Commercial Retrofit Needs to Enable Zero Emissions Equipment Installation in Nonresidential Buildings

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ABSTRACT

In the 2022 State Strategy for the State Implementation Plan (SIP), the California Air Resources Board described a concept for a zero-emission (ZE) greenhouse gas standard that would require new space and water heaters sold in California to be ZE beginning in 2030. This paper assesses the retrofit needs of California's nonresidential building stock when installing ZE equipment under the SIP concept and under alternative scenarios.

The study team uses ComStock as the foundational data source for building characteristics and integrates it with other datasets via a joint distribution model in R software. The paper estimates the associated retrofit needs when installing ZE equipment for space and water-heating, pool heating, cooking, and clothes drying. The paper discusses the rubric developed to categorize retrofit thresholds, ranging from 'no retrofit' to 'major,' across four retrofit categories: electrical, physical space, heat source, and structural.

The paper identifies the main drivers of retrofits for all equipment categories. Space heating is the equipment category with the most retrofit needs, where 38 percent of buildings need moderate or major retrofits. Variable Air Volume systems are the space conditioning system requiring the most heat source and physical space retrofits. Single zone rooftop space conditioners have predominantly minor retrofit needs for electrical circuitry and structure. Whole building electrical infrastructure is not a driver of retrofits because most buildings have sufficient capacity for ZE equipment.

The paper concludes with a summary of strategies to support future ZE policies and decrease retrofit needs, such as technological innovations and changes to building codes.

Introduction

Nonresidential buildings account for approximately one-third of California's building-related greenhouse gas (GHG) emissions, making their decarbonization a critical component of California's climate goals. Zero-emission standards for new space and water heaters sold in California would decrease GHG emissions from buildings and are part of California's climate strategy as laid out in the California Air Resources Board (CARB)'s 2022 Scoping Plan (CARB 2022a). These standards would also reduce nitrogen oxides (NOx) emissions to assist California in meeting state and federal air quality standards and achieving public health benefit goals.

In 2024, CARB initiated the "Nonresidential Building Retrofit Assessment for Installing Zero-Emission Equipment" study to evaluate the retrofit needs of nonresidential buildings in California to transition to zero-emission (ZE) equipment. This paper provides an overview of the study, which focuses on the feasibility of replacing emissive systems for space heating, water heating, pool heating, cooking, and laundry with ZE alternatives. By addressing these systems, the state could reduce overall emissions by 3.6% (CARB 2022b), contributing significantly to its environmental targets.

Methodology

The study employed the Zero-Emission Retrofit Assessment Model, or the "Model," developed by TRC, which simulates retrofit needs using data from over 10,000 building prototypes provided by ComStock (Parker, A and Horsey, H, 2025). The Model integrates Comstock building characteristics, equipment types, and geographic data with supplemental sources such as the California Commercial End-Use Survey (CEUS), Commercial Buildings Energy Consumption Survey (CBECS), and Database for Energy Efficient Resources (DEER), (ADM Associates 2024), (EIA 2022) (California Public Utilities Commission 2025) to better represent the California building stock with additional building types and equipment categories. This analysis used all building types available in ComStock, noted as such, plus a few additional key building types and equipment categories, noted as "Custom". These include:

- Full Service Restaurant (ComStock)
- Quick Service Restaurant (ComStock)
- Hospital (ComStock)
- Outpatient Facilities (ComStock)
- Small Hotel (ComStock with Custom modifications)
- Large Hotel (ComStock with Custom modifications)
- Offices (ComStock)
- Primary School (ComStock)
- Secondary School (ComStock with Custom modifications)
- Retail (ComStock with Custom modifications)
- Strip Mall (ComStock with Custom modifications)
- Warehouse (ComStock)
- Grocery Store (ComStock with Custom modifications)
- Laundromat (Custom)
- Refrigerated Warehouse (Custom)

Once the building population was developed, the project team developed 1) the Retrofit Level Criteria (i.e., how to define various retrofit needs) and 2) the Retrofit Criteria for Each Equipment Category (i.e., the magnitude of each retrofit need). Finally, the project team developed five different policy scenarios, denoted as "Cases," for assessing retrofit needs:

