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BongGil Jeon
Purdue University, United States of America, jeonb@purdue.edu

W. Travis Horton
Purdue University, United States of America, wthorton@purdue.edu

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Bonggil JEON[1]*, W. Travis HORTON[1]

[1]Purdue University, School of Civil Engineering,
West Lafayette, IN, USA
bongway@purdue.edu, wthorton@purdue.edu

* Corresponding Author

ABSTRACT

According to the Commercial Building Energy Consumption Survey 2003 (CBECS 2003) conducted by the U.S. Energy Information Administration, over 70% of existing commercial buildings across the United States are more than twenty years old, with many of these buildings soon in need of renovation. Also, CBECS 2003 reports that existing small- and medium-sized commercial buildings (smaller than 200,000 ft^2 or 18,580.6 m^2) consume about 75% of the energy used in this sector, which means there is a great potential for energy savings with integrated technologies and building retrofit solutions, such as HVAC (Heating, Ventilating, and Air Conditioning) and envelope integration, and window and lighting integration. The primary focus of this study is to compare the annual performance of different types of HVAC equipment in existing small- and medium-sized commercial buildings, and to identify appropriate HVAC systems that could be retrofit into different commercial building types in a cost effective manner. Prototypical building types and characteristics for baseline models are proposed based on the CBECS 2003 microdata; and annual energy simulation results from EnergyPlus are utilized to analyze the different HVAC retrofit technology options.

1. INTRODUCTION

Existing commercial building retrofits have received considerable attention from the U. S. government and the building industry (IBE, 2013). According to the Commercial Building Energy Consumption Survey (CBECS) 2003 (EIA, 2006) conducted by the U.S. Energy Information Administration (EIA), over 70% of existing commercial buildings across the United States are more than twenty years old, with many of these buildings soon in need of renovation. These old buildings consume about 20% of the primary energy in the United States, which means there is a great potential for energy savings with integrated technologies and building retrofit solutions, such as HVAC and envelope integration, and window and lighting integration. Figure 1 shows the ranking of the highest energy consumption for all commercial buildings by Principal Building Activity (PBA). The first seven principal buildings account for 76% of the building energy usage of commercial buildings (EIA, 2008). Since 99% of commercial buildings are smaller than 200,000 ft^2 (18,580.6 m^2), a lot of attention has been paid to retrofitting small- and medium-sized commercial buildings (SMSCB). Furthermore, CBECS 2003 shows that existing small- and medium-sized commercial buildings, within the 1,001 – 200,000 ft^2 (93 – 18,580.6 m^2) range, consume about 75% of the energy used in all commercial buildings.

In retrofit projects of small- and medium-sized commercial buildings, decisions are typically made without a detailed evaluation of the design alternatives due to cost and schedule constraints (IBE, 2011). Also, due to the lack of proper design and application guidelines some small- and medium-sized commercial buildings that have incorporated new technologies in the retrofit process, fail to achieve energy savings targets. This is because inadequate understanding of their operation and poor compatibility between retrofit components are not properly integrated through a holistic design process. Therefore, it is important to understand the features of new technologies and the interaction between potential retrofit components. This study will demonstrate how to develop prototypical building types and characteristics for baseline models based on the CBECS 2003 database and how to analyze annual energy simulation results from EnergyPlus employing the different HVAC retrofit technology options. The objective of this study is to evaluate and select HVAC retrofit solutions for target buildings providing 50% HVAC energy savings with a payback of less than 4 years with available incentive programs.

