone else over the age of 18 be available to accommodate a visit to your home as part of this study? The visit would take up to two hours and involves an engineer completing a walk-through energy survey of your home. **[FORCED RESPONSE]**

1. Yes
2. No **[TERMINATE]**

B. Your Details

B1. What type of residence do you live in?

1. Detached home (a building not attached to any others) **[FOR QUOTAS=SINGLE FAMILY]**
2. Attached home (a building with other homes attached) **[FOR QUOTAS=MULTIFAMILY]**
3. Mobile home **[TERMINATE]**
4. Other (please specify) **[RECORD RESPONSE: __________]**

B2. **[ASJ IF B1=2 OR 4]** How many homes are attached to the building?

1. **[WHOLE NUMBER RESPONSE: __________]**

B3. Do you own or rent this home?

1. Own
2. Rent/lease
3. Live in home rent-free **[FOR QUOTAS=RENTED]**

B4. Including yourself, how many people live in this home year-round?

1. **[RECORD RESPONSE: __________]**

B5. Which category best describes your total household income in 2019 before taxes?

1. Less than $15,000 **[FOR QUOTAS=INCOME QUALIFIED]**
2. $15,000 to $19,999 **[FOR QUOTAS=INCOME QUALIFIED]**
3. $20,000 to $29,999 **[FOR QUOTAS=INCOME QUALIFIED]**
4. $30,000 to $39,999 **[FOR QUOTAS=INCOME QUALIFIED]**
5. $40,000 to $49,999 **[FOR QUOTAS≠INCOME QUALIFIED]**
6. $50,000 to $74,999 **[FOR QUOTAS≠INCOME QUALIFIED]**
7. $75,000 to $99,999 **[FOR QUOTAS≠INCOME QUALIFIED]**
8. $100,000 to $124,999 **[FOR QUOTAS≠INCOME QUALIFIED]**
9. $125,000 or more **[FOR QUOTAS≠INCOME QUALIFIED]**
10. Prefer not to answer

B6. **[ASK IF B5=10]** We understand that income is a sensitive topic, but one purpose of the study is to represent all income levels equally, so it is a requirement to participate. Which would you say best describes your household income?

1. More than equal to $40,000 per year **[FOR QUOTAS≠INCOME QUALIFIED]**
2. Less than $39,999 per year **[FOR QUOTAS=INCOME QUALIFIED]**
3. Prefer not to answer **[TERMINATE]**

B7. **[IF MODE=EMAIL]** Is this the address where you receive electric service? **[DISPLAY ADDRESS FIELDS] [FORCED RESPONSE]**

1. Yes
2. No

B8. **[ASK IF B7=2 OR MODE=MAIL]** What is the address where you receive electric service? **[ASK IF MODE=MAIL:]** Please enter the address where you received the invitation. **[ALL DETAILS ARE OPEN-ENDED QUESTIONS THAT THE CUSTOMER CAN FILL IN.]**

1. Address 1
2. Address 2
3. Unit number**[LEAVE BLANK IF NOT APPLICABLE]**
4. City **[FORCED RESPONSE]**
5. State
6. Zip code

B9. Who provides **electric** service to this address? **[FORCED RESPONSE]**

1. Consumers Energy
2. DTE Energy
3. Other (please specify) **[RECORD RESPONSE: __________]**

B10. Who provides **<u>natural gas</u>** service to this address? **[FORCED RESPONSE]**

1. Consumers Energy
2. DTE Energy
3. Other (please specify) **[RECORD RESPONSE: __________]**
4. I don't have natural gas service

B11. Was this home occupied for the past 12 months? **[FORCED RESPONSE]**

1. Yes, I lived here last year
2. Yes, others live here last year
3. No, this home was not occupied for the past 12 months **[TERMINATE]**

B12. Do you anticipate that this home will be occupied for the next 12 months? **[FORCED RESPONSE]**

1. Yes
2. No **[TERMINATE]**

[IF A1=2 OR (B9=3 AND B10=3 OR 4) OR B11=3 OR B12=2, THEN DISPLAY THE FOLLOWING TERMINATION MESSAGE] You are not eligible to participate in this Consumers Energy study. Thank you for your interest.

B13. Do you have a front office or security gate we would need to contact in order to visit your home?

1. Yes
2. No

B14. **[ASK IF B13=1]** Please share the contact information for the front office or security gate.

1. **[RECORD NAME AND PHONE NUMBER: __________]**

B15. If you participate in this study, could the heating, cooling, and water heating equipment be accessed by our engineer during their visit?

1. Yes
2. No

98. Don't know

B16. **[IF B1=2 AND B15=2]** Is there someone we could contact at the property such as a property manager to access your heating, cooling, or water heating equipment?

1. Yes **[RECORD NAME AND PHONE NUMBER: __________]**

FOR CLIMATE ZONE 5 SURVEY ONLY.

B17. **[ASK IF B15=1]** Is your home heated by a natural gas furnace?

1. Yes
2. No

98. Don't know

B18. **[ASK IF B17=1 OR 0.709842048.98]** You will receive an additional $50 gift card if we are able to meter your furnace. This meter does not affect the operation of your furnace and the data it gathers will only be used for research purposes. If you agree, you may still opt out later. Would you be interested in having this meter installed?

1. Yes, I am interested and I would like to learn more
2. No, I am not interested

98. Don't know

C. Closing and Contact Details

Thank you, your home is eligible for our study. Please note that eligible homes are not guaranteed participation in this study.

Please enter your contact information below so that our scheduling team can contact you to either schedule a convenient time for you to participate or notify you that the study is full. If we visit your home, you will receive the $200 gift card.

[INCLUDE FIELDS FOR "PERSONS NAME," "EMAIL," AND "PHONE NUMBER" AND DISPLAY MESSAGE "A PHONE NUMBER MUST BE ENTERED" IF THIS FIELD IS LEFT BLANK]

[INCLUDE BUTTON AFTER CONTACT DETAILS LABELED "SUBMIT." IF REQUIRED FIELDS ARE COMPLETED AND "SUBMIT" IS CLICKED, THEN DISPLAY MESSAGE "THANK YOU, WE WILL CONTACT YOU SOON."]

Appendix B. Certification Letter

DTE

Consumers Energy
Count on Us

Dear Customer,

Thank you for completing the online survey conducted by our research vendor, Cadmus, and for being willing to work with Cadmus to schedule a visit to your home. The purpose of this letter is to provide further information on the study and contacts for your reference.

Consumers Energy and DTE Energy have joined forces to conduct a study of 200 customers across the state. The goal is to better understand how the structure, insulation, and heating and cooling systems of our customers' homes affect energy use and costs.

The study's results will help us **improve our energy efficiency programs and rebates to help you save energy, money and protect Michigan's environment**. **In appreciation for your time, you'll receive your choice of a $100 Amazon or Meijer gift card at the start of the home visit.**

If you are able to participate, Cadmus, a national research firm, will visit your home to gather information on energy-related features like heating system and insulation levels. **The information gathered about your home will be kept strictly confidential and will be combined with data from other participants to represent homes across the state.**

We understand your need to ensure that these kinds of efforts are legitimate. We encourage you to contact DTE and Consumers Energy to verify the legitimacy of this study;

Consumers Energy: Jenny Sample Sr. Analyst, Evaluation, Measurement & Verification Office: (517) 788-0089 Jenny.Sample@cmsenergy.com **OR** Consumer Energy Customer service printed on the back of your bill 1 (800) 477-5050	**DTE Energy:** Customer Service 800.477.4747

Additionally, Cadmus staff visiting your home will have Consumers Energy or DTE authorized contractor badges as well as a Cadmus badge, and you can call the CE or DTE contacts above to verify their identities.

Thank you for considering this request and helping us serve you better;

Joseph Forcillo

Director of Evaluation, Measurement & Verification
Clean Energy Products
Consumers Energy

Jason Kupser

Manager, Evaluation, Measurement & Verification
Energy Efficiency
DTE Energy

Appendix C. Datapoints Collected

The Cadmus team collected data in the tablet-based Arkenstone data collection tool, which categorized collected data by type, category, element, and variable. Each variable details a specific datapoint collected for the study.

For each customer we visited, we collected details about the home unit and details about multifamily buildings. We categorized the questions based on the physical location and collected data elements as a module, where each element represents a specific group of related questions.

The Cadmus team collected several details for each variable:

- ***Facility type.*** Dwelling units (Table 35) refer to data collected specific to the customer dwelling type, where multifamily buildings (Table 36) refer to building-specific data outside the customer's dwelling unit.
- ***Category.*** The customer location when the team collected data. These are presented as subheadings within each table.
- ***Element type.*** The type of data being collected.
- ***Variable name.*** The data point the technician collected.
- ***Question prompt.*** The specific question the technician asked and the customer answered.
- ***Response type.*** The type of data the technician collected.
- ***Response options.*** For questions with multiple response options, list of acceptable answers.
- ***Help text.*** Additional data the technical considered for a specific variable.

Table 35. Data Collected for Dwelling Unit Facility Type

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
Customer Interview					
Demographics	dwlg_giftcard_amount	After giving the occupant the gift card, record the dollar amount. Please take a photo of the exact gift card given to the occupant and upload.	Numeric	N/A	Will likely be $100 or $200. Please take a photo of the exact gift card given to the occupant and upload.
	dwlg_giftcard_type	After giving the occupant the gift card, record the type of gift card (Meijer or Amazon).	Text	N/A	
	dwlg_ownership_status	Does the occupant own or rent the dwelling?	Options	Own, Rent, Other	
	dwlg_fulltime	Does the occupant live in the home full time?	Options	Yes, No	
	dwlg_year_built	What year was the house built?	Integer	N/A	
	dwlg_number_of_occupants	How many occupants live in the dwelling?	Integer	N/A	
	years_in_dwelling	How long has the person on the utility account lived in this dwelling?	Options	Less than six months, Six months to one year, One to two years, Longer than two years	
	dwlg_moved_in	In the past 12 months, how many people have moved out of the dwelling?	Integer	N/A	Enter 0 if none
	dwlg_moved_out	In the past 12 months, how many people have moved into the dwelling?	Integer	N/A	Enter 0 if none
	dwlg_occupant_status	How many occupants are typically outside the home during a typical weekday?	Integer	N/A	Enter 0 if none
Number of Rooms	number_bedrooms	Number of bedrooms	Integer	N/A	
	number_bathrooms	Number of bathrooms	Numeric	N/A	
	number_kitchens	Number of kitchens	Integer	N/A	

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
	number_common_rooms	Number of living/family/dining rooms	Integer	N/A	
User Habits	dwlg_window_usage_summer	Do you open your windows in the summer?	Options	Often, Rarely, Never	
	dwlg_window_usage_spring_fall	Do you open your windows in the spring and fall?	Options	Often, Rarely, Never	
	dwlg_window_usage_winter	Do you open your windows in the winter?	Options	Often, Rarely, Never	
	dwlg_thermostat_type_int	What type of thermostat do you have for your heating and cooling equipment?	Options	Smart, Programmable, Manual, Other, None	Smart thermostats have learning capabilities and are also programmable, such as a Nest. Programmable thermostats do not have learning capabilities.
	dwlg_thermostat_smart	Do you let the smart thermostat automate your heating/cooling or do you typically override settings?	Options	Automate, Override	
	dwlg_thermostat_prog	Do you have your programmable thermostat scheduled or do you mostly leave it on hold at a single temperature?	Options	Scheduled, Hold at single temperature	
	dwlg_thermostat_manual	Do you often manually make adjustments to the thermostat or do you mostly leave it on hold at a single temperature?	Options	Manual, Hold at single temperature	
	dwlg_HVAC_sys_broken	Is your heating/cooling system able to maintain your desired temperature?	Options	Yes my home feels comfortable warm in winter and cool in summer, No my home feels too cold in the winter and too warm in the summer, other	
	dwlg_HVAC_sys_notes	If Other, please specify	Text	N/A	Specify when home is too warm and/or cold due to broken heating and/or cooling systems

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
	dwlg_humid_usage_pattern	Do you use a humidifier?	Options	Always, Occasionally, Rarely, Never	
	dwlg_de_humid_usage_pattern	Do you use a dehumidifier?	Options	Always, Occasionally, Rarely, Never	
	dwlg_air_pure	Is there a powered air purification system that plugs into the HVAC system?	Options	Yes, No	If do not know, select “Unable to Determine”
	dwlg_electric_cars	How many electric cars does the resident(s) own?	Numeric	N/A	Enter 0 if none
	dwlg_electric_car_plugin	Is there an electric car plug-in at the home or apartment?	Options	Yes, No	
	dwlg_electric_car_plugin_count	How many electric car plug-ins are included in this dwelling’s electric bill?	Numeric	N/A	In other words, how many electric car plug-ins are metered on the customer’s meter (that they pay for)
	dwlg_hot_tubs	How many hot tubs are there at the home or apartment and included in this dwelling's electric bill (not shared)?	Numeric	N/A	Enter 0 if none
	dwlg_pools	How many pools are there at the home or apartment and included in this dwelling's electric bill (not shared)?	Numeric	N/A	Enter 0 if none
	dwlg_other_plug_loads	Please specify any other large plug loads at this house and included in this dwelling’s electric bill (such as large machinery), if applicable	Text	N/A	Enter “Not Applicable” if none
Improvements	dwlg_improvement_type	Renovations/improvements to the dwelling	Options	HVAC, Domestic hot water, Doors, Windows, Air sealing, Insulation upgrade, Addition, None	Create a separate improvements entry for each renovation type
	dwlg_year_of_improvement	What year did the renovations/improvements occur?	Integer	N/A	

