



**NIST Technical Note
NIST TN 2329**

A Collection of Dwellings to Represent the U.S. Housing Stock

2024 Update

Nathan M. Lima
Andrew K. Persily
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Abstract

This report presents a comprehensive update to an existing collection of dwellings used to represent the U.S. housing stock [1], reflecting changes and trends up to the year 2024. This update aims to ensure the collection remains relevant and accurately mirrors the diverse characteristics of residential buildings across the U.S., facilitating more precise modeling and analysis of ventilation, indoor air quality, and energy usage. Through a thorough examination of current data sources, including the most recent U.S. DOE Residential Energy Consumption Surveys (RECS 2020) and the Department of Housing and Urban Development's (HUD) American Housing Survey (AHS 2021), updates relative to the previous 2006 collection were identified and addressed.

A systematic approach was adopted to select a representative sample of dwellings, considering various parameters such as year of construction, type of households, number of stories, floor area, and specific architectural and mechanical features. The report also describes the CONTAM modeling methodology used to analyze multizone building representations, facilitating detailed studies on airflow patterns, contaminant dispersion, and energy implications of various ventilation strategies, building features, and contaminant characteristics.

Key findings underscore the evolving nature of the U.S. housing stock, particularly in terms of increased energy efficiency, shifts in heating equipment types, and variations in dwelling design that impact indoor air quality. The updated collection is expected to be a robust resource for researchers, policymakers, and industry professionals in developing more effective building codes, standards, and practices that ensure healthier and more sustainable residential environments.

The report concludes with recommendations for future updates to the collection, suggesting topics for research and data collection efforts to capture emerging trends, advancements in building technologies, and changes in occupancy behaviors. This ongoing refinement process is essential to maintain the relevance and utility of the collection in supporting the design and evaluation of buildings that meet the changing needs and preferences of the U.S. population.

Keywords

Database; dwelling; indoor air quality; modeling; residential buildings; ventilation.

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1. Introduction

Building ventilation, including mechanical and natural ventilation and infiltration, is a significant driving factor of not only indoor air quality (IAQ) but also material degradation and energy usage [2–12]. Ventilation’s impact on IAQ can play a role in occupant health, comfort, and productivity within a space [5–7, 13–16]. Building ventilation typically carries the vast majority of all water vapor into and out of buildings relative to any other indoor moisture source [8, 17, 18]. The moisture in buildings, when it gets to the point of dampness, has been shown to increase the probability of multiple diseases and symptoms [19]. The adverse effects of excessive indoor dampness are not only limited to health effects; extended dampness or periodic condensation has also been documented to reduce the load-bearing capacity of wood framing as well as corrode critical structural fasteners [19, 20]. Building space conditioning systems are responsible for the most significant proportion of building energy consumption, making up 38 % of energy usage in buildings, which is equivalent to 12 % of the total energy used by all sectors [21]. Building heating, ventilation, and air-conditioning (HVAC) systems are the main components in space conditioning energy use; as such, they have become a prime target for reducing energy usage [9]. Poor air quality, in both indoor and outdoor environments, is considered to be one of the leading causes of global non-communicable disease and mortality [13, 22–25]. The National Human Activity Pattern Survey (NHAPS) found that people in the United States spend 87 % of their time in enclosed buildings and 69 % of that time in their residences [26]. The remaining 18 % of the time in enclosed buildings consists of 5.4 % in offices/factories, 1.8 % in bars/restaurants, and 11 % in other indoor locations [26]. Given the time people spend indoors, IAQ can significantly impact human health. IAQ concerns, specifically residential IAQ and energy conservation, have led to various design approaches and interventions to control and improve the indoor environment and reduce the energy used. The understanding of the impacts of ventilation on IAQ, including moisture and energy use, can be increased through building simulation analysis using tools such as CONTAM [27–29].

1.1. Background

A collection of dwellings and corresponding airflow models to represent the U.S. dwelling stock was developed in 2006 using data from the 1997 U.S. Department of Energy Residential Energy Consumptions Survey (RECS). As part of that study, the 1997 RECS database statistics were compared with the 1999 U.S. Census Bureau’s American Housing Survey (AHS) to assess their similarity, as shown in Table 1 below. The 1997 RECS database comprised 5686 dwelling units and was used to develop the collection of dwelling models due to its electronic format's ease of access and manipulation. The 5686 dwelling units in the survey were categorized using the following characteristics of the dwellings: building age, floor area, number of floors, foundation type, forced-air distribution or central heating system, and the existence of a garage. Based on this categorization, there were 848 unique dwelling types (Single Family Detached and Attached Dwellings: 432; Apartment Units: 400; and Manufactured Dwellings: 16). These unique dwelling types were determined by analyzing the RECS data using these six criteria for single-family

attached and detached dwellings, four of them for apartments, and three for manufactured dwellings (see column one of Table 2.) The RECS and AHS databases assign a *weight* for each survey response and dwelling unit that takes part in the survey. This weighting value is the estimated number of units the given survey response represents nationwide; this calculated weighting allowed the 2006 effort to achieve 80 % nationwide representation with the 209 different dwelling models. The 209 different dwelling CONTAM models were also accompanied by their associated floor plans. The original collection can be found in the CONTAM case studies section of the NIST multizone modeling website (link: <https://www.nist.gov/el/energy-and-environment-division-73200/nist-multizone-modeling/case-studies/case-11>)

Table 1 Summary of data from AHS and RECS.

Variable	Variable Values	1999 AHS	1997 RECS	2021 AHS	2020 RECS
Unit Type	Single-Family Detached	72.4 %	62.9 %	62.4 %	62.4 %
	Single-Family Attached	5.8 %	9.8 %	6.3 %	6.0 %
	Apartment	16.1 %	21.1 %	25.7 %	26.0 %
	Manufactured Dwelling	5.7 %	6.2 %	5.6 %	5.5 %
Region	Northeast	16.6 %	19.4 %	17.5 %	17.7 %
	Midwest	26.0 %	23.7 %	21.6 %	21.9 %
	South	34.2 %	35.4 %	39.0 %	37.9 %
	West	23.0 %	21.5 %	21.9 %	22.4 %
Forced-Air Distribution	Yes	63.2 %	53.4 %	74.8 %	72.6 %
	No	36.8 %	46.6 %	25.2 %	27.4 %
Floor Area, m² (ft²)	< 93 (1000)	14.0 %	29.0 %	24.0 %	24.5 %
	93 to 186 (1000 to 1999)	46.1 %	45.1 %	46.2 %	48.5 %
	186 to 279 (2000 to 2999)	21.7 %	13.0 %	19.9 %	19.3 %
	> 279(3000)	10.7 %	4.0 %	9.9 %	7.7 %
Occupants per Household	1	24.3 %	25.2 %	30.3 %	27.2 %
	2	33.9 %	32.5 %	34.4 %	36.7 %
	3-4	31.6 %	32.2 %	27.5 %	27.4 %
	≥ 5	8.9 %	10.1 %	7.7 %	8.8 %
Central Air Conditioning	Yes	52.0 %	42.1 %	77.4 %	75.4 %
	No	48.0 %	57.9 %	22.6 %	24.6 %
Year Built	<1940	17.3 %	19.9 %	14.3 %	N/A
	1940-1949	7.4 %	9.3 %	4.1 %	N/A
	<1950 ^a	24.7 %	29.2 %	18.4 %	16.4 %
	1950-1959	13.1 %	13.1 %	7.2 %	10.1 %
	1960-1969	14.4 %	14.9 %	9.0 %	10.3 %
	1970-1979	19.8 %	13.2 %	16.0 %	14.8 %
	1980-1989	6.4 %	6.2 %	16.3 %	13.2 %
	1990-1997	21.6 %	23.4 %	N/A	N/A
	1990-1999	N/A	N/A	14.2 %	13.9 %
	2000-2009	N/A	N/A	13.8 %	13.1 %
	2010-2020	N/A	N/A	5.2 %	8.2 %
Garage or Carport ^b	Yes	56.4 %	53.7 %	52.1 %	61.3 %
	No	43.5 %	25.2 %	47.9 %	38.7 %
Foundation Type ^c	Basement	44.6 %	32.7 %	36.4 %	37.6 %
	Crawlspace	25.8 %	22.2 %	33.9 %	26.0 %
	Slab	28.7 %	22.6 %	29.7 %	36.4 %
Number of Stories ^d	1	35.1 %	55.8 %	42.9 %	57.3 %
	2	35.1 %	39.8 %	15.6 %	39.5 %
	≥ 3	29.6 %	3.1 %	41.5 %	3.2 %

^a Value calculated from the <1940 & 1940-1949 values for 1999 AHS, 1997 RECS, & 2021 AHS

^b Does not include apartment units.

^c Does not include apartment units or manufactured dwellings.

^d RECS does not include apartment units or manufactured dwellings.

Table 2 Variable range or level for each dwelling type.

Variable		Original Variable Range or Level	Current Variable Range or Level
Single-Family (Attached & Detached)	<i>Forced-Air Distribution</i>	No	No
		Yes	Yes
	<i>Floor Area, m² (ft²)^a</i>	< 149 (1600)	<139 (1500)
		149 to 223 (1600-2399)	139 to 232 (1500-2500)
		> 223 (2400)	> 232 (2500)
	<i>Year Built^b</i>	<1940	<1960
		1940-1969	1960-1969
		1970-1989	1970-1979
		>1990	1980-1989
			1990-1999
		>2000	
	<i>Garage or Carport</i>	No	No
		Yes	Yes
	<i>Foundation Type</i>	Slab	Slab
Crawlspace		Crawlspace	
Basement		Basement	
<i>Number of Stories</i>	1	1	
	2	2	
	≥3	≥3	
Apartments	<i># of Units in Building^a</i>	2-4	2-4
		5-9	5-9
		10-19	10-19
		20-39	20-49
		>40	>50
	<i>Floor Area, m² (ft²)</i>	<93 (1000)	<93 (1000)
		>93 (1000)	>93 (1000)
	<i>Year Built^b</i>	<1940	<1960
		1940-1969	1960-1969
		1970-1989	1970-1979
		>1990	1980-1989
			1990-1999
		>2000	
	<i>Central Heating System</i>	Yes	Yes
No		No	
Manufactured Dwellings	<i>Floor Area, m² (ft²)^a</i>	< 149 (1600)	<139 (1500)
		> 149 (1600)	>139 (1500)
	<i>Year Built^b</i>	<1940	<1960
		1940-1969	1960-1969
		1970-1989	1970-1979
		>1990	1980-1989
			1990-1999
		>2000	
	<i>Central Heating System</i>	Yes	Yes
No		No	

^a The ranges have changed to match the distribution in the AHS databases.

^b Year-built ranges were changed to match the Lawrence Berkeley National Laboratory (LBNL) residential diagnostics database for envelope leakage.

1.2. Usage of 2006 Collection of Dwellings

The 209 dwelling models and the accompanying report have been used many times since their development, as reflected in two book sections, fifteen conference papers, seven reports, thirty-one journal articles, one master's thesis, six doctoral dissertations, and three unknown citations; for a total of 65 (66¹) works citing the report Table 1 (see Appendix A for a complete list of citations). Seventy-three percent of the cited works focused on ventilation and/or indoor air quality, twenty-three percent focused on energy modeling and/or usage, and the remaining four percent focused on fire science and earthquake research. The complete set of 209 dwellings was used in two studies, but only a subset of the models was used in most cases, with the average number of models used being nineteen. The maximum and average (Max/Avg) number of models used for each publication type can be seen in the outermost ring in Fig. 1. In most cases where a subset of the models was used, the number of models used was under ten; for the cited works where we were able to get the complete text, twenty-six used no models, nineteen used less than ten but greater than the zero, and twelve used greater than ten models. There are two primary case types for the works where the models were not used. In one case type, models were created in a different software program, examples being well-mixed box models in their preferred code language, flame spread models, etc. In the second case type, the models and their accompanying report were used as guidance to develop a similar model set for their project or country.

¹ The 66th citation was not included in this report's analysis of the usage of the original collection of dwellings discussed in Section 1.2, Usage of 2006 Collection of Dwellings, as the document was published during the final review process of this report. This 66th citation is a Fire Science Journal Article in which they utilized 8 of the residential models as references for their fire model training strategy.

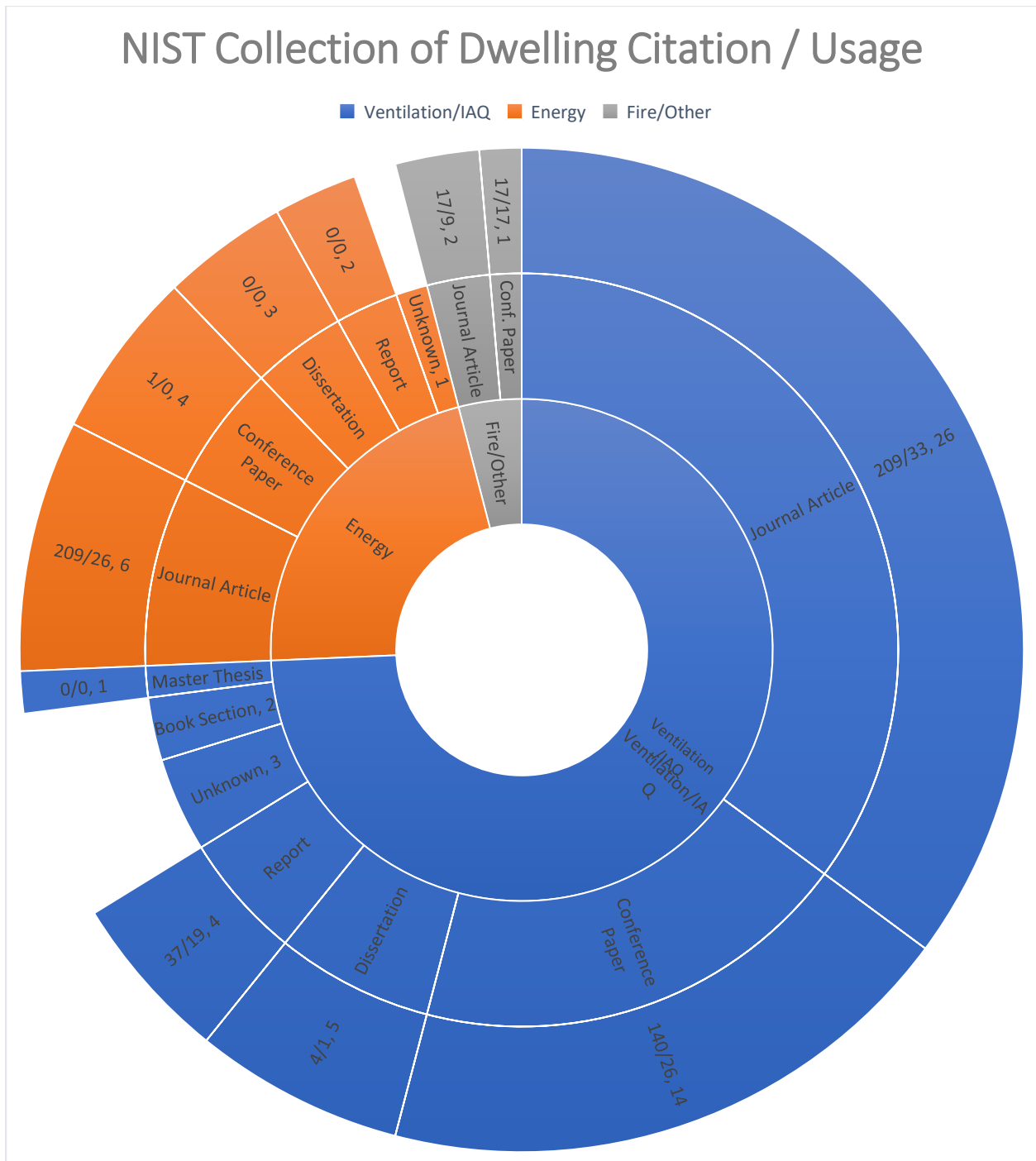


Fig. 1 NIST Collection of Dwelling Citation / Usage.

Note: The outer ring denotes the maximum and average (Max/Avg) number of models used for each publication type and the number of publications in that category.

1.3. Motivation for Collection of Dwellings Update

The motivations for updating the original collection of dwelling models are two-fold. The primary motivation is to add representation of more current-period dwellings. The original database's most contemporary category of dwelling was 1990 and later, which at the time was modeled as a 1998 dwelling with its air leakage determined using the Lawrence Berkeley National Laboratory's (LBNL) normalized leakage (NL) rate regression model [1, 30]. The LBNL NL model has been updated to represent newer dwelling test results that have been added to the Residential Diagnostics Database (ResDB) since the original database was developed [31]. LBNL's updated NL rate regression model added additional considerations regarding dwelling layout, features, and location. The second motivation for the update is that the original CONTAM models are not modeled to scale. The model scale was not an issue as it did not affect CONTAM's ability to calculate the airflows and indoor contaminant concentrations. However, when CONTAM is coupled or co-simulated with other modeling programs, such as an energy modeling program, the scale of the model can be critical to the coupled or co-simulated analysis.

2. Data Sources for Update

The most recent versions of the AHS and RECS surveys were used to update the collection of dwelling models (AHS 2021 and RECS 2020). In the previous study, the RECS dataset was chosen since the dataset was more accessible and manipulable. However, both datasets had a similar representation of the U.S. dwelling stock, albeit the AHS dataset was made from about ten times as many dwelling surveys as the RECS dataset. Like the previous study, the two recent databases have similar statistical data. However, the number of respondents has increased (64 141 dwellings for AHS and 18 496 dwellings for RECS), and both datasets are now more easily accessible digitally. When comparing the same variables used in the previous study (Unit type, Region, Forced-air distribution, Floor area, Occupants per household, Central air conditioning, Year built, Garage or carport, Foundation type, and Number of stories) in Table 1, the representation is very similar between the two surveys. However, some statistical data from the two surveys is different and has given rise to issues when analyzing the data for this project. Some of these issues are discussed below in sections 2.1.1 (Gaps with AHS 2021) and 2.2.1 (Gaps with RECS 2020). There are also notable changes to the dwelling stock reflected in both datasets; one is the shift to apartments from other dwelling types. A second notable change is the increase in the percentage of dwellings with forced air distribution and central air conditioning. A third significant change is a decrease in the representation of the dwellings built before 1950 and an increase in the representation of dwellings constructed between 1980 and 1989. One variable where the RECS 2020 and AHS 2021 datasets are quite different is the number of stories for dwellings. This difference was also present in the original study, possibly due to the RECS not including apartment buildings in the reported value of their number of stories variable.

2.1. American Housing Survey (AHS) Overview

The American Housing Survey (AHS) is a biennial survey conducted by the U.S. Census Bureau for the Department of Housing and Urban Development (HUD). Since 1973, it has provided comprehensive data on housing conditions, costs, and demographics across the United States. The AHS gathers detailed information on the physical condition of homes, housing affordability, and household characteristics, including income, size, and homeownership status. The survey covers a broad range of housing types, including single-family homes, apartments, and mobile homes, and includes both urban and rural areas. The AHS is designed to broadly represent the U.S. housing stock, using a stratified sampling methodology to ensure diverse geographic and demographic coverage. This makes it a crucial tool for policymakers, researchers, and housing advocates, providing essential data to inform housing policy, economic development, and housing affordability initiatives.

2.1.1. Gaps with AHS 2021

In the case of the AHS dataset, approximately 29 % of the dwelling surveys (apartments: 33.4 %, attached dwellings: 25.0 %, detached dwellings: 22.5 %, and manufactured dwellings: 33.5 %) are missing the floor area of the units. Estimating a percentage of the represented U.S. dwelling

stock would cause problems as units without floor area would need to be removed to categorize the dwellings into unique classes. An additional issue regarding the floor area variable is that it includes basement spaces (when a basement is present) regardless of whether the space is conditioned. Other issues with the AHS dataset are that it does not have variables for the *number of other rooms* in the dwelling or the *number of windows*. While the *number of bedrooms* and the *number of bathrooms* are defined in the dataset when they are removed from the total rooms variable, it leads to negative numbers of rooms remaining in some cases. These variables (*number of other rooms* and *number of windows*) are less of an issue as they are not used to classify the dwelling models but only to create each dwelling's CONTAM model. Reasonable assumptions can be made from the floor area for the *number of other rooms* and room types for the *number of windows*, though actual data would be preferred. It is also possible to use the RECS database in concert with the AHS database to estimate missing variables within the AHS database.

2.2. Residential Energy Consumption Survey (RECS) Overview

The Residential Energy Consumption Survey (RECS) is a national survey conducted by the U.S. Energy Information Administration (EIA) to collect data on energy use in U.S. households. First conducted in 1978, the RECS provides detailed information on the types and amounts of energy consumed in residential buildings, including electricity, natural gas, heating oil, and renewable sources. It also gathers data on factors influencing energy consumption, such as household size, building characteristics, and energy-related behaviors. The RECS is designed to represent all U.S. households, using a stratified sampling approach to capture a diverse range of geographic locations, home types, and demographic groups. This ensures the survey reflects national energy consumption patterns and helps policymakers, utilities, and researchers understand trends in residential energy use, energy efficiency, and the impact of energy policies on households nationwide.

2.2.1. Gaps with RECS 2020

In the case of the RECS dataset, two key variables are missing: the *number of units* in an apartment building and the *number of floors* in an apartment building. The *number of units* and *number of floors* in apartments are no longer part of the dataset as they are no longer included in the survey. Removing these variables in 2015 was part of the changes when switching the survey to a web/mail format. The lack of variables regarding the *number of units* and *number of floors* in apartments is problematic for the present work, as without them, defining the number of units or floors in an apartment building in the same way as the original study would not be possible. Unlike the missing *number of other rooms* and the *number of windows* in the AHS dataset, these variables are criteria used to classify the apartment dwelling models. Fortunately, a data-sharing agreement was established between NIST and the U.S. Energy Information Administration (EIA) to obtain the *number of units*. The *number of units* is information in the EIA's Delivery Sequence File (DSF) frame, based on the United States Postal Service (USPS) postal address information from the survey participants. This variable has some

errors due to varying address structures and their derivation, resulting in contradictory values (for example, the *apartment 5+ units* home type classification that the DSF lists as having less than five units). An example of the varying address structures causing an error would be a townhome community in which all dwellings share the same street address but use unit numbers for the individual dwellings; these would be considered individual single-family attached dwellings for RECS but would show up as townhouses with units in the EIA's DSF. Unfortunately, despite attempts by the EIA contractor to correct the varying address structures and home type inconsistencies, these errors still exist in the EIA's DSF. As the *number of units* variable is only used for the apartment dwelling type, this error is not an issue for this project. EIA was contacted about the *number of floors* for the apartment's variable. However, this variable is no longer available as part of the survey or within the EIA's DSF. For more details on how the *number of floors* variable was handled for this project, see Sec. 5.2 (Number of Stories).

3. Sample Selection for Updated Collection

Given that the previous U.S. collection of 209 dwellings was rarely used in its entirety, the new collection described in this report contains fewer dwellings and, therefore, a lower fraction of coverage of the U.S. dwelling stock. The total number of usable dwelling surveys in the RECS 2020 dataset is 18 496, and in the AHS 2021 dataset is 56 736 (see Table 3 for a more detailed breakdown by dwelling type). Dwellings that lacked the floor area or were categorized as *boat, RV, etc.*², were removed from the AHS responses pool, leaving the noted number of usable dwellings. Based on the RECS survey data, 1232 unique dwellings can be identified using the variable ranges or levels in Table 2, as seen in Table 3. From the AHS 56 736 dwelling surveys, 1616 unique dwellings were identified. The term unique in this context means a combination of Table 2 elements that define a distinctly different dwelling, for each of the different dwelling types. Each survey response was assigned to one of these 1232 and 1616 unique RECS and AHS dwelling models, respectively.

Table 3 Number of survey responses and unique number of dwellings by dwelling type.

Dwelling Types	RECS (All)	RECS (Unique)	AHS (All)	AHS (Unique)
Apartments	3452	143 ^a	17 547	351
Attached Dwellings	1751	443	4041	475
Detached Dwellings	12 319	628	32 550	769
Manufactured Dwellings	974	23	2598	24
Total Dwellings	18 496	1232	56 736	1616

^a The unique number of apartments in RECS is not a direct comparison to AHS, as there is currently no data for the *number of floors* in each apartment complex, and the *number of units* is based on EIA’s evaluation of the USPS postal address. Both variables are accounted for in AHS. The RECS’ value is the number of unique dwellings when not considering the *number of floors* and using address to account for the *number of units*.

