# Prototypes Project Documentation 2023

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## Contents

# 1. Introduction

Prototype building models are used to represent the building stock of a region and in combination with construction data (by building type and climate zone), they can be used to predict the aggregate impact of various decisions on the building stock. The U.S. Department of Energy (DOE) uses these commercial prototype models, based on EnergyPlus, to compare national energy codes, to make determinations of the savings of new addenda and energy codes, for cost-effectiveness analyses of energy codes, and in the analyses of emerging technologies. Additionally, prototype building models inform target-setting for beyond code programs, analysis of deemed and custom measures for beyond code programs, analysis of reach codes, and many other analyses. However, there is not a single set of prototype models that are used for these various analyses in California; instead, there are multiple California prototype model sets available and government agencies, private agencies, consultants, and other market actors use models that are accessible to them, resulting in a lack of uniformity in predicted outcomes as well as market confusion about which models are appropriate for use. On the other hand, the U.S. Department of Energy (DOE) offers a unified set of prototype models to evaluate measure impacts on national energy codes, to make determinations of the savings of proposed code changes, for cost-effectiveness analyses of energy codes, and in the analyses of emerging technologies.

This California Prototypes Development project was funded by Southern California Edison's (SCE) Codes and Standards Program with the goal of developing a single set of prototype building models representing California's building stock. This would enable the California Energy Commission (CEC) and the California Public Utilities Commission (CPUC) to use the same underlying set of assumptions about the building stock when performing a variety of analyses, including the evaluation of proposed changes to the energy code, and the evaluation of deemed- and custom measures for incentive programs. The prototypes project scope included the development of prototype models for the single-family, multifamily, and nonresidential building sectors. A Technical Advisory Group (TAG) was convened comprising the CEC, CPUC, SCE, NORESCO, Energy Solutions, and other interested parties, including DOE national laboratories and national experts. This TAG guided the development of California prototypes. NORESCO led the technical development of the prototype models and Energy Solutions managed the project on behalf of SCE. The TAG met on a bi-monthly basis since the beginning of 2021 to develop the project framework and guide model creation.

This report describes the work to date (2021-2023) on the Prototypes project. For each of the three building sectors (single-family, multifamily, and nonresidential), the development of prototype models was divided into four major tasks:

1. **Building stock assessment:** To develop models that represent the California building stock, the buildings within the stock must be understood. Based on the stock assessment, a mix of prototype models was selected to represent key characteristics of buildings within the California stock, such as building floor area, number of dwelling units, number of stories, etc.
2. **Model inputs development:** Once the prototype models were identified, each was characterized further by developing key inputs for the envelope, lighting, HVAC, water heating, plug and process loads, and other energy systems. The inputs needed to define model characteristics were documented with the intent of being simulation engine-neutral.

3. **Model construction:** Using the inputs developed in the previous step, models were constructed in DOE's EnergyPlus™ simulation engine. The intent is to host these EnergyPlus™ models as well as the underlying input assumptions in a publicly accessible workspace; so that all entities can share and use the same prototype models. The models were reviewed by the development team (NORESCO) and will be posted for review by the TAG and the broader stakeholder group. Feedback received on the models will be incorporated in the final versions.
4. **Validation:** Prototype models were validated at the end-use level using stock energy consumption data from the 2019 Residential Appliance Saturation Survey (RASS) for single-family and multifamily buildings. The 2020 Commercial End-Use Survey (CEUS) will be used, when available, for validating nonresidential buildings.

Model input documentation and the open nature of dialogue and collaboration between critical stakeholders via the TAG are key features of this project. The objective is to rigorously document the assumptions, host the models and documentation on a public platform, and provide a forum for future process and/or methodology's improvement, maintenance, and development of the prototype models.

The following sections describe the prototype model development for single-family and low-rise multifamily buildings. High-rise multifamily and nonresidential prototype models are slated for development in 2024.

## 2. Single-Family Prototype Development

Recent studies indicate that single-family homes make up the majority of California's housing sector, accounting for about 74% [1] of the state's residential buildings floor area (Figure 1). These homes represent approximately 60% [2] of the total number of residential buildings in California as illustrated in Figure 2 and contribute to about 83% [1] of the state's residential sector energy demand, as shown in Figure 3.

In addition to single-family homes, the American Housing Survey (AHS) and the Residential Appliance Saturation Survey (RASS) classify the residential sector into "apartments with 2-4 units", "apartments with five or more units", townhomes, and mobile homes. The first two building types (apartments with 2-4 units and apartments with five or more units) were studied under the multifamily sector. However, townhomes are excluded from this analysis as they contribute a relatively small portion of the housing stock and share similarities with single-family homes. They represent only 7% of California's residential buildings floor area (Figure 1) and contribute to 6% of the total energy demand of the state's residential sector (Figure 3). Similarly, mobile homes, which form approximately 2% of the state's residential building stock in both floor area and energy demand (Figure 1 and Figure 3), are also excluded from this analysis[1].

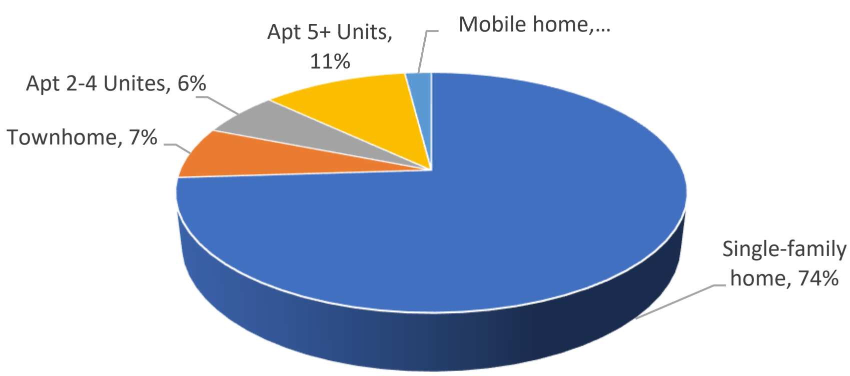



Figure 1: California residential buildings floor area distribution (Source: American Housing Survey (AHS) 2019 [1])

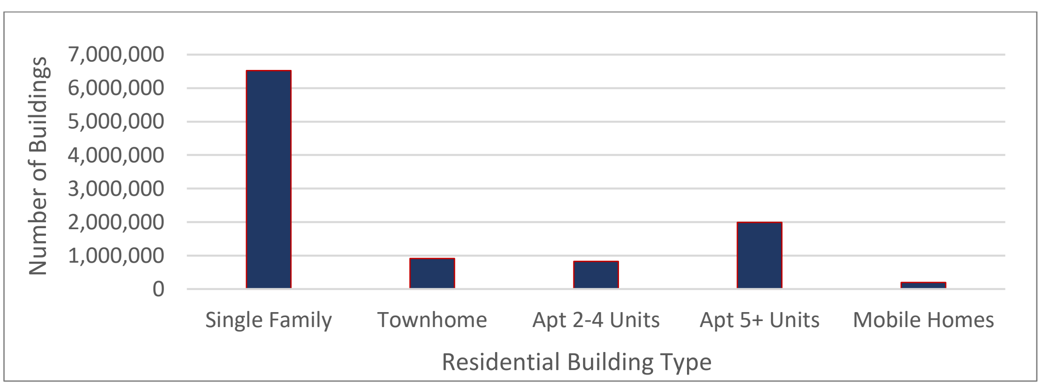



Figure 2: Number of residential buildings by building type (Source: RASS 2019 [2])

[1] CPUC provides incentives for mobile homes and therefore it may be important to develop a mobile home prototype. This topic will be revisited in the next phase of Prototype updates.

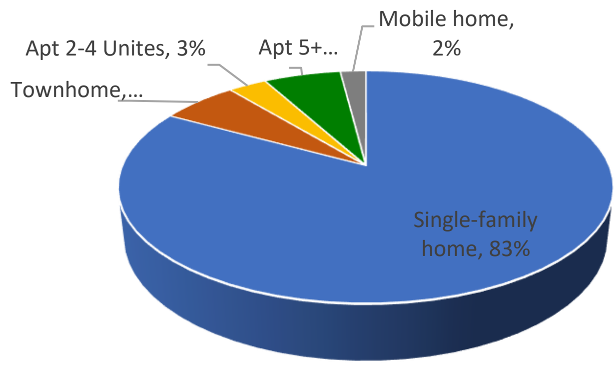



Figure 3: Residential buildings energy consumption by building type (kWh) (Source: RASS 2019 [2])

To develop prototype models representing the single-family building stock, an assessment of the building stock was conducted to capture the primary characteristics of single-family homes in California, including the floor area, number of stories, number of bedrooms, and foundation type. A set of prototype models was formulated based on the assessment and proposed to the TAG. After gaining consensus on the prototype mix, other characteristics of single-family homes were identified, such as the envelope insulation, construction assemblies, window-to-wall ratio (WWR), air leakage, HVAC and water heating systems type and efficiency, and internal and external loads, including people, lighting, and appliances. A variety of sources were used to determine the required model inputs. These model inputs were used to develop the energy models using EnergyPlus™. Lastly, the energy consumption of the prototype models went under validation against the RASS 2019 dataset at the end-use level for each climate zone. The following sections describe the model development process in greater detail.

## 2.1. Single-Family Building Stock Assessment

The focus of the residential building stock assessment was to establish the prototype composition for the residential sector, starting with the single-family prototypes. The 2019 RASS [2] and the 2019 American Housing Survey (AHS) [1] were the primary sources of the data for the assessment. RASS provides California-specific characteristics for saturation, energy consumption patterns, and data about equipment energy use. AHS contains nationwide survey data on homes and apartments constructed over the past few decades. The data offers a representation of the residential building stock in terms of floor area, number of stories, foundation type, number of bedrooms, year built, HVAC and water heating system types, as well as the presence of appliances in residential buildings. Although AHS offers extensive data for the entire residential building stock, it has limitations regarding the data available for each specific building type. The distribution of residential buildings was extracted from the aforementioned datasets, emphasizing critical single-family building designations for floor area, vintage, and other defining features, including the number of bedrooms, number of stores, and floor condition.

### 2.1.1. Floor Area Distribution

The conditioned floor area directly influences the building energy demand for heating, ventilation, and air conditioning. It is the most important parameter for determining the mix of single-family prototypes. Figure 4 illustrates the distribution of the single-family homes' floor area across seven area bins. Single-family homes with floor areas lower than 750 square feet ($ft^2$) constitute a minimal portion of the building stock. Conversely, those within the range of 1,000 to 1,500 $ft^2$ and 1,500 to 2,000 $ft^2$ are the most prevalent, indicating that a prototype in each range may be an optimal choice. Overall, 81% of the single-family building stock has floor area in the range of 1,000 to 3,000 $ft^2$, which was set to be the focus of the prototype model development.

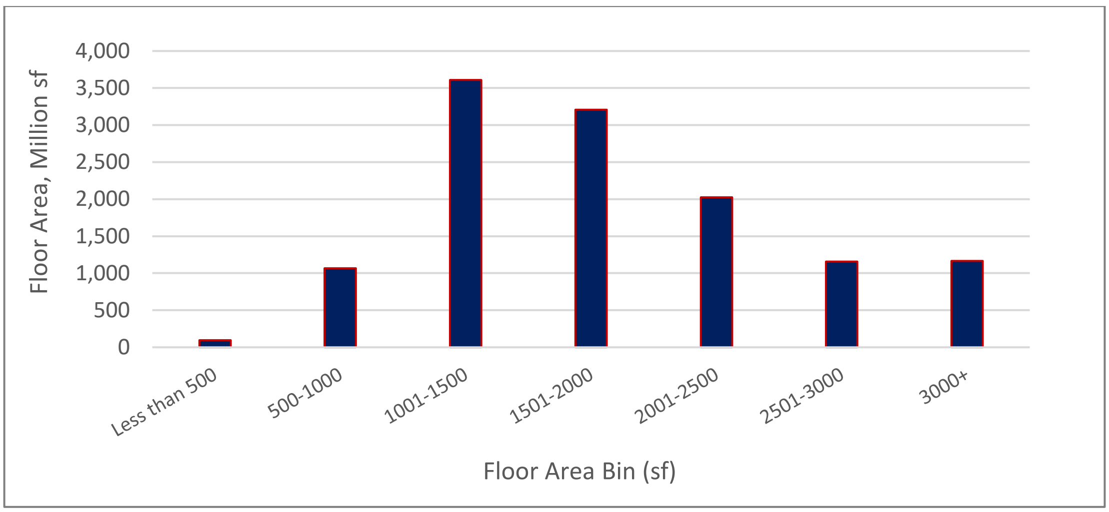



Figure 4: Single-family floor area distribution across floor area bins (Source: RASS 2019 [2])

Distribution of the floor area across climate zones shows that the single-family building stock in California is dominated by construction in CZ12, i.e., the Sacramento region, CZ3, the Bay Area, and several counties in the coastal, southern part of the state (Figure 5). "Appendix A: California Building climate zones" showcases the California Building climate zone map and highlights at least one city within each climate. Climate zone is significant not only because of the influence of weather on the heating or cooling load, but also because of the variation it introduces in certain building characteristics, such as HVAC and domestic hot water (DHW) system type and size, and insulation thickness.

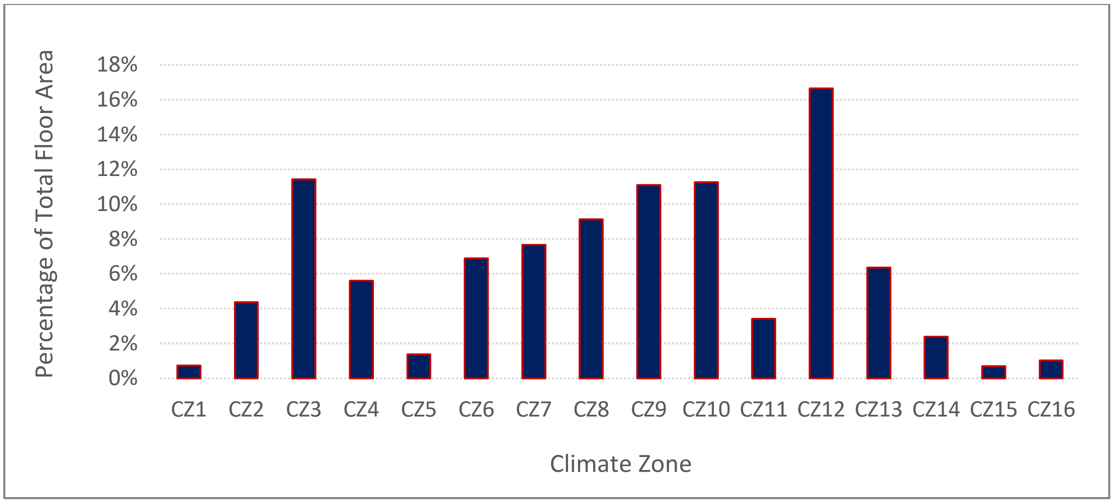



Figure 5: Single-family floor area distribution across California climate zones (Source: RASS 2019 [2])

### 2.1.2. Vintage

Prototype models are intended to serve as reasonable representations of the diverse existing building stock. Given that the building stock encompasses structures spanning from one to over 100 years old, constructed under varying regulations and construction practices, it is important to classify the residential building stock into distinct vintage bins for the prototype models to be representative.

The existing building stock could be categorized by various features, such as the floor area distribution, the floor area and vintage bins distribution, or the approximate energy performance achieved within a specific construction year range. A hybrid approach was employed here where the floor area distribution and change in building regulations (representative of the approximate energy performance) over a period of time were used to develop a representative depiction of the existing stock.

In Figure 6, the floor area distribution by vintage bin is presented, relying on data from RASS [2]. The vintage bins were drawn directly from RASS and were established based on various parameters, including the Energy Commission's forecasting requirements and changes to codes' requirements [3]. A substantial portion of the existing single-family homes were constructed before 1975. California's first energy code was developed after 1975[2], following the Warren Alquist Act. The energy efficiency of single-family homes was not regulated prior to 1975 and homes constructed before 1975 are often characterized by a lack of insulation in the walls, roofs, or around the slab edge, along with single pane windows. Therefore, homes constructed prior to 1975 were grouped into a "pre-1975" vintage bin.

Figure 7 illustrates the floor area distribution by vintage and floor area bins. As shown, for homes constructed before the year 2000, a majority of the stock is occupied by floor area bins smaller than 2,000 $ft^2$. Conversely, for homes constructed after the year 2000, the distribution skews slightly towards homes larger than 2,000 $ft^2$. It is implied that from a weighting perspective, newer vintage bins should be weighted towards the higher end of the floor area bins, while older vintages should be weighted towards smaller floor area bins.

[2] Subsequent editions of the energy code were regularly introduced approximately every three years after 1978.

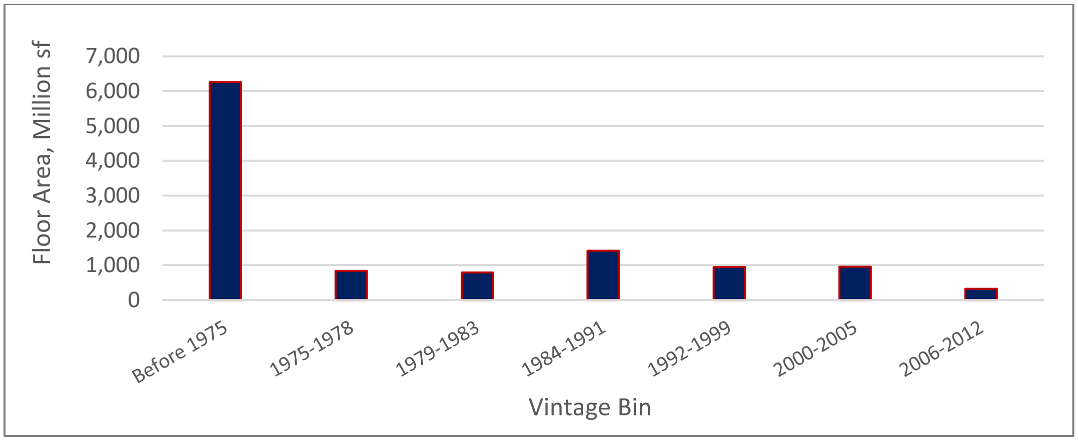



Figure 6: Single-family floor area distribution by vintage (Source: RASS 2019 [2])

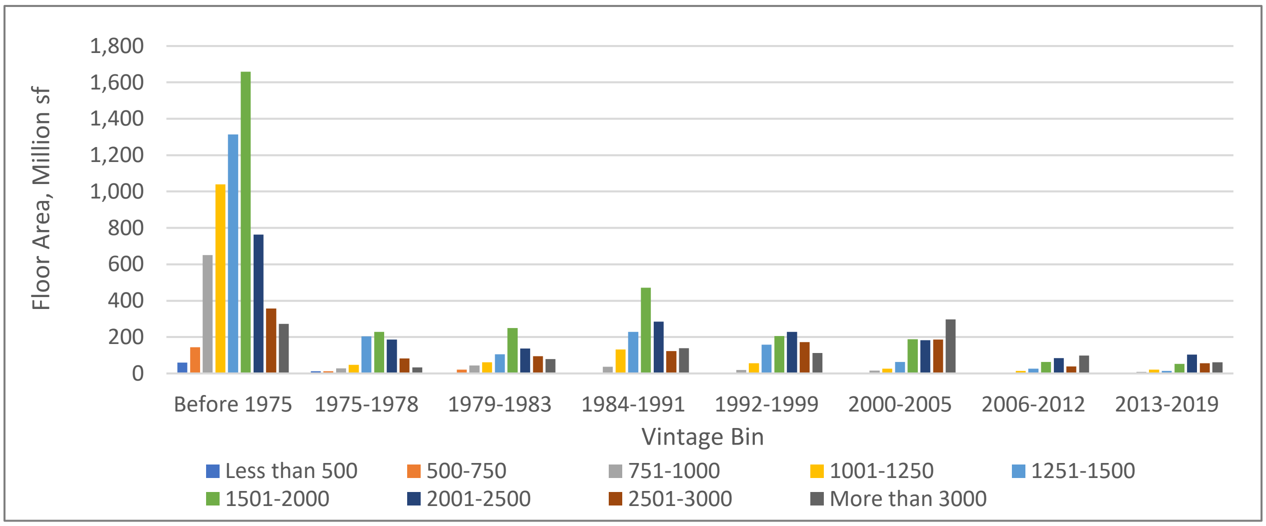



Figure 7: Single-family floor area distribution by vintage and by floor area bins (Source: RASS 2019 [2])

### 2.1.3. Other Single-Family Home Defining Features

#### 2.1.3.1. Number of Bedrooms

Plug and appliance loads are a key factor in determining the energy consumption of a single-family home. While envelope loads scale with floor area, plug and appliance loads (for example, the DHW consumption) scale with the number of bedrooms. The number of bedrooms determines the home's occupancy, which, in turn, affects the plug load intensity and the hot water usage.

Table 1 shows the floor area distribution by number of bedrooms for single-family buildings based on the data from RASS [2]. 3- and 4-bedroom homes occupy a majority of the floor area and should be represented in the prototypes mix. However, given the prevalence of homes smaller than 1,500 ft$^2$ in the existing building stock, including a two-bedroom prototype may enhance the overall representation of the stock.

Table 1: Floor area distribution by number of bedrooms for single-family homes (Source: RASS 2019 [2])

| Number of bedrooms | Floor area distribution |
|---|---|
| 0-1 | 1% |
| 2 | 14% |
| 3 | 47% |
| 4 | 29% |
| 5+ | 9% |

#### 2.1.3.2. Number of Stories

The number of stories influences the ratio of exposed envelope to the building conditioned floor area and therefore it is essential in developing the prototype mix. Table 2 shows the portion of floor area by number of stories. One- and two-story homes are the dominant forms and should be reflected in the prototype mix.

Table 2: Floor area distribution by number of stories for single-family homes (Source: RASS 2019 [2])

| Number of stories | Floor area distribution |
|---|---|
| 1 | 63% |
| 2 | 33% |
| 3 | 4% |

#### 2.1.3.3. Impact of Energy Codes

Since 1978, energy codes editions in California have regulated the energy efficiency of residential buildings. It may be logical to group vintage bins into year ranges where the stringency of the energy code remained approximately the same. To achieve this, a review of past energy codes was conducted.

The codes enacted between 1975-1982 were the first generation of California energy codes that outlined prescriptive residential requirements for all major building components, including the building envelope, lighting, HVAC, and water heating system. From 1984 onwards, the residential code format changed from a prescriptive standard to a performance standard accompanied by pre-calculated prescriptive packages. Between 1992 and 1999, codes underwent revisions in performance specification, and it appeared that, at least for the water heating system, the performance requirements were less stringent than in previous codes. On the prescriptive side, there was a reduction in the number of available prescriptive packages for residential single-family buildings. Post-2000, prescriptive packages were further reduced, and the performance path adopted a differential approach, similar to the commercial performance compliance approach.

It was difficult to further ascertain the stringency of past energy codes because the approaches change dramatically between code editions. Absent a full-scale simulation-based investigation of the relative stringencies of each code edition, it is difficult to determine the relative changes in stringency between two sequential energy code editions. An approximate demarcation between the various code editions was created, as described above, and vintage bins were formulated based on this demarcation. There were many changes to the code in the intervening years of a vintage bin, but the bins as arranged follow time periods when the residential energy code remained relatively unchanged.

### 2.1.3.4. Floor-to-Ground Interface

The floor-to-ground interface plays a key role in heat transfer between the home and the exterior. Table 3 shows the proportion of floor area by foundation type for single-family homes in California. 66% of single-family homes in California were built with concrete slab followed by 30% with a crawlspace.

Table 3: Floor area distribution by foundation type for single-family homes (Source: AHS 2019 [1])

| Foundation type | Floor area distribution |
|---|---|
| Basement under all of homes | 2% |
| Basement under part of homes | 2% |
| Crawlspace | 30% |
| Concrete slab | 66% |

### 2.1.3.5. Sensitivity Analyses

#### 2.1.3.5.1. Sensitivity to Floor Condition

The prototype mix could be defined to represent homes with both concrete slabs and crawlspaces; However, to evaluate whether a crawlspace results in significant variations in energy consumption, a sensitivity analysis was performed using CBECC-Res [4] and the 2,100 $ft^2$ Title 24 CEC prototype in three climate zones 12, 15, and 16 representing mild (CZ12), hot (CZ15), and cold (CZ16) climates in California. Table 4 shows the results of the analysis. The maximum heating and cooling normalized annual energy difference between the crawlspace and concrete slab configuration was found to be 13%. Although the impact on the heating and cooling loads is relatively small between the two floor conditions, given that crawlspace represents 30% of the stock, it was decided to use a concrete slab for 67%[3] of the prototype floor area and a crawlspace for the rest of the floor.