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
	dwlg_improvement_notes	Describe the renovations/improvements	Text	N/A	
Thermostat Logger Info	onset_installed	Was an Onset logger successfully installed?	Options	Yes, No	Please include a photo of the installed Onset logger
	onset_not_installed_notes	Notes field regarding why Onset logger was not installed	Text	N/A	The logger installation is optional if the customer declined or it cannot be installed
	onset_serial_number	Onset logger serial number	Text	N/A	Please include a photo
	onset_location_notes	Onset logger location notes	Text	N/A	Please include a photo
Utilities	solar_PV	Does the home have solar PV?	Options	Yes, No	
	natural_gas_meter_number	Natural gas meter number	Text	N/A	This will likely be on the side of the house, please include a photo, attempt to find for multifamily; however, click “Unable to Determine” if unable to determine confidently.
	natural_gas_meter_serves	Does this meter serve this unit only?	Options	Yes, No	
	natural_gas_meter_multiple	Are there multiple natural gas meters?	Options	Yes, No	
	electric_meter_number	Electricity meter number	Text	N/A	This will likely be on the side of the house, please include a photo, attempt to find for multifamily; however, click “Unable to Determine” if unable to determine confidently.
	electric_meter_serves	Does this meter serve this unit only?	Options	Yes, No	
	electric_meter_multiple	Are there multiple electric meters?	Options	Yes, No	
	other_fuel_types	What other fuels does this home have? (select all that apply)	Multiselect	Propane, Wood, Oil, Coal, Other, None	
	other_fuel_type_specify	What is the other fuel type?	Text	N/A	If fuel type is “Other,” please describe.

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
Dwelling Exterior					
Dwelling Overview	dwlg_SF_MF	Is this dwelling in a single or multifamily house?	Options	Single-Family (one unit), Multifamily (two or more units)	If multifamily, make sure to fill out the multifamily building facility as well.
	dwlg_perimeter_ft	Total exposed perimeter of dwelling unit in feet	Numeric	N/A	
	dwlg_height_total_ft	Dwelling unit total height in feet	Numeric	N/A	This is the height of the dwelling only: the house height for single-family and the apartment height for multifamily.
	dwlg_area_total_ft	Total area (footprint) of dwelling unit in square feet	Numeric	N/A	
	dwlg_area_conditioned_ft	Area of conditioned space only in square feet	Numeric	N/A	Include all intentionally conditioned spaces. If helpful, make drawing of area and take photo with dimensions.
	dwlg_area_unconditioned_ft	Area of unconditioned space only in square feet	Numeric	N/A	Include unconditioned garages and basements, non-vented crawl spaces.
	dwlg_garage_present	Is there a garage?	Options	Yes, No	
	dwlg_garage_type	Type of garage	Options	Attached to dwelling, Attached to building, Attached carport, Below living space, Free standing	
	dwlg_stories_above_grade	Number of above-grade stories	Numeric	N/A	
	dwlg_stories_below_grade	Number of below-grade stories	Numeric	N/A	Do not include crawl spaces
	dwlg_description	Describe the home in a sentence (include home style)	Text	N/A	Please include photos of all four sides of the house
	dwlg_roof_type	Type of roof	Options	Flat, Gable, Hip, Mansard, Gambrel (barn), Shed (pitched), Other	
	dwlg_roof_material	Roof material	Options	Asphalt shingle, Rubber, Metal, Clay tile, Stone (slate), Other	
	dwlg_roof_eave_thickness_inch	What is the roof eave thickness in inches?	Numeric	N/A	
	dwlg_roof_soffit_venting	Is there soffit venting?	Options	Yes, No	

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
	dwlg_siding_material	Siding material	Options	Mixed, Aluminum, Asbestos, Asphalt, Brick, Block, Concrete, Cedar, Cement, Fiberglass, Hard board, Metal, Shake, Stone, Stucco, T1-11, Vinyl, Wood, Other	
Dwelling Doors	dwlg_door_ext_type	Door type	Options	No light, Half light, Full light	Exterior doors. Create a separate dwelling doors entry for each door type.
	dwlg_door_ext_material	Door material	Options	Wood, Metal, Fiberglass, Other	
	dwlg_door_ext_height_inch	Door height in inches	Numeric	N/A	
	dwlg_door_ext_width_inch	Door width in inches	Numeric	N/A	
	dwlg_door_ext_thickness_inch	Door thickness (inches)	Numeric	N/A	
	dwlg_door_ext_orientation	Door orientation	Options	N, NE, E, SE, S, SW, W, NW	
	dwlg_door_location	Where is the door located?	Options	Between conditioned space and ambient, Between conditioned space and garage, Between conditioned space and open crawl, Between conditioned space and attic, Between conditioned space and unconditioned basement, Between conditioned space and enclosed crawl, Between conditioned crawl and ambient, Between conditioned crawl and garage, Between conditioned crawl and open crawl, Between unconditioned basement and ambient, Between unconditioned basement and garage, Between unconditioned basement and open crawl, Between enclosed crawl and	

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
				ambient, Between enclosed crawl and garage, Between enclosed crawl and open crawl, Between sealed attic and ambient	
	dwlg_door_ext_count	Number of doors of same type	Integer	N/A	Count of doors that have all the same characteristics just entered
Dwelling Above Grade Walls	dwlg_wall_type	Type of wall (select one)	Options	Masonry, Framed 2x2, Framed 2x3, Framed 2x4, Framed 2x6, Framed 2x8, Knee wall, Insulated concrete form, Structural insulated panels, Log, Structural steel, Infill frame, Other	Do not collect walls between conditioned spaces (where there is no heat transfer). Create a separate dwelling above-grade walls entry for each type of wall.
	dwlg_wall_thickness_inch	Total thickness of wall in inches	Numeric	N/A	Thickness of wall inside to outside
	dwlg_wall_furred	Additional furred wall?	Options	Yes, No	For masonry or double stud walls with second wall
	dwlg_wall_furred_type	Furred wall type	Options	Framed 2x2, Framed 2x4, Framed 2x6, Framed 2x8, Other	
	dwlg_wall_height_ft	Height of wall in feet	Numeric	N/A	
	dwlg_wall_length_ft	Length of wall in feet	Numeric	N/A	
	dwlg_wall_cavity_ins_cond	Is the wall cavity insulated?	Options	No, Fully, Partially	
	dwlg_wall_cavity_ins_type	Wall cavity insulation type	Options	Mixed, Fiberglass batts, Mineral wool batts, Cellulose batts, Blown fiberglass, Blown mineral wool, Blown cellulose, Foil-faced polyisocyanurate foam board, Foamboard, Extruded polystyrene foam board (pink or blue), Expanded polystyrene foam board (white), Open-cell spray foam, Closed-cell spray foam, Vermiculite, Perlite, Saw dust insulation, None	
	dwlg_wall_cavity_ins_source	Wall cavity insulation data source	Options	Visual inspection, Homeowner plans, Estimated	

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
	dwlg_wall_cont_ins_yes_no	Is there continuous wall insulation?	Options	Yes, No	
	dwlg_wall_cont_ins_type	Continuous wall insulation type	Options	Mixed, Fiberglass batts, Mineral wool batts, Cellulose batts, Blown fiberglass, Blown mineral wool, Blown cellulose, Foil-faced polyisocyanurate foam board, Foamboard, Extruded polystyrene foam board (pink or blue), Expanded polystyrene foam board (white), Open-cell spray foam, Closed-cell spray foam, Vermiculite, Perlite, Saw dust insulation, None	
	dwlg_wall_cont_ins_thickness_inch	Continuous wall insulation thickness (inches)	Numeric	N/A	
	dwlg_wall_cont_ins_source	Source of continuous wall insulation data	Options	Visual inspection, Homeowner plans, Estimated	
	dwlg_wall_location	Where is the wall located?	Options	Between conditioned space and ambient, Between conditioned space and garage, Between conditioned space and open crawl, Between conditioned space and attic, Between conditioned space and unconditioned basement, Between conditioned space and enclosed crawl, Between conditioned crawl and ambient, Between conditioned crawl and garage, Between conditioned crawl and open crawl, Between unconditioned basement and ambient, Between unconditioned basement and garage, Between unconditioned basement and open crawl, Between enclosed crawl and ambient, Between enclosed crawl and garage, Between enclosed crawl and	

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
				open crawl, Between sealed attic and ambient	
	dwlg_wall_count	Number of walls of same type	Numeric	N/A	Count of walls that have all the same characteristics just entered
Interior					
Windows	window_height_inch	Height of window in inches	Numeric	N/A	Create a separate Windows entry for each type of window.
	window_width_inch	Width of window in inches	Numeric	N/A	
	window_orientation	Window orientation	Options	N, NE, E, SE, S, SW, W, NW	
	window_treatments	What treatments are on the window?	Multiselect	Exterior storm window, Interior storm window, Plastic film storm present, Solar screen, Blinds, Shades, None	Select all that apply
	window_glazing	Type of window glazing	Options	Single, Double, Triple	
	window_frame	Type of window frame	Options	Vinyl, Metal, Wood, Fiberglass, Other	
	window_count	Number of windows of same type	Numeric	N/A	Count of windows that have all the same characteristics just entered
	window_U_factor	Window U-factor, if available (please do not estimate)	Numeric	N/A	If recording a U-factor, please include a picture of the source. Select “Unable to Determine” if not available.
	window_SHGC	Window solar heat gain coefficient, if available (please do not estimate)	Numeric	N/A	If recorded, please include a picture of the source. Select “Unable to Determine” if not available.
	window_U_factor_SHGC_source	Source of window U-factor and/or SHGC data	Options	Window sticker, Homeowner plans	Select “Not Applicable” if U-factor and solar heat gain coefficient are not available.
Skylights	skylight_yes_no	Are there any skylights in the dwelling?	Options	Yes, No	
	skylight_height_inch	Height of skylight in inches	Numeric	N/A	Create a separate entry for each type of skylight.
	skylight_width_inch	Width of skylight in inches	Numeric	N/A	
	skylight_glazing	Type of skylight glazing	Options	Single, Double, Triple	
	skylight_frame	Type of skylight frame	Options	Vinyl, Metal, Wood, Fiberglass, Other	
	skylight_pitch	Skylight pitch	Options	Pitched roof, Flat section	

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
	skylight_count	Number of skylights of same type	Numeric	N/A	Count of skylights that have all the same characteristics that you just entered
	skylight_U_factor	Skylight U-factor, if available (please do not estimate)	Numeric	N/A	If you record a U-factor, please include a picture of the source. Select “Unable to Determine” if not available.
	skylight_SHGC	Skylight solar heat gain coefficient, if available (please do not estimate)	Numeric	N/A	If recorded, please include a picture of the source. Select “Unable to Determine” if not available.
	skylight_U_factor_SHGC_source	Source of skylight U-factor and/or solar heat gain coefficient data	Options	Window sticker, Homeowner plans	Select “Not Applicable” if U-factor and solar heat gain coefficient are not available.
Attic/Ceiling	attic_yes_no	Is there an unconditioned attic?	Options	Yes, No	If there is a conditioned attic (or part of the attic is conditioned), record those walls in dwelling above grade walls and do not record the floor data (because there is no heat transfer). Create a separate attic entry for each type/thickness of attic insulation.
	attic_access	Is attic access possible?	Options	Yes, No	In other words, is it possible for you to go into/look in the attic
	attic_size_ft	Total area of unconditioned attic in square feet	Numeric	N/A	
	attic_percent_insulated	Percentage of unconditioned attic that contains insulation	Integer	From 0 to 100	Use notes button to explain area/insulation/etc. if needed by estimating an R-value.
	attic_ins_type	Type of unconditioned attic insulation	Options	Mixed, Fiberglass batts, Mineral wool batts, Cellulose batts, Blown fiberglass, Blown mineral wool, Blown cellulose, Foil-faced polyisocyanurate foam board, Foamboard, Extruded polystyrene foam board (pink or blue), Expanded polystyrene foam board (white), Open-cell spray foam, Closed-	Use notes button to explain area/insulation/etc. if needed by estimating an R-value.