3.1. Number of Models in the Updated Collection

Given the goal of representing a fixed percentage of the U.S. dwelling stock, as was done in the 2006 effort, a reduction of the total dwelling models to 50 % coverage was pursued (Table 4 and Table 5). A 50 % U.S. coverage required 139 dwelling models to be used to represent the AHS 2021 or 152 models for the RECS 2020 surveys (see B.2 AHS 2021 Dwelling Characteristics and B.3 RECS 2020 Dwelling Characteristics), decreasing the number of total models in the dataset, as compared to the 209 included in the original database. When utilizing a defined number of models instead of aiming for a specific coverage percentage, such as 50 % of the U.S. dwelling stock, Table 6, Table 7, Fig. 2, and Fig. 3 provide insight into the potential representation of the U.S. dwelling stock that can be achieved. Table 6 and Table 7 show the percentage of building stock representation for seven distinct model counts across four dwelling types, while Fig. 2 and Fig. 3 display a continuous curve for these dwelling types. The curves initially rise steeply and then level off, indicating that higher levels of dwelling representation require an increasing number of models. However, significantly reducing the

² Boat, RV, etc. is a class of homes in the AHS. As these classes of dwellings are not being considered in the update to the collections of dwellings they were removed from the response pool.

number of models may lead to problems with the diversity of dwelling characteristics represented. An example of such a problem can be seen when examining the six most prevalent apartment models in the AHS database. Three (*# of floors, year built, and forced air*) of the five variables for the models are the same, and this type of similarity is common in the different dwelling category types. If too few models are used, the collection could achieve a given percentage of U.S. representation but with a low variety of dwelling characteristics within the model set.

To have a complete representation of all variable levels (Table 2) within each dwelling type, 59 apartment models (if the number of floors is not included in the variables, only 35 models would be needed³), 36 attached dwellings, 25 detached dwellings, and 15 manufactured dwellings would be required when considering the AHS 2021 dataset. The original project did not consider the complete representation of all variable levels for all dwelling types. We chose not to pursue such a representation for this project as well, as some additional models would have had a meager representation in the U.S. dwelling stock.

Table 4 Number of dwelling models needed for a given percentage of U.S. coverage (AHS 2021).

Dwelling Type	10 %	20 %	30 %	50 %	60 %	80 %
Apartments	5	11	21	49	67	124
Attached	4	9	15	38	57	128
Detached	4	11	20	48	71	161
Manufactured	1	2	3	4	5	9
Total	14	33	59	139	200	422

Table 5 Number of dwelling models needed for a given percentage of U.S. coverage (RECS 2020).

Dwelling Type	10 %	20 %	30 %	50 %	60 %	80 %
Apartments	3	7	12	27	36	66
Attached	4	12	24	59	84	167
Detached	5	12	24	62	85	177
Manufactured	1	2	3	4	6	10
Total	13	33	63	152	211	420

Table 6 Percentage of U.S. coverage given the number of dwelling models (AHS 2021).

Dwelling Type	1	5	10	20	30	40	50
Apartments	3.65 %	11.5 %	19.1 %	29.6 %	38.3 %	45.4 %	51.4 %
Attached	4.34 %	13.8 %	23.0 %	36.1 %	45.1 %	51.5 %	56.8 %
Detached	3.65 %	12.2 %	19.6 %	30.7 %	38.4 %	45.4 %	51.2 %
Manufactured	14.4 %	62.9 %	86.2 %	99.3 %	n/a	n/a	n/a

Table 7 Percentage of U.S. coverage given the number of dwelling models (RECS 2020).

Dwelling Type	1	5	10	20	30	40	50
Apartments	4.18 %	16.2 %	26.9 %	42.5 %	54.4 %	63.3 %	70.5 %
Attached	3.42 %	11.8 %	18.3 %	27.4 %	34.5 %	40.8 %	46.3 %

³ Though it was not stated in the original U.S. collection of 209 dwellings, report text, the number of floors of an apartment building was a determining variable in defining dwelling characteristics, and as such, it was shown in the original report's modeling details tables and is discussed in greater detail in Section 5.2 Number of Stories of this report.

Dwelling Type	1	5	10	20	30	40	50
Detached	3.08 %	10.9 %	18.3 %	27.6 %	34.3 %	39.1 %	45.3 %
Manufactured	14.0 %	58.5 %	82.5 %	98.9 %	n/a	n/a	n/a

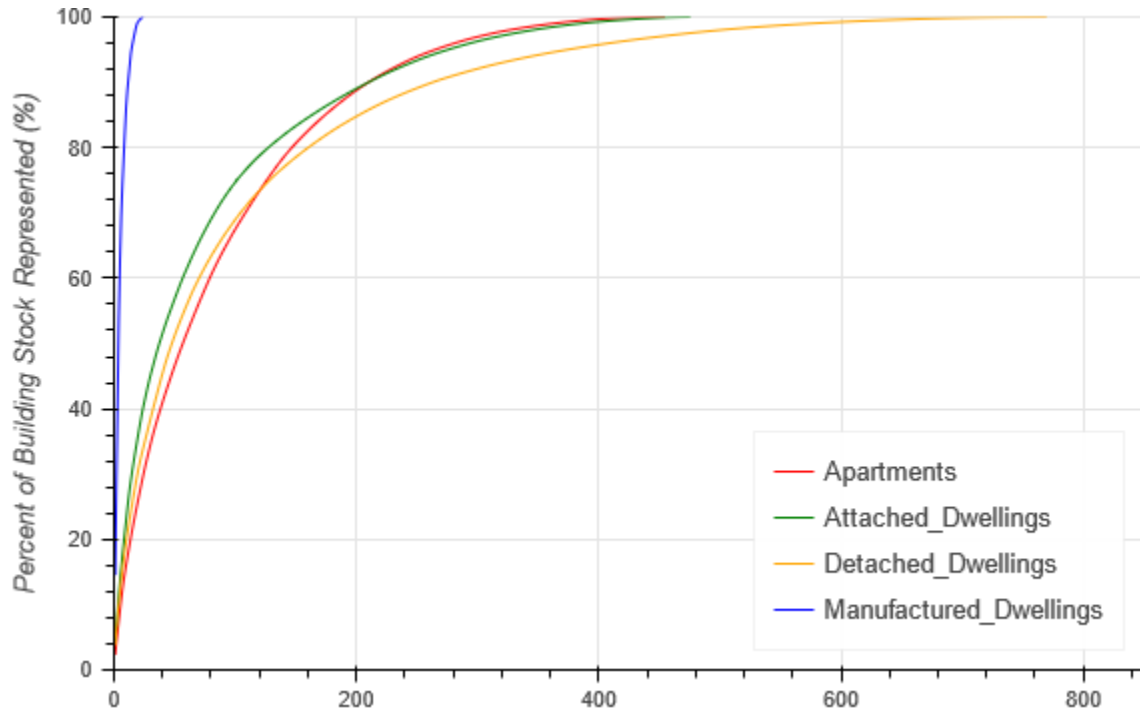


Fig. 2 Percentage coverage as a function of the number of dwelling models for AHS 2021.

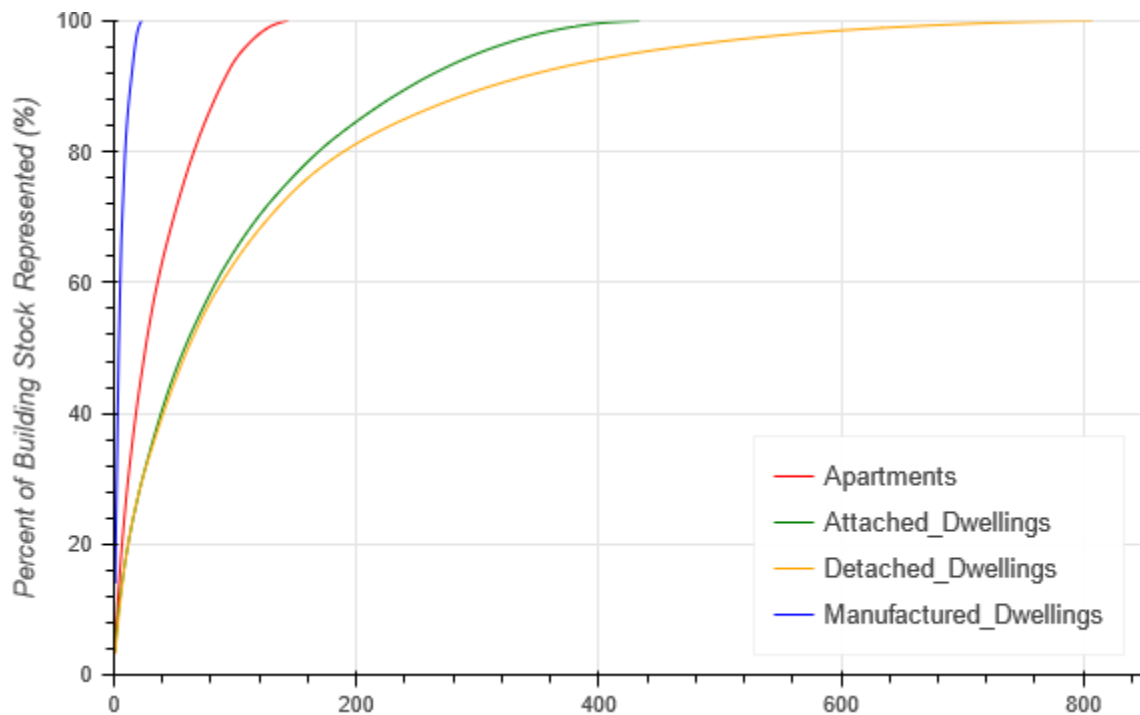


Fig. 3 Percentage coverage as a function of the number of dwelling models for RECS 2020.

3.2. Defining the Number of Models in the New Collection

All variables that represent differing dwelling characteristics, as listed in Table 2, have corresponding elements within the CONTAM dwelling models (see Section 5, Multizone Building Representations, for a more detailed discussion of these elements). This section discusses how these dwelling characteristics define the number of models needed to achieve a given percent representation of the U.S. dwelling stock representation for a new collection of models. While this report lays the groundwork for modeling a new collection of models, the current modeling completed as part of the report will consist of only the *2000 and later* models that can be used at this time as a starting point for a new collection as well as temporary to fill in the past collection. See section 3.2.2, Representation of Existing Suite of Dwellings, and section 4, CONTAM Modeling Methodology, for a more thorough discussion.

3.2.1. Year of Construction

The *year of construction* (*year built* in Table 2) variable is used to assign the exterior wall leakage for the model, as explained below. For the RECS and AHS surveys, this variable is defined as the year a structure was first constructed, not when it was remodeled, added to, or converted. The exterior wall leakage defines values in the flow path elements of the CONTAM models but is not associated with any other changes to the model. A dwelling model with all other variables in common will have the same CONTAM model, with only the values of the exterior wall leakage being different. The values within the flow path elements of a model can easily be edited with a script or other program and do not require creating a whole different model. When the *year of construction* is not considered part of the dwelling characteristics, leaving all other variables the same, there can be a notable decrease in the number of floor plans and CONTAM models that need to be created, as seen in Table 8 through Table 11. Table 8 and Table 9 show how many unique CONTAM dwelling models would be needed for each dwelling type and the varying percentages of U.S. dwelling coverage. Table 10 and Table 11 show the total difference between the number of CONTAM models needed with (Table 4 and Table 5) and without (Table 8 and Table 9) the *year of construction* as part of the dwelling characteristics.

Table 8 Number of dwelling models needed for a given percentage of U.S. coverage (AHS 2021) when the year of construction (year built) is not considered.

Dwelling Type	5 %	10 %	15 %	20 %	25 %	30 %	50 %	60 %	75 %	80 %
Apartments	2	5	8	10	12	15	22	27	33	35
Attached	2	4	5	7	9	10	17	23	40	48
Detached	2	4	6	8	10	12	20	30	45	56
Manufactured	1	1	1	1	1	1	1	2	3	3
Total	7	14	20	26	33	38	60	82	121	142

Table 9 Number of dwelling models needed for a given percentage of U.S. coverage (RECS 2020) when the year of construction (year built) is not considered.

Dwelling Type	5 %	10 %	15 %	20 %	25 %	30 %	50 %	60 %	75 %	80 %
Apartments	1	3	5	6	7	8	10	12	16	17
Attached	2	4	8	9	13	17	28	34	54	59
Detached	2	5	7	9	13	18	33	38	53	59
Manufactured	1	1	1	1	1	1	1	2	3	3
Total	6	13	21	25	34	44	72	86	126	138

Table 10 Comparison of the number of dwelling models needed for a given percentage of U.S. coverage (AHS 2021) when the year of construction (year built) is and is not considered.

Dwelling Type	5 %	10 %	15 %	20 %	25 %	30 %	50 %	60 %	75 %	80 %
Total with Year	7	14	23	33	45	59	139	200	348	433
Total without Year	7	14	20	26	33	38	61	82	121	142

Table 11 Comparison of the number of dwelling models needed for a given percentage of U.S. coverage (RECS 2020) when the year of construction (year built) is and is not considered.

Dwelling Type	5 %	10 %	15 %	20 %	25 %	30 %	50 %	60 %	75 %	80 %
Total with Year	6	13	23	33	47	63	152	211	366	420
Total without Year	6	13	21	25	34	44	72	86	126	138

Reviewing the year-built variable to determine the distribution of dwellings, 25.5 % of all dwellings in the AHS 2021 are *2000 and later* (see Table 12) and 23 % of all dwellings in the RECS 2020 were built in *2000 and later* (see Table 13). The AHS *2000 and later* range is made up of 270 unique dwellings (apartment: 57, attached: 85, detached: 124, and manufactured dwellings: 4), and the RECS *2000 and later* range is made up of 223 unique dwellings (apartment: 24, attached: 84, detached: 111, and manufactured dwellings: 4). An 80+ % representation of the *2000 and later* dwellings of the AHS dataset can be achieved with only 54 dwellings (apartment: 17, attached: 19, detached: 16, and manufactured dwellings: 2) -- see Table 14. A 20+ % representation of the full AHS 2021 dataset can be achieved with 61 dwellings (apartment: 16, attached: 13, detached: 30, and manufactured dwellings: 2) -- see Table 14. An 80+ % representation of the *2000 and later* dwellings of the RECS dataset can be achieved with only 56 dwellings (apartment: 11, attached: 30, detached: 21, and manufactured dwellings: 2) -- see Table 15. A 20+ % representation of the full RECS 2020 dataset can be achieved with 119 dwellings (apartment: 15 attached: 26, detached: 86, and manufactured dwellings: 3) -- see Table 15. The relatively low number of dwellings still provides a good representation of the *2000 and later* group of dwellings. The next step for the project was to update the original suite of dwelling models with their new representation (see Appendix B Dwelling Characteristics section) and focus design and modeling efforts on the *2000 and later* dwelling models.

Table 12 Year built dwelling distribution unique dwelling counts and percentage (AHS 2021).

Year Built	Apartments (# (%))	Attached Dwellings (# (%))	Detached Dwellings (# (%))	Manufactured Dwelling (# (%))	Total Unique Dwellings
Before 1960	59 (22.46 %)	95 (19.45 %)	143 (29.36 %)	4 (2.36 %)	301
1960 – 1969	59 (10.26 %)	64 (6.17 %)	133 (10.86 %)	4 (6.44 %)	260
1970 – 1979	59 (15.93 %)	78 (14.27 %)	127 (13.55 %)	4 (20.44 %)	268
1980 – 1989	60 (15.60 %)	83 (19.12 %)	125 (11.63 %)	4 (20.74 %)	272
1990 – 1999	57 (10.33 %)	70 (12.09 %)	117 (12.30 %)	4 (24.50 %)	248
2000 and later	57 (25.42 %)	85 (28.90 %)	124 (22.32 %)	4 (25.53 %)	270

Table 13 Year built dwelling distribution unique dwelling counts and percentage (RECS 2020).

Year Built	Apartments (# (%))	Attached Dwellings (# (%))	Detached Dwellings (# (%))	Manufactured Dwelling (# (%))	Total Unique Dwellings
Before 1960	24 (23.17 %)	75 (20.68 %)	128 (30.47 %)	3 (3.78 %)	230
1960 – 1969	23 (10.96 %)	55 (8.40 %)	106 (10.68 %)	4 (5.44 %)	188
1970 – 1979	24 (17.29 %)	63 (13.06 %)	120 (13.58 %)	4 (19.58 %)	211
1980 – 1989	24 (15.63 %)	74 (16.95 %)	113 (11.26 %)	4 (19.49 %)	215
1990 – 1999	24 (10.88 %)	68 (14.55 %)	114 (13.82 %)	4 (28.12 %)	210
2000 and later	24 (22.08 %)	84 (26.36 %)	111 (20.19 %)	4 (23.58 %)	223

Table 14 Number of unique 2000 and later dwellings (AHS 2021).

Dwelling Type	80+ % Rep. of 2000 and later Dwellings (# of Dwellings)	20+ % Rep. of the Full Dataset (# of Dwellings)
Apartment	17	16
Attached Dwelling	19	13
Detached Dwelling	16	30
Manufactured Dwelling	2	2
Total	54	61

Table 15 Number of unique 2000 and later dwellings (RECS 2020).

Dwelling Type	80+ % Rep. of 2000 and later Dwellings (# of Dwellings)	20+ % Rep. of the Full Dataset (# of Dwellings)
Apartment	11	15
Attached Dwelling	30	26
Detached Dwelling	21	86
Manufactured Dwelling	2	3
Total	64	130

3.2.2. Representation of Existing Suite of Dwellings

By evaluating the current AHS 2021 (AHS21) and RECS 2020 (RECS20) datasets with the same parameters (where possible) as was done with the RECS 1997 (REC97) dataset, the U.S. dwelling stock representation (% Rep.) and weight of the existing suite of dwellings can be updated (See Table 16 for a summary and Appendix B Dwelling Characteristics for Table 23, Table 24, Table 25, and Table 26 for a complete breakdown). Due to the changes in the U.S. dwelling stock since the 209 dwelling models were developed in 2006, the existing model set now represents 38.5 % of the AHS 2021 U.S. dwelling stock (detached dwellings: 37.7 %, attached dwellings:

27.5 %, apartments: 39.6 %, and manufactured dwellings: 49.1 %) and 44.1 % of the RECS 2020 U.S. dwelling stock (detached dwellings: 42.4 %, attached dwellings: 32.4 %, apartments: 50.2 %, and manufactured dwellings: 51.5 %). While a smaller collection of models might be preferred, our focus has been on the strategic addition of more recent models (*2000 and later*) to complement the original collection of dwelling models. By concentrating on dwellings built in *2000 and later*, we can better address the project's stated goals.

Table 16 Summary of the original RECS 1997 selected dwelling percent of representation.

Type of Dwelling	Sample Size	RECS97 % Rep.	AHS21 % Rep. ^a	RECS20 % Rep. ^b
Detached Dwelling	83	80.2	37.7	42.4
Attached Dwelling	53	80.2	27.5	32.4
Apartments	69	80.4	39.6	50.2 ^c
Manufactured Dwelling	4	80.4	49.1	51.5
Total	209	80.2	38.5	42.1

^a AHS21 does not have the number of other rooms variable as noted previously; as such, the mean number of rooms for a given Dwelling Number as shown in B.1 Original Dwelling Characteristics Update cannot be verified to match.

^b RECS20's mean number of rooms for a given Dwelling Number as shown in B.1 Original Dwelling Characteristics Update may not match the RECS97 survey.

^c The RECS 2020 database does not have a number (#) of floors variable for apartments as it did in the past. This means there was no way to directly compare the RECS 2020 data to the RECS 1997 data. The technique used to compute the number for Table 26 was as follows. The Dwelling Variables minus the *# of floors* variable were used to group survey responses. The resulting group of values was then broken out into the final values for this table using the AHS 2021 survey distribution. Example: APT-1 and APT-2 have the same Dwelling Variables, excluding the *# of floors*. The calculated row of values for the Number (#) of Dwellings (DWLG), Weight, and % representation for RECS 2020 was multiplied by the ratio of the AHS 2021 Weight for APT-1 (344 295) and APT-2 (190 458).

It's worth noting that in instances where only one or two models from a specific dwelling type have been used in previous research projects (see section 1.2, Usage of 2006 Collection of Dwellings), the most commonly used models were those with the highest single model representation. For the AHS 2021 datasets, the most common models would be those from the *2000 and later* year-built variable group. However, in the case of the RECS 2020 dataset, the *2000 and later* year built variable group may not always be the most common; nevertheless, they still rank among the top of the highest-representing models.

4. CONTAM Modeling Methodology

The original intent of this effort was to use a portion of the original suite of 209 dwelling models in the new collection of models. These original models were not updated for three reasons. First, the floor area category change accommodates the AHS and RECS datasets (i.e., numerical floor area values that fit into a given category). Second, the past CONTAM models are not built to scale (which is needed when coupled for energy modeling). Third, the changes in the average floor area, as discussed in 5.3 Floor Area, which was driven by both survey responses as well as changed to the floor area range categories of the surveys. Instead, the 209 original models are left as they are (other than correcting models with errors), and their representation/statistics and documentation are updated for the current database(s) (see section Appendix B Dwelling Characteristics for this information). The models that needed corrections are DH-6, DH-63, DH-77, and AH-27. DH-6 needed the model's exterior wall leakage corrected so that the normalized leakage area was 1.29 (dwelling built before 1940) instead of 0.65 (dwelling built 1970 - 1989). DH-63 needed floor leakage paths to be added between the first floor and the basement level, as well as a closed door between the basement and the first floor. DH-77 needed an open door added to bathroom 2, and AH-27 needed an open door added to bathroom 1.

This report describes and documents a 50 % U.S. representation with the most common dwellings from 2000 and later in the AHS database, constituting eighteen additional models (apartment: 6, attached: 6, detached: 5, & 1 manufactured dwellings). These models were selected because they represent a slight majority of their given variable range (apartment: 52.2 %, attached: 50.9 %, detached: 51.7 %, & manufactured dwellings: 56.5 %) for the AHS dataset and the original collection of dwelling is lacking homes from this time period. These 18 models also represent the variable range and models with the most significant representation value for the whole dataset (i.e., AHS detached [top 21 %]: <1960 [22 %] (3 dwellings), 1960-1969 [0 %] (0 dwellings), 1970-1979 [8 %] (1 dwelling), 1980-1989 [7 %] (1 dwelling), 1990-1999 [7 %] (1 dwelling), >2000 [55 %] (5 dwellings)). See the Tables in the sections B.2 AHS 2021 Dwelling Characteristics and B.3 RECS 2020 Dwelling Characteristics for the full breakdown of 50 % U.S. dwelling stock coverage. The eighteen additional models represent 42.3 % (apartment: 39.9 %, attached: 37.5 %, detached: 35.4 %, & manufactured dwellings: 56.5 %) of the *2000 and later* variable range in RECS 2020. In addition to the 18 new models, we intend to develop models to represent net-zero energy dwelling(s) in the future. The description and documentation of the 18 new models were done similarly to the previous study. Once the description of the eighteen new dwellings was completed, floor plans were developed, followed by the development of scaled CONTAM models.

5. Multizone Building Representations

Once the eighteen new dwellings were defined, floor plans were developed to create a multizone CONTAM model for each dwelling. The floor plans were drafted in Computer-Aided Design (CAD) software, and individual floor plans were plotted into a single Portable Document Format (PDF) file. These floor plans were based on the following variables from the AHS and RECS surveys: dwelling type, number of stories, floor area, year built, foundation type, garage, type of heating equipment, number of bedrooms, number of bathrooms, and number of other rooms. The total number of units in each building was also considered for apartment buildings. The discussion below explains how each variable was considered in developing the multizone representation. The floor plan names, as well as the dwelling's variable information and subsequent CONTAM multizone representation, can be found in Table 17.

Table 17 2000 and later 18 dwelling representation details and floor plans.