[3] About the difference between 67% and 66%, it is worth mentioning that we focused on concrete slabs and crawlspaces that account for almost 96% of the single-family homes' foundation type. However, 4% remains which belongs to single-family homes with basements - 2% for full basement, and 2% for partial basement. In order to determine the share of the concrete slab in the prototype model, the remaining 4% was distributed between the two categories. Half of the homes with partial basement was integrated with concrete slab homes. In this way:

- Share of the concrete slab floor area in a single-family prototype model = Percentage of homes with a concrete slab (66%) + half of the percentage of homes with a partial basement (1%) = 67%
- Share of the crawlspace floor area in a single-family prototype model =percentage of homes with crawlspace (30%) + percentage of buildings with full basement (2%) + half of the percentage of homes with partial basement (1%) = 33%

Table 4: Slab and crawlspace sensitivity analysis for a 2,100 $ft^2$ CEC prototype

| Climate zone | Total space heating and cooling ($kBtu/ft^2$) Concrete slab | Total space heating and cooling ($kBtu/ft^2$) Crawlspace | % Change |
|---|---|---|---|
| **CZ12** | 8.02 | 7.02 | 13% |
| **CZ15** | 6.75 | 7.53 | -12% |
| **CZ16** | 16.62 | 14.77 | 11% |

Note: CZ=Climate zone

#### 2.1.3.5.2. Sensitivity to Floor Area

Figure 7 shows that homes smaller than 2,500 $ft^2$ are the most dominant homes in California. They stand for over 80% of the single-family homes and this prompted the question of whether it would be appropriate to discard the larger prototypes (over 2,500 $ft^2$) in lieu of prototypes smaller than 2,500 $ft^2$ to represent new construction and existing building stock.

To answer this question, CEC single-family prototypes including a single-story 2,100 $ft^2$ prototype and a two-story 2,700 $ft^2$ prototype were selected. A sensitivity analysis was performed using CBECC-Res [4], to determine the heating and cooling annual energy consumption difference between the two prototypes. Table 5 outlines the results of the analysis. It indicates a decrease in the normalized heating and cooling annual energy consumption when moving to the larger prototype. This decrease in consumption for larger homes can be attributed to the fact that smaller homes have a higher proportion of plug and process loads than larger homes, and their envelope-to-floor area ratio is also proportionally greater than that of larger homes.

Considering the observed 12 % difference in total heating demand in the cold climate zone (CZ16) and the need for uniformity, it was decided to develop an additional prototype model for homes larger than 2,500 $ft^2$ in each climate zone.

Table 5: Sensitivity of CEC single-family prototypes energy consumption to floor area

| Climate zone | Total space heating and cooling ($kBtu/ft^2$) 2,100 ft2 | Total space heating and cooling ($kBtu/ft^2$) 2,700 ft2 | % Change |
|---|---|---|---|
| **CZ12** | 8.02 | 7.43 | 7% |
| **CZ15** | 6.75 | 6.55 | 3% |
| **CZ16** | 16.62 | 14.65 | 12% |

## 2.2. Single-family Prototypes Selection

### 2.2.1. Existing Single-Family Prototype Models

Current single-family prototype models from CEC and CPUC were reviewed. Both agencies provide two single-family prototypes, a one-story and a two-story model, and one of each for each climate zone. Figure 8 and Figure 9 display the geometry of one home in each of these models, and Table 6 compares some of their significant features. Despite the similarity in the size of the two-story home in the models, the one-story home of the CEC prototype has a larger floor area compared to the one-story home of the CPUC prototype. Each CPUC single-family prototype consists of two homes oriented with a 90-degree difference, surrounded by shading on all sides (as can be seen in Figure 10).

The current CEC prototype models (both 2,100 $ft^2$ and 2,700 $ft^2$) are representative of code editions and not vintages; however, for CPUC's use cases, the age of the existing building stock and its incorporation into the prototypes are significant factors. The CPUC single-family prototype models were originally developed for eQUEST/DOE2 and were based on eleven vintage bins. However, CPUC were in the process of transitioning the models to EnergyPlus™, and during this process CPUC simplified the vintage selection strategy and used one vintage for each climate zone. In doing so, CPUC now offers two single-family prototype models for each climate zone: one for existing buildings that consist of one vintage (out of two), and another for newly constructed buildings. The models for existing homes have been characterized based on the vintage and floor area distributions in each climate zone. They exclusively rely on either 1975 (pre-1978) or 1985[4] vintage, chosen based on the predominant vintage of the homes (year built) within each climate zone [5].

Table 6: CPUC and CEC single-family prototype characteristics

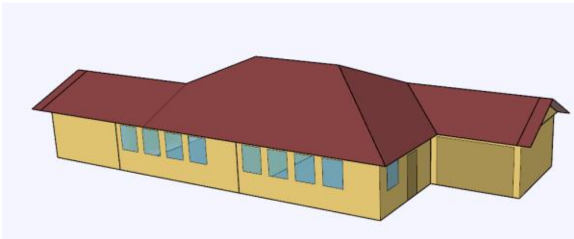
| Prototype feature | CEC | CPUC |
|---|---|---|
| Number of stories | One-story & two-story | One-story & two-story |
| Conditioned floor area ($ft^2$) of each home | 2,100 & 2,700 | 1,453 & 2,906 |
| Number of bedrooms in each home | 3 & 4 | 3 & 3 |
| Vintage | No vintage<br>New Construction model per climate zone | One vintage per climate zone<br>CZs 1-9: pre-1975 and New Construction<br>CZs 10-16: 1985 and New Construction |


(One-story)

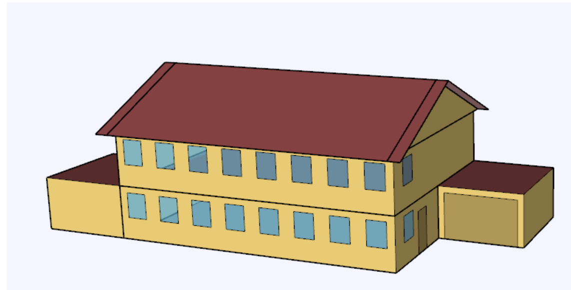

(Two-story)

Figure 8: CEC single-family prototypes 3D view (Source: [6])

[4] '1985' is used to refer to a period after 1978, but the exact period is unclear from the CPUC document [5].

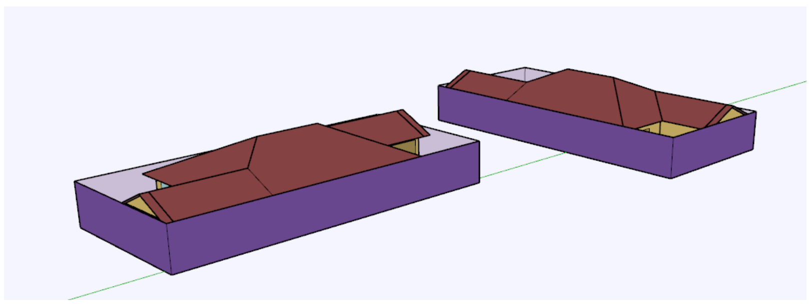


(One-story)



(Two-story)

Figure 9: Single-family CPUC prototype with crawlspace below conditioned area (Source: [7])



(One-story prototype)

(Two-story prototype)

Figure 10: CPUC single-family prototype (Source: [7])

### 2.2.2. Single-Family Prototype Composition

The floor area distribution by vintage and floor area bins provides a clear direction for the prototype mix. Based on the building stock assessment, a set of vintage bins and prototype mix was formulated and proposed to the TAG. After discussion with the TAG, a decision was made to represent California single-family building stock through four types of prototype models, as shown in Table 7, in five vintage bins per climate zone, as shown in Table 8.

Table 7 shows the key features of the single-family prototype models. There are four prototypes, with increasing floor area, from 1,250 ft$^2$ and up to 2,750 ft$^2$, with a spread of 500 ft$^2$ between two prototypes. The number of stories and bedrooms align with the floor area. For each prototype, the foundation type was set to concrete slab-on-grade for 67% of the floor area and the crawlspace assembly for 33% of the rest of the floor (as discussed in Section 2.1.3.5.1 and following Table 3).

The approach used for proposing the prototype mix aimed at balancing the needs of the agencies with the need to represent the various trends observed in the floor area, vintage, and other stock attributes. With the four prototypes and their variation within each climate zone, and by applying weighting factors, it is possible to represent the California residential single-family building stock properly. These are the primary single-family prototype models. However, other variations of the prototype models were identified while collecting the input data, which are presented in the next section.

Table 7: Single-family prototype composition

| Prototype name | Floor area ($ft^2$) | Number of stories | Number of bedrooms |
|---|---|---|---|
| SF1250 | 1,250 | 1 | 2 |
| SF1750 | 1,750 | 1 | 3 |
| SF2250 | 2,250 | 2 | 4 |
| SF2750 | 2,750 | 2 | 4 |

Table 8: Vintage bins of single-family prototypes

| Vintage bin | Prototype |
|---|---|
| Pre-1975 | four single-family prototypes |
| 1975-1983 | four single-family prototypes |
| 1984-2005 | four single-family prototypes |
| 2006-2019 | four single-family prototypes |
| New Construction | four single-family prototypes |

## 2.3. Inputs Collection

After determining the prototypes mix, the next step was to collect model inputs for each prototype. Table 9 shows the list of necessary modeling inputs needed for each prototype. This list was subsequently expanded in a spreadsheet format, with some of the key inputs presented in “Appendix B: Inputs for SF”.

### 2.3.1. Sources Used

Model input data for single-family prototypes was collected from the sources listed below.

- 2019 Residential Appliance Saturation Study (RASS) [2].
- NREL ResStock Database (ResStock) [8]
- Building Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24) [9]
- California Appliance Efficiency Regulations (Title 20) [10]
- California Energy Commission (CEC) [11]
- Building America House Simulation Protocols [12]
- California's Building Energy Code Compliance Software - Residential (CBECC-Res) [4]
- PNNL Residential Prototype Buildings [13]
- Code of Federal Regulations, Title 10 CFR 430 [14]

The input data define various features of the prototype models by vintage and climate zone. For each building characteristic, the priority was to extract the data from the building stock; otherwise, the data was obtained from other resources. For certain characteristics, such as aspect ratio and floor height, the current PNNL and CEC prototypes were used as a reference.

RASS was the primary resource to extract building stock information, while ResStock was utilized to cross-reference the RASS data and extract data for inputs that were either unavailable or limited by RASS. Title 24 (or other codes) was referenced for some characteristics, such as U/R values, particularly for “New Construction” or when RASS or ResStock lacked the required data. Other sources, such as Ecobee [15], were consulted when the data from RASS or ResStock was insufficient. “Appendix B: Inputs for SF” presents the most important input data for single-family prototypes.

Table 9: Summary of the data sources overview

| Tab | Characteristic | Source | Notes |
|---|---|---|---|
| Building Description | Aspect Ratio | PNNL Residential Prototype [13] | |
| | WWR | ResStock [8] | |
| | Floor Height | CEC Prototypes [16] | |
| | Framing | RASS [2] | |
| | Foundation | RASS [2] | |
| | U-factor /R-values | RASS [2] /ResStock [8] /Title 24, 2022 [9] | From RASS where possible, otherwise ResStock. New Construction from Title 24, 2022. |
| Envelope | Walls | ResStock [8] | No viable RASS data. |
| | Roof | RASS [2] | Based on "inches of attic insulation". |
| | Slab | ResStock [8] | No viable RASS data. |
| | Window U-factor | RASS [2] | Validated with ResStock. |
| | Window SHGC | RASS [2] | Validated with ResStock. |
| | Air Leakage | ResStock [8] | No viable RASS data. |
| Lighting | Interior | Building America [12] | |
| | Exterior | RESNET [17] | |
| | Lamp Type | RASS [2] | Generally, less incandescent, more CFL/LED in newer vintages. |
| Appliances | Design Level | Building America [12] | Calculated from the Building America schedule with RASS annual consumption. |
| | Consumption | RASS [2] | |
| | Saturation | RASS [2] | |
| People | Heat Gain | CEC Prototypes [16] | |
| HVAC | Heating Fuel | RASS [2] /ResStock [8] | RASS primary but checked against ResStock when data were thin. |
| | Air Conditioner Present | RASS [2] /ResStock [8] | RASS primary but checked against ResStock when data were thin. |
| | Efficiency | 10 CFR 430 [14] | |
| Fan | Power | Title 24 [9] | Based on the effective date and age of the cooling equipment. |
| Thermostat | Setpoints | Ecobee [15] | Ecobee shared user data for another project and allowed us to use it here. |
| | Setback | | None (prior to validation). |
| DHW | DHW Fuel | RASS [2] /ResStock [8] | RASS as the primary source but checked against ResStock when data were thin; Title 24 for new. |
| | Efficiency | 10 CFR 429, 430, 431 [14] | |
| Schedules | Appliances | Building America [12] | Not including hot water appliances. |
| | Occupancy | CEC Prototypes [16] | |
| | Lighting | CPUC [7] and PNNL [13] Residential Prototype | |
| | DHW Fixtures | CEC Prototypes [16] | |

### 2.3.2. HVAC and DHW Systems

#### 2.3.2.1. Space Heating

Distribution of the heating fuel type in single-family homes across the vintage bins and climate zones (Figure 11) illustrates that gas is the primary fuel type in California. However, at the climate zone level, it becomes apparent that alternative fuel types dominate in certain climate zones. To enhance prototype coverage, two sets of models were considered for representing the heating system in individual climate zones:

- **SET1:** Gas space heating. All prototype models in all climate zones and vintage bins modeled with gas as the primary source for space heating. Gas-powered furnaces were the most common system in nearly all climate zones. This set of models would provide ample coverage of the building stock for statewide analyses.
- **SET2:** Gas or electric space heating. This set of models includes either gas or a mixture of gas and electricity as the primary source of heating. Specifically, in each climate zone and vintage bin, the heating fuel was selected depending on whether gas achieves at least 75% saturation. If so, the fuel type was designated as gas; otherwise, a second model with electricity heating fuel was considered. Thus, for those climate zones where gas does not meet the 75% threshold, there will be two models under SET2—one with gas and another with electricity as the heating system's fuel type). SET2 models are intended for analysis at the climate zone level, where better representation of impacts within the climate zone is desired.

For the "New Construction" prototype models, the 2022 Title 24 Building Standards [9] were used to define whether the space heating should be a gas furnace or heat pump.

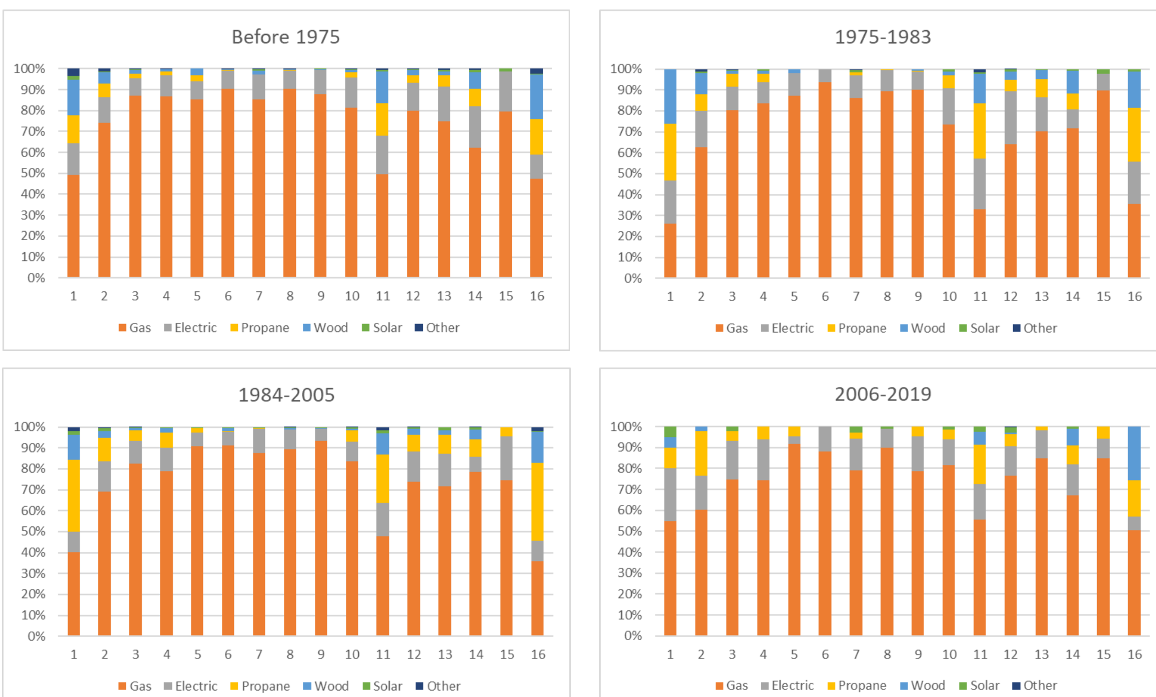



Figure 11: Distribution of single-family heating fuel type (Source: RASS 2019 [2])

Table 10 indicates the climate zones and vintage bins that need additional models with a different heating system in single-family prototypes.

Table 10: Mapping SET2 of single-family heating fuel type to climate zones and vintage bins (Source: RASS 2019 [2])

| Vintage bin | CZ1 | CZ2 | CZ3 | CZ4 | CZ5 | CZ6 | CZ7 | CZ8 | CZ9 | CZ10 | CZ11 | CZ12 | CZ13 | CZ14 | CZ15 | CZ16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pre-1975 | Mix | Mix | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Mix | Gas | Mix | Mix | Mix | Mix |
| 1975-1983 | Mix | Mix | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Mix | Mix | Mix | Mix | Mix | Gas | Mix |
| 1984-2005 | Mix | Mix | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Mix | Mix | Mix | Gas | Mix | Mix |
| 2006-2019 | Mix | Mix | Mix | Mix | Gas | Gas | Gas | Gas | Gas | Gas | Mix | Gas | Gas | Mix | Gas | Mix |
| New Construction | Gas | Gas | HP | HP | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | HP | HP | Gas | Gas |

Note: Mix = Presence of gas and electric space heating; no single heating fuel is dominant.

### 2.3.2.2. Space Cooling

Unlike heating systems, which are commonly found in residential buildings across all climate zones, the presence of cooling systems in single-family homes varies. In certain climate zones (e.g., climate zones 1, 3, and 5) many older single-family homes lack any form of cooling. Table 11 illustrates the availability of cooling systems in single-family homes, categorized by climate zones and vintage bins.

Table 11: Availability of cooling systems in various climate zones and vintage bins for single-family homes (Source: RASS 2019 [2])

| Vintage bin | CZ1 | CZ2 | CZ3 | CZ4 | CZ5 | CZ6 | CZ7 | CZ8 | CZ9 | CZ10 | CZ11 | CZ12 | CZ13 | CZ14 | CZ15 | CZ16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pre-1975 | No | Yes | No | Yes | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| 1975-1983 | No | Yes | Yes | Yes | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| 1984-2005 | No | Yes | Yes | Yes | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| 2006-2019 | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| New Construction | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

### 2.3.2.3. HVAC Efficiency

Given that HVAC systems have a shorter lifespan compared to the buildings they serve, it is highly likely that older buildings have undergone updates to their HVAC systems. Consequently, the efficiency of HVAC infrastructure varies across different age categories. According to RASS 2019 data [2], the average lifespan of HVAC system in single-family homes is 15, 14, and 16 years for vintages pre-1975, 1975-1983, and 1984-2005, respectively. For these three vintages, Annual Fuel Utilization Efficiency (AFUE) was selected as 78%, meeting the 10 CFR requirements effective at the time. For buildings constructed between 2006-2019, the heating efficiency was based on the 2013 10 CFR, with AFUE 80. And for the new construction bin, heating efficiency was set to 80%, as required by Title 24, 2022 [9].

Table 12 summarizes furnace efficiencies that were selected to match the enacted code requirements at the time of installation.

Table 12: HVAC efficacy for single-family prototype models

| Vintage bin | Heating efficiency | Cooling efficiency |
|---|---|---|
| Pre-1975 | AFUE 78 | SEER 13.0 |
| 1975-1983 | AFUE 78 | SEER 13.0 |
| 1984-2005 | AFUE 78 | SEER 13.0 |
| 2006-2019 | AFUE 80 | SEER 14.0 |
| New Construction | 80% Ec | SEER2 14.3 |

Note: SEER = Seasonal Energy Efficiency Ratio
SEER 2 = Seasonal Energy Efficiency Ratio under updated blower testing procedure
Ec = Efficiency of Combustion (100% less flue losses)

#### 2.3.2.4. DHW

Similar to the space heating system, the distribution of the DHW system for single-family homes was investigated over vintage bins and climate zones (Figure 12). The study revealed that there was more than one dominant fuel type at the climate zone level. As was done for the space heating fuel type, two sets of fuel types were considered for the DHW system of single-family prototype models including:

- **SET1:** Gas as the source of the DHW system. All prototype models–within 16 California climate zones as well as four vintage bins–were modeled with gas as the primary source of water heating.
- **SET2:** Gas or electricity or mix as the primary source of the DHW system. Within every climate zone and vintage bin, multiple models may be created representing the fuel type of the DHW system.

For the "New Construction" prototype models, the 2022 Title 24 Building Standards [9] were used to define whether the water heater should be an instantaneous gas water heater[5] or a heat pump water heater (HPWH).

[5] Gas tankless water heater

Figure 12: Distribution of the single-family DHW fuel type (Source: RASS 2019 [2])

Table 13 highlights the climate zones and vintage bins that require additional single-family prototype models with different water heating systems.

Table 13: Mapping SET2 of DHW Fuel type to climate zones and vintage bins (Source: RASS 2019 [2])

| Vintage bin | CZ1 | CZ2 | CZ3 | CZ4 | CZ5 | CZ6 | CZ7 | CZ8 | CZ9 | CZ10 | CZ11 | CZ12 | CZ13 | CZ14 | CZ15 | CZ16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Pre-1975** | Mix | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Mix | Gas | Gas | Gas | Gas | Mix |
| **1975-1983** | Electric | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Mix | Gas | Gas | Gas | Gas | Mix |
| **1984-2005** | Mix | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Mix |
| **2006-2019** | Mix | Mix | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Mix | Gas | Gas | Gas | Gas | Mix |
| **New Construction** | HPWH | HPWH | Insta. Gas | Insta. Gas | HPWH | HPWH | HPWH | HPWH | HPWH | HPWH | HPWH | HPWH | Insta. Gas | Insta. Gas | HPWH | HPWH |

Note: Mix = No single heating fuel is dominant.

### 2.3.2.5. DHW Efficiency

To determine the DHW efficiency inputs, we calculated a Uniform Efficiency Factor (UEF) for each model. These calculations were carried out using equations from the Water Heater Analysis Model (WHAM), incorporating 10 CFR Parts 429, 430, and 431 [14], along with a procedure developed by the National Renewable Energy Laboratory (NREL) [18]. More specifically, we converted the Efficiency Factor (EF) to UEF using the following equations:

$$UA_{gas} = \frac{\frac{RE}{UEF} - 1}{(T_{set} - T_{amb})\frac{t_d}{Q_{load}} - \frac{T_{set} - T_{amb}}{P_{in} * UEF}}$$

$$UA_{elec} = \frac{Q_{load}(\frac{1}{UEF} - 1)}{t_d(T_{set} - T_{amb})(f_{high} + f_{low}\left(\frac{T_{inlet} - T_{amb}}{T_{set} - T_{amb}}\right))}$$

These two equations were driven based on certain assumptions. These assumptions involve a thermal efficiency of 80% for gas burners and 100% for electric burners. Moreover, the setpoint temperature was assumed to be 120°F and the recovery efficiency was set at 79%. Table 14 provides an overview of the UEF values considered in the calculations.

