CONSORTIUM for BUILDING ENERGY INNOVATION

REPORT

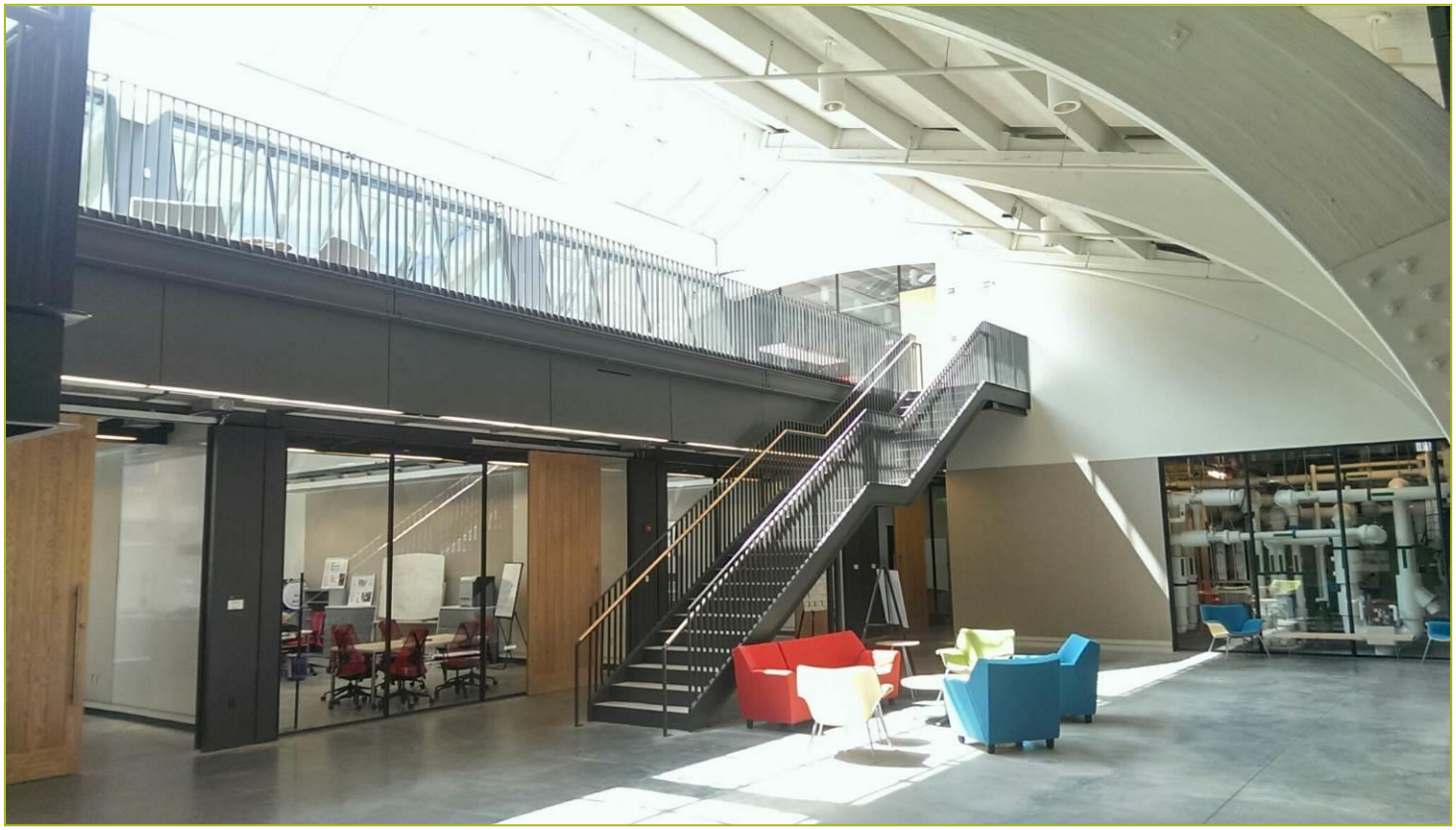
Title: Expand Analysis of HVAC Retrofit Solutions for Other Building Types and Climate Zones - BP5

Report Date: April 30, 2016

Report Author: Russell D. Taylor*, Tim Wagner*, Travis Horton, Bonggil Jeon**, Janghyun Kim**,Yeonjin Bae****

*** United Technologies Research Center**

**** Purdue University**



Funded by U.S. DOE

Report Abstract

Project objectives.

The objective of the Expand Analysis of HVAC Retrofit Solutions for Other Building Types and Climate Zones project is to evaluate and select at least 4 packaged HVAC solutions. The packages will be suitable for SMSCB in at least 3 different climate zones and provide 50% HVAC energy savings with a payback of less than 4 years.

Contact Information for lead researcher

Name: Russell Taylor
Institution: United Technologies Research Center
Email address: taylorrd@utrc.utc.com
Phone number: 860-610-7485

Contributors

Russell D. Taylor, United Technologies Research Center; Tim Wagner, United Technologies Research Center; Travis Horton, Purdue University; Bonggil Jeon, Purdue University; Janghyun Kim, Purdue University; Yeonjin Bae, Purdue University

Executive Summary

HVAC package solutions were identified that meet the stated objectives, based on 6 building types (quick service restaurant, full service restaurant, small hotel. large hotel, supermarket, and convenience store) in 6 region/climate zone combinations. The modeling tool used was EnergyPlus. The technologies used in the package solutions were developed from the DOE P-Tool and selected to be consistent with the High Impact Technology Program to expand deployment of established but underutilized retrofit solutions.

For each of the 30 building type-region/climate zone combinations, the baseline, standard HVAC retrofit and packaged retrofit solutions were evaluated for both energy savings potential and retrofit first cost, simple paybacks were computed based on the incremental cost and annual HVAC energy cost savings of the packaged retrofit solutions over the standard retrofit were determined. Standard retrofits are defined as replacing HVAC equipment with new equipment that meets the code requirements without changing the HVAC system configuration. For each building type-region/climate zone combination, 5-7 retrofit packages were evaluated.

The results show that, for the building types and climate zones analyzed, many of the proposed packaged retrofit solutions can achieve 50% or greater HVAC energy savings. A simple payback analysis was performed for each retrofit package combination, which showed that packages meet the project goals for a majority of the building types and climate zones. The packages with the highest percentage HVAC savings that achieve a 4 year or less un-incentivized payback are shown in Table 1. The number of compliant packages increases when energy efficiency financial incentives are applied based on the selected locations as shown in Table 2. These incentives are an important component to reduce the simple payback below the maximum acceptable to most commercial building owners and operators.

Largest Energy Savings and Corresponding Un-incentivized Simple Paybacks in Years						
U. S. Census Regions and Divisions	South	Midwest	South	Northeast	Midwest	West
U. S. Climate Zones for 2003 CBECS	Zone 4	Zone 2	Zone 5	Zone 2	Zone 1	Zone 4
Representative City (ASHRAE Climate Zone)	Charlotte NC (3A)	Indianapolis IN (5A)	Houston TX (2A)	Boston MA (5A)	Minneapolis MN (6A)	Los Angeles CA (3B)
Quick Service Restaurant	64% 3.5		55% 2.1			
Full Service Restaurant	53% 4					
Small Hotel	61% 3.4	58% 3.5	66% 3.8	59% 3.1		59% 3.4
Large Hotel	79% 4	84% 3.2	77% 3.7	74% 2.7	75% 3.2	56% 3.9
Supermarket			78% 3.7	57% 2.9		
Convenience Store						

Table 1: Summary of Un-Incentivized Retrofit Packages Which Exceed 50% HVAC Energy Savings and Have a Simple Payback of 4 Years or Less

Largest Energy Savings and Corresponding Incentivized Simple Paybacks in Years						
U. S. Census Regions and Divisions	South	Midwest	South	Northeast	Midwest	West
U. S. Climate Zones for 2003 CBECS	Zone 4	Zone 2	Zone 5	Zone 2	Zone 1	Zone 4
Representative City (ASHRAE Climate Zone)	Charlotte NC (3A)	Indianapolis IN (5A)	Houston TX (2A)	Boston MA (5A)	Minneapolis MN (6A)	Los Angeles CA (3B)
Quick Service Restaurant	64% 3.5		55% 1.3			
Full Service Restaurant	53% 4	60% 4				
Small Hotel	61% 2.5	58% 1.5	66% 1.8	59% 1.3		59% 2.4
Large Hotel	79% 3.4	84% 2.9	77% 2.9	74% 1.4	75% 3.1	58% 3.5
Supermarket	67% 3.7		78% 2.9	57% 1.4		
Convenience Store		72% 1.5		61% 3.3		

Table 2: Summary of Un-Incentivized Retrofit Packages Which Exceed 50% HVAC Energy Savings and Have a Simple Payback of 4 Years or Less

1. Introduction

The project was executed in the following 3 stages.

- Identify target building type and HVAC system configurations based on CBECS-2003 data; Identify a prioritized HVAC retrofit measures / technologies.
- Define baseline building and HVAC system model; Define HVAC standard retrofit scenarios; Define advanced HVAC retrofit solution packages.
- Evaluate potential energy savings of packaged retrofit solutions through energy simulation; Evaluate cost of retrofit and payback of packaged retrofit solutions with consideration of the availability and magnitude of incentives.
- Identify retrofit technology options and package solutions for refrigeration systems relevant to the building types under consideration
- Identify retrofit technology options and package solutions for service hot water systems relevant to the building types under consideration

The final outcome of BP5 is multiple packaged HVAC retrofit solutions for validation through demonstration.

2. Baseline Building Model

Target building types were identified based on results of the CBECS 2003 database. Three building types such as food service, lodging, and food sales were selected as baseline among the Principal Building Activity (PBA). Six different buildings were additionally chosen within those three types of buildings: Quick and full Service Restaurant from food service, small and large hotel from lodging, and supermarket and convenience store from food sales. Table 3 shows selected target building configuration.

In this study, DOE's post-1980 reference building models were referred for baseline models. However, these building models do not represent existing commercial buildings in the present era. In other words, these building models are needed to modify because they have outdated occupancy and operating schedules which are consistent with previous ASHRAE Standard 90.1-1989. Thus, in this study building physical parameters were the same as post-1980 construction models and other internal gains with relative schedules were adjusted with current ASHRAE Standard 90.1-2013. Detailed modification indicated in Table 4 to Table 9. Since there is no convenience store reference model to refer, convenience store baseline model was developed based on supermarket construction parameters and CBECS 2003 database.

Table 3. Baseline Building Models

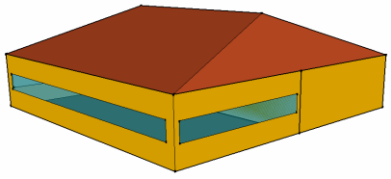
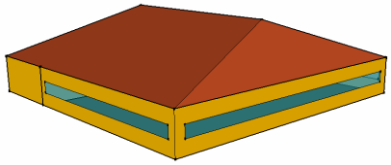
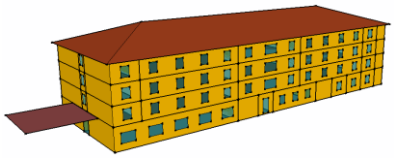
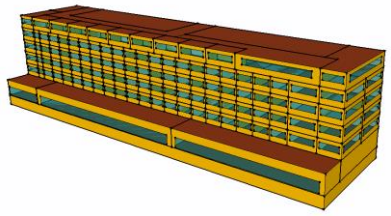
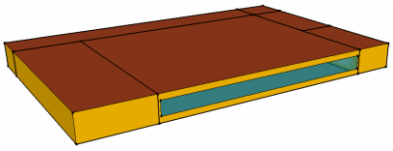
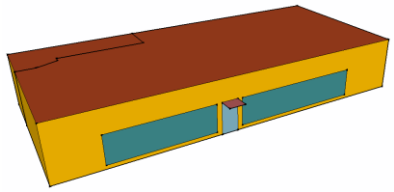
Quick-service Restaurant	Full-service Restaurant	Small Hotel
		
Large Hotel	**Supermarket**	**Convenience Store**
		

Table 4. Occupancy, Lighting Power Density, Outdoor Air Requirement, and Plug & Process Loads for Quick Service Restaurant

Zone	Area [ft²]	Multipliers	Assumed Space Type			Lighting [W/ft²]	Outdoor Air Requirement 62-1999	Outdoor Air Requirement 62.1-2013	Occupant Density [#/1,000 ft²] 62.1-2013	Person/ft²	Number of People	Plug & Process Loads [W]
			STD 62-1999 for OA	STD 90.1-2004 for LPD	STD 62.1-2013 for Occupancy & OA							
Dining	1,250	1	Food and Beverage Service - Fast Food	Dining: Fast Food	Food and Beverage Service - Fast-food dinign	1.4	20 cfm/person	9 cfm/person	100	0.1	125	13,567
Kitchen	1,250	1	Food and Beverage Service - Kitchen	Food Preparation	Food and Beverage Service - Kitchen	1.2	15 cfm/person	14 cfm/person	20	0.02	25	32,496

Table 5. Occupancy, Lighting Power Density, Outdoor Air Requirement, and Plug & Process Loads for Full Service Restaurant

Zone	Area [ft²]	Multipliers	Assumed Space Type			Lighting [W/ft²]	Outdoor Air Requirement 62-1999	Outdoor Air Requirement 62.1-2013	Occupant Density [#/1,000 ft²] 62.1-2013	Person/ft²	Number of People	Plug & Process Loads [W]
			STD 62-1999 for OA	STD 90.1-2004 for LPD	STD 62.1-2013 for Occupancy & OA							
Dining	1,501	1	Food and Beverage Service - Dining rooms	Dining: Family	Food and Beverage Service - Fast-food dinign	1.6	20 cfm/person	10 cfm/person	70	0.07	105	24,137
Kitchen	4,001	1	Food and Beverage Service - Kitchen	Food Preparation	Food and Beverage Service - Kitchen	1.2	15 cfm/person	14 cfm/person	20	0.02	80	57,346

Table 6. Occupancy, Lighting Power Density, Outdoor Air Requirement, and Plug & Process Loads for Small Hotel

Zone	Area [ft²]	Multipliers	Assumed Space Type			Lighting [W/ft²]	Outdoor Air Requirement 62-1999	Outdoor Air Requirement 62.1-2013	Occupant Density [#/1,000 ft²] 62.1-2013	Person/ft²	Number of People	Plug & Process Loads [W/ft²]
			STD 62-1999 for OA	STD 90.1-2004 for LPD	STD 62.1-2013 for Occupancy & OA							
REARSTAIRSFLR1	216	1	-	Stairs-Active	-	0.6	NA	NA	NA	0	0	0
CORRIDORFLR1	1,620	1	Public Spaces - Corridors	Corridor/Transition	General - Corridors	0.5	0.05 cfm/ft2	0.06 cfm/ft2	0	0	0	0
REARSTORAGEFLR1	216	1	-	Active Storage	-	0.8	NA	NA	NA	0	0	0
FRONTLOUNGEFLR1	1,755	1	Hotels - Lobbies	Lounge/Recreation	Hotel - Lobbies	1.2	15 cfm/person	10 cfm/person	30	0.03	53	2
RESTROOMFLR1	351	1	-	Restrooms	-	0.9	NA	NA	NA	0	0	0
MEETINGROOMFLR1	864	1	Hotels - Conference rooms	Conference/Meeting	General - Meeting	1.3	20 cfm/person	6 cfm/person	50	0.05	43	1
MECHANICALROOMFLR1	351	1	Public Spaces - utilities	Electrical/Mechanical	-	1.5	0.05 cfm/ft2	NA	NA	0	0	0
GUESTROOM101	351	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	2	1.1
GUESTROOM102	351	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	2	1.1
GUESTROOM103	351	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	2	1.1
GUESTROOM104	351	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	2	1.1
GUESTROOM105	351	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	2	1.1
EMPLOYEELOUNGEFLR1	351	1	Hotel - Lobbies	Lounge/Recreation	General - Break rooms	1.2	15 cfm/person	7 cfm/person	25	0.025	9	2
LAUNDRYROOMFLR1	1,053	1	Laundries - Commercial laundry	Laundry-Washing	Hotel - Laundry rooms	0.6	25 cfm/person	17 cfm/person	10	0.01	11	2,709 [W]
ELEVATORCOREFLR1	162	1	-	-	-	-	NA	NA	NA	0	0	32,110 [W]
EXERCISECENTERFLR1	351	1	Sports - Gymnasium	Exercise Center	Sports - Weight rooms	1.0	20 cfm/person	26 cfm/person	10	0.01	4	2
FRONTOFFICEFLR1	1,404	1	Office - Office space	Office-Open Plan	Office - Office space	1.1	20 cfm/person	17 cfm/person	5	0.005	7	1
FRONTSTAIRSFLR1	216	1	-	Stairs-Active	-	0.6	NA	NA	NA	0	0	0
FRONTSTORAGEFLR1	135	1	-	Active Storage	-	0.8	NA	NA	NA	0	0	0
REARSTAIRSFLR2	216	1	-	Stairs-Active	-	0.6	NA	NA	NA	0	0	0
CORRIDORFLR2	1,350	1	Public Spaces - Corridors	Corridor/Transition	General - Corridors	0.5	0.05 cfm/ft2	0.06 cfm/ft2	0	0	0	0
REARSTORAGEFLR2	216	1	-	Active Storage	Storage rooms	0.8	NA	NA	NA	0	0	0
GUESTROOM201	351	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	2	1.1
GUESTROOM202_205	1,404	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	120 cfm/room	11 cfm/person	10	0.01	8	1.1
GUESTROOM206_208	1,134	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	90 cfm/room	11 cfm/person	10	0.01	6	1.1
GUESTROOM209_212	1,404	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	120 cfm/room	11 cfm/person	10	0.01	8	1.1
GUESTROOM213	351	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	2	1.1
GUESTROOM214	351	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	2	1.1
GUESTROOM215_218	1,404	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	120 cfm/room	11 cfm/person	10	0.01	8	1.1
ELEVATORCOREFLR2	162	1	-	-	-	-	NA	NA	NA	0	0	0
GUESTROOM219	351	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	2	1.1
GUESTROOM220_223	1,404	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	120 cfm/room	11 cfm/person	10	0.01	8	1.1
GUESTROOM224	351	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	2	1.1
FRONTSTORAGEFLR2	135	1	-	Active Storage	-	0.8	NA	NA	NA	0	0	0
FRONTSTAIRSFLR2	216	1	-	Stairs-Active	-	0.6	NA	NA	NA	0	0	0
REARSTAIRSFLR3	216	1	-	Stairs-Active	-	0.6	NA	NA	NA	0	0	0
CORRIDORFLR3	1,350	1	Public Spaces - Corridors	Corridor/Transition	General - Corridors	0.5	0.05 cfm/ft2	0.06 cfm/ft2	0	0	0	0
REARSTORAGEFLR3	216	1	-	Active Storage	-	0.8	NA	NA	NA	0	0	0
GUESTROOM301	351	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	2	1.1
GUESTROOM302_305	1,404	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	120 cfm/room	11 cfm/person	10	0.01	8	1.1
GUESTROOM306_308	1,134	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	90 cfm/room	11 cfm/person	10	0.01	6	1.1
GUESTROOM309_312	1,404	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	120 cfm/room	11 cfm/person	10	0.01	8	1.1
GUESTROOM313	351	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	2	1.1
GUESTROOM314	351	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	2	1.1
GUESTROOM315_318	1,404	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	120 cfm/room	11 cfm/person	10	0.01	8	1.1
ELEVATORCOREFLR3	162	1	-	-	-	-	NA	NA	NA	0	0	0
GUESTROOM319	351	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	2	1.1
GUESTROOM320_323	1,404	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	120 cfm/room	11 cfm/person	10	0.01	8	1.1
GUESTROOM324	351	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	2	1.1
FRONTSTORAGEFLR3	135	1	-	Active Storage	-	0.8	NA	NA	NA	0	0	0
FRONTSTAIRSFLR3	216	1	-	Stairs-Active	-	0.6	NA	NA	NA	0	0	0
REARSTAIRSFLR4	216	1	-	Stairs-Active	-	0.6	NA	NA	NA	0	0	0
CORRIDORFLR4	1,350	1	Public Spaces - Corridors	Corridor/Transition	General - Corridors	0.5	0.05 cfm/ft2	0.06 cfm/ft2	0	0	0	0
REARSTORAGEFLR4	216	1	-	Active Storage	-	0.8	NA	NA	NA	0	0	0
GUESTROOM401	351	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	2	1.1
GUESTROOM402_405	1,404	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	120 cfm/room	11 cfm/person	10	0.01	8	1.1
GUESTROOM406_408	1,134	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	90 cfm/room	11 cfm/person	10	0.01	6	1.1
GUESTROOM409_412	1,404	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	120 cfm/room	11 cfm/person	10	0.01	8	1.1
GUESTROOM413	351	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	2	1.1
GUESTROOM414	351	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	2	1.1
GUESTROOM415_418	1,404	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	120 cfm/room	11 cfm/person	10	0.01	8	1.1
ELEVATORCOREFLR4	162	1	-	-	-	-	NA	NA	NA	0	0	0
GUESTROOM419	351	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	2	1.1
GUESTROOM420_423	1,404	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	120 cfm/room	11 cfm/person	10	0.01	8	1.1
GUESTROOM424	351	1	Hotels - Bedrooms	Hotel/Motel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	2	1.1
FRONTSTORAGEFLR4	135	1	-	Active Storage	-	0.8	NA	NA	NA	0	0	0
FRONTSTAIRSFLR4	216	1	-	Stairs-Active	-	0.6	NA	NA	NA	0	0	0

Table 7. Occupancy, Lighting Power Density, Outdoor Air Requirement, and Plug & Process Loads for Large Hotel

Zone	Area [ft²]	Multipliers	Assumed Space Type			Lighting [W/ft²]	Outdoor Air Requirement 62-1999	Outdoor Air Requirement 62.1-2013	Occupant Density [#/1,000 ft²] 62.1-2013	Person/ft²	Number of People	Plug & Process Loads [W]
			STD 62-1999 for OA	STD 90.1-2004 for LPD	STD 62.1-2013 for Occupancy & OA							
BASEMENT	21,300	1	Office - Office space	office	Office - Office space	1.0	20 cfm/person	17 cfm/person	5	0.005	106	10,646
RETAIL_1_FLR_1	722	1	Retail - Basement and street	Retail	Retail - Sales	1.5	0.3 cfm/ft²	16 cfm/person	15	0.015	11	722
RETAIL_2_FLR_1	836	1	Retail - Basement and street	Retail	Retail - Sales	1.5	0.3 cfm/ft2	16 cfm/person	15	0.015	13	836
MECH_FLR_1	1,768	1	Public Spaces - Utilities	Mechanical	-	1.5	0.05 cfm/ft²	-	0	0	0	884
STORAGE_FLR_1	1,020	1	Retail - Storage rooms	Active Storage	-	0.8	0.15 cfm/ft2	-	0	0	0	255
LAUNDRY_FLR_1	840	1	Laundry - Commercial laundry	Hospital - Laundry	Hotel - Laundry rooms	0.6	25 cfm/person	17 cfm/person	10	0.01	8	4,813
CAFE_FLR_1	2,033	1	Food - Dining rooms	Dining Area for hotel	Food - Dining rooms	1.3	20 cfm/person	10 cfm/person	70	0.07	142	1,016
LOBBY_FLR_1	14,081	1	Hotel - Lobbies	Lobby for hotel	Hotel - Lobbies	1.1	15 cfm/person	10 cfm/person	30	0.03	422	10,557
ROOM_1_FLR_3	420	4	Hotel - Bedroom	Hotel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	8	263
ROOM_2_FLR_3	420	4	Hotel - Bedroom	Hotel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	8	263
ROOM_3_MULT19_FLR_3	264	76	Hotel - Bedroom	Hotel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	152	258
ROOM_4_MULT19_FLR_3	264	76	Hotel - Bedroom	Hotel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	152	258
ROOM_5_FLR_3	420	4	Hotel - Bedroom	Hotel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	8	263
ROOM_6_FLR_3	420	4	Hotel - Bedroom	Hotel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	8	263
CORRIDOR_FLR_3	4,191	4	Public Spaces - Corridors	Corridor	-	0.5	0.05 cfm/ft2	-	0	0	0	0
ROOM_1_FLR_6	420	1	Hotel - Bedroom	Hotel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	2	263
ROOM_2_FLR_6	420	1	Hotel - Bedroom	Hotel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	2	263
ROOM_3_MULT9_FLR_6	264	9	Hotel - Bedroom	Hotel Guest Rooms	Hotel - Bedroom	1.1	30 cfm/room	11 cfm/person	10	0.01	18	258
BANQUET_FLR_6	3,570	1	Food - Dining rooms	Dining Area for hotel	Food - Dining rooms	1.3	20 cfm/person	10 cfm/person	70	0.07	250	22,493
DINING_FLR_6	3,570	1	Food - Dining rooms	Dining Area for hotel	Food - Dining rooms	1.3	20 cfm/person	10 cfm/person	70	0.07	250	22,493
KITCHEN_FLR_6	1,112	1	Food - Kitchen	Food Preparation	Food - Kitchen	1.2	15 cfm/person	14 cfm/person	20	0.02	22	52,483
CORRIDOR_FLR_6	4,436	1	Public Spaces - Corridors	Corridor	-	0.5	0.05 cfm/ft2	-	0	0	0	0

Table 8. Occupancy, Lighting Power Density, Outdoor Air Requirement, and Plug & Process Loads for Supermarket

Zone	Area [ft²]	Multipliers	Assumed Space Type			Lighting [W/ft²]	Outdoor Air Requirement 62-1999	Outdoor Air Requirement 62.1-2013	Occupant Density [#/1,000 ft²] 62.1-2013	Person/ft²	Number of People	Plug & Process Loads [W/ft²]
			STD 62-1999 for OA	STD 90.1-2004 for LPD	STD 62.1-2013 for Occupancy & OA							
Office	956	1	Office - Office space	Office-Enclosed	Office - Office space	1.1	20 cfm/person	17 cfm/person	5	0.005	5	0.75
Dry Storage	6,694	1	Retail Stores - Storage rooms	Active Storage	General - Occupiable storage rooms for liquids or gels	0.8	0.15 cfm/ft²	65 cfm/person	2	0.002	13	0.75
Deli	2,419	1	Specialty Shops - Supermarkets	Food Preparation	Retail - Supermarket	1.2	15 cfm/person	15 cfm/person	8	0.008	19	5.0
Sales	25,025	1	Specialty Shops - Supermarkets	Retail - Sales Area	Retail - Supermarket	1.7	15 cfm/person	15 cfm/person	8	0.008	200	0.5
Produce	7,657	1	Specialty Shops - Supermarkets	Retail - Sales Area	Retail - Supermarket	1.7	15 cfm/person	15 cfm/person	8	0.008	61	0.5
Bakery	2,250	1	Specialty Shops - Supermarkets	Food Preparation	Retail - Supermarket	1.2	15 cfm/person	15 cfm/person	8	0.008	18	5.0

Table 9. Occupancy, Lighting Power Density, Outdoor Air Requirement, and Plug & Process Loads for Convenience Store

Zone	Area [ft²]	Multipliers	Assumed Space Type			Lighting [W/ft²]	Outdoor Air Requirement 62-1999	Outdoor Air Requirement 62.1-2013	Occupant Density [#/1,000 ft²] 62.1-2013	Person/ft²	Number of People	Plug & Process Loads [W]
			STD 62-1999 for OA	STD 90.1-2004 for LPD	STD 62.1-2013 for Occupancy & OA							
Back Area	303	1	Office - Office space	Office-Enclosed	Office - Office space	1.1	20 cfm/person	17 cfm/person	5	0.005	2	150
Main Area	3,134	1	Specialty Shops - Supermarkets	Retail - Sales Area	Retail - Supermarket	1.7	15 cfm/person	15 cfm/person	8	0.008	25	6,100

According to CBECS 2003 micro data analysis, eight different heating systems and four different cooling systems were determined by building type and climate zone. Although most of the heating and cooling configurations were reasonable in terms of their physical configuration, the lodging has slightly different from CBECS database. Since the lodging has two major conditioned spaces, public space and guest rooms, two different HVAC configurations were defined based on space function.