1. **All ZE Equipment**. Assumes all non-residential emissive equipment is included in scope.
2. **2022 SIP Concept**. Following CARB's 2022 Scoping Plan, assumes only water, space, and pool heaters below 2,000,000 BTU/hr are in scope.
3. **Added Equipment Types**. Same as 2022 SIP Concept but including cooking and laundry (i.e., more equipment covered in the scope).
4. **Reduced Capacity Thresholds**. Same as 2022 SIP Concept but with lower maximum capacity scope bounds (i.e., less equipment capacities covered in scope).
5. **Increased Capacity Thresholds**. Same as 2022 SIP Concept but with higher maximum capacity scope bounds (i.e., more equipment capacities covered in scope).

Retrofit Level by Criteria

Each equipment replacement was categorized into a retrofit need based on the needs for each of four key criteria: electrical capacity, physical space, access to heat source, and structural needs. Engineering calculations and assumptions were formulated based on professional judgment to determine the retrofit needs across four thresholds (no retrofit, minor, moderate, or major) for each building, across all equipment categories, and across retrofit criteria, according to Table 1 below.

Table 1. Retrofit levels and definitions

Retrofit threshold	**Interior space and exterior space**	**Structural**	**Electrical**	**Heat source**
No retrofit	Limited or no changes required for ZE equipment in comparison to a like-for-like replacement.	No structural impact.	ZE peak electrical demand increases less than 20% or equal to the existing peak electrical demand, AND <10% increase of existing electrical panel and service capacity is needed. Most if not all existing circuits, breakers, and other infrastructure are adequate for ZE equipment replacement.	No additional ventilation needs.
Minor	Estimated cost increase over a like-for-like replacement of approximately 10-50%.	Structural review. May require additional structural support.	10-50% increase in existing electrical panel and service capacity. New circuits and breaker installation necessary. Subpanels, low voltage devices, or power control devices may avoid a service upgrade.	Ventilation to mechanical room on exterior wall.
Moderate	Estimated cost increase over a like-for-like replacement of greater than 50%, a combination of the existing mechanical room, roof, or adjacent ground-level is anticipated to meet the need.	Moderate reinforcement necessary.	50-300% increase in existing electrical panel and service capacity. New circuits, breakers, panel, and a new electrical service is necessary.	Ventilation to interior mechanical room via ductwork.

Retrofit threshold	Interior space and exterior space	Structural	Electrical	Heat source
Major	Significant cost increase and existing occupancies are likely needed to be repurposed to house ZE equipment or infrastructure needs.	Significant reinforcement necessary.	>300% increase in existing electrical panel and service capacity. New circuits, panels, electrical service, and likely enlarged electrical room to accommodate larger equipment.	Ventilation to interior mechanical room and potential additional equipment such as ground source loops or cooling towers.
Already ZE	Buildings and equipment categories that are already ZE, therefore they can install ZE replacement equipment with no additional retrofit needs.			
Not applicable	Equipment categories that are not applicable to the analysis because 1) the equipment category is not present in that building and therefore a replacement is not applicable, or 2) the equipment category is not within the scope of the assessment for the case analyzed, due to the equipment type or equipment capacity.			

Retrofit Criteria by Retrofit Category

For all prototype buildings in the Model, the team determined the existing (baseline) equipment types, equipment sizes/capacities, and selected relevant building characteristics from Comstock and other primary data sources.

The next step was to determine the necessary ZE replacement equipment. For existing gas and propane emissive systems, the team mapped the replacement system type to the existing system type based on a review of several data sources (California Energy Codes & Standards 2025) (CBE 2025) (Houssainy and Landan 2024) (Guidehouse and Opinion Dynamics 2024) (Itron 2014) and the experience of engineers on the team. The team estimated the building's potential replacement equipment, prioritizing options that minimize the need for other building upgrades. Where there was more than one likely ZE replacement option, the team estimated the likelihood of each system based on judgment and validated with our engineering subcontractor.

The project team used a sample of product specifications to determine the ZE retrofit needs. Basic information about the existing emissive equipment, such as water heating energy consumption and served occupancies, were used to estimate the ZE alternative equipment peak energy usage. Table 2 below summarizes the primary references for determining the ZE retrofit needs of each equipment category, which then serve as inputs to the retrofit criteria thresholds. However, for water heating and multizone space heating, the project team relied on engineering judgment to assign probabilities for various replacement options, accounting for factors such as building type, climate, retrofit scope and cost, and replacement system complexity.