House Variables							AHS Data			RECS Data			Mean # of Rooms				A/C	Floor Plan ^a
# of Floors	# of Units	Floor Area	Year Built	Foundati ON	Garage	Forced Air	# of DWLG	Weight	% Rep.	# of DWLG	Weight	% Rep.	Bedroom	Full Bath	Half Bath	Other		
Detached Dwellings																		
1	n/a	2	6	1	2	2	1249	3 018 932	3.65	360	2 370 861	3.08	3	2	0	3	1	DH-A23 (1)
2	n/a	3	6	1	2	2	1079	2 190 347	2.65	214	1 429 143	1.85	4	3	0	5	1	DH-B23 (2)
2	n/a	3	6	3	2	2	674	1 803 856	2.18	253	1 275 713	1.66	4	3	0	5	1	DH_C23 (1)
2	n/a	2	6	1	2	2	675	1 534 536	1.86	140	926 219	1.20	3	2	1	3	1	DH-B23 (1)
1	n/a	3	6	1	2	2	462	986 486	1.19	113	720 269	0.93	4	3	0	4	1	DH-A23 (2)
Attached Dwellings																		
2	n/a	2	6	1	2	2	147	341 326	4.34	49	221 891	2.98	3	2	1	2	1	AH-B23 (2)
1	n/a	1	6	1	2	2	74	188 760	2.40	35	125 689	1.69	2	2	0	3	1	AH-A23 (1)
3	n/a	2	6	1	2	2	99	185 326	2.36	17	69 863	0.94	3	2	0	3	1	AH-C23 (1)
2	n/a	1	6	1	2	2	80	169 333	2.15	26	110 647	1.48	2	2	1	2	1	AH-A23 (2)
2	n/a	2	6	3	2	2	62	146 586	1.86	32	92 788	1.25	3	2	1	4	1	AH-C23 (2)
1	n/a	2	6	1	2	2	46	125 667	1.60	43	161 980	2.17	2	2	0	4	1	AH-B23 (1)
Manufactured Dwellings																		
n/a	n/a	1	6	n/a	n/a	2	376	1 030 052	14.42	130	843 098	12.34	3	2	0	2	1	MH-A23 (1)
Apartments ^b																		
3	5	1	6	n/a	n/a	2	722	1 143 120	3.65	n/a	n/a	n/a	1	1	0	2	1	APT-3A23 (10)
3	5	2	6	n/a	n/a	2	424	703 594	2.25	n/a	n/a	n/a	2	2	0	2	1	APT-3B23 (5)
3	3	2	6	n/a	n/a	2	230	594 062	1.90	n/a	n/a	n/a	2	2	0	2	1	APT-3B23 (3)
3	3	1	6	n/a	n/a	2	277	591 377	1.89	n/a	n/a	n/a	1	1	0	2	1	APT-3A23 (8)
3	4	2	6	n/a	n/a	2	233	565 690	1.81	n/a	n/a	n/a	2	2	0	2	1	APT-3B23 (4)
3	4	1	6	n/a	n/a	2	259	554 337	1.77	n/a	n/a	n/a	1	1	0	2	1	APT-3A23 (9)

^a Floor plans and floor plan numbers are based on similar floor plans from the original collection of dwellings.

^b The RECS 2020 database does not have a number (#) of floors variable for apartments as it did in the past. This means there was no way to directly compare the RECS and AHS data.

The key for Table 17:

of floors: 1 = 1 story; 2 = 2 story; 3 = 3 to 5 stories; 4 = 6+ stories

of units: 1 = 2 to 4 (modeled as 4); 2 = 5 to 9 (modeled as 6); 3 = 10 to 19 (modeled as 16); 4 = 20 to 49 (modeled as 32); 5 = 50+ units in building (modeled as 20 units per floor)

Detached and Attached Dwelling Floor Area: 1 = less than 139.3 m (1499 ft); 2 = 139.4 m to 232.2 m (1500 ft to 2499 ft); 3 = 232.1 m (2500 ft) or more

Manufactured Dwelling Floor area: 1 = less than 139.3 m² (1499 ft²); 2 = 139.4 m² (1500 ft²) or more

Apartment Floor area: 1 = less than 92.8 m² (999 ft²); 2 = 92.9 m² (1000 ft²) or more

Year Built: 1 = before 1960; 2 = 1960-69; 3 = 1970-79; 4 = 1980-89; 5 = 1990-99; 6 = 2000 and newer

Foundation: 1 = concrete slab; 2 = crawlspace; 3 = finished basement, 4 = Other

Garage: 1 = none; 2 = attached garage

Forced Air: 1 = other; 2 = central system present

of DWLG: number of dwellings in the survey data

Weight: weighting factor of the dwelling number for all U.S. dwellings for the survey data

% Rep.: percentage representation of each dwelling number in the survey

5.1. Type of Household

The household types used match those used in the previous NIST study, the AHS database, and the RECS database, which consists of detached, attached apartment buildings and manufactured dwellings. The detached and manufactured dwellings were modeled as free-standing structures exposed to the outdoor environment on all sides of the building. The attached dwellings were modeled as single townhouses with no leakage paths in the sidewalls between the adjoining units. This arrangement is consistent with an interior unit where the outdoor environment only interacts with the front and back walls, with no significant airflow or contaminant transport to or from the adjacent units. While having no leakage between adjacent units is not necessarily a reasonable assumption in all cases, it is a practical necessity given the lack of data describing the airtightness of such walls. Apartment buildings were modeled as entire buildings made up of identical apartment units, with leakage between units included.

5.2. Number of Stories

For the AHS 2021 database, all dwelling types are listed in the survey as 1, 2, 3, 4, 5, 6, and 7+ stories, whereas in the RECS 2020 database, only the attached and detached homes have the number of stories listed as 1, 2, 3, 4+, and split-level. As with the original study's models of split-level homes, it is necessary to include an extra level in the CONTAM model that is one-half story high. Each room is then modeled at its full height using phantom zones, a CONTAM feature that allows a zone to extend through multiple building levels. No split-level homes are among the additional models as they are not sufficiently representative of homes built in 2000 and later. If more dwellings are added in the future, then the split-level story type may need to be used. The RECS 2020 has no story information for apartments or manufactured homes. For all building types, one-story and two-story buildings were modeled as such. The 3 to 5-story dwellings were modeled as 4-story buildings. The 6+ story dwellings were modeled as ten-story buildings. All floors of multistory apartment buildings were modeled as identical, except for minor differences related to entrances on the first floors. All apartment buildings with four or more stories were modeled as having elevators, except for the six-story building, which only had one unit per floor. In the case of six-story buildings which only had one unit per floor, the buildings were modeled without elevators.

5.3. Floor Area

Floor area data for the 2021 AHS and 2020 RECS datasets are like the 1997 RECS dataset, with a small number of defined category ranges representing the survey response's floor area. Still, each of the three surveys has different floor area ranges. See Table 18, column number one for 1997 RECS floor area ranges, column two for 2021 AHS floor area ranges, and column three for 2020 RECS floor area ranges. The differences in the floor area ranges for the 2021 AHS and 2020 RECS, when compared to the floor area ranges from the 1997 RECS, mean a direct one-to-one comparison of the weighted floor areas is impossible. However, the percent change was

still calculated and can be found in Table 19, columns four and six for 2021 AHS and 2020 RECS, respectively. This calculation was done to help determine if a change to the weighted floor areas defined for the models was needed. Table 19 notes that the floor area category in Table 19 and Table 20 is different due to the change in the floor area ranges of the datasets.

The floor areas used for the model floor plans are calculated as the weighted average of the category ranges in the datasets that make up a floor area category for each dwelling type. A given category range is represented by the mean of the upper and lower bound for each floor area category (see Table 18 columns three and five for 2021 AHS and 2020 RECS, respectively). To match the methods used in the original report, categories with only an upper or lower bound were represented by values 10 % less than the upper bound and 10% greater than the lower bound. The resulting weighted average floor areas for AHS 2021 and RECS 2020 datasets can be seen in Table 19 columns three and five, respectively, and the percent change from the original study in columns four and six. The percent change of the floor area from the original research to the newer datasets shows that, in most cases, there has been a shift to larger dwellings in each floor area category. This increase in model floor area for a given dwelling type is even more notable because the ranges for floor area categories for attached dwellings, detached dwellings, and manufactured dwellings were shifted down to fit the current survey floor area ranges.

In addition to the defined categories for floor area, the 2020 RECS also contains a unique floor area value for each survey response. The weighted average for floor area was also calculated using these unique floor area values, see Table 20 column four. Using the unique floor area response allows for the use of the same floor area category ranges that were defined in the original project report (see Table 20 column two). Table 20's weighted average floor areas (column four) are more representative of the survey data since all dwellings in a category would not be considered the mean of the category, as was discussed above, and instead, the unique floor area from each survey response was used. While this method accurately represents the floor area of the given dwelling type and floor area category, it is not a one-to-one comparison to the original report's values. When the weighted average floor area is calculated for each category range with the unique floor areas for dwellings, the percent change for floor area shows an increase for all dwelling types other than the 92.9 m² (1000 ft²) or more apartments. There is a notable decrease in the 92.9 m² (1000 ft²) or more apartments.

For this project, the floor areas that were used for the *2000 and later* models are based on the 2021 AHS survey results (Table 19 column three). The 2021 AHS weighted floor area results were used for two reasons. First, the 2021 AHS survey comprises nearly 3.5 times as many responses as the 2020 RECS database. The second reason is that in the 2021 AHS database, the *2000 and later* year-built variable group possesses the highest number of individually representative dwellings (as discussed in Section 3.2.1 Year of Construction and 3.2.2 Representation of Existing Suite of Dwellings).

Table 18 Floor area ranges of the AHS and RECS datasets with the floor area used for the weight average floor area calculations.

RECS97 Floor Area Ranges m ² (ft ²)	AHS21 Floor Area Range m ² (ft ²)	Floor Area Used for AHS21 Range m ² (ft ²)	RECS20 Floor Area Ranges m ² (ft ²)	Floor Area Used for RECS20 Range m ² (ft ²)
Less than 55.7 (600)	Less than 46.5 (500)	41.8 (450.0)	Less than 55.7 (600)	50.2 (540.0)
55.7 to 92.8 (600 to 999)	46.5 to 69.6 (500 to 749)	58.0 (624.5)	55.7 to 74.2 (600 to 799)	65.0 (699.5)
92.9 to 148.6 (1000 to 1599)	69.7 to 92.8 (750 to 999)	81.2 (874.5)	74.3 to 92.8 (800 to 999)	83.5 (899.0)
148.6 to 185.7 (1600 to 1999)	92.9 to 139.3 (1000 to 1499)	116.1 (1249.5)	92.9 to 139.3 (1000 to 1499)	116.1 (1249.5)
185.8 to 222.9 (2000 to 2399)	139.4 to 185.7 (1500 to 1999)	162.5 (1749.5)	139.4 to 185.7 (1500 to 1999)	162.5 (1749.5)
222.9 to 278.6 (2400 to 2999)	185.8 to 232.2 (2000 to 2499)	209.0 (2249.5)	185.8 to 232.2 (2000 to 2499)	209.0 (2249.5)
278.7 (3000) or more	232.3 to 278.6 (2500 to 2999)	255.4 (2749.5)	232.3 to 278.6 (2500 to 2999)	255.4 (2749.5)
	278.7 to 371.5 (3000 to 3999)	325.1 (3499.5)	278.7 (3000) or more	(3300.0)
	371.6 (4000) or more	408.8 (4400.0)		

Table 19 Weighted average floor area by dwelling type and category for 2021 AHS and 2020 RECS.

Dwelling Type	Floor Area Category m ² (ft ²)	AHS21 Floor Area m ² (ft ²)	Change (%) ^b	RECS20 Floor Area m ² (ft ²)	Change (%) ^b
Apartment, 2-4 Units	Less than 92.9 (1000)	69.4 (747)	6.2 %	70.8 (762)	8.2 %
	92.9 (1000) or more	144.0 (1550)	1.3 %	131.2 (1412)	-7.7 %
Apartments, 5+ Units	Less than 92.9 (1000)	67.1 (722)	2.6 %	69.3 (746)	5.9 %
	92.9 (1000) or more	132.3 (1425)	1.8 %	126.2 (1359)	-2.9 %
Attached Dwelling ^a	Less than 139.4 (1500)	99.1 (1066)	2.9 %	102.9 (1119)	7.9 %
	139.4 to 232.3 (1500-2500)	177.2 (1907)	0.9 %	174.2 (1875)	-0.8 %
	232.3 (2500) or more	310.6 (3344)	18.9 %	278.9 (2999)	6.6 %
Detached Dwelling ^a	Less than 139.4 (1500)	105.2 (1132)	-1.7 %	107.2 (1154)	0.2 %
	139.4 to 232.3 (1500-2500)	181.9 (1958)	0.8 %	181.3 (1952)	0.5 %
	232.3 (2500) or more	312.9 (3368)	13.6 %	283.1 (3048)	2.8 %
Manufactured DWLG ^a	Less than 139.4 (1500)	92.8 (999)	7.5 %	95.1 (1024)	10.2 %
	139.4 (1500) or more	190.4 (2049)	N/A	178.5 (1822)	N/A

^a The floor area category ranges (column two) for these dwelling types were shifted to match the data distribution in the AHS databases.

^b The percent change is a comparison between the 1997 RECS original study's floor area categories (seen in Table 20 column two) and the floor area categories shown (column two).

Table 20 Weighted average floor area by dwelling type and category for 1997 RECS and 2020 RECS.

Dwelling Type	Floor Area Category m ² (ft ²)	RECS97 Floor Area m ² (ft ²)	RECS20 Floor Area m ² (ft ²)	Change (%)
Apartment, 2-4 Units	Less than 92.9 (1000)	65.4 (704)	68.3 (735)	4.5 %
	92.9 (1000) or more	142.1 (1530)	122.0 (1314)	-14.1 %
Apartments, 5+ Units	Less than 92.9 (1000)	65.4 (704)	67.4 (726)	3.1 %
	92.9 (1000) or more	130.0 (1399)	117.9 (1269)	-9.3 %
Attached Dwelling	Less than 148.5 (1600)	96.3 (1037)	105.9 (1140)	10.0 %
	148.5 to 222.9 (1600-2399)	175.6 (1891)	177.1 (1906)	0.9 %
	222.9 (2400) or more	261.3 (2813)	287.0 (3089)	9.8 %
Detached Dwelling	Less than 148.5 (1600)	107.0 (1152)	109.7 (1181)	2.6 %
	148.5 to 222.9 (1600-2399)	180.4 (1942)	181.4 (1953)	0.6 %
	222.9 (2400) or more	275.5 (2966)	313.8 (3377)	13.9 %
Manufactured DWLG	Less than 148.5 (1600)	86.3 (929)	96.7 (1041)	12.1 %
	148.5 (1600) or more	N/A	178.5 (1921)	N/A

5.4. Exterior Wall Leakage

The exterior wall leakage in the models is based on data from the references of the original study as well as the updates and additions to the ResDB that the Residential Building Systems (RBS) group at LBNL compiled [32, 30, 33–36, 31, 37, 38]. Currently, the ResDB contains exterior wall leakage data from about 147 000 dwellings and duct leakage data from 28 000 dwellings [38]. The exterior wall leakage, expressed as normalized leakage (NL), is defined in ResDB as a function of the dwelling’s floor area, ceiling height, year built, pre-weatherization for Weatherization Assistance Program (WAP) dwellings, energy efficiency rated dwellings⁴, climate zone, foundation type, and HVAC duct location. These NL calculations are described in Appendix C Exterior Leakage Values using LBNL Database and presented in Table 21. Appendix C documents how the LBNL database was used to estimate NL values for the new collection of dwellings and describes how users can modify these values.

Table 21 Normalized leakage by construction year and floor area.

Year Built	Floor Area Less Than 148.5 m ² (1600 ft ²)	Floor Area Between 148.5 to 222.9 m ² (1600 to 2399 ft ²)	Floor Area Greater Than 222.9 m ² (2400 ft ²)
Before 1960	1.19	1.02	0.79
1960 - 1969	0.99	0.85	0.66
1970 - 1979	0.97	0.83	0.65
1980 - 1989	0.79	0.68	0.53
1990 - 1999	0.61	0.52	0.41
2000 and later	0.53	0.45	0.35

The NL values from Table 21 are converted to effective leakage areas (ELA) using Eq. (1) [39–41], as the latter are used in the dwelling CONTAM models. The effective leakage area (ELA) divided by the surface area of a dwelling envelope yields a unique leakage area for each

⁴ Energy efficiency rated dwellings is a term used by the LBNL report. This calcification is used to identify a home that have participated in any type or version of an energy efficiency rating system. One of the most common of which is the ENERGY STAR program.

dwelling. For dwelling models that have an attached garage, the ELA of the exterior garage walls was set to be double that of the dwelling's exterior wall leakage. This was the same approach used in the original collection of dwelling models. See Section 5.6 for more information. The leakage area is the specified term for the *one-way flow using the powerlaw* model used for the airflow path in CONTAM.

$$NL = 1000 \left(\frac{ELA}{A_{floor}} \right) \left(\frac{H}{H_r} \right)^{0.4} \quad (1)$$

Where:

NL	=	normalized leakage
ELA	=	effective leakage area, m ² , using 4 Pa reference pressure (ft ²)
A_{floor}	=	floor area, m ² (ft ²)
H_r	=	reference height, 2.5 m (8.2 ft)
H	=	vertical distance from the lowest above-grade floor to the highest ceiling, m (ft)

5.5. Foundation Type

In the AHS and RECS databases, the foundations used are slab-on-grade (commonly called a concrete slab) foundations, crawlspace foundations, and basement foundations (both finished and unfinished). For this project, the attached and detached dwellings are classified using these three foundation types. For apartments, all dwellings are classified with slab-on-grade/concrete slabs, and all manufactured dwellings are classified with a crawlspace foundation.

5.5.1. Slab-on-grade Foundations

The dwelling models with a concrete slab-on-grade were modeled with no leakage paths to the outdoors through the floor. The first floor of the CONTAM model was modeled at ground level.

5.5.2. Crawlspace Foundations

The dwelling models with crawlspaces were modeled similarly to the past study, with a 0.9 m (3 ft) high crawlspace underneath the dwelling with ventilation openings to outdoors (ambient). Four total openings are used for each dwelling, located at the corners, and outdoor openings totaling 1/150 of the crawlspace floor area. The 1/150 floor area is consistent with the International Building Code (IBC) section 1202.4.1.1 on the ventilation area of crawlspaces with open earth floors [43]. The leakage between the crawlspace and the dwelling is the same as the exterior wall leakage per unit area for the dwelling, as defined in 5.4 Exterior Wall Leakage above.

5.5.3. Unfinished and Finished Basement Foundations

The dwelling models with basements are modeled with 2.4 m (8 ft) high spaces with the same footprint as the dwelling. Unfinished basements are modeled as unconditioned spaces and are closed off from the upper part of the dwelling with a closed door. If unfinished, they are

assumed to have leakage to the outdoors at the top 0.6 m (2 ft) of each wall and to the floor of the conditioned dwelling above. This leakage is the same as the exterior wall leakage for the exterior walls of the dwelling as defined in 5.4 Exterior Wall Leakage above.

Finished basements are modeled with an open staircase to the upper floors, and the leakage per area of the basement-dwelling interface is the same as the interior walls. Finished basements are modeled with leakage at the top 1.2 m (4 ft) of walls without doors to attached garages and with leakage on the entire 2.4 m (8 ft) of walls with garage doors. This leakage is the same as the exterior wall leakage of the dwelling, as defined in 5.4 Exterior Wall Leakage above.

5.6. Garage

Some original detached (68.7 %) and attached (43.4 %) dwellings have attached garages, whereas all the identified *2000 and later* detached and attached dwellings have attached garages. The attached garages are located beside or under a dwelling floor and are considered unconditioned spaces. Detached dwellings are modeled with a two-car garage, either 45.0 m² or 53.5 m² (484 ft² or 576 ft²) in size, depending on the house floor plan, attached to the home's first story. The attached homes are modeled with one or two-car garages, which are 35.7 m², 53.5 m², or 59.1 m² (384 ft², 576 ft², or 636 ft²) depending on the floor plan, on the lowest ground level story of the home. The modeled garage floor areas are consistent in size and placement with the past study. Garage exterior walls are modeled with leakage values two times that of the dwelling's exterior walls. This is based on two studies of the leakage between attached garages and living spaces of the dwellings [42, 44]. Unfortunately, limited research exists on the leakage rates of exterior garage walls or garage doors that can be used to inform the leakage rates in relation to the garage zone.

5.7. Number of Rooms

The AHS and RECS datasets include information on the number of rooms in each dwelling. For each unique dwelling definition, the percentage of dwellings with each number of the following room types was determined: bedrooms, bathrooms, half baths, and others. Since each unique dwelling definition is a combination of survey responses, a weighted average of the number of each room type for each of the unique dwelling definitions was calculated. The weighted average for each room type was rounded to the nearest whole number and used to define the modeling parameters. The tables in Appendix B summarize the number of rooms and other key modeling variables for the dwelling definitions. Note that tables for the original 209 dwellings (B.1 Original Dwelling Characteristics Update) had the number of rooms removed to fit the AHS 2021 and RECS 2020 surveys' representation values for the dwellings. When translating the number of rooms that are presented in the dwelling characteristics tables in Appendix B, residential building construction conventions were used to model floor plans.

Several of these conventions are as follows: The first full bathroom in a dwelling has access from the main living space. An additional half or full bathroom was modeled as a primary bathroom near the largest bedroom. When there are more than two full bathrooms in a

dwelling, one bathroom was modeled as a primary bathroom, the second full bathroom was located near additional bedrooms, and the following half or full bathroom was located with access from the main living space.

With the AHS and RECS datasets only defining room types as bedrooms, bathrooms, half baths, and others, the construction conventions used in the original study were utilized to determine the other room(s) type variable. The number of other rooms in the models varies from one to five. The naming convention for *other* rooms is as follows: the first other room is labeled as the *kitchen*, the second as the *living room*, the third as the *dining room*, the fourth as the *den*, and the fifth as *storage*. For the floor plans and CONTAM models, all rooms are defined spaces with walls and doorways (with or without doors) separating the spaces. This approach was done to enable the rooms to be specified separately in CONTAM. For contemporary dwellings, it is typical for the kitchen, living room, and dining room to be open spaces with no or limited physical separation. The large doorways between the kitchen, living room, and dining room enable users to model the spaces separately and change the opening area between them if they choose.

5.8. Attics

An unconditioned attic space was included for the attached, detached, and manufactured dwellings. An unconditioned attic space was also included in the models of one and two story apartment buildings with four units or fewer per building. The attic of the dwellings is modeled with vents to the outdoors, with a free area equal to 1/150 of the area of the attic. The 1/150 value is in line with the International Building Code (IBC) section 1202.2.1 ventilated attics and rafter spaces [43].

5.9. Doors

The effect of closed exterior doors on exterior wall leakage is included in the exterior wall leakage values discussed in section 5.4 Exterior Wall Leakage. Since the effect of closed exterior doors on the building envelope is included in the NL of the exterior wall, there is no need in most cases to include closed exterior doors in the models as was done in the original 2006 collection of dwellings. The closed door leakages that were included in the original collection were a single exterior door with an effective leakage area of 12 cm² (1.9 in²), a closed door connecting the garage and house (when a garage was present) with a leakage area of 21 cm² (3.3 in²), and a closed basement door (when an unfinished basement was present) also with a leakage area of 21 cm² (3.3 in²). The above effective air leakage areas are the “Best Estimated” values from Table 1 Effective Air Leakage Areas (Low-Rise Residential Applications Only) of the 2001 ASHRAE Fundamentals Handbook’s chapter Ventilation and Infiltration for single doors weather-stripped and not weather-stripped, respectively [45]. (The noted table was removed from the subsequent versions of the ASHRAE Fundamentals Handbook’s chapter, Ventilation and Infiltration). These door leakages could be removed from the original collection of dwellings to align with the updated collection of dwellings discussed in this report.

Doors are addressed in the updated collection of dwellings as follows. For attached, detached, and manufactured dwellings, as well as individual apartments in apartment buildings, open interior doors connecting interior zones conditioned in the same manner (including conditioned basements) are included. These open doors are modeled as a *one-opening, two-way flow* model with a cross sectional area equal to the fully opened door of its given size. This *one-opening, two-way flow* model is not the same model used for the original collection of dwellings' interior doors, the *one-way flow using powerlaw* model was used instead. The *one-way flow using powerlaw* model is more suited for small orifice leakage like would be present with a closed door, as such it would be recommended that modelers that used the original collection of dwellings could edit the open interior doors to align with the updated collection of dwellings discussed in this report. For apartment buildings, in addition to interior doors linking the interior zones of individual apartments, for apartment buildings that include elevators, the elevator doors are modeled with a leakage area of 226 cm² (35 in²). This effective leakage area is the average leakage from a study of eight multi-story buildings [46]. All closed door leakages discussed here and modeled in the collection of dwellings are only used to account for the effects of a closed door where not accounted for in the NL. Any closed door that needs to be opened will need to be scheduled in the model. For all models, modelers are responsible for adding other doors, i.e., exterior doors to be used with an opening and closing schedule, as needed for a project.

5.10. Windows

As mentioned in Section 5.9 Doors, the impact of closed windows on exterior wall leakage is accounted for in the exterior wall leakage values discussed in Section 5.4 Exterior Wall Leakage. Consequently, windows are not included in the dwelling models. Modelers can incorporate windows into their models and implement an appropriate opening and closing schedule if required for their project.

5.11. Number of Units

Like the previous study, the apartment buildings are assigned a number of units. Unlike in the past, the number of units is not stored similarly in the most recent RECS and AHS databases. In the past study, the RECS database and NIST modeling effort had a variable for the number of apartments in each apartment building with five categories: 2 to 4, 5 to 9, 10 to 19, 20 to 39, and 40+ units. The 2021 AHS database does report the number of units in a building; however, the categories' range is slightly different compared to the prior NIST study. The AHS 2021 category ranges for the number of units are 2 to 4, 5 to 9, 10 to 19, 20 to 49, and 50+. The *number of units* variable is no longer included in the publicly available RECS database. A data-sharing agreement was established between NIST and EIA to acquire the number of units in a building for the RECS respondents. However, as noted previously in this document, this data is not directly acquired from survey respondents but is generated from a USPS database based on the address of a survey respondent. The resulting number of units generated this way is a unique value for each survey response. These unique values were then used to assign the 2020

RECS survey responses into the 2 to 4, 5 to 9, 10 to 19, 20 to 49, and 50+ ranges that appear in the 2021 AHS database.

The defined values representing the number of units from the RECS database's frame file made it possible to calculate the average number of units for each home type category and the number of unit groups (see Table 22). Though using the average number of units with current data, as opposed to the past values assigned for each category, was possible, this was not done due to a lack of confidence as to the quality of the *number of units* variable. Based on further discussions with EIA, neither the home type nor the number of units are variables in which EIA has a high degree of confidence. This issue potentially becomes apparent when reviewing U.S. representation weight and percentage of weight for the 2 to 4-unit apartments. In the 2 to 4 units apartment home type group, only 49 % fall within that 2 to 4 units category (see Table 22).

Table 22 RECS 2020 number of units.

Home Type	# of Units Group	Avg. # of Units	# of Surveys	Weight (U.S. Rep.)	% Weight (Home Type)	% Weight (Whole Survey)
Manufactured Dwellings	1	1	774	5 184 977	75.9 %	4.2 %
	2 to 4	3	23	187 768	2.7 %	0.2 %
	5 to 9	9	5	45 259	0.7 %	0.0 %
	10 to 19	15	13	93 205	1.4 %	0.1 %
	20 to 49	33	32	238 767	3.5 %	0.2 %
	>50	210	127	1 082 522	15.8 %	0.9 %
Detached Dwellings	1	1	12 129	75 902 080	98.5 %	61.4 %
	2 to 4	2	168	1 061 710	1.4 %	0.9 %
	5 to 9	6	8	30 866	0.0 %	0.0 %
	10 to 19	11	4	14 916	0.0 %	0.0 %
	20 to 49	29	7	36 056	0.0 %	0.0 %
	>50	416	3	22 062	0.0 %	0.0 %
Attached Dwellings	1	1	1261	5 208 762	69.9 %	4.2 %
	2 to 4	3	266	1 228 422	16.5 %	1.0 %
	5 to 9	7	70	311 338	4.2 %	0.3 %
	10 to 19	13	44	217 245	2.9 %	0.2 %
	20 to 49	32	40	169 693	2.3 %	0.1 %
	>50	165	70	315 718	4.2 %	0.3 %
Apartment, 2-4 Units	1	1	160	1 273 176	13.6 %	1.0 %
	2 to 4	3	488	4 600 174	49.2 %	3.7 %
	5 to 9	7	111	1 048 790	11.2 %	0.8 %
	10 to 19	13	69	608 757	6.5 %	0.5 %
	20 to 49	32	54	534 288	5.7 %	0.4 %
	>50	199	131	1 276 610	13.7 %	1.0 %
Apartment, 5+ Units	1	1	137	1 062 834	4.7 %	0.9 %
	2 to 4	3	52	558 461	2.4 %	0.5 %
	5 to 9	7	308	2 961 126	13.0 %	2.4 %
	10 to 19	13	325	3 072 518	13.5 %	2.5 %
	20 to 49	32	488	4 520 955	19.8 %	3.7 %
	>50	191	1129	10 659 970	46.7 %	8.6 %

Generally, the >50 units category for this project is modeled as a building with 20 units per floor. The 20 to 49 category has 32 units; the 10 to 19 category has 16 units; the 5 to 9 category has six; and the 2 to 4 category has four. These values were selected to match the previous study and to provide conveniently divisible numbers of units, ensuring most buildings could be modeled with identical floors. In cases where this modeling convention was not possible, for example, in a four-story building with six total units, the building was modeled with two identical lower floors with two units each and two identical upper floors with one unit each.

5.12. Conditioned and unconditioned spaces

Every defined zone in the CONTAM models is classified as either a conditioned or unconditioned zone. In this project, attics, unfinished basements, crawlspaces, and garages are considered unconditioned zones. Within a CONTAM model, a designation of unconditioned

means that when the building air change rate is calculated, these zones and their associated volumes are not included in that calculation and are considered part of the ambient zone (outdoors). This approach means that only the conditioned zones are included in the building volume, and only outdoor air flows into and out of these conditioned zones. The outdoor air, in this case, includes air from both the outdoors and from the non-conditioned spaces with both being included in the outdoor air change rate calculation. For the apartment building models, corridors, stairs, and elevators are considered part of the conditioned space and designated as conditioned zones. All defined conditioned or unconditioned zones of the CONTAM models have the zone temperature set to be the same as the indoor temperature. This temperature value is user-changeable if desired.

5.13. Type of Heating Equipment

The dwelling definitions in the current and past studies had HVAC equipment classifications. These classifications are either a central system, which signifies a central forced air distribution system, or *other*, which is assumed not to include forced air fans or outdoor air ventilation. The latter are not included in the airflow models as they would alter the temperature in a zone without altering the zone pressure. A simple air-handling system (AHS) is modeled for dwellings with central systems with a balanced supply and return airflows of $5 \text{ L/s} \cdot \text{m}^2$ (1 cfm/ft^2) of floor area. The $5 \text{ L/s} \cdot \text{m}^2$ (1 cfm/ft^2) airflow rate is based on the standard rule of thumb estimates for schematic design [47–49] as well as being $1.25 \text{ L/s} \cdot \text{m}^2$ (0.25 cfm/ft^2) over the ASHRAE airflow estimates for schematic design minimum value of $3.75 \text{ L/s} \cdot \text{m}^2$ (0.75 cfm/ft^2) air supply for interior spaces [50]. This airflow rate of $5 \text{ L/s} \cdot \text{m}^2$ (1 cfm/ft^2) has been reduced from the original study's $6.1 \text{ L/s} \cdot \text{m}^2$ (1.2 cfm/ft^2) of floor area to reduce the potential of over-ventilating spaces. The typical 54 L/s per kW (400 cfm/ton) air supply for all-air systems that ASHRAE estimates for schematic designs was not utilized due to the need to first calculate a thermal design load, which would differ based on the climate region, number of occupants, dwelling square footage, ceiling height, insulation, windows, and external walls [48, 50]. Utilizing a varied thermal design load would necessitate a drastic increase in the number of models required for the collection of dwellings. No outdoor air ventilation was added to any of the single-family building models. Outdoor air ventilation was not included in the dwelling models because many states and localities within the United States have not adopted an outdoor air ventilation requirement into their building codes. Some U.S. states currently have outdoor air ventilation requirements for new construction, but most contemporary models for this study are made up of dwellings from *2000 and later*. There were even fewer states with an outdoor air ventilation requirement in 2000.

5.13.1. Air-Handling System (AHS) Duct leakage for Detached, Attached, and Manufactured Dwellings

Depending on the features of a given dwelling, duct leakage was added to the CONTAM models. Since the CONTAM models utilize a simple air-handling system (AHS) instead of a

detailed duct system, the modeled duct leakage is only the duct leakage to the outdoor (ambient) environment. While total duct leakage (duct leakage to both the indoor and outdoor environment on both the supply and return side of the system) influences dwelling energy usage, duct leakage to and from the outdoors influences the pressure difference and, in turn, the airflow between the dwelling and the outdoors. The outdoor duct leakage was achieved by adding a supply and/ or return register to a given zone that is not included in the CONTAM conditioned building volume and depends on the features of a given dwelling. The original NIST collection of dwellings assumed that dwellings with unconditioned basements had return duct leakage that was 10 % of the total AHS flow and dwellings with a crawlspace or a slab-on-grade foundation had a supply duct leakage of 10 % of the AHS flow. Dwellings with a garage had a return duct leakage of 10 % of the AHS flow. These values gave dwellings with HVAC systems between 10 % and 20 % duct leakage to the outside, depending on the features of the dwelling.

5.13.1.1. Modeled Outdoor Duct Leakage Locations

The duct leakage assumptions were changed from the original NIST collection of dwellings for location-based leakage and the leakage amounts. For dwellings with basements, it was assumed that a portion of the dwelling's HVAC system is in the basement. If the basement for a dwelling is unconditioned, then the duct leakage in the zone would be outdoor duct leakage. No duct leakage (supply or return) was added for dwellings with conditioned basements due to the widespread practice of placing ductwork in the floor plenum between the basement and the first floor. In this case, all duct leakage would be entering conditioned space(s) and, therefore, unable to leak outside the dwelling envelope. For dwellings with slab-on-grade foundations, the HVAC system was modeled with leakage in the attic due to portions of the HVAC system being in the attic. The HVAC system was also modeled with leakage in the attic for dwellings with a crawlspace foundation, other than manufactured dwellings. For manufactured dwellings with a crawlspace foundation, the HVAC system was modeled with leakage in the crawlspace due to portions of the HVAC system being in the crawlspace. When a dwelling model has a garage, it was assumed that some of the HVAC systems are located in the garage; in that case, 25 % of the system's (supply and return) leakage was modeled in the garage.

5.13.1.2. Duct Leakage Research Studies and Standards

Duct leakage amounts for residential dwellings, though becoming an area of greater interest as codes and standards related to them have become more prevalent, have a high degree of variation based on in-situ testing. There are an ever-growing number of ways in which building scientists, researchers, and consultants evaluate the leakage of both the building envelope and HVAC duct systems. These test methods include but are not limited to blower door or duct blaster pressurization, depressurization, or both methods, with varying requirements depending on the test standard, the DeltaQ method, the Zone DeltaP method, and the tracer gas method. All the different test methods have their advantages and disadvantages. A study from 2005 indicated that between 10 % and 30 % of the total duct flow of an HVAC system escapes from the ductwork [51]. A report from 2008 stated that existing residential HVAC systems typically lose 40 % of the total air supply due to duct leakage, though this was based on

a review of papers from the early to late 1990s [52]. An article from 2014 and revised in 2015 reported tests of thirty residential dwellings with ten each in Champaign, IL, Minneapolis, MN, and Atlanta, GA, and found an average total duct leakage of 121 % of blower fan flow at 25 Pa, 48 % of which was leakage to the outside environment [53]. What is meant by 121 % of blower fan flow is that when the duct system is sealed at the diffusers and the duct system is pressurized with a duct pressurization system, the flow required from the duct pressurization system to maintain 25 Pa was 121 % of the flow that the HVAC systems blower fan is capable of supplying. The average found for each city varied quite a bit, with the duct leakage from the ten dwellings in Champaign, IL, being 72 % total and 56 % outdoors, Minneapolis, MN, being 110 % of total and 9 % outdoors, and Atlanta, GA, being 181 % total and 80 % to outdoors. Note that the age of the dwellings was not given in the report, as the focus was on the repeatability of the test methods. Five of the HVAC systems achieved less than 6 % leakage to the outside during a pressurization test. Twelve of the HVAC systems achieved less than 6 % leakage, including four of the five systems previously noted, during duct testing under the DeltaQ method. These twelve HVAC systems had an average total pressurized leakage of 91 % of blower flow and 14 % of leakage to outside. California State University at Chico (CSUC) and LBNL completed a program of field testing over 100 duct systems in California that were between 5 and 20 years old at the time (2002) and found that some duct systems were so leaky that they were unable to pressurize the systems to 25 Pa as required by the test procedure [54, 55]. This left the CSUC project with results from 87 of the 110 dwellings to be analyzed, and from these dwellings, they found that average duct leakage to the outside was 20 % (11 % supply and 9 % return); this was not total duct leakage but only the leakage to the outdoor environment. A California Energy Commission (CEC) 2009 report examined 108 new single-family detached dwellings and found that 86 % had duct leakage that exceeded the California Title 24 maximum of 6 % total duct leakage [56]. The median duct leakage for the 108 dwellings was 10 % and ranged from 1.9 % to 73 % of blower fan flow. A 2017 study presented the results of the first 16 dwellings of their 70 planned California dwellings built from 2002 through 2004. These dwellings were measured from 2005 through 2007 and found that the mean duct leakage was 8 % of blower fan flow, ranging from 1.5 % to 38 % [57]. Only 13 of the 16 dwellings had valid duct leakage tests, 9 of which met the maximum allowable 6 % duct leakage. The mean duct leakage is much higher due to the single 38 % duct leakage outlier.

In the early 2000s, more progressive standards related to the total acceptable duct leakage were put in place, though these standards were not implemented in all states simultaneously, if at all. There was no mention of duct leakage in the ASHRAE Standard 62-2001 Ventilation and Acceptable Indoor Air Quality nor its later addendum [58, 59]. Following the publication of ASHRAE Standard 62.2 Ventilation and Acceptable Indoor Air Quality in Residential Buildings in 2004, there were criteria for low duct leakage [60]. ASHRAE-compliant HVAC systems (sometimes referred to as "low leakage") are defined as systems with total air leakage that is less than 6 % of the blower fan flow. These low leakage duct system requirements were also included in the California Energy Commission's AB970 energy code in 1998 [54] which made its way into the 2005 California Energy Code [61]. The 2014 study noted above examined thirty residential dwellings in Champaign, IL, Minneapolis, MN, and Atlanta, GA. The initial goal of that

study was to focus on the repeatability of different test methods on systems that met the low leakage standards (less than 6 % total leakage of blower fan flow during pressurization testing), but they found that no duct systems met the 6 % total leakage requirement; instead, the group pivoted to evaluating the repeatability of test methods on systems that leaked 6% or less to the outdoors during pressurization testing [53].

5.13.1.3. Modeled Duct Leakage Amounts

For this project, the amount of leakage to the outdoors was assumed to be related to the age of the dwelling. For dwellings built before 2000, the outdoor duct leakage should be updated in the original models to be 13 % supply leakage and 7 % return leakage to the outdoors. This update was not completed as part of this report and is only a recommendation if models from the original 2006 collection of dwellings are used. For dwellings built after 2000, the outdoor duct leakage was set to 5 % supply leakage and 3 % return leakage to the outdoors. These values would make the models more aligned with the research reviewed above. In the future, if the *2000 and later* dwelling group is categorized with more detailed resolution (which would also depend on the LBNL ResDB NL model being updated), the duct leakage values could be updated as the prevalence of dwellings that have HVAC systems that perform to code standards would increase. For a net-zero (future) dwelling, the duct leakage outdoors would be set to zero, as it is standard practice in dwellings of that kind to have the HVAC duct system completely within the dwelling's envelope.

5.13.2. Modeled Air-Handling Systems (AHS) for Apartment Building

In the previous study (existing collection of dwellings), the large apartment buildings (32 units and greater) with central HVAC systems, the buildings were modeled with simple air handling systems that supply the apartments with balanced supply and return airflows of $6.1 \text{ L/s} \cdot \text{m}^2$ (1.2 cfm/ft^2) of floor area and no outdoor air or duct leakage. The air handling systems for the large apartment building were shared, with all units on a given floor sharing the same system. Per the original study, large apartment buildings were only part of the first three *Year Built* categories (of the original research) (<1940, 1940-1969, and 1970-1989), meaning that no apartment was newer than 1989. In the current AHS and RECS data, there is no need or recommendation to add apartment dwelling models from the 1990-1999 *Year Built* categories as they have meager representation in the surveys. The previous study's apartment buildings were also modeled with kitchen and bathroom exhaust fans in addition to the HVAC system(s) that remove 47 L/s (100 cfm) per kitchen and 22 L/s (50 cfm) per bathroom. These exhaust systems were modeled using single simple air handling units with only returns to the given apartment building locations; these returns are scheduled as "off" in the models but can be scheduled to operate as desired. The make-up air for these exhaust systems was achieved by building and/ or corridor leakage. For the apartments with corridors, the corridors have 100 % outdoor air systems that supply 21 L/s (45 cfm) per apartment unit serviced from the corridor. The corridor airflow is used to help maintain the pressurization of the building and provide make-up air for the kitchen and bathroom exhaust systems within the units. This method of

ventilating apartment buildings is not practical for the 2000 and later dwelling models due to explicit standards that are part of the International Code Council's (ICC) 2012 International Fire Code (IFC) [62] and unit compartmentalization standards as part of ASHRAE 62.2-2007 [63].

For this project, all 2000s and later *Year Built* apartment buildings are modeled with a simple air handling system dedicated to each unit. Like the other dwelling types, the simple air-handling system (AHS) for an apartment was modeled with a balanced supply and return airflows of $5 \text{ L/s} \cdot \text{m}^2$ (1 cfm/ft^2) of unit floor area as discussed above and is based on common rule of thumb estimates for schematic design [47–49]. A balanced AHS is also used for all the shared apartment corridors, with matching $5 \text{ L/s} \cdot \text{m}^2$ (1 cfm/ft^2) of airflow per corridor floor area. The previous study's models would be improved by updating their AHS's to $5 \text{ L/s} \cdot \text{m}^2$ (1 cfm/ft^2) of unit floor area. This update was not completed as part of this report and is only a recommendation when models from the 2006 collection of dwellings are used in the future.

5.13.2.1. Compartmentalization

Compartmentalization in dwellings refers to the separation(s) between different spaces within a building, including a separation between different living or occupied spaces and interstitial spaces like framing cavities and shafts, as well as from other living or occupied spaces.

Compartmentalization in apartment buildings is important for controlling the flow of odors, air, smoke, airborne contaminants, and pests between units and adjoining spaces within the building. The concept of compartmentalization dates back to the Empire State Building during the Great Depression and was described in Handegord's 2001 conference proceeding "A New Approach to Ventilation of High Rise Apartments." [64, 65]. Lstiburek, in "Multifamily Buildings: Controlling Stack Effect-Driven Airflows," proposed a series of performance metrics that were later adopted into ASHRAE Standard 189.1-2009 [66], with aspects also being included in ASHRAE 62.2-2007 [63]. Comparable performance metrics were later adopted by both the 2012 International Code Council's International Energy Conservation Code [67] and the 2010 U.S. Green Building Council's LEED for Homes Rating System Multifamily Mid-Rise [68]. The performance metrics were then improved and tightened in the ASHRAE Standard 62.2-2013 [69] and have remained relatively unchanged to the present. There are also similar Compartmentalization requirements in the International Code Council's (ICC) 2012 International Fire Code (IFC) [62] as well as in the National Fire Protection Association (NFPA) codes and standards (namely codes 92, 101, and 105) [70, 71]. This means, like the duct leakage above, it is challenging to select a single compartmentalization value for the *Year Built* category of *2000 and later* as different standards existed for buildings built from 2000-2010 compared to buildings constructed during the later 2010s.

Field studies of existing low-rise multifamily dwelling buildings have been shown to have a typical compartmentalization leakage rate of $\approx 5.1 \text{ L/s} \cdot \text{m}^2$ (1.0 cfm/ft^2) at 50 Pa with current practice (building code compliant) rates being around a third of that (1.5 L/s per m^2 (0.3 cfm per ft^2) at 50 Pa) [72–75]. In the previous study, the compartmentalization leakage rates were the same as the exterior Normalized Leakage (NL) rate. This past leakage

assumption resulted in variation based on the year and size of the dwellings. The authors recommend that the apartment models for the *Year Built* categories before 2000 be updated with the compartmentalization leakage rate of 5.1 L/s • m² (1.0 cfm/ft²) at 50 Pa. The compartmentalization leakage rate for the 2000 and later models is set to 2.55 L/s per m² (0.5 cfm/ft²) at 50 Pa. This value was chosen because most of the dwellings were built after a time in which the dwellings should conform to the current practice leakage rate of 1.5 L/s per m² (0.3 cfm/ft²) at 50 Pa, while also factoring in those *2000 and later Year Built* dwellings constructed prior to the implementation of the current practice and reports that the ASHRAE Standard 62.2-2013 requirement was difficult to meet when it was implemented [64].

5.13.2.2. Ventilation

Ventilation in residential dwellings is used to control indoor air quality by diluting and displacing indoor-generated pollutants with outdoor air. The amount or rate at which outdoor air is recommended or required to be supplied to dwellings has been an aspect of building design that has changed as building airtightness and indoor and outdoor contaminant generation have changed. The codes that influence building ventilation for a given U.S. state are developed from the implementation of the International Code Council (ICC) [76], the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) [77], and the National Fire Protection Association (NFPA) [78] codes and standards. Like most of the other concepts discussed above, these codes have changed over the years. The ventilation codes that were in effect in the U.S. at the start of the 2000s are different than they are today and vary throughout the country. For this project, we used a blend of current practice(s) and what was prevalent during the last twenty years for the *2000 and later Year Built* category of apartments.

For the apartment common corridors, a dedicated supply outdoor air rate of 0.3 L/s per m² (0.06 cfm/ft²) through a central system was used. This outdoor air rate is from the ASHRAE 62.1-2022 minimum ventilation rate in the breathing zone table for common corridors in the residential occupancy category [79]. Dwelling unit ventilation was defined by ASHRAE 62.2 total ventilation rate in section 4.1.1 [80].

$$Q_{tot} = 0.03A_{floor} + 7.5(N_{br} + 1)$$

Where:

Q_{tot} = total required ventilation rate, cfm

A_{floor} = dwelling-unit floor area, ft²

N_{br} = number of bedrooms (not to be less than 1),

and when evaluated using SI units,

$$Q_{tot} = 0.15A_{floor} + 3.5(N_{br} + 1)$$

Where:

Q_{tot} = total required ventilation rate, L/s

A_{floor} = dwelling-unit floor area, m²

N_{br} = number of bedrooms (not to be less than 1).

A continuous bathroom exhaust central shaft system is capable of providing this level of ventilation. This style of ventilation system, however, is not used to meet the current building codes of some progressive U.S. states, but it was in common practice into the 2010s in these states and is still used in many other states [81–85]. The continuous bathroom exhaust central shaft system was modeled as a single simple air handling unit with only returns; these returns are scheduled as “on” in the model.

5.13.3. Modeled Air-Handler System (AHS) Volumes

The air-handler system (AHS) volumes were calculated in the following way. For each air handling system, the supply ducts are assumed to be 20 cm (8 in.) in diameter and to be twice the length of the longest dimension of the dwelling, building, or apartment unit. The return duct volume of each air handling system is calculated assuming its ductwork is 20 cm (8 in.) in diameter and only half the length of the longest dimension of the dwelling, building, or apartment unit.

5.14. Exhaust fan(s)

All dwellings are modeled with kitchen and bathroom exhaust fans that remove 47 L/s (100 cfm) per kitchen and 24 L/s (50 cfm) per bathroom. For apartment buildings, these exhausts are modeled using a single simple air handling unit (per building) with only returns; these returns are scheduled as “off” in the model but can be scheduled to operate if desired. For all other dwelling types, these exhausts are modeled using a constant mass flow fan airflow element; these fan flow elements are also scheduled as “off” in the model but can be scheduled to operate if desired. This approach was used for kitchen and bath fan usage and is intermittent and very occupant-dependent in most cases.

6. CONTAM Project Files

The CONTAM project files for the original 209 dwelling and their associated floor plans are available for download at the NIST Multizone modeling [CONTAM website](#) under the [A Collection of Homes Representing U.S. Housing Stock Case Study](#) page. These original dwellings are summarized in Appendix B.1 Original Dwelling Characteristics Update. The tables identify the corresponding project file name, associated floor plan, and current U.S. dwelling stock representation (AHS and RECS). The CONTAM project files for the 2000 and later home category identified and documented in this update, along with their associated floor plans, are available for download at [A Collection of Dwellings to Represent the U.S. Housing Stock Case Study](#) page.

7. Summary and Discussion

This report describes an update to the 2006 NIST collection of dwellings, which was developed to allow analyses of ventilation and IAQ issues in residential buildings using documented building models that represented 80 % of the U.S. housing stock as of 1997. The motivation for updating the original collection of dwelling models was to add a representation of more current-period dwellings. The report lays out the framework used for the development of a new collection of dwellings. The significant additions include a complete analysis of the current 2020 RECS and 2021 AHS databases for the development of a new national collection of dwellings, a framework/plan for a new collection of dwellings that could be developed with additional resources, and the development of 18 new CONTAM models that will be added to the 2006 collection of dwellings to represent dwellings built after the year 2000. This update is available for researchers and others to conduct nationwide analyses and risk assessments of residential ventilation and IAQ issues and coupled energy IAQ-related issues for dwellings built after 2000.

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Appendix A. Selected Bibliography

This section documents all known citations for 65 (66⁵) works citing the report, which are listed below. This bibliography below does not list the citations of reference [86] (Persily A, Musser A, Emmerich SJ (2010) Modeled infiltration rate distributions for U.S. housing. *Indoor Air* 20(6):473–485), which is known to be cited 154 times.

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⁶ The last citation was not included in this report's analysis of the usage of the original collection of dwellings discussed in Section 1.2, Usage of 2006 Collection of Dwellings, as the document was published during the final review process of this report.

Appendix B. Dwelling Characteristics

B.1. Original Dwelling Characteristics Update

This section contains four tables that define the 209 dwellings from the original 2006 report, with one table for each dwelling type: detached (Table 23), attached (Table 24), manufactured dwelling (Table 25), and apartment (Table 26). The dwelling model with the highest representation for each of the AHS 2021 and RECS 2020 is identified with a superscript a and b for each respective database. The dwelling definitions in the table are in terms of the variables discussed in the body of the original report and this document (note: the mean number of rooms value of the original tables has been removed for space). Other information related to the dwelling models, including the number of dwellings and weight in the RECS 1997 survey represented by the model and the floor plan code for that dwelling, the number of dwellings, weight, and % or representation in the AHS 2021 and RECS 2020 survey represented by the model, are also listed in the tables.

Table 23 RECS 1997 modeling details updated – Detached Dwellings (83 total).

DWLG Number	# of Floors	Dwelling Variable					RECS 1997 Data		Floor Plan	AHS 2021 Data			RECS 2020 Data		
		Floor Area	Year Built	Found-ation	Garage	Forced Air	# of DWLG	Weight		# of DWLG	Weight	% Rep.	# of DWLG	Weight	% Rep.
DH-1	1	2	3	1	2	2	109	2185179	DH-B(1)	613	1400324	1.69	234	1730712	2.25
DH-2	1	1	2	3	2	2	111	1930684	DH-A(8)	52	134218	0.16	165	1095128	1.45
DH-3	1	1	2	2	1	1	114	1730307	DH-A(1)	177	527976	0.64	107	783559	1.02
DH-4	1	1	2	2	2	2	83	1491818	DH-A(7)	810	2059814	2.49	97	817618	1.06
DH-5	1	1	3	1	2	2	65	1306058	DH-A(2)	407	975017	1.18	113	975007	1.27
DH-6	2	1	1	3	2	2	66	1140420	DH-D(3)	73	192319	0.23	N/A	N/A	N/A
DH-7	1	2	2	3	2	2	61	1107980	DH-B(5)	35	106580	0.13	129	779738	1.01
DH-8	1	1	2	1	2	2	56	1029268	DH-A(2)	1059	2215133	2.68	65	552823	0.72
DH-9	2	1	2	3	2	2	53	1022407	DH-D(3)	570	1570428	1.90	44	256946	0.33
DH-10	2	2	3	3	2	2	55	1016922	DH-E(8)	224	627547	0.76	138	771517	1.00
DH-11	1	1	2	2	2	1	57	1016685	DH-A(7)	265	645247	0.78	43	347994	0.45
DH-12	2	3	3	3	2	2	59	1013802	DH-F(4)	106	305894	0.37	116	574486	0.75
DH-13	1	2	2	2	2	2	56	997221	DH-B(1)	627	1689006	2.04	96	780487	1.01

DWLG Number	# of Floors	Dwelling Variable					RECS 1997 Data		Floor Plan	AHS 2021 Data			RECS 2020 Data		
		Floor Area	Year Built	Found-ation	Garage	Forced Air	# of DWLG	Weight		# of DWLG	Weight	% Rep.	# of DWLG	Weight	% Rep.
DH-14	2	2	1	3	2	2	55	970354	DH-E(5)	72	173516	0.21	N/A	N/A	N/A
DH-15	2	3	4	3	2	2	36	947526	DH-F(5)	135	435299	0.53	129	778514	1.01
DH-16	1	1	2	2	1	2	56	838556	DH-A(7)	326	883924	1.07	253	191127	2.48
DH-17	2	2	2	3	2	2	43	803384	DH-E(6)	539	1576919	1.91	98	587555	0.76
DH-18	2	1	1	3	1	2	45	742844	DH-D(3)	68	160631	0.19	N/A	N/A	N/A
DH-19	1	1	3	3	2	2	40	727963	DH-A(8)	14	42412	0.05	95	499515	0.65
DH-20	2	2	1	3	2	1	39	720815	DH-E(7)	20	61194	0.07	N/A	N/A	N/A
DH-21	1	1	2	1	1	2	47	708504	DH-A(7)	337	765524	0.93	101	775848	1.01
DH-22	2	3	3	1	2	2	27	690163	DH-F(1)	104	225497	0.27	61	419740	0.54
DH-23	2	1	1	3	2	1	44	684661	DH-D(3)	25	74213	0.09	N/A	N/A	N/A
DH-24	2	2	3	1	2	2	31	645193	DH-E(3)	149	318239	0.39	93	669157	0.87
DH-25	1	1	2	3	2	1	45	642330	DH-A(8)	12	40112	0.05	34	198320	0.26
DH-26	1	1	2	1	1	1	39	635246	DH-A(1)	138	336535	0.41	39	334141	0.43
DH-27 ^b	1	1	2	3	1	2	38	601468	DH-A(8)	17	32837	0.04	312	2164564	2.81
DH-28	2	3	4	1	2	2	19	580448	DH-F(2)	334	594226	0.72	74	570810	0.74
DH-29	1	1	1	2	1	1	39	574063	DH-A(3)	75	216239	0.26	N/A	N/A	N/A
DH-30	1	2	3	2	2	2	31	571692	DH-B(1)	209	640745	0.78	71	439917	0.57
DH-31	1	1	3	2	2	2	32	565329	DH-A(2)	188	584012	0.71	55	364260	0.47
DH-32	1	1	4	1	2	2	20	552255	DH-A(6)	247	581955	0.70	48	421165	0.55
DH-33	1	3	3	1	2	2	27	549619	DH-C(1)	112	254973	0.31	44	360474	0.47
DH-34	1	1	3	1	1	2	31	524933	DH-A(7)	88	186868	0.23	80	645090	0.84
DH-35 ^a	1	2	2	1	2	2	29	520116	DH-B(1)	1233	2577732	3.12	85	729765	0.95
DH-36	2	2	4	1	2	2	20	519749	DH-E(3)	295	604392	0.73	52	406361	0.53
DH-37	1	2	3	3	2	2	27	511492	DH-B(4)	8	19510	0.02	134	645137	0.84
DH-38	1	1	3	2	1	2	30	497620	DH-A(7)	69	216582	0.26	70	445855	0.58
DH-39	1	2	2	2	1	2	30	469257	DH-B(1)	109	343954	0.42	96	744428	0.97
DH-40	2	2	3	2	2	2	22	447207	DH-E(3)	83	213463	0.26	53	308300	0.40

DWLG Number	# of Floors	Dwelling Variable					RECS 1997 Data		Floor Plan	AHS 2021 Data			RECS 2020 Data		
		Floor Area	Year Built	Found-ation	Garage	Forced Air	# of DWLG	Weight		# of DWLG	Weight	% Rep.	# of DWLG	Weight	% Rep.
DH-41	2	2	1	3	1	2	32	446950	DH-E(1)	25	52901	0.06	N/A	N/A	N/A
DH-42	1	1	3	2	1	1	27	442268	DH-A(4)	28	95806	0.12	44	249062	0.32
DH-43	2	2	2	3	2	1	26	410024	DH-E(2)	121	372734	0.45	54	295276	0.38
DH-44	1	1	1	3	2	2	26	409001	DH-A(9)	10	25887	0.03	N/A	N/A	N/A
DH-45	2	2	3	4	2	1	30	398786	DH-E(3)	21	65877	0.08	29	126768	0.16
DH-46	1	1	2	1	2	1	24	380772	DH-A(1)	247	564912	0.68	23	198380	0.26
DH-47	1	1	3	2	2	1	25	376507	DH-A(7)	52	157494	0.19	18	103263	0.13
DH-48	1	1	4	2	1	2	17	368757	DH-A(2)	40	125561	0.15	26	172403	0.22
DH-49	1	1	2	3	1	1	26	361389	DH-A(8)	10	23150	0.03	46	275840	0.36
DH-50	2	1	1	3	1	1	23	351778	DH-D(3)	19	43907	0.05	N/A	N/A	N/A
DH-51	2	3	3	2	2	2	19	348213	DH-F(3)	62	158941	0.19	40	233423	0.30
DH-52	2	3	1	4	2	2	22	347787	DH-F(3)	9	18643	0.02	N/A	N/A	N/A
DH-53	1	2	3	1	1	2	18	327779	DH-B(1)	69	178512	0.22	61	465676	0.60
DH-54	1	1	1	2	1	2	19	323291	DH-A(3)	84	195031	0.24	N/A	N/A	N/A
DH-55	1	1	4	2	2	2	14	320900	DH-A(6)	66	219787	0.27	29	162220	0.21
DH-56	2	1	2	3	1	2	21	314026	DH-D(3)	119	254213	0.31	183	1298533	1.68
DH-57	1	2	2	2	2	1	18	309112	DH-B(3)	93	270148	0.33	12	74587	0.10
DH-58	2	2	4	3	2	2	17	299726	DH-E(6)	146	435323	0.53	89	619884	0.80
DH-59	2	3	2	3	2	1	17	293015	DH-F(4)	59	153739	0.19	25	176523	0.23
DH-60	1	1	3	4	2	1	18	285825	DH-A(7)	5	18726	0.02	9	49037	0.06
DH-61	1	1	1	4	1	2	17	285549	DH-A(1)	11	28531	0.03	N/A	N/A	N/A
DH-62	2	3	1	3	2	1	18	283742	DH-F(4)	4	5565	0.01	N/A	N/A	N/A
DH-63	2	1	2	4	2	1	23	282152	DH-D(4)	16	42714	0.05	13	85168	0.11
DH-64	1	2	4	1	2	2	13	276193	DH-B(1)	546	1223836	1.48	144	1204034	1.56
DH-65	1	1	1	4	1	1	20	273431	DH-A(3)	19	47082	0.06	N/A	N/A	N/A
DH-66	1	2	2	1	2	1	17	273259	DH-B(2)	114	254537	0.31	27	185878	0.24
DH-67	1	1	1	2	2	2	13	270968	DH-A(7)	132	334026	0.40	N/A	N/A	N/A

DWLG Number	# of Floors	Dwelling Variable					RECS 1997 Data		Floor Plan	AHS 2021 Data			RECS 2020 Data		
		Floor Area	Year Built	Found-ation	Garage	Forced Air	# of DWLG	Weight		# of DWLG	Weight	% Rep.	# of DWLG	Weight	% Rep.
DH-68	2	1	2	3	1	1	16	269052	DH-D(3)	47	121431	0.15	52	328487	0.43
DH-69	2	3	3	4	2	1	16	265490	DH-F(3)	7	25448	0.03	25	81481	0.11
DH-70	1	1	3	1	1	1	16	263674	DH-A(1)	33	90856	0.11	27	175797	0.23
DH-71	2	1	3	1	2	2	15	263107	DH-D(1)	36	91816	0.11	9	53505	0.07
DH-72	1	2	1	4	2	2	13	250826	DH-B(3)	12	38980	0.05	N/A	N/A	N/A
DH-73	2	1	3	4	2	2	13	244715	DH-D(2)	27	78084	0.09	21	103367	0.13
DH-74	1	3	3	4	2	2	13	237998	DH-C(2)	4	5687	0.01	26	172738	0.22
DH-75	3	2	3	1	2	2	11	237637	DH-G(1)	18	46436	0.06	2	15987	0.02
DH-76	1	1	4	4	2	2	11	235564	DH-A(5)	5	15311	0.02	14	101491	0.13
DH-77	3	2	3	4	2	2	12	235357	DH-G(2)	105	264702	0.32	11	48192	0.06
DH-78	1	1	3	1	2	1	12	234540	DH-A(7)	50	134652	0.16	34	266655	0.35
DH-79	1	2	3	2	1	2	14	234475	DH-B(1)	41	155708	0.19	60	386070	0.50
DH-80	1	2	2	4	1	2	12	222802	DH-B(3)	6	15419	0.02	86	589880	0.77
DH-81	2	2	1	4	1	1	13	206578	DH-E(4)	12	30089	0.04	N/A	N/A	N/A
DH-82	1	2	2	4	2	1	13	205183	DH-B(1)	9	26839	0.03	22	134144	0.17
DH-83	1	1	3	3	1	2	13	204007	DH-A(8)	5	7961	0.01	63	348847	0.45

^a Model with the highest representation in the AHS 2021 database

^b Model with the highest representation in the RECS 2020 database

Key for Table 23:

of floors: 1 = 1 story; 2 = 2 story; 3 = 3 story

Floor area: 1 = less than 148.5 m (1599 ft); 2 = 148.6 m to 222.9 m (1600 ft to 2399 ft); 3 = 223.0 m (2400 ft) or more

AHS21 & RECS20 Floor area less than 139.3 m (1499 ft); 2 = 139.4 m to 232.2 m (1500 ft to 2499 ft); 3 = 232.1 m (2500 ft) or more

Year Built: 1 = before 1940; 2 = 1940-69; 3 = 1970-89; 4 = 1990 and newer

Foundation: 1 = concrete slab; 2 = crawlspace; 3 = finished basement, 4 = unfinished basement

AHS21 & RECS20 Foundation: 1 = concrete slab; 2 = crawlspace; 3 = finished basement, 4 = Other

Garage: 1 = none; 2 = attached garage

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Forced Air: 1 = other; 2 = central system present

of DWLG: number of dwellings in the survey data

Weight: weighting factor of the dwelling number for all U.S. dwellings for the survey data

% Rep.: percentage representation of each dwelling number in the survey

Table 24 RECS 1997 modeling details updated – Attached Dwellings (53 total).

DWLG Number	# of Floors	Dwelling Variable					RECS 1997 Data		Floor Plan	AHS 2021 Data			RECS 2020 Data		
		Floor Area	Year Built	Found-ation	Garage	Forced Air	# of DWLG	Weight		# of DWLG	Weight	% Rep.	# of DWLG	Weight	% Rep.
AH-1	2	1	1	3	1	2	35	578214	AH-C(11)	5	18001	0.23	N/A	N/A	N/A
AH-2	2	1	3	1	1	2	23	521245	AH-C(7)	56	88404	1.12	35	168024	2.25
AH-3	1	1	3	1	1	2	17	459153	AH-A(2)	92	137929	1.75	36	170622	2.29
AH-4	1	1	3	1	2	2	13	321363	AH-A(3)	57	102594	1.30	20	87902	1.18
AH-5	2	1	2	3	1	1	14	316699	AH-C(15)	4	10090	0.13	9	60673	0.81
AH-6	2	1	3	1	2	2	11	268691	AH-C(4)	43	85057	1.08	19	105372	1.41
AH-7	2	1	3	3	1	2	11	252037	AH-C(16)	4	2276	0.03	29	126682	1.70
AH-8	1	1	2	1	1	1	16	233618	AH-A(2)	53	78940	1.00	16	93098	1.25
AH-9	2	1	1	3	2	1	11	231469	AH-C(17)	1	3262	0.04	N/A	N/A	N/A
AH-10	2	1	1	3	1	1	15	220760	AH-C(11)	9	14922	0.19	N/A	N/A	N/A
AH-11 ^b	2	1	2	3	1	2	15	212814	AH-C(15)	17	30591	0.39	58	316771	4.25
AH-12	1	1	4	1	2	2	5	173022	AH-A(1)	30	54381	0.69	12	51183	0.69
AH-13	2	1	2	1	1	2	10	149352	AH-C(6)	105	180475	2.29	11	49798	0.67
AH-14 ^a	1	1	2	1	1	2	13	144284	AH-A(2)	164	264456	3.36	12	51831	0.70
AH-15	2	2	3	1	2	2	8	138425	AH-D(1)	40	86709	1.10	15	77496	1.04
AH-16	2	1	1	2	1	1	4	114912	AH-C(2)	6	4879	0.06	N/A	N/A	N/A
AH-17	1	1	2	2	1	1	8	111713	AH-A(5)	17	28725	0.37	6	31353	0.42
AH-18	2	1	3	1	1	1	6	107467	AH-C(2)	13	15511	0.20	10	25349	0.34
AH-19	2	1	2	1	2	2	6	106839	AH-C(3)	97	182677	2.32	4	25090	0.34
AH-20	2	1	1	4	2	2	7	100827	AH-C(12)	1	1113	0.01	N/A	N/A	N/A
AH-21	2	2	1	4	2	2	7	98706	AH-D(4)	1	3880	0.05	N/A	N/A	N/A
AH-22	2	1	3	1	2	1	4	98643	AH-C(1)	5	10498	0.13	6	20090	0.27
AH-23	2	1	3	4	2	2	4	94223	AH-C(13)	3	3669	0.05	12	66593	0.89
AH-24	2	2	1	3	1	1	6	91427	AH-D(5)	N/A	N/A	N/A	N/A	N/A	N/A
AH-25	1	1	2	1	2	1	6	91173	AH-A(1)	27	34305	0.44	5	35158	0.47

DWLG Number	# of Floors	Dwelling Variable					RECS 1997 Data		Floor Plan	AHS 2021 Data			RECS 2020 Data		
		Floor Area	Year Built	Found-ation	Garage	Forced Air	# of DWLG	Weight		# of DWLG	Weight	% Rep.	# of DWLG	Weight	% Rep.
AH-26	2	1	4	1	1	2	3	90212	AH-C(5)	39	84899	1.08	9	37914	0.51
AH-27	2	2	1	4	2	1	5	89646	AH-D(6)	N/A	N/A	N/A	N/A	N/A	N/A
AH-28	2	2	3	3	1	2	4	85872	AH-D(7)	N/A	N/A	N/A	19	77721	1.04
AH-29	2	2	4	1	2	2	2	83853	AH-D(2)	39	81091	1.03	9	42052	0.56
AH-30	1	1	3	2	2	1	6	80968	AH-A(1)	5	7861	0.10	3	10999	0.15
AH-31	1	1	2	3	1	2	4	80714	AH-A(7)	1	517	0.01	10	47770	0.64
AH-32	1	1	2	4	2	2	5	80666	AH-A(4)	2	3786	0.05	2	14548	0.20
AH-33	1	1	1	3	1	2	4	79408	AH-A(6)	1	2570	0.03	N/A	N/A	N/A
AH-34	2	3	3	3	1	2	3	74965	AH-E(1)	N/A	N/A	N/A	2	6261	0.08
AH-35	2	1	2	1	1	1	5	73883	AH-C(2)	35	43528	0.55	8	43384	0.58
AH-36	1	1	2	1	2	2	4	71401	AH-A(1)	114	208630	2.65	6	27299	0.37
AH-37	1	1	2	2	2	1	4	68914	AH-A(1)	11	22194	0.28	2	4552	0.06
AH-38	1	1	1	4	2	1	4	67275	AH-A(4)	1	1933	0.02	N/A	N/A	N/A
AH-39	1	1	4	1	1	2	3	65157	AH-A(2)	33	59959	0.76	11	51982	0.70
AH-40	2	1	1	1	1	1	3	64445	AH-C(8)	3	2219	0.03	N/A	N/A	N/A
AH-41	2	2	2	3	1	2	3	63302	AH-D(8)	6	7450	0.09	17	77843	1.04
AH-42	2	1	2	4	2	2	3	61601	AH-C(10)	7	25213	0.32	2	15180	0.20
AH-43	1	2	3	1	2	2	3	61587	AH-B(1)	24	38711	0.49	8	30461	0.41
AH-44	1	1	3	2	1	1	4	60364	AH-A(5)	3	11987	0.15	8	26231	0.35
AH-45	1	1	2	2	1	2	4	60074	AH-A(2)	24	34332	0.44	21	98806	1.33
AH-46	2	1	2	2	1	2	2	59507	AH-C(9)	4	9883	0.13	8	46523	0.62
AH-47	1	1	3	4	2	2	3	59499	AH-A(8)	1	606	0.01	6	22369	0.30
AH-48	2	1	3	2	1	2	5	54415	AH-C(6)	6	9488	0.12	13	42855	0.58
AH-49	1	1	1	2	2	1	3	54145	AH-A(1)	6	16375	0.21	N/A	N/A	N/A
AH-50	2	1	3	2	2	2	3	53687	AH-C(4)	7	8336	0.11	5	21259	0.29
AH-51	2	1	3	3	1	1	4	52821	AH-C(11)	N/A	N/A	N/A	13	49528	0.66
AH-52	2	2	3	1	1	2	3	52106	AH-D(3)	16	28189	0.36	9	41767	0.56

DWLG Number	# of Floors	Dwelling Variable					RECS 1997 Data		Floor Plan	AHS 2021 Data			RECS 2020 Data		
		Floor Area	Year Built	Found-ation	Garage	Forced Air	# of DWLG	Weight		# of DWLG	Weight	% Rep.	# of DWLG	Weight	% Rep.
AH-53	1	1	4	2	1	2	3	51848	AH-A(2)	3	9177	0.12	4	14917	0.20

^a Model with the highest representation in the AHS 2021 database

^b The model with the highest representation in the RECS2020 database

Key for Table 24:

of floors: 1 = 1 story; 2 = 2 story

Floor area: 1 = less than 148.5 m (1599 ft); 2 = 148.6 m to 222.9 m (1600 ft to 2399 ft); 3 = 223.0 m (2400 ft) or more

AHS21 & RECS20 Floor area less than 139.3 m (1499 ft); 2 = 139.4 m to 232.2 m (1500 ft to 2499 ft); 3 = 232.1 m (2500 ft) or more

Year Built: 1 = before 1940; 2 = 1940-69; 3 = 1970-89; 4 = 1990 and newer

Foundation: 1 = concrete slab; 2 = crawlspace; 3 = finished basement, 4 = unfinished basement

AHS21 & RECS20 Foundation: 1 = concrete slab; 2 = crawlspace; 3 = finished basement, 4 = Other

Garage: 1 = none; 2 = attached garage Forced Air: 1 = other; 2 = central system present

of DWLG: number of dwellings in the survey data

Weight: weighting factor of the dwelling number for all U.S. dwellings for the survey data

% Rep.: percentage representation of each dwelling number in the survey

Table 25 RECS 1997 modeling details updated – Manufactured Dwellings (4 total).

DWLG Number	Dwelling Variable			RECS 1997 Data		Floor Plan	AHS 2021 Data			RECS 2020 Data		
	Floor Area	Year Built	Forced Air	# of DWLG	Weight		# of DWLG	Weight	% Rep.	# of DWLG	Weight	% Rep.
MH-1 ^b	1	3	2	171	2664598	MH-B(1)	351	925701	12.96	238	1642536	24.04
MH-2	1	4	2	56	883158	MH-A(1)	363	1011283	14.16	121	955007	13.98
MH-3	1	3	1	39	595936	MH-B(1)	118	333710	4.67	85	613064	8.97
MH-4 ^a	1	2	2	38	580199	MH-B(1)	474	1236082	17.31	44	310600	4.55

^a Model with the highest representation in the AHS 2021 database

^b The model with the highest representation in the RECS2020 database

Key for Table 25:

Floor area: 1 = less than 148.5 m (1599 ft); 2 = 148.6 m (1600 ft) or more

AHS21 & RECS20 Floor area less than 139.3 m (1499 ft); 2 = 139.4 m (1500 ft) or more

Year Built: 1 = before 1940; 2 = 1940-69; 3 = 1970-89; 4 = 1990 and newer

Forced Air: 1 = other; 2 = central system present

of DWLG: number of dwellings in the survey data

Weight: weighting factor of the dwelling number for all U.S. dwellings for the survey data

% Rep.: percentage representation of each dwelling number in the survey

Table 26 RECS 1997 modeling details updated – Apartments (69 total).

DWLG Number	# of Floors	Dwelling Variable				RECS 1997 Data		Floor Plan	AHS 2021 Data			RECS 2020 Data ^c		
		# of Units	Floor Area	Year Built	Forced Air	# of DWLG	Weight		# of DWLG	Weight	% Rep.	# of DWLG	Weight	% Rep.
APT-1	2	3	1	3	2	42	664721	APT-2A(7)	190	344295	1.10	27	256411	0.80
APT-2	3	3	1	3	2	21	511570	APT-3A(7)	102	190458	0.61	15	141842	0.44
APT-3	4	5	1	3	1	37	489530	APT-4B(1)	163	134357	0.43	75	692584	2.15
APT-4	2	1	1	1	1	33	479427	APT-2A(1)	123	273616	0.87	N/A	N/A	N/A
APT-5	2	1	1	2	1	27	459130	APT-2A(1)	186	401002	1.28	81	808443	2.51
APT-6	2	2	1	3	2	25	441017	APT-2A(4)	188	342343	1.09	29	302493	0.94
APT-7	2	1	1	2	2	19	389364	APT-2A(2)	298	570043	1.82	N/A	N/A	N/A
APT-8	2	2	2	3	2	22	388484	APT-2B(3)	81	134677	0.43	27	253427	0.79
APT-9	2	1	1	3	2	19	344153	APT-2A(2)	141	288476	0.92	84	781717	2.43
APT-10	2	3	1	3	1	17	309964	APT-2A(7)	77	150880	0.48	26	229915	0.71
APT-11 ^a	2	2	1	2	2	14	285231	APT-2A(5)	366	618619	1.98	35	354196	1.10
APT-12	3	5	1	3	1	14	267078	APT-3A(10)	79	79973	0.26	44	412248	1.28
APT-13	4	5	1	1	1	13	254804	APT-4B(1)	103	155476	0.50	N/A	N/A	N/A
APT-14	2	1	2	3	2	13	246843	APT-2B(1)	92	187028	0.60	73	719000	2.23
APT-15	2	2	1	3	1	17	245944	APT-2A(5)	85	158182	0.51	38	337039	1.05
APT-16	1	1	1	2	1	19	244120	APT-1A(2)	111	197548	0.63	40	398268	1.24
APT-17	3	4	1	2	1	16	223585	APT-3A(9)	162	252837	0.81	50	482071	1.50
APT-18	3	1	1	1	1	19	213875	APT-3A(1)	94	234905	0.75	N/A	N/A	N/A
APT-19	3	3	1	3	1	14	213350	APT-3A(7)	57	95434	0.30	16	145425	0.45
APT-20	2	3	1	2	2	16	209785	APT-2A(7)	320	525563	1.68	37	371270	1.15
APT-21 ^b	2	3	2	3	2	11	205202	APT-2B(6)	64	119415	0.38	26	262910	0.82
APT-22	2	1	1	3	1	14	204024	APT-2A(2)	67	150361	0.48	96	871194	2.71
APT-23	3	4	1	3	2	6	199294	APT-3A(9)	97	178512	0.57	22	205731	0.64
APT-24	5	5	1	2	1	14	174581	APT-5A(1)	N/A	N/A	N/A	N/A	N/A	N/A
APT-25	2	3	1	2	1	10	173628	APT-2A(7)	171	326991	1.04	23	225189	0.70

DWLG Number	# of Floors	Dwelling Variable				RECS 1997 Data		Floor Plan	AHS 2021 Data			RECS 2020 Data ^c		
		# of Units	Floor Area	Year Built	Forced Air	# of DWLG	Weight		# of DWLG	Weight	% Rep.	# of DWLG	Weight	% Rep.
APT-26	3	3	1	2	1	11	170140	APT-3A(8)	135	243543	0.78	17	167721	0.52
APT-27	3	4	1	2	2	6	169678	APT-3A(9)	191	319141	1.02	36	361247	1.12
APT-28	2	1	2	1	1	10	164628	APT-2B(2)	99	207412	0.66	N/A	N/A	N/A
APT-29	3	2	1	2	1	14	160066	APT-3A(3)	73	112727	0.36	16	155731	0.48
APT-30	4	5	1	2	1	12	156932	APT-4B(1)	275	344677	1.10	84	797011	2.48
APT-31	2	2	2	2	1	10	155497	APT-2B(4)	35	58090	0.19	10	134535	0.42
APT-32	2	1	1	1	2	9	155420	APT-2A(3)	136	323162	1.03	N/A	N/A	N/A
APT-33	2	5	1	3	2	8	135934	APT-2A(10)	51	77890	0.25	18	188992	0.59
APT-34	3	4	1	1	1	8	132732	APT-3A(9)	83	161067	0.51	N/A	N/A	N/A
APT-35	2	2	2	4	2	2	129848	APT-2B(5)	88	187212	0.60	6	78778	0.24
APT-36	4	5	1	3	2	11	129466	APT-4B(2)	180	173636	0.55	39	421309	1.31
APT-37	3	5	1	2	1	5	127308	APT-3A(10)	151	175221	0.56	43	405171	1.26
APT-38	2	4	1	3	2	10	121922	APT-2A(8)	92	119588	0.38	15	137823	0.43
APT-39	3	4	1	3	1	9	120021	APT-3A(9)	69	103195	0.33	35	344295	1.07
APT-40	2	2	1	2	1	11	119872	APT-2A(5)	148	266465	0.85	37	368117	1.14
APT-41	1	2	2	3	2	6	116485	APT-1B(1)	7	7042	0.02	1	13251	0.04
APT-42	3	2	1	1	1	6	113702	APT-3A(4)	74	153107	0.49	N/A	N/A	N/A
APT-43	3	3	2	3	1	7	113334	APT-3B(2)	10	28424	0.09	15	152115	0.47
APT-44	3	3	1	1	1	7	111144	APT-3A(8)	79	148882	0.48	N/A	N/A	N/A
APT-45	3	5	2	2	1	5	109309	APT-3B(5)	21	20713	0.07	39	405911	1.26
APT-46	3	1	1	2	1	7	106822	APT-3A(2)	42	100844	0.32	20	203306	0.63
APT-47	1	1	1	3	2	7	106196	APT-1A(1)	122	159614	0.51	46	432524	1.34
APT-48	3	5	1	1	1	8	105582	APT-3A(10)	58	94644	0.30	N/A	N/A	N/A
APT-49	3	5	1	2	2	6	104279	APT-3A(10)	233	275671	0.88	25	246260	0.77
APT-50	3	4	2	3	2	2	100899	APT-3B(4)	33	45767	0.15	24	276332	0.86
APT-51	3	1	2	1	1	8	97205	APT-3B(1)	132	233093	0.74	N/A	N/A	N/A
APT-52	4	5	1	2	2	3	96106	APT-4B(3)	308	363824	1.16	33	325009	1.01

DWLG Number	# of Floors	Dwelling Variable				RECS 1997 Data		Floor Plan	AHS 2021 Data			RECS 2020 Data ^c		
		# of Units	Floor Area	Year Built	Forced Air	# of DWLG	Weight		# of DWLG	Weight	% Rep.	# of DWLG	Weight	% Rep.
APT-53	2	5	1	2	2	4	91792	APT-2A(11)	125	169536	0.54	16	151449	0.47
APT-54	2	4	1	3	1	6	87866	APT-2A(9)	47	92827	0.30	32	309706	0.96
APT-55	2	2	2	2	2	4	86579	APT-2B(3)	182	359485	1.15	10	83176	0.26
APT-56	2	4	1	2	1	5	85183	APT-2A(8)	95	182901	0.58	36	348728	1.08
APT-57	1	2	1	3	2	5	83830	APT-1A(3)	40	38458	0.12	3	33981	0.11
APT-58	2	3	2	2	1	6	80915	APT-2B(6)	35	71254	0.23	11	98097	0.30
APT-59	2	2	1	4	2	3	74528	APT-2A(6)	92	177490	0.57	6	67360	0.21
APT-60	3	2	1	4	2	1	74274	APT-3A(5)	23	44260	0.14	1	16797	0.05
APT-61	3	2	1	2	2	3	73726	APT-3A(3)	94	156427	0.50	9	89564	0.28
APT-62	2	2	1	4	1	3	73558	APT-2A(4)	31	60539	0.19	12	125090	0.39
APT-63	3	5	2	2	2	3	71765	APT-3B(6)	64	114428	0.37	41	368446	1.15
APT-65	3	5	1	3	2	3	70356	APT-3A(10)	126	178280	0.57	40	432578	1.34
APT-66	3	3	2	1	2	2	70066	APT-3B(3)	16	38296	0.12	N/A	N/A	N/A
APT-67	1	3	1	2	1	3	69529	APT-1A(4)	20	38682	0.12	3	26639	0.08
APT-68	3	2	1	3	1	3	66016	APT-3A(6)	25	63828	0.20	15	135999	0.42
APT-69	4	2	1	4	2	1	64924	APT-4A(1)	N/A	N/A	N/A	N/A	N/A	N/A

^a The model with the highest representation in the AHS 2021 database

^b The model with the highest representation in the RECS2020 database

^c The RECS 2020 database does not have a number (#) of floors variable for apartments as it did in the past. This means there was no way to directly compare the RECS 2020 data to the RECS 1997 data. The technique used to compute the number for Table 24 was as follows. The Dwelling Variables minus the # of floors variable were used to group survey responses. The resulting group of values was then broken out into the final values for this table using the AHS 2021 survey distribution. Example: APT-1 and APT-2 have the same Dwelling Variables, excluding the # of floors. The calculated row of values for the Number (#) of Dwellings (DWLG), Weight, and % representation for RECS 2020 was multiplied by the ratio of the AHS 2021 Weight for APT-1 (344295) and APT-2 (190458).

Key for Table 26:

of floors: 1 = 1 story; 2 = 2 story; 3 = 3 to 5 stories (modeled as 4); 4 = 6-15 stories (modeled as 10); 5 = 16+ stories (modeled as 10)

AHS # of floors: 1 = 1 story; 2 = 2 story; 3 = 3 to 5 stories; 4 = 6+ stories

of units: 1 = 2 to 4 (modeled as 4); 2 = 5 to 9 (modeled as 6); 3 = 10 to 19 (modeled as 16); 4 = 20 to 39 (modeled as 32); 5 = 40+

units in the building (modeled as 20 units per floor)

AHS # of units: 1 = 2 to 4 (modeled as 4); 2 = 5 to 9 (modeled as 6); 3 = 10 to 19 (modeled as 16); 4 = 20 to 49 5 = 50+ units in building

Floor area: 1 = less than 92.8 m (999 ft); 2 = 92.9 m (1000 ft) or more

Year Built: 1 = before 1940; 2 = 1940-69; 3 = 1970-89; 4 = 1990 and newer

Forced Air: 1 = other; 2 = central system present

of DWLG: number of dwellings in the survey data

Weight: weighting factor of the dwelling number for all U.S. dwellings for the survey data

% Rep.: percentage representation of each dwelling number in the survey

B.2. AHS 2021 Dwelling Characteristics

This section contains four tables that define the top 50 % of each dwelling type from the AHS 2021 report, with one table for each dwelling type: detached (Table 27), attached (Table 28), manufactured dwelling (Table 29), and apartment (Table 30). The dwelling definitions in the table are in terms of the variables discussed in the body of the above document (Note: number of other rooms is unavailable).

Table 27 AHS 2021 50 % dwelling representation details – Detached (48 total).

Dwelling Definition	# of Floors	Floor Area	Year Built	Found-ation	Garage	Forced Air	# of DWLG	Weight	% Rep.	# of Bedrooms	# of Bathrooms	# of Half Baths	A/C
126122	1	2	6	1	2	2	1249	3018932	3.65	3	2	0	1
236122	2	3	6	1	2	2	1079	2190347	2.65	4	3	0	1
336322	2	3	6	3	2	2	674	1803856	2.18	4	3	0	1
226122	2	2	6	1	2	2	675	1534536	1.86	3	2	1	1
111222	1	1	1	2	2	2	625	1527419	1.85	3	1	0	1
123122	1	2	3	1	2	2	613	1400324	1.69	3	2	0	1
321322	2	2	1	3	2	2	429	1226887	1.48	3	1	0	1
125122	1	2	5	1	2	2	546	1223836	1.48	3	2	0	1
124122	1	2	4	1	2	2	584	1204438	1.46	3	2	0	1
211322	1	1	1	3	2	2	427	1090491	1.32	3	1	0	1
136122	1	3	6	1	2	2	462	986486	1.19	4	3	0	1
113122	1	1	3	1	2	2	407	975017	1.18	3	2	0	1
335322	2	3	5	3	2	2	427	970866	1.17	4	3	0	1
116122	1	1	6	1	2	2	344	928784	1.12	3	2	0	1
311322	2	1	1	3	2	2	321	918155	1.11	3	1	0	1
121222	1	2	1	2	2	2	359	911453	1.10	3	2	0	1
221322	1	2	1	3	2	2	318	878800	1.06	3	1	0	1
111122	1	1	1	1	2	2	430	869120	1.05	3	1	0	1
122122	1	2	2	1	2	2	380	849086	1.03	3	2	0	1
114122	1	1	4	1	2	2	395	820565	0.99	3	2	0	1

Dwelling Definition	# of Floors	Floor Area	Year Built	Found-ation	Garage	Forced Air	# of DWLG	Weight	% Rep.	# of Bedrooms	# of Bathrooms	# of Half Baths	A/C
236322	1	3	6	3	2	2	227	731106	0.88	4	3	0	1
111212	1	1	1	2	1	2	276	686081	0.83	2	1	0	1
123222	1	2	3	2	2	2	209	640745	0.78	3	2	0	1
223322	1	2	3	3	2	2	224	627547	0.76	3	2	0	1
321321	2	2	1	3	2	1	233	617833	0.75	3	1	0	2
226322	1	2	6	3	2	2	184	616234	0.75	3	2	0	1
112122	1	1	2	1	2	2	276	615214	0.74	3	1	0	1
111221	1	1	1	2	2	1	245	611935	0.74	2	1	0	2
236222	2	3	6	2	2	2	224	611431	0.74	4	3	0	1
331322	2	3	1	3	2	2	220	608228	0.74	3	2	0	1
225122	2	2	5	1	2	2	295	604392	0.73	3	2	1	1
235122	2	3	5	1	2	2	334	594226	0.72	4	3	0	1
122222	1	2	2	2	2	2	212	593373	0.72	3	2	0	1
121122	1	2	1	1	2	2	293	584358	0.71	3	2	0	1
113222	1	1	3	2	2	2	188	584012	0.71	3	1	0	1
111211	1	1	1	2	1	1	196	582422	0.70	2	1	0	2
115122	1	1	5	1	2	2	247	581955	0.70	3	2	0	1
112222	1	1	2	2	2	2	226	578762	0.70	3	1	0	1
126222	1	2	6	2	2	2	159	565652	0.68	3	2	0	1
224122	2	2	4	1	2	2	282	549768	0.67	3	2	1	1
326322	2	2	6	3	2	2	186	547470	0.66	4	2	1	1
321422	3	2	1	4	2	2	188	542778	0.66	3	2	0	1
222322	1	2	2	3	2	2	167	506202	0.61	3	2	0	1
125222	1	2	5	2	2	2	143	496255	0.60	3	2	0	1
212322	1	1	2	3	2	2	156	459204	0.56	3	1	0	1
334322	2	3	4	3	2	2	204	458279	0.55	4	2	0	1
111112	1	1	1	1	1	2	219	453569	0.55	3	1	0	1
325322	2	2	5	3	2	2	160	438492	0.53	3	2	1	1

The key for Table 27:

of floors: 1 = 1 story; 2 = 2 story; 3 = 3 story

Floor Area: 1 = less than 139.3 m (1499 ft); 2 = 139.4 m to 232.2 m (1500 ft to 2499 ft); 3 = 232.1 m (2500 ft) or more

Year Built: 1 = before 1960; 2 = 1960-69; 3 = 1970-79; 4 = 1980-89; 5 = 1990-99; 6 = 2000 and newer

Foundation: 1 = concrete slab; 2 = crawlspace; 3 = finished basement, 4 = Other

Garage: 1 = none; 2 = attached garage

Forced Air: 1 = other; 2 = central system present

of DWLG: number of dwellings in the survey data

Weight: weighting factor of the dwelling number for all U.S. dwellings for the survey data

% Rep.: percentage representation of each dwelling number in the survey

Table 28 AHS 2021 50 % dwelling representation details – Attached (38 total).

Dwelling Definition	# of Floors	Floor Area	Year Built	Found-ation	Garage	Forced Air	# of DWLG	Weight	% Rep.	# of Bedrooms	# of Bathrooms	# of Half Baths	A/C
226122	2	2	6	1	2	2	147	341326	4.34	3	2	1	1
311312	2	1	1	3	1	2	98	199448	2.54	3	1	0	1
116122	1	1	6	1	2	2	74	188760	2.40	2	2	0	1
326122	3	2	6	1	2	2	99	185326	2.36	3	2	0	1
216122	2	1	6	1	2	2	80	169333	2.15	2	2	1	1
214122	2	1	4	1	2	2	76	151720	1.93	2	2	1	1
114112	1	1	4	1	1	2	79	146814	1.87	2	1	0	1
326322	2	2	6	3	2	2	62	146586	1.86	3	2	1	1
113112	1	1	3	1	1	2	92	137929	1.75	2	1	0	1
311311	2	1	1	3	1	1	72	137888	1.75	3	1	0	2
114122	1	1	4	1	2	2	75	137468	1.75	2	2	0	1
126122	1	2	6	1	2	2	46	125667	1.60	2	2	0	1
214112	2	1	4	1	1	2	66	119681	1.52	2	1	1	1
113122	1	1	3	1	2	2	57	102594	1.30	2	2	0	1
116112	1	1	6	1	1	2	42	102330	1.30	2	1	0	1
224122	2	2	4	1	2	2	53	93455	1.19	3	2	1	1
216112	2	1	6	1	1	2	50	90813	1.15	2	2	1	1
213112	2	1	3	1	1	2	56	88404	1.12	2	1	1	1
223122	2	2	3	1	2	2	40	86709	1.10	3	2	1	1
213122	2	1	3	1	2	2	43	85057	1.08	3	2	1	1
215112	2	1	5	1	1	2	39	84899	1.08	2	2	1	1
215122	2	1	5	1	2	2	43	81784	1.04	2	2	1	1
225122	2	2	5	1	2	2	39	81091	1.03	3	2	1	1
321312	2	2	1	3	1	2	40	72045	0.92	3	1	0	2
325322	2	2	5	3	2	2	30	68352	0.87	3	2	1	1
112112	1	1	2	1	1	2	44	66647	0.85	2	1	0	1

Dwelling Definition	# of Floors	Floor Area	Year Built	Found-ation	Garage	Forced Air	# of DWLG	Weight	% Rep.	# of Bedrooms	# of Bathrooms	# of Half Baths	A/C
336322	2	3	6	3	2	2	26	66568	0.85	3	3	0	1
324312	2	2	4	3	1	2	40	63060	0.80	3	2	1	1
111112	1	1	1	1	1	2	54	61356	0.78	2	1	0	1
115112	1	1	5	1	1	2	33	59959	0.76	2	2	0	1
111111	1	1	1	1	1	1	31	55484	0.71	1	1	0	2
115122	1	1	5	1	2	2	30	54381	0.69	2	2	0	1
316322	2	1	6	3	2	2	15	54239	0.69	3	2	1	1
311322	2	1	1	3	2	2	22	53987	0.69	3	1	0	1
314312	2	1	4	3	1	2	33	52929	0.67	3	1	1	1
226222	2	2	6	2	2	2	18	50210	0.64	3	2	1	1
336122	3	3	6	1	2	2	30	49321	0.63	3	2	0	1
226322	1	2	6	3	2	2	20	46566	0.59	2	2	0	1

Key for Table 28:

of Floors: 1 = 1 story; 2 = 2 story; 3 = 3 story

Floor Area: 1 = less than 139.3 m (1499 ft); 2 = 139.4 m to 232.2 m (1500 ft to 2499 ft); 3 = 232.1 m (2500 ft) or more

Year Built: 1 = before 1960; 2 = 1960-69; 3 = 1970-79; 4 = 1980-89; 5 = 1990-99; 6 = 2000 and newer

Foundation: 1 = concrete slab; 2 = crawlspace; 3 = finished basement, 4 = Other

Garage: 1 = none; 2 = attached garage

Forced Air: 1 = other; 2 = central system present

of DWLG: number of dwellings in the survey data

Weight: weighting factor of the dwelling number for all U.S. dwellings for the survey data

% Rep.: percentage representation of each dwelling number in the survey

Table 29 AHS 2021 50 % dwelling representation details – Manufactured Dwelling (4 total).

Dwelling Definition	Floor Area	Year Built	Forced Air	# of DWLG	Weight	% Rep.	# of Bedrooms	# of Bathrooms	# of Half Baths	A/C
162	1	6	2	376	1030052	14.42	3	2	0	1
152	1	5	2	363	1011283	14.16	3	2	0	1
132	1	3	2	351	925701	12.96	2	1	0	1
142	1	4	2	353	888622	12.44	2	2	0	1

Key for Table 29:

Floor area: 1 = less than 139.3 m (1499 ft); 2 = 139.4 m (1500 ft) or more

Year Built: 1 = before 1960; 2 = 1960-69; 3 = 1970-79; 4 = 1980-89; 5 = 1990-99; 6 = 2000 and newer

Forced Air: 1 = other; 2 = central system present

of DWLG: number of dwellings in the survey data

Weight: weighting factor of the dwelling number for all U.S. dwellings for the survey data

% Rep.: percentage representation of each dwelling number in the survey

Table 30 AHS 2021 50 % dwelling representation details – Apartments (48 total).