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
				cell spray foam, Vermiculite, Perlite, Saw dust insulation, None	
	attic_ins_thickness_inch	Thickness of attic insulation in inches	Numeric	N/A	Use notes button to explain area/insulation/etc. if needed by estimating an R-value. Select “Not Applicable” if no insulation.
	attic_ins_source	Source of unconditioned attic insulation data	Options	Visual inspection, Homeowner plans, Estimated	
	attic_venting	Is the unconditioned attic vented?	Options	Yes, No	Select “Unable to Determine” or “Unable to Access” if you do not know.
	ceiling_ins_yes_no	Is there enclosed ceiling insulation (likely if there is no attic)?	Options	Yes, No	If the house does not have an attic, there may be ceiling insulation instead (or the house may have both attic and ceiling insulation).
	ceiling_ins_type	Type of enclosed ceiling insulation	Options	Mixed, Fiberglass batts, Mineral wool batts, Cellulose batts, Blown fiberglass, Blown mineral wool, Blown cellulose, Foil-faced polyisocyanurate foam board, Foamboard, Extruded polystyrene foam board (pink or blue), Expanded polystyrene foam board (white), Open-cell spray foam, Closed-cell spray foam, Vermiculite, Perlite, Saw dust insulation	
	ceiling_thickness_inch	Ceiling thickness from roof to ceiling (inches)	Numeric	N/A	
	ceiling_size_ft	Enclosed ceiling area in square feet	Numeric	N/A	
	ceiling_percent_insulated	Percentage of enclosed ceiling that contains insulation	Integer	From 0 to 100	
	ceiling_ins_source	Source of ceiling insulation data	Options	Visual inspection, Homeowner plans, Estimated	

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
Floors	floor_type	Type of floor	Options	Framed floor, Slab below grade, Other	Do not collect floors between conditioned spaces (where there is no heat transfer). Create a separate floors entry for each type of floor insulation.
	floor_ins_type	Type of floor insulation	Options	Mixed, Fiberglass batts, Mineral wool batts, Cellulose batts, Blown fiberglass, Blown mineral wool, Blown cellulose, Foil-faced polyisocyanurate foam board, Foamboard, Extruded polystyrene foam board (pink or blue), Expanded polystyrene foam board (white), Open-cell spray foam, Closed-cell spray foam, Vermiculite, Perlite, Saw dust insulation, None	
	floor_ins_thickness_inch	Thickness of floor insulation (inches)	Numeric	N/A	
	floor_ins_cond	Floor insulation condition?	Options	Fully contacting surface, Intermittent contact with surface, No contact	
	floor_ins_source	Source of floor insulation data	Options	Visual inspection, Homeowner plans, Estimated	
	floor_area_ft	Area of floor in square feet	Numeric	N/A	
	floor_location	Where is the floor located?	Options	Between conditioned space and ambient conditions, Between conditioned space and ground (slab on grade), Between conditioned space and garage, Between conditioned space and unconditioned crawl space, Between conditioned space and unconditioned basement	Do not collect floors between conditioned spaces (where there is no heat transfer).
Foundation	foundation_type	What type of foundation?	Options	Slab on grade, Conditioned basement, Unconditioned basement, Conditioned crawl space, Unconditioned crawl space, Other	Insert type of building foundation for the element, conditioned basement and crawl spaces are intentionally heated. Unconditioned base/crawls

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
					and not intentionally heated. Create a separate foundation entry for each type of foundation.
	foundation_vented	Is foundation vented?	Options	Yes, No	Does the foundation contain venting (openings) that allow outside air to enter the foundation and maintain a temperature close to the outside? If vents present but sealed shut assume no venting.
	foundation_wall_material	Foundation wall material	Options	Concrete, Stone, CMU, Other	Do not collect foundation walls between conditioned spaces (where there is no heat transfer). Create a separate foundation entry for each type of foundation wall.
	foundation_wall_length_ft	Foundation wall length (feet)	Numeric	N/A	Enter total perimeter if foundation is same exposure type.
	foundation_wall_height_ft	Foundation wall height (feet)	Numeric	N/A	Enter average height.
	foundation_wall_ft_below_grade	Feet below grade of the foundation wall	Numeric	N/A	Enter average below-grade height.
	foundation_wall_thickness_inch	Foundation wall thickness (inches)	Numeric	N/A	Thickness of the masonry or concrete only
	foundation_ins_type	Foundation insulation type	Options	None, Continuous interior, Continuous exterior, Furred wall, Slab edge, Other	
	foundation_ins_material	Foundation insulation material	Options	None, Mixed, Fiberglass batts, Mineral wool batts, Cellulose batts, Blown fiberglass, Blown mineral wool, Blown cellulose, Foil-faced polyisocyanurate foam board, Foamboard, Extruded polystyrene foam board (pink or blue), Expanded polystyrene foam board (white), Open-cell spray foam, Closed-cell spray foam, Vermiculite, Perlite, Saw dust insulation	

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
	foundation_ins_thickness_inch	Thickness of insulation (inches)	Numeric	N/A	For continuous insulation enter total thickness, for furred wall enter thickness of insulation in wall.
	foundation_ins_orientation	Slab edge insulation orientation	Options	Horizontal, Vertical	
	foundation_ins_depth	Slab edge insulation depth	Numeric		
	foundation_ins_source	Source of foundation insulation data	Options	Visual inspection, Homeowner plans, Estimated	
	foundation_ins_cond	Foundation insulation condition	Options	Fully contacting surface, Intermittent contact with surface, No contact	
	foundation_location	Where is the foundation wall located?	Options	Between conditioned space and ambient/ground, Between conditioned space and garage/ground, Between conditioned space and unconditioned crawl space/ground, Between conditioned space and unconditioned basement/ground, Between unconditioned basement and ambient/ground, Between unconditioned basement and garage/ground, Between unconditioned crawl space and ambient/ground, Between unconditioned crawl space and garage/ground	Do not collect foundation walls between conditioned spaces (where there is no heat transfer).
	foundation_wall_count	Number of foundation walls of same type	Integer	N/A	Count of foundation walls that have all the same characteristics just entered
Rim and Band	rim_band_material	Rim and band framing material	Options	Metal, Wood, Other	Create a separate rim and band entry for each type of rim and band insulation.
	rim_band_length_ft	Rim and band length (feet)	Numeric	N/A	
	rim_band_ins_length_ft	Rim and band insulated length (feet)	Numeric	N/A	
	rim_band_cavity_ins_type	Rim and band cavity insulation type	Options	Mixed, Fiberglass batts, Mineral wool batts, Cellulose batts, Blown fiberglass,	

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
				Blown mineral wool, Blown cellulose, Foil-faced polyisocyanurate foam board, Foamboard, Extruded polystyrene foam board (pink or blue), Expanded polystyrene foam board (white), Open-cell spray foam, Closed-cell spray foam, Vermiculite, Perlite, Saw dust insulation, None	
	rim_band_cavity_ins_thickness_inch	Rim and band cavity insulation thickness (inches)	Numeric	N/A	
	rim_band_ins_source	Rim and band insulation data source	Options	Visual inspection, Homeowner plans, Estimated	
	rim_band_ins_cond	Rim and band insulation condition	Options	Fully contacting surface, Intermittent contact with surface, No contact	
	rim_band_location	Where is the rim band located?	Options	Between conditioned space and ambient, Between conditioned space and garage, Between conditioned space and unconditioned crawl, Between conditioned space and attic, Between conditioned space and unconditioned basement, Between unconditioned basement and ambient, Between unconditioned basement and garage, Between unconditioned crawl and ambient, Between unconditioned crawl and garage, Between sealed attic and ambient	
Dwelling HVAC					
Dwelling Heating	dwlg_heating_sys_type	Type of heating system (not including heat pumps) for this dwelling only	Options	None, Boiler (steam), Boiler (water), Combi boiler, Ducted furnace, Electric baseboard, Gas baseboard, Fireplace, Furnace (gravity), Space heater, Wall furnace, Wood stove, Other	Please include photos of the heating equipment and nameplates. Create a separate dwelling heating entry for each heating system. If the heating system serves multiple units, fill that information out in the “Building

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
					Heating” element in the “Multifamily Building” facility, and select “None” here. Document heat pumps in the “Dwelling Heat Pump” element. Create a separate dwelling heating entry for each type of heating system.
	dwlg_heating_sys_location	Where is the heating indoor system located?	Options	Dwelling conditioned, Dwelling unconditioned, Common space conditioned, Common space unconditioned	
	dwlg_heating_primary_secondary	Describe whether system is primary or secondary	Options	Primary, Secondary	
	dwlg_heating_sys_count	Count of this type of heating system	Numeric	N/A	
	dwlg_heating_efficiency_type	Heating efficiency type	Options	AFUE percentage	Search for online for efficiency or select “Unable to Determine” if not available.
	dwlg_heating_rated_efficiency	Rated efficiency of the type previously selected	Numeric	N/A	Include photo of equipment and nameplate.
	dwlg_heating_efficiency_source	Heating efficiency source	Options	Nameplate, Homeowner	Search for online for efficiency or select “Unable to Determine” if not available.
	dwlg_heating_manufacturer	Name of manufacturer, as shown on system	Text	N/A	Include photo of nameplate.
	dwlg_heating_model	Model number, as shown on system	Text	N/A	Select “Unable to Determine” if not available.
	dwlg_heating_serial_number	Serial number, as shown on system	Text	N/A	Select “Unable to Determine” if not available.
	dwlg_heating_percent_conditioned_space	What percentage of conditioned space does the system serve?	Integer	From 0 to 100	Estimate the percentage of conditioned space the system serves.
	dwlg_heating_capacity_BTUhr	Maximum rated input capacity of the system in Btu/hr	Numeric	From 1,000 to 1,000,000	Select “Unable to Determine” if not available.

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
	dwlg_heating_capacity_min_BTUhr	Minimum rated input capacity of the system in Btu/hr	Numeric	From 1,000 to 1,000,000	
	furnace_type	What is the furnace type?	Options	Single stage, Two stage, Modulating, Other	
	furnace_type_other	Specify the other furnace type	Text	N/A	
	furnace_stages	If the furnace is multi-stage, can you get the furnace to run in each of the stages?	Options	Yes, No	
	furnace_meter_yes_no	Were you able to meter the furnace?	Options	Yes, No	
	furnace_not_metered	Specify why you were unable to meter the furnace	Text	N/A	
	furnace_num_meters	How many meters did you install?	Integer	From 1 to 3	Add a note if you installed more than three meters.
	furnace_meter_serial1	Meter serial number (1)	Text	N/A	This is the UX90-04 motor logger number or energy logger pro number. Please take a photo of meter serial number.
	furnace_meter_serial1_location	What is this metering? (1)	Options	Gas valve high stage, Gas valve low stage, Thermostat high stage, Thermostat low stage, Other	Please take a photo of installed meter.
	furnace_meter_serial1_location_other	Specify the meter location (1)	Text	N/A	
	furnace_meter_serial2	Meter serial number (2)	Text	N/A	This is the UX90-04 motor logger number or energy logger pro number. Please take a photo of meter serial number.
	furnace_meter_serial2_location	What is this metering? (2)	Options	Gas valve high stage, Gas valve low stage, Thermostat high stage, Thermostat low stage, Other	Please take a photo of installed meter.
	furnace_meter_serial2_location_other	Specify the meter location (2)	Text	N/A	
	furnace_meter_serial3	Meter serial number (3)	Text	N/A	This is the UX90-04 motor logger number or energy logger pro number.

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
					Please take a photo of meter serial number.
	furnace_meter_serial3_location	What is this metering? (3)	Options	Gas valve high stage, Gas valve low stage, Thermostat high stage, Thermostat low stage, Other	Please take a photo of installed meter.
	furnace_meter_serial3_location_other	Specify the meter location (3)	Text	N/A	
	dwlg_heating_baseboard_length_ft	If baseboard electric, total linear feet of baseboard	Numeric	N/A	
	dwlg_heating_year	Year of manufacture of heating system	Integer	N/A	
	dwlg_heating_year_source	Year of manufacture estimated or known?	Options	Estimated, Known	
	dwlg_heating_fuel	Fuel the system uses	Options	Coal, Electricity, Kerosene, Natural gas, Oil, Propane, Wood, None, Other	
Dwelling Cooling	dwlg_cooling_sys_type	Type of cooling system (not including heat pumps) for this dwelling only	Options	None, Central AC, Window AC, Ductless mini-split AC, Ducted mini-split AC, Packaged terminal air conditioners, Swamp/evaporative cooler, Other	Please include photos of the cooling equipment and nameplates. Create a separate dwelling cooling entry for each cooling system. If the cooling system serves multiple units, fill that information out in the “Building Cooling” element in the “Multifamily Building” facility, and select “None” here. Heat Pumps should be documented in the "Dwelling Heat Pumps" element. Create a separate Dwelling Cooling entry for each type of cooling system.
	dwlg_cooling_sys_location	Where is the cooling indoor system located?	Options	Dwelling conditioned, Dwelling unconditioned, Common space conditioned, Common space unconditioned	
	dwlg_cooling_sys_count	Count of this type of cooling system	Integer	N/A	