Table 2. Retrofit specifications for each equipment category

Equipment Category	**Criteria: Physical Space and Structural**	**Criteria: Electrical**	**Criteria: Heat source**
Space Heating - Single zone	Rooftop Units (RTUs): Manufacturer specifications All others: Engineering judgment	RTUs: Manufacturer specifications All others: IECC Appendix CH (IECC 2025)	All: Engineering judgment
Space Heating – Multizone	Engineering judgment	IECC Appendix CH	Engineering judgment
Water Heating	Engineering judgment	ASHRAE 2019 Handbook and California Energy Code (ASHRAE 2019)	Engineering judgment
Pool Heating	Engineering judgment	Dept of Energy and Title 24 CASE Report on Pools and Spas (Schellinger, 2023) (US DOE 2025)	Engineering judgment
Cooking	Not applicable: ZE equipment not expected to require retrofits for this equipment category and criterion	Manufacturer specifications and professional judgement	Not applicable
Laundry	Not applicable	Manufacturer specifications and professional judgment (Zhang and Wei, 2013) (US DOE, 2014)	Not applicable

Table 3 below depicts an example of the professional judgement used to estimate the ZE replacements and their retrofit levels in multizone space conditioning systems. These assumptions were informed by and large by a database from the Center for the Built Environment (CBE 2025).

Table 3. Heat source retrofit path example for variable air volume (VAV) direct expansion (DX) air handling unit (AHU) with emissive boiler reheat being replaced with a ZE system in any building type.

ZE system	Replacement percentage	Potential retrofit to accommodate physical access to exterior for heat source	Retrofit path formula	Retrofit level
Variable Air Volume (VAV) reheat with Direct Expansion (DX) cooling and air-to-water heat pump for terminal reheat	60%	Locate heat pump **outside**, pipe hot water to previous boiler location. Storage tank located inside or outside.	True if >2,000 ft^2/floor OR rural/suburban zoning	Minor
		Locate heat pump and tanks inside in **existing** mechanical room, and punch holes in exterior wall for louvers.	All other. A combination of the existing mechanical room, roof, and exterior space suffices.	Moderate
		Change occupancy types to make space for heat pump.	True if < 2,000 ft^2/floor AND urban zoning	Major
Dedicated Outside Air System (DOAS) with air-source Variable Refrigerant Volume (VRF)	30%	Locate VRF outdoor units on roof or terrace.	True if >2,000 ft^2/floor OR rural/suburban zoning	Moderate
		Locate VRF outdoor units inside existing mechanical rooms or garage.	All other	Moderate
Other (ground-source or water-source heat pumps, with cooling towers or small electric resistance backup)	10%	Significant retrofit costs associated with equipment, electrical infrastructure, and/or piping, and/or requires a reclassification of habitable occupancy to mechanical space.	All	Major

Cases

The project team used the Model to simulate five different policy scenarios, referred to as Cases, to evaluate how statewide needs would change under different ZE equipment installation scenarios. Cases are defined per Table 4 below.

Table 4. Cases matrix

Equipment types	**Case #1: All ZE Equipment**	**Case #2: 2022 SIP Concept**	**Case #3: Added Equipment Types**	**Case #4: Reduced Capacity Thresholds**	**Case #5: Increased Capacity Thresholds**
Boilers and tanked water heaters	No limit	≤ 2,000,000 BTU/hr	≤ 2,000,000 BTU/hr	≤ 500,000 BTU/hr	≤ 10,000,000 BTU/hr
Pool heaters	No limit	≤ 2,000,000 BTU/hr	≤ 2,000,000 BTU/hr	≤ 250,000 BTU/hr	≤ 10,000,000 BTU/hr
Furnaces	No limit	≤ 2,000,000 BTU/hr	≤ 2,000,000 BTU/hr	≤ 300,000 BTU/hr	≤ 10,000,000 BTU/hr
Commercial cooking equipment	All	None	All	None	None
Clothes drying	All	None	All	None	None

Limitations

The study faced several limitations, including:

- Data gaps in ComStock related to certain building types, such as refrigerated warehouses, grocery stores, and laundromats, and equipment types, such as steam boilers and instantaneous water heaters. The team developed the missing prototypes using external data sources combined with ComStock building prototypes and did not account for missing equipment types because of the low prevalence.
- Reliance on engineering judgments and assumptions regarding retrofit needs and ZE equipment configurations, which do not precisely reflect real-world conditions.
- Limited data availability on structural assessments and physical space (such as the location of mechanical rooms or free space on a lot), requiring qualitative evaluations.