Table 14: HVAC efficacy for single-family prototype models

| Vintage | Gas (EF) | Gas (UEF) | Electric (EF) | Electric (UEF) | HPWH (UEF) |
|---|---|---|---|---|---|
| Pre-1975 (EF) | 0.58 | 0.56 | 0.90 | 0.89 | NA |
| 1975-1983 (EF) | 0.58 | 0.56 | 0.90 | 0.89 | NA |
| 1984-2005 (EF) | 0.58 | 0.56 | 0.90 | 0.89 | NA |
| 2006-2019 (EF) | 0.60 | 0.58 | 0.90 | 0.89 | NA |
| New Const. (UEF) | NA | 0.56 | NA | 0.92 | CZ 1,2,5: 2.82<br>CZ 6,8,9,10,15: 2.47<br>CZ 7,11: 2.61<br>CZ 16: 3 |

## 2.3.3. DHW, Infiltration, and Schedules Inputs Development

### 2.3.3.1. DHW

The hot water draw schedule is one of the most important variables impacting energy consumption and energy cost, particularly when it comes to heat pump water heaters. Two DHW schedule modeling approaches were investigated.

1. Weekday and weekend schedules, which do not vary by day or time of the year.
2. Stochastic minute-based schedules, which vary by time of the day and time of the year. These schedules are used by CBECC-Res to model heat pump water heaters. Because the CEC models use time-dependent metric, a shuffling scheme is used with the schedules to provide diversity, as would be the case with a population of homes.

The stochastic approach requires using a CSV file using the "*Schedule:File*" object in EnergyPlus™. Upon discussion with the TAG, it was decided that the minute-based schedules were appropriate for modeling heat pump water heaters, but that those minute-based schedules do not provide any benefit to gas water heaters, whose performance is not weather-based and nor are the energy cost impacts different by the time of use.

To minimize model complexity and simulation time, for natural gas DHW models, the minute-based stochastic schedules were aggregated into hourly schedules for each of the DHW fixtures. These schedules vary for each hour across a representative day, encompassing the entire year. Thus, while the same underlying CEC schedules were used, the complexity was reduced. It should be noted that for HPWH, minute-based stochastic schedules would be used, which would include 25 schedules[6] for each prototype model. The HPWH schedules consist of 5 different fixture types (bathtub, clothes washer, dishwasher, faucet, shower) as well as 5 different schedules for each fixture (accounts for shuffling impacts). In addition, the stochastic schedules vary based on the number of bedrooms. Thus, model SF1250 (with 2 bedrooms) has a different schedule compared to model SF1750 (with one bedroom) and SF2250 (with three bedrooms) as well as model SF2750 (with four bedrooms).

#### 2.3.3.2. Infiltration

Several infiltration approaches were reviewed to characterize their benefits and limitations when modeling air leakage through envelopes and predicting air infiltration rates in buildings. The approaches include the Lawrence Berkeley Laboratory (LBL) model [19], the Alberta air Infiltration Model (AIM-2) – also known as the EMS approach, and the Airflow Network (AFN) model. A summary of these approaches is presented in Table 15.

Table 15: Summary of the infiltration approach

| Aspect | LBL | AIM/EMS | AFN |
|---|---|---|---|
| Typical field-tested inputs inform the model, i.e., end-user-friendly | Yes | Yes* | No |
| Improved accuracy | No | Yes | Yes |
| Native deployment on multiple modeling engines/platforms | Yes | No* | Yes |
| Captures leakage effect in existing residential building scenarios | Yes | Yes | Yes |
| Captures leakage effect in new residential building scenarios | Yes | Yes | Yes |
| Captures envelope and HVAC duct leakage | No | Yes* | Yes |

Note: *Depends on pre-processor and user interface.

The decision-making process took into account the limitations associated with each approach. Specifically, AFN requires substantial input details that were not available for this study. The most reliable field data for modeling infiltration, air change per hour at 50 pascal (ACH 50), limits flexibility in selecting approaches which require several inputs. Therefore, the LBL simplified model [19] was selected because it relies primarily on homes tightness (ACH50) and weather files. In addition, a CONTAM-informed approach was investigated as a potential improvement to the accuracy of the simplified model approach. CONTAM is a physics-based simulation engine specifically for modeling air leakage and duct leakage in buildings. In the CONTAM approach, a standalone leakage preprocessor provides coefficients to inform the simpler leakage model. It is possible to use CONTAM for deriving simplified coefficients that can then be used in EnergyPlus™. This type of hybrid CONTAM-EnergyPlus approach may be investigated later.

[6] Each schedule is a stochastic 60*24*365 minute-based schedule.

#### 2.3.3.3. Occupancy/activity schedules

To calculate the amount of heat gained by the building occupants (both sensible and latent), a consistent activity schedule was defined for all single-family models (SF1250, SF1750, SF2250, SF2750). This schedule was defined based on the CBECC-Res activity schedule, with a baseline activity assumed to generate 117.28 Watts/person. The number of people per home was determined based on the number of bedrooms and incorporated into the models, as shown in Table 16 below. A radiant fraction of 0.3 and a sensible heat fraction of 0.573 was assumed.

Table 16: Number of bedrooms and people distribution within single-family models

| Model | SF1250 | SF1750 | SF2250 | SF2750 |
|---|---|---|---|---|
| Number of bedrooms | 2 | 2 | 3 | 4 |
| Number of people | 2.55 | 2.55 | 2.95 | 3.35 |

#### 2.3.3.4. Other schedules

The appliance design load was determined by combining the annual Unit Energy Consumption (UEC) from RASS and using schedule assumptions sourced from Building America [12]. Table 17 provides a summary of the UEC numbers and saturation (from RASS), and schedules. For interior lighting, RASS does not provide data and the application of ASHRAE 90.2 [20] lighting assumptions results in a very high lighting load (e.g., 30% of the total electricity load in Prototype SF-1750 in climate zone 7). Therefore, the CPUC models [7] were used to calculate the annual interior lighting consumption and the lighting power density (LPD) was set to 2 Watts/$m^2$.

Table 17: Other schedules, consumption, and design loads within single-family models

| Appliances | Annual Average Design Level (RASS 2019 [2]) | Annual Consumption (RASS 2019 [2]) | Saturation | Schedules |
|---|---|---|---|---|
| Washer | 28.5 W | 94 kWh | 94% | Building America Standard Schedules |
| Dryer | 141.2 W | 552 kWh | 35% | Building America Standard Schedules |
| Dishwasher | 44.3 W | 93 kWh | 74% | Building America Standard Schedules |
| Refrigerator | 164.6 W | 1,209 kWh | 100% | Building America Standard Schedules |
| Cooking Range/Oven | 166.0 W | 404 kWh | 43% | Building America Standard Schedules |
| Microwave | 64.5 W | 157 kWh | 90% | Building America Standard Schedules |
| TV | 169.4 W | 483 kWh | 66% | Building America Standard Schedules |
| Miscellaneous (plug load, home office, PC) | 414 W | 2,450 kWh | 100% | Building America Standard Schedules |
| Lighting (Exterior) | 88 W | 251 kWh | 76% | Building America Standard Schedules |

## 2.4. Single-Family Prototype Models Composition

Table 18 lays out the various combinations of single-family prototype models in each vintage bin. These models differ not only in geometry and building characteristics but also in heating and DHW systems, where applicable. As shown, a total of 524 prototype models are planned to be developed, including both SET1 and SET2.

Table 18: Single-family prototype composition

| Vintage bin | Geometry | Climate Zone | Heating fuel type | DHW fuel type | Number of models | Models<br>H=Heating System |
|---|---|---|---|---|---|---|
| Pre-1975 | 4 forms | 16 | 2 sets:<br>SET1: Gas in all CZs<br>SET2: Electric in 7 CZs [1,2,11,13,14,15,16} | 2 sets:<br>SET1: Gas in all CZs<br>SET2: Electric in CZ 1 and Propane in CZ 2 | 100 | 4*16: models with Gas H & Gas DHW in all CZs<br>4*5: models with Electric H & Gas DHW in CZs 11,13,14,15,16<br>4*1: models with Electric H & Electric DHW in CZ 1<br>4*1: models with Electric H & Propane DHW in CZ 2<br>4*1: models with Gas H & Electric DHW in CZ 1<br>4*1: models with Gas H & Propane DHW in CZ 2 |
| 1975-1983 | 4 forms | 16 | 2 sets:<br>SET1: Gas in all CZs<br>SET2: Electric in 8 CZs {1,2,10,11,12,13,14,16} | 2 sets:<br>SET1: Gas in all CZs<br>SET2: Electric in CZ 1 and Propane in CZ 2 | 104 | 4*16: models with Gas H & Gas DHW in all CZs<br>4*6: models with Electric H & Gas DHW in CZs 10,11,12,13,14,16<br>4*1: models with Electric H & Electric DHW in CZ 1<br>4*1: models with Electric H & Propane DHW in CZ 2<br>4*1: models with Gas H & Electric DHW in CZ 1<br>4*1: models with Gas H & Propane DHW in CZ 2 |
| 1984-2005 | 4 forms | 16 | 2 sets:<br>SET1: Gas in all CZs<br>SET2: Electric in 7 CZs {1,2, 11,12,13,15,16} | 2 sets:<br>SET1: Gas in all CZs<br>SET2: Propane in CZ 1 | 96 | 4*16: models with Gas H & Gas DHW in all CZs<br>4*6 models with Electric H & Gas DHW in CZs 2,11,12,13,15,16<br>4*1: models with Electric H & Propane DHW in CZ<br>4*1: models with Gas H & Propane DHW in CZ |
| 2006-2019 | 4 forms | 16 | 2 sets:<br>SET1: Gas in all CZs<br>SET2: Electric in 7 CZs {1,2,3,4,11,14,16} | 2 sets:<br>SET1: Gas in all CZs<br>SET2: Electric in CZ 3 | 96 | 4*16: models with Gas H & Gas DHW in all CZs<br>4*6: models with Electric H & Gas DHW in CZs 1,2,4,11,14,16<br>4*1: models with Electric H & Electric DHW in CZ 34*1: models with Gas H & Electric DHW in CZ 3 |
| New Construction | 4 forms | 16 | 2 sets:<br>SET1: Gas in all CZs<br>SET2: HP in 4 CZs 3,4,13,14} | 2 sets:<br>SET1: Gas in all CZs<br>SET2: Instant Gas in 4 CZs {3,4,13,14} & HPWH in the other 12 CZs. | 128 | 4*16: models with Gas H & Gas DHW<br>4*4: models with HP H & Instant Gas in CZs 3,4,13,14<br>4*12: models with Gas H & HPWH in CZs 1,2,5,6,7,8,9,10,11,12,15,16 |
| 5 | 4 | 16 | 2 Sets | | **524** | **Total** |

Note: SET2 models are scheduled for development in 2024.

## 2.5. Single-Family Prototype Model Construction

The construction of the single-family prototype models was carried out in four steps:

1. Develop four base prototype models with SET1 of the space heating system and SET1 of the DHW system (Section 2.5.1) for CZ 12.
2. Expand the SET1 base models to all vintage bins in CZ 12 and then to all climate zones (Section 2.5.2).
3. Generate SET2 of the base prototype models by changing the space heating and DHW system from SET1 to SET2, if applicable according to Table 10 and Table 13. (Section 2.5.1).
4. Expand the SET2 base models to all vintage bins and all climate zones (Section 2.5.2).

The modeling process of SET1 prototypes (Step 1 and 2) has been completed; however, the development of SET2 models (Steps 3 and 4) is scheduled for 2024. The process of creating the base models and expanding them to all climate zones is discussed below.

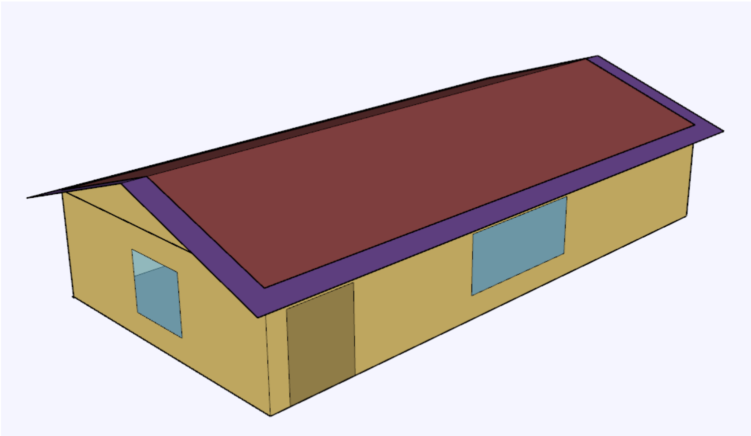
### 2.5.1. Modeling Approach

EnergyPlus™ [21] has been selected for the energy modeling of the prototypes. It is a well-known open-source energy modeling software with detailed calculation algorithms and the capability to model a wide range of HVAC systems and conservation measures. EnergyPlus™ generates reliable results and is commonly used for compliance with energy codes and standards; however, it does not have a graphical interface. To address this difficulty, SketchUp Pro was selected for the 3D design of the single-family prototypes. SketchUp with OpenStudio® plugin provides an energy simulation package with a design interface that integrates with EnergyPlus™. In this project, only the 3D design functionality of SketchUp OpenStudio® Plugin was utilized for developing the prototype models. EnergyPlus™, itself, provides more flexibility and capabilities for modeling HVAC, DHW, and infiltration in comparison with OpenStudio®.

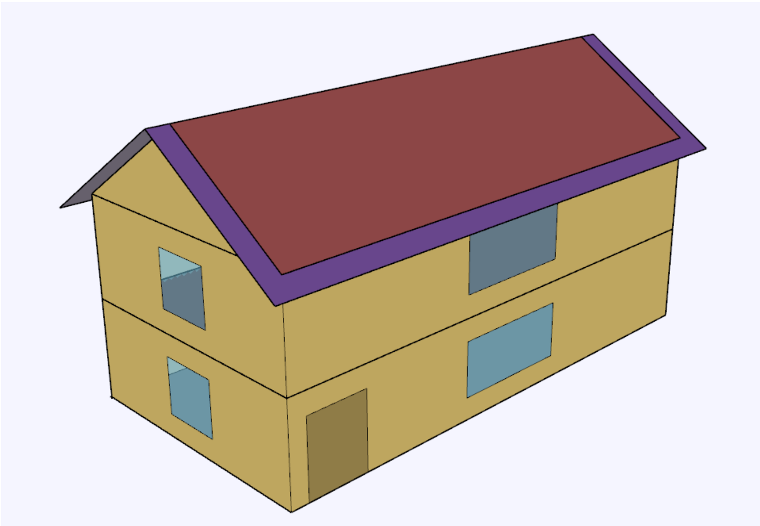
To develop the four base models, the geometry of each of the four types of single-family prototypes (SF1250, SF1750, SF220, SF2750) was generated separately in SketchUp Pro version 2023 based on SF input data (Appendix B: Inputs for SF). This includes the geometry of all elements of the building's envelope such as the floor, walls, roof, windows, overhangs, and door(s). Table 19 presents the characteristics of each geometry model, and Figure 13 displays the northeast view of the developed 3D geometry of the models in SketchUp. The height of each floor was set to 9 ft, and an attic roof type was used for each model. The distinction between the geometry of prototype SF1250 and SF1750 is solely in the floor area, not in the height of the building or WWR; hence, both models provide the same view, as presented within one group. Similarly, the SF2250 and SF2750 differ only in floor area. It is important to note that even though the models share a similar appearance, they differ in their size and dimensions.

Table 19: Geometry characteristics of the single-family prototypes

| Prototype | form | Floor area ($ft^2$) | Aspect ratio | Number of stories | WWR | Number of zones |
|---|---|---|---|---|---|---|
| SF1250 | A | 1,250 | 2 | 1 | 12.7% | 2 (1 units & 1 attic) |
| SF1750 | B | 1,750 | 2 | 1 | 12.7% | 2 (1 units & 1 attic) |
| SF2250 | C | 2,250 | 2 | 2 | 12.7% | 3 (2 units & 1 attic) |
| SF2750 | D | 2,750 | 2 | 2 | 12.7% | 3 (2 units & 1 attic) |



Schematic for Prototype SF1250 and SF1750



Schematic for Prototype SF2250 and SF2750

Figure 13: N-E view of the single-family prototype models

Once the geometry design of the prototypes was finalized, the 3D design models were exported to EnergyPlus™ in the "idf" format. To carry out the remaining simulation tasks in EnergyPlus™, it was necessary to identify the following parameters for each prototype:

- Climate zone
- Vintage bin
- Set of HVAC/DHW

Table 20 presents the specifications of the base single-family prototype for the above-mentioned parameters. As can be seen in this table, the base prototypes are representative of the buildings constructed pre-1975 in climate zone 12. They are equipped with gas heating and gas DHW systems.

Table 20: Specifications of the base single-family prototype models

| Feature | Base single-family prototype |
| --- | --- |
| Vintage bin | Pre-1975 |
| Climate zone | Sacramento |
| Heating fuel type | Gas heating (SET1) |
| DHW heating type | Gas DHW (SET1) |

By identifying the prototype characteristics, the four base models were simulated individually using the step-by-step process described below (Figure 14) and by using the specific input data presented in "Appendix B: Inputs for SF". The approach previously described in Section 2.3.2 and Section 2.3.3 has been applied to model the HVAC, DHW, and infiltration systems. Following the modeling process, each model's output was verified by checking for unmet hours and error messages. Unmet hours were limited to 300. Having the base models, the next step was to expand the models to all climate zones and vintage bins using the input data.

Develop prototype form in SketchUp and export it to EnergyPlus™ (E+)

Open the file in E+ and set the simulation assumptions and building description such as surface convection algorithm, zone timestep, zoning assumptions, location, and design data information in E+

Assign constructions and add material input data to the opaque elements of the model (wall, roof, floor, door, overhang, and blin)

Assign constructions and add material input data to the glazing elements (including frame) of the model in E+

Add schedules, including occupancy and activity, appliance, lighting, HVAC system, setpoints, temperature, and infiltration

Add internal gains: people, lighting, and electric and gas appliances, and exterior equipment (lights)

Add HVAC system

Add DHW system

Add infiltration

Run and validate the model behavior (unmet hours and review of error messages)

Figure 14: The process of prototype energy modeling

### 2.5.2. Expansion to Climate Zones

Prototype model expansion refers to the process of developing all the combinations of the prototype models from the base models. The models' expansion was carried out by utilizing NORESCO's internal parametric simulation infrastructure to perform parametric simulation runs. Using this tool, each SET1 base prototype model was expanded to all 16 climate zones and all five vintage bins using input data presented in "Appendix B: Inputs for SF". Performing the same process for all the base models, all combinations of the SET1 prototype models were generated following the steps outlined in Table 18.

## 2.6. Single-Family Prototype Models' Validation

### 2.6.1. Validation Approach

The single-family prototype SET1 models went under validation against the appliance consumption in RASS. Appliance consumption is specified at the climate zone level, and therefore, prototype model consumption must be aggregated at the climate zone level to perform validation. RASS's climate-zone weighted appliance consumption was developed using statistical techniques. It is the average consumption of an appliance within the sample and is expected to be at the 50th percentile in a normal distribution. As such, given the wide variability of consumption patterns in the building stock, and the fact that there are four prototype models and five vintage bins in each climate zone, there is potential for the aggregated consumption to depart from the mean and still be considered appropriate.

The following process was followed to perform the validation:

- End-use consumption from the four prototype models for each of the five vintage bins in each climate zone was aggregated, such that there was a single number for each end-use in each climate zone. Floor area weighting factors provided in Section 2.6.3 were used.
- Validation was performed at the CZ and end-use level for the following end-uses:
    - Cooling and heating
    - Water heating
    - Lighting
    - Plug and process loads (washer, dryer, and miscellaneous loads)

### 2.6.2. Adjustments

RASS provides annual appliance consumption data in the form of 'unit energy consumption' or UEC. The UECs of various appliances for single-family buildings were used to validate the prototype model output. As described previously, model validation was performed at the climate zone level. For certain end-uses, such as dishwashers, the consumption does not vary by climate zone, and therefore, these end-uses could be validated at the statewide level.

- Lighting, washer/dryer, and plug load consumption: These end-uses are a function of the peak load and the schedule. UEC from RASS was combined with Building America schedules to determine the design load for systems (as discussed in Section 2.3.3.4). In this case, the model output was checked to confirm that it matches the RASS-predicted consumption. As expected, reported end-uses varied by less than 1 percent.
- Water heating: DHW consumption is a function of the number of occupants, which in turn is a function of the number of bedrooms and floor area of the prototype. There is slight variation by climate zone because of the inlet water temperature variation. Peak draw and schedule were fixed by the assumptions. The available variables for adjustments were setpoint temperature and heat loss to ambient; to be adjusted across all CZs.
- Cooling and heating: These end-uses needed to be adjusted by climate zone. The key variables were as follows:

- Thermostat setpoint, setback and turn off.
- Infiltration.
- Duct leakage.
- Assumed equipment performance degradation with age.

Model output was compared to RASS data. It was observed that, without making any adjustments, the models-predicted cooling and heating end-use were not within an acceptable range of the RASS cooling and heating consumption in most climate zones.
When addressing cooling consumption, several actions were undertaken, including cutting down lighting power density to 2 Watts/$m^2$, decreasing the windows SHGC by 0.86% to factor in shadings and blinds impacts, and establishing a setback temperature of 80°F from 10:00 pm and 6:00 am. Additionally, the cooling system was set to operate seasonally and only from May 1st to October 30th.
Regarding heating consumption, there is a suspicion of significant duct losses, or a possibility that occupants are adjusting the thermostat to a higher setting during the heating season. This adjustment may be made to compensate for lower mean radiant temperatures in older homes lacking insulation. To decrease the heating consumption, the thermostat setpoint was decreased from 74°F to 69°F between 6 am to 9 pm and also was set to 66°F for the remaining hours of the day as the setback. Also, similar to cooling consumption, heating was set to run seasonally from January 1st to April 30th as well as November 1st to December 31st.
Applying the above-mentioned adjustment, the cooling and heating loads of the models approached RASS data, yet they still did not fall within an acceptable range. The validation process is ongoing and the outcomes will be reported separately in 2024.

### 2.6.3. Weighting Factors

The most important weighting factors for aggregating simulation results is the floor area-based weighting factors. Table 21 displays this set of factors for single-family prototype models by climate zones, single-family prototype forms, and vintage bins. Area-based weighting factors were extracted from RASS and used to aggregate simulation results at the state level. These factors were the only ones applied to the simulation results of SET1 prototype models.

For each vintage bin and climate zone, the simulation results of SET1 prototype models were multiplied by the related weighting factor. Combining all the aggregated results, the statewide-weighted energy consumption for single-family homes in California was calculated.

In addition to the mentioned above weighting factors, there are two additional weighting factors for SET2 prototype models. SET2 weighting factors will be incorporated into the simulation results of those single-family prototype models that are equipped with a mix DHW system and mix heating system. These two sets of weighting factors have not been developed yet and are scheduled to be done in 2024.