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
	dwlg_cooling_primary_secondary	Describe whether system is primary or secondary	Options	Primary, Secondary	
	dwlg_cooling_efficiency_type	Cooling efficiency type	Options	SEER, EER, COP, Percentage	
	dwlg_cooling_rated_efficiency	Rated efficiency of the type previously selected	Numeric	N/A	Include photo of nameplate.
	dwlg_cooling_efficiency_source	Cooling efficiency source	Options	Nameplate, Homeowner	Select "Unable to Determine" if not available.
	dwlg_cooling_manufacturer	Name of manufacturer, as shown on system	Text	N/A	
	dwlg_cooling_model	Model number, as shown on system	Text	N/A	
	dwlg_cooling_serial_number	Serial number, as shown on system	Text	N/A	
	dwlg_cooling_percent_conditioned_space	What percentage of conditioned space does the system serve?	Integer	From 0 to 100	
	dwlg_cooling_capacity_BTUhr	Rated nominal capacity of the system (in Btu/hr)	Numeric	From 1,000 to 1,000,000	
	dwlg_cooling_year	Year of manufacture of cooling system	Integer	N/A	
	dwlg_cooling_year_source	Year of manufacture estimated or known?	Options	Estimated, Known	
	dwlg_cooling_fuel	Fuel the system uses	Options	Coal, Electricity, Kerosene, Natural gas, Oil, Propane, Wood, None, Other	
Dwelling Heat Pump	dwlg_heatpump_heating_cooling	Is a heat pump used for heating, cooling, both, or neither for this dwelling only?	Options	Heating only, Cooling only, Both, Neither (no heat pumps)	Please include photos of the heat pump equipment and nameplates. Create a separate dwelling heat pump entry for each heat pump system. If the heat pump serves multiple units, fill that information out in the "Building Heat Pump" element in the "Multifamily Building" facility, and

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
					select "Neither (no heat pumps)" here.
	dwlg_heatpump_type	Type of heat pump	Options	Ground-source heat pump, Air-source heat pump, Ductless mini-split heat pump, Packaged terminal heat pump, Ducted mini-split heat pump	
	dwlg_heatpump_location	Where are the heat pump indoor units located?	Options	Dwelling conditioned space, Common space conditioned	
	dwlg_heatpump_indoor_units	Number of indoor units	Integer	N/A	
	dwlg_heatpump_outdoor_units	Number of outdoor units	Integer	N/A	
	dwlg_heatpump_primary_secondary_heating	Describe whether system is primary or secondary for heating	Options	Primary, Secondary	
	dwlg_heatpump_primary_secondary_cooling	Describe whether system is primary or secondary for cooling	Options	Primary, Secondary	
	dwlg_heatpump_efficiency_type_heating	Heat pump efficiency type for heating	Options	Heating seasonal performance factor, Coefficient of performance, Other	
	dwlg_heatpump_efficiency_heating	Rated efficiency for heating of the type previously selected	Numeric	N/A	Take photo of nameplate.
	dwlg_heatpump_efficiency_source_heating	Source of rated efficiency for heating	Options	Nameplate, Homeowner	Search for online for efficiency or select "Unable to Determine" if not available.
	dwlg_heatpump_efficiency_type_cooling	Heat pump efficiency type for cooling	Options	SEER, EER, Other	
	dwlg_heatpump_efficiency_cooling	Rated efficiency for cooling of the type previously selected	Numeric	N/A	Take photo of nameplate.
	dwlg_heatpump_efficiency_source_cooling	Source of rated efficiency for cooling	Options	Nameplate, Homeowner	Search for online for efficiency or select "Unable to Determine" if not available.
	dwlg_heatpump_capacity_heating	Nominal capacity for heating in Btu/hr	Numeric	From 1,000 to 1,000,000	

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
	dwlg_heatpump_capacity_cooling	Nominal capacity for cooling in Btu/hr	Numeric	From 1,000 to 1,000,000	
	dwlg_heatpump_manufacturer	Name of manufacturer, as shown on system	Text	N/A	
	dwlg_heatpump_model	Model number of outdoor unit, as shown on system	Text	N/A	
	dwlg_heatpump_serial_number	Serial number of outdoor unit, as shown on system	Text	N/A	
	dwlg_heatpump_model_indoor1	Model number of indoor unit 1	Text	N/A	
	dwlg_heatpump_serial_indoor1	Serial number of indoor unit 1	Text	N/A	
	dwlg_heatpump_model_indoor2	Model number of indoor unit 2	Text	N/A	
	dwlg_heatpump_serial_indoor2	Serial number of indoor unit 2	Text	N/A	
	dwlg_heatpump_model_indoor3	Model number of indoor unit 3	Text	N/A	
	dwlg_heatpump_serial_indoor3	Serial number of indoor unit 3	Text	N/A	
	dwlg_heatpump_model_indoor4	Model number of indoor unit 4	Text	N/A	
	dwlg_heatpump_serial_indoor4	Serial number of indoor unit 4	Text	N/A	
	dwlg_heatpump_percent_conditioned_space_heating	What percentage of conditioned space does the system serve for heating?	Integer	From 0 to 100	
	dwlg_heatpump_percent_conditioned_space_cooling	What percentage of conditioned space does the system serve for cooling?	Integer	From 0 to 100	
	dwlg_heatpump_year	Year of manufacture of heat pump	Integer	N/A	

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
	dwlg_heatpump_year_source	Year of manufacture estimated or known?	Options	Estimated, Known	
	dwlg_heatpump_fuel	Fuel the system uses	Options	Coal, Electricity, Kerosene, Natural gas, Oil, Propane, Wood, None, Other	
Dwelling Domestic Hot Water (DHW)	dwlg_DHW_type	Type of DHW system for this dwelling only, if any	Options	None, Dedicated boiler with tank, Heat pump water heater, Instantaneous, Space heating boiler with coil, Space heating boiler with tank, Storage water heater with atmospheric vent, Sealed combustion, Combination boiler	Please include photos of the DHW equipment and nameplates. Create a separate dwelling DHW entry for each DHW system. If the DHW system serves multiple units, fill that information out in the “Building DHW” element in the “Multifamily Building” facility, and select “None” here.
	dwlg_DHW_location	Where is the DHW unit located?	Options	Dwelling conditioned space, Dwelling unconditioned space, Common space conditioned, Common space unconditioned	
	dwlg_DHW_count	Count of type of DHW unit	Integer	N/A	
	dwlg_DHW_manufacturer	Name of manufacturer, as shown on system	Text	N/A	
	dwlg_DHW_model	Model number, as shown on system	Text	N/A	
	dwlg_DHW_serial_number	Serial number, as shown on system	Text	N/A	
	dwlg_DHW_energy_factor	DHW energy factor, if available	Numeric	N/A	Only record if available, select “Unable to Determine” or “Unable to Access” if not available. Include photo of nameplate.
	dwlg_DHW_energy_factor_source	DHW energy factor source	Options	Nameplate, Homeowner	Select “Unable to Determine” if not available
	dwlg_DHW_tank_insul	DHW tank insulation stated on nameplate	Text	N/A	Describe tank insulation from nameplate, if no information select N/A.

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
	dwlg_DHW_energy_guide_units	DHW Energy Guide label Units	Options	kWh/year, therms/year, $/year	Unit of measure on the Energy Guide Sticker, prefer kilowatt-hours or therms, select “Unable to Determine/Access” if not available.
	dwlg_DHW_energy_guide_value	DHW Energy Guide label units of usage per year	Numeric	N/A	Value of units on Energy Guide sticker
	dwlg_DHW_ins_blanket	Does the tank have an add-on insulation blanket?	Options	Yes, No	
	dwlg_DHW_fuel	DHW fuel type	Options	Coal, Electricity, Kerosene, Natural gas, Oil, Propane, Wood, None, Other	
	dwlg_DHW_capacity_units	DHW input capacity units	Options	Btu/hr, kW	Use units of Btu/hr for fuel and kilowatts for electric. Select “Unable to Determine” if capacity information is not available.
	dwlg_DHW_capacity	DHW input capacity	Numeric	N/A	Use units selected in previous question.
	dwlg_DHW_year	Year of manufacture of DHW system	Integer	N/A	
	dwlg_DHW_year_source	Year of manufacture estimated or known?	Options	Estimated, Known	
	dwlg_DHW_storage_volume_gal	DHW storage volume in gallons	Numeric	N/A	
Dwelling Humidifiers and Dehumidifiers	dwlg_humid	Is a humidifier installed on central air for this unit only?	Options	Yes, No	Create a separate dwelling humidifiers/dehumidifiers entry for each humidifier and dehumidifier system. If the humidifier serves multiple units, fill that information out in the “Building Humidifiers/ Dehumidifiers” element in the “Multifamily Building” facility and select “No” here.
	dwld_humid_oper	Is the humidifier operational?	Options	Yes, No	If it is operational, check if water line is connected and water is on.

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
	dwlg_humid_setpoint	Humidifier setpoint, if applicable	Numeric	N/A	Older systems have a dial on the humidifier. Newer systems are controlled by the thermostat.
	dwlg_de_humid	Is there a dehumidifier in the home for this unit only?	Options	Yes, No	Typically in the basement. If the dehumidifier serves multiple units, fill that information out in the "Building Humidifiers/Dehumidifiers" element in the "Multifamily Building" facility and select "No" here.
	dwlg_de_humid_make	Dehumidifier make	Text	N/A	Take photo of equipment and nameplate.
	dwlg_de_humid_model	Dehumidifier model	Text	N/A	Take photo of equipment and nameplate.
	dwlg_de_humid_current_amp	Dehumidifier rated current (amps)	Numeric	N/A	Take photo of equipment and nameplate.
	dwlg_de_humid_current_source	Dehumidifier rated current source	Options	Nameplate, Homeowner	Select "Unable to Determine" if not available.
	dwlg_de_humid_year	Year of manufacture of system	Integer		
	dwlg_de_humid_year_source	Year of manufacture estimated or known?	Options	Estimated, Known	
Dwelling Ventilation	dwlg_ventilation_type	What type of mechanical ventilation is there for this unit only?	Options	None, Whole-house fan, Single exhaust, Air cycler (attached to air handler), Other	Mechanical ventilation that moves air between the inside of the home and outside. Create a separate dwelling ventilation entry for each ventilation system. If the mechanical ventilation serves multiple units, fill that information out in the "Building Ventilation" element in the "Multifamily Building" facility and select "None" here.
	dwlg_ventilation_count	Count of this type of equipment	Integer		
	dwlg_ventilation_heat_recovery	Does the system recover heat from ventilation?	Options	Yes, No	

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
	dwlg_ventilation_operation_hours	Typical number of hours a day system is in operation	Numeric	N/A	Hours per day the control system mandates this system is operating
	dwlg_ventilation_rate	Rated CFM	Numeric	N/A	Rated CFM of the system while operating
	dwlg_ventilation_system_config	What is the system configured to do?	Options	Balanced, Exhaust, Intake	Is the system only exhausting, pulling in air (intake), or both supplying and exhausting?
Dwelling Controls	dwlg_thermostat_type	What type of thermostat is installed in the unit?	Options	Manual, Programmable, Web enabled, Smart, None	Please take a photo of the thermostat. A smart thermostat is both web-enabled and is capable of self-programming like the Nest or Ecobee 4. Web-enabled do not self-program such as the Ecobee 3 lite or Honeywell Wi-Fi. Create a separate dwelling controls entry for each thermostat.
	dwlg_thermostat_location	Where is the thermostat installed?	Text	N/A	Describe the location, specifically for homes with multiple thermostats.
	dwlg_system_served	Which systems are controlled?	Options	All systems (heating and cooling), Cooling only, Cooling (partial zone), Heating (partial zone), Heating only	
	dwlg_cooling_setup_temperature_F	Occupied cooling temperature setpoint in Fahrenheit	Numeric	N/A	Typically this is the morning setting. Cooling setpoint temperature should be lower than the cooling setback temperature. For a manual thermostat, the current temp is the setpoint temp.
	dwlg_cooling_setback_hours	Number of cooling setback hours	Numeric	N/A	Total hours the thermostat is at a higher temperature while cooling
	dwlg_cooling_setback_temperature_F	Cooling setback temperature in Fahrenheit	Numeric	N/A	Typically this is the night setting. Cooling setback temperature should be higher than cooling setpoint temperature. Select “Not Applicable” if manual thermostat.

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
	dwlg_heating_setup_temperature_F	Occupied heating temperature setpoint in Fahrenheit	Numeric	N/A	Typically this is the morning setting. Heating setpoint temperature should be higher than the heating setback temperature. For a manual thermostat, the current temp is the setpoint temp.
	dwlg_heating_setback_hours	Number of heating setback hours	Numeric	N/A	Total hours the thermostat is at a lower temperature when heating
	dwlg_heating_setback_temperature_F	Heating setback temperature in Fahrenheit	Numeric	N/A	Typically this is the night setting. Heating setback temperature should be lower than the heating setpoint temperature. Select "Not Applicable" if manual thermostat.
	dwlg_thermostat_current_status	Current thermostat status at time of visit	Options	Auto, Manual/hold, Off	
	dwlg_thermostat_current_programming	Programming status at time of visit	Options	Programmed, Programmable but not programmed, Not programmed	If you cannot figure out the thermostat program, then put "Unable to Determine."
	dwlg_thermostat_auto_fan	Is the fan on?	Options	Auto, On, Off, None	Typically called fan and the setting is auto or on. Select "None" if there is no fan.
Dwelling Distribution	dwlg_distrib_heat_type	What type of heating distribution system is used?	Options	None, Central forced air, Hydronic, Steam, Zonal, Other	Use zonal to describe ductless mini-split or electric baseboard or unit heaters. Create a separate dwelling distribution entry for each distribution system.
	dwlg_distrib_heat_location	Percentage of heating distribution system in unconditioned space?	Integer	From 0 to 100	
	dwlg_distrib_heat_insul	What percentage of heating distribution in unconditioned space is insulated?	Integer	From 0 to 100	
	dwlg_distrib_cool_type	What type of cooling distribution system is used?	Options	None, Central forced air, Chilled water, Zonal, Other	Use zonal to describe ductless mini-split.