The paper later discusses next steps that may refine the Model through additional research.

Key Findings

Figure 1 shows the percentage of buildings with no retrofit needs, including equipment that is already ZE or not applicable, for each case and equipment category other than pool heating. Pool heating is excluded from this graph because the change in the overall building stock between cases is less than one percent. This figure summarizes the results described by Case in the following sections. Space heating retrofit needs are most affected by what capacities are within scope. Water heating retrofit needs do not change substantially between cases. Even in cases where cooking and clothes drying are in scope, most buildings have no retrofit needs associated with them because they do not contain those appliances. Overall, around a third of buildings in the study have no retrofit needs regardless of case, except for Case 4, which shows around half of buildings as having no retrofit needs due to the smaller scope of equipment covered.

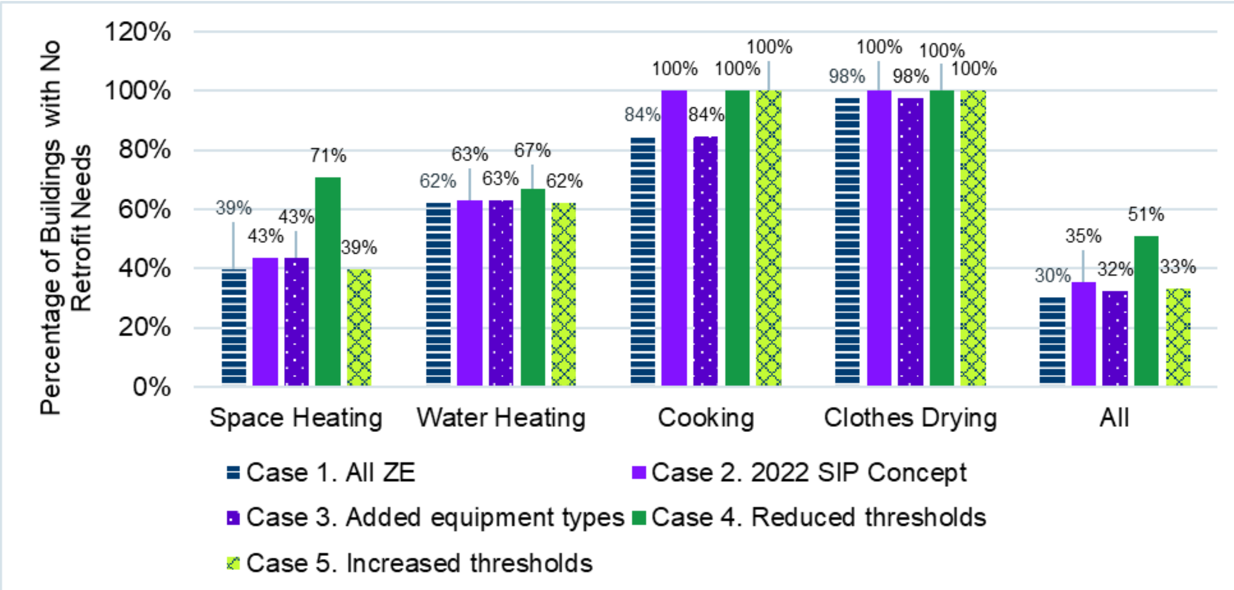

Figure 1. Percentage of buildings with no retrofit needs for all cases, by equipment category.

The remainder of this section discusses case-specific findings.

Case 1: All ZE Equipment

Case 1 illustrates the retrofit needs of the current nonresidential building stock in total, where all equipment categories of any capacity would be replaced with ZE equipment.