Table 21: Single-family prototypes weighting factors (Source: RASS 2019 [2])

| Vintage | Prototype | CZ1 | CZ2 | CZ3 | CZ4 | CZ5 | CZ6 | CZ7 | CZ8 | CZ9 | CZ10 | CZ11 | CZ12 | CZ13 | CZ14 | CZ15 | CZ16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pre-1975 | SF1250 | 0.00107149 | 0.008124 | 0.02254 | 0.009774 | 0.001964 | 0.015743 | 0.011192 | 0.020021 | 0.026778 | 0.024607 | 0.009875 | 0.033402 | 0.01585 | 0.007371 | 0.002302 | 0.002772 |
| | SF1750 | 0.00057901 | 0.00439 | 0.01218 | 0.005282 | 0.001061 | 0.008507 | 0.006048 | 0.010819 | 0.01447 | 0.013297 | 0.005336 | 0.01805 | 0.008565 | 0.003983 | 0.001244 | 0.001498 |
| | SF2250 | 0.00036576 | 0.002773 | 0.007694 | 0.003336 | 0.00067 | 0.005374 | 0.00382 | 0.006834 | 0.009141 | 0.0084 | 0.003371 | 0.011402 | 0.005411 | 0.002516 | 0.000786 | 0.000946 |
| | SF2750 | 0.00063001 | 0.004777 | 0.013253 | 0.005747 | 0.001155 | 0.009256 | 0.006581 | 0.011772 | 0.015745 | 0.014468 | 0.005806 | 0.019639 | 0.009319 | 0.004334 | 0.001353 | 0.00163 |
| 1975-1983 | SF1250 | 0.00028058 | 0.002127 | 0.005902 | 0.002559 | 0.000514 | 0.004122 | 0.002931 | 0.005243 | 0.007012 | 0.006444 | 0.002586 | 0.008747 | 0.00415 | 0.00193 | 0.000603 | 0.000726 |
| | SF1750 | 0.00015162 | 0.00115 | 0.003189 | 0.001383 | 0.000278 | 0.002228 | 0.001584 | 0.002833 | 0.003789 | 0.003482 | 0.001397 | 0.004726 | 0.002243 | 0.001043 | 0.000326 | 0.000392 |
| | SF2250 | 9.5779E-05 | 0.000726 | 0.002015 | 0.000874 | 0.000176 | 0.001407 | 0.001 | 0.00179 | 0.002394 | 0.0022 | 0.000883 | 0.002986 | 0.001417 | 0.000659 | 0.000206 | 0.000248 |
| | SF2750 | 0.00016497 | 0.001251 | 0.00347 | 0.001505 | 0.000302 | 0.002424 | 0.001723 | 0.003083 | 0.004123 | 0.003789 | 0.00152 | 0.005143 | 0.00244 | 0.001135 | 0.000354 | 0.000427 |
| 1984-2005 | SF1250 | 0.00057132 | 0.004332 | 0.012018 | 0.005212 | 0.001047 | 0.008394 | 0.005968 | 0.010675 | 0.014278 | 0.013121 | 0.005265 | 0.01781 | 0.008451 | 0.00393 | 0.001227 | 0.001478 |
| | SF1750 | 0.00030873 | 0.002341 | 0.006494 | 0.002816 | 0.000566 | 0.004536 | 0.003225 | 0.005769 | 0.007716 | 0.00709 | 0.002845 | 0.009624 | 0.004567 | 0.002124 | 0.000663 | 0.000799 |
| | SF2250 | 0.00019503 | 0.001479 | 0.004103 | 0.001779 | 0.000357 | 0.002865 | 0.002037 | 0.003644 | 0.004874 | 0.004479 | 0.001797 | 0.00608 | 0.002885 | 0.001342 | 0.000419 | 0.000505 |
| | SF2750 | 0.00033592 | 0.002547 | 0.007066 | 0.003064 | 0.000616 | 0.004936 | 0.003509 | 0.006277 | 0.008395 | 0.007715 | 0.003096 | 0.010472 | 0.004969 | 0.002311 | 0.000722 | 0.000869 |
| 2006-2019 | SF1250 | 0.00010979 | 0.000832 | 0.00231 | 0.001002 | 0.000201 | 0.001613 | 0.001147 | 0.002052 | 0.002744 | 0.002521 | 0.001012 | 0.003423 | 0.001624 | 0.000755 | 0.000236 | 0.000284 |
| | SF1750 | 5.9329E-05 | 0.00045 | 0.001248 | 0.000541 | 0.000109 | 0.000872 | 0.00062 | 0.001109 | 0.001483 | 0.001363 | 0.000547 | 0.001849 | 0.000878 | 0.000408 | 0.000127 | 0.000153 |
| | SF2250 | 3.7479E-05 | 0.000284 | 0.000788 | 0.000342 | 6.87E-05 | 0.000551 | 0.000391 | 0.0007 | 0.000937 | 0.000861 | 0.000345 | 0.001168 | 0.000554 | 0.000258 | 8.05E-05 | 9.7E-05 |
| | SF2750 | 6.4555E-05 | 0.000489 | 0.001358 | 0.000589 | 0.000118 | 0.000948 | 0.000674 | 0.001206 | 0.001613 | 0.001483 | 0.000595 | 0.002012 | 0.000955 | 0.000444 | 0.000139 | 0.000167 |
| **Total weight** | | **0.0050214** | **0.038071** | **0.105629** | **0.045804** | **0.009204** | **0.073776** | **0.052449** | **0.093827** | **0.12549** | **0.115318** | **0.046276** | **0.156533** | **0.074279** | **0.03454** | **0.010787** | **0.01299** |

# 3. Low-Rise Multifamily Prototype Development

To model the low-rise multifamily (LRMF) prototypes[7], the same process used in developing single-family prototype was applied. First, a building stock assessment was conducted, then the CEC and CPUC prototypes were evaluated against the characteristics of the building stock to determine whether existing prototypes could be leveraged for future work. Subsequently, a recommendation on the LRMF prototype mix was formulated and proposed to the TAG. After finalizing the primary characteristics, the required input data was collected from available sources. Following this, base prototype models were developed and tested in EnergyPlus™. With all the generated models in place, the next steps involve model expansion and validating the models' performance using the available stock data. In this way, and by applying area-based weighting factors, the validated statewide LRMF prototype models can support almost all the existing LRMF buildings in California. In the following sections, this process is discussed in more detail.

## 3.1. Multifamily Building Stock Assessment

The focus of the building stock assessment was to determine the LRMF prototype composition that best matches the LRMF building stock in California. The assessment relied on the California-specific residential survey, RASS [2], as the main resource, and the American Housing Survey [1] as a secondary resource. The primary attributes under consideration were floor area distribution across LRMF building types, vintage, climate zone, and number of bedrooms. The primary features of interest were:

a. distribution of the apartment floor area by area bins,

b. distribution of the apartment units by number of bedrooms,

c. distribution of the apartment floor area by number of bedrooms, and

d. distribution of the number of buildings by vintage and climate zone.

### 3.1.1. Mean Apartment Floor Area

Figure 15 shows the distribution of the floor area of individual apartment units by LRMF building types (2–4-unit, and 5+ unit apartment buildings). The mean floor area of individual apartments in 2–4-unit and 5+ unit apartment buildings is 1,105 $ft^2$ and 930 $ft^2$, respectively. This mean floor area is not differentiated by the number of bedrooms but would help compile LRMF prototype models so that the mean floor area of the units in the LRMF prototypes approximately matches the mean floor area of the LRMF buildings in the building stock.

[7] LRMF buildings in this report are defined as multifamily buildings three stories or less. Multifamily buildings with four or more stories will be analyzed together with the nonresidential building stock.

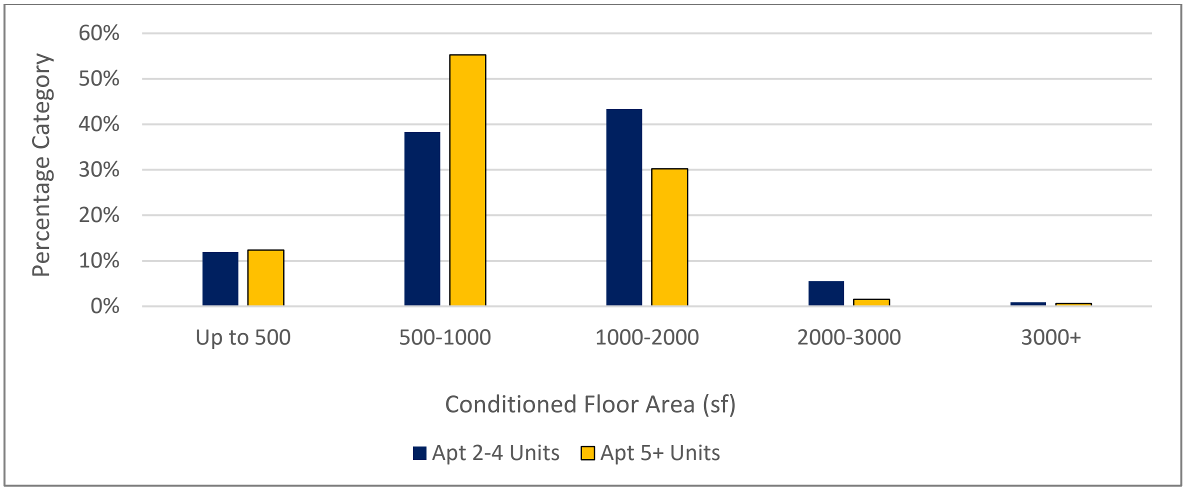



Figure 15: Conditioned floor area distribution of individual apartment units (Source: RASS 2019 [2])

### 3.1.2. Distribution by Number of Bedrooms

Figure 16 shows that within the 2–4-unit apartment building category, the majority of apartments are 2-bedroom units. Whereas, in 5+ unit apartment buildings, the proportion of 1-bedroom and 2-bedroom apartments is about even. There is also a small proportion of studio, 3-, and 4-bedroom apartments in both types of LRMF buildings.

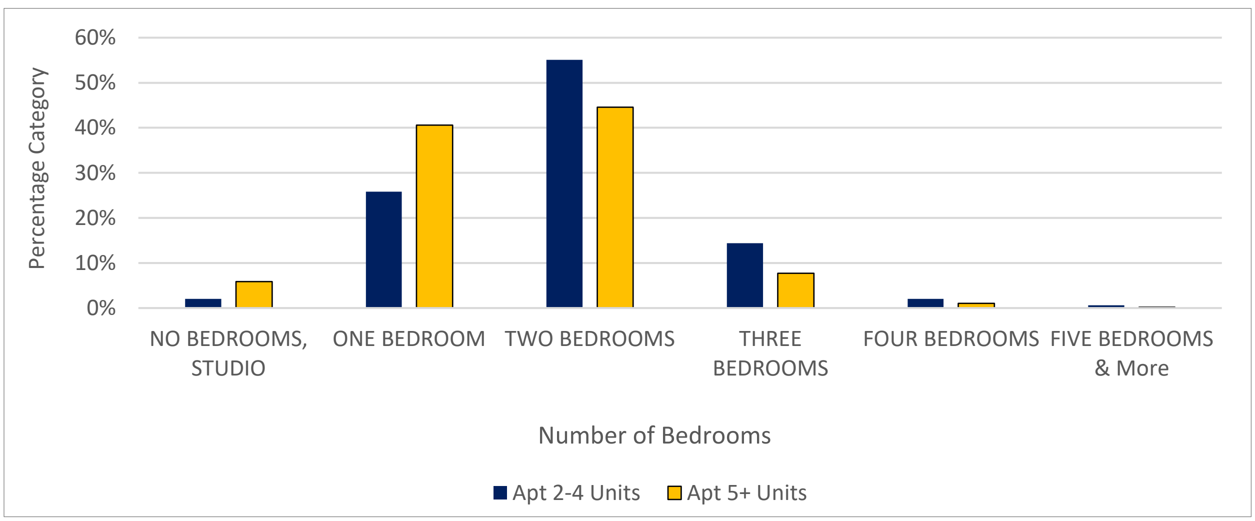



Figure 16: Distribution of apartment units by number of bedrooms (Source: RASS 2019 [2])

Figure 17 and Figure 18 display the floor area distribution by number of bedrooms for 2–4-unit and 5+ unit apartment buildings. This distribution shows how the mean floor area of apartments changes with the number of bedrooms.

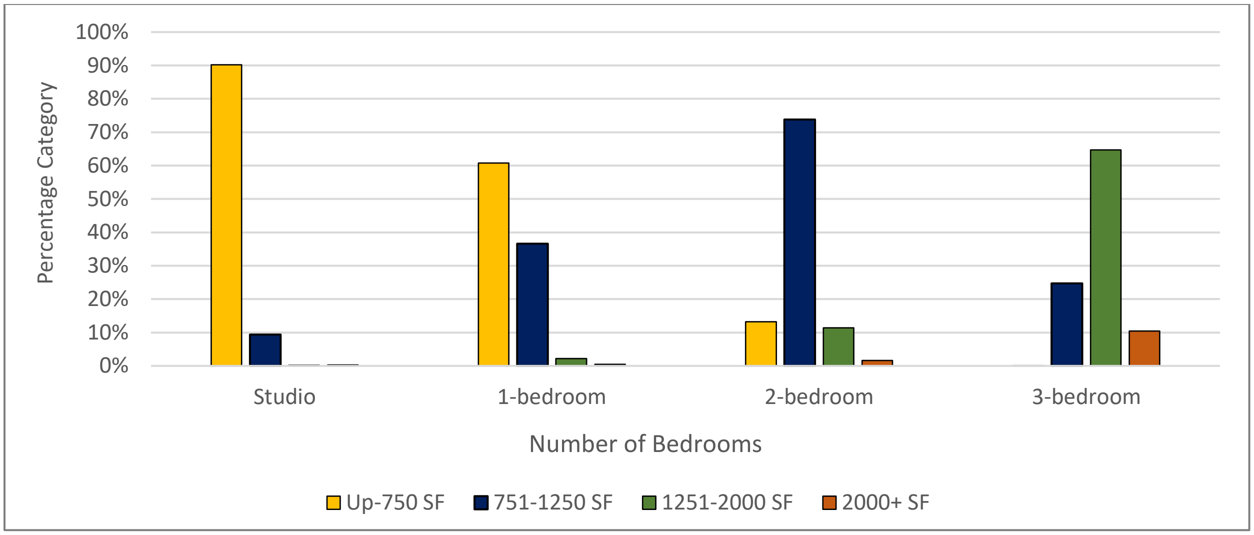



Figure 17: 2-4 Unit apartment building floor area distribution by number of bedrooms (Source: RASS 2019 [2])

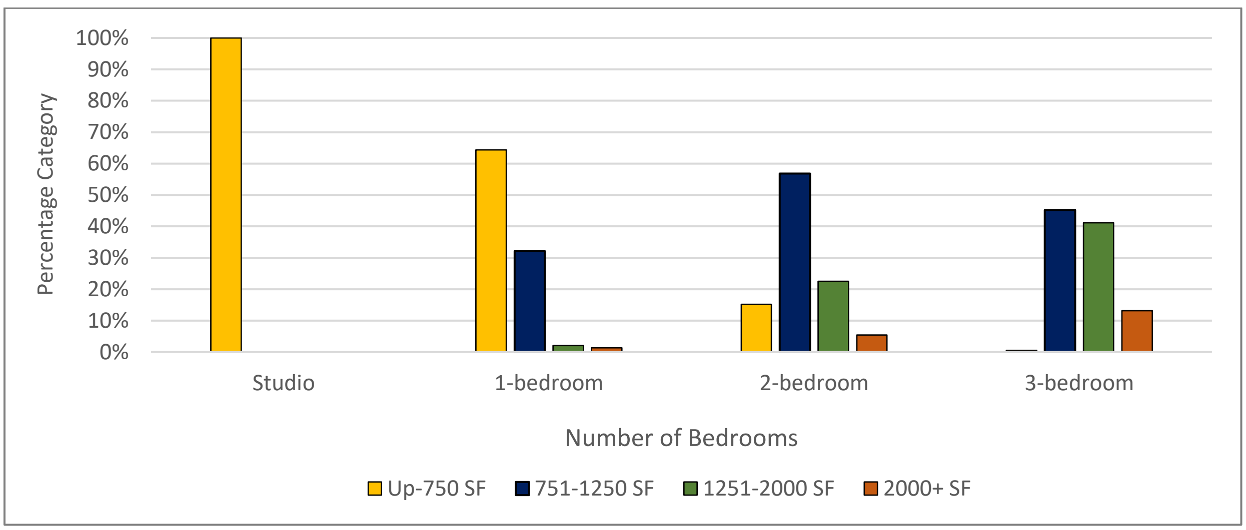



Figure 18: 5+ Unit apartment building floor area distribution by number of bedrooms (Source: RASS 2019 [2])

### 3.1.3. Vintage and Climate Zone

Figure 19 shows the distribution of apartment units by vintage. Similar to the single-family building stock, there are a significant number of apartment units constructed before 1975. The vintage distribution follows a similar binning to the single-family as described in the single-family Section 2.1.2.

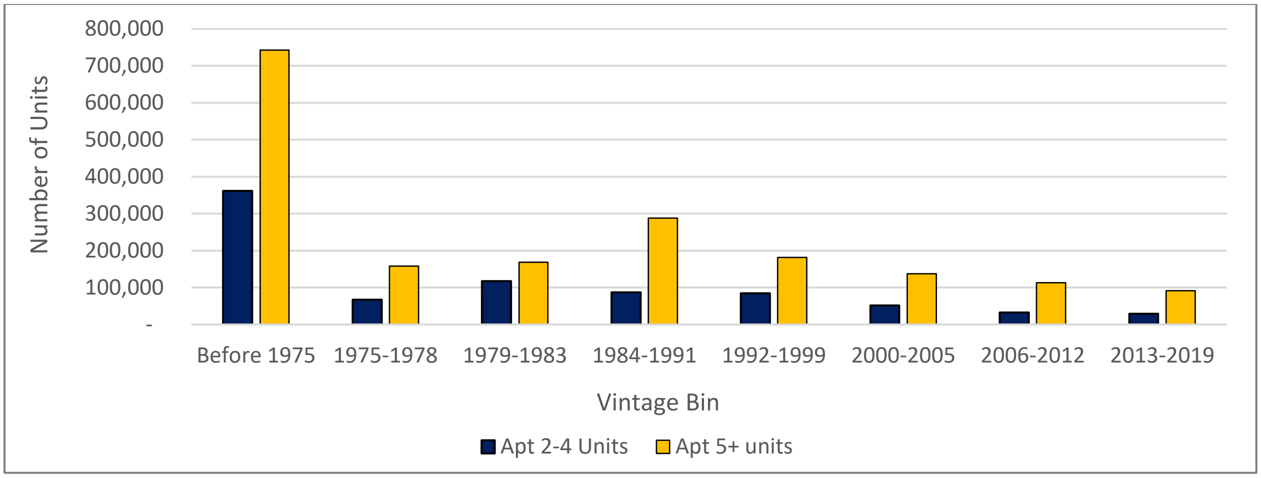



Figure 19: Number of apartments constructed since 1975 binned into vintage bins (Source: RASS 2019 [2])

Figure 20 shows the distribution of the number of apartment buildings by climate zone. The climate zone and vintage distribution were used to weigh the LRMF prototypes and simulation outputs to determine the statewide impact.

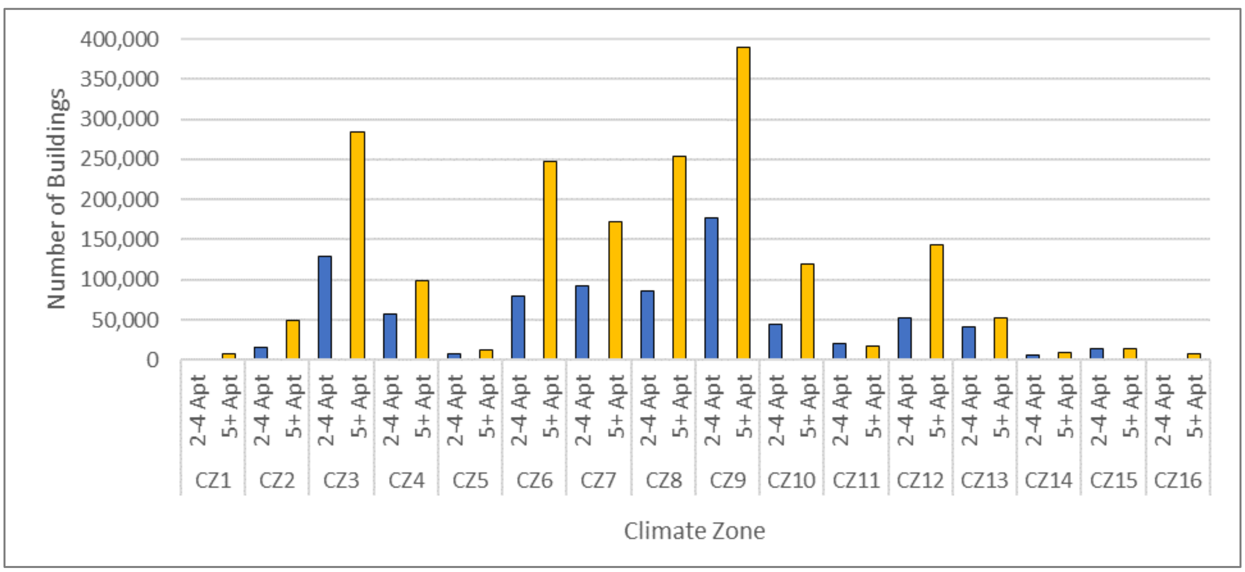



Figure 20: Number of apartment buildings constructed in California climate zones (Source: RASS 2019 [2])

### 3.1.4. Summary

Table 22 summarizes the major findings of the building stock analysis and shows the distribution of the LRMF building stock by number of bedrooms and the median size (floor area bin) by apartment type. The climate zone distribution will be reflected in the weighting factors to develop statewide impacts. After consulting with the TAG and considering the floor area distribution, it was agreed that both the single-family and multifamily building categories should follow the same vintage bins. Both single-family and multifamily fall under the residential sector and using unified vintage bins for each category provides consistency between the output and facilitates subsequent analysis for the residential sector.

The LRMF prototypes are intended to represent the California building stock both in terms of both the distribution of the apartments based on the number of bedrooms and the distribution of apartments based on the floor area bins corresponding to the number of bedrooms. This would provide the appropriate diversity and mapping to the building stock. Table 22 presents these main prototype mix features. However, some other variations of the LRMF prototype models were identified while collecting the input data, which are discussed in the next Section 3.3.2 and Section 3.4.

Table 22: Summary of LRMF building stock

| Apartment type | floor area bin (ft$^2$) | percentage of the total floor area |
|---|---|---|
| Studio | Up to 750 | 5% |
| 1-Bedroom | Up to 750 | 36% |
| 2-bedroom | 751-1,250 | 46% |
| 3-bedroom | 1,251-2,000 | 10% |

## 3.2. Multifamily Prototypes Selection

### 3.2.1. Existing LRMF Prototype Models

Two sets of prototypes, one from the CEC and another one from the CPUC were evaluated against the characteristics of the building stock to determine if existing prototypes could be leveraged for future work.

#### 3.2.1.1. CEC Multifamily Prototypes

Two LRMF prototypes were created as part of the 2022 Title 24 code development cycle under funding from SCE [16]. Figure 21 shows the 3D image of the two prototypes that were developed. These prototypes were subsequently translated to CBECC-Res [4], which is California's code compliance software for residential buildings. The translation was necessary so that the prototypes could be used during the code development process. Throughout the 2022 development cycle, several improvements were made to the prototype models. However, the geometry, number of apartments, the mix of apartments by number of bedrooms, and the floor area did not change, and these are the primary characteristics of interest for this analysis.

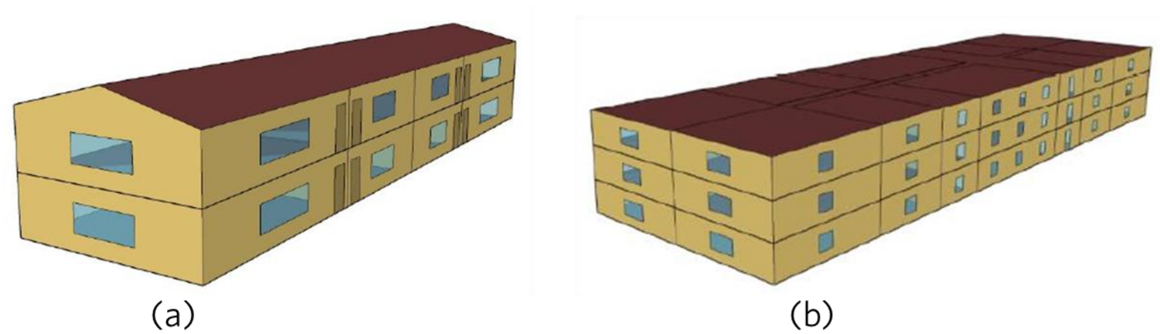



Figure 21: CEC multifamily Prototypes: (a) Low-rise Garden Style and (b) Low-rise Loaded Corridor.

Table 23 shows the characteristics of the CEC multifamily prototypes, including the number of stories, the number of dwelling units, the conditioned floor area, and the mean apartment floor area. The Garden Style prototype has an even split of four 1- and 2-bedroom apartments. The Loaded Corridor prototype has studio, 1-, 2-, and 3-bedroom apartments. The name "Loaded Corridor" implies that there is a central corridor that is enclosed by apartments and conditioned.

Table 23: CEC LRMF prototype characteristics (Source: [16])

| Prototype feature | Garden Style | Loaded Corridor |
|---|---|---|
| Number of Stories | Two | Three |
| Number of Dwelling Units | Eight apartments:<br>Four 1-bedroom<br>Four 2-bedroom | 36 apartments:<br>Six studios<br>Twelve 1-bedroom<br>Twelve 2-bedroom<br>Six 3-bedroom |
| Conditioned Floor Area ($ft^2$) | 7,321 | 34,863.4 |
| Apartment Mean Floor Area ($ft^2$) | 915 | 938 |

### 3.2.1.2. CPUC Multifamily Prototypes

Figure 22 shows the CPUC multifamily prototype, which is a single model with a 12-unit, two-story apartment building. The model was recently translated from DOE-2 [22] to EnergyPlus™ and the details were shared in a CPUC memo [5]. The memo states that most features of the DOE-2 model were translated directly to EnergyPlus™. Features that did not change in the translation include the number of apartments, apartment mean floor area, and number of bedrooms. These features were the subject of interest for this analysis.