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
	dwlg_distrib_cool_location	Percentage of cooling distribution system in unconditioned space?	Integer	From 0 to 100	
	dwlg_distrib_cool_insul	What percentage of cooling distribution in unconditioned space is insulated?	Integer	From 0 to 100	
	dwlg_duct_cond	Average condition of ductwork (for ducts in unconditioned spaces)	Options	No obvious leaks, Normal, Significant obvious leaks	If all ductwork is in conditioned space, select “Not Applicable.”
	dwlg_duct_sealing	Is there evidence of duct sealing? (for ducts in unconditioned spaces)	Options	Yes, No	If all ductwork is in conditioned space, select “Not Applicable.” If unsure, select “Unable to Determine.”
	dwlg_sealing_material	Sealing material (for ducts in unconditioned spaces)	Options	Mortite, Caulking, Other	If all ductwork is in conditioned space, select “Not Applicable.” If unsure, select “Unable to Determine.”

Table 36. Data Collected for Multifamily Building Facility Type

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
Building Exterior					
Building Overview	bldg_MF_check	Is this a multi-family (two or more units) house?	Options	Yes	Only fill this facility out if it is a multifamily house with two or more units. All of this data is for the outer building, not the dwelling unit.
	bldg_perimeter_ft	Total perimeter of building in feet	Numeric	N/A	
	bldg_height_total_ft	Total height of building in feet	Numeric	N/A	
	bldg_area_total_ft	Total area (footprint) of building in square feet	Numeric	N/A	
	bldg_area_conditioned_ft	Area of conditioned space only in square feet	Numeric	N/A	Include all intentionally conditioned spaces. If helpful, make drawing of area and take photo with dimensions.

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
	bldg_area_unconditioned_ft	Area of unconditioned space only in square feet	Numeric	N/A	Include unconditioned garages and basements, exclude crawl spaces.
	bldg_stories_above_grade	Number of above-grade stories	Numeric	N/A	
	bldg_stories_below_grade	Number of below-grade stories	Numeric	N/A	
	bldg_number_of_units	Number of dwelling units in the building	numeric	N/A	
	bldg_description	Describe the building in a sentence	Text	N/A	Please include photos of all four sides of the building.
	bldg_roof_type	Type of roof	Options	Flat, Gable, Hip, Mansard, Gambrel (barn), Shed (pitched)	
	bldg_roof_material	Roof material	Options	Asphalt shingle, Rubber, Metal, Clay tile, Stone (slate)	
	bldg_roof_eve_thickness_inch	What is the roof eve thickness in inches?	Numeric	N/A	
	bldg_roof_soffit_venting	Is there soffit venting?	Options	Yes, No	
	bldg_siding_material	Siding material	Options	Mixed, Aluminum, Asbestos, Asphalt, Brick, Block, Concrete, Cedar, Cement, Fiberglass, Hard board, Metal, Shake, Stone, Stucco, T1-11, Vinyl, Wood	
	bldg_elevators	How many elevator shafts are in the building?	Numeric	N/A	
	bldg_elevators_upgrade	Have the elevators been upgraded since the building was built?	Options	Yes, No	If you do not know, select “Unable to Determine.”
	bldg_elevators_upgrade_year	What year were the elevators upgraded?	Numeric	N/A	If you do not know, select “Unable to Determine.”
	bldg_elevators_type	Are the elevators cable drawn or hydraulic?	Options	Cable drawn, Hydraulic	You can usually tell which option is correct by how the elevator feels. Hydraulic elevators usually have a hum when they start up and are

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
					slower. Select "Unable to Determine" if unsure.
	bldg_hot_tub	How many shared hot tubs are in this building?	Numeric	N/A	
	bldg_pools	How many shared pools are in this building?	Numeric	N/A	
Building HVAC					
Building Heating	bldg_heating_sys_type	Type of heating system (not including heat pumps) that serves multiple units, if any	Options	None, Boiler (steam), Boiler (water), Combination boiler, Ducted furnace, Electric baseboard, Gas baseboard, Fireplace, Furnace(gravity), Space heater, Wall furnace, Wood stove	Please include photos of the heating equipment and nameplates. Create a separate building heating entry for each building heating system. Heat pumps should be documented in the "Building Heat Pumps" element.
	bldg_heating_sys_location	Where is the indoor heating system located?	Options	Conditioned space, Unconditioned space	
	bldg_heating_primary_secondary	Describe whether system is primary or secondary	Options	Primary, Secondary	
	bldg_heating_percent_serves	What percentage of the building does this system serve?	Integer	From 0 to 100	
	bldg_heating_sys_count	Count of this type of heating system	Numeric	N/A	
	bldg_heating_efficiency_type	Heating efficiency type	Options	AFUE, Percentage	
	bldg_heating_rated_efficiency	Rated efficiency of the type previously selected	Numeric	N/A	Please include photos of the heating equipment and nameplates.
	bldg_heating_efficiency_source	Heating efficiency source	Numeric	Nameplate, Homeowner	Select "Unable to Determine" if not available.
	bldg_heating_manufacturer	Name of manufacturer, as shown on system	Text	N/A	Include photo of nameplate.
	bldg_heating_model	Model number, as shown on system	Text	N/A	Include photo of nameplate.
	bldg_heating_serial_number	Serial number, as shown on system	Text	N/A	Include photo of nameplate.

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
	bldg_heating_percent_conditioned_space	What percentage of conditioned space does the system serve?	Integer	From 0 to 100	Estimation
	bldg_heating_capacity_BTUhr	Rated input capacity of the system in Btu/hr	Numeric	From 1,000 to 1,000,000	
	bldg_heating_year	Year of manufacture of heating system	Integer	N/A	
	bldg_heating_year_source	Year of manufacture estimated or known?	Options	Estimated, Known	
	bldg_heating_fuel	Fuel the system uses	Options	Coal, Electricity, Kerosene, Natural gas, Oil, Propane, Wood, None, Other	
Building Cooling	bldg_cooling_sys_type	Type of cooling system (not including heat pumps) that serves multiple units, if any	Options	None, Roof-top units, Air-cooled chiller, Water-cooled chiller	If individual units have independent cooling or there is no cooling, select "None." Independent cooling should be documented in the "Dwelling Cooling" element. Create a separate building cooling entry for each building cooling system. Heat pumps should be documented in the "Building Heat Pumps" element.
	bldg_cooling_sys_location	Where is the cooling system located?	Options	Conditioned space, Unconditioned space	
	bldg_cooling_sys_count	Count of this type of cooling system	Numeric	N/A	
	bldg_cooling_primary_secondary	Describes whether system is primary or secondary	Options	Primary, Secondary	
	bldg_cooling_percent_serves	What percentage of the building does this system serve?	Integer	From 0 to 100	
	bldg_cooling_efficiency_type	Cooling efficiency type	Options	SEER, EER, COP, Percentage	
	bldg_cooling_rated_efficiency	Rated efficiency of the type previously selected	Numeric	N/A	Please include photos of the cooling equipment and nameplates.

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
	bldg_cooling_efficiency_source	Cooling efficiency source	Options	Nameplate, Homeowner	Select "Unable to Determine" if not available.
	bldg_cooling_manufacturer	Name of manufacturer, as shown on system	Text	N/A	
	bldg_cooling_model	Model number, as shown on system	Text	N/A	
	bldg_cooling_serial_number	Serial number, as shown on system	Text	N/A	
	bldg_cooling_capacity_BTUhr	Rated nominal capacity of the system in Btu/hr	Numeric	From 1,000 to 1,000,000	
	bldg_cooling_year	Year of manufacture of system	Integer	N/A	
	bldg_cooling_year_source	Year of manufacture estimated or known?	Options	Estimated, Known	
	bldg_cooling_fuel	Fuel the system uses	Options	Coal, Electricity, Kerosene, Natural gas, Oil, Propane, Wood, None, Other	
Building Heat Pump	bldg_heatpump_heat_cool	Is a heat pump that serves multiple units used for heating, cooling, both, or neither?	Options	Heating only, Cooling only, Both, Neither (no heat pumps)	Please include photos of the heat pump equipment and nameplates. Create a separate building heat pump entry for each building heat pump system.
	bldg_heatpump_type	Type of heat pump	Options	Ground-source heat pump, Air-source heat pump, Ductless mini-split heat pump, Packaged terminal heat pump, Ducted mini-split heat pump	
	bldg_heatpump_location	Where are the heat pump(s) indoor units located?	Options	Conditioned space, Unconditioned space	
	bldg_heatpump_percent_conditioned_space_heating	What percentage of conditioned space does the system serve for heating?	Integer	From 0 to 100	
	bldg_heatpump_percent_conditioned_space_cooling	What percentage of conditioned space does the system serve for cooling?	Integer	From 0 to 100	

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
	bldg_heatpump_primary_secondary_heating	Describe whether system is primary or secondary for heating	Options	Primary, Secondary	
	bldg_heatpump_primary_secondary_cooling	Describe whether system is primary or secondary for cooling	Options	Primary, Secondary	
	bldg_heatpump_indoor_units	Number of indoor units	Integer	N/A	
	bldg_heatpump_outdoor_units	Number of outdoor units	Integer	N/A	
	bldg_heatpump_efficiency_type_heating	Heat pump efficiency type for heating	Options	Heating seasonal performance factor, COP, Other	Select “Unable to Determine/Access” if not available.
	bldg_heatpump_efficiency_heating	Rated efficiency for heating of type previously selected, if available	Numeric	N/A	Take photo of nameplate Select “Unable to Determine/Access” if not available.
	bldg_heatpump_efficiency_source_heating	Source of rated efficiency for heating	Options	Nameplate, Homeowner	Select “Unable to Determine/Access” if not available.
	bldg_heatpump_efficiency_type_cooling	Heat pump efficiency type for cooling	Options	SEER, EER, Other	Select “Unable to Determine/Access” if not available.
	bldg_heatpump_efficiency_cooling	Rated efficiency for cooling of type previously selected, if available	Numeric	N/A	Take photo of nameplate Select “Unable to Determine/Access” if not available.
	bldg_heatpump_efficiency_source_cooling	Source of rated efficiency for cooling	Options	Nameplate, Homeowner	Select “Unable to Determine/Access” if not available.
	bldg_heatpump_capacity_heating	Nominal capacity for heating in Btu/hr	Numeric	From 1,000 to 1,000,000	Select “Unable to Determine/Access” if not available.
	bldg_heatpump_capacity_cooling	Nominal capacity for cooling in Btu/hr	Numeric	From 1,000 to 1,000,000	Select “Unable to Determine/Access” if not available.
	bldg_heatpump_manufacturer	Name of manufacturer, as shown on system	Text	N/A	Take photo of nameplate. Select “Unable to Determine/Access” if not available.
	bldg_heatpump_model	Model number of outdoor unit, as shown on system	Text	N/A	Take photo of nameplate. Select “Unable to Determine/Access” if not available.

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
	bldg_heatpump_serial_number	Serial number of outdoor unit, as shown on system	Text	N/A	Take photo of nameplate. Select "Unable to Determine/Access" if not available.
	bldg_heatpump_model_indoor1	Model number of indoor unit 1	Text	N/A	
	bldg_heatpump_serial_indoor1	Serial number of indoor unit 1	Text	N/A	
	bldg_heatpump_model_indoor2	Model number of indoor unit 2	Text	N/A	
	bldg_heatpump_serial_indoor2	Serial number of indoor unit 2	Text	N/A	
	bldg_heatpump_model_indoor3	Model number of indoor unit 3	Text	N/A	
	bldg_heatpump_serial_indoor3	Serial number of indoor unit 3	Text	N/A	
	bldg_heatpump_model_indoor4	Model number of indoor unit 4	Text	N/A	
	bldg_heatpump_serial_indoor4	Serial number of indoor unit 4	Text	N/A	
	bldg_heatpump_year	Year of manufacture of heat pump	Integer	N/A	Take photo of nameplate. Select "Unable to Determine/Access" if not available.
	bldg_heatpump_year_source	Year of manufacture estimated or known?	Options	Estimated, Known	
	bldg_heatpump_fuel	Fuel the system uses	Options	Coal, Electricity, Kerosene, Natural gas, Oil, Propane, Wood, None, Other	
Building DHW	bldg_DHW_type	Type of DHW system that serves multiple units, if any	Options	None, Dedicated boiler with tank, Heat pump water heater, Instantaneous, Space heating boiler with coil, Space heating boiler with tank, Storage water heater, Combination boiler	Please include photos of the DHW equipment and nameplates. Create a separate building DHW entry for each building DHW system.
	bldg_DHW_location	Where are the DHW unit(s) located?	Options	Conditioned space, Unconditioned space	

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
	bldg_DHW_percent_serves	What percentage of the building does this system serve?	Integer	From 0 to 100	
	bldg_DHW_count	Count of type of DHW unit	Integer	N/A	Count of DHW unit of same type/specifications
	bldg_DHW_manufacturer	Name of manufacturer, as shown on system	Text	N/A	
	bldg_DHW_model	Model number, as shown on system	Text	N/A	
	bldg_DHW_serial_number	Serial number, as shown on system	Text	N/A	
	bldg_DHW_energy_factor	DHW energy factor, if available	Numeric	N/A	Select "Unable to Determine/Access" if not available.
	bldg_DHW_energy_factor_source	DHW energy factor source	Options	Nameplate, Homeowner	Select "Unable to Determine/Access" if not available.
	bldg_DHW_tank_insul	DHW tank insulation on nameplate	Text	N/A	Describe tank insulation from nameplate.
	bldg_DHW_energy_guide_units	DHW Energy Guide label units	Options	Kilowatt-hours per year, Therms per year, Cost per year	Unit of measure on the Energy Guide sticker
	bldg_DHW_energy_guide_value	DHW Energy Guide label units of usage per year	Numeric	N/A	Value of units of Energy Guide sticker
	bldg_DHW_ins_blanket	Does the tank have an add-on insulation blanket?	Options	Yes, No	
	bldg_DHW_capacity_units	DHW input capacity units	Options	Btu per hour, kilowatts	Use units of Btu per hour for fuel and kilowatts for electric.
	bldg_DHW_capacity	DHW input capacity	Text	N/A	Use units selected in previous question.
	bldg_DHW_fuel	DHW fuel	Options	Coal, Electricity, Kerosene, Natural gas, Oil, Propane, Wood, None, Other	
	bldg_DHW_year	Year of manufacture of DHW system	Integer	N/A	Take photo of nameplate. Select "Unable to Determine/Access" if not available.