A significant portion of the buildings are already ZE. 26% of nonresidential buildings already have ZE equipment for all five equipment categories (or the equipment, such as district systems, is out of scope in this analysis). This portion of buildings is constant across all cases. Space heating is the main driver for overall building retrofit needs, with 61% of buildings needing some level of retrofit (minor, moderate, or major). Of the four key retrofit criteria considered, physical space is the single biggest constraint, with 62% of buildings requiring a minor, moderate, or major retrofit.

Cooking, pool, and laundry equipment categories rarely drive overall building retrofit needs. These equipment categories are less common, and electrical panel impacts are the only criteria this analysis considered for retrofit needs. 74% of nonresidential buildings do not have cooking equipment, and 97% do not have the laundry equipment category. Of the buildings that do include these equipment categories, the majority can either upgrade to ZE equipment without additional retrofit needs or are already ZE. Of the buildings with cooking as an equipment category, 8% are already ZE (2% of all buildings) and 88% have minor or no retrofit needs (23% of all buildings). The remaining 4% have moderate or major retrofit needs (<1% of all buildings).

Of the buildings with laundry as an equipment category (3% of all buildings), 11% are already ZE. 53% have minor or no retrofit needs, and the remaining 36% have moderate or major retrofit needs. Pool and spa heating are only present in an estimated 0.3% of nonresidential buildings and none are assumed to be ZE in this analysis. Of the buildings with pool and spa heating as an equipment category, none have no retrofit needs, 20% with minor retrofits, 36% with moderate retrofits, and 44% with major retrofits.

Case 2: 2022 SIP Concept

For Case 2, which represents the concept introduced in CARB's 2022 SIP, findings show that across all equipment categories, 28% of nonresidential buildings require no retrofits or minor retrofits, with the most prevalent building types being offices (43% of this building type requiring no or minor retrofits), restaurants (34%), and healthcare buildings (27%). One reason for the lower retrofit needs is because these buildings tend to have adequate electrical capacity and fewer structural considerations. Larger equipment is also not in scope for this case, which is why large offices and hospitals have limited retrofit needs.

41% percent of buildings require moderate or major retrofits overall, with the most prevalent types being laundromats (68% of laundromats requiring moderate or major retrofits), retail (67%), and hotels (60%). These buildings have higher retrofit needs because they tend to have limited physical space.

Generally, space heating and water heating retrofit needs across all building types are primarily driven by the need for adequate physical space and access to a heat source. As an example, VRF+DOAS is estimated to result in limited structural retrofit needs because of smaller and modular outdoor equipment, resulting in a distributed footprint, but still require significant accommodations for heat source, physical space, and electrical supply.

Generally, the other retrofit criteria (electrical and structural) seem to require comparatively minor modifications. Based on the analysis, nonresidential buildings tend to have adequate headroom in their electrical service sizes, and -- by the project team's estimates – most heat pump equipment will necessitate structural review as opposed to significant reinforcement, though data is lacking and these retrofit thresholds are imprecise.

All Cases

Cases 1 and 2 represent the primary retrofit scenarios evaluated, while Cases 3, 4, and 5 represent modifications of Case 2 (the 2022 SIP Concept). Comparing results across the cases analyzed, retrofit needs in buildings with cooking and laundry equipment categories increase when upgrading to ZE in Cases 2 and 3. Of the buildings with cooking and/or laundry equipment categories, the percentage of buildings with retrofit needs increased from 77% in Case 2 (the 2022 SIP Concept), to 89% in Case 3 (which adds these equipment categories to the 2022 SIP Concept). The overall building population with retrofit needs increased from 65% in Case 2 to 68% in Case 3.

For space heating, changing equipment capacity thresholds across cases is inconsequential for multizone boiler systems because central boilers are modular and come in a wide range of sizes, without significant changes to form and infrastructure needs across sizes, aside from district applications. Similarly, heat pumps are also modular and retrofit needs scale according to size. In contrast to multizone systems, retrofit needs increase significantly for packaged single zone RTUs above 300,000 Btu/h, which represent about 1% of the buildings with single zone systems, because these larger units require two heat pumps to replace a single AC + furnace.