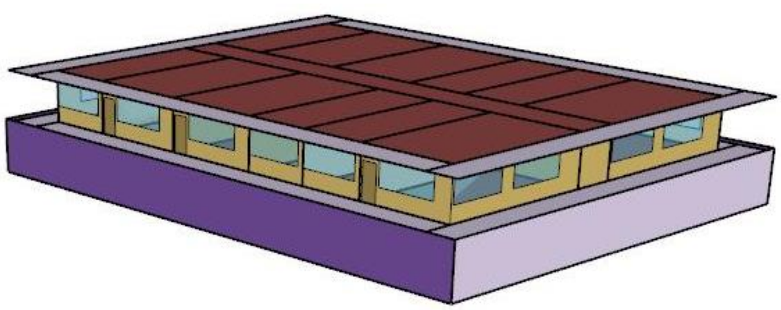


Figure 22: CPUC multifamily prototype: 12-unit apartment building

Table 24 shows the characteristics of the CPUC multifamily prototype. It is a two-story prototype with 12 identical apartment units of 1,000 $ft^2$ each. The interior corridor is unconditioned (like a breezeway, typical of Garden Style apartment buildings). For each apartment, the model has a living room zone of 600 $ft^2$ and a bedroom zone of 400 $ft^2$, which means the total apartment area matches the building stock mean apartment floor area for a 2-bedroom apartment (refer to Figure 17 and Figure 18).

Table 24: CPUC multifamily prototype characteristics (Source: [5])

| Prototype feature | CPUC multifamily prototype |
|---|---|
| Number of Stories | Two |
| Number of Dwelling Units | Twelve apartments: 2-bedroom* |
| Conditioned Floor Area (ft$^2$) | 12,000 |
| Apartment mean floor area (ft$^2$) | 1,000 |

*Assumption based on the mean apartment floor area in building stock

### 3.2.2. Comparison to Building Stock

Table 25 and Table 26 compare various features of apartment units and apartment buildings in the building stock to the existing prototypes. Table 25 shows that the individual apartment floor area in the CEC multifamily prototype for apartments with different number of bedrooms is well aligned with the building stock.

Table 25: Comparison of apartment floor area by number of bedrooms between building stock and existing multifamily prototypes

| Apartment type | RASS area Bin (ft$^2$) | CEC prototypes floor area (ft$^2$) | CPUC prototype floor area (ft$^2$) |
|---|---|---|---|
| Studio | Up to 750 | 540 | - |
| 1-Bedroom | Up to 750 | 720 | - |
| 2-bedroom | 751-1,250 | 1,080 | 1,000* |
| 3-bedroom | 1,251-2,000 | 1,410 | - |

* Assumption based on the mean apartment floor area in the building stock

Table 26 shows the distribution of apartment units by number of bedrooms in LRMF building stock and within the existing CEC and CPUC prototypes. Between the two CEC prototypes, there is significant diversity in the number of bedrooms and while it does not precisely match the building stock, the building stock would be sufficiently well represented between the two prototypes.

Table 26: Comparison of apartment type distribution between building stock and existing LRMF prototypes

| Apartment type | RASS Apt. 2-4 units | RASS Apt. 5+ units | RASS All apt. units | CEC Low-rise Garden Style | CEC Low-rise Loaded Corridor | CEC Combined distribution (50/50 split) | CEC 12-unit apartment building |
|---|---|---|---|---|---|---|---|
| Studio | 2% | 6% | 5% | 0% | 17% | 8.5% | 0% |
| 1-Bedroom | 25% | 41% | 36% | 50% | 33% | 41.5% | 0% |
| 2-bedroom | 50% | 44% | 46% | 50% | 33% | 41.5% | 100% |
| 3-bedroom | 18% | 7% | 10% | 0% | 17% | 8.5% | 0% |
| Apartment mean floor area (ft$^2$) | 1,105 | 930 | 984 | 915 | 1,094 | 1,005 | 1,000 |

The building stock data reveals that 2–4-unit apartment buildings constitute 30.6% of all LRMF buildings in terms of number of buildings, highlighting their significant presence within the LRMF building stock. Currently, the CEC prototypes do not represent typical 2–4-unit apartment buildings separately, at least in terms of geometry. However, the energy impact is likely to be negligible because other features of 2–4-unit apartment buildings, such as HVAC systems, ventilation, and envelope exposure are likely to be similar to the Garden Style prototype.

The existing CEC prototypes have significant diversity in the number of bedrooms and will therefore have diversity in terms of occupancy, plug loads, and DHW consumption. Additionally, the two CEC prototypes provide different coupling to the central corridor, which is important from an energy perspective. As shown in Table 25 and Table 26, the CEC prototypes are representative of the building stock concerning the distribution of apartment units by the number of bedrooms, as well as the composition of an apartment building in terms of the number of units allocated to specific bedrooms counts. Therefore, the existing CEC prototypes were proposed (and discussed) to the TAG as the starting point for the LRMF prototype development. Upon TAG approval, the forms of CEC multifamily prototype models (Table 23) were used in the development of the geometry of the LRMF prototype models.

## 3.3. Inputs Collection

### 3.3.1. Sources Used

Table 9 shows the sources that were utilized to extract the required input data for developing LRMF prototype models, except for the geometry design, which was based on CEC low-rise multi-family prototypes. Results of the space heating and DHW fuel type investigation are summarized in the following section, and more detailed input data can be found in “Appendix C: Inputs for MF.”

### 3.3.2. Space Heating and DHW System Type

#### 3.3.2.1. Space Heating

Distribution of the heating fuel type in multifamily houses over the vintage bins and climate zones showed that there was more than one dominant fuel type in a few climate zones. To enhance prototype coverage to the multifamily building stock, two sets of fuel types were considered for the heating system of multifamily prototype models including:

- **SET1:** Gas space heating. Prototype models for all 16 climate zones and the four vintage bins would use gas as the primary source of space heating. These set of models would be used when the primary objective is the statewide impact. Climate zone focused analyses could use SET2, when needed.
- **SET2:** Gas, electric, or propane space heating. This set of models includes either gas, electric, or a mixture of gas and electricity as the primary source of heating. Specifically, in a climate zone and vintage bin, if gas or electricity heating fuel achieves at least 75% saturation, then the fuel type would be gas or electricity. If not, a second space heating system with the other heating fuel would be modeled, according to Table 27.

For the “New Construction” prototype models, the 2022 Title 24 Building Standards [9] were used to define whether the space heating should be a gas furnace or heat pump.

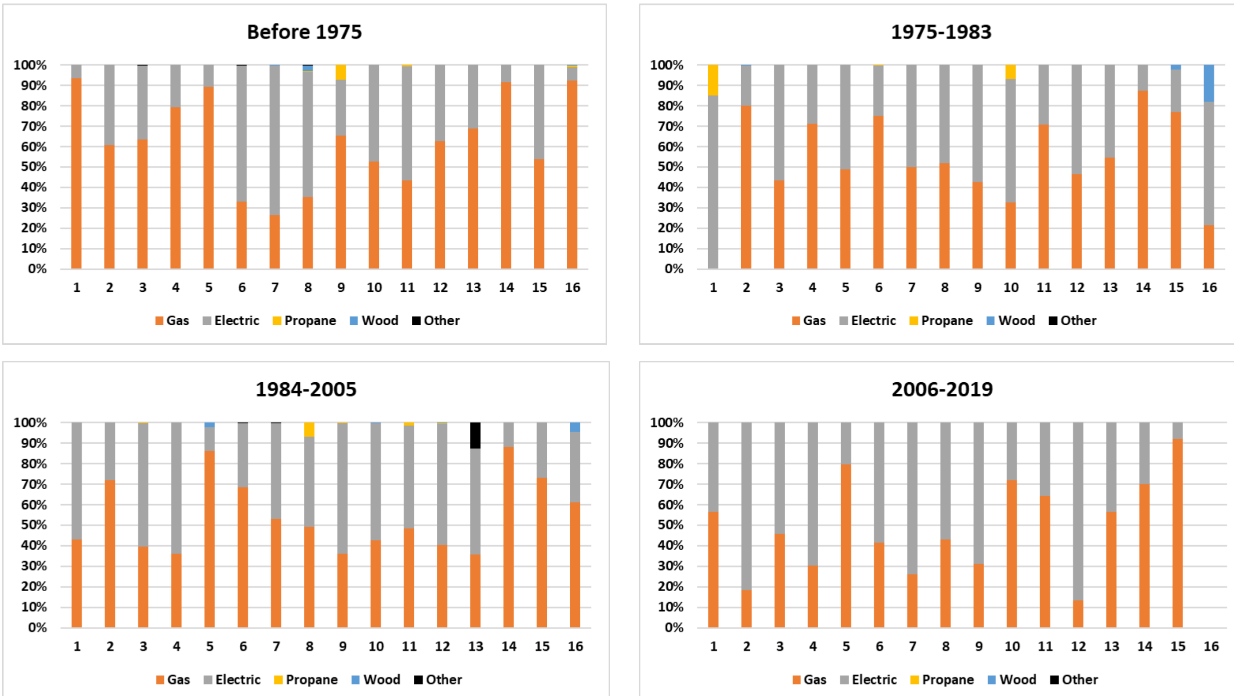



Figure 23: Distribution of the multifamily heating fuel type (Source: RASS 2019 [2])

Table 27 indicates the climate zones and vintage bins that need additional models with a different heating system in LRMF prototypes.

Table 27: Mapping SET2 of heating Fuel type to climate zones and vintage bins for LRMF prototype models

| Vintage bin | CZ1 | CZ2 | CZ3 | CZ4 | CZ5 | CZ6 | CZ7 | CZ8 | CZ9 | CZ10 | CZ11 | CZ12 | CZ13 | CZ14 | CZ15 | CZ16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pre-1975 | Gas | Mix | Mix | Gas | Gas | Mix | Electric | Mix | Gas | Gas | Mix | Mix | Mix | Gas | Mix | Mix |
| 1975-1983 | Mix | Gas | Mix | Mix | Gas | Mix | Mix | Mix | Mix | Mix | Mix | Mix | Mix | Gas | Mix | Mix |
| 1984-2005 | Mix | Gas | Mix | Mix | Gas | Mix | Mix | Mix | Electric | Mix | Mix | Mix | Mix | Gas | Mix | Mix |
| 2006-2019 | Mix | Electric | Mix | Mix | Gas | Mix | Electric | Mix | Electric | Mix | Mix | Electric | Mix | Mix | Mix | Electric |
| New Construction | HP | HP | HP | HP | HP | HP | HP | HP | HP | HP | HP | HP | HP | HP | HP | Gas |

### 3.3.2.2. Space cooling

The assessment of data provided by RASS 2019 [2] showed some of the existing multifamily buildings in specific climate zones are not equipped with any cooling system. This data was applied accordingly in the models. Table 28 displays the availability of cooling systems in multifamily buildings across climate zones and vintage bins.

Table 28: Availability of cooling systems in various climate zones and vintage bins for multifamily buildings (Source: RASS 2019 [2])

| Vintage bin | CZ1 | CZ2 | CZ3 | CZ4 | CZ5 | CZ6 | CZ7 | CZ8 | CZ9 | CZ10 | CZ11 | CZ12 | CZ13 | CZ14 | CZ15 | CZ16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pre-1975 | No | No | No | No | No | No | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| 1975-1983 | No | No | No | No | No | Yes | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| 1984-2005 | No | Yes | No | Yes | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| 2006-2019 | No | Yes | No | Yes | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| New Construction | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

### 3.3.2.3. HVAC Efficiency

The approach used for single-family prototype models (as described in Section 2.3.2.3) was applied to determine the efficiency of heating and cooling systems in LRMF prototype models. The efficiency is based on the age of the HVAC system, which is a function of the building vintage and supported by data in RASS. Detailed information about the efficiency of HVAC systems is presented in the "Appendix C: Inputs for MF."

### 3.3.2.4. DHW

As was done for the space heating fuel type, two sets of fuel types were considered for DHW systems of multifamily prototype models, including:

- **SET1:** Gas as the source of the DHW system. Prototype models for all 16 climate zones as well as four vintage bins would use gas as the primary source of the water heating system.
- **SET2:** Gas or electricity as the primary source of the DHW system. Similar to the space heating approach, a mix of gas and electric water heating was applied if no single fuel type claimed more than 75% of the saturation. Table 29 provides information on the climate zones and vintage bins requiring additional LRMF prototype models with different fuel types for DHW systems.

For the "New Construction" prototype models, prescriptive requirements outlined in the 2022 Title 24 Building Standards [9] were used to define instantaneous gas water heaters for all climate zones.

Table 29: Mapping SET2 of DHW fuel type to climate zones and vintage bins for LRMF prototype models

| Vintage bin | CZ1 | CZ2 | CZ3 | CZ4 | CZ5 | CZ6 | CZ7 | CZ8 | CZ9 | CZ10 | CZ11 | CZ12 | CZ13 | CZ14 | CZ15 | CZ16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pre-1975 | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Mix |
| 1975-1983 | Mix | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas |
| 1984-2005 | Electric | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Gas | Mix | Gas |
| 2006-2019 | Electric | Electric | Mix | Gas | Gas | Mix | Mix | Gas | Gas | Gas | Gas | Gas | Mix | Mix | Mix | Electric |
| New Construction | Insta. Gas | Insta. Gas | Insta. Gas | Insta. Gas | Insta. Gas | Insta. Gas | Insta. Gas | Insta. Gas | Insta. Gas | Insta. Gas | Insta. Gas | Insta. Gas | Insta. Gas | Insta. Gas | Insta. Gas | Insta. Gas |

#### 3.3.2.5. DHW Efficiency

The approach used to determine single-family DHW efficiency (as described in Section 2.3.2.5) was applied to LRMF prototype models. Burner efficiency was determined based on the age of the system, which is a function of the building vintage. Detailed information about the efficiency of DHW systems is presented in the "Appendix C: Inputs for MF."

### 3.3.3. DHW, Infiltration, and Schedules Inputs Development

#### 3.3.3.1. DHW and Infiltration

The modeling approach previously explained in Section 2.3.3.1 and Section 2.3.3.2 for single-family prototype models was utilized to add DHW and infiltration schedules to the multifamily prototypes' models. Detailed information about the input data is presented in the "Appendix C: Inputs for MF."

#### 3.3.3.2. Occupancy/Activity Schedules

Heat gain generated by the occupants was modeled with the same approach used for single-family prototypes. A consistent activity schedule was defined based on the CBECC-Res activity schedule, with a baseline activity assumed to generate 117.28 Watts/person within two LRMF prototype models (MF-Garden and MF-Corridor). The radiant fraction was set to 0.3 and the sensible heat fraction was established at 0.573. Table 30 summarizes the number of people per model. The Loaded Corridor model has other zones except dwelling units (such as gym and offices) which were modeled with their specific occupancy load and schedule.

Table 30: Number of bedrooms and people within LRMF prototype models

| Model | MF-Garden | MF-Corridor |
|---|---|---|
| Number of occupied units | Four 1-bedroom<br>Four 2-bedroom | 36 apartments<br>Six studios<br>Twelve 1-bedroom<br>Twelve 2-bedroom<br>Six 3-bedroom |
| Design number of people in the prototype | 18.8 | 84.7 |

### 3.3.3.3. Other Schedules

Similar to single-family prototypes, schedules for appliances, lighting, and miscellaneous loads of LRMF prototypes were sourced from Building America. UEC from RASS was combined with the Building America schedules to determine the system design load. Table 31 summarizes the UEC numbers, saturation, and schedules applied to both multifamily prototype models.

Table 31: Other schedules, energy consumption, and design loads within LRMF prototype models

| Appliances | MF-Garden<br>Annual Average Design Level | MF-Garden<br>Annual Consumption (RASS [2]) | MF-Garden<br>Saturation | MF-Corridor<br>Annual Average Design Level | MF-Corridor<br>Annual Consumption (RASS [2]) | MF-Corridor<br>Saturation | Schedules for both models |
|---|---|---|---|---|---|---|---|
| Washer | 24.0 W | 79 kWh | 51% | 18.8 W | 62 kWh | 36% | Building America Standard Schedules |
| Dryer | 110.0 W | 430 kWh | 23% | 90.6 W | 354 kWh | 21% | Building America Standard Schedules |
| Dishwasher | 32.8 W | 69 kWh | 48% | 30.0 W | 63 kWh | 56% | Building America Standard Schedules |
| Refrigerator | 136.4 W | 1,002 kWh | 100% | 131.8 W | 968 kWh | 100% | Building America Standard Schedules |
| Cooking Range/Oven | 120.8 W | 294 kWh | 52% | 105.2 W | 256 kWh | 59% | Building America Standard Schedules |
| Microwave | 59.6 W | 145 kWh | 82% | 53.8 W | 131 kWh | 81% | Building America Standard Schedules |
| TV | 149.0 W | 425 kWh | 68% | 136.4 W | 389 kWh | 57% | Building America Standard Schedules |
| Miscellaneous (plug load, home office, PC) | 236.3 W | 1,558 kWh | 100% | 240.1 W | 1,421 kWh | 100% | Building America Standard Schedules |
| Lighting (Exterior) | 50.5 W | 144 kWh | 38% | 40.7 W | 116 kWh | 25% | Building America Standard Schedules |

## 3.4. Multifamily Prototypes Models Composition

Table 32 presents the combination of multifamily prototype models in each vintage bin. These prototype models differ not only in geometry and building characteristics but also in the heating and DHW systems, if applicable. As shown, a total of 338 prototype models were planned to be developed for the multifamily sector in all climate zones, including both SET1 and SET2.

Table 32: LRMF prototype composition

| Vintage | Geometry | Climate Zone | Heating fuel type | DHW fuel type | Number of models | Models H=Heating System |
|---|---|---|---|---|---|---|
| Pre-1975 | 2 | 16 | 2 sets:<br>SET1: Gas in all CZs<br>SET2: Electric in 10 CZ s {2,3,6,7,8,11,12,13,15,16} & Gas in all CZs except CZ 7 | 2 sets:<br>SET1: Gas in all CZs<br>SET2: Electric in CZ 16 & Gas in all CZs | 56 | 2*16: models with Gas H & Gas DHW in all CZs<br>2*10: models with Electric H & Gas DHW in CZ {2,3,6,7,8,11,12,13,15,16}<br>2*1: models with Electric H & Electric DHW in CZ 16<br>2*1: models with Gas H & Electric DHW in CZ 16 |
| 1975-1983 | 2 | 16 | 2 sets:<br>SET1: Gas in all CZs<br>SET2: Electric in 13 CZs {1,3,4,6,7,8,9,10,11,12,13,15,16} & Gas in all CZs | 2 sets:<br>SET1: Gas in all CZs<br>SET2: Electric in CZ 1 & Gas in all CZs | 62 | 2*16: models with Gas H & Gas DHW in all CZs<br>2*13: models with Electric H & Gas DHW in CZs {1,3,4,6,7,8,9,10,11,12,13,15,16}<br>2*1: models with Electric H & Electric DHW in CZ 1<br>2*1: models with Gas H & Electric DHW in CZ 1 |
| 1984-2005 | 2 | 16 | 2 sets:<br>SET1: Gas in all CZs<br>SET2: Electric in 13 CZs {1,3,4,6,7,8,9,10,11,12,13,15,16} & Gas in all CZs except CZ 9 | 2 sets:<br>SET1: Gas in all CZs<br>SET2: Electric in 2 CZs {1,15} & Gas in all CZ s except CZ 1 | 64 | 2*16: models with Gas H & Gas DHW in all CZs<br>2*12: models with Electric H & Gas DHW in CZs {3,4,6,7,8,9,10,11,12,13,15,16}<br>2*2: models with Electric H & Electric DHW in CZ 1,15<br>2*2: models with Gas H & Electric DHW in CZ 1,15 |
| 2006-2019 | 2 | 16 | 2 sets:<br>SET1: Gas in all CZs<br>SET2: Electric in all CZs except CZ 5 & Gas in 11 CZs {1,3,4,5,6,8,10,11, 13,14,15} | 2 sets:<br>SET1: Gas in all CZs<br>SET2: Electric in 9 CZs {1,2,3,6,7,13,14,15,16} & Gas in 13 CZs {3,4,5,6,7,8,9,10,11,12,13,14, 15} | 92 | 2*16: models with Gas H & Gas DHW in all CZs<br>2*12: models with Electric H & Gas DHW in CZ 3,4,6,7,8,9,10,11,12,13,14,15<br>2*9: models with Electric H & Electric DHW in 9 CZ 1,2,3,6,7,13,14,15,16<br>2*9: models with Gas H & Electric DHW in 6 CZ 1,3,6,13,14,15 |
| New Construction | 2 | 16 | 2 sets:<br>SET1: Gas in all CZs<br>SET2: HP in all CZs except CZ 16 & Gas in CZ 16 | 2 sets:<br>SET1: Gas in all CZs<br>SET2: Instant Gas in all CZs zones. | 64 | 2*16: models with Gas H & Gas DHW<br>2*15: models with HP H & Instant Gas in all CZs except CZ 16<br>2*1: models with Gas H & Instant Gas DHW in CZ 16 |
| 5 | 2 | 16 | 2 Sets | | **338** | **Total** |

## 3.5. Multifamily Prototype Model Construction

The construction of LRMF prototype models was carried out using the following steps:

1. Develop two base prototype models with SET1 of the space heating system and SET1 of the DHW system.
2. Expand the SET1 base models to all vintage bins and all climate zones of California.
3. Generate SET2 of the base prototype models by changing the space heating and DHW system from SET1 to SET2, if applicable according to Table 27 and Table 29.
4. Expand the SET2 base models to all vintage bins and all climate zones of California.

Step 1 has been completed and Step 2 is currently in progress. Completing Step 2 and developing SET2 prototype models is scheduled to be carried out in 2024.

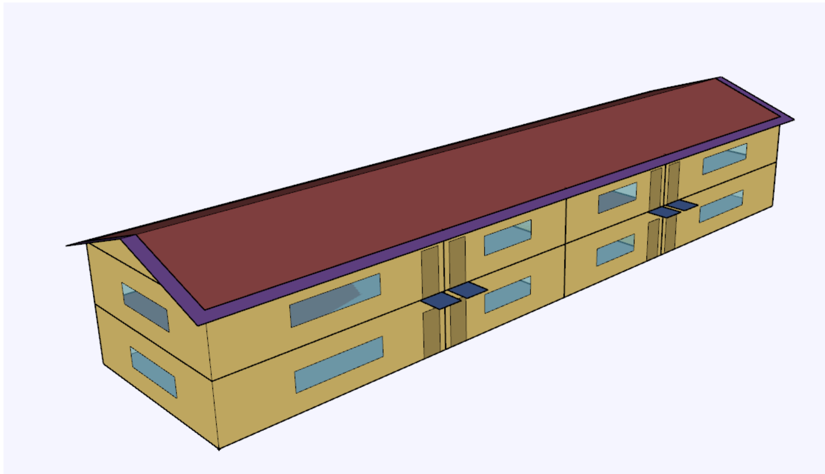
### 3.5.1. Modeling Approach

The Garden Style prototype, named MF-Garden, was designed using SketchUp 2023 and OpenStudio® Plugin. For the more complex Loaded Corridor prototype, named MF-Corridor, Design Builder v6 was used for the geometry design[8]. Table 33 presents the characteristics of each geometry model, and Figure 24 shows the northeast view of both prototypes that were designed based on the CEC prototypes in line with the discussion in Section 3.2.1.1.