Dwelling Definition	# of Floors	# of Units	Floor Area	Year Built	Forced Air	# of DWLG	Weight	% Rep.	# of Bedrooms	# of Bathrooms	# of Half Baths	A/C
35162	3	5	1	6	2	722	1143120	3.65	1	1	0	1
35262	3	5	2	6	2	424	703594	2.25	2	2	0	1
33262	3	3	2	6	2	230	594062	1.90	2	2	0	1
33162	3	3	1	6	2	277	591377	1.89	1	1	0	1
34262	3	4	2	6	2	233	565690	1.81	2	2	0	1
34162	3	4	1	6	2	259	554337	1.77	1	1	0	1
21112	2	1	1	1	2	229	515906	1.65	2	1	0	1
21111	2	1	1	1	1	209	477219	1.52	2	1	0	2
35111	3	5	1	1	1	279	423127	1.35	1	1	0	2
35112	3	5	1	1	2	249	397635	1.27	1	1	0	1
22142	2	2	1	4	2	201	365653	1.17	2	1	0	1
35132	3	5	1	3	2	306	351916	1.12	1	1	0	1
23132	2	3	1	3	2	190	344295	1.10	1	1	0	1
22132	2	2	1	3	2	188	342343	1.09	2	1	0	1
34111	3	4	1	1	1	164	330400	1.06	1	1	0	2
23142	2	3	1	4	2	181	330175	1.05	2	1	0	1
21211	2	1	2	1	1	146	320813	1.02	2	1	0	2
21212	2	1	2	1	2	156	307359	0.98	2	1	0	2
31111	3	1	1	1	1	123	305481	0.98	2	1	0	2
22162	2	2	1	6	2	117	296292	0.95	2	1	0	1
21132	2	1	1	3	2	141	288476	0.92	2	1	0	1
21262	2	1	2	6	2	114	287687	0.92	3	2	0	1
22262	2	2	2	6	2	135	283093	0.90	2	2	0	1
31212	3	1	2	1	2	141	279547	0.89	2	1	0	1
31112	3	1	1	1	2	122	275923	0.88	2	1	0	2
31211	3	1	2	1	1	152	272291	0.87	2	1	0	2

Dwelling Definition	# of Floors	# of Units	Floor Area	Year Built	Forced Air	# of DWLG	Weight	% Rep.	# of Bedrooms	# of Bathrooms	# of Half Baths	A/C
33111	3	3	1	1	1	142	267822	0.86	1	1	0	2
22242	2	2	2	4	2	129	256990	0.82	2	2	0	1
33142	3	3	1	4	2	129	255258	0.82	1	1	0	1
21242	2	1	2	4	2	119	246137	0.79	2	2	0	1
35152	3	5	1	5	2	175	242765	0.78	1	1	0	1
21142	2	1	1	4	2	127	241027	0.77	2	1	0	1
35161	3	5	1	6	1	194	241005	0.77	1	1	0	1
35142	3	5	1	4	2	249	238723	0.76	1	1	0	1
35122	3	5	1	2	2	183	232669	0.74	1	1	0	1
33152	3	3	1	5	2	97	216271	0.69	1	1	0	1
35131	3	5	1	3	1	242	214330	0.68	1	1	0	2
23162	2	3	1	6	2	109	211689	0.68	1	1	0	1
33132	3	3	1	3	2	112	203795	0.65	2	1	0	1
33252	3	3	2	5	2	94	203529	0.65	2	2	0	1
32111	3	2	1	1	1	107	202791	0.65	1	1	0	2
23262	2	3	2	6	2	95	200169	0.64	2	2	0	1
35121	3	5	1	2	1	158	199462	0.64	1	1	0	2
22252	2	2	2	5	2	88	187212	0.60	2	2	0	1
21232	2	1	2	3	2	92	187028	0.60	2	1	0	1
35242	3	5	2	4	2	119	186669	0.60	2	2	0	1
23152	2	3	1	5	2	102	185970	0.59	1	1	0	1
34132	3	4	1	3	2	102	182340	0.58	1	1	0	1

Key for Table 30:

of floors: 1 = 1 story; 2 = 2 story; 3 = 3 to 5 stories; 4 = 6+ stories

of units: 1 = 2 to 4 (modeled as 4); 2 = 5 to 9 (modeled as 6); 3 = 10 to 19 (modeled as 16); 4 = 20 to 49 (modeled as 32); 5 = 50+ units in building (modeled as 20 units per floor)

Floor area: 1 = less than 92.8 m (999 ft); 2 = 92.9 m (1000 ft) or more

Year Built: 1 = before 1960; 2 = 1960-69; 3 = 1970-79; 4 = 1980-89; 5 = 1990-99; 6 = 2000 and newer

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Forced Air: 1 = other; 2 = central system present

of DWLG: number of dwellings in the survey data

Weight: weighting factor of the dwelling number for all U.S. dwellings for the survey data

% Rep.: percentage representation of each dwelling number in the survey

B.3. RECS 2020 Dwelling Characteristics

This section contains four tables that define the top (50 %) dwellings from the RECS 2020 report, with one table for each dwelling type: detached (Table 31), attached (Table 32), manufactured dwelling (Table 33), and apartment (Table 34). The dwelling definitions in the table refer to the variables discussed in the body of this report.

Table 31 RECS 2020 50 % dwelling representation details – Detached (60 total).

Dwelling Definition	# of Floors	Floor Area	Year Built	Found-ation	Garage	Forced Air	# of DWLG	Weight	% Rep.	# of Bedrooms	# of Bathrooms	# of Half Baths	# of Other Rooms	A/C
126122	1	2	6	1	2	2	360	2370861	3.08	3	2	0	4	1
111312	1	1	1	3	1	2	261	1854007	2.41	2	1	0	3	1
111212	1	1	1	2	1	2	186	1471211	1.91	2	1	0	3	1
236122	2	3	6	1	2	2	214	1429143	1.85	4	3	1	5	1
221312	2	2	1	3	1	2	192	1294151	1.68	3	1	0	4	1
236322	2	3	6	3	2	2	253	1275713	1.66	4	3	1	6	1
211312	2	1	1	3	1	2	173	1227212	1.59	3	1	0	3	1
125122	1	2	5	1	2	2	144	1204034	1.56	3	2	0	4	1
111412	1	1	1	4	1	2	131	1026111	1.33	3	1	0	3	1
226122	2	2	6	1	2	2	140	926219	1.20	3	2	1	4	1
123122	1	2	3	1	2	2	124	917610	1.19	3	2	0	4	1
124122	1	2	4	1	2	2	110	813102	1.06	3	2	0	4	1
235322	2	3	5	3	2	2	129	778514	1.01	4	3	1	6	1
221412	2	2	1	4	1	2	107	762394	0.99	3	2	0	4	1
136122	1	3	6	1	2	2	113	720269	0.93	4	3	1	5	1
111322	1	1	1	3	2	2	99	694391	0.90	3	1	0	3	1
126322	1	2	6	3	2	2	147	646282	0.84	3	2	0	4	1
111211	1	1	1	2	1	1	83	619980	0.80	2	1	0	3	2
225322	2	2	5	3	2	2	89	619884	0.80	3	2	1	4	1
111222	1	1	1	2	2	2	67	615532	0.80	3	1	0	3	1
226322	2	2	6	3	2	2	128	615184	0.80	3	2	1	4	1

Dwelling Definition	# of Floors	Floor Area	Year Built	Found-ation	Garage	Forced Air	# of DWLG	Weight	% Rep.	# of Bedrooms	# of Bathrooms	# of Half Baths	# of Other Rooms	A/C
235122	2	3	5	1	2	2	74	570810	0.74	4	3	1	5	1
236422	2	3	6	4	2	2	108	555332	0.72	4	3	1	5	1
113122	1	1	3	1	2	2	62	523117	0.68	3	2	0	2	1
121212	1	2	1	2	1	2	63	519594	0.67	3	2	0	4	1
116122	1	1	6	1	2	2	79	491201	0.64	3	2	0	3	1
221422	2	2	1	4	2	2	75	489005	0.63	3	2	0	4	1
221311	2	2	1	3	1	1	79	466601	0.61	3	2	0	4	2
121412	1	2	1	4	1	2	64	457732	0.59	3	2	0	3	1
111112	1	1	1	1	1	2	57	454544	0.59	3	1	0	3	1
211412	2	1	1	4	1	2	62	453222	0.59	3	1	0	3	1
114122	1	1	4	1	2	2	51	451890	0.59	3	2	0	3	1
236222	2	3	6	2	2	2	90	451680	0.59	4	3	1	6	1
123322	1	2	3	3	2	2	93	447115	0.58	3	2	0	4	1
121222	1	2	1	2	2	2	53	442640	0.57	3	2	0	4	1
112212	1	1	2	2	1	2	67	440062	0.57	3	1	0	3	1
121312	1	2	1	3	1	2	71	428702	0.56	3	1	0	3	1
125222	1	2	5	2	2	2	69	428119	0.56	3	2	0	4	1
223422	2	2	3	4	2	2	72	427486	0.55	3	2	1	4	1
113112	1	1	3	1	1	2	55	425925	0.55	3	1	0	4	1
115122	1	1	5	1	2	2	48	421165	0.55	3	2	0	3	1
122122	1	2	2	1	2	2	50	418129	0.54	3	2	0	3	1
136322	1	3	6	3	2	2	105	415512	0.54	4	3	0	5	1
121322	1	2	1	3	2	2	64	413170	0.54	3	2	0	4	1
224322	2	2	4	3	2	2	67	411813	0.53	3	2	1	4	1
125322	1	2	5	3	2	2	57	406882	0.53	3	2	0	4	1
225122	2	2	5	1	2	2	52	406361	0.53	4	2	1	4	1
121422	1	2	1	4	2	2	53	404742	0.53	3	2	0	4	1
112322	1	1	2	3	2	2	66	400737	0.52	3	1	0	3	1

Dwelling Definition	# of Floors	Floor Area	Year Built	Found-ation	Garage	Forced Air	# of DWLG	Weight	% Rep.	# of Bedrooms	# of Bathrooms	# of Half Baths	# of Other Rooms	A/C
235422	2	3	5	4	2	2	64	399535	0.52	4	3	1	5	1
111411	1	1	1	4	1	1	53	399515	0.52	2	1	0	2	2
224122	2	2	4	1	2	2	53	396954	0.52	3	2	1	4	1
225422	2	2	5	4	2	2	57	395479	0.51	3	2	1	4	1
221322	2	2	1	3	2	2	59	387191	0.50	3	2	1	3	1
126222	1	2	6	2	2	2	88	375025	0.49	3	2	0	4	1
226222	2	2	6	2	2	2	81	369289	0.48	3	2	1	4	1
111422	1	1	1	4	2	2	46	367245	0.48	3	1	0	2	1
122322	1	2	2	3	2	2	65	366567	0.48	3	2	0	3	1
126121	1	2	6	1	2	1	51	361335	0.47	3	2	0	3	1
223322	2	2	3	3	2	2	71	359703	0.47	4	2	1	4	1

Key for Table 31:

of floors: 1 = 1 story; 2 = 2 story; 3 = 3 story

Floor Area: 1 = less than 139.3 m (1499 ft); 2 = 139.4 m to 232.2 m (1500 ft to 2499 ft); 3 = 232.1 m (2500 ft) or more

Year Built: 1 = before 1960; 2 = 1960-69; 3 = 1970-79; 4 = 1980-89; 5 = 1990-99; 6 = 2000 and newer

Foundation: 1 = concrete slab; 2 = crawlspace; 3 = finished basement, 4 = Other

Garage: 1 = none; 2 = attached garage

Forced Air: 1 = other; 2 = central system present

of DWLG: number of dwellings in the survey data

Weight: weighting factor of the dwelling number for all U.S. dwellings for the survey data

% Rep.: percentage representation of each dwelling number in the survey

Table 32 RECS 2020 50 % dwelling representation details – Attached (58 total).

Dwelling Definition	# of Floors	Floor Area	Year Built	Found-ation	Garage	Forced Air	# of DWLG	Weight	% Rep.	# of Bedrooms	# of Bathrooms	# of Half Baths	# of Other Rooms	A/C
211312	2	1	1	3	1	2	46	255046	3.42	3	1	0	3	1
226122	2	2	6	1	2	2	49	221891	2.98	3	2	1	2	1
126122	1	2	6	1	2	2	43	161980	2.17	2	2	0	4	1
116122	1	1	6	1	2	2	35	125689	1.69	2	2	0	3	1
214112	2	1	4	1	1	2	22	117382	1.58	2	2	1	3	1
216122	2	1	6	1	2	2	26	110647	1.48	2	2	1	2	1
221311	2	2	1	3	1	1	16	95193	1.28	4	1	0	4	2
114112	1	1	4	1	1	2	17	94148	1.26	2	1	0	2	1
226322	2	2	6	3	2	2	32	92788	1.25	3	2	1	4	1
216112	2	1	6	1	1	2	22	87483	1.17	2	2	1	3	1
214122	2	1	4	1	2	2	15	79713	1.07	2	2	1	3	1
213312	2	1	3	3	1	2	16	76546	1.03	2	1	1	3	1
113112	1	1	3	1	1	2	19	76474	1.03	2	1	0	2	1
326122	3	2	6	1	2	2	17	69863	0.94	3	2	1	3	1
111212	1	1	1	2	1	2	12	68805	0.92	2	1	0	3	2
226422	2	2	6	4	2	2	20	65059	0.87	3	2	1	3	1
126322	1	2	6	3	2	2	19	62198	0.83	3	2	0	4	1
212312	2	1	2	3	1	2	12	61725	0.83	3	1	1	2	1
211311	2	1	1	3	1	1	9	60673	0.81	2	1	0	4	2
221312	2	2	1	3	1	2	13	60537	0.81	4	1	0	4	1
215122	2	1	5	1	2	2	11	59835	0.80	2	2	1	3	1
221411	2	2	1	4	1	1	13	57390	0.77	4	1	0	4	2
211411	2	1	1	4	1	1	9	54657	0.73	2	1	0	5	2
115112	1	1	5	1	1	2	11	51982	0.70	2	2	0	2	1
115122	1	1	5	1	2	2	12	51183	0.69	2	2	0	3	1
213112	2	1	3	1	1	2	13	50642	0.68	2	1	1	3	1
223312	2	2	3	3	1	2	11	50456	0.68	3	1	0	3	1

Dwelling Definition	# of Floors	Floor Area	Year Built	Found-ation	Garage	Forced Air	# of DWLG	Weight	% Rep.	# of Bedrooms	# of Bathrooms	# of Half Baths	# of Other Rooms	A/C
214312	2	1	4	3	1	2	13	50135	0.67	2	1	1	3	1
111111	1	1	1	1	1	1	8	50019	0.67	2	1	0	2	2
116322	1	1	6	3	2	2	12	50006	0.67	2	2	0	4	1
211412	2	1	1	4	1	2	10	49662	0.67	1	1	0	2	2
115111	1	1	5	1	1	1	8	48599	0.65	1	1	0	2	1
125122	1	2	5	1	2	2	13	47156	0.63	2	2	0	4	1
114111	1	1	4	1	1	1	8	47138	0.63	2	2	0	3	1
113111	1	1	3	1	1	1	7	46905	0.63	2	1	0	3	4
214412	2	1	4	4	1	2	9	46772	0.63	2	1	0	4	1
116112	1	1	6	1	1	2	11	46355	0.62	2	2	0	3	1
225322	2	2	5	3	2	2	9	46276	0.62	2	2	1	4	1
114122	1	1	4	1	2	2	11	45909	0.62	2	2	0	2	1
215322	2	1	5	3	2	2	10	45164	0.61	2	1	1	3	1
224322	2	2	4	3	2	2	13	43470	0.58	3	2	1	3	1
112111	1	1	2	1	1	1	8	43079	0.58	1	1	0	2	2
211212	2	1	1	2	1	2	7	42099	0.57	3	1	0	5	1
225122	2	2	5	1	2	2	9	42052	0.56	3	2	1	4	1
113122	1	1	3	1	2	2	9	41993	0.56	3	2	0	2	1
236322	2	3	6	3	2	2	14	41241	0.55	3	2	1	5	1
223122	2	2	3	1	2	2	7	40563	0.54	3	2	1	4	1
214322	2	1	4	3	2	2	9	39600	0.53	2	1	1	3	1
215112	2	1	5	1	1	2	9	37914	0.51	2	1	1	3	1
211112	2	1	1	1	1	2	8	37638	0.51	3	1	0	2	1
213422	2	1	3	4	2	2	6	37479	0.50	3	1	0	2	1
326422	3	2	6	4	2	2	9	37041	0.50	3	2	1	3	1
224122	2	2	4	1	2	2	8	36933	0.50	3	2	1	4	1
224412	2	2	4	4	1	2	9	36766	0.49	3	2	0	4	1
221412	2	2	1	4	1	2	8	34339	0.46	3	1	1	4	1

Dwelling Definition	# of Floors	Floor Area	Year Built	Found-ation	Garage	Forced Air	# of DWLG	Weight	% Rep.	# of Bedrooms	# of Bathrooms	# of Half Baths	# of Other Rooms	A/C
111412	1	1	1	4	1	2	5	34078	0.46	1	1	0	1	1
224422	2	2	4	4	2	2	6	33535	0.45	3	2	1	3	1
226112	2	2	6	1	1	2	8	33336	0.45	3	2	1	4	1

Key for Table 32:

of Floors: 1 = 1 story; 2 = 2 story; 3 = 3 story

Floor Area: 1 = less than 139.3 m (1499 ft); 2 = 139.4 m to 232.2 m (1500 ft to 2499 ft); 3 = 232.1 m (2500 ft) or more

Year Built: 1 = before 1960; 2 = 1960-69; 3 = 1970-79; 4 = 1980-89; 5 = 1990-99; 6 = 2000 and newer

Foundation: 1 = concrete slab; 2 = crawlspace; 3 = finished basement, 4 = Other

Garage: 1 = none; 2 = attached garage

Forced Air: 1 = other; 2 = central system present

of DWLG: number of dwellings in the survey data

Weight: weighting factor of the dwelling number for all U.S. dwellings for the survey data

% Rep.: percentage representation of each dwelling number in the survey

Table 33 RECS 2020 50 % dwelling representation details – Manufactured Dwelling (4 total).

Dwelling Definition	Floor Area	Year Built	Forced Air	# of DWLG	Weight	% Rep.	# of Bedrooms	# of Bathrooms	# of Half Baths	# of Other Rooms	A/C
152	1	5	2	121	955007	13.98	3	2	0	3	1
132	1	3	2	128	878192	12.85	2	1	0	2	1
162	1	6	2	130	843098	12.34	3	2	0	3	1
142	1	4	2	110	764344	11.19	2	2	0	2	1

Key for Table 33:

Floor area: 1 = less than 139.3 m (1499 ft); 2 = 139.4 m (1500 ft) or more

Year Built: 1 = before 1960; 2 = 1960-69; 3 = 1970-79; 4 = 1980-89; 5 = 1990-99; 6 = 2000 and newer

Forced Air: 1 = other; 2 = central system present

of DWLG: number of dwellings in the survey data

Weight: weighting factor of the dwelling number for all U.S. dwellings for the survey data

% Rep.: percentage representation of each dwelling number in the survey

Table 34 RECS 2020 50 % dwelling representation details – Apartments (8 total).

Dwelling Definition	# of Floors	# of Units	Floor Area	Year Built	Forced Air	# of DWLG	Weight	% Rep.	# of Bedrooms	# of Bathrooms	# of Half Baths	# of Other Rooms	A/C
n/a5162	n/a	5	1	6	2	154	1344685	4.18	1	1	0	3	1
n/a5161	n/a	5	1	6	1	122	1095376	3.40	1	1	0	2	1
n/a1111	n/a	1	1	1	1	109	1067014	3.32	1	1	0	2	2
n/a5262	n/a	5	2	6	2	98	859996	2.67	2	2	0	2	1
n/a1211	n/a	1	2	1	1	84	836722	2.60	2	1	0	3	2
n/a1112	n/a	1	1	1	2	76	767715	2.39	1	1	0	2	2
n/a5111	n/a	5	1	1	1	71	693108	2.15	1	1	0	2	2
n/a1212	n/a	1	2	1	2	69	681355	2.12	2	1	0	2	2
n/a1132	n/a	1	1	3	2	76	668306	2.08	2	1	0	2	1
n/a5131	n/a	5	1	3	1	73	634200	1.97	1	1	0	2	2
n/a4111	n/a	4	1	1	1	61	607078	1.89	1	1	0	2	2
n/a1142	n/a	1	1	4	2	54	545935	1.70	2	1	0	2	1
n/a5142	n/a	5	1	4	2	47	533955	1.66	2	1	0	2	1
n/a5121	n/a	5	1	2	1	56	509074	1.58	1	1	0	2	2
n/a5132	n/a	5	1	3	2	50	508923	1.58	1	1	0	2	1
n/a5261	n/a	5	2	6	1	57	502923	1.56	2	2	0	3	1
n/a1141	n/a	1	1	4	1	53	477346	1.48	2	1	0	2	2
n/a5141	n/a	5	1	4	1	46	470632	1.46	1	1	0	2	1
n/a1122	n/a	1	1	2	2	46	440441	1.37	2	1	0	2	1
n/a1262	n/a	1	2	6	2	58	428866	1.33	3	2	0	3	1
n/a4131	n/a	4	1	3	1	45	425256	1.32	1	1	0	2	2
n/a1162	n/a	1	1	6	2	51	401769	1.25	2	1	0	3	1
n/a2111	n/a	2	1	1	1	40	395678	1.23	1	1	0	2	2
n/a1131	n/a	1	1	3	1	43	393849	1.22	2	1	0	2	2
n/a5112	n/a	5	1	1	2	42	393327	1.22	1	1	0	2	1
n/a1242	n/a	1	2	4	2	39	388875	1.21	2	1	0	2	1

Dwelling Definition	# of Floors	# of Units	Floor Area	Year Built	Forced Air	# of DWLG	Weight	% Rep.	# of Bedrooms	# of Bathrooms	# of Half Baths	# of Other Rooms	A/C
n/a5152	n/a	5	1	5	2	37	383677	1.19	1	1	0	2	1

Key for Table 34:

of floors: 1 = 1 story; 2 = 2 story; 3 = 3 to 5 stories; 4 = 6+ stories

of units: 1 = 2 to 4 (modeled as 4); 2 = 5 to 9 (modeled as 6); 3 = 10 to 19 (modeled as 16); 4 = 20 to 49 (modeled as 32); 5 = 50+ units in building (modeled as 20 units per floor)

Floor area: 1 = less than 92.8 m (999 ft); 2 = 92.9 m (1000 ft) or more

Year Built: 1 = before 1960; 2 = 1960-69; 3 = 1970-79; 4 = 1980-89; 5 = 1990-99; 6 = 2000 and newer

Forced Air: 1 = other; 2 = central system present

of DWLG: number of dwellings in the survey data

Weight: weighting factor of the dwelling number for all U.S. dwellings for the survey data

% Rep.: percentage representation of each dwelling number in the survey

Appendix C. Exterior Leakage Values using LBNL Database

Data for exterior envelope leakage as a function of building age have been examined in several studies as part of the Residential Diagnostics Database (ResDB) curated by the Residential Building Systems (RBS) group at Lawrence Berkeley National Laboratory (LBNL) [32, 30, 33–36, 31, 37] Currently, the ResDB contains exterior wall leakage data from about 147 000 dwellings and duct leakage data from 28 000 dwellings. From the ResDB, a regression model has been developed by LBNL that estimates the Normalized Leakage (NL) rate of U.S. dwellings stock. The regression model is as follows:

$$\ln(NL) = \beta_{area}Area + \beta_h H + \overleftarrow{\beta_{year}I_{year}} + \beta_{IL}I_{IL} + \beta_e I_e + \overleftarrow{\beta_{cz}I_{cz}} + \beta_{slab}I_{slab} + \beta_{floor1}I_{floor1} + \beta_{floor2}I_{floor2} + \beta_{cond}I_{cond} + \beta_{duct1}I_{duct1} + \beta_{duct2}I_{duct2} + e \quad (2)$$

The NL rate regression model contains variables that account for the floor area ($\beta_{area}Area$), ceiling height ($\beta_h H$), year built ($\overleftarrow{\beta_{year}I_{year}}$), pre-weatherization of Weatherization Assistance Program (WAP) dwellings ($\beta_{LI}I_{LI}$), energy efficiency rated dwellings ($\beta_e I_e$), climate zone ($\overleftarrow{\beta_{cz}I_{cz}}$), foundation type ($\beta_{slab}I_{slab} + \beta_{floor1}I_{floor1} + \beta_{floor2}I_{floor2}$), HVAC duct location ($\beta_{cond}I_{cond} + \beta_{duct1}I_{duct1} + \beta_{duct2}I_{duct2}$), and a residual term (e) that is roughly a normal distribution $N(\mu = 0, \sigma^2 = 0.2)$. The different consideration elements in the regression model make estimating a given dwelling’s NL value worthwhile. The LBNL estimated explanatory variable coefficient values for the regression model and housing characteristics are shown in Table 35. For this project, the NL of each specific dwelling was not determined and instead, the NL for all dwellings in each age range and size was determined (Table 21)

Table 35 Results of regression models that relate $\ln(NL)$ and various housing characteristics from the LBNL studies.