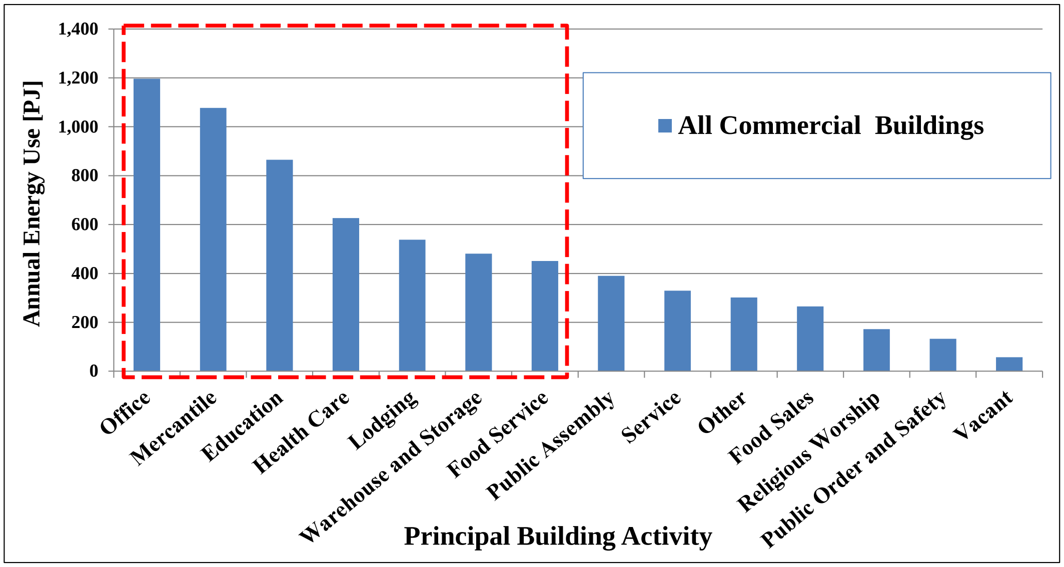

Figure 1: Annual energy use in all commercial buildings (EIA, 2008)

2. TARGET BUILDINGS AND HVAC SYSTEM CHARACTERISTICS

2.1 Target Building Types

Target retrofit building types were identified based on results of the CBECS (Commercial Buildings Energy Consumption Survey) 2003 database (EIA, 2006). For the purposes of this current study, three building types including mercantile, office, and education were selected from among the Principal Building Activities (PBA). Since small- and medium-sized commercial buildings are defined as those buildings with less than 200,000 ft^2 (18,580.6 m^2), a total of five target buildings were selected from within these three buildings types, namely: 1) stand-alone retail, 2) strip mall, 3) small office, 4) medium office, and 5) primary school. These five target buildings are included in both DOE (Department of Energy)'s Commercial Reference Buildings (NREL, 2011) and Commercial Prototype Building Models (PNNL, 2011) and these three building types consumed 46.2% of the energy usage of SMSCB which corresponds to 4,866 trillion Btu (5,134 PJ).

Major fuel consumption for Small- to Medium-Sized Commercial Buildings (SMSCB) within each Principal Building Activity (PBA) was extracted from CBECS 2003. Table 1 details the major fuel consumption for each PBA with different categories of building floorspace. Also, the results show that energy consumption of SMSCB covered about 75% of the energy consumption of all commercial buildings which corresponds to 6,523 trillion Btu (6,882 PJ). Therefore, it is of great importance to investigate SMSCB retrofit opportunities. In Figure 1, the rank order of PBA was defined by the most energy consumption of all commercial buildings; however, it may be different when it comes to SMSCB. Table 1 shows that the first three highest energy consuming building types of SMSCB are mercantile, office, and education.

In this study, it is important to choose the building vintage prior to modeling. Fortunately, in the CBECS 2003 database, it is possible to extract both annual energy consumption and number of building types by year of construction. The results show that the highest annual energy consumption was presented between 1970 and 1999 for all commercial buildings as well as SMSCB. In addition, more than half of buildings were constructed between

1970 and 1999. Accordingly, these two results led to the approach of using DOE's post-1980 reference building models to represent baseline energy consumption.

Table 1: Major Fuel consumption with Principal Building Activity (PBA)