Table 10 shows target building types and HVAC systems for each building and climate zone.

Table 10. Target Building Types, Region, Representative Cities and Baseline HVAC System Configuration

U. S. Census Regions and Divisions				South	Midwest	South	Northeast	Midwest	West
U. S. Climate Zones for 2003 CBECS				Zone 4	Zone 2	Zone 5	Zone 2	Zone 1	Zone 4
Representative City (ASHRAE Climate Zone)				Charlotte, NC (3A)	Indianapolis, IN (5A)	Houston, TX (2A)	Boston, MA (5A)	Minneapolis, MN (6A)	Los Angeles, CA (3B)
Food Service	Quick Service Restaurant		Heating	Packaged Heating Unit (Natural Gas)	Furnace (Natural Gas)	Packaged Heating Unit (Electricity)	Furnace (Natural Gas)	Furnace (Natural Gas)	Furnace (Natural Gas)
			Cooling	Packaged A/C unit	Packaged A/C Unit	Packaged A/C Unit	Packaged A/C Unit	Packaged A/C Unit	Packaged A/C Unit
	Full Service Restaurant		Heating	Packaged Heating Unit (Natural Gas)	Furnace (Natural Gas)	Packaged Heating Unit (Electricity)	Furnace (Natural Gas)	Furnace (Natural Gas)	Furnace (Natural Gas)
			Cooling	Packaged A/C unit	Packaged A/C Unit	Packaged A/C Unit	Packaged A/C Unit	Packaged A/C Unit	Packaged A/C Unit
Lodging	Small Hotel	Public Space	Heating	Packaged Heating Unit (Electricity)	Packaged Heating Unit (Electricity)	Packaged Heating Unit (Electricity)	Boiler (Fuel Oil)	Boiler (Natural Gas, VAV)	Packaged Heating Unit (Electricity)
			Cooling	Packaged A/C unit	Packaged A/C unit	Packaged A/C unit	Packaged A/C Unit	Packaged A/C unit (VAV)	Packaged A/C unit
		Guest Room	Heating	Individual Space Heater (Electricity)	Individual Space Heater (Electricity)	Individual Space Heater (Electricity)	Individual Space Heater (Electricity)	Individual Space Heater (Electricity)	Individual Space Heater (Electricity)
			Cooling	Individual Room A/C	Individual Room A/C	Individual Room A/C	Individual Room A/C	Individual Room A/C	Individual Room A/C
	Large Hotel	Public Space	Heating	Packaged Heating Unit (Electricity)	Packaged Heating Unit (Electricity)	Packaged Heating Unit (Electricity)	Boiler (Fuel Oil)	Boiler (Natural Gas, VAV)	Packaged Heating Unit (Electricity)
			Cooling	Packaged A/C unit	Packaged A/C unit	Packaged A/C unit	Packaged A/C Unit	Packaged A/C unit (VAV)	Packaged A/C unit
		Guest Room	Heating	Individual Space Heater (Electricity)	Individual Space Heater (Electricity)	Individual Space Heater (Electricity)	Individual Space Heater (Electricity)	Individual Space Heater (Electricity)	Individual Space Heater (Electricity)
			Cooling	Individual Room A/C	Individual Room A/C	Individual Room A/C	Individual Room A/C	Individual Room A/C	Individual Room A/C
Food Sales	Supermarket		Heating	Packaged Heating Unit (Electricity)	Furnace (Natural Gas)	Packaged Heating Unit (Electricity)	Heat Pump (Elect.) - Air Source - Packaged Unit	Furnace (Natural Gas)	Furnace (Electricity)
			Cooling	Packaged A/C Unit	Packaged A/C Unit	Packaged A/C Unit	Heat Pump - Air Source - Packaged Unit	Packaged A/C Unit	Packaged A/C Unit
	Convenience Store		Heating	Packaged Heating Unit (Electricity)	Packaged Heating Unit (Electricity)	Packaged Heating Unit (Electricity)	Heat Pump (Elect.) - Air Source - Packaged Unit	Packaged Heating Unit (Electricity)	Packaged Heating Unit (Electricity)
			Cooling	Packaged A/C Unit	Packaged A/C Unit	Packaged A/C Unit	Heat Pump - Air Source - Packaged Unit	Packaged A/C Unit	Packaged A/C Unit

3. Baseline Model Validation

After developing baseline models, it is important to confirm that baseline models are reasonable to utilize, comparing with both NREL and PNNL models. As has been noted above, current DOE reference building models do not represent existing commercial building model in the present era. Since baseline models have updated with up-to-date several internal gains including schedules, updated annual energy consumption needs to check with indicator to verify that the baseline models are moderate. Figure 1 to Figure 5 show annual energy consumption comparison between baseline models and DOE's reference building models. And supermarket baseline model compared with NREL reference model because there is no PNNL supermarket building model (Figure 5). Since convenience store reference model does not exist, convenience store EUI (Energy Use Intensity) of CBECS 2003 was utilized as a reference (Figure 6).

The results show that annual energy consumptions of the most building types are within energy consumption scope of DOE reference buildings. In addition, EUI of convenience store is well matched with CBECS 2003.

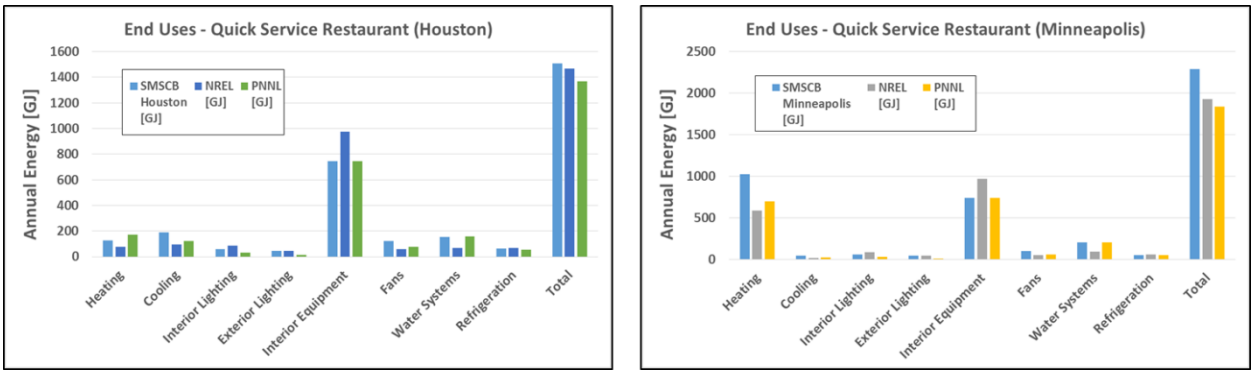


Figure 1. Annual Energy Consumption Comparison with PNNL and NREL Reference Models for Quick Service Restaurant

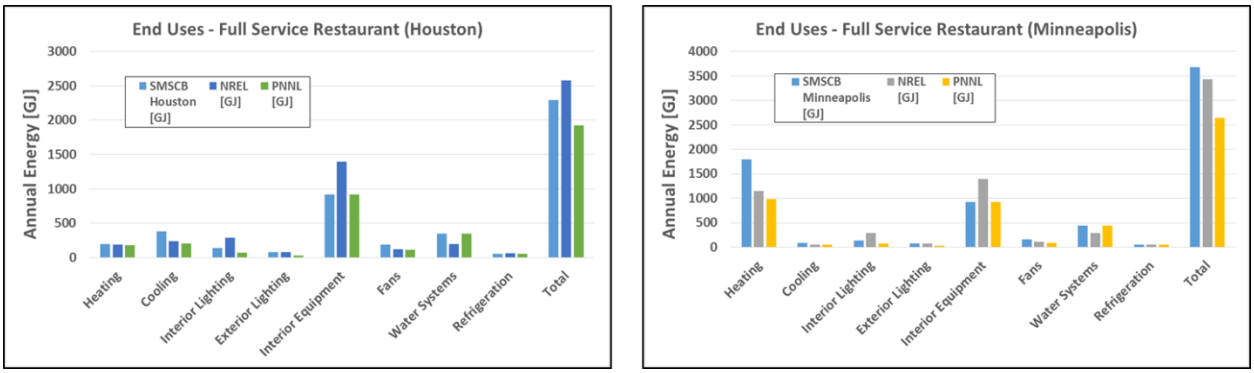


Figure 2. Annual Energy Consumption Comparison with PNNL and NREL Reference Models for Full Service Restaurant

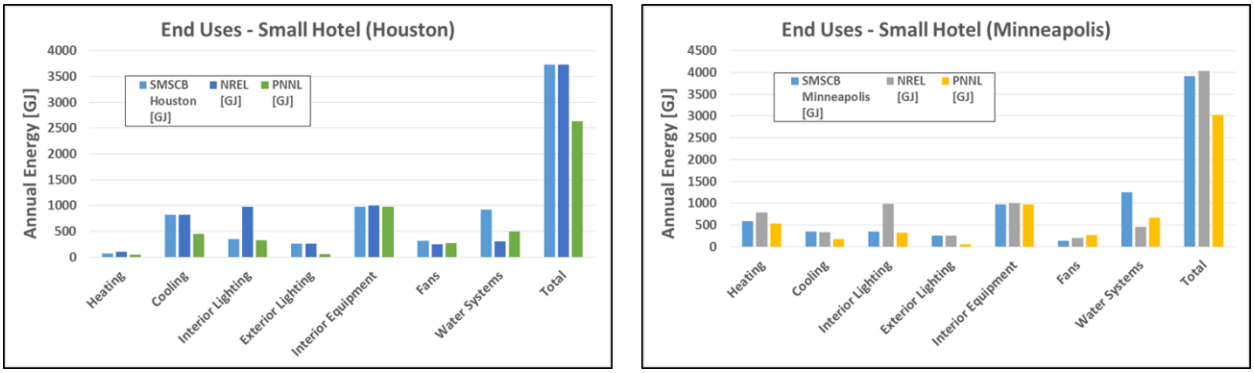
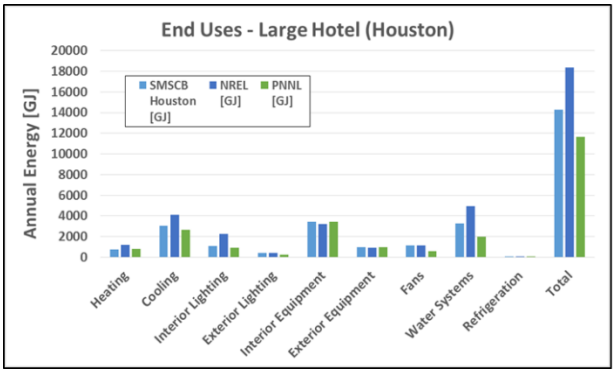


Figure 3. Annual Energy Consumption Comparison with PNNL and NREL Reference Models for Small Hotel



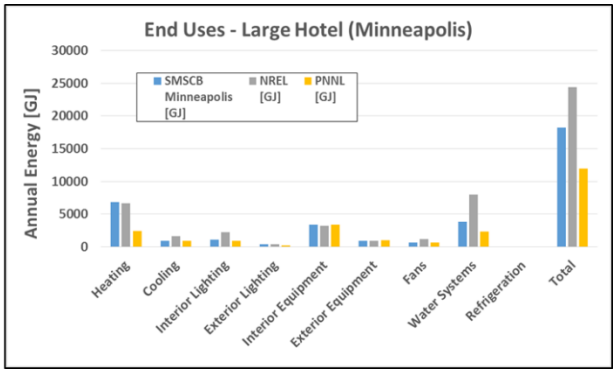
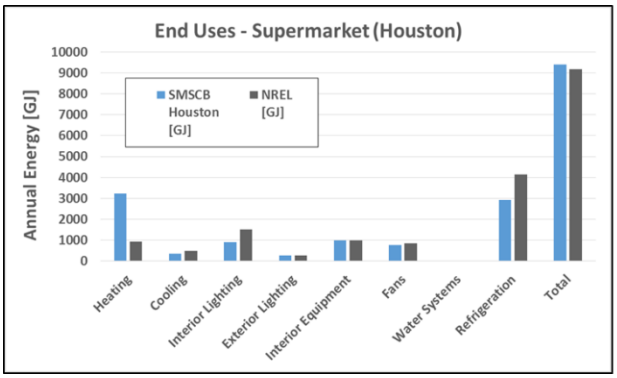


Figure 4. Annual Energy Consumption Comparison with PNNL and NREL Reference Models for Large Hotel



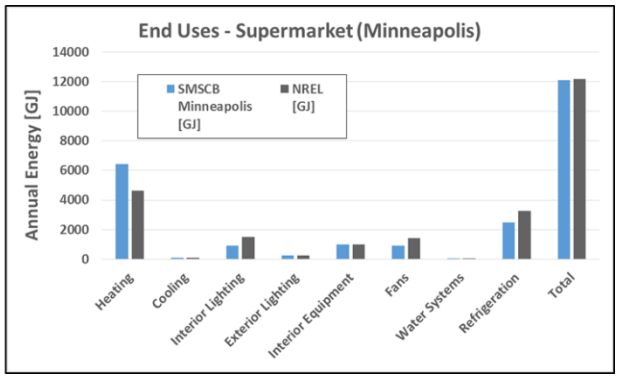
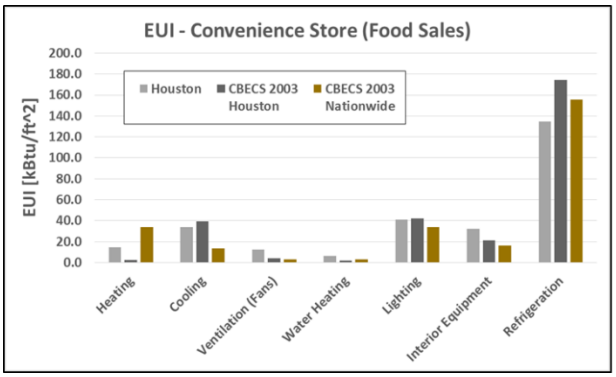


Figure 5. Annual Energy Consumption Comparison with PNNL and NREL Reference Models for Supermarket



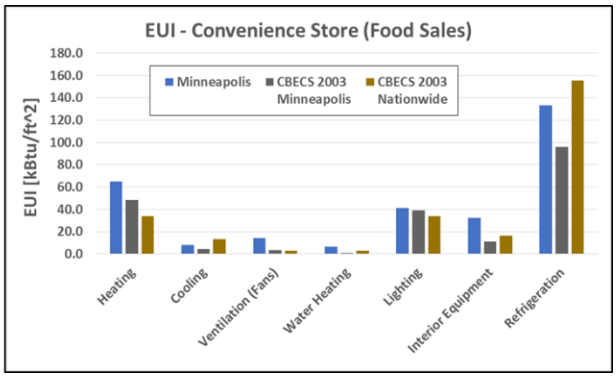


Figure 6. Convenience Store Baseline EUI Comparison with CBECS 2003

4. Retrofit Package Development and Analysis

As in the analysis conducted during BP4, it was assumed that standard retrofit practice is to replace existing HVAC systems at end-of-life with similar equipment that meets current energy efficiency performance standards. As a result, even standard retrofits should result in energy savings over the baseline case. The baseline systems for each building type are described in

Table 10.

4.1.Standard Retrofit Systems Description

Cost estimates were developed for each building type's baseline system using data derived from RS Means Mechanical Cost Data 2014 and Square Foot Costs Data 2014 so that the values are consistent with the BP4 cost analysis. Engineering judgment was employed to select the components required to accurately cost the baseline systems.

The results of the baseline systems cost analysis for the quick service and full service restaurants are shown in Table 11. These building types predominantly use packaged rooftop air conditioners with the selection of gas heat or electric resistance heating depending primarily on geography. Gas heat is the more expensive of the two as shown below.

Quick Service & Full Service Restaurant Baseline Systems		
		Average Installed Cost
Description	Operating Mode	$/sf
Packaged Rooftop Unit	Electric Heat, Electric Cool	8.56
Packaged Rooftop Unit	Gas Heat, Electric Cool	10.62

Table 11: QSR and FSR Baseline HVAC System Per Square Foot Installed Cost Estimate

The results of the baseline systems cost analysis for the large and small hotels are shown in Table 12. These building types predominantly use packaged rooftop air conditioners for building common areas, with the selection of gas heat or electric resistance heating depending primarily on geography. Gas heat is the more expensive of the two as shown below. The guest rooms are typically served by cabinet or through the wall air conditioners with electric resistance heating. The installed cost for the each baseline building was computed using an area weighted average of the guest room system costs plus the costs of the appropriate common space HVAC system.

Small & Large Hotel Baseline Systems		
		Average Installed Cost
Description	Operating Mode	$/sf
Packaged Rooftop Unit: Common Areas	Electric Heat, Electric Cool	8.56
Packaged Rooftop Unit: Common Areas	Gas Heat, Electric Cool	10.62
Unitary Cabinet A/C with Electric Heat: Guest Rooms	Electric Heat, Electric Cool	6.75

Table 12: Small and Large Hotel Baseline HVAC System Per Square Foot Installed Cost Estimate

The results of the baseline systems cost analysis for the supermarket and convenience stores are shown in Table 13. These building types predominantly use packaged rooftop air conditioners, with the selection of gas heat or electric resistance heating depending primarily on geography. Gas heat is the more expensive of the two as shown below. In the US Northeast, packaged heat pumps are the most numerous system type according to analysis of CBECS data. This system type is significantly more expensive than the other baseline systems but has significantly lower site energy use as well.

Supermarket & Convenience Store Baseline Systems		
		Average Installed Cost
Description	Operating Mode	$/sf
Packaged Rooftop Unit	Electric Heat, Electric Cool	8.56
Packaged Rooftop Unit	Gas Heat, Electric Cool	10.62
Air Source Heat Pump	Electric Heat, Electric Cool	15.35

Table 13: Supermarket and Convenience Store Baseline HVAC System Per Square Foot Installed Cost Estimate

4.2.Comparison of Standard Retrofit Performance to Baseline

The geographically appropriate standard retrofit HVAC system was modeled in EnergyPlus for each climate zone as shown in

Table 10. The energy consumption was then compared to the baseline building. A modest energy savings was expected from each standard retrofit because newer equipment performance is improved over baseline due to the higher performance of newer codes and standards. This expectation was reflected, for the most part, in the results.

The baseline end use energy consumption for the quick service restaurant baseline cases are shown in Table 14. Energy consumption is reported in gigajoules for electricity and gas to make it easier to compare the two. The energy consumption of the quick service restaurant standard retrofit case is shown in Table 15. Finally, Table 16 shows the computed HVAC energy savings fraction as a percentage of the baseline HVAC energy use. The savings range from a minimum of 1% in cold climate Minneapolis to 11% in warm climate Houston. This is likely due to current standards for cooling equipment performance being significantly improved compared to baseline while heating system performance has only changed marginally or not at all for electric resistance systems.

	Charlotte		Indianapolis		Houston		Boston		Minneapolis		LA	
Baseline Model	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]
Heating	0	388.87	0	754.51	124.81	0	0	731.34	0	1029.02	0	123.76
Cooling	105.92	0	69.11	0	190.74	0	40.66	0	47.05	0	30.91	0
Interior Lighting	59.15	0	59.15	0	59.15	0	59.15	0	59.15	0	59.15	0
Exterior Lighting	46.57	0	46.5	0	46.56	0	46.51	0	46.54	0	46.61	0
Interior Equipment	265.86	477.16	265.86	477.16	265.86	477.16	265.86	477.16	265.86	477.16	265.86	477.16
Exterior Equipment	0	0	0	0	0	0	0	0	0	0	0	0
Fans	118.19	0	101.84	0	122.77	0	101.2	0	101.17	0	105.02	0
Pumps	0	0	0	0	0	0	0	0	0	0	0	0
Heat Rejection	0	0	0	0	0	0	0	0	0	0	0	0
Humidification	0	0	0	0	0	0	0	0	0	0	0	0
Heat Recovery	0	0	0	0	0	0	0	0	0	0	0	0
Water Systems	0	173.6	0	194.22	0	155.34	0	196.11	0	207.99	0	169.98
Refrigeration	60.44	0	58.26	0	63.48	0	57.38	0	56.79	0	60.83	0
Generators	0	0	0	0	0	0	0	0	0	0	0	0
Total End Uses	656.13	1039.63	600.72	1425.89	873.37	632.5	570.76	1404.61	576.56	1714.17	568.38	770.9

Table 14: QSR Baseline Energy Consumption by Location and End Use Type

	Charlotte		Indianapolis		Houston		Boston		Minneapolis		LA	
STD Retrofit	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]
Heating	0	394.31	0	760.75	127.19	0	0	738.29	0	1036.05	0	128.52
Cooling	83.25	0	50.38	0	150.15	0	27.56	0	33.06	0	11.35	0
Interior Lighting	59.15	0	59.15	0	59.15	0	59.15	0	59.15	0	59.15	0
Exterior Lighting	46.57	0	46.5	0	46.56	0	46.51	0	46.54	0	46.61	0
Interior Equipment	265.86	477.16	265.86	477.16	265.86	477.16	265.86	477.16	265.86	477.16	265.86	477.16
Exterior Equipment	0	0	0	0	0	0	0	0	0	0	0	0
Fans	108.75	0	93.87	0	112.91	0	93.29	0	93.25	0	96.76	0
Pumps	0	0	0	0	0	0	0	0	0	0	0	0
Heat Rejection	0	0	0	0	0	0	0	0	0	0	0	0
Humidification	0	0	0	0	0	0	0	0	0	0	0	0
Heat Recovery	0	0	0	0	0	0	0	0	0	0	0	0
Water Systems	0	173.61	0	194.23	0	155.35	0	196.13	0	208	0	170.01
Refrigeration	60.43	0	58.24	0	63.47	0	57.35	0	56.77	0	60.77	0
Generators	0	0	0	0	0	0	0	0	0	0	0	0
Total End Uses	624.01	1045.08	574	1432.14	825.29	632.51	549.72	1411.58	554.63	1721.21	540.5	775.69

Table 15: QSR Standard Retrofit Energy Consumption by Location and End Use Type

Quick Service Restaurant Standard Retrofit Savings					
Charlotte	Indianapolis	Houston	Boston	Minneapolis	LA
4%	2%	11%	2%	1%	9%

Table 16: QSR Standard Retrofit Energy Savings Compared to Baseline

The baseline end use energy consumption for the full service restaurant baseline cases are shown in Table 17. The energy consumption of the full service restaurant standard retrofit case is shown in Table 18. Finally, Table 19 shows the computed HVAC energy savings fraction as a percentage of the baseline HVAC energy use. The savings range from a minimum of 1% in cold climate Minneapolis to 13% in warm climate Houston. This is likely due to current standards for cooling equipment performance being significantly improved compared to baseline while heating system performance has only changed marginally or not at all for electric resistance systems.