For water heating, the project team observed that moderate and major retrofit needs increase significantly around 500,000 Btu/h. While there is not a consistent trend, generally moderate retrofit needs continue to increase above 2,000,000 Btu/h, suggesting that the buildings covered by the 2022 SIP Concept are more likely to have no and minor retrofit needs.

Strategies to Minimize Retrofit Needs

The project team assembled potential strategies to reduce retrofit needs by building equipment category, including technology development, building code changes, building-level improvements, and policy interventions. These strategies may all be candidates for investment and incentives, though the priority will depend on further analysis into comparable costs across equipment and retrofit categories.

Space Heating

The most prevalent system types in the Comstock dataset are single zone systems, including packaged RTUs, packaged terminal air conditioners (PTAC)s, and residential-style systems. Packaged RTU single zone air conditioners (SZACs) are the most common space heating system; the team assumes these are replaced with ZE single zone heat pumps (SZHPs) and that this replacement strategy is illustrative of the remaining single zone systems. Driven primarily by Comstock peak sizing assumptions, SZHPs need to be significantly larger physically than SZACs, which introduces moderate retrofit needs for physical space and structural updates. Some minor retrofits to the electrical infrastructure are also required, but these are primarily interior branch circuits and not whole-building service upgrades.

Results indicate that the footprint of the SZAC is nearly doubled when transitioning to a SZHP, which means significant adjustments to the curb (which are essentially vertical sections of roof upon which the HVAC unit rests) and could trigger a structural review. To avoid increasing the footprint and weight during the ZE replacement of single zone units:

1. **Temporarily allow emissive backup heating.** Where designers perform a thorough review of the building characteristics and loads and still determine that the design heating load exceeds the design cooling load, backup heating with emissive equipment could be considered as an intermediary transition to fully ZE operation. Policies should require adherence to best practice load calculation methods in ASHRAE and other relevant standards. A thorough load calculation is needed because mechanical contractors commonly increase the equipment size in existing buildings beyond what is necessary to avoid callbacks. These changes must be coordinated with the California Energy Commission, which allows the use of dual-fuel heat pumps in alterations via the Energy Code.
2. **Promote whole-building efficiency measures.** Incentivize or require the integration of cost-effective whole-building efficiency measures that reduce the overall peak heating load. These measures could include increased wall insulation, air-sealing retro-commissioning, or controls updates. Efficiency measures can reduce the annual and peak energy consumption for space conditioning. As a result, it may be possible to size space heating and cooling equipment for a smaller load, resulting in smaller and lighter equipment with lower structural, ventilation, space, and electrical needs. Lighting

efficiency measures, such as LED lamps, may slightly increase the heating load demands of the building, but they also free significant amounts of electrical capacity to be used for ZE equipment and help avoid whole-building panel upgrades. Examples of policies that promote efficiency measures as well as ZE equipment include Building Performance Standards and the single-family Flexible Compliance Pathway (Krause and De Snoo 2023).

3. **Promote mechanical equipment technology improvements.** Support manufacturers in developing smaller and lighter heat pump equipment, or more efficient heat pumps that deliver higher output during winter design conditions. Multiyear efforts are already underway by CalMTA to engage HVAC manufacturers in improving the design of SZHP equipment through measures such as insulated RTU boxes, low leakage dampers, energy or heat recovery (E/HRV), or controls upgrades (CalMTA 2025).
4. **Encourage or require electric-readiness measures during roof or RTU replacements.** Develop policies that encourage or require electric-readiness for existing buildings, such as in the Energy Code, so that building features needed for ZE single zone equipment are integrated during pertinent projects, such as re-roofing projects. Such electric-readiness measures at the time of roof or RTU replacement may include considerations for the feasibility of future ZE equipment in terms of rooftop curbs (including pre-fabricated options) or structural review. Electric readiness is difficult to ascertain for future equipment due to an evolving technology market and uncertain future needs, but the Energy Code does encourage SZHPs replacing SZACs (also known as either AC to Heat Pump or Two-Way AC) for units under 5 tons and where there is no increase in the electrical service to the building. Note that the Title 24 CASE study supporting this requirement did not report significant modifications to the rooftop curb or structural reviews as being necessary due to changes in equipment size (Tsan, et al. 2024).