Principal Building Activity	Sum of Major Fuel Consumption [PJ] Building Floorspace [Square Feet] (93-18,580.6 m^2)							All Buildings Total [PJ]	SMSCB Ratio [%]
	1,001 - 5,000	5,001 - 10,000	10,001 - 25,000	25,001 - 50,000	50,001 - 100,000	100,001 - 200,000	SMSCB Total		
Education	**31**	**36**	**72**	**149**	**226**	**213**	**725**	**865**	**83.8**
Food Sales	**105**	**47**	**45**	**28**	**35**	**4**	**264**	**264**	**100.0**
Food Service	**217**	**119**	**61**	**33**	**21**	**0**	**450**	**451**	**100.0**
Health Care	**11**	**23**	**21**	**22**	**67**	**85**	**229**	**626**	**36.5**
Inpatient	0	0	0	4	37	71	112	501	22.4
Outpatient	11	23	21	18	30	13	116	126	92.7
Lodging	**8**	**22**	**45**	**91**	**83**	**104**	**353**	**538**	**65.7**
Mercantile	**76**	**104**	**219**	**108**	**181**	**191**	**880**	**1,078**	**81.6**
Retail (Other Than Mall)	62	55	89	36	19	53	314	336	93.2
Enclosed and Strip Malls	15	49	129	72	163	138	566	741	76.4
Office	**112**	**68**	**175**	**142**	**118**	**152**	**767**	**1,196**	**64.1**
Public Assembly	**18**	**44**	**62**	**40**	**56**	**108**	**329**	**390**	**84.2**
Public Order and Safety	**11**	**12**	**12**	**11**	**18**	**34**	**98**	**133**	**73.5**
Religious Worship	**20**	**37**	**59**	**40**	**6**	**9**	**171**	**172**	**99.3**
Service	**77**	**50**	**92**	**38**	**21**	**7**	**286**	**329**	**86.9**
Warehouse and Storage	**24**	**25**	**50**	**52**	**63**	**85**	**300**	**481**	**62.3**
Other	**8**	**5**	**33**	**22**	**51**	**118**	**237**	**302**	**78.7**
Vacant	**4**	**1**	**2**	**7**	**18**	**13**	**45**	**57**	**78.8**
Total	**723**	**594**	**948**	**782**	**963**	**1,123**	**5,134**	**6,882**	**74.6**

2.2 Representative Climate Zones

To select relevant cities that accurately represent national climatic and energy usage variation, U.S. Census Regions & Divisions as well as U.S. Climate Zones for CBECS 2003 were used. A total of six different locations were selected based on the annual energy consumption of the proposed buildings. The first five locations represent those places where the selected building types exhibit the highest energy consumption. However, West-Zone 4 was also included for sake of diversity even though the annual energy consumption in that climate zone did not rank within the top five. These six combinations of regions and climate zones consumed 32.4% of the total energy (1,576 trillion Btu or 1,663 PJ) of SMSCB. Figure 2 shows the annual energy consumption for three proposed building types by regions and climate zones.

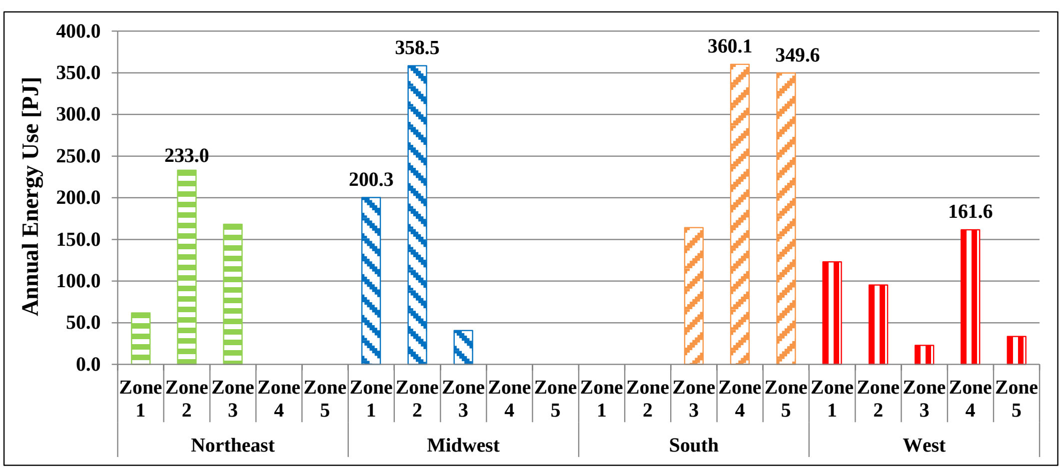

Figure 2: Annual energy consumption for three proposed building types by regions and climate zone

Table 2 shows the rank order of highest energy consumption by region & climate zone, and their representative cities. These representative cities were determined based on population according to the 2010 U.S. Census. Cities with the highest population in each region and climate zone except Midwest-Zone 1 and 2 were selected for use as representative weather data input to the building simulation. Milwaukee and Chicago are the cities with the highest population in Midwest-Zone 1 and Zone 2 respectively. However, Chicago was excluded because it is located close to Zone 1. And also Milwaukee was rejected because it is located near Chicago. Therefore, it is more reliable to use other representative cities, such as Minneapolis, MN and Indianapolis, IN instead. Figure 3 shows the final representative cities in a combination map of regions and climate zones.