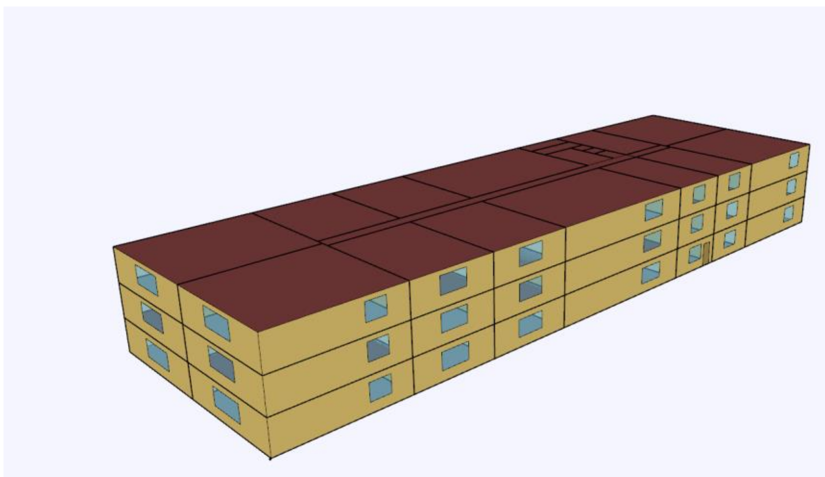
Table 33: Geometry characteristics of the LRMF prototypes

| Prototype | Floor area ($ft^2$) | Aspect ratio | Floor-to-floor (ft) | Number of Stories | WWR | Roof type | Number of zones |
|---|---|---|---|---|---|---|---|
| MF-Garden | 7,320 | 4.07 | 9 | 2 | 12.8% | Attic 4:12 | Nine (Eight dwelling units and one attic) |
| MF-Corridor | 39,372 | 3.14 | 9 | 3 | 19% | Low slope | 53 (36 dwelling units and 17 other) |

[8] The geometry models of LRMF prototypes were developed mostly from scratch because there are no 3-D viewing tools readily available to view or extract geometry from CBECC-RES models.



(MF-Garden)



(MF-Corridor)

Figure 24: N-E view of the multifamily prototypes in SketchUp

After finalizing the 3D model design of the multifamily prototypes, the geometry models were exported to EnergyPlus™ 23.1.0. Additional development was conducted with the editing functions of EnergyPlus™ and other text editors using the multifamily input data (Appendix C: Inputs for MF) and following the process described in Figure 14 for single-family prototypes. Table 34 presents these features.

Table 34: Specifications of the base LRMF prototype models

| Feature | Base LRMF prototype |
|---|---|
| Vintage bin | Pre-1975 |
| Climate zone | Sacramento |
| Foundation | Concrete slab-on-grade |
| Heating fuel type | Gas heating (SET1) |
| DHW fuel type | Gas DHW (SET1) |

The approaches previously described in Section 3.3.2 and Section 3.3.3 were applied to simulate the HVAC, DHW, and infiltration systems. Having the finalized model, the next step was to expand the models to other climate zones and vintage bins using the multifamily input data.

### 3.5.2. Expansion to CZs

LRMF prototype model expansion follows the same process previously discussed for single-family model expansion in Section 2.5.2. SET1 base prototype models were expanded to all vintage bins of climate zone 12. Expansion of the SET1 models to all other climate zones is scheduled to be done in 2024.

## 3.6. Multifamily Prototype Model Validation

Validation of LRMF prototype models follows the same process previously discussed in Section 2.6. using the results of the LRMF prototype simulations and LRMF weighting factors. This work is scheduled to be completed in 2024.

### 3.6.1. LRMF Prototype Models Weighting Factors

Same with the single-family prototype models, there are three sets of weighting factors for LRMF buildings that were used for aggregating the simulation results.

Table 35 presents floor area based weighting factors for multifamily prototype models based on climate zones, LRMF prototype forms, and vintage bins. This set of factors was extracted from RASS 2019 [2] and California-specific permit starts data Dodge[9] [23], and was utilized to aggregate the simulation results to the state level. By multiplying the simulation results with these weighting factors, the statewide results will be produced.

There are additional weighting factors (for heating fuel type and DHW fuel type) for models in SET2 that have not been extracted yet and will be done in 2024. These factors should be applied to the results of those SET2 LRMF prototype models that have the mix fuel type for their heating or/and DHW system according to Table 27 and Table 29.

[9] Construction starts data by Dodge, 2023. It is a paid date that was provided to NORESCO by the CEC. Dodge was consulted because RASS was down, and the floor area and vintage data were unavailable.

Table 35: Weighting factor for LRMF prototype models (Source RASS 2019 [2] and Dodge 2023 [23])

| Vintage bin | Prototype | CZ1 | CZ2 | CZ3 | CZ4 | CZ5 | CZ6 | CZ7 | CZ8 | CZ9 | CZ10 | CZ11 | CZ12 | CZ13 | CZ14 | CZ15 | CZ16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pre-1975 | MF-Garden | 0.0004243 | 0.002846 | 0.018159 | 0.006899 | 0.000915 | 0.014157 | 0.011650 | 0.014698 | 0.024867 | 0.007166 | 0.00173 | 0.008569 | 0.004166 | 0.00072 | 0.001284 | 0.0004191 |
| | MF-Corridor | 0.001348 | 0.009042 | 0.057688 | 0.021917 | 0.002907 | 0.044973 | 0.037009 | 0.04669 | 0.078996 | 0.022764 | 0.005494 | 0.027222 | 0.013233 | 0.002286 | 0.004078 | 0.001331 |
| 1975-1983 | MF-Garden | 0.0001342 | 0.0009 | 0.005745 | 0.002183 | 0.000289 | 0.004478 | 0.003685 | 0.004649 | 0.007866 | 0.002267 | 0.000547 | 0.002711 | 0.001318 | 0.000228 | 0.000406 | 0.000133 |
| | MF-Corridor | 0.0004264 | 0.00286 | 0.018249 | 0.006933 | 0.00092 | 0.014227 | 0.011707 | 0.01477 | 0.024989 | 0.007201 | 0.001738 | 0.008611 | 0.004186 | 0.000723 | 0.00129 | 0.000421 |
| 1984-2005 | MF-Garden | 0.000247 | 0.001657 | 0.010572 | 0.004016 | 0.000533 | 0.008242 | 0.006782 | 0.008556 | 0.014476 | 0.004172 | 0.001007 | 0.004989 | 0.002425 | 0.000419 | 0.000747 | 0.000244 |
| | MF-Corridor | 0.0007847 | 0.005264 | 0.033583 | 0.012759 | 0.001692 | 0.026181 | 0.021545 | 0.02718 | 0.045987 | 0.013252 | 0.003198 | 0.015847 | 0.007703 | 0.001331 | 0.002374 | 0.000775 |
| 2006-2019 | MF-Garden | 5.0529E-05 | 0.000339 | 0.002162 | 0.000822 | 0.000109 | 0.001686 | 0.001387 | 0.00175 | 0.002961 | 0.000853 | 0.000206 | 0.00102 | 0.000496 | 8.57E-05 | 0.000153 | 4.99E-05 |
| | MF-Corridor | 0.0001605 | 0.001077 | 0.006869 | 0.00261 | 0.000346 | 0.005355 | 0.004407 | 0.00556 | 0.009406 | 0.002711 | 0.000654 | 0.003241 | 0.001576 | 0.000272 | 0.000486 | 0.000159 |
| **Total weight** | | **0.0035758** | **0.023986** | **0.153026** | **0.058139** | **0.007711** | **0.119299** | **0.098174** | **0.123853** | **0.209549** | **0.060385** | **0.014574** | **0.072211** | **0.035103** | **0.006064** | **0.010818** | **0.003532** |

# 4. Summary and Next Steps

This report outlines the progress made to date (2021-2023) on the residential section of the Prototypes project. Residential prototype models were developed for both single-family homes and LRMF apartments. The building stock assessment within each segment was conducted to facilitate the development of the models. Based on the stock assessment, a mix of prototype models and vintage bins for both single-family and multifamily were selected to represent key characteristics of buildings within the stock, such as building floor area, number of dwelling units, number of stories, and roof and foundation type. Input from the TAG was sought during every step of the development process. After gaining consensus on the prototype mix, other characteristics of the models were identified, such as the envelope insulation, construction assemblies, WWR, air leakage, HVAC and water heating systems type and efficiency, and internal and external loads, including people, lighting, and appliances. A variety of sources were used to determine the model inputs. Two sets of models were defined to covers various HVAC and DHW systems type including SET1 and SET2. For each building sector, SET1 prototype models were developed in one climate zone. Single-family prototype models were expanded to all vintage bins and climate zones and went under validation process. The expansion and validation of the LRMF prototypes are scheduled to be completed in 2024, along with the development of the nonresidential prototypes. The tasks slated for development in 2024 are as follows:

Single-Family Prototypes:

- Improve SET1 models
- Develop SET2 models.
- Determine SET2 weighting factors and perform validation for SET2 models.
- Improve infiltration modeling using a hybrid CONTAM-EnergyPlus approach and incorporate duct leakage modeling.
- Model HPWH for the "New Construction" vintage bin using minute-based schedules.

LRMF Prototypes:

- Finalize SET1 models and perform validation.
- Develop SET2 models.
- Determine SET2 weighting factors and perform validation for SET2 models.
- Improve infiltration modeling using a hybrid CONTAM-EnergyPlus approach and incorporate duct leakage modeling.
- Model HPWH for the "New Construction" vintage bin using minute-based schedules.

Nonresidential prototypes:

- Determine prototypes mix using CEUS data.
- Develop key characteristics of nonresidential prototypes to match the building stock.
- Develop prototype input data.
- Develop prototype models.

# 5. References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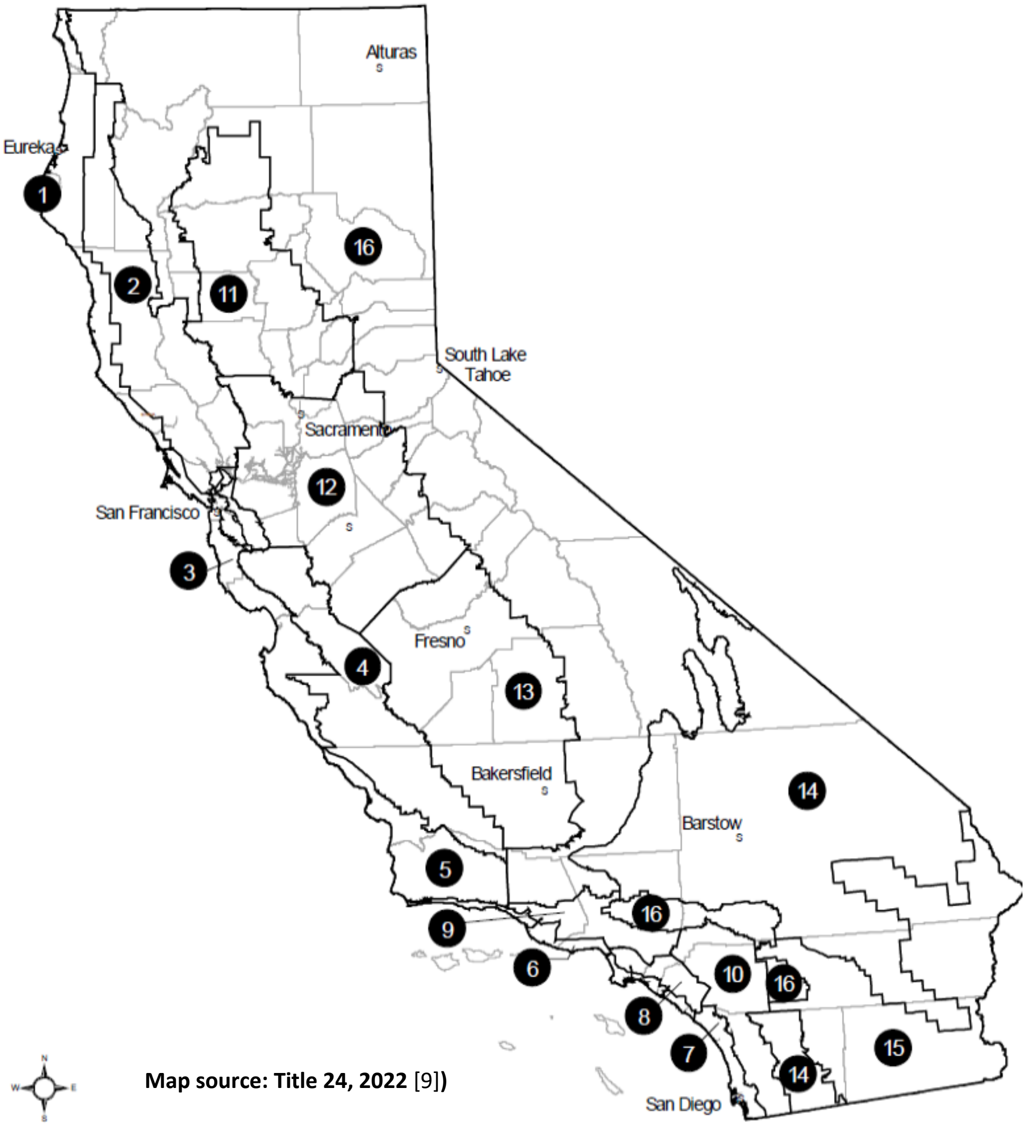
## 6. Appendix A: California Building climate zones




**Map source: Title 24, 2022** [9]**)**

| California Building Climate Zones | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **City** | **County** | **Climate Zone** | **City** | **County** | **Climate Zone** | **City** | **County** | **Climate Zone** |
| Arcata | Humboldt | 1 | San Diego | San Diego | 7 | Fresno | Fresno | 13 |
| Santa Rosa | Sonoma | 2 | Fullerton | Orange | 8 | Palmdale | Los Angeles | 14 |
| Oakland | Alameda | 3 | Burbank | Los Angeles | 9 | Palm Spring | Riverside | 15 |
| San Jose | Santa Clara | 4 | Riverside | Riverside | 10 | Blue canyon | Placer | 16 |
| Santa Maria | Santa Barbara | 5 | Red Bluff | Tehama | 11 | | | |
| Terrace | Los Angeles | 6 | Sacramento | Sacramento | 12 | | | |

# 7. Appendix B: Inputs for SF

| Architecture | | |
|---|---|---|
| **Item** | **Description** | **Source** |
| **Exterior walls** | | |
| Construction | Wood-framed | *RASS 2019* [2] |
| Dimensions | Based on floor area and aspect ratio | |
| Tilts and orientations | Vertical | |
| **Roof** | | |
| Construction | Wood-framed attic | *RASS 2019* [2] |
| Dimensions | Based on floor area and aspect ratio | |
| Tilts and orientations | Horizontal | |
| **Window** | | |
| Dimensions | Based on window fraction, location, glazing sill height, floor area, and aspect ratio | |
| Glass-type and frame | Hypothetical window with weighted U-factor and SHGC | |
| **Foundation** | | |
| Foundation type | Slab-on-grade floors (unheated) - 67% of floor area<br>Crawlspace - 33% of floor area | *RASS 2019* [2] |
| Construction | 6" concrete slab poured directly onto the earth + carpet | |
| **Interior Partitions** | | |
| Construction | 2 x 4 uninsulated steel stud wall | |
| Dimensions | based on floor plan and floor-to-floor height | |

| Envelope properties by vintage | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Vintage** | **Wall cavity insulation R-Value** | **Roof attic insulation R-Value** | **Slab/ crawlspace insulation** | **Window U-Factor** | **Window SHGC** | **Air leakage (ACH50)** | **Air leakage (4Pa) one-story model** | **Air leakage (4Pa) two-story model** |
| Pre-1975 | R-1.0 | R-17 | None | 0.78 | 0.44 | 16.0 | 0.82 | 0.93 |
| 1975-1983 | R-7.0 | R-19 | None | 0.82 | 0.44 | 13.0 | 0.67 | 0.76 |
| 1984-2005 | R-13 | R-27 | None | 0.74 | 0.44 | 8.0 | 0.41 | 0.47 |
| 2006-2019 | R-15 | R-31 | None | 0.49 | 0.44 | 6.0 | 0.31 | 0.35 |
| New Construction | R-21 | R-38<br>R-30 (CZ 2-10) | None | 0.3 | 0.20 | 5.0 | 0.26 | 0.29 |

Source: Built by 2019: RASS 2019 [2], ResStock 2021 [8]
Source: New Construction: Title 24 2022 [9]

| HVAC and DHW | | |
|---|---|---|
| **Item** | **Description** | **Data Source** |
| **System type** | | |
| Heating type | Gas central furnace<br>Electric resistance | *RASS 2019* [2]<br>*Title 24 2022* [9] |
| Cooling type | Split air conditioner | |
| **HVAC sizing** | | |
| Air conditioning | Autosized to design day conditions | *ACCA Manual J & Manual S* |
| Heating | Autosized to design day conditions | |
| **HVAC efficiency** | | |
| Air conditioning | Various by climate location and design cooling capacity | *RASS 2019* [2] |
| Heating | Various by climate location and design heating capacity | *RASS 2019* [2] |
| **HVAC control** | NA | |
| Initial thermostat Setpoint | 24-27°F for cooling/19-20°F for heating depending on season and climate zones | *Various sources.* |
| Thermostat setback | After validation | |
| Ventilation | NA | |
| Fan power | See under fan Power | *Title 20 2015* [10]<br>*Department of Energy. 10 CFR Part 430* [14] |
| **Domestic water heating** | | |
| DHW type | Storage tank | *RASS 2019* [2] |
| Thermal efficiency (%) | See under DHW | *NAECA (National Appliance Energy Conservation Act)*<br>*Title 24 2022* [9] |
| Tank volume (gal) | 50 | |
| Water temperature setpoint | 120 F | *PNNL Residential Prototype* [13] |

| Furnace fan power | |
|---|---|
| **Vintage** | **Maximum electric furnace AHU fan Watts/cfm** |
| Pre-1975 | 0.58 |
| 1975-1983 | 0.58 |
| 1984-2005 | 0.58 |
| 2006 -2019 | 0.58 |
| New Construction | 0.45 |

Source: Title 24 (2022, 2019, 2007, 2005) [9], based on the effective date and age of cooling equipment

| DHW assumptions | | |
|---|---|---|
| **Gas DHW system** | Recovery efficiency | 79% |
| | Ambient temperature | 67.5 F |
| | $Q_{load}$ based on medium usage | 30,584 Btu |

| | | |
|---|---|---|
| **Electric DHW system** | Recovery efficiency | 79% |
| | Ambient temperature | 67.5 F |
| | Ambient air temperature | 58 F |
| | flow: fraction of the tank area below the lower element | 0.2 |
| | $Q_{load}$ based on medium usage | 30,584 Btu |

| UEF to model inputs | | | |
|---|---|---|---|
| Water heater type | Burner thermal efficiency (%) | Shell losses-UA (Btu/hr-ºF) UEF-0.56 | Shell losses-UA (Btu/hr-ºF) UEF-0.58 |
| Gas-fired storage | 80% | 9.97 | 8.79 |

| | | | |
|---|---|---|---|
| Water heater type | Burner thermal efficiency (%) | Shell losses-UA (Btu/hr-ºF) UEF-0.89 | Shell losses-UA (Btu/hr-ºF) UEF-0.92 |
| Electric storage | 100% | 3.96 | 2.79 |

Source:
https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22068.pdf
https://www.ashrae.org/file%20library/conferences/specialty%20conferences/2020%20building%20performance/papers/d-bsc20-c039.pdf
http://www.ibpsa.org/proceedings/BS2017/BS2017_237.pdf
https://www.energy.ca.gov/sites/default/files/2020-10/2016%20Water%20Heater%20Efficiency%20Guide_ada.pdf

| Approximate distribution based on subjective responses in RASS 2019<br>Responses are subjective and do not total to 100% | | | |
|---|---|---|---|
| **Vintage** | **Incandescent** | **CFL** | **LED** |
| Pre-1975 | 28% | 36% | 35% |
| 1975-1983 | 29% | 36% | 42% |
| 1984-2005 | 28% | 34% | 42% |
| 2006-2019 | 22% | 38% | 45% |
| New Construction | | | 100% |

Subjective response, "mostly" = 75%

| People internal gain | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Hour** | **SF1250** | | **SF1750** | | **SF2250** | | **SF2750** | |
| | **Sensible heat gain (Btu /hr)** | **Latent heat gain (Btu /hr)** | **Sensible heat gain (Btu /hr)** | **Latent heat gain (Btu /hr)** | **Sensible heat gain (Btu /hr)** | **Latent heat gain (Btu /hr)** | **Sensible heat gain (Btu /hr)** | **Latent heat gain (Btu /hr)** |
| 1 | 348.1 | 259.4 | 348.1 | 259.4 | 402.7 | 300.1 | 457.3 | 340.8 |
| 2 | 348.1 | 259.4 | 348.1 | 259.4 | 402.7 | 259.4 | 457.3 | 340.8 |
| 3 | 348.1 | 259.4 | 348.1 | 259.4 | 402.7 | 259.4 | 457.3 | 340.8 |
| 4 | 348.1 | 259.4 | 348.1 | 259.4 | 402.7 | 259.4 | 457.3 | 340.8 |
| 5 | 348.1 | 259.4 | 348.1 | 259.4 | 402.7 | 259.4 | 457.3 | 340.8 |
| 6 | 586.8 | 437.3 | 586.8 | 437.3 | 678.8 | 437.3 | 770.8 | 574.4 |
| 7 | 815.5 | 607.7 | 815.5 | 607.7 | 943.4 | 607.7 | 1071.3 | 798.4 |
| 8 | 547.0 | 407.6 | 547.0 | 407.6 | 632.8 | 407.6 | 718.6 | 535.5 |
| 9 | 268.5 | 200.1 | 268.5 | 200.1 | 310.6 | 200.1 | 352.8 | 262.9 |
| 10 | 139.2 | 103.8 | 139.2 | 103.8 | 161.1 | 103.8 | 182.9 | 136.3 |
| 11 | 139.2 | 103.8 | 139.2 | 103.8 | 161.1 | 103.8 | 182.9 | 136.3 |
| 12 | 139.2 | 103.8 | 139.2 | 103.8 | 161.1 | 103.8 | 182.9 | 136.3 |
| 13 | 139.2 | 103.8 | 139.2 | 103.8 | 161.1 | 103.8 | 182.9 | 136.3 |
| 14 | 139.2 | 103.8 | 139.2 | 103.8 | 161.1 | 103.8 | 182.9 | 136.3 |
| 15 | 189.0 | 140.8 | 189.0 | 140.8 | 218.6 | 140.8 | 248.2 | 185.0 |
| 16 | 268.5 | 200.1 | 268.5 | 200.1 | 310.6 | 200.1 | 352.8 | 262.9 |
| 17 | 407.7 | 303.9 | 407.7 | 303.9 | 471.7 | 303.9 | 535.7 | 399.2 |
| 18 | 547.0 | 407.6 | 547.0 | 407.6 | 632.8 | 407.6 | 718.6 | 535.5 |
| 19 | 676.3 | 503.9 | 676.3 | 503.9 | 782.3 | 503.9 | 888.4 | 662.1 |
| 20 | 815.5 | 607.7 | 815.5 | 607.7 | 943.4 | 607.7 | 1071.3 | 798.4 |
| 21 | 815.5 | 607.7 | 815.5 | 607.7 | 943.4 | 607.7 | 1071.3 | 798.4 |
| 22 | 696.2 | 518.8 | 696.2 | 518.8 | 805.4 | 518.8 | 914.6 | 681.5 |
| 23 | 527.1 | 392.8 | 527.1 | 392.8 | 609.8 | 392.8 | 692.4 | 516.0 |
| 24 | 348.1 | 259.4 | 348.1 | 259.4 | 402.7 | 259.4 | 457.3 | 340.8 |

Source: Internal gain: CEC 2,100 ft$^2$ single-family prototype (CBECC-Res Ruleset [4])
Source: Number of people: RASS 2019 [2]

Sensible internal gain and latent internal gain are, respectively, 57.3% and 42.7% of people internal gain.