The next most common heating system type in the Comstock dataset is multizone systems, including VAV-reheat and DOAS-based configurations. The moderate and major retrofit needs are largely driven by the ZE replacement needing access to a heat source, meaning that the equipment is likely to be in a different location than the emissive boiler serving the existing system. This relocation means increased retrofits are required to enhance physical space or structural capacity. Again, electrical retrofits are needed but the additional electrical loads are estimated to be relatively small compared to the overall building service capacity. To avoid retrofits for heat source access or physical space during the ZE replacement of multizone units, all the above recommendations are valid, and in addition:

5. **Expand electric-readiness requirements in the new construction building code.** Currently, the nonresidential code requires hot water piping to be sized to no more than 130°F, a temperature readily achievable by space heating heat pumps. However, there is no accommodation for the physical space and routing for heat source ventilation necessary for future heat pumps anywhere in the building. In contrast, the Energy Code requires electric-readiness provisions for central domestic water heating in multifamily applications precisely due to the same heat source and physical space challenges faced by ZE multizone space heating. Enacting similar requirements for multizone central plants in all building types will be complex but is likely to reduce future retrofit challenges.

6. **Require electric-readiness measures during tenant improvement projects.** Tenant improvements in commercial buildings are common and involve multimillion-dollar renovations of interior wall framing, ductwork, envelope, and lighting. Increasing requirements during these pivotal points in construction will increase project costs, and thus should be offset through rebate programs, but nonetheless represent the least-cost opportunity to progress to ZE readiness. Integrating considerations for heat source access, such as designating future spaces for louvers and ductwork, and/or requiring building owners to develop electrification feasibility plans that identify the future space for ZE equipment during tenant improvements will instill a common long-term goal across the market (both tenants as well as building owners).

Service Hot Water

Service hot water ZE retrofits, including for pools and clothes washing, appear to be largely driven by heat source and electrical infrastructure needs, and secondarily by physical space and structural needs. For service hot water and clothes washing applications, the locations of emissive hot water systems may not have access to an exterior heat source, requiring significant equipment relocation or ductwork additions. For all water heating applications (including pools), the existing emissive hot water system likely runs on 120V equipment, and pool heating will need substantial electrical infrastructure upgrades. High-load applications like restaurants or hospitals require ZE equipment that are built-up with multiple compressors and tanks, which require more physical space (potentially moving the equipment to the roof) and potential structural upgrades.

The following strategies can help ameliorate retrofits when the equipment footprint and weight increase during a ZE water heating system replacement:

1. **Promote efficiency measures that reduce peak hot water demand.** Efficiency measures can reduce the peak demands and the corresponding hot water equipment size necessary, reducing retrofit needs across all categories. Existing nonresidential buildings may lack simple efficiency measures, such as pipe insulation and low-flow fixtures, which can be highly impactful on equipment sizing. For pools, a pool cover can dramatically reduce energy consumption and peak heating loads. For restaurants, commercial dishwashers are available that use 20% less water than ENERGYSTAR specifications through heat recovery features, and hotels can add ozone clothes washers that clean fabrics through chemical reactions and thus reduce hot water usage.
2. **Promote hot water equipment innovations.** Some manufacturers have responded to the electrification needs of unique hot water applications through innovations such as AO Smith’s CHP-120, the largest tanked heat pump water heater available and developed specifically for quick-service restaurant needs. In locations with limited physical space or electrical infrastructure, battery-embedded water heaters can store energy overnight and be ready to heat water to higher temperatures using an electric resistance element, even with a small storage tank. In unique situations, existing technologies could be promoted, such as drain water energy recovery where the site sewer later is being exposed, or combined space- and service-hot water systems where both retrofits are occurring simultaneously (although both will require significantly more engineering design resources to implement).