Table 2: Ranking of highest energy consumption by regions & climate zones and representative cities

Rank	Regions & Climate	Representative Cities	ASHRAE Climate Zone
1	South, Zone 4	Charlotte, NC	3A
2	Midwest, Zone 2	Indianapolis, IN	5A
3	South, Zone 5	Houston, TX	2A
4	Northeast, Zone 2	Boston, MA	5A
5	Midwest, Zone 1	Minneapolis, MN	6A
6	West, Zone 4	Los Angeles, CA	3B

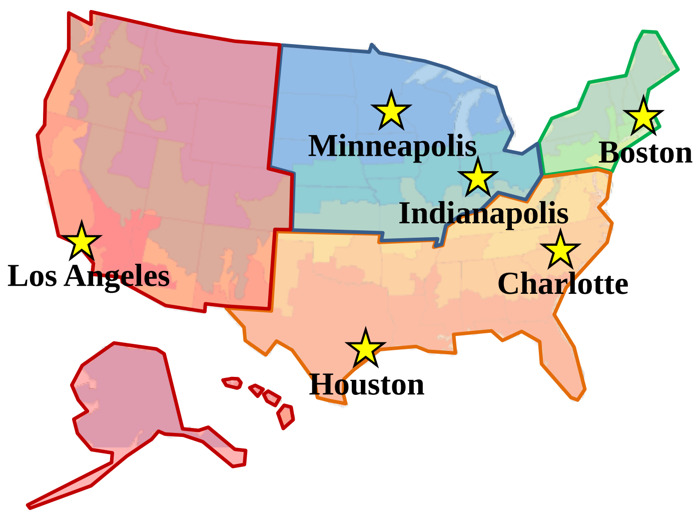

Figure 3: Representative cities in a combination map of regions and climate zones

2.3 Baseline HVAC System Characteristics

According to the CBECS 2003 database, there are seven different heating systems and eight different cooling systems in the building questionnaire. Based on an analysis of the database, baseline heating and 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, there were two building types and climate zone where the system configurations were not reasonable based only on the CBECS database. For example, for offices in South-Zone 4, heat pump heating systems are the dominant source for heating equipment and packaged A/C units for cooling equipment. Since heat pumps can provide both heating and cooling, this specific scenario was modified to a heat pump system providing both heating and cooling. Another irrelevant HVAC system configuration was found in Northeast-Zone 2. In nature, Packaged A/C units with a furnace are more appropriate HVAC systems than Individual Room A/C with furnace. Figure 4 shows the dominant heating system for office buildings in each region and climate zone. The results show that the majority of small- and medium-sized office buildings in Northeast-Zone

2 and Midwest-Zone 1 and 2 employ furnaces for major heating system. On the other hand, a heat pump is the main heating system in South-Zone 4 and a packaged heating unit is the primary heating system for South-Zone 5 and West-Zone 4.

In the CBECS 2003 questionnaire, once the responders selected the heat pump system for their heating and cooling equipment, they also needed to answer which heat pump system and what type the heat pump is. In this study, two building types, office and education, in South-Zone 4 have heat a pump system. Detailed heat pump systems and types of heat pumps for those building types are indicated in Table 3.

Since detailed HVAC systems were determined from previous data analysis, the major heat source for each HVAC system may also be filtered from the CBECS 2003 database. Identifying the major heating source is important because source energy prices may have an impact on economic analysis. Natural gas is the most dominant heating source for cold locations. On the other hand, office and education located in South-Zone 4 and 5 where cooling is more important than heating employ electricity for heating source. Also, the major heating source for the proposed building types is presented in Table 3.

For selection of the main air distribution system, a detailed analysis of the raw data was conducted. Air distribution systems are one of the important factors for HVAC system energy consumption. In this study, air distribution systems for the proposed building type were identified using several criteria from the database: region and climate zone; heating and cooling equipment; and buildings within 1,001 – 200,000 ft^2 (93 – 18,580.6 m^2). A detailed raw data analysis from CBECS 2003 reveals that CAV (Constant Air Volume) systems are dominant for most building types in each region and climate zone regardless of whether the data is sorted by the total number of buildings or total floorspace conditioned using CAV systems. However, air distribution systems for mercantile and education in West-Zone 4 is different. For mercantile building types in West-Zone 4, the CAV system is dominant when sorting the data by total building floorspace; however, VAV (Variable Air Volume) systems are dominant when sorted by the total the number of buildings using them. In addition, for education building types in West-Zone 4, VAV is the main air distribution system in both the number of buildings and floorspace.