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
	bldg_DHW_year_source	Year of manufacture estimated or known?	Options	Estimated, Known	
	bldg_DHW_storage_volume_gal	DHW storage volume in gallons	Text	N/A	
Building Humidifiers and Dehumidifiers	bldg_humid	Is a humidifier installed on central air for the building?	Options	Yes, No	Create a separate building humidifiers/dehumidifiers entry for each building humidifier and dehumidifier system.
	bldg_humid_oper	Is the humidifier operational?	Options	Yes, No	If it is operational, check if water line is connected and water is on.
	bldg_humid_setpoint	Humidifier setpoint, if applicable	Numeric	N/A	Older systems have a dial on the humidifier. Newer systems are controlled by the thermostat.
	bldg_de_humid	Is there a dehumidifier for the building?	Options	Yes, No	Typically in the basement
	bldg_de_humid_type	Dehumidifier type	Options	Vapor compressor, Enthalpy wheel, Other	
	bldg_de_humid_make	Dehumidifier make	Text	N/A	Take photo of equipment and nameplate.
	bldg_de_humid_model	Dehumidifier model	Text	N/A	Take photo of equipment and nameplate.
	bldg_de_humid_current_amp	Dehumidifier rated current (amps), if available	Numeric	N/A	Take photo of equipment and nameplate.
	bldg_de_humid_year	Year of manufacture of system	Integer	N/A	
	bldg_de_humid_year_source	Year of manufacture estimated or known?	Options	Estimated, Known	
Building Ventilation	bldg_ventilation_type	What type of ventilation is there, if any?	Options	None, Fixed Outside Air, Carbon dioxide sensor, Economizer, Heat recovery, Other	Create a separate building ventilation entry for each building ventilation system.
	bldg_ventilation_operation_hours	Typical number of hours a day system is in operation	Integer	N/A	
	bldg_ventilation_system_config	What is the system configured to do?	Options	Balanced, Exhaust, Intake	How is outside air used? Exhausting indoor air? Intaking Outside Air? Balanced exhaust and supply?

Element Type	Variable Name	Question Prompt	Response Type	Response Options	Help Text
Building Controls	bldg_controls_type	What type of building HVAC controls are there?	Options	Pneumatic, Building automation system, Simple analog, Other	Create a separate building controls entry for each controls system. Select "Unable to Determine/Access" if not available.
	bldg_system_served	Which systems are controlled?	Options	All systems (heating and cooling), Cooling only, Cooling - partial zone, Heating - partial zone, Heating only	

Appendix D. Thermal Transmittance Calculations

This appendix outlines the Cadmus team's methodology for calculating thermal transmittance (UA) values and estimating total heat loss for the Michigan Baseline Housing Study. In these methods, we synthesize methodologies for assessing heat loss through building assemblies from a combination of *ASHRAE Fundamentals*[20], Regional Technical Forum standard practices, the National Renewable Energy Laboratory *Efficiency Measure Database*[21], and *Super Good Cents*[22] load calculations.

Total Heat Loss UA Values

We calculated the total heat loss per home as the sum of the heat loss for each envelope component of the sampled homes (walls, rim and band joists, ceilings, floors and foundations, windows, and doors), using Equation 1. These heat loss values do not include infiltration/exfiltration losses.

Equation 1. Total Heat Loss UA Calculation

$$Total\ Heat\ Loss\ (UA) = UA_{wall} + UA_{Rim+Band} + UA_{ceiling} + UA_{floor\ \&\ foundation} + UA_{windows} + UA_{doors}$$

The Cadmus team conducted parallel-path heat transfer calculations for each building element, making reasonable assumptions about construction materials used in the home where these data were unknown. We also included interior buffer space coefficients and exterior air films.

Unknown Constructions

For many components, the Cadmus team could not collect complete information without destructive or potentially dangerous data collection methods. In these cases, we applied an average U-factor for records of the same category (wall, ceiling, floor), type (2x2, 2x4, attic, sloped/vaulted ceiling), state, and home type.

Insulation Properties

The team documented the type and thickness of insulation in homes. We calculated the resistance to heat transfer using the properties outlined in Table 37.

Table 37. Insulation Type and R-Values

Insulation Type	Average R-Value Per Inch (hr * ft^2 * °F)/(Btu * in)	Conductivity k (Btu * in)/(hr * ft^2 * °F)
Blown cellulose	3.4	0.293

[20] American Society of Heating Refrigeration and Air Conditioning Engineers. 2017. *ASHRAE Handbook Fundamentals IP Edition*.

[21] National Renewable Energy Laboratory, Efficiency Measures Database, 2020, https://remdb.nrel.gov/

[22] Ecotope (Baylon, David, and Jonathan Heller). October 24, 1988. *Super Good Cents Heat Loss Reference.* Volume I, Volume II and Volume IV. https://cadmus.sharepoint.com/sites/collaboration/6409-P01/Portfolio%20Research/Baseline%20Housing%20Study/Analysis/UA%20Calculation%20Methodology/1988_010_SuperGoodCentsHeat-V2.pdf

Insulation Type	Average R-Value Per Inch (hr * ft^2 * °F)/(Btu * in)	Conductivity k (Btu * in)/(hr * ft^2 * °F)
Cellulose batts	2.5	0.400
Blown fiberglass	2.8	0.354
Fiberglass batts	3.4	0.293
Perlite	2.7	0.375
Foil-faced polyisocyanurate foam board	6.3	0.159
Extruded polystyrene foam board	5.4	0.187
Expanded polystyrene foam board	4.2	0.241
Closed-cell spray foam	5.8	0.174
Open-cell spray foam	3.5	0.288
Blown mineral wool	2.9	0.347
Mineral wool batts	3.6	0.278
Saw dust insulation	2.0	0.500
Vermiculite	2.5	0.400
Unknown	3.0	0.333
Mixed	3.0	0.333
Other	3.0	0.333
Foamboard	5.7	0.175
Wood	1.1	1.0
Brick masonry wall type (unknown thickness assumes 4-inch masonry)	0.1	9.0
None/skipped	0	0

Note: Values estimated from American Society of Heating Refrigeration and Air Conditioning Engineers. 2017. *ASHRAE Handbook Fundamentals IP Edition*.

Wall insulation was observed by probing around penetration in exterior walls, viewing unfinished walls in utility and mechanical spaces, and consulting building plans available from the occupant. In some cases wall insulation is not accessible as all evidence has been covered up or cannot be probed around electrical outlets and would be marked as unable to determine. The Cadmus team measured wall thickness at each site and used this value to calculate the R-value for wall insulation (multiplying the R-value per inch by the number of inches of insulation). For framed walls, we applied a standard insulation thickness based on the observed framed wall size. Table 38 outlines the insulation thicknesses in inches for the various wall types.

Table 38. Assumed and Calculated Wall Thicknesses

Wall Type	Thickness (inches)	Arkenstone Variable
Masonry	Field data	dwlg_wall_thickness_inch
Framed 2x2	1.5	1.5
Framed 2x3	2.5	2.5
Framed 2x4	3.5	3.5
Framed 2x6	5.5	5.5
Framed 2x8	7.5	7.5
Knee wall	Field data	dwlg_wall_thickness_inch
Insulated concrete form	Field data	dwlg_wall_thickness_inch
Structural insulated panels	Field data	dwlg_wall_thickness_inch
Log	Field data	dwlg_wall_thickness_inch
Structural steel	Field data	dwlg_wall_thickness_inch
Infill frame	Field data	dwlg_wall_thickness_inch
Other	Field data	dwlg_wall_thickness_inch

Above-Grade Wall UA Values

The team calculated above-grade wall UA values for each home by summing the UA values for each wall segment defined during data collection. In the field, staff collected information corresponding to each unique wall type encountered on site. For instance, a home might have above-grade and below-grade walls for the main portion of the house, plus above-grade walls for an addition with a slab foundation. In this scenario, the technician would create one wall element for the below-grade foundation walls, and then as many wall elements as needed to capture variations in construction type and insulation levels for the above-grade walls. We used parallel path analysis for each segment to calculate the U-factor for each wall element observed in the field. The three paths considered for wall construction were: framing and continuous insulation, cavity and continuous insulation, and insulation quality. The team weighted each path using the assumed path weightings in Table 39 and field data we collected about the completeness of the insulation. Values for wall type are shown in Arkenstone under the variable name *dwlg_wall_type*.

Table 39. Above-Grade Wall Values

Wall Type	Solid Construction R-Value Per Inch	Wall Framing R-Value Per Inch	Framing Path Weighting	Cavity Path Weighting
Framed 2x2	0	1.53	0.23	0.77
Framed 2x3	0	2.55	0.23	0.77
Framed 2x4	0	3.57	0.23	0.77
Framed 2x6	0	5.61	0.23	0.77
Framed 2x8	0	7.40	0.23	0.77
Knee wall	0	3.57	0.23	0.77
Insulated concrete form	5.8	0.00	1.00	0.00
Log	1.1	0.00	1.00	0.00
Masonry only [a]	0.1	0.00	1.00	0.00
Masonry with furred wall [b]	0.1	3.57	0.23	0.77
Structural insulated panel	5.8	0.00	1.00	0.00
Structural steel	0	0.5	0.06	0.94
Infill frame	0	8.0	0.08	0.92
Other [c]	0	3.57	0.23	0.77
Unknown [c]	0	3.57	0.23	0.77

[a] American Society of Heating Refrigeration and Air Conditioning Engineers. 2017. *ASHRAE Handbook Fundamentals IP Edition*.
[b] Northwest Council. October 26, 2017. "SEEM Template v1.9." https://nwcouncil.box.com/v/SEEMTemplatev1-9
[c] Ecotope (Baylon, David, and Jonathan Heller). October 24, 1988. *Super Good Cents Heat Loss Reference.* Volume I, Volume II and Volume IV

Based on industry standard assumptions for wall construction characteristics, the Cadmus team defined a U-factor for each instance of wall construction defined for each home using Equation 2 and the data in Table 37, Table 38, and Table 39 (above), as well as Table 40. This method applies a parallel path model accounting for framing and insulations paths of heat transfer through the wall. Both of these paths may or may not intersect with continuously applied insulation on the interior or exterior of the wall.

Equation 2. U-factor Wall Calculation

$$U_{Wall} = \left(\frac{k_{framing}}{a+b+(c*m)+d+(e*n)+(f*p)+g+h}\right)_{framing+\ continuous\ insulation} + \left(\frac{k_{cavity}}{a+b+(i*j*q)+d+(e*n)+(f*p)+g+h}\right)_{cavity\ insulation\ +\ continuous\ insulation}$$

We calculated the UA_{Wall} for each instance of wall construction by multiplying the U_{Wall} by the wall area, as shown in Equation 3.