People per unit = ((1.75 * Number of dwelling units) + (0.4 * Number of bedrooms)) / Number of dwelling units

Unit people gain = People per Unit * (3900/0.573)

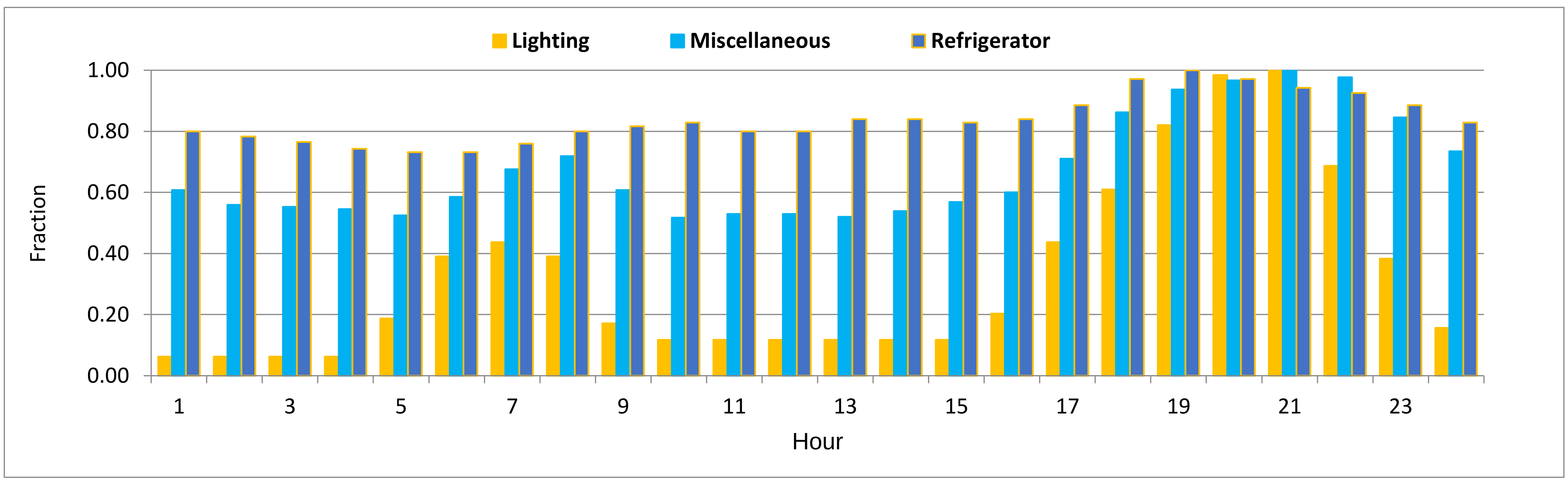
Avg people gain Per conditioned floor area = Unit people gain * Number of dwelling units / Unit total conditioned floor area

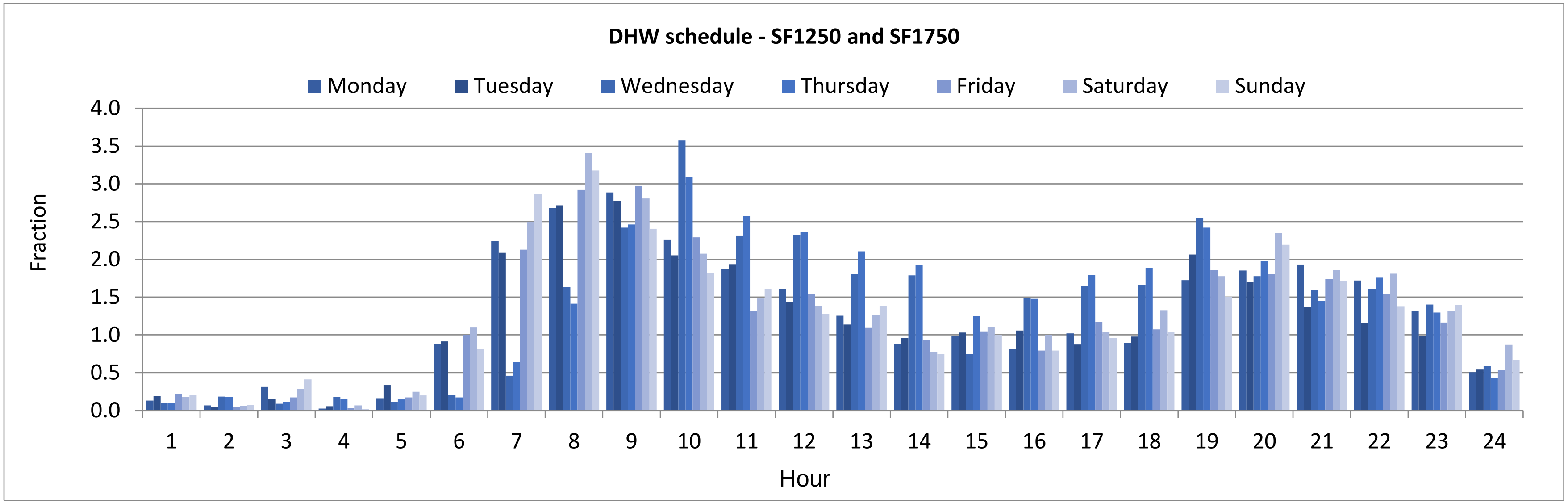
| Internal loads schedules (fraction) | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Schedule** | **Day of week** | **Hour** | | | | | | | | | | | | | | | | | | | | | | | |
| | | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** |
| Gas/Electric dryer schedule | WD | 0.10 | 0.06 | 0.04 | 0.02 | 0.04 | 0.06 | 0.16 | 0.32 | 0.49 | 0.69 | 0.79 | 0.82 | 0.75 | 0.68 | 0.61 | 0.58 | 0.56 | 0.55 | 0.52 | 0.51 | 0.53 | 0.55 | 0.44 | 0.24 |
| | WND | 0.12 | 0.07 | 0.05 | 0.02 | 0.05 | 0.07 | 0.20 | 0.39 | 0.60 | 0.84 | 0.96 | 1.00 | 0.91 | 0.83 | 0.75 | 0.71 | 0.68 | 0.67 | 0.63 | 0.62 | 0.64 | 0.67 | 0.54 | 0.29 |
| Washer schedule | WD | 0.08 | 0.06 | 0.03 | 0.03 | 0.06 | 0.10 | 0.19 | 0.41 | 0.62 | 0.73 | 0.71 | 0.63 | 0.57 | 0.51 | 0.44 | 0.41 | 0.43 | 0.41 | 0.41 | 0.41 | 0.41 | 0.40 | 0.27 | 0.14 |
| | WND | 0.10 | 0.08 | 0.04 | 0.04 | 0.08 | 0.12 | 0.23 | 0.50 | 0.76 | 0.89 | 0.87 | 0.78 | 0.70 | 0.62 | 0.54 | 0.50 | 0.52 | 0.50 | 0.50 | 0.50 | 0.50 | 0.49 | 0.33 | 0.17 |
| Dishwasher schedule | All | 0.12 | 0.05 | 0.04 | 0.03 | 0.03 | 0.08 | 0.16 | 0.25 | 0.47 | 0.52 | 0.45 | 0.38 | 0.33 | 0.37 | 0.30 | 0.29 | 0.30 | 0.40 | 0.70 | 0.89 | 0.73 | 0.54 | 0.36 | 0.25 |
| Refrigerator schedule | All | 0.80 | 0.78 | 0.77 | 0.74 | 0.73 | 0.73 | 0.76 | 0.80 | 0.82 | 0.83 | 0.80 | 0.80 | 0.84 | 0.84 | 0.83 | 0.84 | 0.89 | 0.97 | 1.00 | 0.97 | 0.94 | 0.93 | 0.89 | 0.83 |
| Range schedule | All | 0.05 | 0.05 | 0.02 | 0.02 | 0.05 | 0.07 | 0.17 | 0.28 | 0.31 | 0.32 | 0.28 | 0.33 | 0.38 | 0.31 | 0.29 | 0.38 | 0.61 | 1.00 | 0.78 | 0.40 | 0.24 | 0.17 | 0.10 | 0.07 |
| TV schedule | All | 0.06 | 0.06 | 0.06 | 0.06 | 0.19 | 0.39 | 0.44 | 0.39 | 0.17 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.20 | 0.44 | 0.61 | 0.82 | 0.98 | 1.00 | 0.69 | 0.38 | 0.16 |
| Lights schedule | All | 0.06 | 0.06 | 0.06 | 0.06 | 0.19 | 0.39 | 0.44 | 0.39 | 0.17 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.20 | 0.44 | 0.61 | 0.82 | 0.98 | 1.00 | 0.69 | 0.38 | 0.16 |
| Exterior lights schedule | All | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Miscellaneous schedule | All | 0.61 | 0.56 | 0.55 | 0.55 | 0.52 | 0.59 | 0.68 | 0.72 | 0.61 | 0.52 | 0.53 | 0.53 | 0.52 | 0.54 | 0.57 | 0.60 | 0.71 | 0.86 | 0.94 | 0.97 | 1.00 | 0.98 | 0.85 | 0.73 |
| Occupancy schedule | All | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Activity schedule | All | 0.43 | 0.43 | 0.43 | 0.43 | 0.43 | 0.72 | 1 | 0.67 | 0.33 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.23 | 0.33 | 0.5 | 0.67 | 0.83 | 1 | 1 | 0.85 | 0.65 | 0.43 |

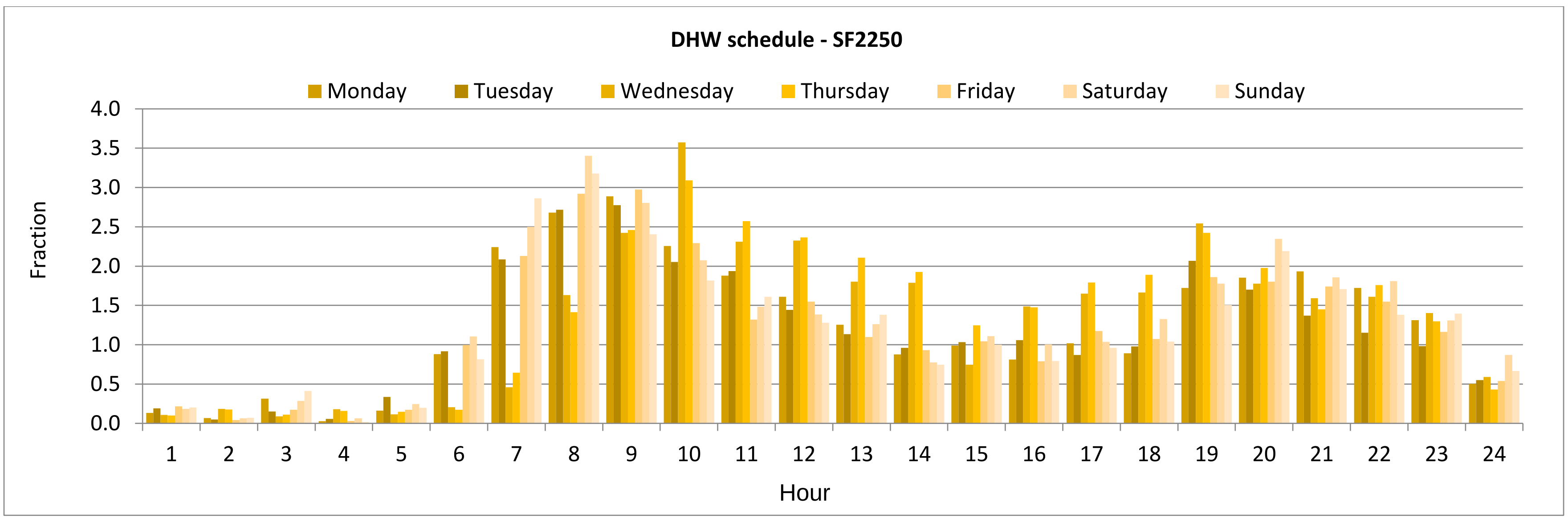
WD= Weekday WND= Weekend Day

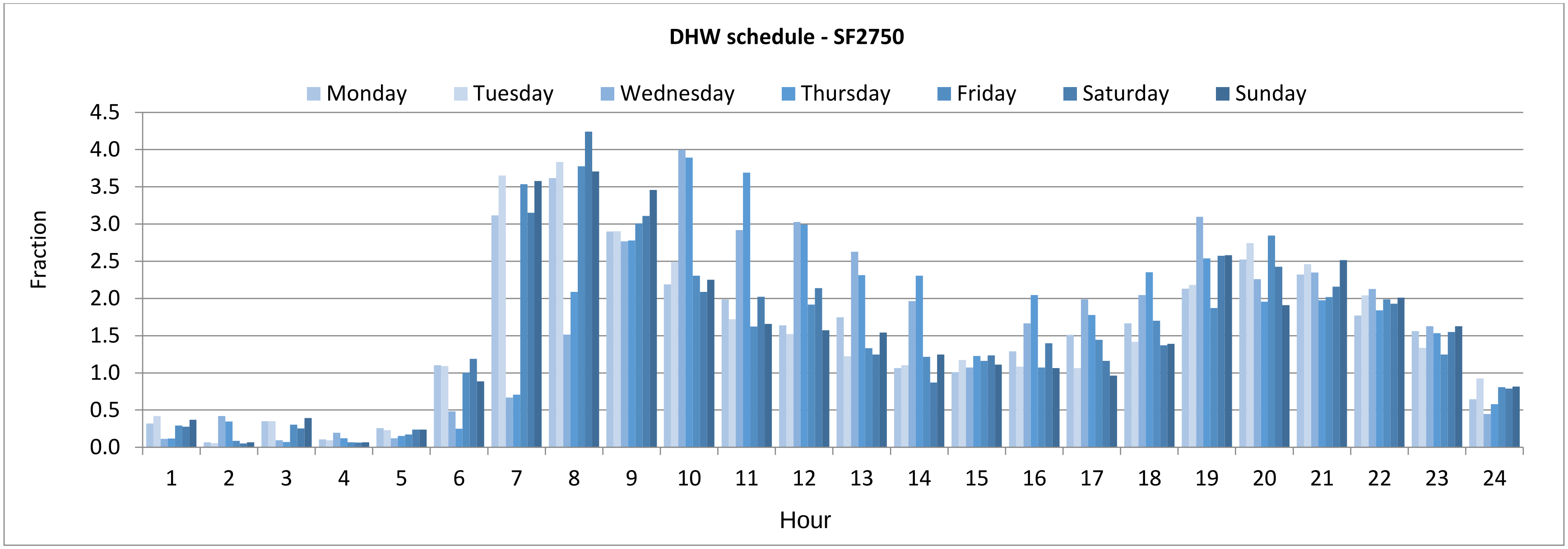
| Gas/Electric domestic water heater schedule (fraction) | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Schedule** | **Hour** | | | | | | | | | | | | | | | | | | | | | | | |
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** |
| Shower schedule | 0.03 | 0.02 | 0.06 | 0.00 | 0.08 | 0.32 | 0.88 | 0.92 | 1.00 | 0.64 | 0.46 | 0.43 | 0.41 | 0.22 | 0.26 | 0.29 | 0.41 | 0.25 | 0.53 | 0.33 | 0.37 | 0.38 | 0.43 | 0.10 |
| Bath schedule | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.28 | 0.10 | 0.37 | 0.09 | 0.17 | 0.08 | 0.49 | 0.31 | 0.00 | 0.09 | 0.21 | 0.69 | 1.00 | 0.10 | 0.70 | 0.17 | 0.00 |
| Sink schedule | 0.09 | 0.03 | 0.07 | 0.03 | 0.09 | 0.23 | 0.46 | 0.97 | 0.81 | 1.00 | 0.83 | 0.59 | 0.64 | 0.55 | 0.45 | 0.45 | 0.50 | 0.67 | 0.82 | 0.87 | 0.81 | 0.63 | 0.39 | 0.37 |
| Washer schedule | 0.00 | 0.00 | 0.04 | 0.12 | 0.00 | 0.04 | 0.17 | 0.36 | 0.59 | 0.91 | 0.79 | 1.00 | 0.28 | 0.36 | 0.21 | 0.38 | 0.20 | 0.45 | 0.51 | 0.58 | 0.35 | 0.40 | 0.39 | 0.40 |
| Dishwasher schedule | 0.12 | 0.14 | 0.23 | 0.04 | 0.00 | 0.00 | 0.02 | 0.29 | 0.81 | 0.71 | 0.57 | 0.69 | 0.52 | 0.27 | 0.27 | 0.40 | 0.13 | 0.32 | 0.30 | 0.97 | 1.00 | 0.49 | 0.34 | 0.19 |
| Total | 0.24 | 0.19 | 0.40 | 0.19 | 0.17 | 0.59 | 1.53 | 2.82 | 3.31 | 3.63 | 2.74 | 2.88 | 1.93 | 1.89 | 1.50 | 1.52 | 1.33 | 1.90 | 2.85 | 3.75 | 2.63 | 2.60 | 1.72 | 1.06 |

## Plots of some weekday schedules

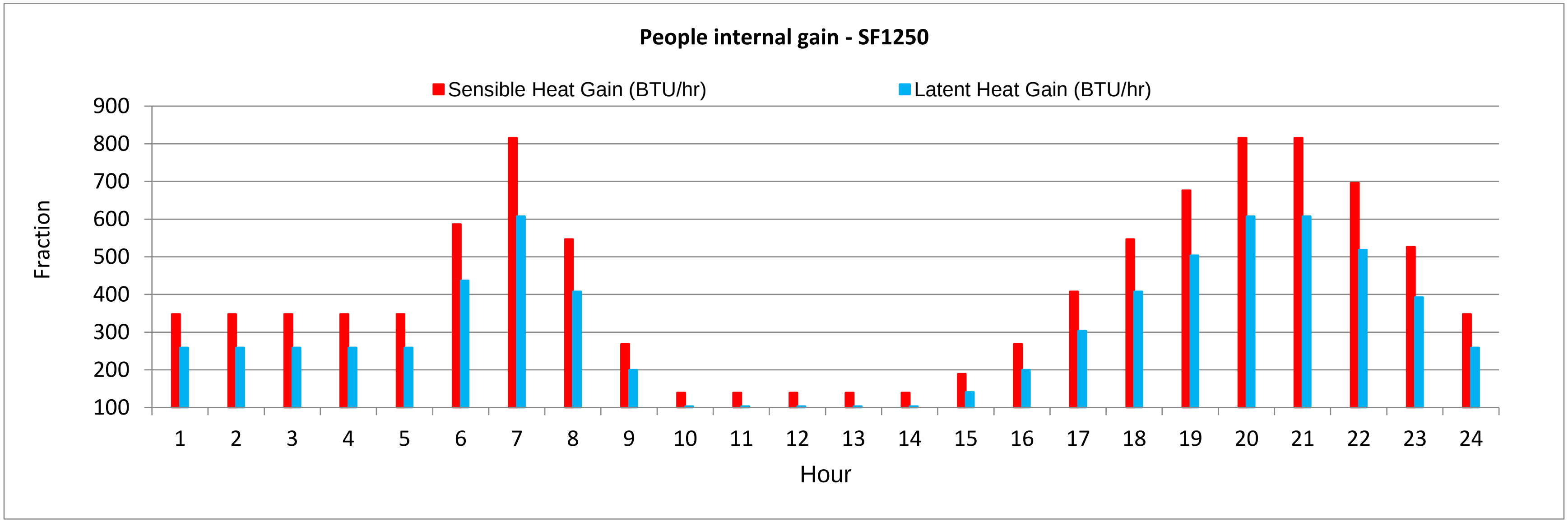



DHW schedule - SF1250 and SF1750
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Fraction
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour


DHW schedule - SF2250
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Fraction
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour



DHW schedule - SF2750
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Fraction
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour

People internal gain - SF1250
Sensible Heat Gain (BTU/hr)
Latent Heat Gain (BTU/hr)
Fraction
900
800
700
600
500
400
300
200
100
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour

# 8. Appendix C: Inputs for MF

| Architecture | | |
|---|---|---|
| **Item** | **Description** | **Source** |
| **Form** | | |
| Total floor area ($ft^2$) | Prototype MF-Garden: 7,320 (4 2-bedroom, 4 1-bedroom)<br>Prototype MF-Corridor: 39,372 (6 studios, 12 1-bedrooms, 12 2-bedrooms, 6 3-bedrooms, 1 gym, 2 offices, 1 laundry, 1 mechanical room, 2 elevators, 1 stairwell, 3 corridors) | *CEC MF prototype* |
| Unit floor area ($ft^2$) | Studio: 540 (MF-Corridor)<br>1-Bedroom: 750 (MF-Garden) - 720 (MF-Corridor)<br>2-Bedroom: 1,080 (MF-Garden) - 1,120 (MF-Corridor)<br>3-Bedroom: 1,410 (MF-Corridor) | *CEC MF prototype* |
| **Exterior walls** | | |
| Construction | Wood-framed | *RASS 2019* [2] |
| Dimensions | Based on floor area and aspect ratio | |
| Tilts and orientations | Vertical | |
| **Roof** | | |
| Construction | Prototype MF-Garden: Wood-framed attic<br>Prototype MF-Corridor: Metal deck | *RASS 2019* [2] |
| Dimensions | Based on floor area and aspect ratio | |
| Tilts and orientations | Horizontal | |
| **Window** | | |
| Dimensions | Based on window fraction, location, glazing sill height, floor area, and aspect ratio | |
| Glass-type and frame | Hypothetical window with weighted U-factor and SHGC | |
| **Foundation** | | |
| Foundation Type | Slab-on-grade floors (unheated) | *RASS 2019* [2] |
| Construction | 6" concrete slab poured directly onto the earth + carpet | |
| **Interior Partitions** | | |
| Construction | 2 x 4 uninsulated steel stud wall | |
| Dimensions | based on floor plan and floor-to-floor height | |

| Envelope properties by vintage | | | | | | |
|---|---|---|---|---|---|---|
| **Vintage** | **Wall cavity insulation R-Value** | **Roof attic insulation R-Value** | **Slab/ crawlspace insulation** | **Window U-Factor** | **Window SHGC** | **Air leakage (ACH50)** |
| Pre-1975 | R-1.0 | R-13 | None | 0.94 | 0.73 | 19 |
| 1975-1983 | R-7.0 | R-12 | None | 0.92 | 0.73 | 15 |
| 1984-2005 | R-13 | R-14 | None | 0.81 | 0.71 | 11 |
| 2006-2019 | R-15 | R-17 | None | 0.50 | 0.52 | 11 |
| New Construction | R-21 | R-38<br>R-30 (CZ 3,5,6,7) | None | 0.30 | 0.24 | 7.0 |

Source: Built by 2019: RASS 2019 [2], ResStock 2021 [8]
Source: New Construction: Title 24 2022 [9]

| HVAC and DHW | | |
|---|---|---|
| **Item** | **Description** | **Data Source** |
| **System Type** | | |
| Heating type | Gas central furnace -Electric resistance | *RASS 2019* [2]<br>*Title 24 2022* [9] |
| Cooling type | Split air conditioner | |
| **HVAC sizing** | | |
| Air conditioning | Autosized to design day conditions | *ACCA Manual J & Manual S* |
| Heating | Autosized to design day conditions | |
| **HVAC efficiency** | | |
| Air conditioning | Various by climate location and design cooling capacity | *RASS 2019* [2] |
| Heating | Various by climate location and design heating capacity | *RASS 2019* [2] |
| **HVAC Control** | NA | |
| Initial thermostat Setpoint | 74°F for cooling/70°F for heating in all climate zones | *Various sources.* |
| Thermostat setback | After validation | |
| Ventilation | NA | |
| Fan power | See under fan power | *Title 20 2015* [10]<br>*Department of Energy. 10 CFR Part 430* [14] |
| **Domestic water heating** | | |
| DHW type | Storage tank | *RASS 2019* [2] |
| Thermal efficiency (%) | See under DHW | *NAECA (National Appliance Energy Conservation Act)*<br>*Title 24 2022* [9] |
| Tank volume (gal) | 50 | |
| Water temperature setpoint | 120 F | *PNNL Residential Prototype* [13] |

| Furnace fan power | |
|---|---|
| **Vintage** | **Maximum electric furnace AHU fan Watts/cfm** |
| Pre-1975 | 0.58 |
| 1975-1983 | 0.58 |
| 1984-2005 | 0.58 |
| 2006 -2019 | 0.58 |
| New Construction | 0.45 |

Source: Title 24 (2022, 2019, 2007, 2005) [9], based on the effective date and age of cooling equipment

| DHW assumptions | | |
|---|---|---|
| **Gas DHW system** | Recovery efficiency | 79% |
| | Ambient temperature | 67.5 F |
| | $Q_{load}$ based on medium usage | 30,584 Btu |

| | | |
|---|---|---|
| **Electric DHW system** | Recovery efficiency | 79% |
| | Ambient temperature | 67.5 F |
| | Ambient air temperature | 58 F |
| | flow: fraction of the tank area below the lower element | 0.2 |
| | $Q_{load}$ based on medium usage | 30,584 Btu |

| UEF to model inputs | | | |
|---|---|---|---|
| Water heater type | Burner Thermal Efficiency (%) | Shell losses-UA (Btu/hr-ºF) UEF-0.56 | Shell losses-UA (Btu/hr-ºF) UEF-0.58 |
| Gas-fired storage | 80% | 9.97 | 8.79 |

| Water heater type | Burner thermal efficiency (%) | Shell losses-UA (Btu/hr-ºF) UEF-0.89 | Shell losses-UA (Btu/hr-ºF) UEF-0.92 |
|---|---|---|---|
| Electric storage | 100% | 3.96 | 2.79 |