Explanatory Variable	Coefficient Estimates
Year Built: $\overleftarrow{\beta_{year}}$	
Before 1960	-0.250
1960 to 1969	-0.433
1970 to 1979	-0.452
1980 to 1989	-0.654
1990 to 1999	-0.915
2000 and after	-1.058
Climate Zone: $\overleftarrow{\beta_{cz}}$	
Humid A 1-2 (Moist in Fig. 4)	0.473
A 3	0.253
A 4	0.326
A 5	0.112
A 6-7	0
Dry B 2-3	-0.038
B 4-5	-0.009
B 6	0.019

Explanatory Variable	Coefficient Estimates
Marine C 3	0.048
C 4	0.258
Alaska AK 7	0.026
AK 8	-0.512
WAP Dwellings (Pre-Weatherization): β_{IL}	0.420
Energy Efficiency Rated Dwellings: β_e	-0.384
Floor Area: β_{area} (m^{-2})	-0.00208
House Height: β_h (m^{-1})	0.064
Foundation Type	
Slab: (β_{slab})	-0.037
Conditioned Basement/Unvented Crawlspace: β_{floor1}	0.109
Unconditioned Basement/Vented Crawlspace: β_{floor2}	0.180
Duct Location	
Conditioned Space: β_{cond}	-0.124
Unconditioned Attic/Basement: β_{duct1}	0.071
Vented Crawlspace: β_{duct2}	0.181

C.1. Normalized Leakage (NL) Coefficient and Variable Description

This section discusses each of the LBNL’s normalized leakage (NL) model’s coefficients and variables used to estimate the NL and, in turn, the ELA that will be used in the CONTAM models. The following calculations and assumptions were intended to account for these factors in the NL model. To find the geometric mean of the NL for the coefficient and the variables of the NL model, the residual term (e) was set to zero.

C.1.1. Dwelling Floor Area and Height Coefficient and Variable ($\beta_{area}Area, \beta_hH$)

Normalized leakage (NL) is already normalized by both $Area$ and H , the $Area$ and H regression model variables are used because there is a correlation between $Area$ and H . In the previous study, the floor area for the NL calculation was described as less than or greater than 148.6 m² (1600 ft²), but no specific floor area was used for the calculation. The new regression model requires a particular floor area to perform the calculation. Therefore, the floor area categories used in Table 20 (<148.5 m² [<1600 ft²], 148.5 m² to 222.9 m² [1600 ft² to 2399 ft²], and 222.9 m² [>2400 ft²]) for the attached and detached dwelling floor areas were used. The specific floor area variable values used for each category are 104 m² (1119 ft²), 179 m² (1927 ft²), and 300 m² (3229 ft²) per the respective categories. The LBNL floor area coefficient was used as stated in Table 35 with no alterations. Regarding height coefficient and variable, the LBNL height coefficient stated in Table 35 was used with no alterations, and a height variable of 4.99 m (16.4 ft) was used. The height variable of 4.99 m was calculated by taking the average number of stories variable from AHS 2021 and RECS 2020 in Table 1 and using a single floor height that is representative of the housing stock (based on each floor being estimated at 2.89 m (9.5 ft)).

C.1.2. Year Built Coefficient and Variable ($\overleftrightarrow{\beta_{year} I_{year}}$)

No changes were made to the LBNL coefficients and variables for the year-built coefficients. The LBNL year-built explanatory variable coefficient for the NL model is the same as the year-built variable from Table 2, and as such, the coefficients are used directly. The NL model variable of one (1) or zero (0) for year built is used to set if a given year-built group is being used. Year built example for dwelling constructed in 1960-1969:

$$\begin{aligned} & \dots + (< 1960)_{yb} + (1960 - 1969)_{yb} + (1970 - 1979)_{yb} + \dots \\ & \dots + (\beta_{year < 60} I_{year < 60}) + (\beta_{year 60} I_{year 60}) + (\beta_{year 70} I_{year 70}) + \dots \\ & \dots + (-0.250 * 0) + (-0.433 * 1) + (-0.452 * 0) + \dots \\ & \dots + (-0.433 * 1) + \dots \end{aligned}$$

C.1.3. Pre-Weatherization of Weatherization Assistance Program (WAP) and Energy Efficiency Rated Dwellings Coefficient and Variable ($\beta_{IL} I_{IL}, \beta_e I_e$)

The AHS and RECS databases do not contain any data on the U.S. representation of dwellings that have participated in a Weatherization Assistance Program (WAP) or are energy efficiency rated (the most common of which is ENERGY STAR). Estimates were made based on the available data found within the AHS, RECS, and other noted resources. These estimates are discussed below and are meant to help give our best estimate for the effects of pre-WAP and ENERGY STAR dwellings in the U.S. dwelling stock.

C.1.3.1. Pre-Weatherization of Weatherization Assistance Program (WAP)

The databases do not directly state the U.S. representation of dwellings that have participated in a Weatherization Assistance Program (WAP) or a household's eligibility for WAP. The eligibility for WAPs is based on household occupancy, income, and location. Currently, WAPs use 200 % of the poverty line as the eligibility criteria [87], but this has varied between 125 % and 150 % [31]. In addition, each state or territory may elect to use the U.S. Department of Health & Human Services (HHS) Low-Income Home Energy Assistance Program (LIHEAP) criteria of 60 % of state-median income to determine WAP eligibility [87]. For our estimate, we used 200 % of the 2021 poverty line. To estimate the number of dwellings eligible for WAP, the location (state), the number of occupants, and household income were analyzed. There were problems with this approach, however, as AHS does not have state-level information, and RECS uses income brackets and a maximum number of seven occupants. The lack of state information in the AHS could cause an overestimation of the WAP dwellings in the AHS dataset; this is because the poverty line is separated by connected forty-eight states, Alaska, and Hawaii, with both Alaska and Hawaii having higher income requirements than the forty-eight other U.S. states. Unlike AHS, RECS does have state-level information, but the income bracket makes 200 % of the poverty line challenging to quantify accurately. The final calculations for the WAP resulted in an estimate of 13.68 % (RECS: 14.46 % & AHS: 12.89 %) of all dwellings being eligible to participate in the WAP. This estimate of WAP eligibility comes with the problem of

calculating all dwellings that could be eligible, including all that have already participated in a WAP.

C.1.3.2. Energy Efficiency Rated Dwellings

The U.S. representation of dwellings that are energy efficiency rated (one typical rating program is ENERGY STAR) is not part of the AHS and RECS databases. The U.S. Census Bureau had the number of U.S. dwellings as 142 153 010 units as of July 2021 [88], the ENERGY STAR Impacts website scope and influence section states that more than “2.4 million ENERGY STAR certified single-family, multifamily, and manufactured new homes and apartments have been built to date, including more than 120 000 in 2021” [89]. The U.S. Environmental Protection Agency (EPA) ENERGY STAR for dwellings program, which includes airtightness, has existed since 1995. With the total number of U.S. dwellings and the rough estimate of the total number of ENERGY STAR-certified dwellings, an estimate was made on the percent of the U.S. dwelling stock that is ENERGY STAR certified ($I_e = 1.7 \%$). No changes were made to LBNL’s energy efficiency-rated dwellings coefficient.

C.1.4. Climate Zone Coefficient and Variable ($\overleftrightarrow{\beta_{cz} I_{cz}}$)

The AHS and RECS databases use the four U.S. census regions to describe the locations of dwellings; the representation of dwellings can be seen in Table 1. The RECS database also describes the locations of dwellings by Building America Climate Zones and International Energy Conservation Code climate codes (IECC). If the four U.S. census regions are used to determine the proportional climate effects for the NL rate calculation, then the climate zone coefficient would be $\beta_{cz} = 0.116$. This coefficient was calculated by taking the average percent of U.S. dwelling stock weighted representation from both AHS and RECS for the four U.S. census regions and multiplying that by the average climate zone coefficient for all climate zones within the census region. A map of the IECC climate zones, with the four U.S. census regions defined in red that were used for the calculation, can be seen in Fig. 4. The average coefficient was a better estimate than not including the climate zone effects. Still, it gives climate zones an equal representation when averaging a given census region.

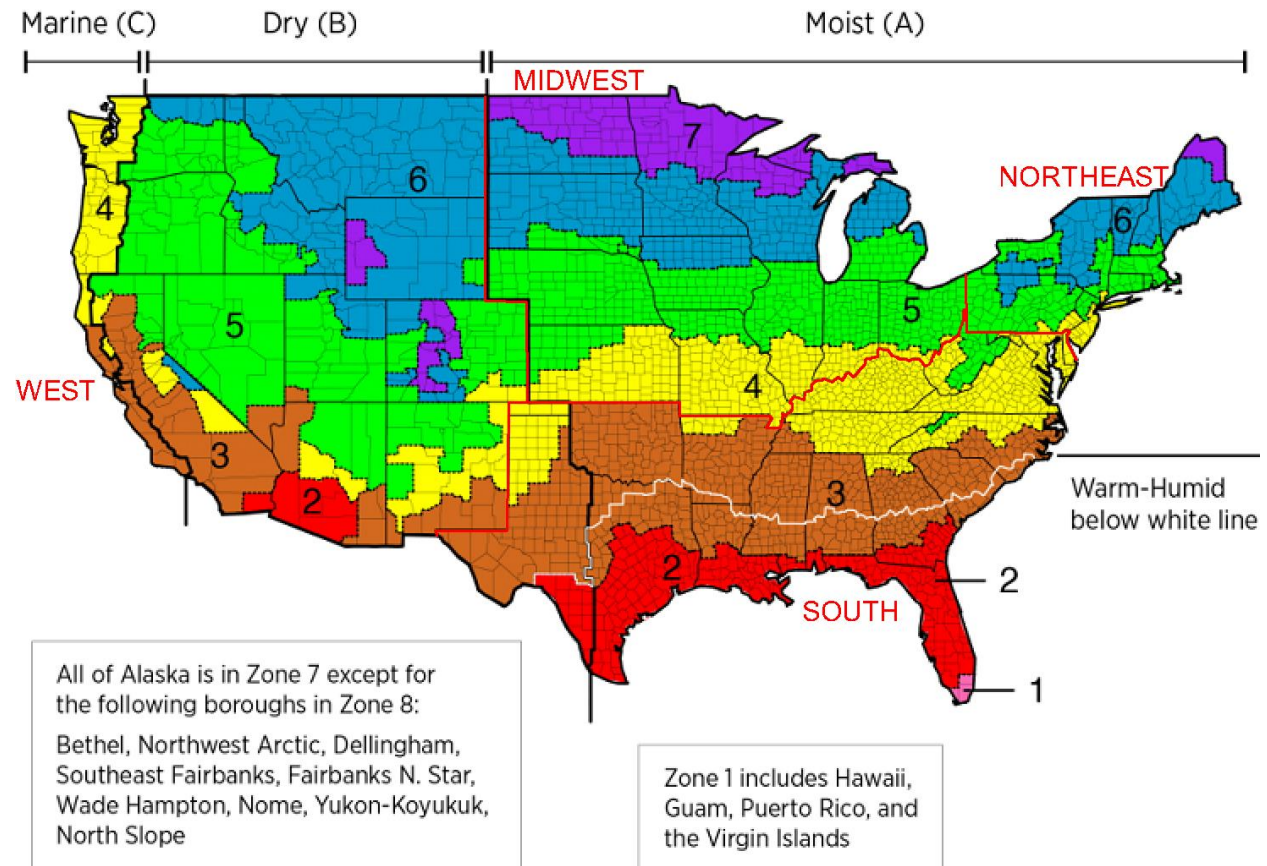


Fig. 4 International Energy Conservation Code (IECC) climate zone map [90] with U.S. census regions shown in red text and region division lines.

Since the RECS database contains the IECC climate zones as part of the survey responses database, a more detailed calculation was performed to estimate a climate coefficient for the NL model based on RECS data alone. Calculations were made using the summation of the dwelling weight for each IECC climate zone (seen in Table 36). The weighting values of the dwellings in each climate zone were then used to calculate the percentage of dwellings that fell into their respective climate zones. This percentage was then multiplied by the LBNL coefficient estimate for each of the zones, and the resulting values were summed up to find a final climate zone coefficient estimate for the NL model of $\beta_{cz} = 0.196$. This climate zone coefficient estimate should be a more accurate representation of the NL model; this coefficient was used for the final NL calculations.

Table 36 NL model climate zone coefficient estimate based on RECS data.

IECC Climate Zones	Coefficient Estimate (#)	RECS Weight (#)	Percentage of RECS (%)
A 1-2	0.473	16611229	13.45 %
A 3	0.253	15948187	12.91 %
A 4	0.326	26419549	21.39 %
A 5	0.112	27927798	22.61 %
A 6-7	0	8226744	6.66 %
B 2-3	-0.038	14317434	11.59 %

IECC Climate Zones	Coefficient Estimate (#)	RECS Weight (#)	Percentage of RECS (%)
B 4-5	-0.009	5883618	4.76 %
B 6	0.019	978829	0.79 %
C 3	0.048	3054445	2.47 %
C 4	0.258	3875771	3.14 %
AK 7	0.026	209788	0.17 %
AK 8	-0.512	47405	0.04 %

C.1.5. Foundation Type Coefficients and Variables ($\beta_{slab}I_{slab}, \beta_{floor1}I_{floor1}, \beta_{floor2}I_{floor2}$)

The RECS database has the following foundation classifications: basement, crawlspace, concrete slab, other foundation, and finished basement. LBNL’s NL model has coefficient estimates for slab floors, conditioned basement/unvented crawlspace, and unconditioned basement/vented crawlspace. The calculation for the representation of concrete slab foundations is straightforward; the resulting representation can be seen in Table 1. Calculating these values for conditioned basement/unvented crawlspace and unconditioned basement/vented crawlspace is difficult. When calculating the conditioned basement/unvented crawlspace representation, it was assumed only the finished basement would be included. For unconditioned basement/vented crawlspace, all basements that are not finished and all dwellings with crawlspace would be included. The AHS database contains the following foundation classifications: for single-family dwellings, there is a basement under the dwelling, a basement under part of the dwelling, a crawlspace, a concrete slab, and a setup in some other way. Like the RECS dataset, the calculation for the representation of concrete slab foundations can be seen in Table 1. Like the RECS dataset, the conditioned basement/unvented crawlspace and unconditioned basement/vented crawlspace for the AHS dataset are more complicated. When calculating the representation of conditioned basement/unvented crawlspace, it was assumed to be all dwellings with a basement under all the dwelling, and for unconditioned basement/vented crawlspace, it was assumed to include all dwellings with a crawlspace as well as dwellings with a basement under part of the house. The results of the above-described assumptions can be seen in Table 37. The calculation of the resulting NL model example can be seen below.

$$\dots + (\beta_{slab}I_{slab}) + (\beta_{floor1}I_{floor1}) + (\beta_{floor2}I_{floor2}) + \dots$$

$$\dots + (-0.037 * 0.2753) + (0.109 * 0.1918) + (0.180 * 0.3082) + \dots$$

Table 37 NL model foundation type variables.

NL Model Foundations Classifications	AHS 2021 (%)	RECS 2020 (%)	Average (%)
Slab Floors	28.87	26.18	27.53
Conditioned Basement/Unvented Crawlspace	17.58	20.79	19.18
Unconditioned Basement/Vented Crawlspace	32.92	28.72	30.82

C.1.6. HVAC Duct Location Coefficients and Variables ($\beta_{cond}I_{cond}$, $\beta_{duct1}I_{duct1}$, $\beta_{duct2}I_{duct2}$)

The AHS and RECS databases do not contain data on the U.S. representation of the location of HVAC ductwork in dwellings. To calculate an estimated normalized leakage related to the location and prevalence of ductwork in U.S. dwellings, values for the percentage of homes with ducts in conditioned space (cond.), unconditioned attic or basement (uncond.), and crawlspace (crawl) based on Home Energy Score inspection and energy audit data were used [36] (see Table 38). The ductwork location percentages given by LBNL were multiplied by the weighted percentage of dwellings with forced air systems to get a final location percentage that accounted for homes without ductwork. These final weighted state-level values for conditioned space, unconditioned attic or basement, and crawlspace ductwork locations were then averaged for a U.S. average duct location distribution. This U.S. average duct location distribution is cond.: 27.08 %, uncond.: 37.01 %, and crawl: 8.15 %. The LBNL calculated variable coefficients for conditioned space (cond.), unconditioned attic or basement (uncond.), and crawlspace (crawl) were unchanged.

Table 38 Percentage of homes with ductwork in various locations.

RECS State Name	LBNL Calculated (%)			Values w/ Dwelling w/o Ductwork Included (%)			
	Cond.	Uncond.	Crawl	Cond.	Uncond.	Crawl	% w/ ducts
Alabama	9 %	55 %	36 %	8 %	46 %	30 %	83.46 %
Alaska	14 %	32 %	54 %	5 %	12 %	20 %	36.91 %
Arizona	8 %	89 %	4 %	6 %	71 %	3 %	79.66 %
Arkansas	5 %	88 %	7 %	4 %	70 %	6 %	79.21 %
California	2 %	88 %	9 %	1 %	57 %	6 %	65.32 %
Colorado	51 %	43 %	6 %	40 %	34 %	5 %	78.07 %
Connecticut	14 %	83 %	2 %	9 %	51 %	1 %	61.98 %
Delaware	68 %	25 %	7 %	56 %	21 %	6 %	82.03 %
District of Columbia	68 %	25 %	7 %	41 %	15 %	4 %	60.82 %
Florida	4 %	91 %	5 %	3 %	58 %	3 %	64.22 %
Georgia	14 %	74 %	12 %	12 %	64 %	10 %	86.49 %
Hawaii	14 %	32 %	54 %	0 %	1 %	1 %	2.45 %
Idaho	48 %	42 %	10 %	37 %	32 %	8 %	76.34 %
Illinois	70 %	26 %	5 %	55 %	20 %	4 %	78.47 %
Indiana	72 %	23 %	4 %	63 %	20 %	4 %	88.05 %
Iowa	87 %	11 %	2 %	76 %	10 %	2 %	87.74 %
Kansas	71 %	25 %	4 %	66 %	23 %	4 %	92.46 %
Kentucky	9 %	55 %	36 %	8 %	48 %	31 %	87.49 %
Louisiana	5 %	88 %	7 %	4 %	68 %	5 %	77.53 %
Maine	14 %	83 %	2 %	6 %	38 %	1 %	46.16 %
Maryland	68 %	25 %	7 %	56 %	21 %	6 %	82.51 %
Massachusetts	11 %	89 %	0 %	6 %	51 %	0 %	57.16 %
Michigan	77 %	15 %	8 %	65 %	13 %	7 %	84.62 %
Minnesota	87 %	11 %	2 %	65 %	8 %	1 %	74.62 %

RECS State Name	LBNL Calculated (%)			Values w/ Dwelling w/o Ductwork Included (%)			
	Cond.	Uncond.	Crawl	Cond.	Uncond.	Crawl	% w/ ducts
Mississippi	9 %	55 %	36 %	7 %	45 %	30 %	82.25 %
Missouri	79 %	17 %	4 %	67 %	14 %	3 %	85.20 %
Montana	48 %	42 %	10 %	32 %	28 %	7 %	66.20 %
Nebraska	71 %	25 %	4 %	63 %	22 %	4 %	89.13 %
Nevada	1 %	88 %	11 %	1 %	71 %	9 %	80.79 %
New Hampshire	14 %	83 %	2 %	8 %	45 %	1 %	54.47 %
New Jersey	17 %	79 %	4 %	11 %	50 %	3 %	63.75 %
New Mexico	1 %	88 %	11 %	1 %	62 %	8 %	71.00 %
New York	16 %	81 %	3 %	7 %	38 %	1 %	46.79 %
North Carolina	9 %	74 %	18 %	8 %	65 %	16 %	88.07 %
North Dakota	87 %	11 %	2 %	57 %	7 %	1 %	65.51 %
Ohio	72 %	23 %	4 %	59 %	19 %	3 %	82.38 %
Oklahoma	5 %	88 %	7 %	4 %	71 %	6 %	80.69 %
Oregon	14 %	32 %	54 %	9 %	20 %	34 %	63.32 %
Pennsylvania	20 %	77 %	2 %	13 %	49 %	1 %	63.09 %
Rhode Island	14 %	83 %	2 %	7 %	44 %	1 %	52.50 %
South Carolina	9 %	74 %	18 %	8 %	64 %	16 %	86.61 %
South Dakota	87 %	11 %	2 %	69 %	9 %	2 %	79.30 %
Tennessee	7 %	46 %	48 %	6 %	40 %	41 %	86.37 %
Texas	5 %	94 %	1 %	4 %	75 %	1 %	79.84 %
Utah	48 %	42 %	10 %	44 %	38 %	9 %	91.15 %
Vermont	14 %	83 %	2 %	7 %	43 %	1 %	51.44 %
Virginia	53 %	41 %	6 %	44 %	34 %	5 %	83.75 %
Washington	14 %	32 %	54 %	8 %	18 %	30 %	56.38 %
West Virginia	68 %	25 %	7 %	50 %	18 %	5 %	73.73 %
Wisconsin	77 %	19 %	4 %	61 %	15 %	3 %	79.12 %
Wyoming	48 %	42 %	10 %	33 %	29 %	7 %	69.17 %

Note: This table shows the percentage of homes with ducts in conditioned space (cond.), unconditioned attic or basement (uncond.), and crawlspace (crawl; assumed all vented), based on LBNL study as well as the Home Energy Score inspection and energy audit data. With calculated values when including dwelling without ductwork.

C.2. Normalized Leakage (NL) Model Calculation

With all variables and coefficients calculated or identified, the normalized leakage (NL) model was used to calculate the leakage for the six-year categories for the three given floor areas. If a user of these models wanted to adjust the leakage of models they are using for a project, the above information can be used to adjust their project specific leakage. An example calculation can be found below; Table 39 contains the NL model results for all years built and floor area ranges identified.

Example calculation for less than 1600 square foot dwellings built before the 1960s:

$$\begin{aligned} \ln(NL) &= \beta_{area}Area + \beta_h H + \overrightarrow{\beta_{year}I_{year}} + \beta_{IL}I_{IL} + \beta_e I_e + \overrightarrow{\beta_{cz}I_{cz}} + \beta_{slab}I_{slab} + \beta_{floor1}I_{floor1} \\ &\quad + \beta_{floor2}I_{floor2} + \beta_{cond}I_{cond} + \beta_{duct1}I_{duct1} + \beta_{duct2}I_{duct2} + e \\ \ln(NL) &= (-0.00208 * 104) + (0.064 * 4.99) + (-0.250 * 1) + (0.420 * 0.1368) \\ &\quad + (-0.384 * 0.0168) + (0.196 * 1) + (-0.037 * 0.2753) + (0.109 * 0.1918) \\ &\quad + (0.180 * 0.3082) + (-0.124 * 0.2708) + (0.071 * 0.3701) \\ &\quad + (0.181 * 0.0815) + 0 \\ \ln(NL) &= (-0.216) + (0.319) + (-0.250) + (0.05746) + (-0.00648) + (0.196) \\ &\quad + (-0.010) + (0.0209) + (0.0555) + (-0.0336) + (0.026) + (0.0148) \\ \ln(NL) &= 0.173 \\ NL &= e^{0.173} \\ NL &= 1.19 \end{aligned}$$

Table 39 Normalized leakage by construction year and floor area.

Year Built	Floor Area Less Than 148.5 m ² (1600 ft ²)	Floor Area Between 148.5 to 222.9 m ² (1600 to 2399 ft ²)	Floor Area Greater than 222.9 m ² (2400 ft ²)
Before 1960	1.19	1.02	0.79
1960-1969	0.99	0.85	0.66
1970-1979	0.97	0.83	0.65
1980-1989	0.79	0.68	0.53
1990-1999	0.61	0.52	0.41
2000 and later	0.53	0.45	0.35

The LBNL’s updated normalized leakage (NL) model (with the above coefficient and variable estimation) resulted in an overall higher normalized leakage than the original suite of dwellings for all year-built groups. The above documentation of the estimates and assumptions made to calculate the coefficients and variables for the NL model were done to the best of the team’s ability and are detailed above so that if a user would like to adjust these values per their needs and knowledge, they have the tools and understanding to do so.