Equation 3. UA Wall Calculation

UAWall = UWall ∗ heightwall ∗ lengthwall

Table 40. Wall Assembly Assumed Layers

Component	Term	Arkenstone Variable Name	Units	Framing Path	Cavity Path	Source
Inside air film	a	N/A	R-Value	0.68	0.68	2017 ASHRAE Fundamentals
1/2-inch wallboard	b	*dwlg_wall_type*	R-Value	If wall type is masonry or log, then 0.00; Otherwise assume 0.45	If wall type is masonry or log, then 0.00; Otherwise assume 0.45	2017 ASHRAE Fundamentals
Wall framing	c	*dwlg_wall_type*	R-Value per inch	See Table 39, column "Wall Framing R-value Per Inch"	N/A	Field Data
Wall framing insulation thickness	m	*dwlg_wall_type*	Inch	See Table 38	N/A	Field Data
1/2-inch plywood sheathing	d	*dwlg_wall_type*	R-Value	If wall type is masonry or log, then 0.00; Otherwise assume 0.79	If wall type is masonry or log, then 0.00; Otherwise assume 0.79	2017 ASHRAE Fundamentals
Solid construction	e	*dwlg_wall_type* *dwlg_wall_furred*	R-Value	See Table 39, column "Solid Construction R-Value Per Inch"	For masonry with furred wall, use values in Table 39, column "Solid Construction R-Value Per Inch"; Otherwise assume 0.00	Field Data
Solid construction thickness	n	*dwlg_wall_thickness_inch*	Inch	If wall thickness (*dwlg_wall_thickness_inch*) value is "Skipped," use 0.00; Otherwise use wall thickness value	If wall thickness (*dwlg_wall_thickness_inch*) value is "Skipped," use 0.00; Otherwise use wall thickness value	Field Data
Continuous insulation	f	*dwlg_wall_cont_ins_type*	R-Value per inch	If continuous insulation type value is "Skipped," use 0.00; Otherwise look up continuous insulation type in Table 37, column "Average R-Value Per Inch"	If continuous insulation type value is "Skipped," use 0.00; Otherwise look up continuous insulation type in Table 37, column "Average R-Value Per Inch"	Field Data
Continuous insulation thickness	p	*dwlg_wall_cont_ins_thickness_inch*	Inch	If continuous insulation thickness (dwlg_wall_cont_ins_thickness_inch) value is "Skipped," use 0.00; Otherwise use continuous insulation thickness value	If continuous insulation thickness (*dwlg_wall_cont_ins_thickness_inch*) value is "Skipped," use 0.00; Otherwise use continuous insulation thickness value	Field data
1/2-inch lapped wood siding	g	*dwlg_wall_type*	R-Value	If wall type is masonry or log, use 0.00; Otherwise assume 0.81	If wall type is masonry or log, then 0.00; Otherwise assume 0.81	2017 ASHRAE Fundamentals
Outside air film	h	*N/A*	R-Value	0.25	0.25	Super Good Cents Volume II

Component	Term	Arkenstone Variable Name	Units	Framing Path	Cavity Path	Source
Wall cavity insulation	i	*dwlg_wall_cavity_ins_type*	R-Value per inch	N/A	See Table 37, column "Average R-Value Per Inch"	Field Data
Wall cavity insulation thickness	q	*dwlg_wall_type*	Inch	N/A	See Table 38	Field data
Cavity insulation condition	j	*dwlg_wall_cavity_ins_cond*	%	N/A	Fully=100%, Partially=50%, No insulation=0%	Field Data, Assumption
Weighting factor	k	*dwlg_wall_type*	%	See Table 39, column "Framing Path Weighting"	See Table 39, column "Cavity Path Weighting"	Assumption

Rim and Band UA Values

The Cadmus team calculated ceiling UA values for rim and band walls using a consistent methodology to calculate UA values for above-grade walls: we determined U-factors for wall segments using a parallel path analysis, using the path weighting assumptions in Table 41.

Table 41. Rim and Band Wall Path Weighting Values

	Solid Construction R-Value	Wall Framing R-Value	Framing Path Weighting	Cavity Path Weighting
Rim and band	N/A	7.40	0.11	0.89

Sources: ASHRAE Fundamentals 2013, RTF SEEM Template Version 1.9, and Super Good Cents Load Calculations.

Based on industry standard assumptions for wall construction characteristics, we defined the U-factor for each instance of wall construction, calculated using Equation 4 and the data in Table 41 and Table 42.

Equation 4. U-factor Rim and Band Calculation

$$U_{Rim\&Band} = \left(\frac{k_{framing} * l}{a + c + d + g + h}\right)_{framing} + \left(\frac{k_{cavity} * l}{a + (i * m * j) + d + g + h}\right)_{cavity\ insulation} + \left(\frac{1 - l}{a + c + d + g + h}\right)_{uninsulated}$$

The team calculated $UA_{RimandBand}$ for each instance of wall construction by multiplying the $U_{RimandBand}$ by the area of the rim and band. We assumed a one-foot thick rim and band, and multiplied the square footage of the rim and band (one) by the rim and band length, as shown in Equation 5.[23]

[23] The Arkenstone variable name for $length_{Rim\&Band}$ is rim_band_length_ft.

Equation 5. UA Value Rim and Band Calculation

$$UA_{Rim\&Band} = U_{Rim\&Band} * 1\text{ ft} * length_{Rim\&Band}$$

Table 42. Rim and Band Assembly Assumed Layers

Variable	Term	Arkenstone Variable Name	Units	Framing Path	Cavity Path	Source
Inside air film	a	N/A	R-Value	0.68	0.68	2017 ASHRAE Fundamentals
Wall framing	c	dwlg_wall_type	R-Value	Table 41, column “Wall Framing R-Value”	N/A	Field Data
1/2-inch plywood sheathing	d	N/A	R-Value	0.79	0.79	2017 ASHRAE Fundamentals
1/2-inch lapped wood siding	g	N/A	R-Value	0.81	0.81	2017 ASHRAE Fundamentals
Outside air film	h	N/A	R-Value	0.25	0.25	2017 ASHRAE Fundamentals
Rim cavity insulation	i	rim_band_cavity_ins_type	R-Value per inch	N/A	Table 37, column “Average R-Value Per Inch”	Field Data
Rim cavity thickness	m	rim_band_cavity_ins_thickness_inch	Inch	N/A	If rim and band insulation thickness *(rim_band_Cavity_ins_thickness_inch)* value is “Skipped,” use 0.00; Otherwise use rim and band insulation thickness value	Field data
Cavity insulation condition	j	rim_band_ins_cond	%	N/A	Fully contacting survey=100%, Intermittent Contact=50%, Not insulated or not in contact=0%	Field Data
Weighting factor	k	N/A	%	See Table 41, column “Framing Path Weighting”	See Table 41, column “Cavity Path Weighting”	Field Data
Percentage insulated	l	rim_band_ins_length_ft, rim_band_length_ft	%	Percentage of length insulated	Percentage of length insulated	Field Data

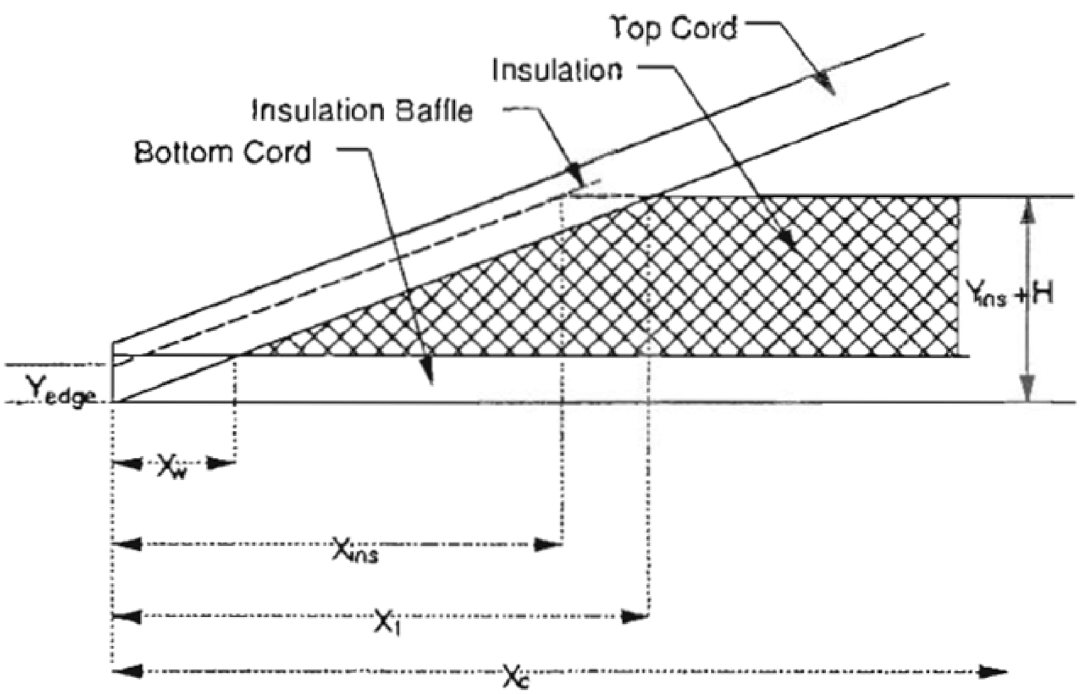
Ceiling UA Values

The Cadmus team calculated ceiling insulation based on the ceiling construction type—attics or enclosed ceilings—and collected data separately for both types. The following sections describe how we calculated U-factors for attics and enclosed ceilings. Some homes had both ceiling types, so we calculated both UAAttic and UACeiling.

Attics

For ceilings with attics, the Cadmus team assumed that the eve of the attic edge was sloped to the end and could not be fully insulated depending on the installed depth of insulation (Figure 3). We calculated the average ceiling assembly U-factor accounting for the diminishing insulation level near the eve of the roof and through the framing assemblies using the assumptions and calculations documented in Table 43.

Figure 3. Standard Blown-in Insulation Ceiling Detail



Source: Super Good Cents Heat Loss Calculations.

Because data such as roof pitch and perimeter of the wall with pitched roof are unknown, the Cadmus team used standard industry assumptions detailed in the Regional Technical Forum's *Simplified Energy Enthalpy Model (SEEM) Template* version 1.9 to calculate these factors, as well as assumptions and methods documented in the Super Good Cents *Heat Loss Calculations*. We assumed that all attic spaces with flat ceilings and a pitched roof were adequately vented and ignored the roof deck for the purposes of calculating the U-factor. The team calculated U-factors for each instance of attic defined for each site during data collection, and used Equation 6 to calculate the attic U-factor, using the values shown in Table 43.

Equation 6. U-factor Attic Calculation

$$U_{Attic} = U_{ins} * \left(1 - FF_{truss} - (1 - FF_{ins})\right) + (U_{truss} * FF_{truss}) + (U_{void} * (1 - FF_{ins}))$$

We calculated UA_{Attic} for each attic by multiplying the U_{Attic} by the attic area, as shown in Equation 7.[24]

Equation 7. UA Value Attic Calculation

$$UA_{Attic} = U_{Attic} * A_{Attic}$$

Table 43. Attic Assumptions and Equations

Term	Arkenstone Variable	Value	Description	Data
X_c	N/A	180	Horizontal distance from peak of roof to edge (inches)	Assumption
P	N/A	0.33	Pitch of roof (rise/run)	Assumption
R_{ins}	attic_ins_type	See Table 37, column "Average R-Value Per Inch"	Thermal resistance of insulation	Field Data
Y_{ins}	attic_ins_thickness_inch	Insulation Depth	Depth of insulation required for nominal R-value (inches)	Field Data
Yedge	N/A	2.25	Minimum depth of insulation at edge of ceiling (inches)	Assumption
R_1	N/A	$Y_{edge} * R_{ins} + 1.22 + 0.6875$	R-value of insulation at edge of ceiling (Yedge * Rins) plus the R-value of the top and bottom air film and ceiling board	RTF SEEM Template V1.9
H	N/A	$X_c * P - (Y_{ins} - Y_{edge}) - \sqrt{{X_c}^2 * P^2 - 2 * X_c * P * (Y_{ins} - Y_{edge})}$	Extra depth of insulation due to piling effect (inches)	RTF SEEM Template V1.9
X_w	N/A	10.50	Horizontal distance from the edge to point where insulation is on top of framing member (inches)	Assumption
X_1	N/A	$\frac{H + Y_{ins}}{P}$	Horizontal distance from edge of ceiling to full depth insulation on top of framing member (inches)	RTF SEEM Template V1.9
Kw	N/A	0.98	Thermal conductivity of wood framing member (k)	RTF SEEM Template V1.9
R_2	N/A	$\frac{3.5}{K_w} + 1.22 + 0.568$	Sum of R-values of framing member, air films, and ceiling board	RTF SEEM Template V1.9
R_{truss}	N/A	$R_2 + (Y_{ins} + H - 3.5) * R_{ins}$	Total R-value of heat flow path through framing member at maximum insulation depth	RTF SEEM Template V1.9
X_{ins}	N/A	$\frac{(Y_{ins} + H) - Y_{edge}}{P}$	Horizontal distance from edge of ceiling to full depth of insulation on top of ceiling board (inches)	RTF SEEM Template V1.9
U_{ins}	N/A	$\frac{1}{X_c * P * R_{ins}} * \ln\left(1 + R_{ins} * \frac{Y_{ins} + H}{R_1}\right) + \frac{1 - \frac{(Y_{ins} + H)}{X_c * P}}{R_1 + R_{ins} * (Y_{ins} - Y_{edge} + H)}$	Overall U-factor of the ceiling assembly between truss framing members	Calculation

24 The Arkenstone variable name for A_{Attic} is attic_size_ft.

Term	Arkenstone Variable	Value	Description	Data
U_{truss}	N/A	$\frac{\ln(Y_{edge} * K_w + X_w * P * K_w) - \ln(Y_{edge} * K_w)}{X_c * P * K_w} + \frac{\ln(R_2 + Y_{edge} * K_w - X_w * P * R_{ins} + X_{ins} * P * R_{i}}{X_c * P * K_w} + \frac{\ln(R_{truss}) - \ln\left(R_{truss} - Y_{edge} * (R_{ins} - K_w)\right)}{X_c * Y_{edge} * \frac{R_{ins} - K_w}{X_1 - X_{ins}}} + \frac{1 - \frac{X_1}{X_c}}{R_{truss}}$	Overall U-factor of the ceiling assembly at the framing members where the insulation value is reduced due to the higher thermal conductivity of the wood	Calculation
U_{void}	N/A	0.52	Overall U-factor of ceiling assembly where there is no insulation	Calculation
FF_{truss}	N/A	0.07	Truss framing fraction (assumes 24-inch on-center spacing and 40-foot structure length)	Assumption
FF_{ins}	attic_percent_insulated	100%	Percentage of attic that is insulated	Field Data

Enclosed Ceilings

Where the ceiling is a closed assembly, such as vaulted ceilings or flat deck ceilings, the Cadmus team used a similar calculation to that for wall assemblies. We assumed that enclosed ceilings had no venting and used a parallel path approach to account for heat transfer through the framing members of the enclosed ceiling, the insulated cavities, and the uninsulated cavities.