	Charlotte		Indianapolis		Houston		Boston		Minneapolis		LA	
Baseline Model	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]
Heating	0	630.46	0	1315.95	197.77	0	0	1266.81	0	1800.82	0	167.4
Cooling	210.4	0	131.92	0	379.84	0	77.37	0	94.7	0	62.16	0
Interior Lighting	136.88	0	136.88	0	136.88	0	136.88	0	136.88	0	136.88	0
Exterior Lighting	79.88	0	79.83	0	79.92	0	79.81	0	79.77	0	79.83	0
Interior Equipment	449.44	469.79	449.44	469.79	449.44	469.79	449.44	469.79	449.44	469.79	449.44	469.79
Exterior Equipment	0	0	0	0	0	0	0	0	0	0	0	0
Fans	180.69	0	164.75	0	184.12	0	163.01	0	162.73	0	175.7	0
Pumps	0.45	0	0.45	0	0.45	0	0.45	0	0.45	0	0.45	0
Heat Rejection	0	0	0	0	0	0	0	0	0	0	0	0
Humidification	0	0	0	0	0	0	0	0	0	0	0	0
Heat Recovery	0	0	0	0	0	0	0	0	0	0	0	0
Water Systems	75.49	300.08	75.52	336.34	75.45	268.02	75.53	339.62	75.54	360.57	75.47	293.66
Refrigeration	50.4	0	49.09	0	52.26	0	48.47	0	48.14	0	51.05	0
Generators	0	0	0	0	0	0	0	0	0	0	0	0
Total End Uses	1183.63	1400.33	1087.88	2122.08	1556.13	737.81	1030.96	2076.22	1047.65	2631.18	1030.98	930.85

Table 17: FSR Baseline Energy Consumption by Location and End Use Type

	Charlotte		Indianapolis		Houston		Boston		Minneapolis		LA	
STD Retrofit	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]
Heating	0	635.45	0	1323.04	199.74	0	0	1274.54	0	1808.8	0	172.47
Cooling	160.9	0	101.58	0	286.77	0	58.05	0	69.16	0	31.64	0
Interior Lighting	136.88	0	136.88	0	136.88	0	136.88	0	136.88	0	136.88	0
Exterior Lighting	79.88	0	79.83	0	79.92	0	79.81	0	79.77	0	79.83	0
Interior Equipment	449.44	469.79	449.44	469.79	449.44	469.79	449.44	469.79	449.44	469.79	449.44	469.79
Exterior Equipment	0	0	0	0	0	0	0	0	0	0	0	0
Fans	170.86	0	155.74	0	174.11	0	154.09	0	153.83	0	166.13	0
Pumps	0.45	0	0.45	0	0.45	0	0.45	0	0.45	0	0.45	0
Heat Rejection	0	0	0	0	0	0	0	0	0	0	0	0
Humidification	0	0	0	0	0	0	0	0	0	0	0	0
Heat Recovery	0	0	0	0	0	0	0	0	0	0	0	0
Water Systems	75.49	300.08	75.52	336.36	75.45	268.03	75.53	339.63	75.54	360.58	75.48	293.71
Refrigeration	50.38	0	49.05	0	52.25	0	48.43	0	48.11	0	50.94	0
Generators	0	0	0	0	0	0	0	0	0	0	0	0
Total End Uses	1124.28	1405.32	1048.49	2129.19	1455.01	737.82	1002.68	2083.96	1013.18	2639.17	990.79	935.97

Table 18: FSR Standard Retrofit Energy Consumption by Location and End Use Type

Full Service Restaurant Standard Retrofit Savings					
Charlotte	Indianapolis	Houston	Boston	Minneapolis	LA
5%	2%	13%	1%	1%	9%

Table 19 FSR Standard Retrofit Energy Savings Compared to Baseline

The baseline end use energy consumption for the small hotel baseline cases are shown in Table 20. The energy consumption of the full service restaurant standard retrofit case is shown in Table 21. Finally, Table 22 shows the computed HVAC energy savings fraction as a percentage of the baseline HVAC energy use. The savings range from a minimum of 5% in cold climate Minneapolis to 15% in warm climate Houston. This is likely due to current standards for cooling equipment performance being significantly improved compared to baseline while heating system performance has only changed marginally or not at all for electric resistance systems.

	Charlotte		Indianapolis		Houston		Boston		Minneapolis		LA	
Baseline Model	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]
Heating	169.36	0	409.29	0	73.83	0	117.2	259.39	157.86	427.26	38.75	0
Cooling	600.86	0	496.27	0	823.86	0	421.89	0	347.22	0	521.25	0
Interior Lighting	346.01	0	346.01	0	346.01	0	346.01	0	346.01	0	346.01	0
Exterior Lighting	262.69	0	262.31	0	262.66	0	262.36	0	262.54	0	262.96	0
Interior Equipment	557.69	421.49	557.69	421.49	557.69	421.49	557.69	421.49	557.69	421.49	557.69	421.49
Exterior Equipment	0	0	0	0	0	0	0	0	0	0	0	0
Fans	307.73	0	296.76	0	318.24	0	283.19	0	139.38	0	290.18	0
Pumps	0.55	0	0.55	0	0.55	0	36.04	0	23.54	0	0.55	0
Heat Rejection	0	0	0	0	0	0	0	0	0	0	0	0
Humidification	0	0	0	0	0	0	0	0	0	0	0	0
Heat Recovery	0	0	0	0	0	0	0	0	0	0	0	0
Water Systems	0	1035.11	0	1161.46	0	924.1	0	1172.41	0	1257.5	0	1013.05
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0
Generators	0	0	0	0	0	0	0	0	0	0	0	0
Total End Uses	2244.89	1456.6	2368.88	1582.95	2382.84	1345.59	2024.38	1853.29	1834.24	2106.25	2017.39	1434.54

Table 20: Small Hotel Baseline Energy Consumption by Location and End Use Type

	Charlotte		Indianapolis		Houston		Boston		Minneapolis		LA	
STD Retrofit	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]
Heating	172.86	0	415.1	0	75.53	0	118.06	264.73	158.51	432.35	40.2	0
Cooling	481.85	0	397.81	0	664.16	0	341.78	0	298.49	0	417.67	0
Interior Lighting	346.01	0	346.01	0	346.01	0	346.01	0	346.01	0	346.01	0
Exterior Lighting	262.69	0	262.31	0	262.66	0	262.36	0	262.54	0	262.96	0
Interior Equipment	557.69	421.49	557.69	421.49	557.69	421.49	557.69	421.49	557.69	421.49	557.69	421.49
Exterior Equipment	0	0	0	0	0	0	0	0	0	0	0	0
Fans	274	0	264.36	0	288.64	0	252.35	0	123.83	0	258.29	0
Pumps	0.55	0	0.55	0	0.55	0	36.18	0	23.54	0	0.55	0
Heat Rejection	0	0	0	0	0	0	0	0	0	0	0	0
Humidification	0	0	0	0	0	0	0	0	0	0	0	0
Heat Recovery	0	0	0	0	0	0	0	0	0	0	0	0
Water Systems	0	1035.12	0	1161.48	0	924.1	0	1172.43	0	1257.5	0	1013.05
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0
Generators	0	0	0	0	0	0	0	0	0	0	0	0
Total End Uses	2095.65	1456.61	2243.83	1582.97	2195.24	1345.59	1914.43	1858.65	1770.61	2111.34	1883.37	1434.54

Table 21: Small Hotel Standard Retrofit Energy Consumption by Location and End Use Type

Small Hotel Standard Retrofit Savings					
Charlotte	Indianapolis	Houston	Boston	Minneapolis	LA
14%	10%	15%	10%	5%	16%

Table 22: Small Hotel Standard Retrofit Energy Savings Compared to Baseline

The baseline end use energy consumption for the large hotel baseline cases are shown in Table 23. The energy consumption of the full service restaurant standard retrofit case is shown in Table 24. Finally, Table 25 shows the computed HVAC energy savings fraction as a percentage of the baseline HVAC energy use. The savings range from a minimum of 2% in cold climate Minneapolis to 15% in warm climate Houston. This is likely due to current standards for cooling equipment performance being significantly improved compared to baseline while heating system performance has only changed marginally or not at all for electric resistance systems.

	Charlotte		Indianapolis		Houston		Boston		Minneapolis		LA	
Baseline Model	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]
Heating	1775.01	0	3790.18	0	771.97	0	617.69	3901.91	901.68	5957.91	216.26	0
Cooling	1879.18	0	1346.58	0	3063.17	0	957.23	0	923.41	0	1045.83	0
Interior Lighting	1099.53	0	1099.53	0	1099.53	0	1099.53	0	1099.53	0	1099.53	0
Exterior Lighting	437.44	0	437.17	0	437.66	0	437.09	0	436.87	0	437.21	0
Interior Equipment	1628.37	1788.85	1628.37	1788.85	1628.37	1788.85	1628.37	1788.85	1628.37	1788.85	1628.37	1788.85
Exterior Equipment	950.45	0	950.45	0	950.45	0	950.45	0	950.45	0	950.45	0
Fans	1151.84	0	1087.95	0	1167.76	0	1052.13	0	634.62	0	1121	0
Pumps	11.35	0	11.35	0	11.35	0	177.89	0	157.03	0	11.35	0
Heat Rejection	0	0	0	0	0	0	0	0	0	0	0	0
Humidification	0	0	0	0	0	0	0	0	0	0	0	0
Heat Recovery	0	0	0	0	0	0	0	0	0	0	0	0
Water Systems	90.83	3367.55	90.89	3573.79	90.79	3184.12	90.85	3591.99	90.85	3729.64	90.82	3331.95
Refrigeration	69.91	0	66.4	0	74	0	66.77	0	66.01	0	70.69	0
Generators	0	0	0	0	0	0	0	0	0	0	0	0
Total End Uses	9093.91	5156.4	10508.87	5362.64	9295.05	4972.97	7078	9282.75	6888.82	11476.4	6671.51	5120.8

Table 23: Large Hotel Baseline Energy Consumption by Location and End Use Type

	Charlotte		Indianapolis		Houston		Boston		Minneapolis		LA	
STD Retrofit	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]
Heating	1808.51	0	3833.6	0	789.62	0	621.86	3959.88	906.56	5998.71	228.79	0
Cooling	1501.36	0	1066.4	0	2433.47	0	767.49	0	803.62	0	814.37	0
Interior Lighting	1099.53	0	1099.53	0	1099.53	0	1099.53	0	1099.53	0	1099.53	0
Exterior Lighting	437.44	0	437.17	0	437.66	0	437.09	0	436.87	0	437.21	0
Interior Equipment	1628.37	1788.85	1628.37	1788.85	1628.37	1788.85	1628.37	1788.85	1628.37	1788.85	1628.37	1788.85
Exterior Equipment	950.45	0	950.45	0	950.45	0	950.45	0	950.45	0	950.45	0
Fans	1028.86	0	972.08	0	1042.16	0	940.48	0	567.11	0	1001.84	0
Pumps	11.35	0	11.35	0	11.35	0	178.62	0	157.04	0	11.35	0
Heat Rejection	0	0	0	0	0	0	0	0	0	0	0	0
Humidification	0	0	0	0	0	0	0	0	0	0	0	0
Heat Recovery	0	0	0	0	0	0	0	0	0	0	0	0
Water Systems	90.83	3367.55	90.89	3573.81	90.79	3184.12	90.85	3591.97	90.85	3729.63	90.82	3331.94
Refrigeration	69.89	0	66.37	0	73.98	0	66.76	0	66	0	70.66	0
Generators	0	0	0	0	0	0	0	0	0	0	0	0
Total End Uses	8626.59	5156.4	10156.21	5362.66	8557.38	4972.97	6781.5	9340.7	6706.4	11517.19	6333.39	5120.79

Table 24: Large Hotel FSR Standard Retrofit Energy Consumption by Location and End Use Type

Large Hotel Standard Retrofit Savings					
Charlotte	Indianapolis	Houston	Boston	Minneapolis	LA
10%	6%	15%	4%	2%	14%

Table 25: Large Hotel Standard Retrofit Energy Savings Compared to Baseline

The baseline end use energy consumption for the supermarket baseline cases are shown in Table 26. The energy consumption of the full service restaurant standard retrofit case is shown in Table 27. Finally, Table 28 shows the computed HVAC energy savings fraction as a percentage of the baseline HVAC energy use. The savings range from a minimum of 0% in cold climate Minneapolis to 7% in cold climate Boston. This is likely due to an improvement in heating and cooling performance standards for heat pumps, which are used in the Boston supermarket baseline system.

	Charlotte		**Indianapolis**		**Houston**		**Boston**		**Minneapolis**		**LA**	
Baseline Model	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]
Heating	2537.36	0	0	5242.49	3238.08	0	1860.41	0	0	6423.9	1751.46	0
Cooling	226.79	0	132.11	0	345.12	0	72.97	0	88.05	0	41.02	0
Interior Lighting	902.98	0	902.98	0	902.98	0	902.98	0	902.98	0	902.98	0
Exterior Lighting	257.77	0	257.4	0	257.74	0	257.45	0	257.62	0	258.04	0
Interior Equipment	774.73	199.13	774.73	199.13	774.73	199.13	774.73	199.13	774.73	199.13	774.73	199.13
Exterior Equipment	0	0	0	0	0	0	0	0	0	0	0	0
Fans	728.12	0	825.59	0	758.59	0	754.16	0	925.68	0	534.58	0
Pumps	0	0	0	0	0	0	0	0	0	0	0	0
Heat Rejection	0	0	0	0	0	0	0	0	0	0	0	0
Humidification	0	0	0	0	0	0	0	0	0	0	0	0
Heat Recovery	0	0	0	0	0	0	0	0	0	0	0	0
Water Systems	0	22.85	0	25.17	0	20.8	0	25.37	0	26.73	0	22.44
Refrigeration	2694.83	0	2574.04	0	2911.95	0	2507.58	0	2481.58	0	2685.6	0
Generators	0	0	0	0	0	0	0	0	0	0	0	0
Total End Uses	8122.58	221.98	5466.85	5466.79	9189.19	219.93	7130.28	224.5	5430.64	6649.76	6948.41	221.57

Table 26: Supermarket Baseline Energy Consumption by Location and End Use Type

	Charlotte		Indianapolis		Houston		Boston		Minneapolis		LA	
STD Retrofit	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]
Heating	2544.24	0	0	5255.04	3243.82	0	1707.55	0	0	6439.49	1756.36	0
Cooling	170.22	0	103.64	0	259.65	0	59.32	0	68.92	0	30.92	0
Interior Lighting	902.98	0	902.98	0	902.98	0	902.98	0	902.98	0	902.98	0
Exterior Lighting	257.77	0	257.4	0	257.74	0	257.45	0	257.62	0	258.04	0
Interior Equipment	774.73	199.13	774.73	199.13	774.73	199.13	774.73	199.13	774.73	199.13	774.73	199.13
Exterior Equipment	0	0	0	0	0	0	0	0	0	0	0	0
Fans	714.32	0	810.85	0	745.85	0	740.51	0	909.33	0	524.06	0
Pumps	0	0	0	0	0	0	0	0	0	0	0	0
Heat Rejection	0	0	0	0	0	0	0	0	0	0	0	0
Humidification	0	0	0	0	0	0	0	0	0	0	0	0
Heat Recovery	0	0	0	0	0	0	0	0	0	0	0	0
Water Systems	0	22.85	0	25.17	0	20.8	0	25.37	0	26.73	0	22.44
Refrigeration	2694.83	0	2574.04	0	2911.95	0	2507.57	0	2481.57	0	2685.59	0
Generators	0	0	0	0	0	0	0	0	0	0	0	0
Total End Uses	8059.09	221.98	5423.64	5479.34	9096.72	219.93	6950.11	224.5	5395.15	6665.35	6932.68	221.57

Table 27: Supermarket FSR Standard Retrofit Energy Consumption by Location and End Use Type

Supermarket Standard Retrofit Savings					
Charlotte	Indianapolis	Houston	Boston	Minneapolis	LA
2%	0%	2%	7%	0%	1%

Table 28: Supermarket Standard Retrofit Energy Savings Compared to Baseline

The baseline end use energy consumption for the convenience store baseline cases are shown in Table 29. The energy consumption of the full service restaurant standard retrofit case is shown in Table 30. Finally, Table 31 shows the computed HVAC energy savings fraction as a percentage of the baseline HVAC energy use. The savings range from a minimum of 3% in cold climate Minneapolis to 15% in warm climate Houston. This is likely due to current standards for cooling equipment performance being significantly improved compared to baseline while heating system performance has only changed marginally or not at all for electric resistance systems.

	Charlotte		Indianapolis		Houston		Boston		Minneapolis		LA	
Baseline Model	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]
Heating	87.33	0	174.57	0	49.83	0	86.44	0	224.89	0	17.95	0
Cooling	57.54	0	43.37	0	117.34	0	25.53	0	28.38	0	29.61	0
Interior Lighting	121.98	0	121.98	0	121.98	0	121.98	0	121.98	0	121.98	0
Exterior Lighting	19.68	0	19.66	0	19.68	0	19.66	0	19.67	0	19.7	0
Interior Equipment	112.02	0	112.02	0	112.02	0	112.02	0	112.02	0	112.02	0
Exterior Equipment	0	0	0	0	0	0	0	0	0	0	0	0
Fans	38.75	0	43.3	0	42.22	0	37.85	0	50.48	0	35.79	0
Pumps	0.02	0	0.02	0	0.02	0	0.02	0	0.02	0	0.02	0
Heat Rejection	0	0	0	0	0	0	0	0	0	0	0	0
Humidification	0	0	0	0	0	0	0	0	0	0	0	0
Heat Recovery	0	0	0	0	0	0	0	0	0	0	0	0
Water Systems	0	22.73	0	23.17	0	22.71	0	23.17	0	23.62	0	22.71
Refrigeration	462.4	0	460.65	0	465.37	0	459.76	0	459.69	0	460.79	0
Generators	0	0	0	0	0	0	0	0	0	0	0	0
Total End Uses	899.72	22.73	975.57	23.17	928.46	22.71	863.26	23.17	1017.13	23.62	797.86	22.71

Table 29: Convenience Store Baseline Energy Consumption by Location and End Use Type

	Charlotte		Indianapolis		Houston		Boston		Minneapolis		LA	
STD Retrofit	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]	Electricity [GJ]	Natural Gas [GJ]
Heating	88.12	0	175.77	0	50.39	0	82.44	0	226.46	0	18.25	0
Cooling	45.91	0	32.61	0	88.4	0	21.13	0	21.26	0	23.52	0
Interior Lighting	121.98	0	121.98	0	121.98	0	121.98	0	121.98	0	121.98	0
Exterior Lighting	19.68	0	19.66	0	19.68	0	19.66	0	19.67	0	19.7	0
Interior Equipment	112.02	0	112.02	0	112.02	0	112.02	0	112.02	0	112.02	0
Exterior Equipment	0	0	0	0	0	0	0	0	0	0	0	0
Fans	36.74	0	41.05	0	40.02	0	35.88	0	47.85	0	33.93	0
Pumps	0.02	0	0.02	0	0.02	0	0.02	0	0.02	0	0.02	0
Heat Rejection	0	0	0	0	0	0	0	0	0	0	0	0
Humidification	0	0	0	0	0	0	0	0	0	0	0	0
Heat Recovery	0	0	0	0	0	0	0	0	0	0	0	0
Water Systems	0	22.73	0	23.17	0	22.71	0	23.17	0	23.62	0	22.71
Refrigeration	462.4	0	460.65	0	465.37	0	459.76	0	459.69	0	460.79	0
Generators	0	0	0	0	0	0	0	0	0	0	0	0
Total End Uses	886.87	22.73	963.76	23.17	897.88	22.71	852.89	23.17	1008.95	23.62	790.21	22.71

Table 30: Convenience Store FSR Standard Retrofit Energy Consumption by Location and End Use Type

Convenience Store Standard Retrofit Savings					
Charlotte	Indianapolis	Houston	Boston	Minneapolis	LA
7%	5%	15%	7%	3%	9%

Table 31: Convenience Store Standard Retrofit Energy Savings Compared to Baseline

4.3.Technologies and Retrofit Package Development

As in BP4, the technologies used to create retrofit packages were derived from primarily from the DOE P-Tool HVAC technology list. These were supplemented with additional technology options based on current industry best practices for high performance buildings to create a master list of candidate retrofit technologies. Particular attention was paid to technologies that were consistent with the High Impact Technology Catalyst program which looks to promote and commercialize underutilized but potentially cost effective energy saving technologies.

Cost data was derived from the P-Tool list and also from RS Means 2014 Square Foot Costs Data and 2014 Mechanical Cost Data. RS Means also provide cost multipliers to estimate regional variations in labor and equipment costs. These factors are shown in Table 32 below.

City Cost Factors	
Boston	1.18
Charlotte	0.81
Houston	0.86
Indianapolis	0.93
Minneapolis	1.07
Los Angeles	1.07

Table 32: City HVAC Equipment Installed Cost Multipliers

The master technology list was then filtered for each building type to remove technologies that were unlikely to be applicable to that building type and to remove technologies that cannot be simulated with EnergyPlus without substantial modifications or approximations. The result of the filtering was a unique technology list applicable to each building type. Finally, retrofit packages were developed by identifying technologies incompatible with other technologies on the list. The incompatible items were primarily found in the technologies representing major system types; e.g. a ground source heap pump would not be applied along with a VRV system. As a result, each building type ended up with from five to seven retrofit package options that could be applied through simulation to evaluate HVAC energy savings compared to the baseline and differential cost compared to the standard retrofit system. It was assumed that these retrofits would be applied at the end-of-life of the baseline system so that the standard retrofit could be considered to be a sunk cost required to maintain the desired level of service in the building. That is, without retrofit the building would have no functioning HVAC system at all. This is also consistent with the methodology from BP4. Consequently, the simple payback of the proposed retrofit packages could be computed based on the differential cost between each retrofit package and the standard retrofit but the energy cost difference between the retrofit package energy cost and the baseline energy cost.

Figure 7 shows the retrofit technology options for the quick service restaurant and that these technologies were down-selected to give 5 unique retrofit package options. Table 33, which follows the figure, shows the differential installed first cost, in $/square foot, between each package and each region specific baseline HVAC system

Tech #	Tech. in EnergyPlus	Package 1	Package 4	Package 5	Package 8	Package 9
1	Increased duct sealing	O	O	O	O	O
3	High efficiency supply fan	O	O	O	O	O
4	Low pressure drop air filter	O	O	O	O	O
5	Standardize PSC motors in fan	O	O	O	O	O
6	CAV to VAV	O	O			
9	Optimize zone mixing	O	O	O	O	O
9.1	Demand control exhaust fan	O	O	O	O	O
14	Evaporative Coolers	O				
19	High efficiency RTU system	O				
22.1	Air source heat pumps				O	
25	Integrated Heat Pumps (heating, cooling and hot water)					O
26	Variable refrigerant flow system (VRF)			O		
28	Optimize equipment sizing	O	O	O	O	O
33	High efficiency furnaces and boilers	O				
43	Demand control ventilation	O	O	O	O	O
44	Min. OA requirement to latest standard	O	O	O	O	O
50	Economizer	O			O	O
52	Optimum temperature setpoint	O	O	O	O	O
53	Steam-clean AC condenser coil	O	O	O	O	O
60	Increase freezer wall insulation	O	O	O	O	O
65	Use most efficient (i.e., max tech) refrigeration system	O	O	O	O	O
68	Use cascade system for refrigeration	O	O	O	O	O
84	Tankless gas water heats	O	O	O	O	
86	Wrap water heaters with insulation blankets					O

Figure 7: Quick Service Restaurant Retrofit Package Technology Components Technology Components

Quick Service Restaurant: Package Per Square Foot Differential Costs Over Standard Retrofit							
		Charlotte	Indianapolis	Houston	Boston	Minneapolis	LA
Package #	1	$5.45	$6.25	$7.61	$7.94	$7.20	$7.24
	4	$2.16	$2.48	$4.09	$3.15	$2.85	$2.87
	5	$9.49	$10.88	$11.93	$13.81	$12.53	$12.60
	8	$8.09	$9.27	$10.43	$11.78	$10.69	$10.75
	8.1	$9.46	$10.84	$11.89	$13.76	$12.49	$12.56
	9	$8.36	$9.59	$10.72	$12.17	$11.05	$11.11
	9.1	$10.26	$11.76	$12.75	$14.93	$13.55	$13.62

Table 33: Quick Service Restaurant Retrofit Package Differential Costs Compared to Standard Retrofit

Figure 8 shows the retrofit technology options for the quick service restaurant and that these technologies were down-selected to give 5 unique retrofit package options. Table 34, which follows the figure, shows the differential installed first cost, in $/square foot, between each package and each region specific baseline HVAC system

Tech #	Tech. in EnergyPlus	Package 1	Package 2	Package 5	Package 8	Package 9
1	Increased duct sealing	O	O	O	O	O
3	High efficiency supply fan	O	O	O	O	O
4	Low pressure drop air filter	O	O	O	O	O
5	Standardize PSC motors in fan	O	O	O	O	O
6	CAV to VAV	O	O			
9	Optimize zone mixing	O	O	O	O	O
9.1	Demand control exhaust fan	O	O	O	O	O
14	Evaporative Coolers	O	O			
19	High efficiency RTU system		O			
22.1	Air source heat pumps				O	
25	Integrated Heat Pumps (heating, cooling and hot water)					O
26	Variable refrigerant flow system (VRF)			O		
28	Optimize equipment sizing	O	O	O	O	O
33	High efficiency furnaces and boilers	O	O			
43	Demand control ventilation	O	O	O	O	O
44	Min. OA requirement to latest standard	O	O		O	O
50	Economizer	O	O		O	O
52	Optimum temperature setpoint	O	O	O	O	O
53	Steam-clean AC condenser coil	O	O	O	O	O
60	Increase freezer wall insulation	O	O	O	O	O
65	Use most efficient (i.e., max tech) refrigeration system	O	O	O	O	O
68	Use cascade system for refrigeration	O	O	O	O	O
78	Employ drain-water waste heat recovery	O	O	O	O	O
82	High Efficiency Water Tank	O	O	O	O	
86	Wrap water heaters with insulation blankets	O	O	O	O	O

Figure 8: Full Service Restaurant Retrofit Package Technology Components

Full Service Restaurant: Package Per Square Foot Differential Costs Over Standard Retrofit							
		Charlotte	Indianapolis	Houston	Boston	Minneapolis	LA
Package #	1	$5.58	$6.39	$4.19	$8.12	$7.37	$7.41
	2	$7.31	$8.38	$6.04	$10.64	$9.65	$9.71
	5	$11.37	$13.04	$10.38	$16.56	$15.02	$15.11
	8	$9.95	$11.40	$8.86	$14.48	$13.13	$13.21
	8.1	$11.31	$12.96	$10.31	$16.46	$14.94	$15.02
	9	$10.22	$11.71	$9.15	$14.87	$13.49	$13.57
	9.1	$11.65	$13.35	$10.68	$16.96	$15.39	$15.47

Table 34: Full Service Restaurant Retrofit Package Differential Costs Compared to Standard Retrofit

Figure 9 shows the retrofit technology options for the quick service restaurant and that these technologies were down-selected to give 5 unique retrofit package options. Table 35, which follows the figure, shows the differential installed first cost, in $/square foot, between each package and each region specific baseline HVAC system

Tech #	Tech. in EnergyPlus	Package 1	Package 2	Package 4	Package 10	Package 11
3	High efficiency supply fan	O	O	O	O	O
4	Low pressure drop air filter	O	O	O	O	O
6	CAV to VAV		O	O	O	
14	Evaporative Coolers			O	O	
18	Multi-split AC units	O*				
19	High efficiency RTU and (or) PTAC system		O	O	O	
26	Variable refrigerant flow system (VRF)					O*
28	Optimize equipment sizing	O	O	O	O	O
33	High efficiency furnaces and boilers		O	O		
41	NEMA premium efficiency motors	O	O	O	O	O
43	Demand control ventilation	O	O	O	O	O
50	Economizer		O	O	O	
52	Optimum temperature setpoint	O	O	O	O	O
53	Steam-clean AC condenser coil	O	O	O	O	O
78	Employ drain-water waste heat recovery	O	O	O	O	O
82	High Efficiency Water Tank	O	O	O	O	O
86	Wrap water heaters with insulation blankets	O	O	O	O	O

Figure 9: Small Hotel Retrofit Package Technology Components

Small Hotel: Package Per Square Foot Differential Costs Over Standard Retrofit							
		Charlotte	Indianapolis	Houston	Boston	Minneapolis	LA
Package #	1	$2.49	$2.86	$2.66	$2.73	$2.48	$3.31
	2	$1.54	$1.77	$1.65	$1.35	$1.23	$2.05
	4	$1.70	$1.95	$1.82	$1.58	$1.44	$2.26
	10	$1.53	$1.76	$1.64	$1.33	$1.21	$2.03
	11	$5.00	$5.74	$5.35	$6.39	$5.80	$6.65

Table 35: Small Hotel Retrofit Package Differential Costs Compared to Standard Retrofit

Figure 10 shows the retrofit technology options for the quick service restaurant and that these technologies were down-selected to give 5 unique retrofit package options. Table 36, which follows the figure, shows the differential installed first cost, in $/square foot, between each package and each region specific baseline HVAC system

Tech #	Tech. in EnergyPlus	Package 1	Package 2	Package 3	Package 4	Package 5	Package 10
3	High efficiency supply fan	O	O	O	O	O	O
4	Low pressure drop air filter	O	O	O	O	O	O
6	CAV to VAV	O	O		O	O	
9	Optimize zone mixing	O	O	O	O	O	O
9.1	Demand control exhaust fan	O	O	O	O	O	O
14	Evaporative Coolers				O		
18	Multi-split AC units			O			
19	High efficiency RTU and (or) PTAC system			O	O	O	O
26	Variable refrigerant flow system (VRF)						O
28	Optimize equipment sizing	O	O	O	O	O	O
30	High efficiency pump	O					
33	High efficiency furnaces and boilers	O	O		O	O	
41	NEMA premium efficiency motors	O	O	O	O	O	O
43	Demand control ventilation	O	O	O	O	O	O
50	Economizer	O	O		O	O	
52	Optimum temperature setpoint	O	O	O	O	O	O
53	Steam-clean AC condenser coil	O	O	O	O	O	O
60	Increase freezer wall insulation	O	O	O	O	O	O
65	Use most efficient refrigeration system	O	O	O	O	O	O
68	Use cascade system for refrigeration	O	O	O	O	O	O
78	Employ drain-water waste heat recovery	O	O	O	O	O	O
82	High Efficiency Water Tank	O	O	O	O	O	O
86	Wrap water heaters with insulation blankets	O	O	O	O	O	O

Figure 10: Large Hotel Retrofit Package Technology Components

Large Hotel: Package Per Square Foot Differential Costs Over Standard Retrofit							
		Charlotte	Indianapolis	Houston	Boston	Minneapolis	LA
Package #	1	$0.80	$0.92	$0.85	($0.27)	($0.24)	$1.06
	2	$0.80	$0.92	$0.85	($0.27)	($0.24)	$1.06
	3	$2.50	$2.86	$2.67	$2.21	$2.00	$3.32
	4	$2.07	$2.37	$2.22	$1.59	$1.44	$2.75
	5	$1.82	$2.08	$1.95	$1.22	$1.11	$2.42
	10	$4.13	$4.74	$4.42	$4.59	$4.16	$5.49

Table 36: Large Hotel Retrofit Package Differential Costs Compared to Standard Retrofit

Figure 11 shows the retrofit technology options for the quick service restaurant and that these technologies were down-selected to give 5 unique retrofit package options. Table 37, which follows the figure, shows the differential installed first cost, in $/square foot, between each package and each region specific baseline HVAC system

Tech #	Tech. in EnergyPlus	Package 1	Package 2	Package 4	Package 7	Package 10	Package 11
4	Low pressure drop air filter	O	O	O	O		O
6	CAV to VAV	O	O	O	O		
9	Optimize zone mixing	O	O	O	O		O
9.1	Demand control exhaust fan	O	O	O	O		O
14	Evaporative Coolers		O				
19	High efficiency RTU			O			
22.1	Air source heat pumps				O		
25	Integrated Heat Pumps (heating, cooling and hot water)						
26	Variable refrigerant flow system (VRF)						O
28	Optimize equipment sizing	O	O	O	O		O
33	High efficiency furnaces and boilers	O	O	O	O		O
41	NEMA premium efficiency motors	O	O	O	O		O
43	Demand control ventilation	O	O	O	O		O
50	Economizer	O	O	O	O		
53	Steam-clean AC condenser coil	O	O	O	O		O
58	DOAS						O
59	Add doors to supermarket display cases						
60	Increase freezer wall insulation						
66	Use most efficient refrigeration system						
68	Use cascade system for refrigeration						
78	Employ drain-water waste heat recovery	O	O	O	O		O
82	High Efficiency Water Tank	O	O	O	O		O
86	Wrap water heaters with insulation blankets	O	O	O	O		O

Figure 11: Supermarket Retrofit Package Technology Components

Supermarket: Package Per Square Foot Differential Costs Over Standard Retrofit							
		Charlotte	Indianapolis	Houston	Boston	Minneapolis	LA
Package #	1	$1.89	$0.26	$2.02	($7.65)	$0.30	$2.51
	2	$2.32	$0.75	$2.48	($7.03)	$0.86	$3.08
	4	$3.62	$2.24	$3.87	($5.13)	$2.58	$4.81
	7	$7.37	$6.54	$7.88	$0.33	$7.54	$9.79
	7.1	$8.74	$8.11	$9.35	$2.32	$9.35	$11.61
	11	$10.05	$9.61	$10.75	$4.23	$11.08	$13.35

Table 37: Supermarket Retrofit Package Differential Costs Compared to Standard Retrofit

Figure 12 shows the retrofit technology options for the quick service restaurant and that these technologies were down-selected to give 5 unique retrofit package options. Table 38, which follows the figure, shows the differential installed first cost, in $/square foot, between each package and each region specific baseline HVAC system

Tech #	Tech. in EnergyPlus	Package 1	Package 3	Package 4	Package 5	Package 7	Package 10
4	Low pressure drop air filter	O	O	O	O	O	O
6	CAV to VAV	O		O	O	O	
14	Evaporative Coolers			O	O		
18	Multi-split AC units		O				
19	High efficiency RTU			O			
22.1	Air source heat pumps					O	
26	Variable refrigerant flow system (VRF)						O
28	Optimize equipment sizing	O	O	O	O	O	O
33	High efficiency furnaces and boilers	O	O	O	O	O	O
41	NEMA premium efficiency motors	O	O	O	O	O	O
43	Demand control ventilation	O	O	O	O	O	O
50	Economizer	O		O	O	O	
52	Optimum temperature setpoint	O	O	O	O	O	O
53	Steam-clean AC condenser coil	O	O	O	O	O	O
58	DOAS		O				O
60	Increase freezer wall insulation						
66	Use most efficient refrigeration system						
68	Use cascade system for refrigeration						

Figure 12: Convenience Store Retrofit Package Technology Components

Convenience Store: Package Per Square Foot Differential Costs Over Standard Retrofit							
		Charlotte	Indianapolis	Houston	Boston	Minneapolis	LA
Package #	1	$6.84	$7.84	$7.31	($0.44)	$9.03	$9.08
	3	$7.79	$8.92	$8.33	$0.93	$10.28	$10.34
	4	$9.00	$10.31	$9.62	$2.70	$11.88	$11.95
	5	$7.27	$8.33	$7.77	$0.18	$9.60	$9.65
	7	$12.32	$14.12	$13.17	$7.53	$16.27	$16.36
	7.1	$13.69	$15.69	$14.64	$9.53	$18.08	$18.18
	10	$12.68	$14.53	$13.55	$8.05	$16.74	$16.83

Table 38: Convenience Store Retrofit Package Differential Costs Compared to Standard Retrofit

4.4.Energy Savings and Payback

The value of the baseline energy consumption and the energy saved by each retrofit was determined by applying regional average utility rates for electricity and natural gas. The rates used are the same as those used in the BP4 analysis for consistency and include distribution charges as well as the commodity charge. There is significant regional variation in utility energy costs as shown in Table 39

	Electric	Nat Gas
	$/kWh	$/therm
Boston	0.16	1.19
Indianapolis	0.12	0.85
Charlotte	0.12	1.50
Minneapolis	0.12	0.85
Houston	0.14	1.06
Los Angeles	0.21	1.14

Table 39: Typical Average Utility Rates by Region

In the BP4 analysis, the effect of energy efficiency incentive programs was factored into the payback calculation for each retrofit package. A survey of incentive programs in the 6 regions considered in the project yielded the following representative rates of incentive payment:

Charlotte, NC: $0.065 per kWh of electric energy saved compared to baseline

Indianapolis, IN: The lesser of $50,000 or the incentive payment required to buy the project down to a 1 ½ year payback.

Houston, TX: $0.11 per kWh of electric energy saved compared to baseline

Boston, MA: 50% of the incremental cost between the energy efficient retrofit option and the standard retrofit

Minneapolis, MN: The lesser of $5,000 or the incentive payment required to buy the project down to a 1 year payback.

Los Angeles, CA: $0.14 per kWh of electric energy saved compared to baseline

The results of the energy analysis for each building type are shown in the following tables. The tables show the percentage HVAC energy savings compared to the baseline (i.e. pre-retrofit) case and the simple payback in years. There are two tables for each building type; one shows the un-incentivized simple payback, while the other shows the incentivized simple payback.

As in BP4, the project goal was to identify packages that save at least 50% HVAC energy, on a site basis, with a 4 year payback or less with available incentives. Additionally, it was recognized in BP4 that packages that save less than 50% HVAC site energy but which have paybacks less than 4 years could still be attractive depending on the specific building, the available budget for retrofits, and the energy conservation goals of the building owner. The tables below are color-coded to help identify which packages meet certain energy saving and financial performance goals as follows:

Green: Saves at least 50% HVAC energy and payback (incentivized or un-incentivized) is 4 years or less

Yellow: Saves less than 50% HVAC energy but payback (incentivized or un-incentivized) is 4 years or less

Orange: Saves more than 50% HVAC energy but payback (incentivized or un-incentivized) is more than 4 years

Red: Saves less than 50% HVAC energy and payback (incentivized or un-incentivized) is more than 4 years

The results for the quick service restaurant energy efficient package solutions are shown below. Table 40 shows the un-incentivized simple paybacks while Table 41 shows the paybacks once incentives are applied. There are 17 combinations of climate region and retrofit package that meet the 50% energy savings threshold and have a 4 year or less simple payback with incentives. There are 5 combinations that have a 4 year or less simple payback, with incentives, but have HVAC energy savings less than 50%.

Quick Service Restaurant - Energy Savings and Un-incentivized Simple Paybacks in Years							
U. S. Census Regions and Divisions		South	Midwest	South	Northeast	Midwest	West
U. S. Climate Zones for 2003 CBECS		Zone 4	Zone 2	Zone 5	Zone 2	Zone 1	Zone 4
Representative City (ASHRAE Climate Zone)		Charlotte NC (3A)	Indianapolis IN (5A)	Houston TX (2A)	Boston MA (5A)	Minneapolis MN (6A)	Los Angeles CA (3B)
Quick Service Restaurant	Packaged 1	58% / 3.1	51% / 5.1	55% / 2.1	51% / 5.8	49% / 6.9	56% / 7.2
	Packaged 4	57% / 1.3	46% / 2.4	52% / 1.2	47% / 2.7	45% / 3.4	53% / 3.4
	Packaged 5	64% / 4.3	66% / 6.1	52% / 3.4	66% / 6.2	68% / 6.3	64% / 8.3
	Packaged 8 Regular HP	64% / 3.5	64% / 42.8	49% / 3.2	69% / 11.3	63% / N/A	60% / 8.5
	Packaged 8 Cold Climate HP		71% / 10.2		74% / 7.6	71% / 21.4	
	Packaged 9 Regular HP	64% / 3.7	63% / 93.5	49% / 3.3	68% / 13.6	62% / N/A	59% / 9
	Packaged 9 Cold Climate HP		70% / 12.1		71% / 10.8	70% / 28.9	

Table 40: Quick Service Restaurant Energy Savings and Un-incentivized Paybacks by Retrofit Package and Climate Region

Quick Service Restaurant - Energy Savings and Incentivized Simple Paybacks in Years							
U. S. Census Regions and Divisions		South	Midwest	South	Northeast	Midwest	West
U. S. Climate Zones for 2003 CBECS		Zone 4	Zone 2	Zone 5	Zone 2	Zone 1	Zone 4
Representative City (ASHRAE Climate Zone)		Charlotte NC (3A)	Indianapolis IN (5A)	Houston TX (2A)	Boston MA (5A)	Minneapolis MN (6A)	Los Angeles CA (3B)
Quick Service Restaurant	Packaged 1	58% 3.1	51% 1.5	55% 1.3	51% 2.9	49% 5	56% 6.9
	Packaged 4	57% 1.3	46% 1.5	52% 0.4	47% 1.4	45% 1	53% 3.2
	Packaged 5	64% 4.2	66% 1.5	52% 2.6	66% 3.1	68% 5.3	64% 7.8
	Packaged 8 Regular HP	64% 3.5	64% 1.5	49% 3.2	69% 5.6	63% N/A	60% 8.5
	Packaged 8 Cold Climate HP		71% 1.5		74% 3.8	71% 17.9	
	Packaged 9 Regular HP	64% 3.7	63% 1.5	49% 3.3	68% 6.8	62% N/A	59% 9
	Packaged 9 Cold Climate HP		70% 1.5		71% 5.4	70% 24.7	

Table 41: Quick Service Restaurant Energy Savings and Incentivized Paybacks by Retrofit Package and Climate Region

The results for the full service restaurant energy efficient package solutions are shown below. Table 42 shows the un-incentivized simple paybacks while Table 43 shows the paybacks once incentives are applied. There are 5 combinations of climate region and retrofit package that meet the 50% energy savings threshold and have a 4 year or less simple payback with incentives. There are 5 combinations that have a 4 year or less simple payback, with incentives, but have HVAC energy savings less than 50%.

Full Service Restaurant - Energy Savings and Un-incentivized Simple Paybacks in Years							
U. S. Census Regions and Divisions		South	Midwest	South	Northeast	Midwest	West
U. S. Climate Zones for 2003 CBECS		Zone 4	Zone 2	Zone 5	Zone 2	Zone 1	Zone 4
Representative City (ASHRAE Climate Zone)		Charlotte NC (3A)	Indianapolis IN (5A)	Houston TX (2A)	Boston MA (5A)	Minneapolis MN (6A)	Los Angeles CA (3B)
Full Service Restaurant	Packaged 1	53% / 4	56% / 7.5	42% / 1.9	57% / 8.2	57% / 7.5	33% / N/A
	Packaged 2	54% / 4.9	56% / 9	46% / 2.5	57% / 10.3	57% / 9.4	33% / 1830.4
	Packaged 5	57% / 7.1	60% / 13.1	45% / 4.4	63% / 13.1	62% / 12.6	46% / 27.9
	Packaged 8 Regular HP	58% / 7	60% / N/A	41% / 4.1	65% / 40.9	61% / 16.7	42% / 38.4
	Packaged 8 Cold Climate HP		67% / 25.6		71% / 16.7	68% / 79.2	
	Packaged 9 Regular HP	58% / 7.2	60% / N/A	41% / 4.3	65% / 44.2	61% / 17.5	41% / 40.4
	Packaged 9 Cold Climate HP		67% / 27.1		70% / 17.5	68% / 90.7	

Table 42: Full Service Restaurant Energy Savings and Un-incentivized Paybacks by Retrofit Package and Climate Region

Full Service Restaurant - Energy Savings and Incentivized Simple Paybacks in Years							
U. S. Census Regions and Divisions		South	Midwest	South	Northeast	Midwest	West
U. S. Climate Zones for 2003 CBECS		Zone 4	Zone 2	Zone 5	Zone 2	Zone 1	Zone 4
Representative City (ASHRAE Climate Zone)		Charlotte NC (3A)	Indianapolis IN (5A)	Houston TX (2A)	Boston MA (5A)	Minneapolis MN (6A)	Los Angeles CA (3B)
Full Service Restaurant	Packaged 1	53% / 4	56% / 1.5	42% / 1.1	57% / 4.1	57% / 6.5	33% / N/A
	Packaged 2	54% / 4.8	56% / 1.5	46% / 1.7	57% / 5.1	57% / 8.5	33% / 1830.4
	Packaged 5	57% / 7	60% / 4	45% / 3.5	63% / 6.5	62% / 11.8	46% / 27.6
	Packaged 8 Regular HP	58% / 7	60% / N/A	41% / 4.1	65% / 20.4	61% / N/A	42% / 38.4
	Packaged 8 Cold Climate HP		67% / 7.7		71% / 8.4	68% / 74.4	
	Packaged 9 Regular HP	58% / 7.2	60% / N/A	41% / 4.3	65% / 22.1	61% / N/A	41% / 40.4
	Packaged 9 Cold Climate HP		67% / 8.7		70% / 8.7	68% / 85.3	

Table 43: Full Service Restaurant Energy Savings and Incentivized Paybacks by Retrofit Package and Climate Region

The results for the small hotel energy efficient package solutions are shown below. Table 44 shows the un-incentivized simple paybacks while Table 45 shows the paybacks once incentives are applied. There are 20 combinations of climate region and retrofit package that meet the 50% energy savings threshold and have a 4 year or less simple payback with incentives. There are 2 combinations that have a 4 year or less simple payback, with incentives, but have HVAC energy savings less than 50%.

Small Hotel - Energy Savings and Un-incentivized Simple Paybacks in Years							
U. S. Census Regions and Divisions		South	Midwest	South	Northeast	Midwest	West
U. S. Climate Zones for 2003 CBECS		Zone 4	Zone 2	Zone 5	Zone 2	Zone 1	Zone 4
Representative City (ASHRAE Climate Zone)		Charlotte NC (3A)	Indianapolis IN (5A)	Houston TX (2A)	Boston MA (5A)	Minneapolis MN (6A)	Los Angeles CA (3B)
Small Hotel	Packaged 1	69% / 4.3	73% / 4.1	66% / 3.8	74% / 4.2	71% / 6.9	70% / 4.2
	Packaged 2	60% / 3.1	58% / 3.2	59% / 2.6	59% / 2.7	49% / 4.2	58% / 3.2
	Packaged 4	61% / 3.4	58% / 3.5	59% / 2.9	59% / 3.1	50% / 4.8	59% / 3.4
	Packaged 10	61% / 3	58% / 3.2	59% / 2.6	59% / 2.6	47% / 4.1	59% / 3.1
	Packaged 11	75% / 8	78% / 7.7	70% / 7.1	80% / 8.9	77% / 14	76% / 7.8

Table 44: Small Hotel Energy Savings and Un-incentivized Paybacks by Retrofit Package and Climate Region

Small Hotel - Energy Savings and Incentivized Simple Paybacks in Years							
U. S. Census Regions and Divisions		South	Midwest	South	Northeast	Midwest	West
U. S. Climate Zones for 2003 CBECS		Zone 4	Zone 2	Zone 5	Zone 2	Zone 1	Zone 4
Representative City (ASHRAE Climate Zone)		Charlotte NC (3A)	Indianapolis IN (5A)	Houston TX (2A)	Boston MA (5A)	Minneapolis MN (6A)	Los Angeles CA (3B)
Small Hotel	Packaged 1	69% / 3.8	73% / 2.4	66% / 3	74% / 2.1	71% / 6.6	70% / 3.5
	Packaged 2	60% / 2.5	58% / 1.5	59% / 1.8	59% / 1.3	49% / 3.8	58% / 2.5
	Packaged 4	61% / 2.8	58% / 1.5	59% / 2.1	59% / 1.5	50% / 4.4	59% / 2.7
	Packaged 10	61% / 2.5	58% / 1.5	59% / 1.8	59% / 1.3	47% / 3.7	59% / 2.4
	Packaged 11	75% / 7.5	78% / 6.1	70% / 6.3	80% / 4.5	77% / 13.7	76% / 7.1

Table 45: Small Hotel Energy Savings and Incentivized Paybacks by Retrofit Package and Climate Region

The results for the large hotel energy efficient package solutions are shown below. Table 46 shows the un-incentivized simple paybacks while Table 47 shows the paybacks once incentives are applied. There are 33 combinations of climate region and retrofit package that meet the 50% energy savings threshold and have a 4 year or less simple payback with incentives.

Large Hotel - Energy Savings and Un-incentivized Simple Paybacks in Years							
U. S. Census Regions and Divisions		South	Midwest	South	Northeast	Midwest	West
U. S. Climate Zones for 2003 CBECS		Zone 4	Zone 2	Zone 5	Zone 2	Zone 1	Zone 4
Representative City (ASHRAE Climate Zone)		Charlotte NC (3A)	Indianapolis IN (5A)	Houston TX (2A)	Boston MA (5A)	Minneapolis MN (6A)	Los Angeles CA (3B)
Large Hotel	Packaged 1	56% / 1.1	52% / 1	55% / 1	58% / 0	52% / 0	54% / 1.8
	Packaged 2	56% / 1.1	52% / 1	55% / 1	58% / 0	52% / 0	54% / 1.8
	Packaged 3	67% / 2.8	71% / 2.3	63% / 2.7	74% / 2.7	75% / 3.2	57% / 5.2
	Packaged 4	58% / 2.7	53% / 2.6	59% / 2.4	59% / 2.4	53% / 3.4	58% / 4.2
	Packaged 5	58% / 2.4	53% / 2.3	59% / 2.1	58% / 1.9	53% / 2.7	56% / 3.9
	Packaged 10	79% / 4	84% / 3.2	77% / 3.7	85% / 4.3	85% / 4.8	64% / 7.7

Table 46: Large Hotel Energy Savings and Un-incentivized Paybacks by Retrofit Package and Climate Region

Large Hotel - Energy Savings and Incentivized Simple Paybacks in Years							
U. S. Census Regions and Divisions		South	Midwest	South	Northeast	Midwest	West
U. S. Climate Zones for 2003 CBECS		Zone 4	Zone 2	Zone 5	Zone 2	Zone 1	Zone 4
Representative City (ASHRAE Climate Zone)		Charlotte NC (3A)	Indianapolis IN (5A)	Houston TX (2A)	Boston MA (5A)	Minneapolis MN (6A)	Los Angeles CA (3B)
Large Hotel	Packaged 1	56% / 0.5	52% / 1	55% / 0.2	58% / 0	52% / 0	54% / 1.1
	Packaged 2	56% / 0.5	52% / 1	55% / 0.2	58% / 0	52% / 0	54% / 1.1
	Packaged 3	67% / 2.3	71% / 2	63% / 1.9	74% / 1.4	75% / 3.1	57% / 4.5
	Packaged 4	58% / 2.2	53% / 2.1	59% / 1.6	59% / 1.2	53% / 3.3	58% / 3.5
	Packaged 5	58% / 1.8	53% / 1.8	59% / 1.3	58% / 0.9	53% / 2.6	56% / 3.2
	Packaged 10	79% / 3.4	84% / 2.9	77% / 2.9	85% / 2.1	85% / 4.7	64% / 7

Table 47: Large Hotel Energy Savings and Incentivized Paybacks by Retrofit Package and Climate Region

The results for the supermarket energy efficient package solutions are shown below. Table 48 shows the un-incentivized simple paybacks while Table 49 shows the paybacks once incentives are applied. There are 5 combinations of climate region and retrofit package that meet the 50% energy savings threshold and have a 4 year or less simple payback with incentives. There are 2 combinations that have a 4 year or less simple payback, with incentives, but have HVAC energy savings less than 50%.

Supermarket - Energy Savings and Un-incentivized Simple Paybacks in Years							
U. S. Census Regions and Divisions		South	Midwest	South	Northeast	Midwest	West
U. S. Climate Zones for 2003 CBECS		Zone 4	Zone 2	Zone 5	Zone 2	Zone 1	Zone 4
Representative City (ASHRAE Climate Zone)		Charlotte NC (3A)	Indianapolis IN (5A)	Houston TX (2A)	Boston MA (5A)	Minneapolis MN (6A)	Los Angeles CA (3B)
Supermarket	Packaged 1	17% / 4.4	38% / N/A	9% / 5.9	-40% / N/A	42% / N/A	8% / 10.5
	Packaged 2	17% / 5.2	38% / N/A	10% / 6.8	-39% / N/A	42% / N/A	9% / 11.1
	Packaged 4	17% / 8.2	38% / N/A	10% / 10.5	-40% / N/A	42% / N/A	8% / 19.6
	Packaged 7	67% / 4.3	67% / 62.8	67% / 3.2	37% / 0.3	63% / N/A	72% / 4.6
	Packaged 7 Cold Climate HP		75% / 13.8		50% / 0.3	72% / 23.5	
	Packaged 11	74% / 5.2	79% / 14	78% / 3.7	57% / 2.9	81% / 13.2	74% / 6.1

Table 48: Supermarket Energy Savings and Un-incentivized Paybacks by Retrofit Package and Climate Region

Supermarket - Energy Savings and Incentivized Simple Paybacks in Years							
U. S. Census Regions and Divisions		South	Midwest	South	Northeast	Midwest	West
U. S. Climate Zones for 2003 CBECS		Zone 4	Zone 2	Zone 5	Zone 2	Zone 1	Zone 4
Representative City (ASHRAE Climate Zone)		Charlotte NC (3A)	Indianapolis IN (5A)	Houston TX (2A)	Boston MA (5A)	Minneapolis MN (6A)	Los Angeles CA (3B)
Supermarket	Packaged 1	17% / 3.8	38% / N/A	9% / 5.1	-40% / N/A	42% / N/A	8% / 9.8
	Packaged 2	17% / 4.6	38% / N/A	10% / 6	-39% / N/A	42% / N/A	9% / 10.4
	Packaged 4	17% / 7.7	38% / N/A	10% / 9.7	-40% / N/A	42% / N/A	8% / 18.9
	Packaged 7	67% / 3.7	67% / 52.2	67% / 2.8	37% / 0.2	63% / N/A	72% / 4.6
	Packaged 7 Cold Climate HP		75% / 11.4		50% / 0.1	72% / 23.2	
	Packaged 11	74% / 4.7	79% / 12.4	78% / 2.9	57% / 1.4	81% / 13	74% / 5.4

Table 49: Supermarket Energy Savings and Incentivized Paybacks by Retrofit Package and Climate Region

The results for the convenience store energy efficient package solutions are shown below. Table 50 shows the un-incentivized simple paybacks while Table 51 shows the paybacks once incentives are applied. There are 6 combinations of climate region and retrofit package that meet the 50% energy savings threshold and have a 4 year or less simple payback with incentives. There are 2 combinations that have a 4 year or less simple payback, with incentives, but have HVAC energy savings less than 50%.

Convenience Store - Energy Savings and Un-incentivized Simple Paybacks in Years							
U. S. Census Regions and Divisions		South	Midwest	South	Northeast	Midwest	West
U. S. Climate Zones for 2003 CBECS		Zone 4	Zone 2	Zone 5	Zone 2	Zone 1	Zone 4
Representative City (ASHRAE Climate Zone)		Charlotte NC (3A)	Indianapolis IN (5A)	Houston TX (2A)	Boston MA (5A)	Minneapolis MN (6A)	Los Angeles CA (3B)
Convenience Store	Packaged 1	-7% / N/A	-23% / N/A	25% / 12.1	-42% / N/A	-6% / N/A	44% / 14.1
	Packaged 3	58% / 7.1	57% / 5.7	64% / 5.4	35% / 1.4	53% / 6.1	63% / 11.4
	Packaged 4	-2% / N/A	-20% / N/A	34% / 11.7	-39% / N/A	-5% / N/A	49% / 16.6
	Packaged 5	-7% / N/A	-23% / N/A	25% / 12.9	-41% / N/A	-7% / N/A	46% / 14.5
	Packaged 7	64% / 10.2	58% / 8.8	64% / 8.4	47% / 8	51% / 10	68% / 16.5
	Packaged 7 Cold Climate HP		68% / 7.6		54% / 7	61% / 8.4	
	Packaged 10	72% / 9.3	72% / 7.3	78% / 7.2	61% / 6.6	73% / 7.2	66% / 17.5

Table 50: Convenience Store Energy Savings and Un-incentivized Paybacks by Retrofit Package and Climate Region

Convenience Store - Energy Savings and Incentivized Simple Paybacks in Years							
U. S. Census Regions and Divisions		South	Midwest	South	Northeast	Midwest	West
U. S. Climate Zones for 2003 CBECS		Zone 4	Zone 2	Zone 5	Zone 2	Zone 1	Zone 4
Representative City (ASHRAE Climate Zone)		Charlotte NC (3A)	Indianapolis IN (5A)	Houston TX (2A)	Boston MA (5A)	Minneapolis MN (6A)	Los Angeles CA (3B)
Convenience Store	Packaged 1	-7% / N/A	-23% / N/A	25% / 11.3	-42% / N/A	-6% / N/A	44% / 13.4
	Packaged 3	58% / 6.6	57% / 1.5	64% / 4.6	35% / 0.7	53% / 5.2	63% / 10.7
	Packaged 4	-2% / N/A	-20% / N/A	34% / 10.8	-39% / N/A	-5% / N/A	49% / 16
	Packaged 5	-7% / N/A	-23% / N/A	25% / 12.1	-41% / N/A	-7% / N/A	46% / 13.8
	Packaged 7	64% / 9.7	58% / 1.5	64% / 8	47% / 4	51% / 9	68% / 16.5
	Packaged 7 Cold Climate HP		68% / 1.5		54% / 3.5	61% / 7.6	
	Packaged 10	72% / 8.8	72% / 1.5	78% / 6.4	61% / 3.3	73% / 6.6	66% / 16.8

Table 51: Convenience Store Energy Savings and Incentivized Paybacks by Retrofit Package and Climate Region

6. Retrofit Opportunities for Water System and Refrigeration System

Although this study focused on HVAC energy savings, there are other energy saving opportunities: water system and refrigeration system. According to CBECS 2003, both food service (Quick and full service restaurants) and lodging (Small and large hotel) have larger water heating energy consumption than others. Also, refrigeration energy consumptions of both food service and food sales show enormous differences from other building types (Table 52). Thus it is important to provide retrofit options for water system and refrigeration system.

Table 52. EUI by Building Types in CBECS 2003 (Nationwide and less than 200,000 ft^2 floorspace)

[kBtu/ft^2]	Office	Stand-alone Retail	Strip Mall	Education	Food Service	Lodging	Food Sales
Heating	**33.6**	**32.7**	**26.8**	**39.4**	**56.9**	**22.3**	**31.6**
Cooling	**8.1**	**6.2**	**13.2**	**8.1**	**19.3**	**5.5**	**10.4**
Ventilation	**3.8**	**3.5**	**8.3**	**7.5**	**13.8**	**3.2**	**4.8**
Water Heating	**1.8**	**1.6**	**8.2**	**6.9**	**56.3**	**35.7**	**2.8**
Lighting	19.9	25.0	33.1	11.5	28.4	23.7	34.3
Cooking	0.1	0.3	4.2	0.8	78.5	2.0	7.2
Refrigeration	**4.3**	**8.0**	**4.3**	**2.6**	**67.3**	**3.2**	**118.0**
Office Equipment	2.8	0.9	0.9	0.6	1.3	0.3	1.6
Computer	5.7	1.3	1.3	3.1	1.3	1.1	1.3
Miscellaneous	7.7	6.0	16.1	3.1	10.4	6.5	8.7
Total	**87.9**	**85.5**	**116.4**	**83.6**	**333.5**	**103.4**	**220.8**

6.1. Retrofit Options for Water System

Five different retrofit technologies of water system were selected at first. Then, four different cases were created from a combination of these to find most energy savings water system. Table 53 shows each water system retrofit item and its application how to implement in EnergyPlus. Each case of water system was applied into full service restaurant Charlotte model to compare energy savings. Table 54 indicates water system retrofit packages and its major energy source.

Table 53. Water System Retrofit Options and Application to Full Service Restaurant in EnergyPlus

Tech #	Water system Retrofit Item	Applicatioin in EnergyPlus
78	**Drain-water waste heat recovery**	WaterUse: Connections - Drain Water Heat Exchanger Type: Counter Flow - Drain Water Heat Exchanger Destination: Plant - Drain Water Heat Exchanger U-Factor Times Area: 1500 W/K
82	**Condensing gas water heaters**	WaterHeater: Mixed - Heater Thermal Efficiency: 0.93
83	**Heat Pump Water Heater**	Use Heat Pump Water Heater objects - Coil COP: 3.2 (Air to Water HP) - Condenser located in kitchen - Evaporator located in dining
84	**Tankless gas water heater with high efficient**	WaterHeater: Mixed - Heater Control Type: Modulate - Tank volume: 1 gal =0.00379 m3
86	**Wrap water heaters with insulation blankets**	WaterHeater: Mixed - On/Off Cycle Loss Coefficient to Ambient Temperature: 2 W/K

The simulation results show that Case 2 has the most energy savings in water system. However, because of a limitation of heat pump water heater's application in EnergyPlus with other HVAC retrofit technologies, Case 1 was selected for proposed retrofit water system for entire building types, except quick service restaurant. In Figure 13, Case 1 provides 44% relative energy savings in water system energy consumption.

Table 54. Water System Retrofit Cases

Case 1 (Gas)	Case 2 (Electric)	Case 3 (Gas)	Case 4 (Gas/Elec.)
78 (DWHR)	78 (DWHR)	78 (DWHR)	78 (DWHR)
82 (Condensing WH)	83 (HPWH)	84 (Tankless WH)	86 (WH Insulation)
86 (WH Insulation)	86 (WH Insulation)	86 (WH Insulation)	-

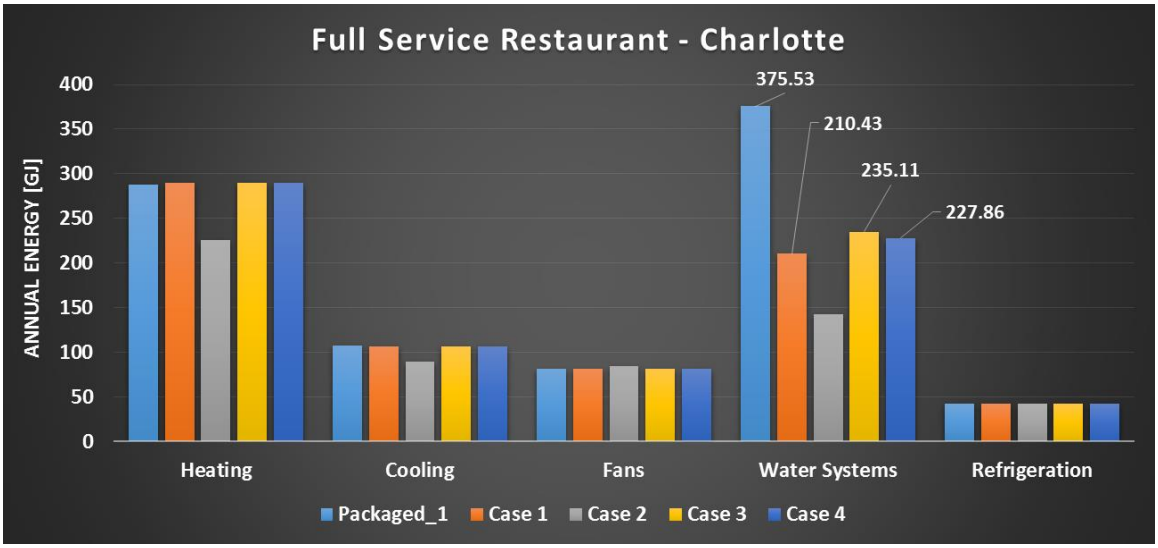


Figure 13. Energy Comparison of Retrofit Water System for Full Service Restaurant in Charlotte

6.2.Refrigeration

This section includes the information how the refrigeration system is modeled in EnergyPlus for quick service restaurant (QSR), full service restaurant (FSR), large hotel (LH), supermarket and convenient store (CS). Refrigeration model in EnergyPlus can be modelled in two different ways; simplified approach and detail approach as shown in Figure 14 with walk-in freezer and self-contained display examples.

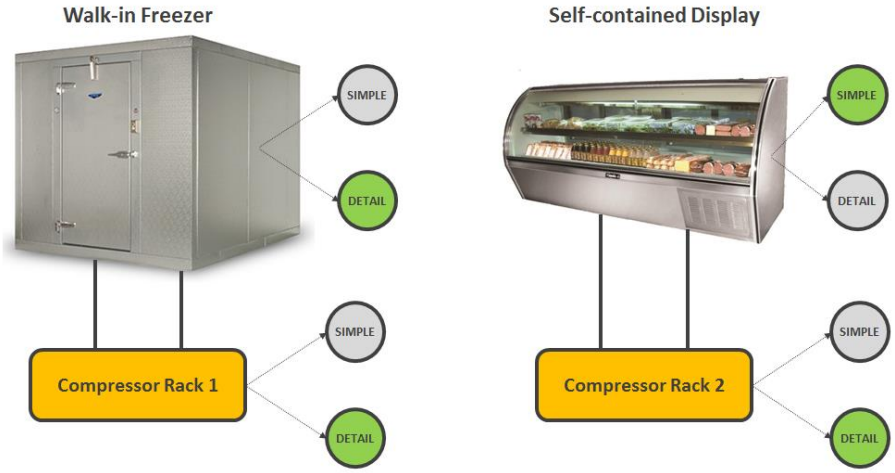


Figure 14. Refrigeration system modelling

Simplified model simplifies the complicated performance of a refrigeration system with minimum parameters to provide easier implementation and less computing effort. For example, a walk-in freezer can be modelled with a “Case” object and a “CompressorRack” object by simplified approach. The case object specifies the details of evaporator fan, defrosting and lighting while the rack object specifies the

details of compressor and condenser. Although this approach provides easy and intuitive implementation of the refrigeration system modelling, there are limitations for considering detail performance evaluation. The detail approach considers relatively more parameters by dividing the system into detail components. The same walk-in freezer can be modelled with a "Walk-in" object, "Compressor" object, "Condenser" object and "System" object. By considering each component of the system separately, it provides more opportunity to analyze how the refrigeration system in different configuration affects the system and the zone. In order to implement appropriate retrofit options with reasonable approach, it was necessary to use detail approach for modelling the refrigeration system in this study. Since all the refrigeration system models that are already implemented in the prototypical building models are using simplified approach, a conversion from simplified model to detail model is performed first. A scaling process as shown in Figure 15 is also included during the conversion to match the performance against the baseline model. After the conversion and the scaling are correctly done, all the retrofit options are then implemented. All the detail process of this modelling is included in the following sections.

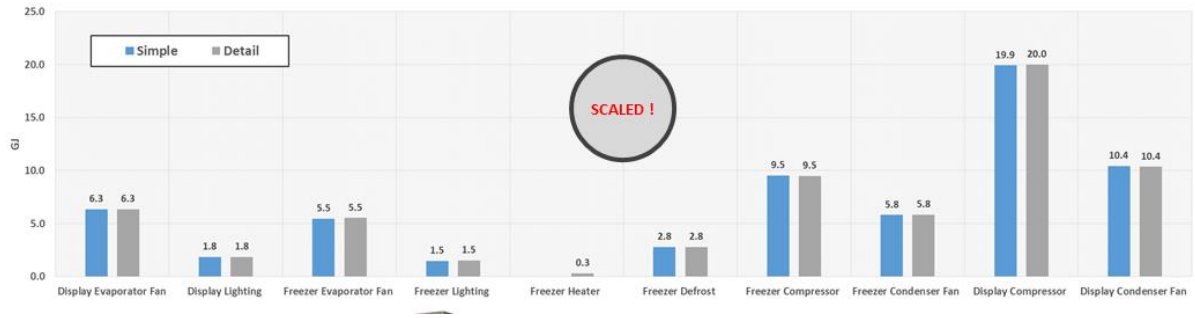


Figure 15. Detail model scaling compare to simple model

6.2.1. efrigeration system modelling in quick service restaurant, full service restaurant, large hotel and convenient store

Refrigeration systems in quick service restaurant (QSR), full service restaurant (FSR), large hotel (LH) and convenient store (CS) include one walk-in freezer and one display. Thus, they all use the same approach and the only difference is the scaling level. The simplified models in baseline models are first converted into detail models. Then they were scaled based on the simplified models' performance.

6.2.1.1. Scaling

The results of scaling of QSR models are shown in the figures below.

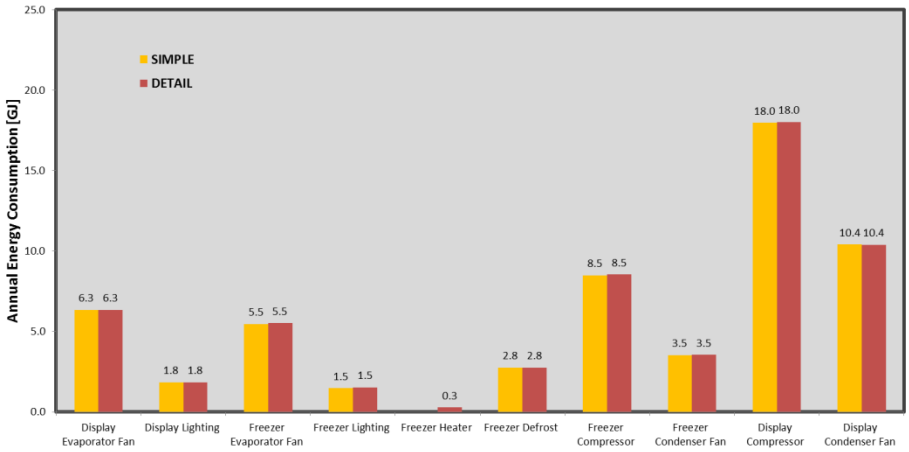


Figure 16. QSR in Indianapolis

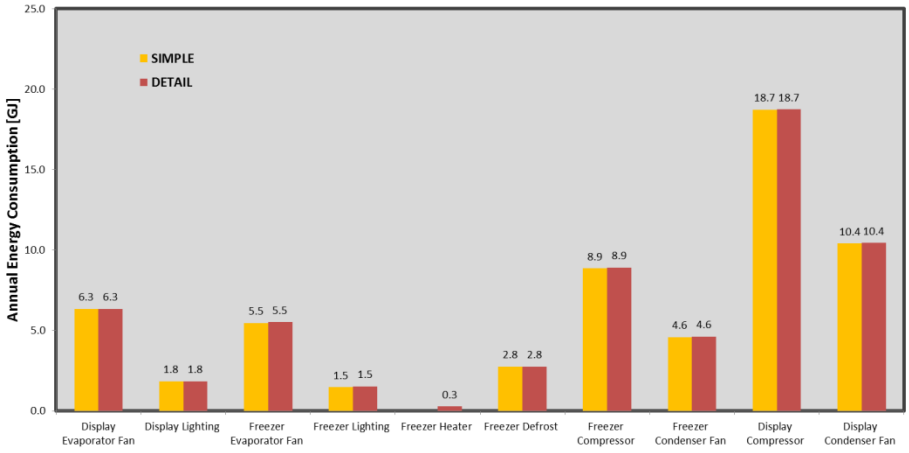


Figure 17. QSR in Charlotte

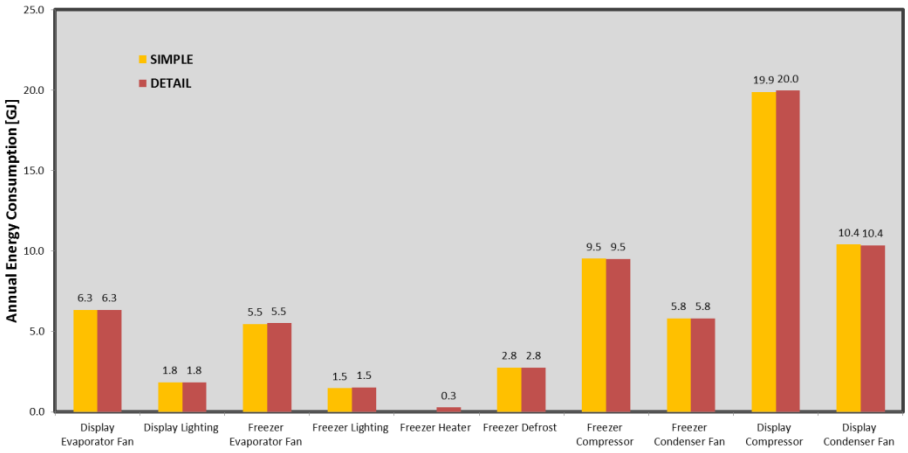


Figure 18. QSR in Houston

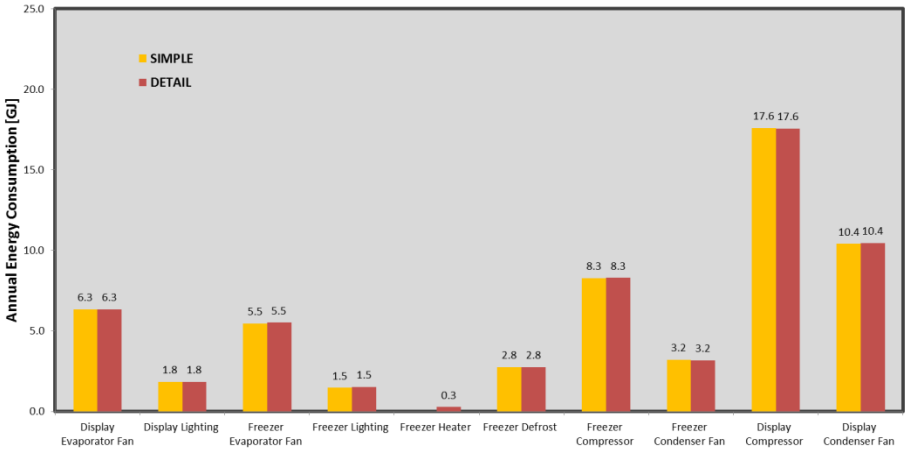


Figure 19. QSR in Boston

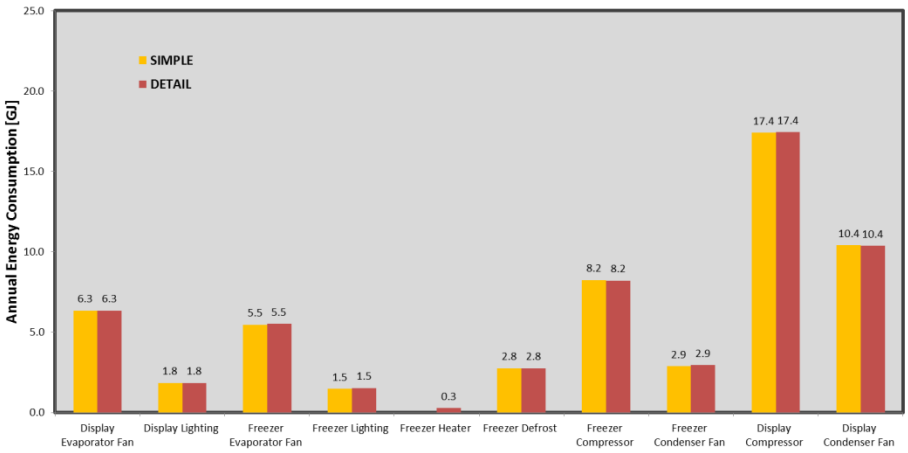


Figure 20. QSR in Minneapolis

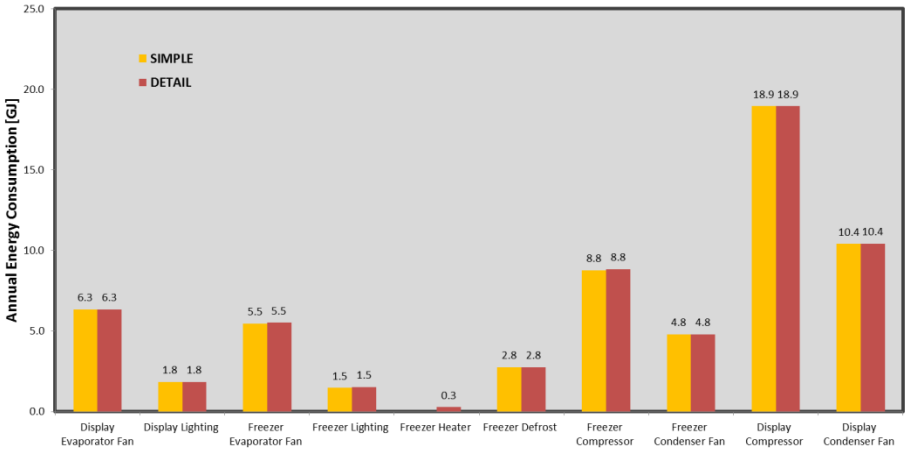


Figure 21. QSR in Los Angeles

The results of scaling of FSR models are shown in the figures below.

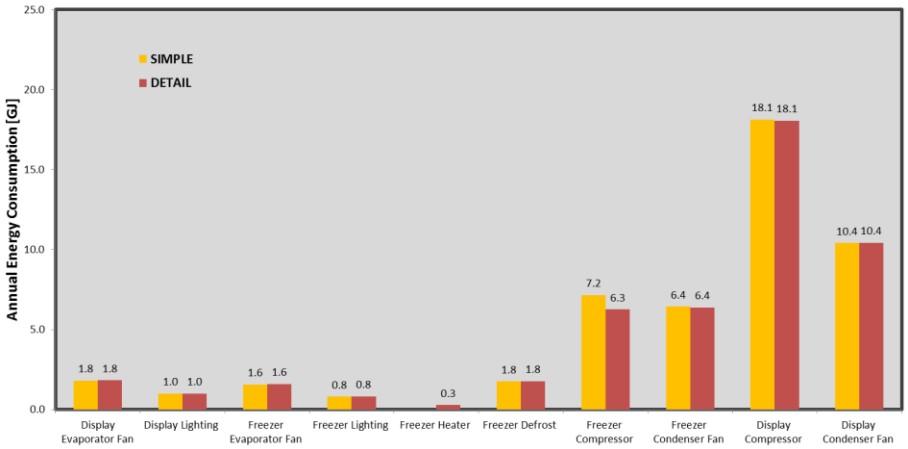


Figure 22. FSR in Indianapolis

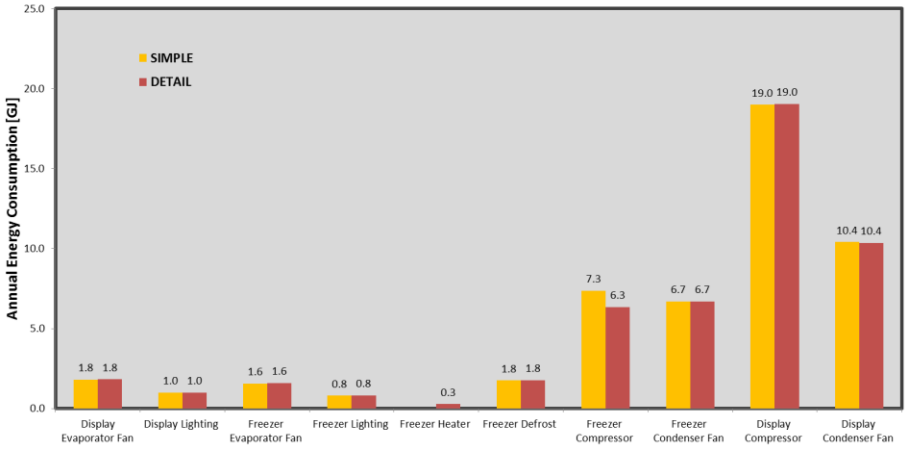


Figure 23. FSR in Charlotte

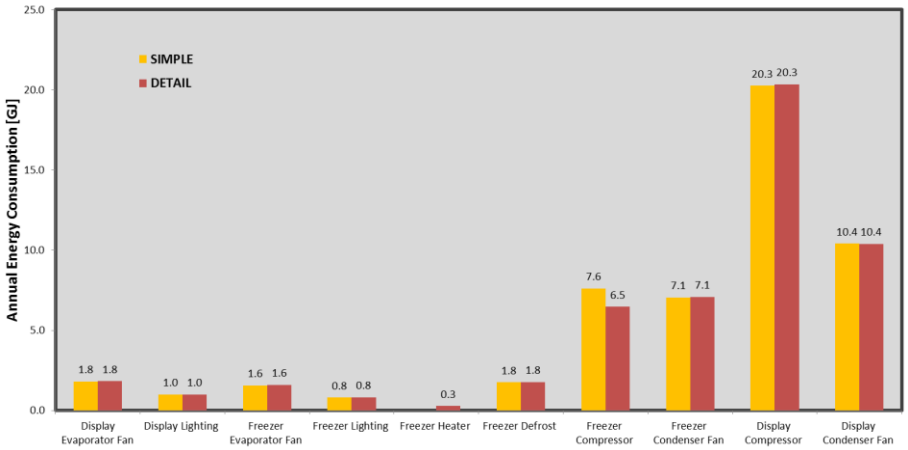


Figure 24. FSR in Houston

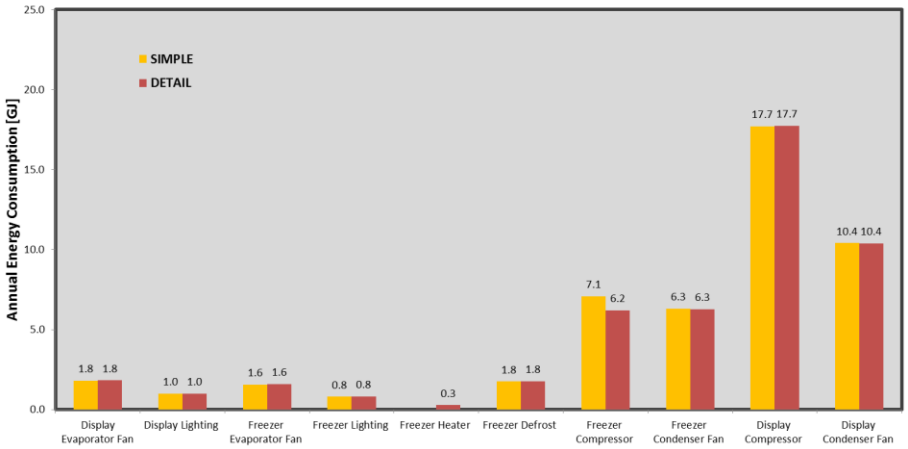


Figure 25. FSR in Boston

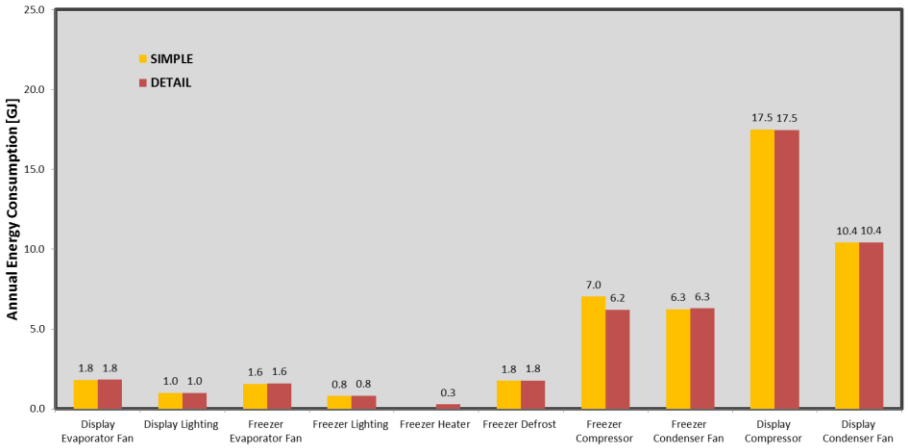


Figure 26. FSR in Minneapolis

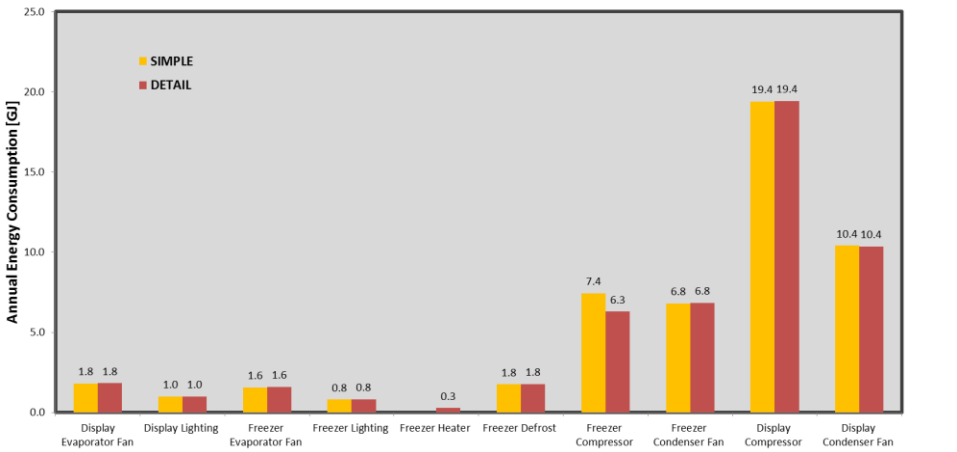


Figure 27. FSR in Los Angeles

There is a slight difference in the energy consumption of the freezer compressor in Figure 22 to Figure 27. This is mostly because of the difference between simplified model's efficiency, and the detail model's efficiency which is based on commercial compressor's performance. Since the portion of difference is small out of entire refrigeration energy consumption, this difference is neglected and the same issue is handled in the same manner in the following models.

The results of scaling of LH models are shown in the figures below.

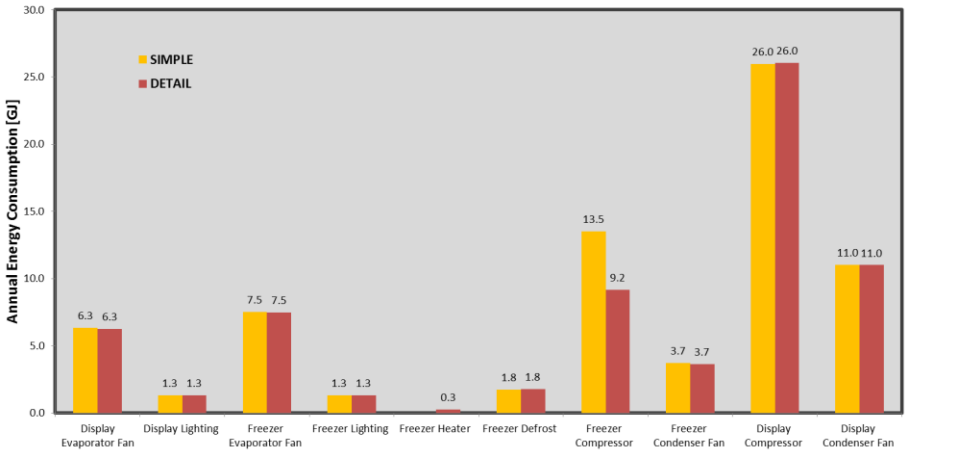


Figure 28. LH in Indianapolis

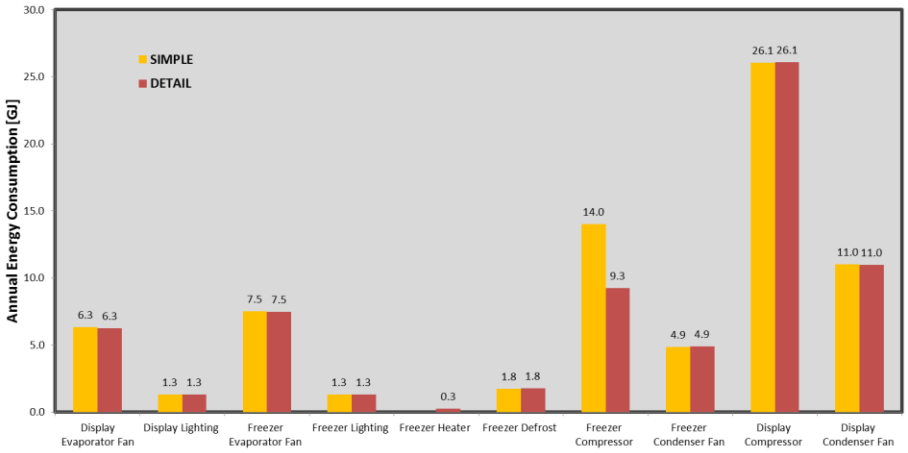


Figure 29. LH in Charlotte

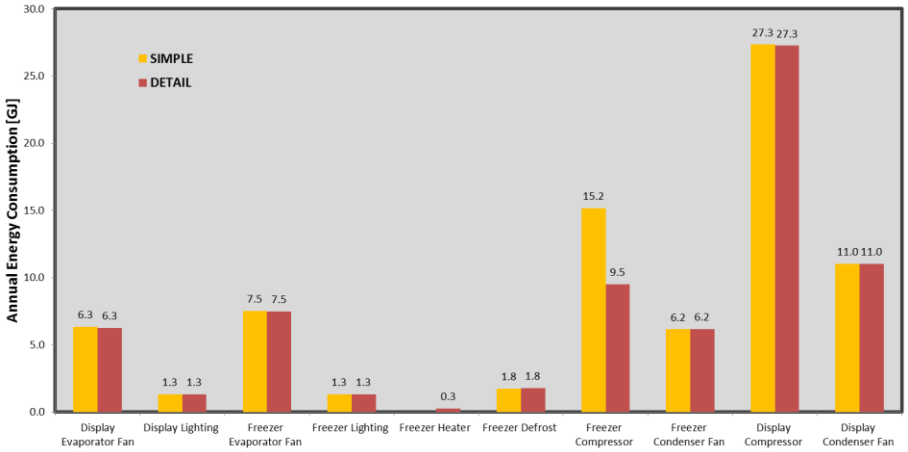


Figure 30. LH in Houston

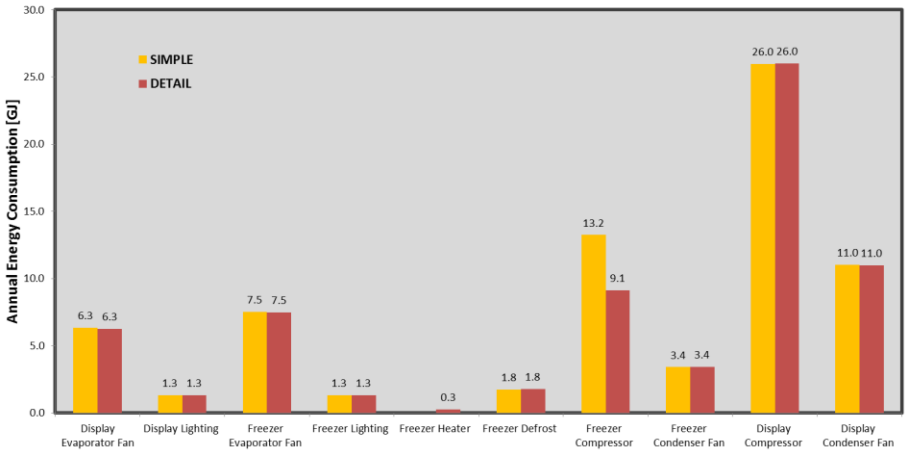


Figure 31. LH in Boston

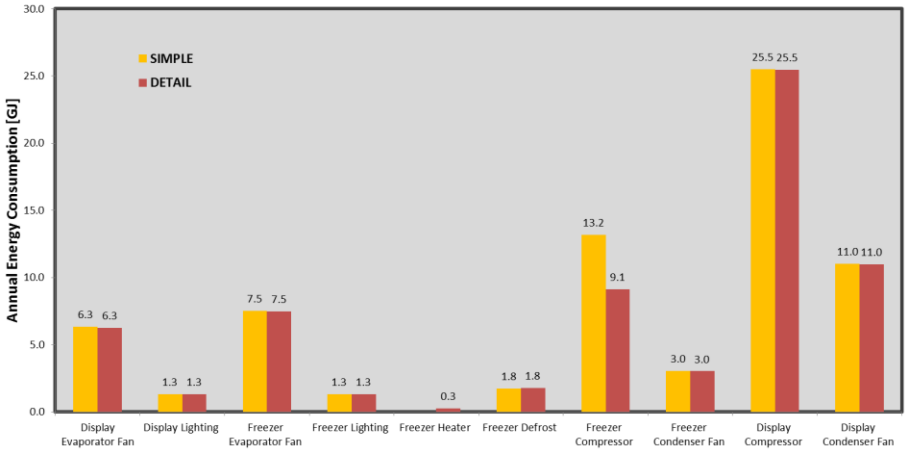


Figure 32. LH in Minneapolis

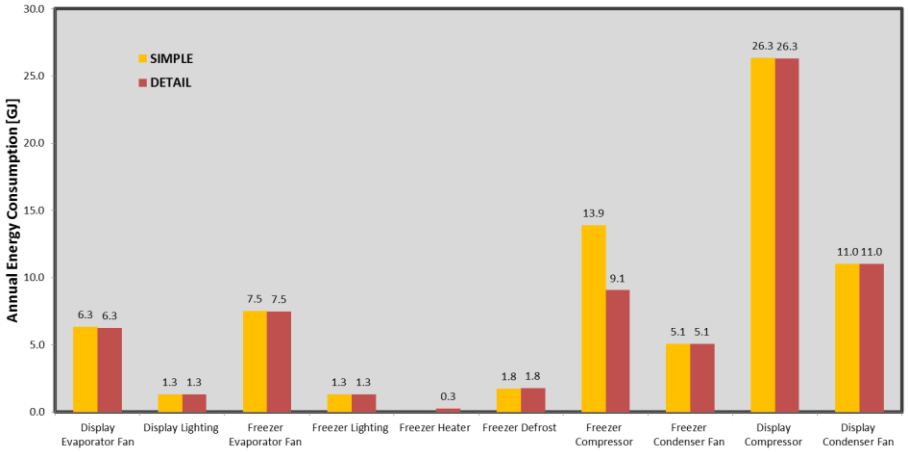


Figure 33. LH in Los Angeles

The results of scaling of CS models are shown in the figures below.

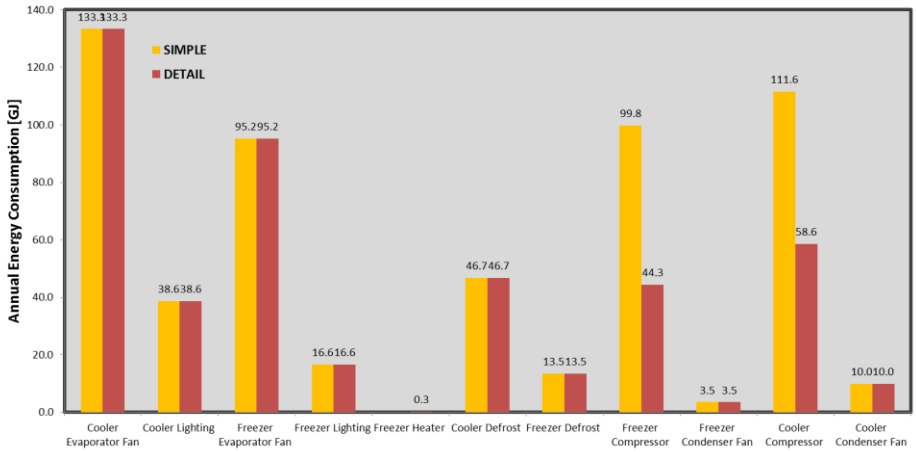


Figure 34. CS in Indianapolis

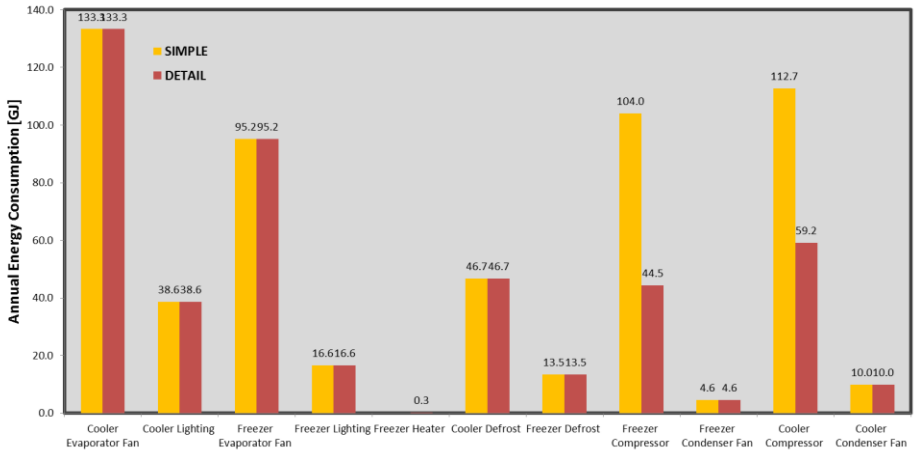


Figure 35. CS in Charlotte

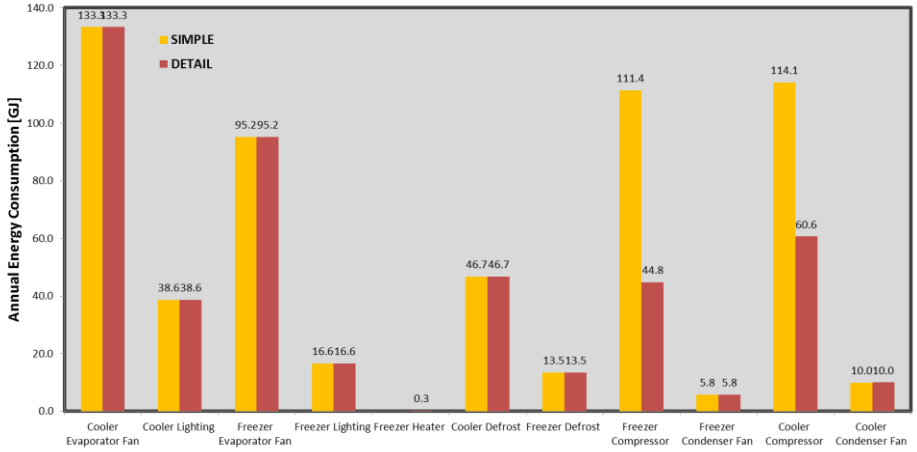


Figure 36. CS in Houston

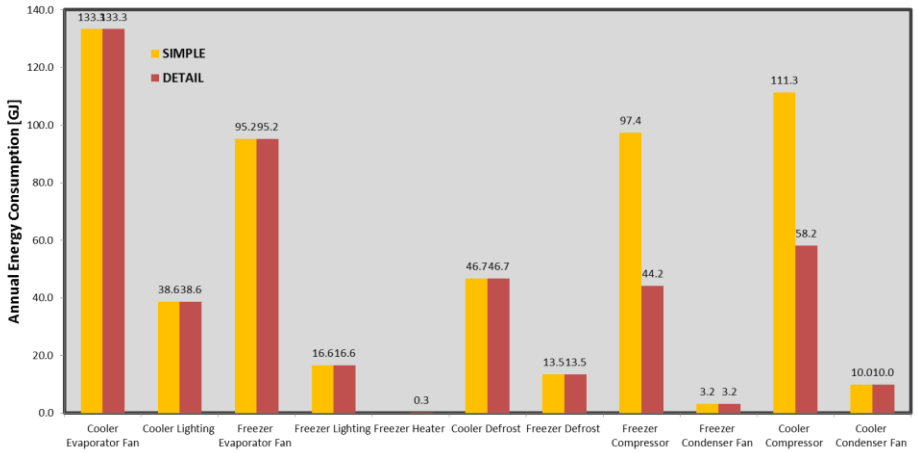


Figure 37. CS in Boston

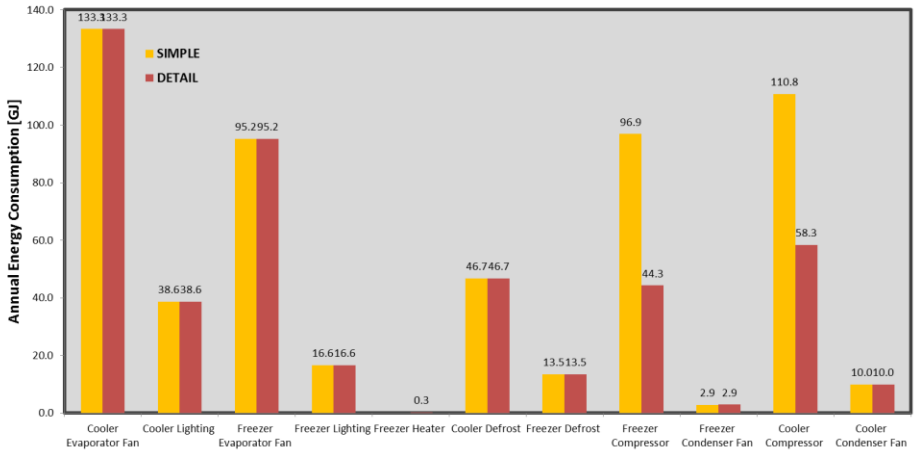


Figure 38. CS in Minneapolis

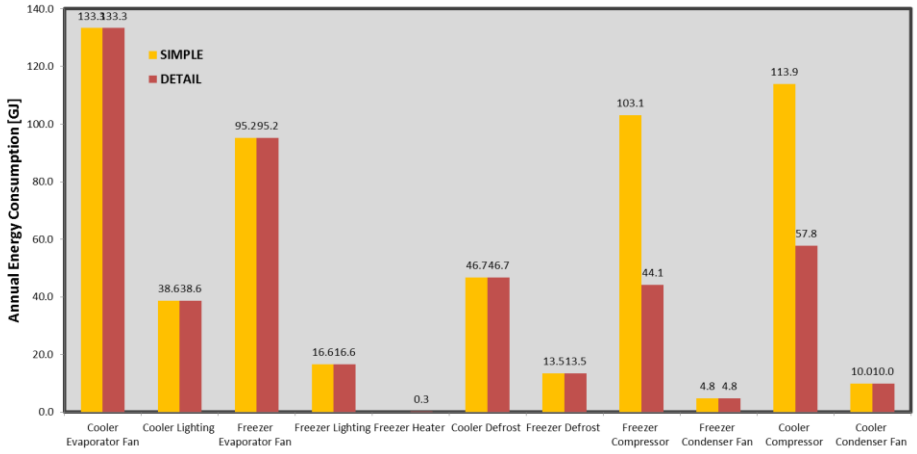


Figure 39. CS in Los Angeles

There is a large difference in the energy consumption of both the freezer and cooler compressor in Figure 34 to Figure 39. This is mostly because of the difference between simplified model's efficiency, and the detail model's efficiency which is based on commercial compressor's performance. Since the portion of difference is relatively larger than other models' difference, particularly detail refrigeration system is used for baseline model in convenience store case.

6.2.1.2. Retrofit application

The retrofit options that are implemented in QSR, FSR, LH and CS are shown in Table 55 below.

Table 55. Retrofit options for refrigeration system

Refrigeration Retrofit Item	Original Model	Retrofit Model
Increase freezer wall insulation	U-value = 0.3154 W/m^2-K	U-value = 0.16 W/m^2-K (Closed cell spray foam)
Use most efficient refrigeration system	COP = 1.1 (freezer) / 2.2 (display)	COP = 1.7 (freezer) / 3.7 (display) 53% and 67% increase
Use cascade system for refrigeration	Separate system	Cascade system

The increased insulation level is based on the U-value of "closed cell spray foam" which is shown in Figure 40 below.

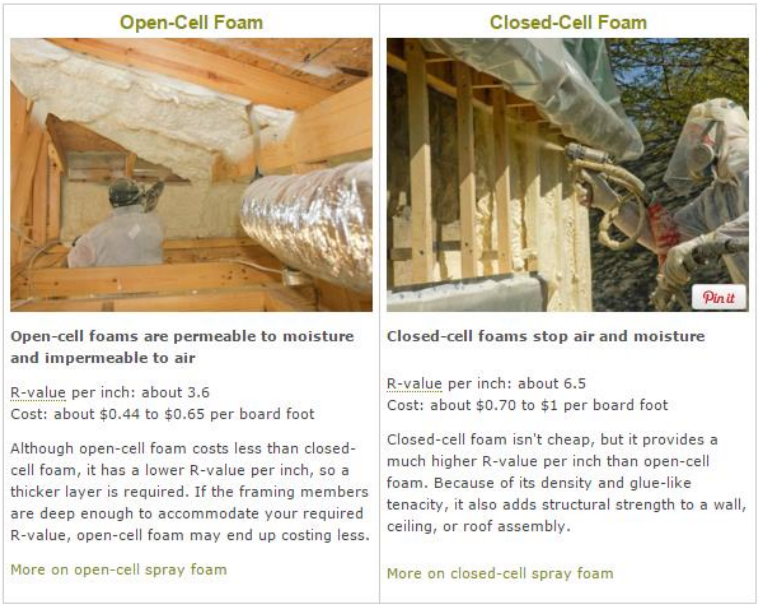


Figure 40. Insulation level for open and closed cell foam

The increased efficiency level is based on the ANSI/AHRI Standard 1321 (SI). Assuming the default efficiency level in EnergyPlus model represents the average performance of a refrigeration system in the market, the most efficient system's efficiency is considered from the standard as shown in the Figure 41 below. The relative increase of COPs in walk-in freezer (53%) and display (67%) are used to increase the efficiency in the compressor performance map to correctly apply the efficiency increase.

Table 1. COP for Remote Commercial Refrigerated Display Merchandisers and Storage Cabinets[1,2]			
Medium Temperature		Low Temperature / Ice Cream	
Adjusted Dew Point °C	COP	Adjusted Dew Point °C	COP
-18	2.69	-39	1.55
-17	2.76	-38	1.59
-16	2.83	-37	1.64
-15	2.89	-36	1.68
-14	2.98	-35	1.73
-13	3.06	-34	1.77
-12	3.15	-33	1.82
-11	3.25	-32	1.86
-10	3.34	-31	1.91
-9	3.44	-30	1.96
-8	3.55	-29	2.01
-7	3.65	-28	2.06
-6	3.78	-27	2.12
-5	3.89	-26	2.17
-4	4.01	-25	2.23
-3	4.13	-24	2.28
-2	4.27	-23	2.34
-1	4.41	-22	2.40
0	4.56	-21	2.46
1	4.71	-20	2.52
2	4.86	-19	2.58

Note:
1. COP values at Medium and Low Temperature/Ice Cream Applications are based on a typical reciprocating compressor.
2. Linear interpolation shall be used to calculate COP values for temperatures not shown in Table 1.

Figure 41. COP for efficiency refrigeration system

The cascade system option is implemented through EnergyPlus library which can be referred with the manual. The schematic of the cascade system is shown in Figure 42 below.

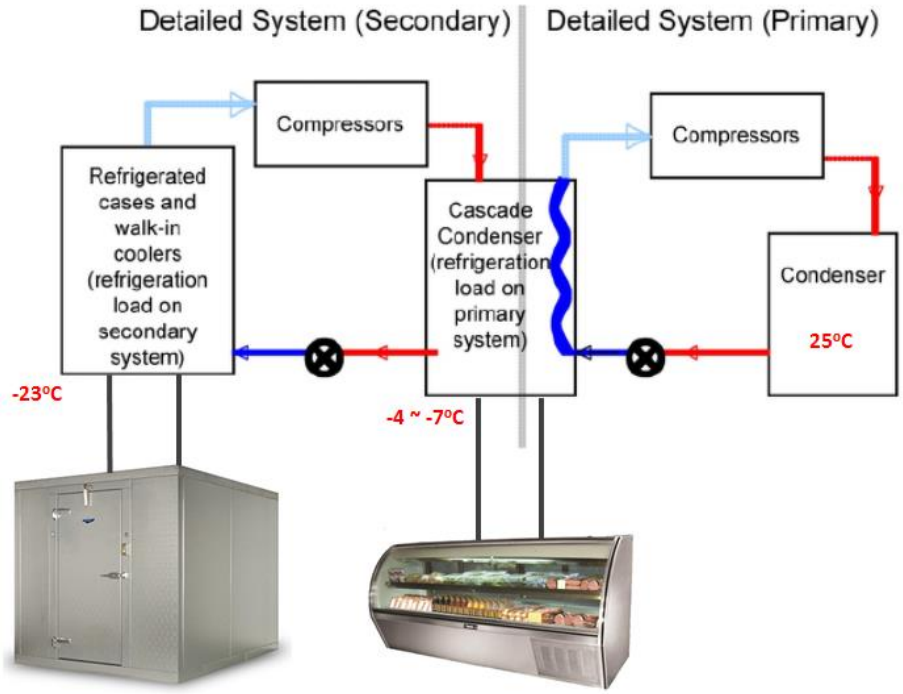


Figure 42. Cascade system

Figure 43 below shows the result of retrofit on QSR model in Houston. The entire package provides 25% relative energy savings in refrigeration energy consumption and this level of savings are also achieved for the other five regions, since these options are relatively less vulnerable under different climate conditions.

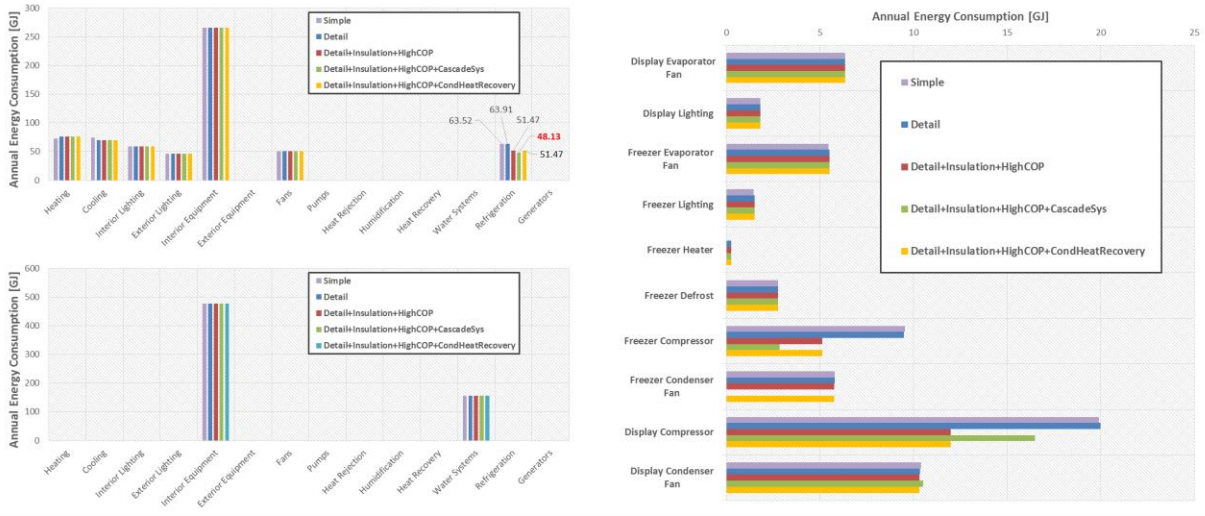


Figure 43. Retrofit result of QSR

Figure 44 below shows the result of retrofit on FSR model in Houston. The entire package provides 32% relative energy savings in refrigeration energy consumption and this level of savings are also achieved for the other five regions.

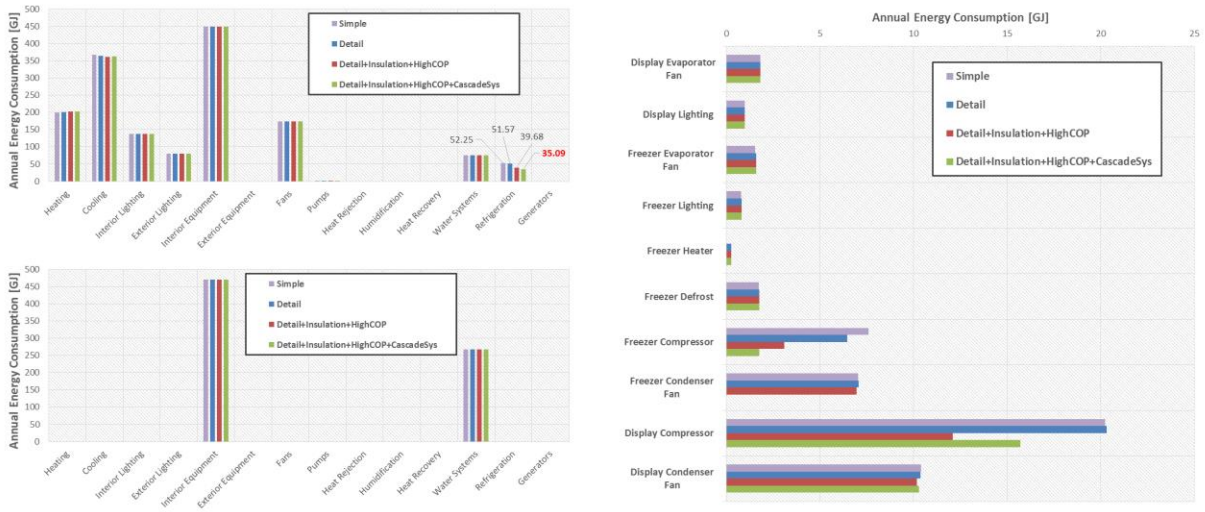


Figure 44. Retrofit result of FSR

Figure 45 below shows the result of retrofit on LH model in Houston. The entire package provides 25% relative energy savings in refrigeration energy consumption and this level of savings are also achieved for the other five regions.

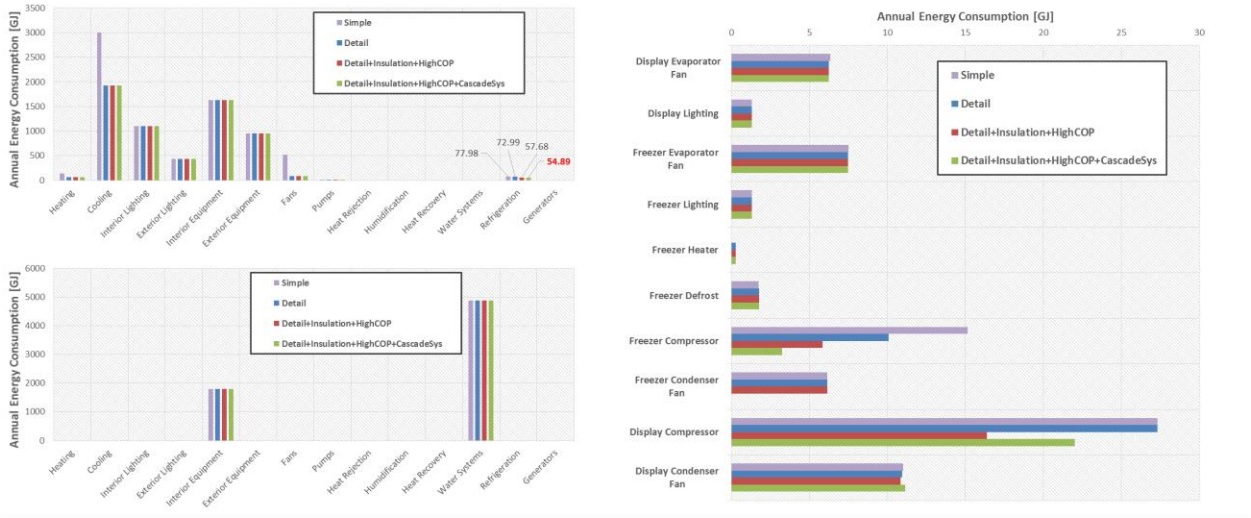


Figure 45. Retrofit result of LH

Figure 46 below shows the result of retrofit on CS model in Houston. The entire package provides 9% relative energy savings in refrigeration energy consumption and this level of savings are also achieved for the other five regions.

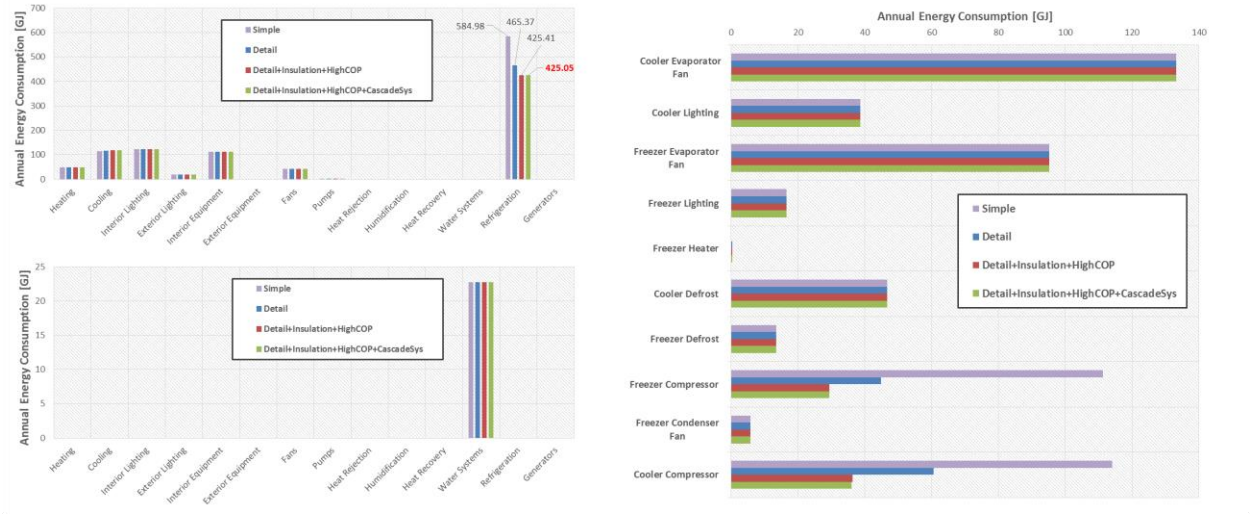


Figure 46. Retrofit result of CS

6.2.2. Refrigeration system in supermarket

Supermarket includes much more variety in terms of a refrigeration system. The table below shows the specification of the refrigeration systems in the supermarket.

Table 56. Refrigeration systems in supermarket

Name	Type	Length	Height	Opt Temp	Rack	Heat Rejtn	Anti-swt Ctrl	Defrost Ctrl	Defrost Sche	Restock, W/m	Restock Pk, W	Red Pk, -	Ratd Cap, W/m	Ratd Cap, kW
Bakery_Case:1_WALKINFREEZER	freezer	2.4	0	2.2	C	Outdoor	none	none	1100-1120 / 2320-2340	725	1740	0.4	461.52	1.11
Deli_Case:1_ MULTIDECKDIARYANDDELICASE	display	3	0	2.2	A	Outdoor	none	offcycle		50	150	0.6	1442.25	4.33
Deli_Case:2_WALKINFREEZER	freezer	4.8	0	2.2	C	Outdoor	none	elec		725	3480	0.4	461.52	2.22
Produce_Case:1_ MULTIDECKDIARYANDDELICASE	display	30	0	2.2	A	Outdoor	none	offcycle		50	1500	0.6	1442.25	43.27
Sales_Case:1_MEATDISPLAYCASE	display	33.58	1.5	2.2	A	Outdoor	linear	elec		50	1679		1442.25	48.43
Sales_Case:2_ MULTIDECKDIARYANDDELICASE	display	49.25	0	2.2	A	Outdoor	none	offcycle		50	2463	0.6	1442.25	71.03
Sales_Case:3_GLASSDOORFROZENFOOD	display	81.69	1.5	-15	B	Outdoor	heatbalance	elec		50	4085	0.6	538.44	43.99
Sales_Case:4_OPENWELLICECREAMDISPLAY CASE	display	39.01	1.5	-12	B	Outdoor	linear	elec		50	1951	0.6	528.83	20.63
Sales_Case:5_WALKINFREEZER	freezer	10.44	0	2.2	C	Outdoor	none	elec		725	7569	0.4	461.52	4.82
Sales_Case:6_WALKINFREEZER	freezer	96.66	0	2.2	C	Outdoor	none	none		725	70079	0.4	461.52	44.61
Sales_Case:7_WALKINFREEZER	freezer	38.1	0	-23.3		Outdoor	none	elec		725	27623	0.4	615.36	23.45

There are eleven refrigerated cases (including freezer and display) and three compressor racks are handling all those cases. As it is done in the previous models, the simplified models in baseline models are first converted into detail models. Then they were scaled based on the simplified models' performance.

6.2.2.1. Scaling

The results of scaling of supermarket models are shown in the figures below.

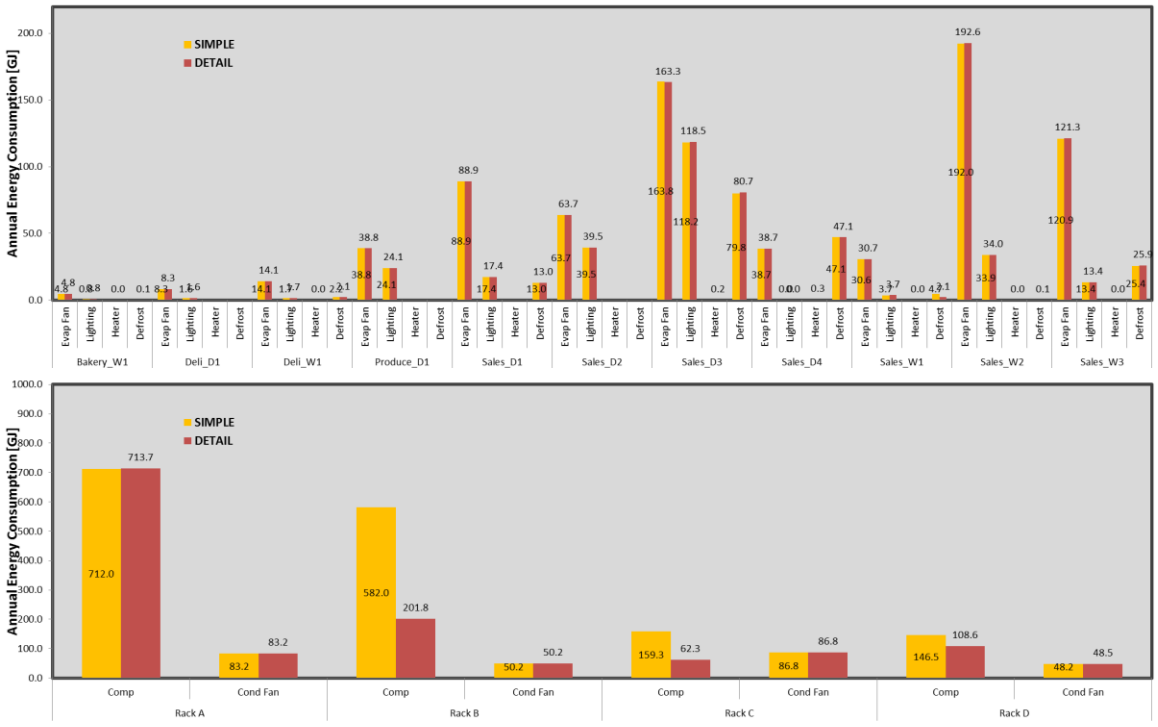


Figure 47. Supermarket in Indianapolis

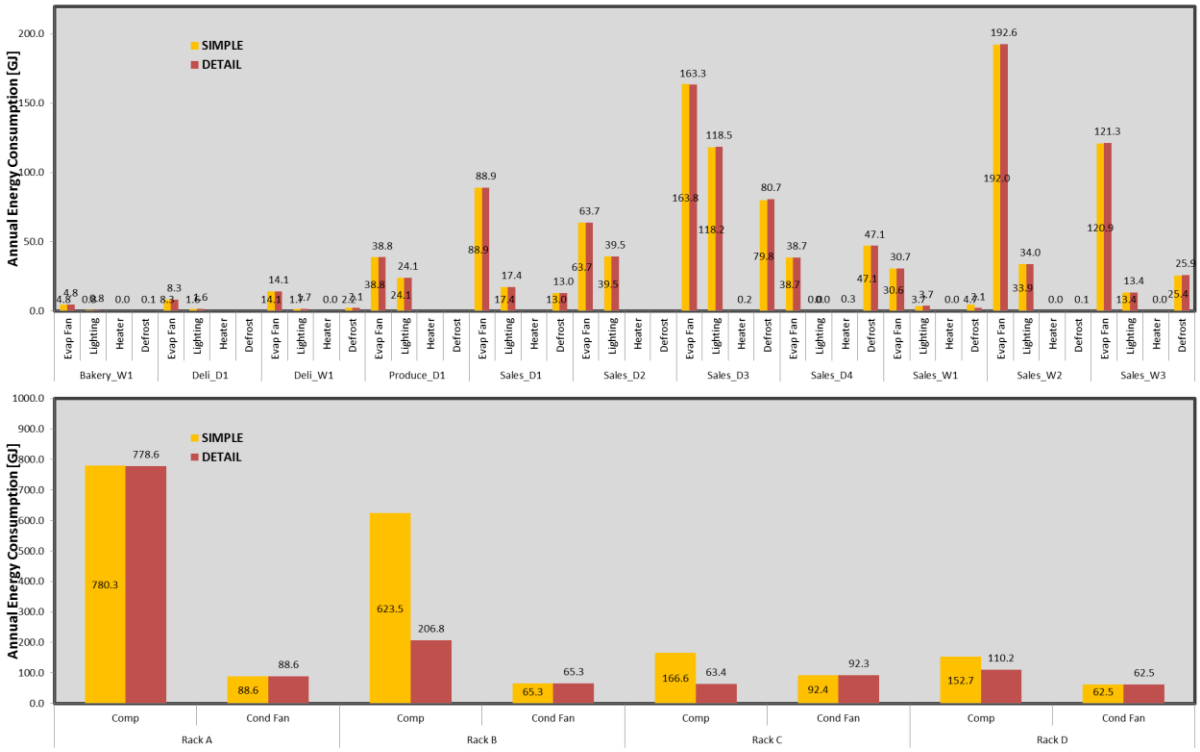


Figure 48. Supermarket in Charlotte

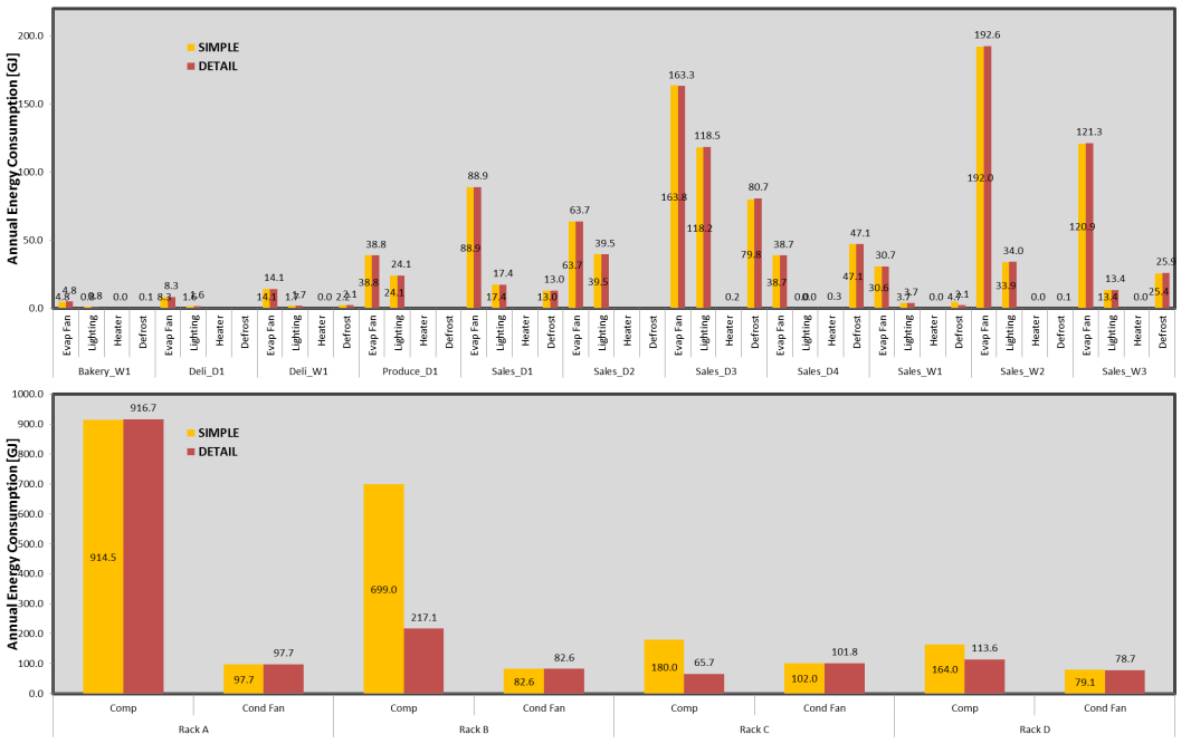


Figure 49. Supermarket in Houston

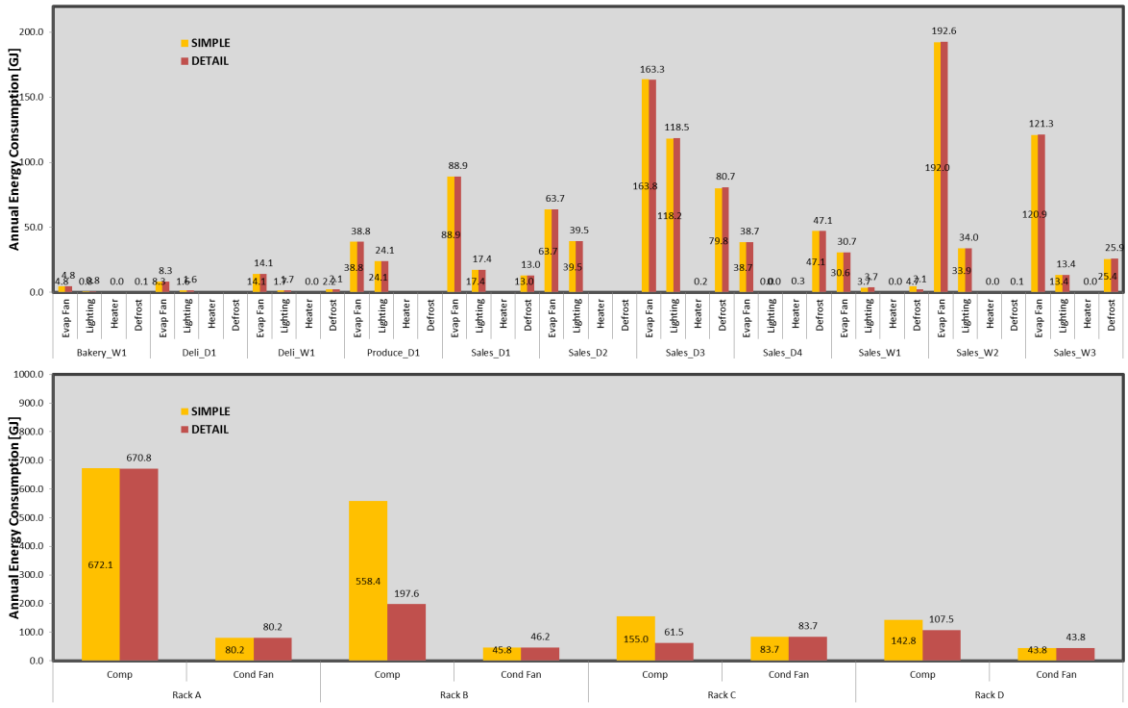


Figure 50. Supermarket in Boston

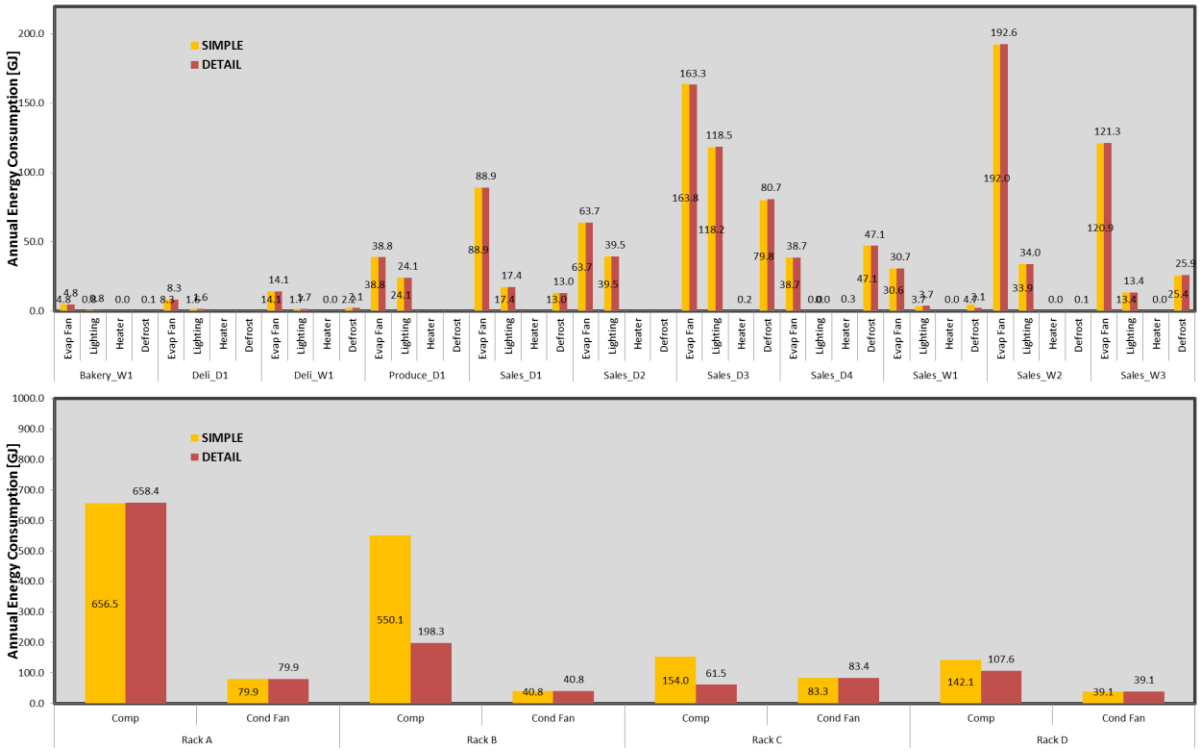


Figure 51. Supermarket in Minneapolis

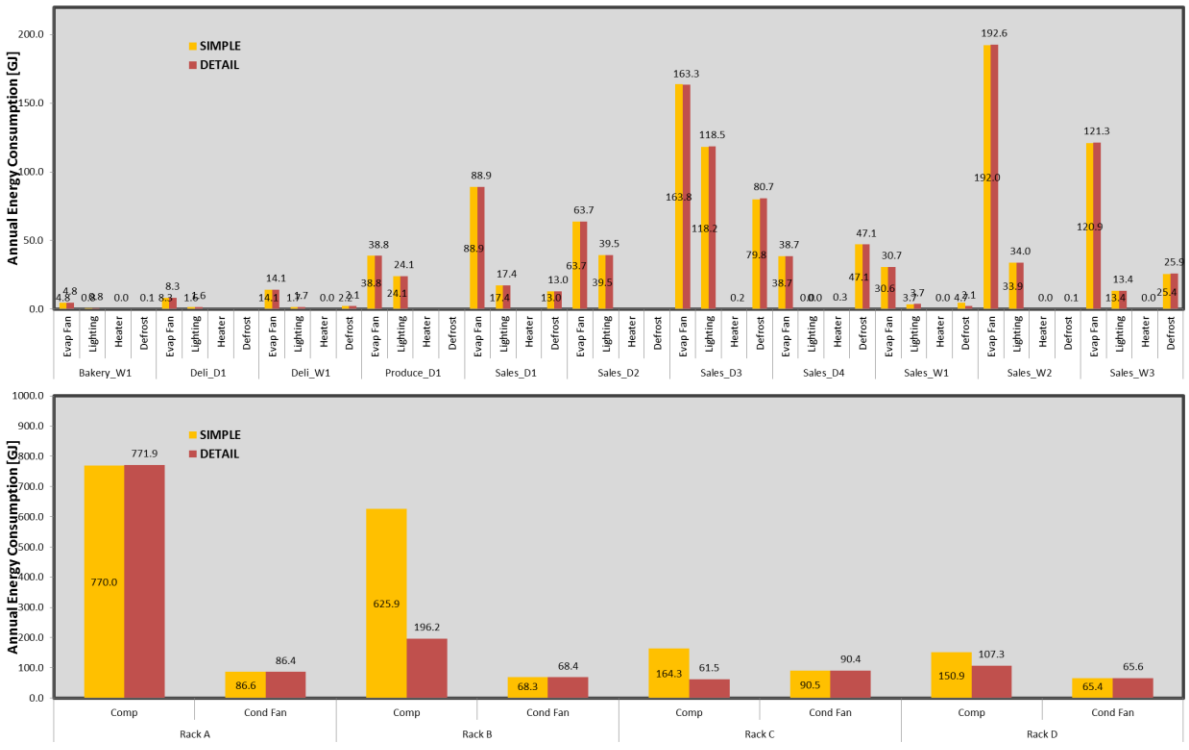


Figure 52. Supermarket in Los Angeles

6.2.2.2. Retrofit application

The retrofit options that are implemented in the supermarket are shown in the table below. Extra insulation and higher efficiency options are implemented in the same way that is implemented in previous models. Adding a door to a display case is included in this retrofit list and it was modelled by reducing (to the reduced level where a freezer affects the zone) the fraction of chilled air affecting the zone condition.

Table 57. Retrofit options for supermarket

Refrigeration Retrofit Item	Original Model	Retrofit Model
Add doors to supermarket display cases	Fraction of cold air to zone 60%	Fraction of cold air to zone 40%
Increase freezer wall insulation	U-value = 0.3154 W/m^2-K	U-value = 0.16 W/m^2-K (Closed cell spray foam)
Use most efficient refrigeration system	COP = 1.1 (freezer) / 2.2 (display)	COP = 1.7 (freezer) / 3.7 (display) 53% and 67% increase

The figure below shows the result of retrofit packages in Minneapolis compare to the baseline model. For a Minneapolis model, the total relative energy saving is calculated as 21%, and this level of saving can be achieved in the other five regions as well. As it is seen from the figure below, adding door (reducing the cooling effect to the zone) to display cases reduced small portion of heating (gas) demand.

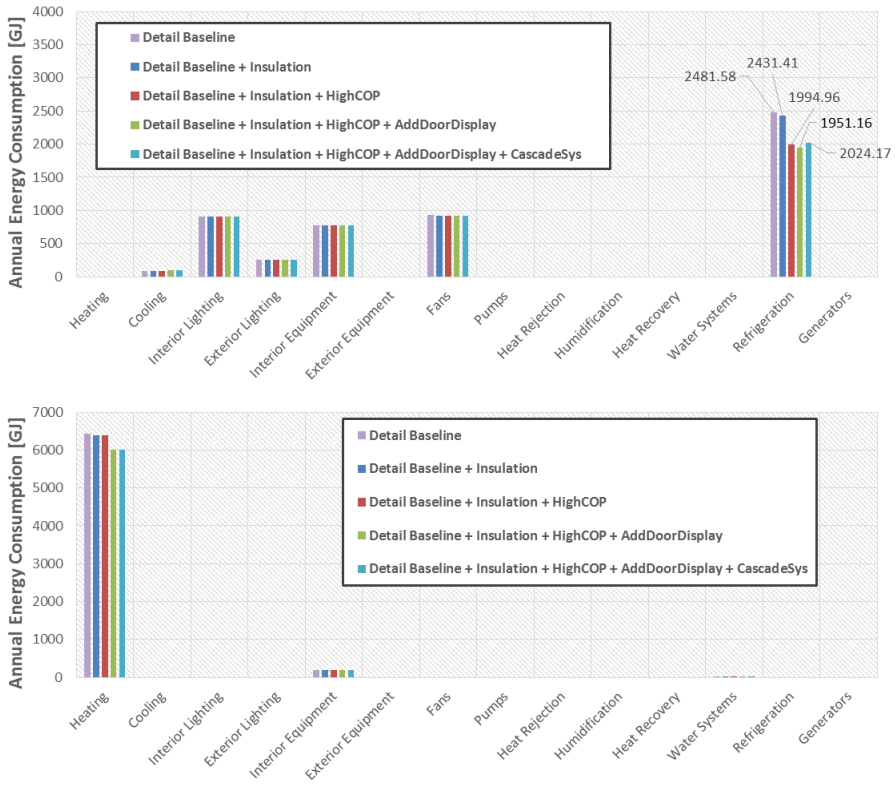


Figure 53. Retrofit result of supermarket

7. Considerations for Implementation of HVAC Packages

The goal of this project was to identify, through simulation, a number of HVAC retrofit packages that would provide substantially improved energy performance over standard equipment retrofits while also working within the strict cost constraints seen in most commercial projects. The building types studied in this analysis typically require turn-key retrofit solutions since retrofit project budgets do not allow for significant design and analysis of alternate retrofit solutions when existing equipment end-of-life is reached. The technologies and packages studied in this project, and described previously, have the potential to provide such turn-key solutions in their present form. However, a number of caveats apply to this statement:

- The building to which any of the packages are applied should be broadly similar in size and configuration to the building description used to generate the baseline energy model. Significant differences will require adjustments to the projected energy and financial performance. An energy audit can determine the extent to which the building being considered for retrofit is similar to one of the building types studied in this analysis.
- The condition of the existing equipment in the building will have an impact on the energy savings projections; well-maintained and correctly operating equipment will typically perform

better than poorly maintained equipment and this fact should be accounted for in estimating likely energy savings from the analysis in this project.

- Utility rates are subject to fluctuations and these can be significant. Payback expectations should be modified accordingly based on comparison of prevailing energy utility rates with the assumptions in this analysis.
- Likewise, energy efficiency incentive programs are subject to change over time as technologies and priorities change. Incentives also vary regionally and by utility company. The incentives described in this analysis are consistent with programs currently available. However, ground truth data will be required to determine the actual incentive programs available in any given location where a building energy retrofit is being considered.

The current project scope did not include the possibility of validating the proposed HVAC packages in real, rather than simulated, building retrofit projects. Absent validation in the field, the HVAC package solutions proposed provide a high likelihood of improved energy and financial performance compared to standard retrofit options. The energy analysis methods used are comparable to those that would be conducted on a real building retrofit project, assuming available budget, but this analysis is no substitute for standard due diligence in making retrofit equipment selections and generating material and installation costs based on these selections.

Finally, sustained performance of a retrofit HVAC system depends on: correct installation; proper commissioning, to verify correct operation; and preventive maintenance in accordance with equipment manufacturer recommendations. Sub-metering electrical power to verify system performance is recommended for: each HVAC packaged system; all unitary air conditioners and heat pumps; indoor and outdoor components of split systems and VRF systems; exhaust fans and DOAS units; pumps; and boilers.

8. Summary

HVAC package solutions were identified that meet the stated objectives, based on 6 building types (quick service restaurant, full service restaurant, small hotel. large hotel, supermarket, and convenience store) in 6 region/climate zone combinations. The modeling tool used was EnergyPlus. The technologies used in the package solutions were developed from the DOE P-Tool and selected to be consistent with the High Impact Technology Program to expand deployment of established but underutilized retrofit solutions.

For each of the 30 building type-region/climate zone combinations, the baseline, standard HVAC retrofit and packaged retrofit solutions were evaluated for both energy savings potential and retrofit first cost, simple paybacks were computed based on the incremental cost and annual HVAC energy cost savings of the packaged retrofit solutions over the standard retrofit were determined. Standard retrofits are defined as replacing HVAC equipment with new equipment that meets the code requirements without changing the HVAC system configuration. For each building type-region/climate zone combination, 5-7 retrofit packages were evaluated.

The results show that, for the building types and climate zones analyzed, many of the proposed packaged retrofit solutions can achieve 50% or greater HVAC energy savings. A simple payback analysis was performed for each retrofit package combination, which showed that packages meet the project goals for a majority of the building types and climate zones. The packages with the highest percentage HVAC savings that achieve a 4 year or less un-incentivized payback are shown in Table 58. The number of compliant packages increases when energy efficiency financial incentives are applied based on the selected locations as shown in Table 59. These incentives are an important component to reduce the simple payback below the maximum acceptable to most commercial building owners and operators.

Largest Energy Savings and Corresponding Un-incentivized Simple Paybacks in Years						
U. S. Census Regions and Divisions	South	Midwest	South	Northeast	Midwest	West
U. S. Climate Zones for 2003 CBECS	Zone 4	Zone 2	Zone 5	Zone 2	Zone 1	Zone 4
Representative City (ASHRAE Climate Zone)	Charlotte NC (3A)	Indianapolis IN (5A)	Houston TX (2A)	Boston MA (5A)	Minneapolis MN (6A)	Los Angeles CA (3B)
Quick Service Restaurant	64% / 3.5		55% / 2.1			
Full Service Restaurant	53% / 4					
Small Hotel	61% / 3.4	58% / 3.5	66% / 3.8	59% / 3.1		59% / 3.4
Large Hotel	79% / 4	84% / 3.2	77% / 3.7	74% / 2.7	75% / 3.2	56% / 3.9
Supermarket			78% / 3.7	57% / 2.9		
Convenience Store						

Table 58: Summary of Un-Incentivized Retrofit Packages Which Exceed 50% HVAC Energy Savings and Have a Simple Payback of 4 Years or Less

Largest Energy Savings and Corresponding Incentivized Simple Paybacks in Years						
U. S. Census Regions and Divisions	South	Midwest	South	Northeast	Midwest	West
U. S. Climate Zones for 2003 CBECS	Zone 4	Zone 2	Zone 5	Zone 2	Zone 1	Zone 4
Representative City (ASHRAE Climate Zone)	Charlotte NC (3A)	Indianapolis IN (5A)	Houston TX (2A)	Boston MA (5A)	Minneapolis MN (6A)	Los Angeles CA (3B)
Quick Service Restaurant	64% / 3.5		55% / 1.3			
Full Service Restaurant	53% / 4	60% / 4				
Small Hotel	61% / 2.5	58% / 1.5	66% / 1.8	59% / 1.3		59% / 2.4
Large Hotel	79% / 3.4	84% / 2.9	77% / 2.9	74% / 1.4	75% / 3.1	58% / 3.5
Supermarket	67% / 3.7		78% / 2.9	57% / 1.4		
Convenience Store		72% / 1.5		61% / 3.3		

Table 59: Summary of Un-Incentivized Retrofit Packages Which Exceed 50% HVAC Energy Savings and Have a Simple Payback of 4 Years or Less