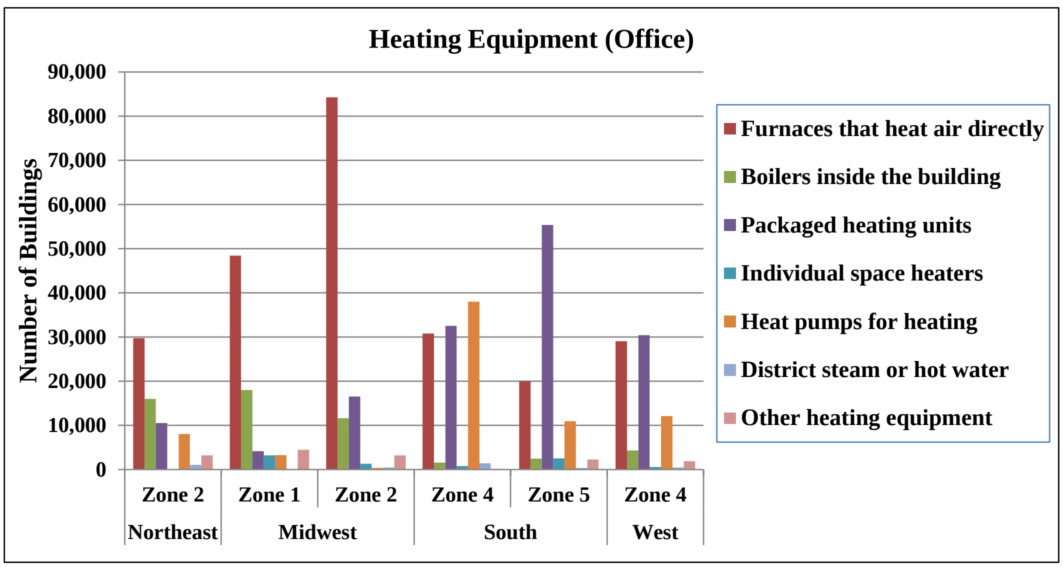

Figure 4: Dominant heating system of office buildings in each region and climate zone

2.4 Baseline SMSCB Models

After selecting the appropriate building types together with their baseline HVAC systems and representative cities, the next step is to develop baseline models for existing SMSCB in EnergyPlus. Even though DOE's post-1980 reference building models (NREL, 2011) are used for baseline models of prototypical SMSCB, they must still be modified because these models have outdated occupancy and operating schedules which are consistent with previous ASHRAE Standard 90.1-1989 (ASHRAE, 1989). Obviously, post-1980 reference building models do not reflect existing commercial buildings in the present era. Thus, in this study baseline prototypical SMSCB models were adjusted with several assumptions; including, 1) the building physical parameters and construction characteristics are the same as post-1980 models, and 2) lighting power density, plug load, and occupancy levels are modified to reflect today's current lifestyle. Table 3 shows a simulation matrix of baseline building models.

Table 3: Simulation matrix of baseline building models

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)
Office	Small Office	Heating	Heat Pump (Elect.) - Air Source - Packaged Unit	Furnace (Natural Gas)	Packaged Heating Unit (Electricity)	Furnace (Natural Gas)	Furnace (Natural Gas)	Packaged Heating Unit (Electricity)
		Cooling	Heat Pump - Air Source - Packaged Unit	Packaged A/C Unit	Residential-type Central A/C	Packaged A/C Unit	Packaged A/C Unit	Packaged A/C Unit
	Medium Office	Heating	Heat Pump (Elect.) - Air Source - Packaged Unit	Furnace (Natural Gas)	Packaged Heating Unit (Electricity)	Furnace (Natural Gas)	Furnace (Natural Gas)	Packaged Heating Unit (Electricity)
		Cooling	Heat Pump - Air Source - Packaged Unit	Packaged A/C Unit	Residential-type Central A/C	Packaged A/C Unit	Packaged A/C Unit	Packaged A/C Unit
Mercantile	Stand-Alone Retail	Heating	Furnace (Natural Gas)	Furnace (Natural Gas)	Furnace (Natural Gas)	Furnace (Natural Gas)	Furnace (Natural Gas)	Furnace (Electricity, VAV)
		Cooling	Packaged A/C unit	Packaged A/C unit	Packaged A/C unit	Packaged A/C unit	Residential-type Central A/C	Packaged A/C unit
	Strip Mall	Heating	Furnace (Natural Gas)	Furnace (Natural Gas)	Furnace (Natural Gas)	Furnace (Natural Gas)	Furnace (Natural Gas)	Furnace (Electricity)
		Cooling	Packaged A/C unit	Packaged A/C unit	Packaged A/C unit	Packaged A/C unit	Residential-type Central A/C	Packaged A/C unit
Education	Primary School	Heating	Heat Pump (Elect.) - Air Source - Individual Room HP	Boiler (Natural Gas)	Packaged Heating Unit (Electricity)	Boiler (Natural Gas)	Boiler (Natural Gas)	Furnace (Natural Gas, VAV)
		Cooling	Heat Pump - Air Source - Individual Room HP	Packaged A/C Unit	Packaged A/C Unit	Packaged A/C Unit	Packaged A/C Unit	Packaged A/C Unit

3. HVAC RETROFIT MEASURES AND PACKAGES

Potential HVAC retrofit measures for SMSCB are collected and identified from previous research. Afterwards, each of the HVAC retrofit technology options for each application were ranked for each of the different climate zones. The ranking scores range from 1 to 5, corresponding to not effective to very effective, respectively. Four team members ranked the table of retrofit options and an average score was computed. The final averaged scores for climate zone 1 and 2 are shown in Table 4.

Based on the effectiveness scores and the baseline HVAC system configurations, the most effective technologies were selected to form different permutations or packages for each specific type of building. Figure 5 shows the technology permutations for office buildings in Midwest-Zone 1 (Minneapolis).

The technology packages are configured in consideration of compatibility issues. At each level, technologies that are compatible with each other are placed in the same block, whereas in compatible technologies are in separate blocks. For example, the three cooling & heating technologies, #5, #21 and #22, are incompatible.

Table 4: List of HVAC retrofit technologies

#	HVAC Technology Option Description	Category	Likely Energy Effectiveness	
			Climate Zone 1	Climate Zone 2
1	Switch from CAV to VAV	Air distribution	4	4
2	Customized AC system for hot-dry climates	Cooling	2	2.25
3	High efficiency vapor compression cycle in AC units	Cooling	2.25	2.75
4	High efficiency evaporator fan in AC units	Air distribution	2.75	3
5	High eficiency RTU system	Cooling and heating	4.25	4.25
6	Energy storage shift A/C operation periods	Cooling and heating	3.25	3.5
7	Chilled beams in temperate climates	Air distribution	2.5	3
8	Right-size A/C units and heaters for retrofit	Design	4.25	4.25
9	Use desiccant-enhanced evaporative cooling in both dry and humid climates	Cooling	1.75	2.25
10	Liquid desiccant AC in humid climates	Cooling	2.25	2.75
11	Maisotsenko cycle cooling (e.g., Coolerado) in hot-dry, cold- and mixed-dry climat	Cooling and heating	2.75	3
12	Use spray-cooled evaporators for packaged A/C	Cooling	1.75	2.75
13	Used sprayed mesh to improve A/C efficiency	Cooling	1.5	2.25
14	Best available duct sealing in exist building retrofit	Air distribution	3.5	3.5
15	Low pressure drop air filters in ducted systems	Air distribution	3.5	3.5
16	High efficiency hot water circulation pumps	Heating	3.75	3.75
17	Add stack economizer to boilers	Heating	3.75	3.75
18	Use most efficient furnaces and boilers (i.e., max-tech)	Heating	4	4
19	Replace large-capacity boilers with cascaded-multiple boilers	Heating	4	4
20	Use integrated heat pumps (heating, cooling and hot water)	Cooling and heating	3	3.5
21	Use ground source heat pumps (EER 42.1 by ClimateMaster)	Cooling and heating	3.75	3.75
22	Use dual source (air and ground) heat pumps	Cooling and heating	4	4
23	Use gas engine driven heat pumps	Cooling and heating	2.25	2.25
24	Use dedicated outdoor air systems with energy recovery	Outside air and ventilation	4	3.5
25	Demand controlled ventilation based on CO2	Operation, Control & Diagnostics	3.75	3.25
26	Apply desiccant wheels in hot humid climates	Outside air and ventilation	2	2.25
27	Operational fault diagnostics for key HVAC system components (outside air, RTU	Operation, Control & Diagnostics	3.5	3.5
28	Steam-clean A/C coils regularly for improved performance	Operation, Control & Diagnostics	3.25	3.25
29	Increased subdivision of building spaces for improved zone thermal control	Design	4	4
30	Model-predictive control for small to medium sized buildings	Operation, Control & Diagnostics	4	3.5
31	Night purge for ruduced day-time cooling load and peak demand in shoulder seaso	Operation, Control & Diagnostics	3	3
32	Operable windows link to HVAC control (shut off zone conditioning when window	Operation, Control & Diagnostics	3.25	3.25
33	Variable refrigerant flow HVAC system	Cooling and heating	3.5	3.5
34	High efficiency Multi-split AC units	Cooling and heating	3.25	3.75
35	Predictive thermostats	Operation, Control & Diagnostics	3.25	3.25
36	Automated whole-building diagnostics (AWBD)	Operation, Control & Diagnostics	3.25	3.25
37	Packaged HVAC controls for existing buildings (economizer, multi-speed fan and c	Operation, Control & Diagnostics	3.5	3.5
38	Wireless temperature sensors	Operation, Control & Diagnostics	2.5	2.5
39	Develop and deploy low cost wireless sensors.	Operation, Control & Diagnostics	2.5	2.5
40	Develop and deploy a controller pack to RTU accomponied by a gas furnace for d	Operation, Control & Diagnostics	4	4
41	robust optimum start, ventilation lockout during warmup, occupancy sensor standby	Operation, Control & Diagnostics	3.75	3.25
42	Upgrade medium or small sized office buildings (<100,000SF) from standalone ther	Operation, Control & Diagnostics	3.75	3.75
43	Move to standardize PSC motors in commercial blowers	Air distribution	3.25	3.25
44	MTAB gas furnaces, comm	Heating	3.5	3.75
45	Regenerative Air source heat pump (The project team, comprised of S-RAM Dyn	Cooling and heating	3.5	3.5
46	Develop and deploy the ThermoLift natural-gas-driven HP. "For heating, the Therr	Cooling and heating	2.75	2.75
47	Develop add-on humidity control packages for retrofit applications	Outside air and ventilation	3.25	3.25