Using standard assumptions for vaulted ceiling construction characteristics, we calculated the U-factor for the ceiling construction using Equation 8 and the values in Table 44.

Equation 8. U-factor Enclosed Ceiling Calculation

$$U_{ceiling} = \left(\frac{k_{framing}}{a + b + c + d + l + h}\right)_{framing} + \left(\frac{k_{cavity}}{a + b + (i * c \; * \; j) + d + l + h}\right)_{cavity\ insulation}$$

The Cadmus team calculated $UA_{ceiling}$ for each construction by multiplying the $U_{ceiling}$ by the area of the ceiling, as shown in Equation 9.[25]

Equation 9. UA Value Enclosed Ceiling Calculation

$$UA_{Enclosed\ ceiling} = U_{Enclosed\ ceiling} * A_{Enclosed\ ceiling}$$

25 The Arkenstone variable name for $A_{Enclosed\ ceiling}$ is ceiling_size_ft.

Table 44. Enclosed Ceiling Assumed Layers

Variable	Term	Arkenstone Variable	Framing Path (R-Values)	Cavity Path (R-Values)	Data
Inside air film	a	N/A	0.62	0.62	2017 ASHRAE Fundamentals
5/8-inch wallboard	b	N/A	0.57	0.57	2017 ASHRAE Fundamentals
Truss	c	ceiling_thickness_inch	0.98	ceiling_thickness_inch	Field Data (assuming roof thickness equals insulation thickness)
Insulation	i	ceiling_ins_type	N/A	See Table 37, column "Average R-Value Per Inch"	Field Data
1/2-inch plywood sheathing	d	N/A	0.79	0.79	2017 ASHRAE Fundamentals
Asphalt shingles	l	N/A	0.44	0.44	2017 ASHRAE Fundamentals
Outside air film (winter)	h	N/A	0.17	0.17	2017 ASHRAE Fundamentals
Insulation condition	j	ceiling_percent_insulated	N/A	ceiling_percent_insulated	Field Data
Weighting factor	k	N/A	0.07	0.93	Assumption

Sources: ASHRAE Fundamentals 2013, RTF SEEM Template Version 1.9, and Super Good Cents Load Calculations.

Foundation and Floor UA Values

The Cadmus team divided the foundation and floor UA values into four sections: framed floor, slab-on-grade, and foundation wall.

The heat loss equation and inputs for each of these three scenarios are outlined below.

Thermal Boundary Framed Floor

The Cadmus team applied Equation 10 to floor elements with the Arkenstone variable "*floor_type* = *Framed floor*. Where the location of the framed floor was between conditioned space and an unconditioned space or ambient.

For homes with a framed floor, the team used a two-path analysis to account for framing and cavity insulation. Using industry-standard assumptions for floor construction characteristics, we calculated the U-factor for the construction using Equation 10 and the data in Table 45.

Equation 10. U-factor for Framed Floor Calculation

$$U_{Framed\ Floor} = \left(\frac{k_{framing}}{a+m+d+n+h}\right)_{framing} + \left(\frac{k_{cavity}}{a+m+d+(i*l*j)+h}\right)_{cavity\ insulation}$$

We calculated the $UA_{Framed\ Floor}$ for each construction using Equation 11,[26] which multiplies the $U_{Framed\ Floor}$ by the floor area.

Equation 11. UA Value for Framed Floor

$$UA_{Framed\ Floor} = U_{Framed\ Floor} * A_{Framed\ Floor}$$

Table 45. Framed Floor Assumed Layers

Variable	Term	Arkenstone Variable	Framing Path (R-Values)	Cavity Path (R-Values)	Data
Inside air film	a	N/A	0.92	0.92	2017 ASHRAE Fundamentals
Hardwood flooring	m	N/A	0.63	0.63	2017 ASHRAE Fundamentals
3/4-inch plywood subfloor	d	N/A	1.08	1.08	2017 ASHRAE Fundamentals
Floor joists	n	N/A	9.44	N/A	2017 ASHRAE Fundamentals
Insulation	i	*floor_ins_type*	N/A	R-Value per inch of cavity insulation	Table 37
Thickness	l	*floor_ins_thickness_inch*	N/A	*floor_ins_thickness_inch*	Field Data
Bottom air film	h	N/A	0.92	0.92	2017 ASHRAE Fundamentals
Insulation condition	j	*floor_ins_cond*	N/A	Fully contacting=100%, Intermittent contact=50%, No contact=0%	Field Data
Weighting factor	k	N/A	0.09	0.91	Assumption

Thermal Boundary Foundation Wall

The team applied Equation 12 to foundation elements with the Arkenstone variable "*foundation_type*" that is equal to any of the following: conditioned basement or conditioned crawl space, and where the location of that space was between conditioned space and unconditioned space or ambient. The F-factor accounts for thermal losses in the below grade floor. While the U-factor accounts for thermal losses in the wall assembly.

For basements and crawl spaces, the team used floor F-factors and wall U-factors outlined in Table 46. We calculated the $UA_{Foundation\ Wall}$ for each construction using Equation 12,[27] multiplying the $F_{Foundation\ Wall}$ by the perimeter of the floor, then multiplied $U_{Foundation\ Wall}$ by the area of the foundation wall.

26 The Arkenstone variable name for $A_{Framed\ Floor}$ is floor_area_ft.

27 The Arkenstone variable name for $P_{Foundation\ Wall}$ is foundation_wall_length_ft, while the name for $L_{Foundation\ Wall}$ is foundation_wall_length_ft and the name for $H_{Foundation\ Wall}$ is foundation_wall_height_ft.

Equation 12. UA Value for Foundation Walls

$$UA_{Foundation\ Wall} = F_{Foundation\ Wall} * P_{Foundation\ Wall} + U_{Foundation\ Wall} * A_{Foundation\ Wall}$$

$$\text{where: } A_{Foundation\ Wall} = L_{Foundation\ Wall} * H_{Foundation\ Wall}$$

Table 46. Foundation Walls F Factors and U-factors

Insulation Strategy	Arkenstone Variable	Depth Below Grade	U-factor	F-Value
Uninsulated	foundation_ins_type=none or foundation_ins_material=none	<2 feet	0.35	0.59
		2 to 4 feet	0.28	0.53
		>4 feet	0.19	0.46
Interior R-11 furred walls (less than or equal to 4-inch insulation)	foundation_ins_material≠none and foundation_ins_thickness_inch≤4 feet	<2 feet	0.07	0.68
		2 to 4 feet	0.06	0.63
		>4 feet	0.05	0.56
Interior R-19 furred walls (greater than 4-inch insulation)	foundation_ins_material≠none and foundation_ins_thickness_inch>4 feet	<2 feet	0.04	0.69
		2 to 4 feet	0.04	0.64
		>4 feet	0.04	0.57

Note: U-factor and F-factors from Ecotope (Baylon, David, and Jonathan Heller). October 24, 1988. *Super Good Cents Heat Loss Reference.* Volume I, Volume II and Volume IV.

Window and Skylight UA Values

For window and skylight heat loss, the Cadmus team used the value from a window sticker or homeowner plans; otherwise, we used lookup tables from the National Renewable Energy Laboratory *Efficiency Measures Database*. We based U-factors on the number of panes and frame type.

If the window or skylight U-factor (Arkenstone variables "*window_U_factor*" and "*skylight_U_factor*") is a numeric value and the window or skylight source (Arkenstone variables "*window_U_factor_SHGC_source*" and "*skylight_U_factor_SHGC_source*") is "*Window sticker*" or "*Homeowner plans*," we used the recorded U-factor. Otherwise, the team used Table 47 to determine the U factor. We calculated the UA_{window} and $UA_{skylight}$ for each home by multiplying the U_{window} and $U_{skylight}$ by the area of the window/skylight, as shown in Equation 13[28] and Equation 14.[29]

Equation 13. UA Value for Windows

$$UA_{Window} = U_{Window} * A_{Window}$$

$$\text{where: } \mathrm{A_{Window}(ft^2)} = \frac{\mathrm{W_{Window} * H_{Window}}}{\mathrm{144\ in^2}}$$

28 The Arkenstone variable name for W_{Window} is window_width_inch and the name for H_{Window} is window_height_inch.

29 The Arkenstone variable name for $W_{Skylight}$ is skylight_width_inch and the name for $H_{Skylight}$ is skylight_height_inch.

Equation 14. UA Value for Skylights

$$UA_{Skylight} = U_{Skylight} * A_{Skylight}$$

$$\text{where: } \mathrm{A_{Skylight}(ft^2)} = \frac{\mathrm{W_{Skylight} * H_{Skylight}}}{\mathrm{144\ in^2}}$$

Table 47. Window/Skylight U-factors

Frame Type	Glazing Type	Average U-Value
Metal	Single	1.13
	Double	0.7
	Triple	0.24
Fiberglass	Single	0.81
	Double	0.38
	Triple	0.24
Vinyl	Single	0.81
	Double	0.38
	Triple	0.24
Wood	Single	0.81
	Double	0.38
	Triple	0.24

Door UA Values

Similar to windows, to determine door heat loss we used lookup tables from the National Renewable Energy Laboratory *Efficiency Measures Database*, supplemented with engineering assumptions. We based the U-factors on the glazing percentage and door material, as shown in Table 48.

We calculated the UA_{door} for each home by multiplying the U_{door} by the area of the door (Equation 15).[30]

Equation 15. UA Value for Doors

$$UA_{Door} = U_{Door} * A_{Door}$$

$$\text{where: } \mathrm{A_{Door}(ft^2)} = \frac{\mathrm{W_{Door} * H_{Door}}}{\mathrm{144\ in^2}}$$

30 The Arkenstone variable name for W_{Door} is dwlg_door_ext_width_inch and the name for H_{Door} is dwlg_door_ext_height_inch.

Table 48. Door U-factors

Material	Percentage Glazing	Average U-Value
Wood	No Light	0.72
	Half Light	0.9
	Full Light	1.08
Metal	No Light	0.2
	Half Light	0.66
	Full Light	1.21
Fiberglass	No Light	0.2
	Half Light	0.26
	Full Light	0.32

Assumptions

The Cadmus team used several assumptions for our calculations, shown by measure below.

Above Grade Walls

- Infill frame path values have 8 inches of solid wood framing covering 8% of the walls area
- Structural steel frame path uses R-0.5 steel framing and covers 6% of the wall area
- If the value for *dwlg_wall_cont_ins_thickness_inch* is not applicable, the value is 0
- If we could not access the value for *dwlg_wall_cont_ins_thickness_inch*, the value is 0
- For *dwlg_wall_cont_ins_thickness_inch*, if *dwlg_wall_cont_ins_yes_no* is yes and we could not determine the thickness, the thickness is 0.5
- If we could not access or could not determine the value for *dwlg_wall_cavity_ins_cond*, the value is 1

Ceilings/Attic

- If we were unable to access or unable to determine *ceiling_percent_insulated*, insulation is 80%
- If we were unable to access or unable to determine *attic_percent_insulated*, insulation is 80%

Rim/Band

- If the *rim_band_ins_cond* value was not applicable, and we were unable to access or unable to determine the *rim_band_ins_type*, the insulation condition value is 0
- If the *rim_band_material* was not applicable, there was no rim/band
- If the *rim_band_location* was not applicable, there was no rim/band
- The percentage of insulated value cannot exceed 100%

Foundations/Floors

- Foundation insulation R-Values are based on the thickness for furred walls, where the value is R-11 if less than 4 inches and R-19 if less than 4 inches
- Slab thickness for on-grade walls was used to separate insulation and F values into 0 to 2 feet and 2 to 4 feet
- Floor joist updated to use average value of 2x10 frame (9.25-inch floor thickness)
- We did not calculate floor entries where *floor_location* is not applicable
- We did not consider heat loss from unconditioned space to unconditioned space for foundation elements

Windows

- We used the window *u_Factor* if *window_U_factor_SHGC_source* was a window sticker or homeowner plans