3. **Promote power efficient design and load management strategies.** Larger and more complex nonresidential buildings typically are equipped with an Energy Management System (EMS) that tracks energy consumption and orchestrates equipment operations. Increasingly, these systems can strategically schedule certain loads (such as EV charging) to occur during off-peak periods, to promote right-sizing of electrical infrastructure and avoid unnecessary electrical upgrades. Ensuring that EMS are retro commissioned to orchestrate strategic energy management, peak load shaving, and fault detection may help buildings avoid electrical retrofits. Simpler versions of EMS include circuit-splitter devices in residential settings, which can temporarily turn off a secondary-priority equipment (e.g., an EV charger) while a primary priority equipment (e.g., a water heater) is running. Simple EMS control upgrades or devices in nonresidential scenarios can enable ZE installation under constrained electrical conditions, particularly for water heating applications, which are relatively predictable and not required for life-safety.
4. **Expand electric readiness requirements in the new construction code.** Currently, there are only prescriptive heat pump water heater requirements in new construction schools smaller than 25,000 ft^2. While a prescriptive ZE water heater requirement applicable to a broader set of nonresidential buildings may be proposed for the 2028 Energy Code, it will not guarantee the installation of ZE equipment due to federal policies. High-intensity water heating applications, such as gyms and restaurants, should have similar provisions for electric readiness as is currently required for central water heating applications for multifamily buildings (TRC 2020), to ensure minimal electrical, heat source, and physical space retrofits later if an emissive water heater is converted to ZE.
5. **Require electric readiness during major retrofits.** As described for space heating, building owners and tenants should leverage opportunities for electric readiness during major existing building retrofits and tenant improvements, such as integrating heat source access and/or developing electrification feasibility plans.

Cooking and clothes drying

Cooking and laundry retrofits will primarily be driven by electrical retrofits. The other retrofit categories of heat source, physical space, and structural upgrades are irrelevant due to the similar size and form of these ZE appliances as compared to emissive appliances. The need for moderate and major electrical retrofits will increase as the number of ZE appliances that are being installed increases.

It is difficult to eliminate the need for electrical retrofits in commercial kitchens and clothes drying facilities, due to the high intensity loads for these applications. Nonetheless, strategies may include:

1. **Encourage power efficient design innovations.** Ranges (cooktop and ovens) with 120-volt are becoming more available in residential settings, especially those which are battery-embedded to allow for an extra heating capacity during peak demand. While commercial kitchens will have both higher and longer-duration loads than residential settings, the increased cost of having a larger battery in a commercial appliance may compensate for the avoided electrical infrastructure costs.

Currently, all ZE oven technology is electric resistance. Almost every other heating application has alternative means of technology available, whether they are heat pumps or induction cooktops. Encouraging innovative ZE oven technologies may lead to energy savings and reduced retrofit costs.

2. **Combine appliances.** For laundry, combination clothes washer-dryers that operate on a 120V circuit and have heat pump technology are available for residential applications and may be appropriate for laundromat setting, which typically see residential-scale loads. Hotel clothes-drying applications are currently only electric resistance technology, leaving room for innovation both in terms of finding heat pump solutions as well as combination clothes washer-dryers to reduce upstream electrical infrastructure retrofits.

   Not every emissive appliance needs to be replaced 1-for-1 with a ZE counterpart. Food service design consultants are becoming more familiar with how electric appliances may combine multiple functions of emissive appliances, such as combination ovens replacing the production tasks of convection ovens and broilers.
3. **Add electric-readiness requirements for both new construction and existing building tenant improvement projects.** The 2025 Energy Code has added electric readiness requirements for new construction commercial kitchens. The 2022 Energy Code added electric readiness requirements for residential clothes drying appliances. A similar concept can be developed that is triggered when installing emissive commercial clothes drying appliances in nonresidential new construction or when new kitchens or laundry facilities tenants move into existing commercial facilities.

Conclusion

This study provides a comprehensive assessment of the retrofit needs for California's nonresidential building stock to transition to ZE equipment. While significant progress has been made, challenges remain, particularly for space and water heating systems. The findings offer a foundation for CARB and other agencies to develop policies and strategies to achieve California's climate goals. By addressing retrofit barriers and promoting innovative solutions, California can accelerate the adoption of ZE equipment and reduce GHG emissions from the building sector.

Future Research Recommendations

To address the limitations and improve the accuracy of future analyses, the study recommends expanding the scope to include residential buildings and other nonresidential building types. Investigating the GHG impacts of backup heating systems could provide additional insights into the environmental benefits of ZE equipment. Refining assumptions about ZE equipment configurations and retrofit needs can enhance the reliability of the Model. Updating the Model with new ComStock data and improved HVAC system-type distributions can further improve the accuracy of retrofit assessments.

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