Source:
https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22068.pdf
https://www.ashrae.org/file%20library/conferences/specialty%20conferences/2020%20building%20performance/papers/d-bsc20-c039.pdf
http://www.ibpsa.org/proceedings/BS2017/BS2017_237.pdf
https://www.energy.ca.gov/sites/default/files/2020-10/2016%20Water%20Heater%20Efficiency%20Guide_ada.pdf

| Interior hard-wired lighting per unit | | |
|---|---|---|
| **Floor area** | **Annual energy consumption (kWh/yr)** | **Source** |
| 540 | 1,694 | ASHRAE Standard 90.2 [20] |
| 720 | 2,258 | ASHRAE Standard 90.2 [20] |
| 750 | 2,353 | ASHRAE Standard 90.2 [20] |
| 1054 | 3,306 | ASHRAE Standard 90.2 [20] |
| 1080 | 3,388 | ASHRAE Standard 90.2 [20] |
| 1410 | 4,423 | ASHRAE Standard 90.2 [20] |

**Formula:**

Interior lighting per unit = 1.1 Watts/ft$^2$ * (conditioned floor area) *2851.6/1000

| Approximate distribution based on subjective responses in RASS 2019<br>Responses are subjective and do not total to 100% | | | |
|---|---|---|---|
| **Vintage** | **Incandescent** | **CFL** | **LED** |
| Pre-1975 | 30% | 40% | 35% |
| 1975-1983 | 28% | 41% | 42% |
| 1984-2005 | 28% | 42% | 42% |
| 2006-2019 | 23% | 50% | 45% |
| New Construction | | | 100% |

Subjective response, "mostly" = 75%

| People internal gain | | | | | | |
|---|---|---|---|---|---|---|
| Hour | 1-Bedroom | | 2-Bedroom | | 3-Bedroom | |
| | Sensible heat gain (Btu/hr) | Latent heat gain (Btu /hr) | Sensible heat gain (Btu /hr) | Latent heat gain (Btu /hr) | Sensible heat gain (Btu /hr) | Latent heat gain (Btu /hr) |
| 1 | 293.5 | 218.7 | 348.1 | 259.4 | 402.7 | 300.1 |
| 2 | 293.5 | 218.7 | 348.1 | 259.4 | 402.7 | 300.1 |
| 3 | 293.5 | 218.7 | 348.1 | 259.4 | 402.7 | 300.1 |
| 4 | 293.5 | 218.7 | 348.1 | 259.4 | 402.7 | 300.1 |
| 5 | 293.5 | 218.7 | 348.1 | 259.4 | 402.7 | 300.1 |
| 6 | 494.7 | 368.7 | 586.8 | 437.3 | 678.8 | 505.8 |
| 7 | 687.6 | 512.4 | 815.5 | 607.7 | 943.4 | 703.0 |
| 8 | 461.2 | 343.7 | 547.0 | 407.6 | 632.8 | 471.5 |
| 9 | 226.4 | 168.7 | 268.5 | 200.1 | 310.6 | 231.5 |
| 10 | 117.4 | 87.5 | 139.2 | 103.8 | 161.1 | 120.0 |
| 11 | 117.4 | 87.5 | 139.2 | 103.8 | 161.1 | 120.0 |
| 12 | 117.4 | 87.5 | 139.2 | 103.8 | 161.1 | 120.0 |
| 13 | 117.4 | 87.5 | 139.2 | 103.8 | 161.1 | 120.0 |
| 14 | 117.4 | 87.5 | 139.2 | 103.8 | 161.1 | 120.0 |
| 15 | 159.3 | 118.7 | 189.0 | 140.8 | 218.6 | 162.9 |
| 16 | 226.4 | 168.7 | 268.5 | 200.1 | 310.6 | 231.5 |
| 17 | 343.8 | 256.2 | 407.7 | 303.9 | 471.7 | 351.5 |
| 18 | 461.2 | 343.7 | 547.0 | 407.6 | 632.8 | 471.5 |
| 19 | 570.2 | 424.9 | 676.3 | 503.9 | 782.3 | 583.0 |
| 20 | 687.6 | 512.4 | 815.5 | 607.7 | 943.4 | 703.0 |
| 21 | 687.6 | 512.4 | 815.5 | 607.7 | 943.4 | 703.0 |
| 22 | 587.0 | 437.4 | 696.2 | 518.8 | 805.4 | 600.1 |
| 23 | 444.4 | 331.2 | 527.1 | 392.8 | 609.8 | 454.4 |
| 24 | 293.5 | 218.7 | 348.1 | 259.4 | 402.7 | 300.1 |

Source: Internal gain: CBECC-Res Ruleset [4]
Source: Number of People: CBECC-Res Ruleset [4]

Sensible internal gain and latent internal gain are, respectively, 57.3% and 42.7% of people internal gain
People per unit = ((1.75 * Number of dwelling units) + (0.4 * Num of bedrooms)) / Number of dwelling units
Unit people gain = People per Unit * (3900/0.573)
Avg people gain per conditioned floor area = Unit people gain / Unit total conditioned floor area

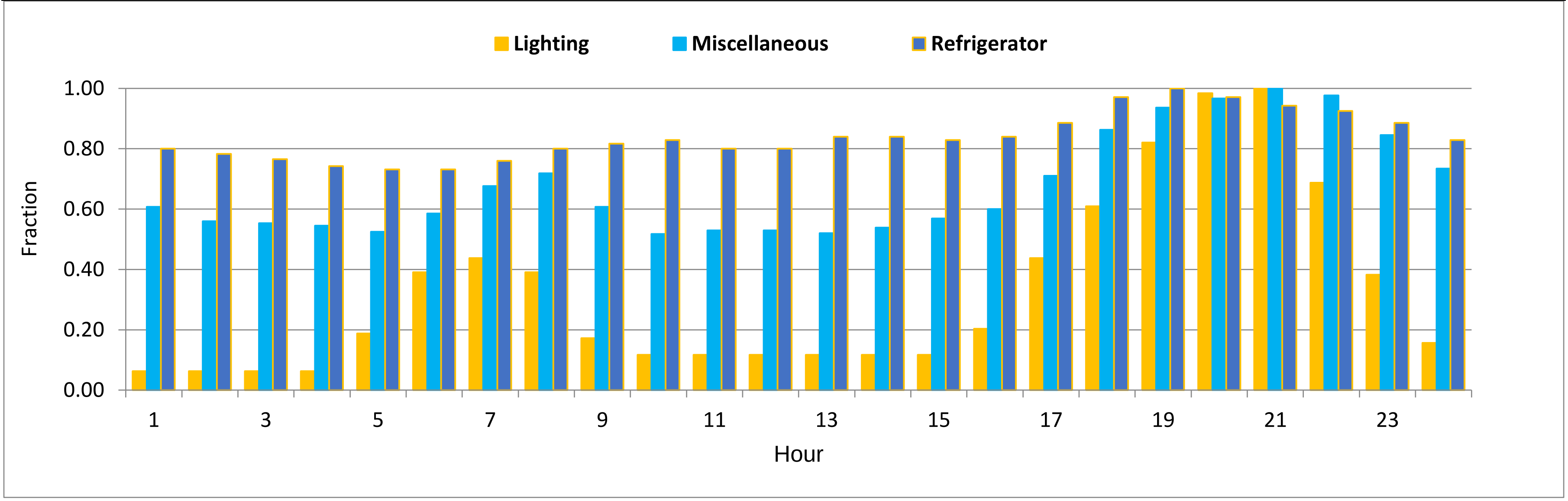
## Internal loads schedules

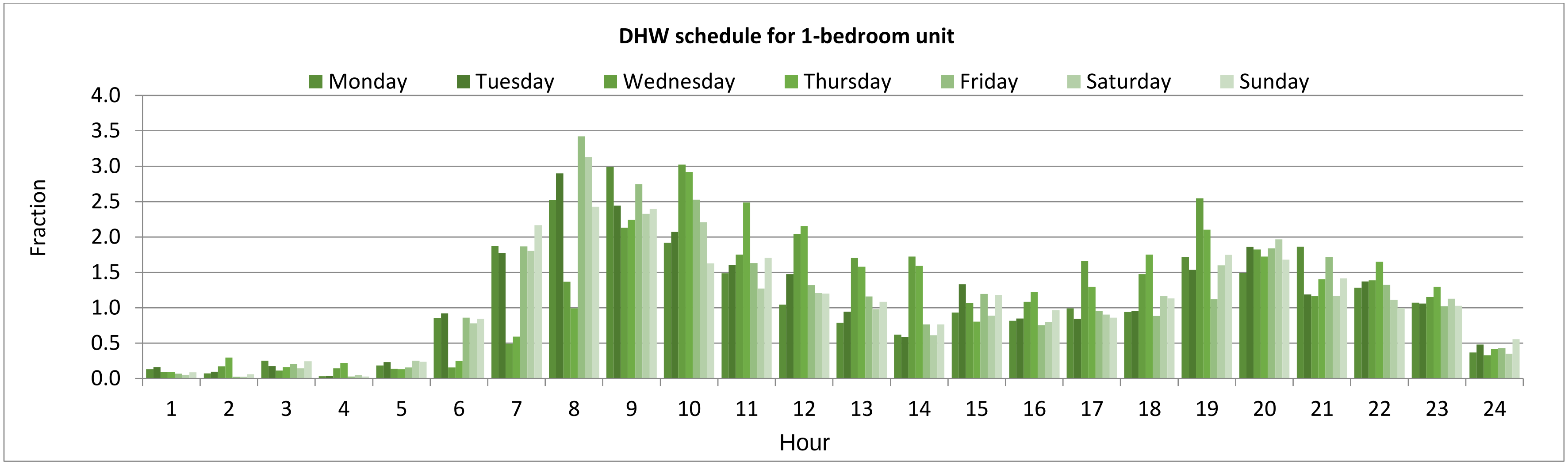
| Schedule | Day of week | Hour | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Gas/Electric Dryer Schedule | WD | 0.10 | 0.06 | 0.04 | 0.02 | 0.04 | 0.06 | 0.16 | 0.32 | 0.49 | 0.69 | 0.79 | 0.82 | 0.75 | 0.68 | 0.61 | 0.58 | 0.56 | 0.55 | 0.52 | 0.51 | 0.53 | 0.55 | 0.44 | 0.24 |
| | WND | 0.12 | 0.07 | 0.05 | 0.02 | 0.05 | 0.07 | 0.20 | 0.39 | 0.60 | 0.84 | 0.96 | 1.00 | 0.91 | 0.83 | 0.75 | 0.71 | 0.68 | 0.67 | 0.63 | 0.62 | 0.64 | 0.67 | 0.54 | 0.29 |
| | Resnet | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.02 | 0.03 | 0.05 | 0.07 | 0.08 | 0.08 | 0.07 | 0.07 | 0.06 | 0.06 | 0.06 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.04 | 0.02 |
| Washer Schedule | WD | 0.08 | 0.06 | 0.03 | 0.03 | 0.06 | 0.10 | 0.19 | 0.41 | 0.62 | 0.73 | 0.71 | 0.63 | 0.57 | 0.51 | 0.44 | 0.41 | 0.43 | 0.41 | 0.41 | 0.41 | 0.41 | 0.40 | 0.27 | 0.14 |
| | WND | 0.10 | 0.08 | 0.04 | 0.04 | 0.08 | 0.12 | 0.23 | 0.50 | 0.76 | 0.89 | 0.87 | 0.78 | 0.70 | 0.62 | 0.54 | 0.50 | 0.52 | 0.50 | 0.50 | 0.50 | 0.50 | 0.49 | 0.33 | 0.17 |
| | Resnet | 0.01 | 0.01 | 0.00 | 0.00 | 0.01 | 0.01 | 0.02 | 0.05 | 0.07 | 0.09 | 0.08 | 0.08 | 0.07 | 0.06 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.03 | 0.02 |
| Dishwasher Schedule | All | 0.12 | 0.05 | 0.04 | 0.03 | 0.03 | 0.08 | 0.16 | 0.25 | 0.47 | 0.52 | 0.45 | 0.38 | 0.33 | 0.37 | 0.30 | 0.29 | 0.30 | 0.40 | 0.70 | 0.89 | 0.73 | 0.54 | 0.36 | 0.25 |
| | Resnet | 0.02 | 0.01 | 0.01 | 0.00 | 0.00 | 0.01 | 0.02 | 0.03 | 0.06 | 0.07 | 0.06 | 0.05 | 0.04 | 0.05 | 0.04 | 0.04 | 0.04 | 0.05 | 0.09 | 0.11 | 0.09 | 0.07 | 0.04 | 0.03 |
| Refrigerator Schedule | All | 0.80 | 0.78 | 0.77 | 0.74 | 0.73 | 0.73 | 0.76 | 0.80 | 0.82 | 0.83 | 0.80 | 0.80 | 0.84 | 0.84 | 0.83 | 0.84 | 0.89 | 0.97 | 1.00 | 0.97 | 0.94 | 0.93 | 0.89 | 0.83 |
| Range Schedule | All | 0.05 | 0.05 | 0.02 | 0.02 | 0.05 | 0.07 | 0.17 | 0.28 | 0.31 | 0.32 | 0.28 | 0.33 | 0.38 | 0.31 | 0.29 | 0.38 | 0.61 | 1.00 | 0.78 | 0.40 | 0.24 | 0.17 | 0.10 | 0.07 |
| | Resnet | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.04 | 0.05 | 0.05 | 0.05 | 0.05 | 0.06 | 0.05 | 0.04 | 0.05 | 0.08 | 0.13 | 0.11 | 0.06 | 0.04 | 0.03 | 0.02 | 0.02 |
| TV Schedule | All | 0.06 | 0.06 | 0.06 | 0.06 | 0.19 | 0.39 | 0.44 | 0.39 | 0.17 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.20 | 0.44 | 0.61 | 0.82 | 0.98 | 1.00 | 0.69 | 0.38 | 0.16 |
| | Resnet | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.04 | 0.04 | 0.05 | 0.05 | 0.06 | 0.08 | 0.11 | 0.13 | 0.13 | 0.08 | 0.03 |
| Lights Schedule | All | 0.06 | 0.06 | 0.06 | 0.06 | 0.19 | 0.39 | 0.44 | 0.39 | 0.17 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.20 | 0.44 | 0.61 | 0.82 | 0.98 | 1.00 | 0.69 | 0.38 | 0.16 |
| Outdoor Lights Schedule | All | 0.06 | 0.06 | 0.06 | 0.06 | 0.19 | 0.39 | 0.44 | 0.39 | 0.17 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.20 | 0.44 | 0.61 | 0.82 | 0.98 | 1.00 | 0.69 | 0.38 | 0.16 |
| Miscellaneous Schedule | All | 0.61 | 0.56 | 0.55 | 0.55 | 0.52 | 0.59 | 0.68 | 0.72 | 0.61 | 0.52 | 0.53 | 0.53 | 0.52 | 0.54 | 0.57 | 0.60 | 0.71 | 0.86 | 0.94 | 0.97 | 1.00 | 0.98 | 0.85 | 0.73 |
| | Resnet | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.04 | 0.04 | 0.04 |

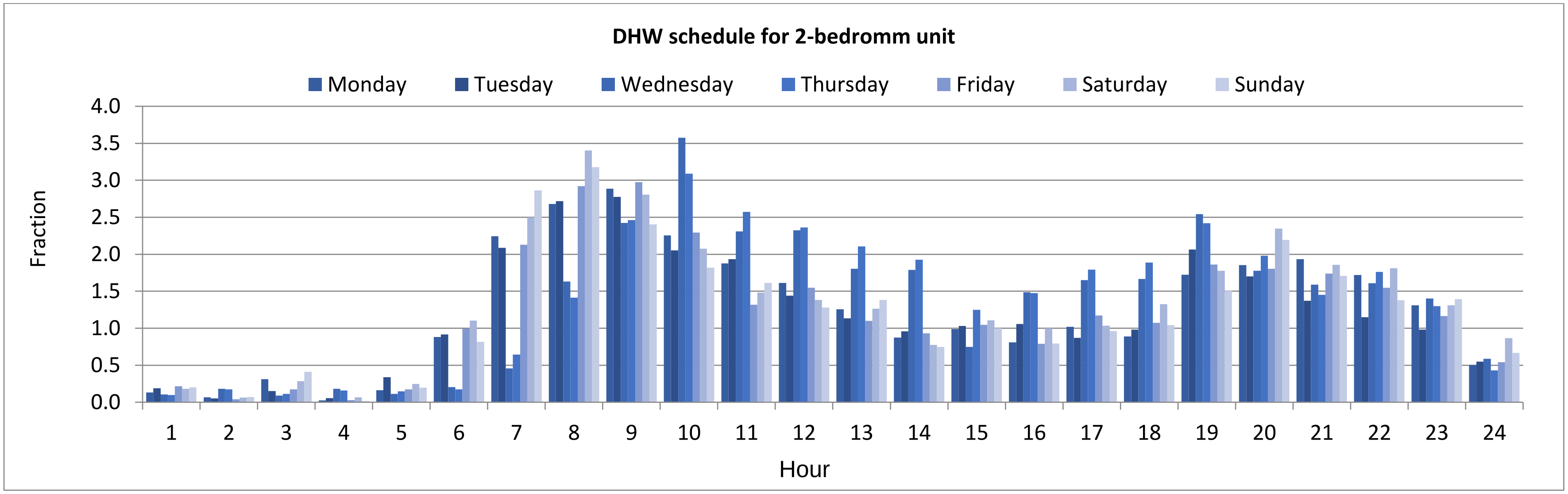
## Gas/Electric domestic water heater schedule

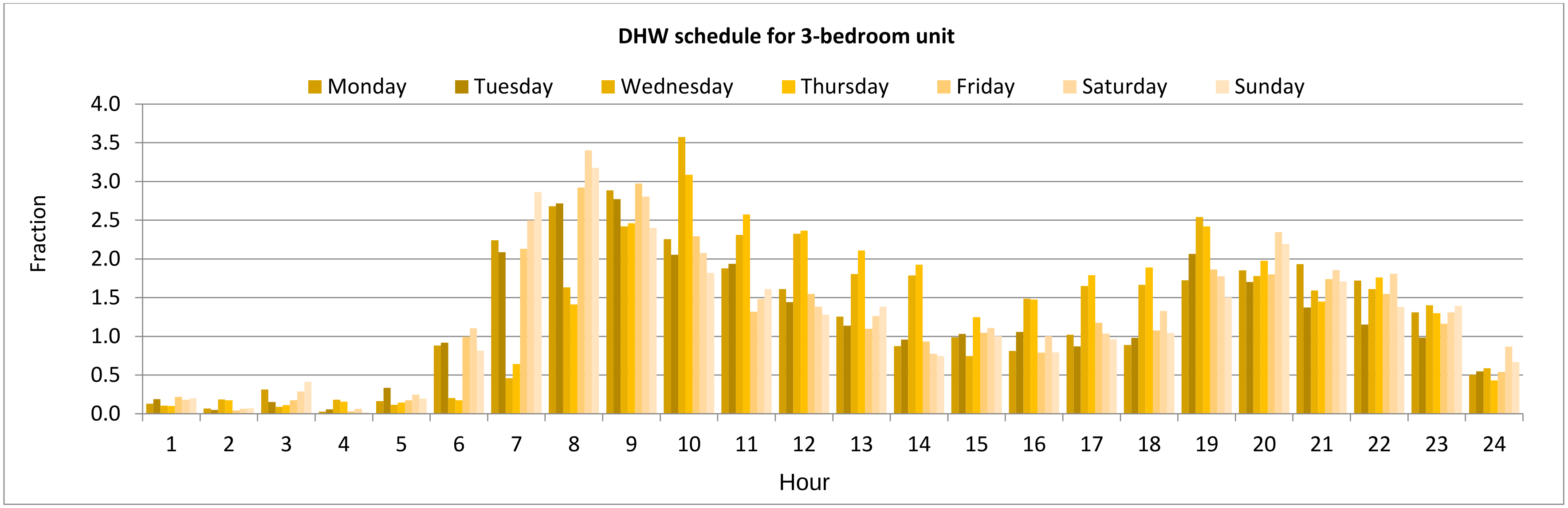
| Schedule | Hour | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Shower Schedule | 0.002 | 0.001 | 0.000 | 0.001 | 0.002 | 0.008 | 0.019 | 0.019 | 0.015 | 0.012 | 0.010 | 0.007 | 0.005 | 0.005 | 0.004 | 0.004 | 0.005 | 0.006 | 0.007 | 0.007 | 0.007 | 0.007 | 0.005 | 0.003 |
| Bath Schedule | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.002 | 0.002 | 0.002 | 0.002 | 0.001 | 0.001 |
| Sink Schedule | 0.004 | 0.002 | 0.001 | 0.001 | 0.002 | 0.005 | 0.012 | 0.017 | 0.018 | 0.017 | 0.015 | 0.014 | 0.014 | 0.012 | 0.012 | 0.011 | 0.013 | 0.018 | 0.021 | 0.019 | 0.016 | 0.013 | 0.011 | 0.007 |
| Total | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.03 | 0.04 | 0.03 | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 | 0.01 |

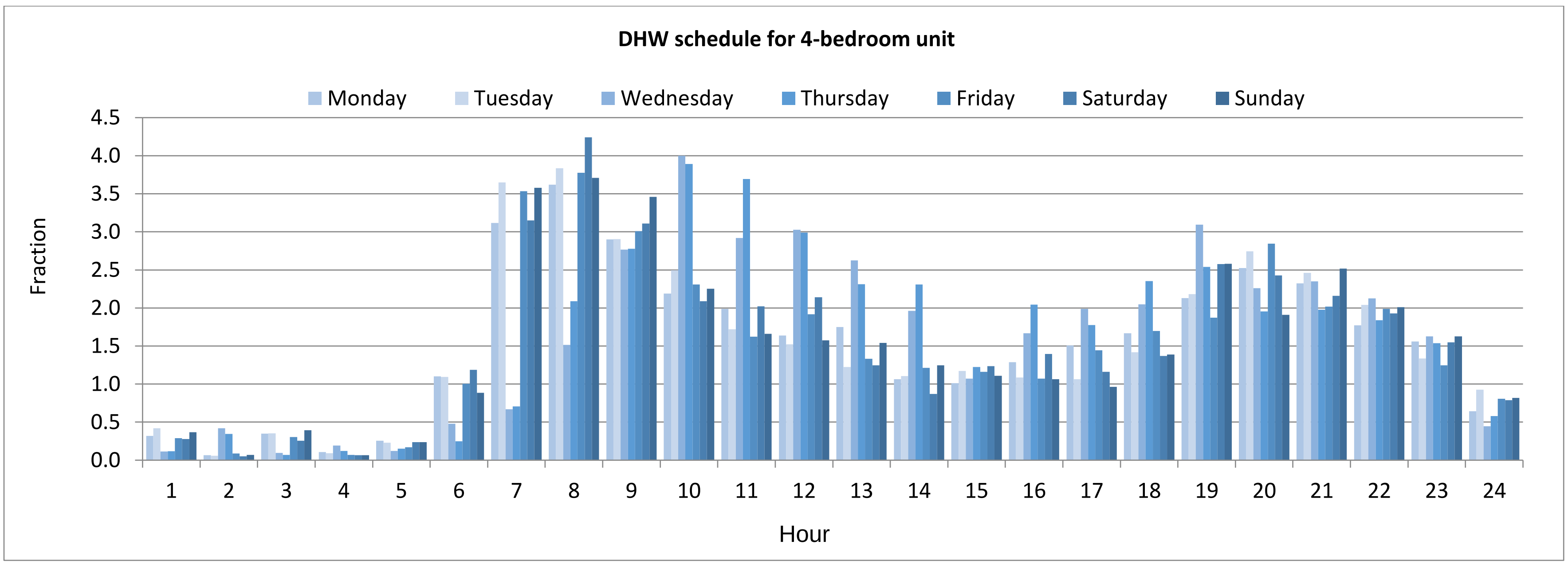
## Plots of some weekday schedules




DHW schedule for 1-bedroom unit
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Fraction
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour


DHW schedule for 2-bedromm unit
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Fraction
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour


DHW schedule for 3-bedroom unit
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Fraction
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour


DHW schedule for 4-bedroom unit
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Fraction
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour