Final Report

Supermarket Emission Reduction Analysis

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I. Executive Summary

Hydrofluorocarbons (HFCs) are synthetic fluorinated greenhouse gases (GHGs) commonly used across a variety of residential, commercial, and industrial applications, including as a refrigerant in commercial refrigeration systems used in supermarkets. The primary refrigerants for these applications are the HFC blends R-404A, which has a global warming potential (GWP) approximately 3,922 times greater than that of carbon dioxide, pound for pound, R-507 (GWP = 3,985), and HFC-134a (GWP = 1,340).

Currently, HFCs are largely not prohibited at the federal level; however, to date, several states (i.e., California, Vermont, Washington, Colorado, Virginia, New Jersey, Maryland, and New York) have implemented restrictions on HFC use in supermarket systems as well as additional refrigeration, air conditioning, foam, and aerosol sectors (NRDC 2019).

Supermarket refrigeration systems that use these refrigerants can have charge sizes up to 3,000 kilograms, with the national average annual leak rate estimated at 25% (U.S. EPA 2012, RTOC 2018), which can result in significant GWP-weighted annual emissions. A typical 46,000 square foot supermarket is estimated to produce roughly 1,500 $MTCO_2eq$ of R-404A emissions annually and 1,400 $MTCO_2eq$ per year from electricity consumption (GreenChill Undated). There is significant opportunity to reduce emissions from supermarket refrigeration systems, from both direct and indirect emissions.[1]

This study evaluates available emission reduction strategies, including emission reduction potential and cost information, for supermarkets and entities providing incentives to reduce emissions for both direct and indirect emissions associated with supermarket refrigeration systems.

Twenty-four unique emission reduction strategies were evaluated for new and existing supermarket stores across five climate zones. These mitigation options were selected based on applicability to typical supermarket systems, current availability, practicality for implementation both technologically and economically, and effective emission reduction potential. For new supermarket systems, mitigation options include five technologies/system designs, eleven leak reduction strategies, and six energy efficiency improvements.

[1] Direct emissions refer to those associated with refrigerant use within the supermarket system (i.e., leakage of refrigerants). Indirect emissions refer to those associated with electricity generation from the running of the refrigeration system (e.g., improvements in energy efficiency).

Exhibit 1: Mitigation Options for New Supermarkets

New Technologies

- Distributed Systems
- Micro Distributed Systems
- HFC Secondary Loop and/or Cascade System
- NH_3 or HC Secondary Loop and/or Cascade Systems
- CO_2 Transcritical Svstems

Energy Efficiency Improvements

- Floating Head Pressure
- Floating Suction Pressure
- Mechanical Subcooling
- Refrigeration Heat Recovery
- Display Case Doors
- Supermarket Monitoring Systems

Leak Mitigation Strategies

- Removal of Threaded Pipe
- Removal of copper tubing with outside diameter smaller than 0.25"
- Removal of flared tubing connections
- Installation of rupture disc for systems with high-GWP refrigerant
- Only brass or steel Schrader access valve
- Corrosion resistant evaporator coils in cases with vinegar and salt
- Installation of piping with accessibility in mind
- Perform system pressure test during installation
- System evacuation during installation
- Installation of refrigerant monitors
- Reduction in the use of short elbow radius

For existing supermarket systems, mitigation options include two refrigerant retrofit options, three leak reduction strategies, and six energy efficiency improvements.

Exhibit 2: Mitigation Options for Existing Supermarkets

Refrigerant Technologies

- HFC Retrofit
- HFC/HFO Blend Retrofit

Energy Efficiency Improvements

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- Floating Suction Pressure
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- Installation of rupture disc for systems with high-GWP refrigerant
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Across all climate zones and store sizes, the combination of leak mitigation strategies are an effective measure for supermarkets, with net annual cost savings and direct emission reductions ranging from 58% to 68%. These measures have low initial costs and reduce the annual leak rate of supermarket refrigeration systems, thus reducing direct emissions and the cost of refilling refrigerant into the system. Additionally, the reduction of leaks can offer energy efficiency benefits which are proxied using data from Figure 1, below (IOR 2013).

Supermarket monitoring systems also consistently offered new stores substantial indirect emission reductions with associated annualized savings. Generally, annualized savings and indirect emissions reductions were larger in warmer climate zones, however colder climates still saw reduced indirect emissions with annualized savings.

New technologies consistently provided the largest emission reduction across all new store sizes and climate regions. These measures nearly or completely reduce direct emissions from refrigerant loss by either replacing the HFC refrigerant or through technologies that significantly reduce the charge size of refrigerant. These mitigation options had lower annualized costs for larger stores, due to significant savings in refrigerant cost compared to HFC systems that offset the initial investment in the new technology. However, new technologies have varying impact on resulting energy performance based on the technology itself and/or the climate.

This analysis demonstrates the large potential for direct and indirect emission reduction in supermarket systems. There are a variety of viable options for all store types, but the reduction potential and cost effectiveness of each option varies based on stores size, climate zone, and other store characteristics. For example, floating head pressure and floating suction pressure are assumed to have negligible costs to implement for all store types and, due to their energy efficiency improvements, result in net annual savings. These mitigation options would be an immediate and simple way for stores already containing this technology but who have not yet updated their system preferences to begin reducing indirect emissions.

Although not shown in this analysis, many of the mitigation options can be implemented in tandem, allowing for further emission reductions and savings. For example, supermarket monitoring systems could be paired with one of the new technologies, allowing for maximum refrigerant emission reduction at a reduced annualized cost. Refrigerated heat recovery could be paired with the leak mitigation measures to decrease the large direct emissions from heat recovery while still benefiting from the natural gas savings.

II. Overview

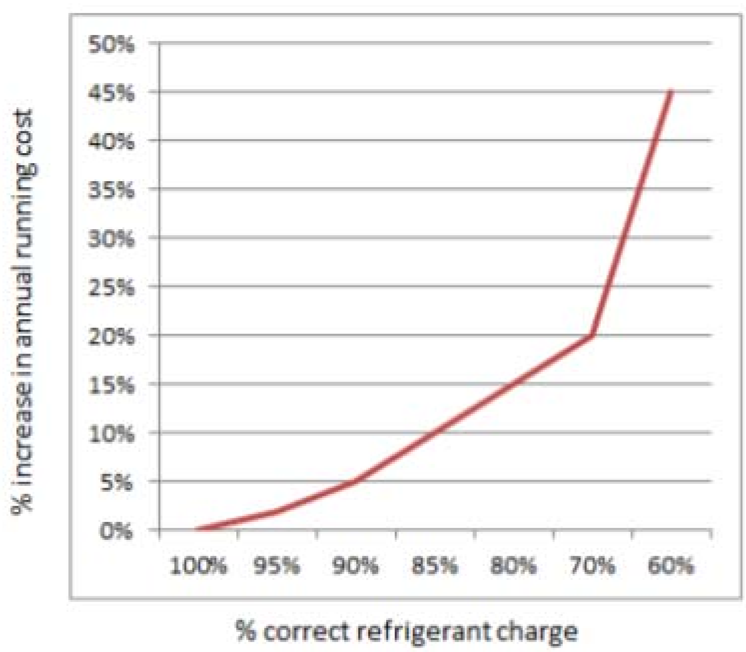
Hydrofluorocarbons (HFCs) are synthetic fluorinated greenhouse gases (GHGs) commonly used across a variety of residential, commercial, and industrial applications, including as a refrigerant in commercial refrigeration systems used in supermarkets. Supermarket systems can be comprised of various equipment types (e.g., direct expansion systems, distributed systems, secondary loop systems). Currently, the most common type of supermarket refrigeration system is the direct expansion system. Direct expansion systems are parallel rack systems that utilize multiple compressors mounted on a rack with parallel piping operating at the same saturated suction temperature to yield smooth capacity control. All display cases and storage rooms are connected to this system, which is typically located in a back room or on the roof. The primary refrigerants for these applications are the HFC blends R-404A, which has a global warming potential (GWP) approximately 3,922 times greater than that of carbon dioxide, pound for pound, R-507 (GWP = 3,985), and HFC-134a (GWP = 1,340).

In July 2015, EPA's Significant New Alternatives Policy (SNAP) program issued a final rulemaking that listed several HFCs as unacceptable for use in various end-uses within the refrigeration, foam blowing, and aerosol sectors, including refrigeration equipment used in supermarkets, such as supermarket rack systems, remote condensing units, and stand-alone refrigeration units. On April 28, 2018, EPA released guidance in response to a decision issued by the Court of Appeals for the District of Columbia Circuit on August 8, 2017 in the case of Mexichem Fluor, Inc. v. EPA indicating that it will not apply the HFC listings in the 2015 Rule in the near-term, pending a rulemaking (U.S. EPA 2018a). Under the July 2015 SNAP program rulemaking, supermarkets were restricted from using several high-GWP refrigerants, including R-404A and R-507A, in new systems as of January 1, 2017. To date, eight states (i.e., California, Vermont, Washington, Colorado, Virginia New Jersey, Maryland, and New York) have passed legislation or promulgated rules adopting the SNAP July 2015 rulemaking (NRDC 2019). An additional, ten states are also in the process of doing so.

Supermarket refrigeration systems can have charge sizes up to 3,000 kilograms and the national average leak rate is estimated to be 25% (U.S. EPA 2012, RTOC 2018), which can result in significant annual emissions. A typical 46,000 square foot supermarket is estimated to produce roughly 1,500 $MTCO_2eq$ of R-404A emissions annually and 1,400 $MTCO_2eq$ per year from electricity consumption (GreenChill Undated), primarily from non-renewable electricity, which adds additional cost implications. As a result, up to 40-50% of a supermarket's energy use is dedicated to refrigeration (U.S. EPA Undated-1). There is significant opportunity to reduce emissions from supermarket refrigeration systems, from both direct and indirect emissions.

Furthermore, literature indicates that the energy efficiency of a system can be impacted by reduced refrigerant charge from leaks. As shown in Figure 1 on studies of small air-conditioning and commercial refrigeration systems, when the charge of the system fell below 75%-80% of the original charge, annual running costs increased (IOR 2013).

Figure 1: Relationship between Annual Running Costs and Refrigerant Leakage for Small Air-conditioning and Commercial Systems (IOR 2013)



The purpose of this study is to provide a summary of available emission reduction strategies, including emission reduction potential and cost information, for supermarkets, and those potentially providing incentives, to reduce direct and indirect emissions from supermarket refrigeration systems in the absence of a federal regulation. Recognizing that supermarkets have unique needs depending on their location, store size, and functionality, this study evaluates available direct and indirect emission reduction strategies across different climate zones and store sizes for both new and retrofit applications.

III. Approach

For the analysis presented in this report, mitigation options for reducing refrigerant emissions and improving energy efficiency in supermarket systems were identified through a systematic literature review, including previous mitigation analyses for the commercial refrigeration sector, case studies, and manufacturer and product literature. In particular, mitigation options for available technologies with low-charge and/or no/low-GWP refrigerants, technologies that improve energy efficiency, and best practices for minimizing refrigerant emissions and maximizing system efficiency were considered. Although supermarkets can utilize multiple types of refrigeration systems, including stand-alone refrigerators, condensing units, and vending machines, this analysis focuses on mitigation options for large supermarket refrigeration systems (i.e., rack systems). This analysis examines the impact of various mitigation options on both new and existing stores.

1. Methodology for Estimating Direct and Indirect Emission Reductions

In order to identify appropriate mitigation strategies, an extensive literature review was conducted (e.g., international mitigation analyses, case studies, government reports). From this review, twenty-four unique emission reduction strategies were selected based on their applicability to new and existing supermarket systems, current availability, practicality for implementation (both technologically and economically), and effective emission reduction potential. The twenty-four mitigation options are outlined in Appendix A. For new supermarket systems, mitigation options include five technologies/system designs, eleven leak reduction strategies, and six energy efficiency improvements.

Exhibit 3: Mitigation Options for New Supermarkets

New Technologies
- Distributed Systems
- Micro Distributed Systems
- HFC Secondary Loop and/or Cascade System
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- CO_2 Transcritical Systems

Energy Efficiency Improvements
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Leak Mitigation Strategies
- Removal of Threaded Pipe
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- Installation of piping with accessibility in mind
- Perform system pressure test during installation
- System evacuation during installation
- Installation of refrigerant monitors
- Reduction in the use of short elbow radius

For existing supermarket systems, mitigation options include two refrigerant retrofit options, three leak reduction strategies, and six energy efficiency improvements. The leak reduction strategies were aggregated to represent an overall mitigation option representing leak reduction measures that are intended to be applied simultaneously to new or existing supermarket refrigeration systems.

Exhibit 4: Mitigation Options for Existing Supermarkets

Refrigerant Technologies
- HFC Retrofit
- HFC/HFO Blend Retrofit

Energy Efficiency Improvements
- Floating Head Pressure
- Floating Suction Pressure
- Mechanical Subcooling
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Leak Mitigation Strategies
- Installation of rupture disc for systems with high-GWP refrigerant
- Only brass or steel Schrader access valve
- Corrosion resistant evaporator coils in cases with vinegar and salt

For each mitigation option, the initial cost, annual costs and/or savings, direct emission reductions (i.e., reductions resulting from a decrease in refrigerant leakage), and indirect emission reductions (i.e., reductions resulting from improvements in efficiency of electricity or natural gas usage) were determined relative to a baseline scenario. The assumptions made to determine baseline emissions for new and existing supermarket equipment are outlined in Section 2.

1.1 Initial Cost

Initial costs for each mitigation option included incremental costs associated with a new technology or system, equipment modification, facility modification, labor for installation, and/or purchasing new refrigerant for the system. Annual costs and savings represented costs associated with refrigerant recharge from leaks and/or electricity and natural gas purchases.

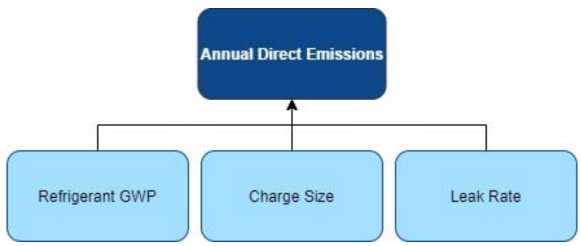
1.2 Emissions Reduction

Each mitigation option was evaluated for its potential for reducing overall direct and/or indirect GHG emissions based on refrigerant reduction, leak mitigation measures, and energy efficiency improvements across five climate zones which represent varied climates across the United States: very hot and humid, warm and dry, mixed and marine, cool and humid, and very cold (U.S. EERE Undated). Some mitigation options may offer reductions in one area (e.g., direct emissions from refrigerant) but increase emissions in another area (e.g., indirect emissions from energy use) due to impacts from climate zone or increased refrigerant capacity requirements.

1.2.1 Direct Emissions Reduction

Annual direct emissions were estimated based on the change in charge size, change in leak rate, and change in GWP of the refrigerant in use. Figure 2 illustrates the calculation of annual direct emissions.

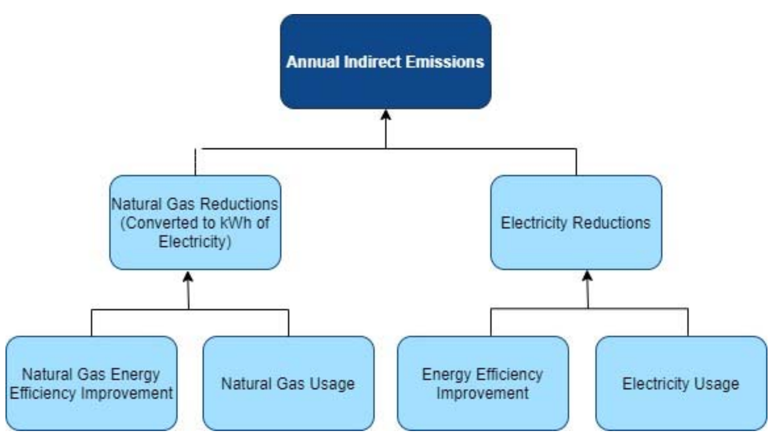
Figure 2. Calculation of Direct Emission Reductions



1.2.2 Indirect Emissions Reduction

Indirect emission reductions were calculated based on energy efficiency reductions of the measure applied to each climate zone's refrigeration electricity usage based on the U.S. Department of Energy's (DOE) commercial reference buildings for supermarkets, explained further below. The reduction in energy usage was then converted to $MTCO_2eq$ using an electricity emission factor of 7.07×10^{-4} $MTCO_2eq/kWh$ (U.S. EPA 2018b). If the relevant mitigation option resulted in indirect natural gas reductions due to reduced space heating demand, this was added to the indirect emissions as outlined in the baseline assumptions below. Figure 3 illustrates the calculation of annual indirect emissions.

Figure 3. Calculation of Indirect Emission Reductions



1.3 Costs and Benefits

As mentioned above, the capital cost for each mitigation option was determined during the literature review. Annual costs and/or savings were then calculated for each mitigation option based on refrigerant savings from reduced direct emissions and energy savings from reduced indirect emissions. Capital costs and annual costs and/or savings were then annualized for each mitigation options using a 7% discount rate and lifetimes of 18 years and 10 years for new and existing equipment, respectively, as shown in Equation 1.

Equation 1. Annualized Cost Calculation

$$Annualized\ Cost = \frac{Capital\ Cost * Discount\ Rate}{1 - (1 + Discount\ Rate)^{-Number\ of\ Periods}}$$

Annualized cost allows for comparison between mitigation options that may have different lifetimes as well as comparison between mitigation options that have high capital cost and low operating costs and those that have low capital costs and high operating costs (Kenton 2019). For each abatement option, the annualized cost is presented with the annual percent reduction in direct and/or indirect emissions.

2. Baseline Supermarket Assumptions

The analysis establishes three store sizes: small supermarkets, large supermarkets, and big box stores. Store sizes were estimated to be 10,000 square feet (ft^2) for small supermarkets, 60,000 ft^2 for large supermarkets, and 80,000 ft^2 for big box stores.[2] These store sizes were estimated based on previous ICF studies conducted on behalf of the California Air Resource Board, EPA studies, and expert opinion (CARB 2012, EPA 2013). These assumptions are intended to represent a “typical” store and may vary significantly across actual store types, store sizes, and store locations.

The impacts of various mitigation options were examined for supermarket systems within both new and existing stores. Refrigeration systems in new stores were assumed to have a lifetime of 18 years, while refrigeration systems in an existing store are assumed to be roughly halfway through their useful life with a remaining lifetime of 10 years.

The baseline stores were assumed to have a centralized direct expansion system containing R-404A with a leak rate equal to the current national average of 25% (U.S. EPA Undated-2) for all stores sizes, which was confirmed by ICF experts. The loss rates at disposal were assumed to be 10% for all systems. Baseline charge sizes for the three store sizes were estimated using values from previous ICF studies conducted on behalf of the California Air Resource Board, EPA, and expert opinion (U.S. EPA 2013, CARB 2012). The supermarket system in the small store was assumed to have a total charge of 255 kilograms, the large supermarket store system was assumed to have a total charge of 1,300 kilograms, and the big box store system is assumed to have a total charge of 1,540 kilograms.

[2] Although big box stores have a floor area of approximately 150,000 square feet, these stores were modeled assuming 80,000 square feet of refrigerated space, as these stores typically have large sections of non-food retail which do not require refrigeration.

Many of the leak reduction mitigation options considered in this analysis are applicable to the individual components of a supermarket system (e.g., racks, valves, circuits). These assumptions are summarized in Table 1.

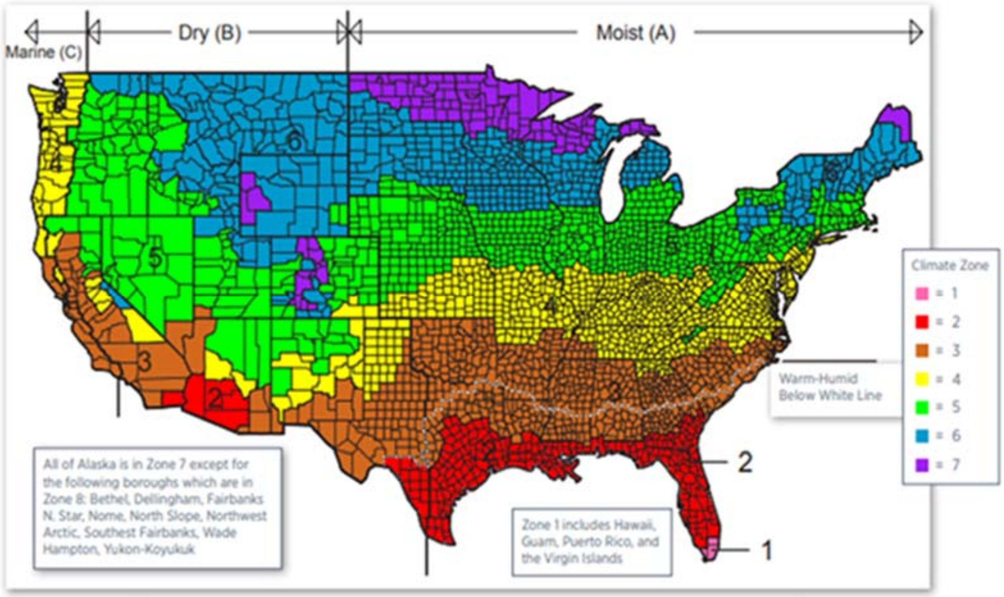
Table 1. Summary of Baseline Assumptions

	Small Supermarket	Large Supermarket	Big Box Store
Store Size (ft^2)	10,000	60,000	80,000[a]
Refrigeration System	Centralized Direct Expansion	Centralized Direct Expansion	Centralized Direct Expansion
Refrigerant	R-404A	R-404A	R-404A
Charge Size (kg)	255	1,300	1,540
Average Leak Rate	25%	25%	25%
Number of Racks	2	3	4
Number of Pressure Relief Valves[b]	4	6	8
Number of Circuits[c]	16	36	48
Number of Valves[d]	52	100	125
Number of Elbows[e]	332	732	972
Number of Display Cases	25	50	70
Feet of Display Cases[f]	275	550	770
Number of Coils in Cases with Salt and Vinegar[g]	2	6	8

[a] 80,000 square feet represents the refrigerated area of big box stores. For natural gas calculations it is assumed the whole store is heated and thus a 150,000 square feet store size is assumed.
[b] There are assumed to be two pressure relief valves per rack.
[c] Small supermarkets are assumed to have eight circuits per rack and large supermarkets and big box stores assumed to have twelve circuits per rack.
[d] The number of valves is based on the number of circuits per rack, the assumption that each circuit has two evaporators as well as an evaporator on each liquid line and four evaporators on the condenser side, and the assumption that there is one expansion valve on each evaporator.
[e] The number of elbows was estimated based on the assumption that each circuit has twenty elbows along with size elbows on the discharge and liquid lines, respectively
[f] Display cases are between 8 and 12 feet with an average length of 11 feet.
[g] Small supermarkets are assumed to have 2 cases that contain products with salt and vinegar, large supermarkets are assumed to have 6, and big box stores are assumed to have 8. There is assumed to be 1 evaporator coil per case.

To account for the variation in energy usage based on climate region, baseline electricity usage from refrigeration and natural gas usage for heating was estimated for each store size based on DOE's commercial reference buildings for supermarkets across the five identified climate regions: very hot and humid (1A), warm and dry (3B), mixed and marine (4C), cool and humid (5A), and very cold (7), as shown in Figure 4 (U.S. DOE 2012b).

Figure 4. DOE Building America Climate Zones



The commercial reference supermarket is 45,000 square feet and was assumed to contain a conventional direct expansion system (U.S. DOE 2012b). The energy usage from the commercial reference supermarkets was scaled proportionally by store square footage to obtain estimates for each store size. For the big box store, an 80,000 square feet area was assumed for the electricity usage from refrigeration, but an area of 150,000 square feet was assumed to estimate natural gas usage, as the entire store (i.e., including areas that do not include refrigeration) is heated.

DOE provides average energy use data for existing supermarkets constructed before 1980 supermarket ("pre-1980"), supermarkets constructed in or after 1980 ("post-1980"), and new construction supermarkets.[3] For the purposes of this analysis, energy data for the new construction reference supermarket was used for the new system baseline and the post-1980 reference supermarket was used for the existing system baseline (U.S. DOE 2012b). The energy usage for new and existing stores for the five climate regions and five representative cities within each climate zone are outlined in Table 2.

Table 2. Summary of Annual Energy Usage Baseline Assumptions for Supermarkets

Climate Type	Climate Zone	Representative City	Post-1980 Refrigeration Electricity Usage (kWh)	Post-1980 Natural Gas Usage (therms)	New Construction Refrigeration Electricity Usage (kWh)	New Construction Natural Gas Usage (therms)
Very hot and humid	1A	Miami	1,255,050	3,058	1,246,014	3,008
Warm and dry	3B	Las Vegas	922,589	16,874	915,047	15,915

[3] U.S. DOE's commercial reference building models were last updated November 12, 2012. More recent energy consumption data for supermarkets by climate zone was not available. The U.S. Energy Information Agency (EIA) Commercial Buildings Energy Consumption Survey (CBECS) (last conducted in 2012) has completed data collection for the 2018 CBECS, but data will not be released until spring/summer 2021.

Climate Type	Climate Zone	Representative City	Post-1980 Refrigeration Electricity Usage (kWh)	Post-1980 Natural Gas Usage (therms)	New Construction Refrigeration Electricity Usage (kWh)	New Construction Natural Gas Usage (therms)
Mixed and marine	4C	Seattle	906,247	31,957	889,664	28,899
Cool and humid	5A	Chicago	924,908	38,873	914,869	32,571
Very cold	7	Duluth	838,747	57,745	831,117	47,065

Two of the mitigation options examined in this analysis have substantial impacts on natural gas usage: refrigeration heat recovery and display case doors, described further below. For analysis of these two mitigation options, the baseline natural gas usage and reductions were converted from therms to the equivalent in electricity (kWh) as shown in Table 3. This conversion allowed for analysis of streamlined emission reduction impacts across all mitigation options, which benefits stores that do not employ natural gas for heating.

Table 3. Summary of Natural Gas Usage Assumptions for Supermarkets[a]

Representative City	Climate Zone	Climate Type	Post-1980 Natural Gas Usage (kWh)	New Construction Natural Gas Usage (kWh)
Miami	1A	Very hot and humid	71,683	70,499
Las Vegas	3B	Warm and dry	395,534	373,055
Seattle	4C	Mixed and marine	749,072	677,386
Chicago	5A	Cool and humid	911,188	763,458
Duluth	7	Very cold	1,353,540	1,103,196

[a] Based on expert opinion, 80% of the natural gas usage was converted to electricity to account for efficiency losses associated with natural gas heating.

To determine the savings from energy efficiency improvements from mitigation options, DOE electricity average utility rate was used for the representative city. DOE provides electricity cost estimates for post-1980 construction as well as new construction shown in Table 4 (U.S. DOE 2012b).

Table 4. DOE Electricity Utility Rates

Climate Type	Representative City	Post-1980 Average Electricity Utility Rate ($/kWh)*	New Construction Average Electricity Utility Rate ($/kWh)
Very hot and humid	Miami	0.080	0.080
Warm and dry	Las Vegas	0.123	0.122
Mixed and marine	Seattle	0.071	0.071
Cool and humid	Chicago	0.097	0.097
Very cold	Duluth	0.054	0.055

* Post-1980 supermarket is based on modeling from 2012 and represents existing supermarkets.

Table 5 provides the resulting baseline emissions from refrigerants (direct), electricity consumption (indirect), and natural gas consumption (indirect from NG) for each supermarket size in each climate zone based on the assumptions detailed above for new supermarkets and existing supermarkets.

Table 5. Summary of Baseline Emissions for New Supermarkets

Climate Type	Small Supermarket Emissions ($MTCO_2e$)			Large Supermarket Emissions ($MTCO_2e$)			Big Box Store Emissions ($MTCO_2e$)		
	Direct	Indirect	Indirect from NG	Direct	Indirect	Indirect from NG	Direct	Indirect	Indirect from NG
New Supermarkets									
Very hot and humid	256	196	11	1,303	1,176	67	1,543	1,567	166
Warm and dry	256	144	589	1,303	863	352	1,543	1,150	880
Mixed and marine	256	140	1067	1,303	839	639	1,543	1,119	1,597
Cool and humid	256	144	120	1,303	863	720	1,543	1,150	1,800
Very cold	256	131	173	1,303	784	1,040	1,543	1,045	2,601
Existing Supermarkets									
Very hot and humid	260	197	11	1,326	1,183	68	1,569	1,578	169
Warm and dry	260	145	62	1,326	870	373	1,569	1,160	932
Mixed and marine	260	142	118	1,326	855	706	1,569	1,139	1,766
Cool and humid	260	145	143	1,326	872	859	1,569	1,163	2,148
Very cold	260	132	213	1,326	791	1,276	1,569	1,055	3,191

Note: NG = Natural Gas

IV. Summary of Results

A range of mitigation options are available for supermarkets that provide direct and indirect emission reductions through reduced refrigerant leaks and/or improved energy efficiency. Each mitigation option differs in terms of the range of incurred costs and realized benefits depending on various characteristics, such as store location, store size, and age of store. The twenty-four mitigation options are described in detail in Appendix A.

1. Summary of Mitigation Scenarios

For each supermarket type (i.e., small, large, or big box store; new or existing; five climate zones), the potential benefits of each mitigation option were first individually evaluated. Potential indirect and direct emission reductions (or increases) and the associated savings (or costs) were compared to the initial costs of implementing the mitigation option. The impacts of each mitigation option by supermarket type and climate zone, including costs and savings and the lifetime direct and indirect emission impacts are summarized in Appendix B. These costs and benefits are meant to serve as a guide to evaluate the potential applicability of the various mitigation options.

To illustrate how the impact of the various mitigation options could be evaluated for a particular supermarket, three scenarios in various supermarket store sizes and climate regions are presented. The three scenarios were selected to show the broadest range of characteristics for supermarkets regarding equipment age (i.e., new or existing equipment), store size, and climate regions:

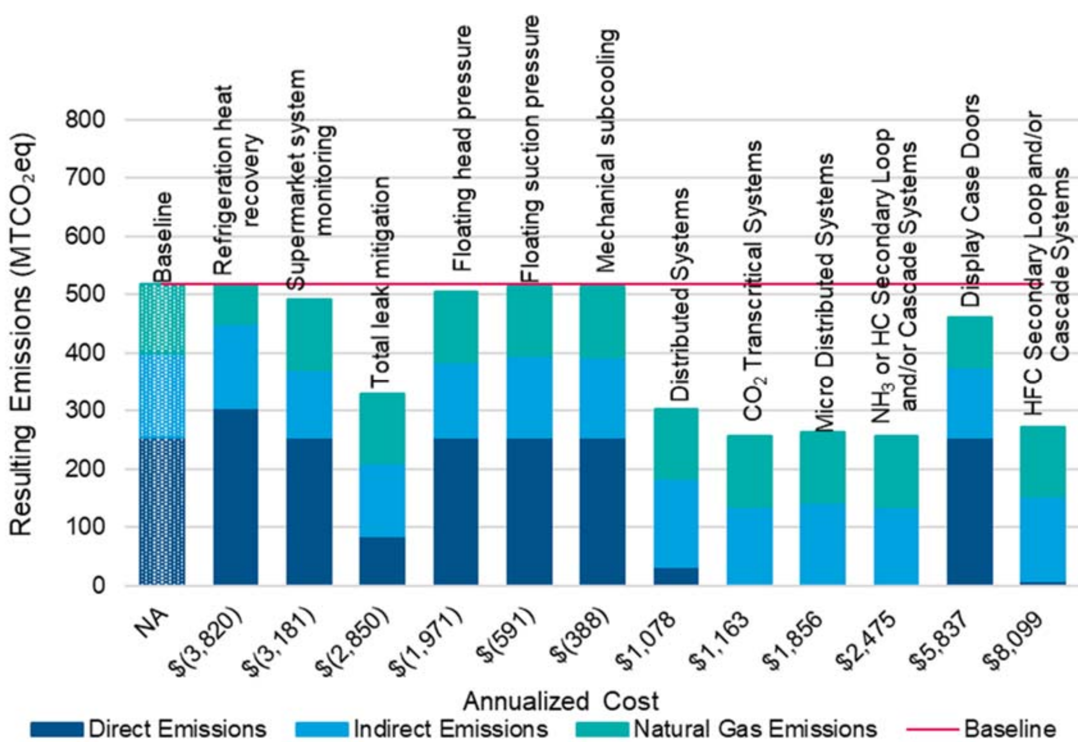
- Scenario 1: Small supermarket, new, cool and humid climate
- Scenario 2: Large supermarket, existing, warm and dry climate
- Scenario 3: Big box store, new, very hot and humid climate

Although the mitigation options are presented independently (with the exception of the leak reduction strategies), it is expected that a supermarket would implement multiple mitigation options concurrently; however, the total costs and benefits may not be directly additive across mitigation options.

1.1 Scenario 1: Small Supermarket, New, Cool and Humid Climate

Figure 5 shows the annualized costs of mitigation options applicable to Scenario 1 for new equipment in a small supermarket in a cool and humid climate compared to the resulting emissions (i.e., direct emissions from refrigerant, indirect emissions from electricity use, and indirect emissions from natural gas use). The store in this scenario has lower baseline refrigerant emissions (i.e., 256 $MTCO_2eq$) compared to the stores in Scenario 2 (i.e., 1,325 $MTCO_2eq$) and Scenario 3 (i.e., 1,543 $MTCO_2eq$) due to its smaller refrigerant charge size and newer refrigeration equipment. This store does, however, have larger energy usage and associated emissions (i.e., 372,950 kWh, 264 $MTCO_2eq$) than small supermarkets in other climate regions due to its location in a cold climate region.

Figure 5. Annualized cost compared to resulting annual emissions for a Small Supermarket with new equipment in cool and humid climates.



As shown, there are several energy efficiency mitigation options available for small supermarkets that result in overall annualized savings. Although these options offer lower emission reductions, many of them, such as floating head pressure and floating suction pressure, have negligible costs allowing them to serve as immediate options for stores to reduce their indirect emissions by approximately 10% and 3%, respectively, and therefore reduce energy costs by approximately $1,970 and $590 per year, respectively. Furthermore, many supermarkets already contain the technology required for these options and thus only require a change in settings to implement, if the settings have not already been implemented.

All five new technology options provide the largest emission reductions across the mitigation options, through either the replacement of HFC refrigerant or through technologies that significantly reduce the charge size of refrigerant, thus nearly or completely reducing direct emissions from refrigerant loss. For example, CO_2 transcritical systems, micro distributed systems, and NH_3 or HC secondary loop and/or cascade systems all result in direct emissions of zero. Although these options have annualized costs of $1,080 to $8,100, they provide nearly complete direct emission reduction. CO_2 transcritical systems and NH_3 or HC secondary loop and/or cascade systems would also result in indirect emission reductions from increased energy efficiency.

The total leak mitigation options result in significant direct and indirect emission reductions without the larger initial costs of installing newer technologies. These leak mitigation strategies offer a simple way for supermarkets to reduce refrigerant leaks from their store by approximately 67%, which would reduce refrigerant costs by $560 per year.

Table 6. Summary of Intervention Types for New Equipment in Small Supermarkets in Cool and Humid Climates[a]

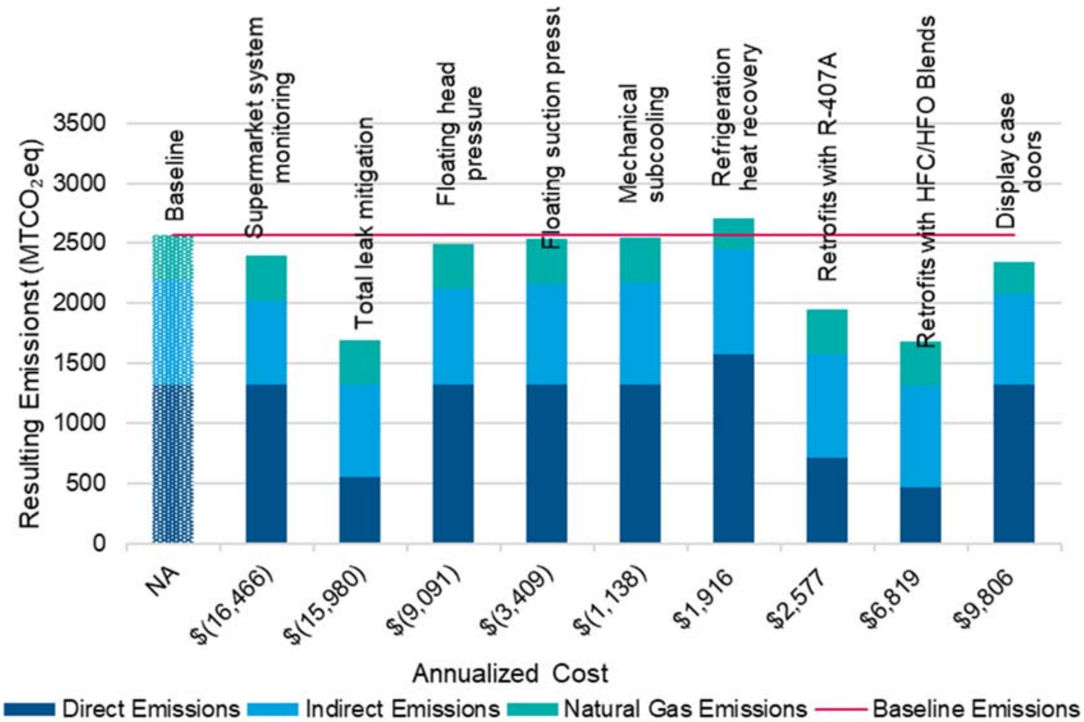
Mitigation Option: Small Supermarket, New, Very Cold	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
Distributed Systems	$8,250	($260)	$1,080	4,600	(130)
Micro Distributed Systems	$27,000	($830)	$1,860	4,600	0
HFC Secondary Loop and/or Cascade System	$89,300	($780)	$8,100	4,440	0
NH_3 or HC Secondary Loop and/or Cascade Systems	$42,500	($1,760)	$2,480	4,600	130
CO_2 Transcritical Systems	$29,100	($1,730)	$1,160	4,600	130
Leak Mitigation	$3,750	($3,220)	($2,850)	3,060	350
Floating Head Pressure	$0	($1,970)	($1,970)	0	260
Floating Suction Pressure	$0	($590)	($590)	0	80
Mechanical Subcooling	$4,000	($790)	($390)	0	100
Refrigeration Heat Recovery	$21,400	($5,950)	($3,820)	(900)	930
Display Case Doors	$137,500	($5,520)	$5,840	0	1,030
Supermarket Monitoring System	$5,700	($1,950)	($3,180)	0	490

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

1.2 Scenario 2: Large Supermarket, Existing, Warm and Dry Climate

Figure 6 shows the annualized costs of mitigation options applicable to existing equipment in a large supermarket in a warm and dry climate compared to the resulting emissions. The store in this scenario has moderate refrigerant emissions (i.e., 1,325 $MTCO_2eq$) compared to the stores in Scenario 1 (i.e., 255.6 $MTCO_2eq$) and Scenario 3 (i.e., 1,543 $MTCO_2eq$) due to its refrigerant charge size and existing refrigeration equipment. This store also has moderate energy usage and associated emissions (i.e., 1,757,500 kWh, 1,242 $MTCO_2eq$) compared to large supermarkets in other climate regions due to its location in a moderate climate region.

Figure 6. Annualized cost compared to resulting annual emissions for a Large Supermarket with existing equipment in warm and dry climates



As shown, there are several energy efficiency mitigation options available for large supermarkets that result in overall annualized savings. Although these options offer lower emission reductions, many of them, such as floating head pressure and floating suction pressure, have negligible costs allowing them to serve as immediate options for stores to reduce their indirect emissions by approximately 3-8% and therefore reduce energy costs by approximately $9,090 and $3,410 per year, respectively. Furthermore, many supermarkets already contain the technology required for these options and thus only require a change in settings to implement.

The retrofitting options provide the largest emission reductions, reducing direct emissions from refrigerant loss by approximately 45-65%, due to the use of a lower GWP refrigerant (i.e., R-407A or HFC/HFO blends). Annualized costs due to the use of new refrigerant can vary largely based on the cost of the refrigerant in use; however, historically, the cost of new refrigerants decreases over time.

The total leak mitigation options result in significant direct and indirect emission reductions without the larger initial costs of retrofitting equipment. These leak mitigation strategies offer a simple way for supermarkets to reduce refrigerant leaks from their store by approximately 58%, which would reduce refrigerant costs by $2,900 per year.

The least effective strategy is refrigerated heat recovery due to its increase in direct HFC emissions from a higher leak rate. The warm and dry climate zone has lower heating requirements, so the savings in indirect emissions due to relieving electricity use from heating does not offset the increased direct emissions.

Table 7. Summary of Intervention Types for Existing Equipment in Large Supermarkets in Mixed and Marine Climates[a]

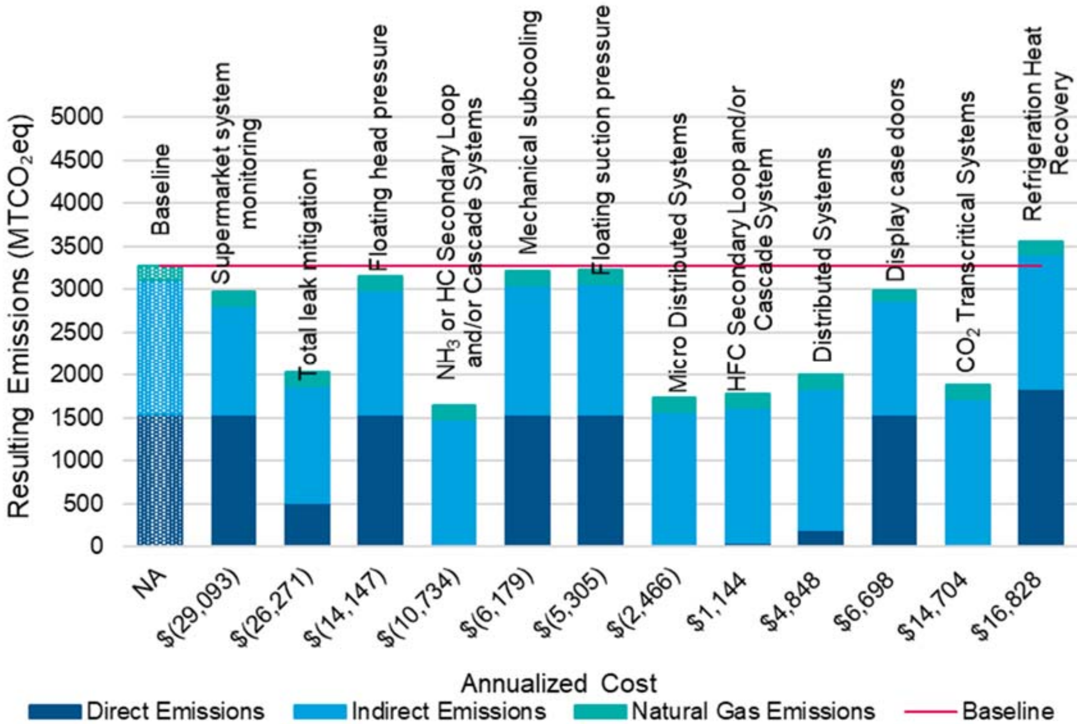
Mitigation Option: Large Supermarket, Existing, Mixed and Marine	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
Retrofits with R-407A	$18,100	$0	$2,580	6,140	0
Retrofits with HFC/HFO Blends	$37,600	$1,470	$6,820	8,560	260
Leak Mitigation	$5,350	($16,740)	$15,980	7,650	1,090
Floating Head Pressure	$0	($9,090)	($9,090)	0	700
Floating Suction Pressure	$0	($3,410)	($3,410)	0	260
Mechanical Subcooling	$8,000	($2,770)	($1,140)	0	170
Refrigeration Heat Recovery	$77,000	($9,040)	NA[b]	(2,550)	1,170
Display Case Doors	$275,000	($29,350)	$9,800	0	2,250
Supermarket Monitoring System	$36,000	($21,590)	$16,470	0	1,650

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.
[b] Refrigeration heat recovery was not deemed an applicable mitigation strategy in this scenario, as it increased emissions.

1.3 Scenario 3: Big Box Store, New, Very Hot and Humid Climate

Figure 7 shows the annualized costs of mitigation options applicable to new equipment in a big box store in a very hot and humid climate compared to the resulting emissions. The store in this scenario has the largest refrigerant emissions (i.e., 1,543 $MTCO_2eq$) compared to the stores in Scenario 1 (i.e., 255.6 $MTCO_2eq$) and Scenario 2 (i.e., 1,325 $MTCO_2eq$) due to its large refrigerant charge size and its additional air-conditioning requirements due to its being located in a very hot and humid climate region. This store also has moderate energy usage and associated emissions (i.e., 2,450,150 kWh, 1,747 $MTCO_2eq$) compared to big box stores in other climate regions due to its low indirect emissions from natural gas used to heat the store.

Figure 7. Annualized cost compared to resulting annual emissions for a Big Box Store with new equipment in very hot and humid climates.



As shown, there are several energy efficiency mitigation options available for big box stores that result in overall annualized savings. Although these options offer lower emission reductions, many of them, such as floating head pressure and floating suction pressure, have negligible costs allowing them to serve as immediate options for stores to reduce their indirect emissions by approximately 3-8% and therefore reduce energy costs by approximately $14,150 and $5,300 per year, respectively. Furthermore, many supermarkets already contain the technology required for these options and thus only require a change in settings to implement.

All five new technology options provide the largest emission reductions across the mitigation options, through either the replacement of HFC refrigerant or through technologies that significantly reduce the charge size of refrigerant, thus nearly or completely reducing direct emissions from refrigerant loss. For example, CO_2 transcritical systems, micro distributed systems, and NH_3 or HC secondary loop and/or cascade systems all result in direct emissions of zero. NH_3 or HC secondary loop and/or cascade systems would also improve energy efficiency and decrease indirect emissions. Due to the inefficiencies of CO_2 transcritical systems in hot and humid climates, indirect emissions from electricity use are increased for this system type.

The total leak mitigation options result in significant direct and indirect emission reductions without the larger initial costs of installing newer technologies. These leak mitigation strategies offer a simple way for supermarkets to reduce refrigerant leaks from their store by approximately 67%, which would reduce refrigerant costs by $3,400 per year.

Table 8. Summary of Intervention Types for New Equipment in Big Box Stores in Very Hot and Humid Climates[a]

Mitigation Option: New, Big Box Store, Very Hot & Humid	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
Distributed Systems	$4,100	$4,440	$4,850	24,200	(1,410)
Micro Distributed Systems	$25,400	($5,000)	($2,465)	27,770	0
HFC Secondary Loop and/or Cascade System	$58,800	($4,700)	$1,140	26,800	0
NH_3 or HC Secondary Loop and/or Cascade Systems	$27,800	($13,500)	($10,730)	27,770	1,400
CO_2 Transcritical Systems	$15,250	$13,190	$14,700	27,700	(2,820)
Leak Mitigation	$10,100	($27,270)	($26,270)	18,470	3,810
Floating Head Pressure	$0	($14,150)	($14,150)	0	2,260
Floating Suction Pressure	$0	($5,300)	($5,300)	0	845
Mechanical Subcooling	$9,000	($7,100)	($6,180)	0	1,130
Refrigeration Heat Recovery[b]	$88,400	$8,040	$16,830	(5,430)	290
Display Case Doors	$385,000	($31,575)	$6,700	0	5,030
Supermarket Monitoring System	$45,300	($33,600)	($29,100)	0	5,360

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.
[b] Refrigeration heat recovery was not deemed an applicable mitigation strategy in this scenario, as it increased emissions.

2. Conclusions

Across all climate zones and store sizes modeled, the aggregate leak mitigation strategies are an effective measure for supermarkets, with net annual cost savings and direct emission reductions ranging from 58% to 68%. These measures have low initial costs and reduce supermarket's annual leak rate, thus reducing the cost of refilling refrigerant into the system yearly, and offeringenergy efficiency benefits.

Supermarket monitoring systems also consistently offered new stores substantial indirect emission reductions with annualized savings. Generally, annualized savings and indirect emissions reductions were larger in warmer climate zones, however colder climates still saw reduced indirect emissions with annualized savings.

New technologies consistently provided the largest emission reduction across all store sizes and climate regions. These measures nearly or completely reduce direct emissions from refrigerant loss by either replacing the HFC refrigerant or through technologies that significantly reduce the charge size of refrigerant. These mitigation options had lower annualized costs for larger stores, due to significant savings in refrigerant cost compared to HFC systems that offset initial investments. The resulting energy performance for new technologies varied based on the technology itself and/or the climate. For some technologies (i.e., CO_2 transcritical systems in warm and hot climates and distributed systems), these options reduced energy efficiency, resulting in increased energy use (and increased annualized costs) and increased emissions; however, CO_2 transcritical systems increased energy efficiency in cooler climates. Other new technologies also improved energy efficiency (i.e., NH_3 or HC secondary loop and/or cascade systems) or had no impact on energy efficiency (i.e., HFC secondary loop and/or cascade systems).

In addition, the use of floating head pressure and floating suction pressure offered energy efficiency improvements for all supermarkets regardless of size, age, or region. Based on expert opinion, most supermarkets are assumed to have the necessary equipment to implement these mitigation strategies (i.e., a programming switch to convert from static head pressure and static floating suction pressure to floating) but may not have the option engaged and, as such, would incur negligible costs to implement.

Aside from these outlined options, reductions from mitigation options generally scaled with electricity usage from refrigeration (i.e., higher reductions for hotter climates) across climates. Because annual costs from energy consumption and indirect emission reductions vary based on climate zone, a range is provided. Detailed summaries of mitigation options for each store size and climate zone can be found in Appendix B.

The analysis presented demonstrates the large potential for direct and indirect emission reduction measures to be implemented in supermarket systems. There are a variety of viable options for all store types, but the reduction potential and cost effectiveness of each option varies based on stores size, climate zone, and other store characteristics.

Reduction of leaks ensures the system is working efficiently and effectively and operating within design range. Mitigation options that affect the heating of the store itself (i.e., refrigeration heat recovery and display case doors) show the most variation with climate zone and store size, being most effective in smaller stores located in cold climates. Colder climates using more energy to heat the store have greater energy efficiency savings that counteract the increased direct emissions making refrigeration heat recovery and display case doors more applicable options.

Although not shown in this analysis, many of the mitigation options can be implemented in tandem, allowing for further emission reductions and savings. For example, supermarket monitoring systems could be paired with one of the new technologies or retrofits, allowing for maximum refrigerant emission reduction at a reduced annualized cost. Refrigerated heat recovery could be paired with the leak mitigation measures to decrease the large direct emissions from heat recovery while still benefiting from the natural gas savings.

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Appendix A: Analysis of Mitigation Options

A description of each mitigation option and discussion of costs and emission reduction potential are discussed below

1. Distributed Systems

Distributed systems are a type of refrigeration technology that consists of multiple compressors that are distributed throughout a store, near the display cases they serve, and are connected by a water loop to a chiller or other type of equipment that rejects heat (e.g., a cooling tower) that is located on the roof or elsewhere outside the store (EPA 2013). Distributed systems are assumed to also use R-404A, but because these systems consist of smaller refrigeration units spread throughout the store, the overall refrigerant charge is smaller than for a comparable traditional direct expansion system. Distributed systems are estimated to reduce the charge size by 50%, which decreases the amount of refrigerant needed at first fill and decreases the potential emissions from operational leaks and during decommissioning of the equipment (EPA 2013). In addition, these systems require less fittings and refrigerant tubing, decreasing the potential for refrigerant leaks to an estimated 6% leak rate compared to a leak rate of 25% for the baseline direct expansion system (EPA, 2013).

Distributed systems are estimated to cost 5% more at installation than conventional HFC centralized direct expansion systems, which is equivalent to an incremental cost of $9,100 per supermarket (IPCC, 2005). Based on expert opinion, incremental costs for distributed systems are assumed to be consistent across store sizes. Although larger stores typically have greater costs associated with longer piping runs and other equipment needs, these costs are often greater on a per square foot basis in smaller stores because of a larger percentage of refrigeration compared to total floor space. Additionally, smaller refrigeration systems typically cost more per unit of capacity compared to larger systems due to the economies of scale. Smaller systems require a similar number of components as larger systems, but smaller components are typically more expensive to manufacture and install. As a result, all three store sizes are estimated to experience the same incremental cost of $9,100 for installation of a distributed system.

Additionally, distributed systems are estimated to be 5% less efficient than the conventional HFC centralized direct expansion systems, which results in an increase in indirect emissions and variable annual costs based on climate region (EPA 2013). Distributed systems are less efficient than conventional HFC centralized direct expansion systems due to the use of smaller, less-efficient compressor motors compared to the larger motors in conventional systems, the presence of two heat exchangers compared to one in baseline systems, and the use of glycol/water loops requiring energy for pumping which reduces the overall efficiency of the system. A summary of this mitigation option for each store size across the five climates is provided in Table 9.

Table 9. Summary of Distributed Systems[a]

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	New	New	New
Increased Installation Cost	$9,100	$9,100	$9,100
Refrigerant Cost from First Fill	($850)	($4,225)	($5,000)
Annual Cost	$640 - $960	$3,800 - $5,750	$5,100 - $7,700
Incremental Annual Savings	$730	$3,700	$4,400
Charge Size Reduction	50%	50%	50%
New Leak Rate	6%	6%	6%
Lifetime Direct Emission Reduction ($MTCO_2eq$)	4,500	23,000	27,200
Energy Efficiency Improvement	(5%)	(5%)	(5%)

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

2. HFC Secondary Loop and/or Cascade Systems

HFC secondary loop systems use a primary and secondary refrigerant. The secondary refrigerant is cooled by the primary refrigerant, the HFC refrigerant, in a machine room and then pumped through the store to cool display equipment. In the HFC secondary loop system the HFC refrigerant remains in the machine room, decreasing the chance for HFC leaks throughout the system as well as decreasing the HFC refrigerant charge needed to cool the system (EPA 2013).

HFC secondary loop systems are often used with cascade systems. Cascade systems consist of two independent refrigeration systems that share a common cascade heat exchanger. The cascade heat exchanger acts as a low temperature refrigerant condenser as well as a high temperature refrigerant evaporator. Each component of the cascade system uses a different refrigerant which allows for increased efficiency as the refrigerant selected for each component can be tailored to the temperature range of that component. CO_2 is typically used for the low temperature circuit of the cascade system, further reducing the amount of HFC refrigerant charge required for the overall system (EPA 2013).

Due to their simplified piping, new pumps and fewer components, the HFC secondary loop and cascade systems have lower leak rates than a traditional direct expansion system, estimated at 5%. In addition, HFC secondary loop and/or cascade systems are found to be just as, if not more efficient, as conventional direct expansion systems (Wang et al. 2010, DelVentura, et al. 2007, SuperValu 2012, WalMart 2006, Hinde, Zha, and Lan 2009). The capital cost of these systems is estimated by a manufacturer to be 50%, 30%, and 35% more than a conventional centralized direct expansion system for a small supermarket, large supermarket, and big box store, respectively. The manufacturer highlighted that the increased initial cost varies due to store structure. Additionally, big box stores often only contain medium temperature systems whereas supermarkets contain low temperature and medium temperature, resulting in differing costs. The large increased cost for small supermarkets was attributed to the non-proportional cost of smaller system components as well as the unfamiliarity with installation of these systems into small format stores (Kysor Warren 2020). These cost assumptions were further confirmed by expert opinion. Assuming the HFC secondary loop and/or cascade systems are equally energy efficient as the conventional direct expansion systems, there is no associated increase or decrease in annual energy consumption costs.

Table 10. Summary of HFC Secondary Loop and/or Cascade Systems[a]

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	New	New	New
Increased Installation Cost	$90,000	$54,000	$63,000
Refrigerant Cost from First Fill	($700)	($3,550)	($4,200)
Annual Cost	$0	$0	$0
Incremental Annual Savings	$780	$4,000	$4,700
Charge Size Reduction	70%	70%	70%
New Leak Rate	5%	5%	5%
Lifetime Direct Emission Reduction ($MTCO_2eq$)	5,280	26,900	31,850
Energy Efficiency Improvement	0	0	0

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

3. NH_3 or HC Secondary Loop and/or Cascade Systems

Similar to the HFC secondary loop and/or cascade system, NH_3 or hydrocarbon (HC) secondary loop and/or cascade systems use a primary and secondary refrigerant. The secondary refrigerant is cooled by the primary refrigerant, NH_3 or HC, in the machine room and then pumped through the store to cool display equipment. NH_3 and HC refrigerants are often not used in conventional systems due to their toxicity and flammability, respectively. The secondary loop system allows these refrigerants to remain in the machine room with controlled access limited to only trained individuals. This also reduces the amount of piping they go through and, thus, the number of leaks. Additionally, when used with a cascade system, the low temperature system does not rely on HFC refrigerants, removing HFC refrigerants from the system completely (EPA 2013).

These systems have an upfront cost of 25% more than conventional direct expansion systems, roughly $45,500 per supermarket. Stores with NH_3 or HC secondary loop and/or cascade systems have reported efficiency gains ranging from 0.5 to 35% (Wang et al. 2010, SuperValu 2012, Hydrocarbonconversions.com 2011, CCAC 2014, CCAC 2016). This large range in reported efficiency gains stems from improvements made to NH_3 or HC secondary loop and/or cascade systems since they first entered the market fifteen years ago. The impact on energy use can also vary depending on the efficiency of the conventional direct expansion system in the comparison as these can differ based on store characteristics. The energy savings for these systems may also vary based on climate region, but due to a lack of detailed information to develop an energy efficiency scale, a 5% energy efficiency gain compared to direct expansion systems is conservatively assumed across all climate zones.

Table 11. Summary of NH_3 or HC Secondary Loop and/or Cascade Systems[a]

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	New	New	New
Increased Installation Cost	$45,500	$45,500	$45,500
Refrigerant Cost from First Fill	($3,000)	($14,950)	($17,700)
Annual Cost	$0	$0	$0
Incremental Annual Savings	$1,400 - $1,750	$7,800 - $9,700	$9,775 – $12,300
Charge Size Reduction	0%	0%	0%
New Leak Rate	15%	15%	15%
Lifetime Direct Emission Reduction ($MTCO_2eq$)	5,600	28,550	33,800
Energy Efficiency Improvement	5%	5%	5%

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

4. CO_2 Transcritical Systems

CO_2 transcritical systems eliminate the use of HFCs throughout the entire refrigeration system through the use of CO_2 as a primary refrigerant. CO_2 transcritical systems are systematically similar to direct expansion systems, except with special controls and components required to operate at high pressures to accommodate the low critical temperature of CO_2. The high volumetric capacity of these systems leads to reduced compressor and pipe size, which reduces the potential for leaks (EPA 2013).

In climates with an average annual temperature below 50°F, CO_2 transcritical systems operate 5 to 10% more efficiently than conventional centralized direct expansion systems. In hot ambient conditions, the subcritical operation of these systems only occurs during a limited number of hours a year, reducing the efficiency of these system types. In the past several years numerous technologies have been developed to increase efficiency of these systems in hot climates such as parallel compression, mechanical expanders, and mechanical ejectors, however these improvements are typically less effective in humid climates (Belusko et al. 2019). Because of these factors, CO_2 transcritical systems are assumed to have scaled efficiency improvements across the climates zones in this analysis as shown in Table 12, with very hot and humid climates having the largest decrease in energy efficiency and very cold climates having the largest increase in energy efficiency. It is worth noting that real-world energy efficiency improvements vary on a case by case basis. For example, a case study done in a CarrefourSA Express supermarket in Turkey with a store area of 765 m^2 saw a reduction of 7% in their annual energy bills compared to their initial R-404A conventional direct expansion system. Another case study at a Sobeys in Canada with a store area of 1950 m^2 combined a CO_2 transcritical with refrigeration heat recovery. This combination led to reductions in energy consumption of 15-18% and reductions in natural gas consumption of 75-80%, reducing their CO_2 emissions by 62% (CCAC 2014).

Table 12. Summary of Energy Efficiency Impacts for CO_2 Transcritical Systems[a]

Climate Type	Energy Efficiency Impact
Very hot and humid	(10%)
Warm and dry	(5%)
Mixed and marine	0%
Cool and humid	5%
Very cold	10%

[a] Energy efficiency impacts given in parentheses represent decreases in efficiency

CO_2 transcritical systems have an upfront cost 17.5% higher than conventional direct expansion systems, costing $32,000 more per supermarket. Similar to distributed systems, incremental costs for CO_2 transcritical systems are assumed to be consistent across store sizes. Although larger stores typically have greater costs associated with longer piping runs and other equipment needs, these costs are often greater on a per square foot basis in smaller stores because of a larger percentage of refrigeration compared to total floor space. Additionally, smaller refrigeration systems typically cost more per unit of capacity compared to larger systems due to the economies of scale. Smaller systems require a similar number of components as larger systems, but smaller components are typically more expensive to manufacture and install. The emission reductions and cost savings from increased energy efficiency vary by climate.

Table 13. Summary of CO_2 Transcritical Systems[a]

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	New	New	New
Increased Installation Cost	$31,850	$31,850	$31,850
Refrigerant Cost from First Fill	($2,750)	($14,050)	($16,600)
Annual Cost	$0 - $1,100	$0 - $6,630	$0 – $8,850
Incremental Annual Savings	$745 - $1,730	$3,800 - $9,580	$4,500 - $12,375
Charge Size Reduction	0%	0%	0%
New Leak Rate	15%	15%	15%
Lifetime Direct Emission Reduction ($MTCO_2eq$)	5,600	28,550	33,800
Energy Efficiency Improvement	(10%) – 10%	(10%) – 10%	(10%) – 10%

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

5. Micro Distributed Systems

Micro distributed systems are similar to stand-alone equipment in that they contain individual condensing units, however they remove exhaust heat through a water loop system that is connected to a chiller or other type of equipment often located on the roof (Emerson 2018). Micro distributed systems are pre-piped at the factory with R-290 and are limited to five ounces of charge per system. The small amount of refrigerant charge reduces the system charge size by 90% compared to the baseline conventional direct expansion system (Emerson 2018). Due to micro distributed units being self-contained and hermetically sealed these systems are virtually leak proof, resulting in leak rates lower than 1% (Hydrocarbons 2013). Due to their small size, a large supermarket could require upwards of one hundred units per store.

Micro distributed systems are assumed to have similar capital costs as a CO_2 transcritical system, however, their overall upfront cost compared to transcritical systems is lower due to their simplicity compared to transcritical systems (i.e., because they are self-contained, stand-alone units) as they are assumed to have lower installation costs (Hydrocarbons 2013). Based on expert opinion, incremental costs for micro distributed systems are assumed to be consistent across store sizes. Although larger stores typically have greater costs associated with additional equipment needs, these costs are often greater on a per square foot basis in smaller stores because of a larger percentage of refrigeration compared to total floor space. Additionally, smaller refrigeration systems typically cost more per unit of capacity compared to larger systems. Micro distributed systems are assumed to have energy efficiency similar to a conventional direct expansion system.

Table 14. Summary of Micro Distributed Systems[a]

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	New	New	New
Increased Installation Cost	$27,300	$27,300	$27,300
Refrigerant Cost from First Fill	($300)	($1,600)	($1,900)
Annual Cost	$0	$0	$0
Incremental Annual Savings	$850	$4,200	$5,000
Charge Size Reduction	90%	90%	90%
New Leak Rate	2%	2%	2%
Lifetime Direct Emission Reduction ($MTCO_2eq$)	5,600	28,550	33,800
Energy Efficiency Improvement	0	0	0

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

6. Refrigerant Retrofits

6.1 Retrofits of Rack Systems with R-407A

Retrofits of existing R-404A rack systems with a lower GWP alternative, such as R-407A, allow a near drop-in solution to reduce direct emissions of conventional direct expansion systems without extensive system updates. The amount of modification to a system prior to a refrigerant retrofit varies across system types and setups, but typically the system must be shut down, checked for leaks, and filter driers changed before the entire system is evacuated so the new fluid can be deposited in the system (EPA 2013). Based on expert opinion, it is assumed that retrofitting an R-404A system with R-407A will require 8 hours of a service technician's time per rack at an assumed rate of $50 per hour (EPA 2013). Although system leaks may be identified and repaired prior to the system retrofit, the retrofitting of an R-404A system with R-407A is not assumed to result in any net energy efficiency improvements or annual leak rate reductions.

Table 15. Summary of R-407A Retrofits[a]

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	Existing	Existing	Existing
Increased Installation Cost	$800	$1,200	$1,600
Refrigerant Cost from First Fill	$3,300	$16,900	$20,000
Incremental Annual Cost	$0	$0	$0
Incremental Annual Savings	$0	$0	$0
Charge Size Reduction	0%	0%	0%
New Leak Rate	25%	25%	25%
Lifetime Direct Emission Reduction ($MTCO_2eq$)	1,650	8,500	10,050
Energy Efficiency Improvement	0	0	0

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

6.2 Retrofits of Rack Systems with HFC/HFO Blends

Retrofits of existing R-404A rack systems with a lower GWP alternative, such as HFC/HFO blends, allow a near drop-in solution to reduce direct emissions of conventional direct expansion systems without extensive system updates or replacement. The amount of modification required prior to a refrigerant retrofit varies across system types and setups, but typically the system must be shut down, checked for leaks, and filter driers changed before the entire system is evacuated so the new fluid can be deposited in the system (EPA 2013). Based on expert opinion, it is assumed that retrofitting an R-404A system with R-448A will require 8 hours of a service technician's time per rack.

HFO/HFC blends such as R-448A, R-449A, and R-452A are expected to increase energy efficiency by 5% compared to R-404A (Honeywell 2016). A case study was done in several mid-size Ahold stores in the Netherlands in 2013 that retrofitted centralized direct expansion systems with R-449A. Two stores were converted from R-507A and one was converted from R-407F. Measurements before and after the retrofit revealed an 8% increase in energy efficiency (CCAC 2016). As there was limited detail provided on how the 8% increase in energy efficiency was determined (e.g., whether this was based on an instantaneous measurement or measured over a longer time period), a conservative 3% energy efficiency improvement is assumed based on expert opinion for a typical store retrofitting from R-404A.

Table 16. Summary of HFC/HFO Blend Retrofits[a]

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	Existing	Existing	Existing
Increased Installation Cost	$800	$1,200	$1,600
Refrigerant Cost from First Fill	$7,100	$36,400	$43,000

	Small Supermarket	Large Supermarket	Big Box Store
Incremental Annual Cost	$950	$4,875	$5,780
Incremental Annual Savings	$390 - $960	$2,300 - $3,500	$3,100 - $4,650
Charge Size Reduction	0%	0%	0%
New Leak Rate	25%	25%	25%
Lifetime Direct Emission Reduction ($MTCO_2eq$)	2,400	12,100	14,400
Energy Efficiency Improvement	3%	3%	3%

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

7. Leak Mitigation Strategies

Eleven leak mitigation strategies are outlined below. Cost assumptions for each individual leak mitigation strategy were available from the CARB *Greenhouse Gas Performance Analysis for Commercial Buildings with Large Refrigeration and Air Conditioning Systems* (2012), but leak reduction was evaluated on an aggregate basis. The emission reductions, annual costs, and annual savings were estimated for new (Table 17) and existing equipment (Table 18) based on all the applicable leak mitigation options being implemented.

The implementation of all eleven leak mitigation strategies for new conventional direct expansion equipment is assumed to reduce the leak rate of the system to 8%. The implementation of the three applicable leak mitigation strategies for existing conventional direct expansion equipment is assumed to reduce the leak rate of the system to 10%. Literature indicates that energy efficiency can be impacted when the charge of a system falls below 75%-80% of the original charge (IOR 2013). The energy efficiency benefits from preventing refrigerant leaks are estimated based on the relationship between annual running costs and refrigerant leakage determined by IOR (2013) shown in Figure 1, above. It is assumed that a reduction in annual running costs is directly proportional to an improvement in energy efficiency of the system (i.e., the energy efficiency improvement for a new system is assumed to be 13.5% based on a reduction in the annual running costs from 17.5% for a system operating with 75% of its charge to 4% for a system operating with 92% of its charge; the energy efficiency improvement for an existing system is assumed to be 12.5% based on a reduction in the annual running costs from 17.5% for a system operating with 75% of its charge to 5% for a system operating with 90% of its charge). The strategies and their respective initial costs are outlined below for small supermarkets, large supermarkets, and big box stores.

Table 17. Summary of Leak Mitigation Strategies in New Equipment[a]

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	New	New	New
Increased Installation Cost	$3,750	$7,750	$10,100
Incremental Annual Cost	$0	$0	$0
Annual Savings	$560	$2,875	$3,400
Charge Size Reduction	0%	0%	0%

	Small Supermarket	Large Supermarket	Big Box Store
New Leak Rate	8%	8%	8%
Lifetime Direct Emission Reduction ($MTCO_2eq$)	3,050	15,600	18,450
Energy Efficiency Improvement	13.5%	13.5%	13.5%

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

Table 18. Summary of Leak Mitigation Strategies in Existing Equipment[a]

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	Existing	Existing	Existing
Increased Installation Cost	$2,500	$5,500	$7,000
Incremental Annual Cost	$0	$0	$0
Annual Savings	$500	$2,550	$3,000
Charge Size Reduction	0%	0%	0%
New Leak Rate	10%	10%	10%
Lifetime Direct Emission Reduction ($MTCO_2eq$)	1,500	7,600	9,050
Energy Efficiency Improvement	12.5%	12.5%	12.5%

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

7.1 Removal of Threaded Pipe for Refrigeration Lines

This leak reduction method involves the removal of threaded pipe for any refrigeration lines, excluding threaded connections at the compressor rack. Welded steel piping is a good substitution for threaded pipes. Threaded pipes often seep refrigerants and do not hold up well against high pressure due to the reduction in steel wall thickness, whereas welded steel piping increases reliability of joints and thus reduces potential for refrigerant leaks (California ARB 2012). Threaded piping is not commonly used in supermarket piping; however, this strategy is included as emission reductions were provided in aggregate across all leak mitigation strategies.

The cost increase of using welded piping instead of threaded depends on the size of the pipe and the skill of the installer, however costs are expected to be minimal, roughly $160 per store regardless of store size (California ARB 2012).

Table 19. Summary of Removal of Threaded Pipe for Refrigerant Lines

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	New	New	New
Increased Installation Cost	$160	$160	$160

7.2 Removal of Copper Tubing with Outside Diameter Smaller Than 0.25”

Small lines are often used for compressor pressure controls, oil supply, and for the equalization and pressure lines to valves. This leak reduction measure prohibits the use of copper tubing with an outside diameter smaller than 0.25” in all systems with a charge size greater than 5 pounds. Copper tubing with a small diameter is more prone to failure under vibration, and therefore removing this material reduces the chance of leaks due to this failure. Steel tubing is a more resilient alternative and costs less than copper tubing, but it is more difficult to install due to its difficulty to be bent, brazed, or flared.

Costs for the use of steel tubing rather than copper tubing for small lines varies based on the number of small lines in a store, however the increased cost for new conventional direct expansion equipment is assumed to be $200 due to the extra time needed to install steel tubing. Replacement of copper tubing in small lines would be significantly more expensive in an existing store, so it was assumed that the high costs would deter the use of this option and therefore this strategy is only considered for use in new stores.

Table 20. Summary of Removal of Copper Tubing on Small Lines

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	New	New	New
Increased Installation Cost	$200	$200	$200

7.3 Removal of Flared Tubing Connections

This leak reduction measure prohibits the use of flared tubing connections on all refrigeration applications except pressure controls, valve pilot lines, and oil lines. For these exceptions, the tubing for the flare connection must either be double-flared or single-flared with a multi-ring seal coated with sealant. Flare fittings are more prone to leaks than brazed or threaded fittings and are likely to loosen overtime, increasing the likelihood of refrigerant leaks. In addition, flare fittings that are on expansion valves are often difficult to see, increasing the chance that a leak goes undetected. In the past few years there has been a large push by concerned groups to convert the supermarket industry to brazed fittings instead of flared fittings. Due to this push many stores no longer contain flare fittings. Once again, this option is included for the overall mitigation values. Considering the additional installation time, the multi-ring seals are estimated to cost $3 more per seal (California ARB 2012).

Table 21. Summary of Removal of Flared Tubing Connections

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	New	New	New
Increased Installation Cost	$300	$450	$600

7.4 Installation of Rupture Disc for Systems with High-GWP Refrigerant

This leak reduction measure requires installing a rupture disc between the outlet of the refrigerant vessel and the inlet of a pressure relief valve for refrigerant systems using high-GWP refrigerants. In addition, there should be a pressure gauge, transducer, or other device between the rupture disc and pressure relief valve to indicate disc rupture and discharge of relief valve.

The rupture disc and pressure gauge provide an easy identification of a valve discharge, allowing it to be checked for any refrigerant seepage. The rupture disc along with the pressure gauge cost roughly $140 per pressure relief valve (California ARB 2012). The cost of this measure is estimated to be the same for new equipment and existing equipment.

Table 22. Summary of Installation of Rupture Discs

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	New or Existing	New or Existing	New or Existing
Increased Installation Cost for New or Existing Equipment	$560	$840	$1,120

7.5 Use of Only Brass or Steel Schrader Access Valves

This leak reduction measure requires that refrigeration systems with charge sizes of 5 pounds or more use only brass or steel Schrader valve caps. In addition, a neoprene O-ring seal should be installed if the valve cap is designed for one. Schrader valves use a two-stage process of sealing, reducing their leakage compared to other valves. The primary sealing mechanism of a Schrader valve is a spring-loaded valve seat which can be prone to leak over time, particularly if there is a buildup of contaminants on the seat. This leakage probability is mitigated by the secondary sealing mechanism which is a valve cap that reduces the chances of the valve being contaminated and thus leaking. Brass or steel valve caps are recommended, as they are stronger than plastic caps. Additionally, cap tethers should be used to reduce the likelihood of caps being misplaced or removed from the valve.

Brass and steel caps are estimated to cost $10 more than plastic caps per valve. Additionally, chain tethers should be attached to seal caps to ensure they are not lost. Tethers are estimated to cost $5 per valve (California ARB 2012). The cost of this measure is estimated to be the same for new equipment and existing equipment.

Table 23. Summary of Schrader Access Valves

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	New or Existing	New or Existing	New or Existing
Increased Installation Cost for New or Existing Equipment	$780	$1,500	$1,875

7.6 Installation of Corrosion-resistant Evaporator Coils in Cases with Vinegar and Salt

This leak reduction measure requires the use of corrosion-resistant material or material coated to prevent corrosion for evaporator coils used in display cases containing food products with vinegar and salt (e.g., display cases containing deli meats and salads). The presence of vinegar and salt can corrode the evaporator coils over time and cause leaks.

Depending on the coil size, coating type, and manufacturer the cost per coil ranges between $300 and $700 (California ARB 2012). For this analysis, the corrosion-resistant coils are assumed to cost $500 per coil. The cost of this measure is estimated to be the same for new equipment and existing equipment.

Table 24. Summary of Corrosions-resistant Evaporator Coils

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	New or Existing	New or Existing	New or Existing
Increased Installation Cost for New or Existing Equipment	$1,000	$3,000	$4,000

7.7 Installation of Refrigerant Piping with Accessibility in Mind

This leak reduction measure is to ensure that refrigerant piping is installed to increase accessibility, which allows equipment to be more easily observed for leak detection and repairs. Piping that is less accessible is more prone to undetected and prolonged leakage. The cost of this abatement measure is assumed to be negligible as it can be addressed during the design process, and therefore this is not considered a viable leak reduction strategy for existing stores (California ARB 2012).

Table 25. Summary of Accessible Refrigerant Piping Installation

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	New	New	New
Increased Installation Cost	$0	$0	$0

7.8 Installation of Refrigerant Monitor in Receivers with Over 200 Pound Capacity

This leak reduction measure requires the installation of a device that indicates the level of refrigerant in the refrigerant receiver in any system with a 200 pound or greater refrigerant capacity. Control companies have developed receiver-level monitor tracking systems that can monitor receiver levels over integrated time periods to smooth out the effects from short duration changes such as weather conditions, system operation, and other external factors which can affect the level of refrigerant. Monitoring receiver levels can increase the detection of changes that are possibly due to leaks. Detecting these changes will decrease the time leaks go undetected.

There are many devices with variable costs that could be used to comply with this abatement measure; however, an increased cost of $50 per rack for new equipment is assumed (California ARB 2012). Although refrigerant monitors could be installed in an existing store, it is assumed that the high costs would deter the use of this option and therefore this strategy is only considered for use in new stores.[4]

[4] Based on expert opinion, installation of refrigerant monitors on existing systems would cost roughly $6,000 per rack. This would lead to costs of $12,000 for small supermarkets, $18,000 for large supermarkets, and $24,000 for big box stores.

Table 26. Summary of Refrigerant Monitor Installation

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	New	New	New
Increased Installation Cost for New Equipment	$100	$150	$200
Increased Installation Cost for Existing Equipment (*Not Modeled*)	$12,000	$18,000	$24,000

7.9 Perform System Pressure Test During Installation

This leak reduction measure involves pressure testing a refrigeration system prior to evacuation and charging to ensure the system's leak tightness prior to use. Pressure testing is required in most building codes; however, this strategy recommends more stringent testing. The system should be charged using dry nitrogen and a tracer gas up to a 300 psig minimum. This high pressure ensures that even small leaks are identified and repaired. After checking and repairing all leaks, the system should remain at 300 psig for 24 hours. If there is no more than one-pound pressure change in either direction over the 24 hours, evacuation and charging can commence (California ARB 2012). Although this measure, does not directly reduce emissions, it is a preventative measure to stop leaks from occurring.

There is no associated increased cost with this measure as the more stringent testing should not require any additional labor. As this pressure test occurs during system installation, it is only appropriate for new systems.

Table 27. Summary of System Pressure Test

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	New	New	New
Increased Installation Cost	$0	$0	$0

7.10 Perform System Evacuation During Installation

Although all refrigeration system installation requires evacuation, this strategy recommends a more stringent evacuation process. After pressure testing and before charging the system, this mitigation option involves a three-stage evacuation of the system. First, the system vacuum should be pulled down to 1,000 microns and held for at least thirty minutes. Next, the system vacuum should be pulled down to 500 microns and held for thirty minutes. Finally, the system vacuum should be pulled down to a minimum of 300 microns and held for 24 hours. If the system remains at 300 microns with a maximum drift of 100 microns over the 24 hours, then the system can be fully charged. If the system cannot remain at vacuum and returns to atmospheric pressure, a leak is likely present. Before proceeding with charging the system, the leak should be identified and repaired. This measure ensures leak tightness as well as ensuring the system is free of impurities. Although this measure, does not directly reduce emissions, it is a preventative measure to stop leaks from occurring.

There is no associated increased cost with this measure as the more stringent testing should not require any additional labor. As this evacuation occurs during system installation, it is only appropriate for new systems.

Table 28. Summary of System Evacuation

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	New	New	New
Increased Installation Cost	$0	$0	$0

7.11 Reduction in the Use of Short Radius Elbows

This leak reduction measure recommends long radius elbows in refrigerant piping when possible. Stress, especially from thermal expansion and vibration, is more prevalent in short radius elbows, making them less durable than long radius elbow in refrigerant piping.

The number of elbows in a system vary depending on the size and design of the store. Long radius elbows are assumed to cost $2 more than short radius elbows (California ARB 2012). Because the use of long radius elbows needs to be addressed during the design process, this is not considered a viable leak reduction strategy for existing stores.

Table 29. Summary of Short Radius Elbow Installation

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	New	New	New
Increased Installation Cost	$0	$0	$0

8. Floating Head Pressure

Often refrigerators operate at a consistently high pressure to accommodate the hottest days of the year. Maintaining a consistently high pressure requires the system compressor to continue running, using more energy than necessary (RTOC 2018). Allowing the pressure to float according to ambient temperature decreases the overall power consumption of the system by reducing the need for the compressor to run. In addition, the reduction in pressure decreases the stress of the system and could also reduce potential leaks due to this stress, not considered in this analysis. Floating head pressure is estimated to result in 8% energy efficiency improvements across all three store sizes (California ARB 2012).

Head pressure should be controlled by modulating the condenser fan speed, cycling condenser fans, or blocking flow through sections of the condenser and should not use the flooded condenser method which increases refrigerant charge requirements in the winter (California ARB 2012). Based on expert opinion, it is assumed that most supermarkets have or will install the programming switch necessary to convert from static to floating head pressure (but may not have the option engaged). Thus, the cost of this measure for new and existing equipment is assumed to be negligible.

Table 30. Summary of Floating Head Pressure for New Equipment[a]

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	New	New	New
Increased Installation Cost	$0	$0	$0
Incremental Annual Cost	$0	$0	$0
Annual Savings	$1,330 - $2,000	$5,800 - $8,700	$8,300 - $12,500
Charge Size Reduction	0%	0%	0%
New Leak Rate	25%	25%	25%
Lifetime Direct Emission Reduction ($MTCO_2eq$)	0	0	0
Energy Efficiency Improvement	8%	8%	8%

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

Table 31. Summary of Floating Head Pressure for Existing Equipment[a]

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	Existing	Existing	Existing
Increased Installation Cost	$0	$0	$0
Incremental Annual Cost	$0	$0	$0
Annual Savings	$1,350 - $2,000	$5,850 - $8,750	$8,400 - $12,550
Charge Size Reduction	0%	0%	0%
New Leak Rate	25%	25%	25%
Lifetime Direct Emission Reduction ($MTCO_2eq$)	0	0	0
Energy Efficiency Improvement	8%	8%	8%

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

9. Floating Suction Pressure

A floating suction pressure system utilizes rack controllers to monitor temperature sensors of the coldest case or circuit in the rack. Based on the temperature sensor, floating suction pressure adjusts the rack suction pressure to satisfy the circuit setpoint. (California Energy Commission 2019). Floating suction pressure is assumed to result in a 3% energy efficiency improvement (California ARB 2012).

Based on expert opinion, it is assumed that most supermarkets have or will install the necessary equipment for floating suction pressure and that the use of this method would be a programming switch. Thus, the cost of this measure for new or existing equipment is assumed to be negligible.

Table 32. Summary of Floating Suction Pressure for New Equipment[a]

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	New	New	New
Increased Installation Cost	$0	$0	$0
Incremental Annual Cost	$0	$0	$0
Annual Savings	$430 - $650	$2,075 - $3,100	$3,450 - $5,150
Charge Size Reduction	0%	0%	0%
New Leak Rate	25%	25%	25%
Lifetime Direct Emission Reduction ($MTCO_2eq$)	0	0	0
Energy Efficiency Improvement	3%	3%	3%

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

Table 33. Summary of Floating Suction Pressure for Existing Equipment[a]

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	Existing	Existing	Existing
Increased Installation Cost	$0	$0	$0
Incremental Annual Cost	$0	$0	$0
Annual Savings	$430 - $650	$2,100 - $3,150	$3,450 - $5,200
Charge Size Reduction	0%	0%	0%
New Leak Rate	25%	25%	25%
Lifetime Direct Emission Reduction ($MTCO_2eq$)	0	0	0
Energy Efficiency Improvement	3%	3%	3%

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

10. Mechanical Subcooling

Liquid refrigerant should be subcooled to 50°F or less for any low-temperature compressor systems with a design cooling capacity of 100,000 BTU/Hr or greater and a saturated suction temperature of -10°F or lower (California Energy Commission 2019). The realized capacity of the refrigerant can be increased by cooling the refrigerant out of the condenser or flash tank. Decreasing the refrigerant's temperature increases the refrigerant's ability to remove heat from the system. In addition, it improves the performance of the expansion device at the inlet to the evaporator. Subcooling the refrigerant also reduces the mass flow rate of the refrigerant through the system liquid lines which could result in a reduction in liquid line size and thus the system refrigerant charge size. For this analysis, no charge size reduction is assumed. Mechanical subcooling is assumed to result in 4% energy efficiency improvements across all three store sizes (California ARB 2012).

The increased cost of mechanical subcooling was assumed to be 10% more for existing systems than for new systems (California ARB 2012).

Table 34. Summary of Mechanical Subcooling for New Equipment[a]

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	New	New	New
Increased Installation Cost	$4,000	$7,200	$9,000
Incremental Annual Cost	$0	$0	$0
Annual Savings	$460 - $700	$1,550 - $2,350	$4,500 - $6,750
Charge Size Reduction	0%	0%	0%
New Leak Rate	25%	25%	25%
Lifetime Direct Emission Reduction ($MTCO_2eq$)	0	0	0
Energy Efficiency Improvement	4%	4%	4%

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

Table 35. Summary of Mechanical Subcooling for Existing Equipment[a]

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	Existing	Existing	Existing
Increased Installation Cost	$4,500	$8,000	$10,000
Incremental Annual Cost	$0	$0	$0
Annual Savings	$460 - $700	$1,575 - $2,350	$4,550 - $6,800
Charge Size Reduction	0%	0%	0%
New Leak Rate	25%	25%	25%
Lifetime Direct Emission Reduction ($MTCO_2eq$)	0	0	0
Energy Efficiency Improvement	4%	4%	4%

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

11. Refrigeration Heat Recovery

The heat generated from the condenser and gas-cooler can be recovered and used to heat the building, heat water, or be used in other capacities. Utilizing the rejected heat from the refrigeration system can lead to an increase in refrigerant charge but reduces the electricity or natural gas needed to provided heating. The increased refrigerant charge and additional refrigerant lines necessary can result in increased refrigerant leaks, assumed to be roughly 5%. It is recommended that stores recover at least 25% of the design refrigeration heat of rejection for space heating (California Energy Commission 2019).

The costs and savings associated with this measure depend on store size, type and location. The heat recovery system was assumed to use an indirect heat exchange loop with water-cooled heat-recover condensers. If possible, the heat reclaim unit should be mounted to allow any liquid to drain by gravity into the condenser to avoid additional pumping energy. Refrigeration heat recovery is estimated to save 43% in natural gas usage for small supermarkets, 27% in natural gas usage for large supermarkets, and 10% in natural gas usage for big box stores. Because not all stores use natural gas for heating, average natural gas use was converted to electricity.

Table 36. Summary of Refrigeration Heat Recovery for New Equipment[a]

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	New	New	New
Increased Installation Cost	$21,400	$70,000	$88,400
Incremental Annual Cost	$150 - $750	$845 - $2,750	$1,000 - $7,200
Annual Savings	$0 – $6,650	$0 - $25,350	$0 – $19,250
Charge Size Reduction	0%	0%	0%
New Leak Rate	30%	30%	30%
Lifetime Direct Emission Reduction ($MTCO_2eq$)	-900	-4,600	-5,430
Energy Efficiency Improvement	-5% electricity; 43% natural gas	-3% electricity; 27% natural gas	-5% electricity; 10% natural gas

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

Table 37. Summary of Refrigeration Heat Recovery for Existing Equipment[a]

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	Existing	Existing	Existing
Increased Installation Cost	$23,500	$77,000	$97,200
Incremental Annual Cost	$150 - $750	$845 - $2,750	$1,000 - $7,250
Annual Savings	$0 - $8,300	$0 - $31,650	$0 - $24,750
Charge Size Reduction	-5%	-5%	-5%
New Leak Rate	25%	25%	25%
Lifetime Direct Emission Reduction ($MTCO_2eq$)	-500	-2,550	-3,000
Energy Efficiency Improvement	-5% electricity; 43% natural gas	-3% electricity; 27% natural gas	-5% electricity; 10% natural gas

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

12. Display Case Doors

The addition of doors to supermarket display cases can greatly reduce the energy consumption of refrigeration systems, because display case doors keep case temperatures consistent and reduce the refrigerant load required to keep them cool. Display case doors also reduce the amount of space heating necessary to counteract the cool air that escapes into the main store space when doors are not in place (U.S. DOE 2013).

The reduction in energy consumption from the addition of display case doors varies based on store type and climate region. Display case doors are estimated to reduce electricity consumption by 16% across climate regions (U.S. DOE 2013). Display case doors are also estimated to reduce natural gas usage for heating by 28% across store types and climate regions (U.S. DOE 2013). For this analysis, natural gas savings generated by this mitigation option were converted to electricity savings to streamline the overall savings of this option, especially for stores that do not use natural gas for heating.

Table 38. Summary of Display Case Doors for New Equipment[a]

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	New	New	New
Increased Installation Cost	$137,500	$275,000	$385,000
Incremental Annual Cost	$0	$0	$0
Annual Savings	$3,200 - $7,000	$19,000 - $41,700	$27,400 - $88,800
Charge Size Reduction	0%	0%	0%
New Leak Rate	25%	25%	25%
Lifetime Direct Emission Reduction ($MTCO_2eq$)	0	0	0
Energy Efficiency Improvement	17% electricity; 28% natural gas	17% electricity; 28% natural gas	17% electricity; 28% natural gas

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

Table 39. Summary of Display Case Doors for Existing Equipment[a]

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	Existing	Existing	Existing
Increased Installation Cost	$137,500	$275,000	$385,000
Incremental Annual Cost	$0	$0	$0
Annual Savings	$3,200 - $8,050	$19,100 - $48,300	$27,650 - $105,100
Charge Size Reduction	0%	0%	0%
New Leak Rate	25%	25%	25%
Lifetime Direct Emission Reduction ($MTCO_2eq$)	0	0	0
Energy Efficiency Improvement	17% electricity; 28% natural gas	17% electricity; 28% natural gas	17% electricity; 28% natural gas

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

13. Supermarket System Monitoring

Comprehensive supermarket monitoring systems allow users to collect and analyze data on numerous systems within individual stores and/or compare performance across stores. Specific characteristics of monitoring systems differ across the market; however, in general, supermarket monitoring systems monitor the general performance of the store including compressor and condenser performance, display case temperatures, underperforming system components, and other supermarket mechanisms. This information allows stores to adjust set points for equipment, optimize energy savings, and detect issues or underperformance in a timely manner (Honeywell 2017, Emerson 2016, Danfoss 2018).

These types of systems are offered by several manufacturers including Honeywell, Emerson, OpSense and Danfoss. These providers estimate energy efficiency savings ranging from 19% (Honeywell 2018) to 50% (Danfoss 2018); however, for the purposes of this analysis a conservative energy efficiency improvement of 19% are assumed so as not to double count benefits from leak mitigation measures.. Although supermarket monitoring systems often include specific refrigerant leak monitoring measures which could result in direct emission reductions, a separate refrigerant leak monitoring measure is included in the leak mitigation measures and thus those impacts are not included here to ensure benefits are not double counted. Monitoring systems could be installed in both new and existing stores.

Table 40. Summary of Supermarket System Monitoring for New Equipment[a]

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	New	New	New
Increased Installation Cost	\$5,700	\$34,000	\$45,300
Incremental Annual Cost	\$0	\$0	\$0
Annual Savings	\$2,450 - \$3,650	\$14,600 - \$21,900	\$19,550 - \$29,200
Charge Size Reduction	0%	0%	0%
New Leak Rate	25%	25%	25%
Lifetime Direct Emission Reduction ($MTCO_2eq$)	0	0	0
Energy Efficiency Improvement	19%	19%	19%

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

Table 41. Summary of Supermarket System Monitoring for Existing Equipment[a]

	Small Supermarket	Large Supermarket	Big Box Store
Applicable Equipment Type	Existing	Existing	Existing
Increased Installation Cost	\$6,000	\$36,000	\$48,000
Incremental Annual Cost	\$0	\$0	\$0
Annual Savings	\$2,450 - \$3,675	\$14,700 - \$22,000	\$19,650 - \$29,400
Charge Size Reduction	0%	0%	0%
New Leak Rate	25%	25%	25%
Lifetime Direct Emission Reduction ($MTCO_2eq$)	0	0	0
Energy Efficiency Improvement	19%	19%	19%

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

Appendix B: Intervention Types Details

All assumptions are based on a typical store and may vary significantly across store types, store sizes, and store locations

Table 42. Summary of Intervention Types for Small Supermarkets in Very Hot and Humid Climates[a]

Mitigation Option: Small Supermarket	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
New Equipment					
Distributed Systems	$8,250	$375	$1,200	4,010	(175)
Micro Distributed Systems	$27,000	($830)	$1,860	4,600	0
HFC Secondary Loop and/or Cascade System	$89,300	($780)	$8,100	4,450	0
NH_3 or HC Secondary Loop and/or Cascade Systems	$42,500	($1,875)	$2,360	4,600	175
CO_2 Transcritical Systems	$29,100	$1,470	$4,360	4,600	(350)
Leak Mitigation	$3,750	($3,550)	($3,175)	3,060	475
Floating Head Pressure	$0	($2,200)	($2,200)	0	350
Floating Suction Pressure	$0	($660)	($660)	0	100
Mechanical Subcooling	$4,000	($885)	($480)	0	140
Refrigeration Heat Recovery[b]	$21,400	$730	$2,860	(900)	85
Display Case Doors	$137,500	($3,650)	$10,030	0	580
Supermarket Monitoring System	$5,700	($4,200)	($3,640)	0	670
Existing Equipment					
Retrofits with R-407A	$4,100	$0	$585	1,200	0
Retrofits with HFC/HFO Blends	$7,900	$285	$1,420	1,680	60
Leak Mitigation	$2,350	($3,290)	($2,950)	1,500	245
Floating Head Pressure	$0	($2,230)	($2,230)	0	200
Floating Suction Pressure	$0	($670)	($670)	0	60
Mechanical Subcooling	$4,500	($900)	($255)	0	80
Refrigeration Heat Recovery[b]	$23,500	$730	$4,080	(500)	50
Display Case Doors	$137,500	($3,680)	$15,900	0	330
Supermarket Monitoring System	$6,000	($4,250)	($3,390)	0	375

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.
[b] Refrigeration heat recovery was not deemed an applicable mitigation strategy in this scenario, as it resulted in increased emissions due to the climate zone.

Table 43. Summary of Intervention Types for Small Supermarkets in Warm and Dry Climates[a]

Mitigation Option: Small Supermarket	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction (tCO_2eq)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
New Equipment					
Distributed Systems	$8,250	$240	$1,050	4,010	(130)
Micro Distributed Systems	$27,000	($830)	$1,860	4,600	0
HFC Secondary Loop and/or Cascade System	$89,300	($780)	$8,100	4,450	0
NH_3 or HC Secondary Loop and/or Cascade Systems	$42,500	($1,735)	$2,500	4,600	130
CO_2 Transcritical Systems	$29,100	$220	$3,110	4,600	(130)
Leak Mitigation	$3,750	($3,170)	($2,790)	3,060	350
Floating Head Pressure	$0	($1,930)	($1,930)	0	260
Floating Suction Pressure	$0	($580)	($580)	0	80
Mechanical Subcooling	$4,000	($770)	($370)	0	100
Refrigeration Heat Recovery[b]	$21,400	($2,260)	($136)	(900)	455
Display Case Doors	$137,500	($4,870)	$8,800	0	650
Supermarket Monitoring System	$5,700	($3,660)	($3,100)	0	490
Existing Equipment					
Retrofits with R-407A	$4,100	$0	$585	1,200	0
Retrofits with HFC/HFO Blends	$7,900	$390	$1,520	1,680	60
Leak Mitigation	$2,350	($2,860)	($2,530)	1,500	180
Floating Head Pressure	$0	($1,900)	($1,900)	0	140
Floating Suction Pressure	$0	($570)	($570)	0	40
Mechanical Subcooling	$4,500	($760)	($120)	0	60
Refrigeration Heat Recovery[b]	$23,500	($2,400)	$960	(500)	290
Display Case Doors	$137,500	($4,900)	$14,690	0	375
Supermarket Monitoring System	$6,000	($3,600)	($2,740)	0	275

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.
[b] Refrigeration heat recovery was not deemed an applicable mitigation strategy in this scenario, as it resulted in increased emissions due to the climate zone.

Table 44. Summary of Intervention Types for Small Supermarkets in Mixed and Marine Climates[a]

Mitigation Option: Small Supermarket	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
New Equipment					
Distributed Systems	$8,250	($30)	$790	4,010	(125)

Mitigation Option: Small Supermarket	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
Micro Distributed Systems	$27,000	($830)	$1,860	4,600	0
HFC Secondary Loop and/or Cascade System	$89,300	($780)	$8,100	4,450	0
NH_3 or HC Secondary Loop and/or Cascade Systems	$42,500	($1,470)	$2,760	4,600	125
CO_2 Transcritical Systems	$29,100	($740)	$2,150	4,600	0
Leak Mitigation	$3,750	($2,450)	($2,080)	3,060	340
Floating Head Pressure	$0	($1,400)	($1,400)	0	250
Floating Suction Pressure	$0	($420)	($420)	0	80
Mechanical Subcooling	$4,000	($560)	($160)	0	100
Refrigeration Heat Recovery[b]	$21,400	($3,730)	($1,600)	(900)	830
Display Case Doors	$137,500	($5,400)	$8,270	0	970
Supermarket Monitoring System	$5,700	($2,660)	($2,100)	0	480
Existing Equipment					
Retrofits with R-407A	$4,100	$0	$585	1,200	0
Retrofits with HFC/HFO Blends	$7,900	$390	$1,660	1,680	40
Leak Mitigation	$2,350	($2,280)	($1,950)	1,500	180
Floating Head Pressure	$0	($1,430)	($1,430)	0	140
Floating Suction Pressure	$0	($430)	($430)	0	40
Mechanical Subcooling	$4,500	($570)	$70	0	60
Refrigeration Heat Recovery	$23,500	($4,200)	($855)	(500)	570
Display Case Doors	$137,500	($5,760)	$13,820	0	575
Supermarket Monitoring System	$6,000	($2,700)	($1,850)	0	270

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.
[b] Refrigeration heat recovery was not deemed an applicable mitigation strategy in this scenario, as it resulted in increased emissions due to the climate zone.

Table 45. Summary of Intervention Types for Small Supermarkets in Cool and Humid Climates[a]

Mitigation Option: Small Supermarket	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
New Equipment					
Distributed Systems	$8,250	$255	$1,080	4,010	(130)
Micro Distributed Systems	$27,000	($830)	$1,860	4,600	0
HFC Secondary Loop and/or Cascade System	$89,300	($780)	$8,100	4,450	0

Mitigation Option: Small Supermarket	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
NH_3 or HC Secondary Loop and/or Cascade Systems	$42,500	($1,760)	$2,475	4,600	130
CO_2 Transcritical Systems	$29,100	($1,730)	$1,160	4,600	130
Leak Mitigation	$3,750	($3,220)	($2,850)	3,060	350
Floating Head Pressure	$0	($1,970)	($1,970)	0	260
Floating Suction Pressure	$0	($590)	($590)	0	80
Mechanical Subcooling	$4,000	($790)	($390)	0	100
Refrigeration Heat Recovery	$21,400	($5,950)	($3,820)	(900)	930
Display Case Doors	$137,500	($7,830)	$5,840	0	1,030
Supermarket Monitoring System	$5,700	($3,740)	($3,180)	0	490
Existing Equipment					
Retrofits with R-407A	$4,100	$0	$585	1,200	0
Retrofits with HFC/HFO Blends	$7,900	$360	$1,490	1,680	40
Leak Mitigation	$2,350	($2,985)	($2,650)	1,500	180
Floating Head Pressure	$0	($1,990)	($1,990)	0	450
Floating Suction Pressure	$0	($600)	($600)	0	40
Mechanical Subcooling	$4,500	($800)	($160)	0	60
Refrigeration Heat Recovery	$23,500	($7,300)	($3,950)	(500)	750
Display Case Doors	$137,500	($8,750)	$10,830	0	640
Supermarket Monitoring System	$6,000	($3,780)	($2,930)	0	275

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

Table 46. Summary of Intervention Types for Small Supermarkets in Very Cold Climates[a]

Mitigation Option: Small Supermarket	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
New Equipment					
Distributed Systems	$8,250	($220)	$600	4,010	120
Micro Distributed Systems	$27,000	($830)	$1,860	4,600	0
HFC Secondary Loop and/or Cascade System	$89,300	($780)	$8,100	4,450	0
NH_3 or HC Secondary Loop and/or Cascade Systems	$42,500	($1,280)	$2,950	4,600	120
CO_2 Transcritical Systems	$29,100	($1,760)	$1,130	4,600	235
Leak Mitigation	$3,750	($1,935)	($1,560)	3,060	320

Mitigation Option: Small Supermarket	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
Floating Head Pressure	$0	($1,020)	($1,020)	0	240
Floating Suction Pressure	$0	($300)	($300)	0	70
Mechanical Subcooling	$4,000	($400)	($6)	0	100
Refrigeration Heat Recovery	$21,400	($5,150)	($3,020)	(900)	1,350
Display Case Doors	$137,500	($5,520)	$8,150	0	1,275
Supermarket Monitoring System	$5,700	($1,930)	($1,370)	0	450
Existing Equipment					
Retrofits with R-407A	$4,100	$0	$585	1,200	0
Retrofits with HFC/HFO Blends	$7,900	$650	$1,780	1,680	40
Leak Mitigation	$2,350	($1,760)	($1,420)	1,500	160
Floating Head Pressure	$0	($1,010)	($1,010)	0	130
Floating Suction Pressure	$0	($300)	($300)	0	40
Mechanical Subcooling	$4,500	($400)	$230	0	50
Refrigeration Heat Recovery	$23,500	($6,350)	($3,000)	(500)	1,140
Display Case Doors	$137,500	($6,280)	$13,300	0	820
Supermarket Monitoring System	$6,000	($1,910)	($1,060)	0	250

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

Table 47. Summary of Intervention Types for Large Supermarkets in Very Hot and Humid Climates[a]

Mitigation Option: Large Supermarket	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
New Equipment					
Distributed Systems	$4,875	$2,900	$3,400	20,450	(1,060)
Micro Distributed Systems	$25,700	($4,200)	$1,660	23,450	0
HFC Secondary Loop and/or Cascade System	$50,450	($3,970)	$1,040	22,630	0
NH_3 or HC Secondary Loop and/or Cascade Systems	$30,550	($10,600)	($7,530)	1,050	1,060
CO_2 Transcritical Systems	$17,800	$9,470	$11,240	23,450	(2,110)
Leak Mitigation	$7,750	($20,780)	($20,000)	15,600	2,850
Floating Head Pressure	$0	($10,600)	($10,600)	0	1,690
Floating Suction Pressure	$0	($4,000)	($4,000)	0	630
Mechanical Subcooling	$7,200	($2,650)	($1,940)	0	420

Mitigation Option: Large Supermarket	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
Refrigeration Heat Recovery[b]	$70,000	$2,775	$9,730	(4,590)	330
Display Case Doors	$275,000	($21,850)	$5,490	0	3,480
Supermarket Monitoring System	$34,000	($25,200)	($21,820)	0	4,020
Existing Equipment					
Retrofits with R-407A	$18,100	$0	$2,580	6,130	0
Retrofits with HFC/HFO Blends	$37,600	$860	$6,210	8,560	355
Leak Mitigation	$5,350	($19,280)	($18,520)	7,650	1,480
Floating Head Pressure	$0	($10,720)	($10,720)	0	950
Floating Suction Pressure	$0	($4,020)	($4,020)	0	355
Mechanical Subcooling	$8,000	($2,680)	($1,550)	0	240
Refrigeration Heat Recovery[b]	$77,000	$2,775	$13,730	(2,550)	190
Display Case Doors	$275,000	($22,100)	$17,070	0	1,950
Supermarket Monitoring System	$36,000	($25,450)	($20,325)	0	2,250

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.
[b] Refrigeration heat recovery was not deemed an applicable mitigation strategy in this scenario, as it resulted in increased emissions due to the climate zone.

Table 48. Summary of Intervention Types for Large Supermarkets in Warm and Dry Climates[a]

Mitigation Option: Large Supermarket	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
New Equipment					
Distributed Systems	$4,875	$2,070	$2,550	20,450	(775)
Micro Distributed Systems	$25,700	($4,200)	$1,660	23,450	0
HFC Secondary Loop and/or Cascade System	$50,450	($3,970)	$1,040	22,630	0
NH_3 or HC Secondary Loop and/or Cascade Systems	$30,550	($9,720)	($6,680)	1,050	775
CO_2 Transcritical Systems	$17,800	$1,990	$3,760	23,450	(775)
Leak Mitigation	$7,750	($18,500)	($17,720)	15,600	2,100
Floating Head Pressure	$0	($9,260)	($9,260)	0	1,240
Floating Suction Pressure	$0	($3,470)	($3,470)	0	465
Mechanical Subcooling	$7,200	($2,310)	($1,600)	0	310
Refrigeration Heat Recovery[b]	$70,000	($8,555)	($1,600)	(4,590)	1,730
Display Case Doors	$275,000	($29,200)	($1,870)	0	3,920
Supermarket Monitoring System	$34,000	($21,990)	($18,600)	0	2,950

Mitigation Option: Large Supermarket	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
Existing Equipment					
Retrofits with R-407A	$18,100	$0	$2,580	6,130	0
Retrofits with HFC/HFO Blends	$37,600	$1,465	$6,820	8,560	260
Leak Mitigation	$5,350	($16,740)	($15,980)	7,650	1,090
Floating Head Pressure	$0	($9,090)	($9,090)	0	695
Floating Suction Pressure	$0	($3,410)	($3,410)	0	260
Mechanical Subcooling	$8,000	($2,270)	($1,140)	0	170
Refrigeration Heat Recovery[b]	$77,000	($9,040)	$1,920	(2,550)	1,170
Display Case Doors	$275,000	($29,350)	$9,800	0	2,250
Supermarket Monitoring System	$36,000	($21,590)	($16,465)	0	1,650

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.
[b] Refrigeration heat recovery was not deemed an applicable mitigation strategy in this scenario, as it resulted in increased emissions due to the climate zone.

Table 49. Summary of Intervention Types for Large Supermarkets in Mixed and Marine Climates[a]

Mitigation Option: Large Supermarket	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
New Equipment					
Distributed Systems	$4,875	$480	$965	20,450	(750)
Micro Distributed Systems	$25,700	($4,200)	$1,660	23,450	0
HFC Secondary Loop and/or Cascade System	$50,450	($3,970)	$1,040	22,630	0
NH_3 or HC Secondary Loop and/or Cascade Systems	$30,550	($8,130)	($5,095)	1,050	750
CO_2 Transcritical Systems	$17,800	($3,800)	($2,025)	23,450	0
Leak Mitigation	$7,750	($14,210)	($13,440)	15,600	2,040
Floating Head Pressure	$0	($6,720)	($6,720)	0	1,210
Floating Suction Pressure	$0	($2,520)	($2,520)	0	450
Mechanical Subcooling	$7,200	($1,680)	($970)	0	300
Refrigeration Heat Recovery[b]	$70,000	($14,080)	($7,130)	(4,590)	3,140
Display Case Doors	$275,000	($32,410)	($5,075)	0	5,830
Supermarket Monitoring System	$34,000	($15,960)	($12,575)	0	2,870
Existing Equipment					
Retrofits with R-407A	$18,100	$0	$2,580	6,130	0
Retrofits with HFC/HFO Blends	$37,600	$2,310	$7,660	8,560	260

Mitigation Option: Large Supermarket	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
Leak Mitigation	$5,350	($13,220)	($12,460)	7,650	1,070
Floating Head Pressure	$0	($6,840)	($6,840)	0	680
Floating Suction Pressure	$0	($2,565)	($2,565)	0	260
Mechanical Subcooling	$8,000	($1,710)	($575)	0	170
Refrigeration Heat Recovery[b]	$77,000	($15,875)	($4,920)	(2,550)	2,420
Display Case Doors	$275,000	($34,565)	$4,590	0	3,450
Supermarket Monitoring System	$36,000	($16,250)	($11,120)	0	1,620

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.
[b] Refrigeration heat recovery was not deemed an applicable mitigation strategy in this scenario, as it resulted in increased emissions due to the climate zone.

Table 50. Summary of Intervention Types for Large Supermarkets in Cool and Humid Climates[a]

Mitigation Option: Large Supermarket	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
New Equipment					
Distributed Systems	$4,875	$2,190	$2,680	20,450	(775)
Micro Distributed Systems	$25,700	($4,200)	$1,660	23,450	0
HFC Secondary Loop and/or Cascade System	$50,450	($3,970)	$1,040	22,630	0
NH_3 or HC Secondary Loop and/or Cascade Systems	$30,550	($9,850)	($6,800)	1,050	775
CO_2 Transcritical Systems	$17,800	($9,700)	($7,940)	23,450	775
Leak Mitigation	$7,750	($18,840)	($18,060)	15,600	2,100
Floating Head Pressure	$0	($9,460)	($9,460)	0	1,240
Floating Suction Pressure	$0	($3,550)	($3,550)	0	470
Mechanical Subcooling	$7,200	($2,360	($1,650)	0	310
Refrigeration Heat Recovery[b]	$70,000	($22,530)	($15,580)	(4,590)	3,540
Display Case Doors	$275,000	($46,995)	($19,655)	0	6,170
Supermarket Monitoring System	$34,000	($22,465)	($19,085)	0	2,950
Existing Equipment					
Retrofits with R-407A	$18,100	$0	$2,580	6,130	0
Retrofits with HFC/HFO Blends	$37,600	$1,290	$6,650	8,560	260
Leak Mitigation	$5,350	($17,460)	($16,700)	7,650	1,090
Floating Head Pressure	$0	($9,550)	($9,550)	0	700
Floating Suction Pressure	$0	($3,580)	($3,580)	0	260

Mitigation Option: Large Supermarket	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
Mechanical Subcooling	$8,000	($2,390)	($1,250)	0	170
Refrigeration Heat Recovery[b]	$77,000	($27,670)	($16,720)	(2,550)	3,360
Display Case Doors	$275,000	($52,480)	($13,330)	0	3,830
Supermarket Monitoring System	$36,000	($22,690)	($17,560)	0	1,660

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.
[b] Refrigeration heat recovery was not deemed an applicable mitigation strategy in this scenario, as it resulted in increased emissions due to the climate zone.

Table 51. Summary of Intervention Types for Large Supermarkets in Very Cold Climates[a]

Mitigation Option: Large Supermarket	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
New Equipment					
Distributed Systems	$4,875	($670)	($180)	20,450	(705)
Micro Distributed Systems	$25,700	($4,200)	$1,660	23,450	0
HFC Secondary Loop and/or Cascade System	$50,450	($3,970)	$1,040	22,630	0
NH_3 or HC Secondary Loop and/or Cascade Systems	$30,550	($6,980)	($3,950)	1,050	705
CO_2 Transcritical Systems	$17,800	($9,900)	($8,130)	23,450	1,410
Leak Mitigation	$7,750	($11,110)	($10,340)	15,600	1,900
Floating Head Pressure	$0	($4,880)	($4,880)	0	1,130
Floating Suction Pressure	$0	($1,830)	($1,830)	0	420
Mechanical Subcooling	$7,200	($1,220)	($510)	0	280
Refrigeration Heat Recovery	$70,000	($19,420)	($12,460)	(4,590)	5,110
Display Case Doors	$275,000	($33,130)	($5,710)	0	7,660
Supermarket Monitoring System	$34,000	($11,590)	($8,210)	0	2,680
Existing Equipment					
Retrofits with R-407A	$18,100	$0	$2,580	6,130	0
Retrofits with HFC/HFO Blends	$37,600	$3,060	$8,420	8,560	240
Leak Mitigation	$5,350	($10,100)	($9,9330)	7,650	990
Floating Head Pressure	$0	($4,840)	($4,840)	0	630
Floating Suction Pressure	$0	($1,810)	($1,810)	0	240
Mechanical Subcooling	$8,000	($1,210)	($75)	0	160
Refrigeration Heat Recovery	$77,000	($23,960)	($13,010)	(2,550)	5,200
Display Case Doors	$275,000	($37,680)	$1,475	0	4,930

Mitigation Option: Large Supermarket	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
Supermarket Monitoring System	$36,000	($11,490)	($6,360)	0	1,500

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.

Table 52. Summary of Intervention Types for Big Box Stores in Very Hot and Humid Climates[a]

Mitigation Option: Big Box Store	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
New Equipment					
Distributed Systems	$4,100	$4,440	$4,850	24,200	(1,410)
Micro Distributed Systems	$25,400	($5,000)	($2,465)	27,770	0
HFC Secondary Loop and/or Cascade System	$58,800	($4,700)	$1,140	26,800	0
NH_3 or HC Secondary Loop and/or Cascade Systems	$27,800	($13,500)	($10,730)	27,770	1,400
CO_2 Transcritical Systems	$15,250	$13,190	$14,700	27,700	(2,820)
Leak Mitigation	$10,100	($27,270)	($26,270)	18,470	3,810
Floating Head Pressure	$0	($14,150)	($14,150)	0	2,260
Floating Suction Pressure	$0	($5,300)	($5,300)	0	845
Mechanical Subcooling	$9,000	($7,100)	($6,180)	0	1,130
Refrigeration Heat Recovery[b]	$88,400	$8,040	$16,830	(5,430)	290
Display Case Doors	$385,000	($31,575)	$6,700	0	5,030
Supermarket Monitoring System	$45,300	($33,600)	($29,100)	0	5,360
Retrofits with R-407A	$21,600	$0	$3,075	7,260	0
Retrofits with HFC/HFO Blends	$44,600	$410	$6,775	10,130	470
Leak Mitigation	$7,000	($23,330)	($24,330)	9,050	1,970
Floating Head Pressure	$0	($14,300)	($14,300)	0	1,260
Floating Suction Pressure	$0	($5,360)	($5,360)	0	470
Mechanical Subcooling	$10,000	($7,140)	($5,720)	0	630
Refrigeration Heat Recovery[b]	$97,200	$8,100	$21,940	(3,020)	190
Display Case Doors	$385,000	($31,940)	$22,880	0	2,820
Supermarket Monitoring System	$48,000	($33,930)	($27,100)	0	3,000

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.
[b] Refrigeration heat recovery was not deemed an applicable mitigation strategy in this scenario, as it resulted in increased emissions due to the climate zone.

Table 53. Summary of Intervention Types for Big Box Stores in Warm and Dry Climates[a]

Mitigation Option: Big Box Store	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
New Equipment					
Distributed Systems	$4,100	$3,310	$3,720	24,200	(1,040)
Micro Distributed Systems	$25,400	($5,000)	($2,465)	27,770	0
HFC Secondary Loop and/or Cascade System	$58,800	($4,700)	$1,140	26,800	0
NH_3 or HC Secondary Loop and/or Cascade Systems	$27,800	($12,370)	($9,600)	27,770	1,040
CO_2 Transcritical Systems	$15,250	$3,220	$4,730	27,700	(1,040)
Leak Mitigation	$10,100	($24,230)	($23,230)	18,470	2,800
Floating Head Pressure	$0	($12,340)	($12,340)	0	1,660
Floating Suction Pressure	$0	($4,630)	($4,630)	0	620
Mechanical Subcooling	$9,000	($6,170)	($5,280)	0	830
Refrigeration Heat Recovery[b]	$88,400	($2,600)	$6,180	(5,430)	1,520
Display Case Doors	$385,000	($54,300)	($16,030)	0	7,290
Supermarket Monitoring System	$45,300	($29,320)	($24,810)	0	3,930
Existing Equipment					
Retrofits with R-407A	$21,600	$0	$3,075	7,260	0
Retrofits with HFC/HFO Blends	$44,600	$1,230	$7,590	10,130	350
Leak Mitigation	$7,000	($21,940)	($20,940)	9,050	1,450
Floating Head Pressure	$0	($12,120)	($12,120)	0	930
Floating Suction Pressure	$0	($4,550)	($4,550)	0	350
Mechanical Subcooling	$10,000	($6,060)	($4,640)	0	460
Refrigeration Heat Recovery[b]	$97,200	($3,110)	$10,730	(3,020)	1,370
Display Case Doors	$385,000	($55,000)	($180)	0	4,210
Supermarket Monitoring System	$48,000	($28,790)	($21,950)	0	2,200

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.
[b] Refrigeration heat recovery was not deemed an applicable mitigation strategy in this scenario, as it resulted in increased emissions due to the climate zone.

Table 54. Summary of Intervention Types for Big Box Stores in Mixed and Marine Climates[a]

Mitigation Option: Big Box Store	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
New Equipment					
Distributed Systems	$4,100	$1,200	$1,600	24,200	(1,000)

Mitigation Option: Big Box Store	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
Micro Distributed Systems	$25,400	($5,000)	($2,465)	27,770	0
HFC Secondary Loop and/or Cascade System	$58,800	($4,700)	$1,140	26,800	0
NH_3 or HC Secondary Loop and/or Cascade Systems	$27,800	($10,250)	($7,490)	27,770	1,000
CO_2 Transcritical Systems	$15,250	($4,490)	($2,980)	27,700	0
Leak Mitigation	$10,100	($18,520)	($17,510)	18,470	2,720
Floating Head Pressure	$0	($8,960)	($8,960)	0	1,610
Floating Suction Pressure	$0	($3,360)	($3,360)	0	600
Mechanical Subcooling	$9,000	($4,480)	($3,580)	0	800
Refrigeration Heat Recovery[b]	$88,400	($8,740)	$50	(5,430)	2,760
Display Case Doors	$385,000	($64,040)	($25,770)	0	11,520
Supermarket Monitoring System	$45,300	($21,270)	($16,770)	0	3,830
Existing Equipment					
Retrofits with R-407A	$21,600	$0	$3,075	7,260	0
Retrofits with HFC/HFO Blends	$44,600	$2,350	$8,710	10,130	340
Leak Mitigation	$7,000	($17,250)	($16,260)	9,050	1,420
Floating Head Pressure	$0	($9,120)	($9,120)	0	910
Floating Suction Pressure	$0	($3,420)	($3,420)	0	340
Mechanical Subcooling	$10,000	($4,560)	($3,140)	0	460
Refrigeration Heat Recovery	$97,200	($10,250)	$3,590	(3,020)	3,220
Display Case Doors	$385,000	($69,110)	($14,290)	0	6,900
Supermarket Monitoring System	$48,000	($21,660)	($14,830)	0	2,160

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.
[b] Refrigeration heat recovery was not deemed an applicable mitigation strategy in this scenario, as it resulted in increased emissions due to the climate zone.

Table 55. Summary of Intervention Types for Big Box Stores in Cool and Humid Climates[a]

Mitigation Option: Big Box Store	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
New Equipment					
Distributed Systems	$4,100	$3,480	$3,890	24,200	(1,040)
Micro Distributed Systems	$25,400	($5,000)	($2,465)	27,770	0
HFC Secondary Loop and/or Cascade System	$58,800	($4,700)	$1,140	26,800	0

Mitigation Option: Big Box Store	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
NH_3 or HC Secondary Loop and/or Cascade Systems	$27,800	($12,540)	($9,770)	27,770	1,040
CO_2 Transcritical Systems	$15,250	($12,375)	($10,860)	27,700	1,040
Leak Mitigation	$10,100	($24,680)	($23,680)	18,470	2,790
Floating Head Pressure	$0	($12,610)	($12,610)	0	1,660
Floating Suction Pressure	$0	($4,730)	($4,730)	0	620
Mechanical Subcooling	$9,000	($6,300)	($5,410)	0	830
Refrigeration Heat Recovery[b]	$88,400	($14,790)	($6,000)	(5,430)	3,100
Display Case Doors	$385,000	($94,800)	($56,520)	0	12,450
Supermarket Monitoring System	$45,300	($29,950)	($25,450)	0	3,930
Existing Equipment					
Retrofits with R-407A	$21,600	$0	$3,075	7,260	0
Retrofits with HFC/HFO Blends	$44,600	$990	$7,360	10,130	350
Leak Mitigation	$7,000	($22,900)	($21,910)	9,050	1,450
Floating Head Pressure	$0	($12,740)	($12,740)	0	930
Floating Suction Pressure	$0	($4,775)	($4,775)	0	350
Mechanical Subcooling	$10,000	($6,370)	($4,940)	0	470
Refrigeration Heat Recovery	$97,200	($19,260)	($5,420)	(3,020)	5,210
Display Case Doors	$385,000	($108,290)	($53,480)	0	7,910
Supermarket Monitoring System	$48,000	($30,250)	($23,420)	0	2,210

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.
[b] Refrigeration heat recovery was not deemed an applicable mitigation strategy in this scenario, as it resulted in increased emissions due to the climate zone.

Table 56. Summary of Intervention Types for Big Box Stores in Very Cold Climates[a]

Mitigation Option: Big Box Store	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
New Equipment					
Distributed Systems	$4,100	($340)	$70	24,200	(940)
Micro Distributed Systems	$25,400	($5,000)	($2,465)	27,770	0
HFC Secondary Loop and/or Cascade System	$58,800	($4,700)	$1,140	26,800	0
NH_3 or HC Secondary Loop and/or Cascade Systems	$27,800	($8,720)	($5,960)	27,770	940
CO_2 Transcritical Systems	$15,250	($12,630)	($11,110)	27,700	1,880
Leak Mitigation	$10,100	($14,380)	($13,380)	18,470	2,540

Mitigation Option: Big Box Store	Initial Cost	Net Incremental Annual Cost	Annualized Cost	Lifetime Direct Emission Reduction ($MTCO_2eq$)	Lifetime Indirect Emission Reduction ($MTCO_2eq$)
Floating Head Pressure	$0	($6,510)	($6,510)	0	1,500
Floating Suction Pressure	$0	($2,440)	($2,440)	0	560
Mechanical Subcooling	$9,000	($3,250)	($2,360)	0	750
Refrigeration Heat Recovery[b]	$88,400	($14,350)	($5,570)	(5,430)	4,490
Display Case Doors	$385,000	($70,540)	($32,270)	0	16,310
Supermarket Monitoring System	$45,300	($15,450)	($10,950)	0	3,570
Existing Equipment					
Retrofits with R-407A	$21,600	$0	$3,075	7,260	0
Retrofits with HFC/HFO Blends	$44,600	$3,350	$9,720	10,130	320
Leak Mitigation	$7,000	($13,080)	($12,080)	9,050	1,320
Floating Head Pressure	$0	($6,450)	($6,450)	0	840
Floating Suction Pressure	$0	($2,420)	($2,420)	0	320
Mechanical Subcooling	$10,000	($3,220)	($1,800)	0	420
Refrigeration Heat Recovery	$97,200	($18,375)	($4,530)	(3,020)	8,400
Display Case Doors	$385,000	($82,020)	($27,200)	0	10,730
Supermarket Monitoring System	$48,000	($15,320)	($8,480)	0	2,000

[a] Costs given in parentheses represent savings. Emission reductions given in parentheses represent increases in emissions.
[b] Refrigeration heat recovery was not deemed an applicable mitigation strategy in this scenario, as it resulted in increased emissions due to the climate zone.