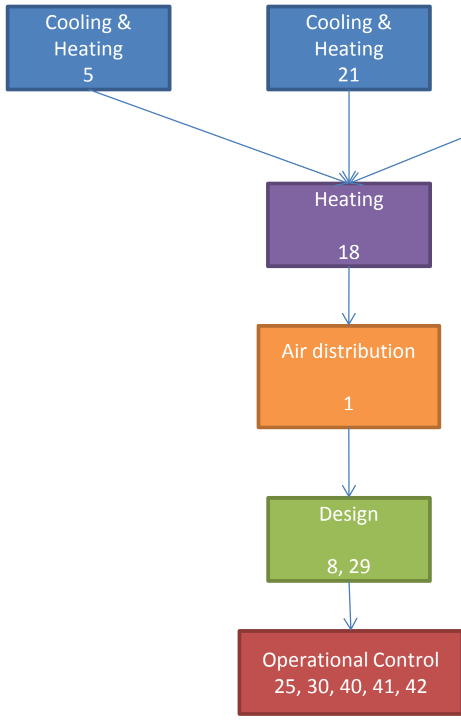

Figure 5: HVAC retrofit technology permutations for "Midwest-Zone 1: Small Office" (Minneapolis)

4. EVALUATION OF THE TECHNOLOGY PACKAGES

To evaluate the energy consumption of the various HVAC retrofit packages, EnergyPlus was selected as the simulation platform. For cost estimation, data in RSMeans (RSMeans, 2013a; RSMeans, 2013b; RSMeans, 2013c) and DOE's P-Tool (NREL, 2012) were used. Also, availability and magnitude of incentives were considered for simple payback analysis. The evaluation involves the following steps.

Step 1: Develop Pre-Retrofit Building Energy Models and Validate Against CBECS 2003 Data

In this step, pre-retrofit baseline models were derived from DOE's Commercial Reference Building Models ("post-1980"). The building envelope information was kept unchanged from the original commercial reference models. The HVAC system configuration was modified according to information shown in Table 3. HVAC equipment performance complies with ASHRAE Standard 90.1-1989 (ASHRAE, 1989). The interior lighting gain was changed to comply with ASHRAE Standard 90.1-2001 (ASHRAE, 2001), assuming that the building has gone through lighting retrofits. Plug load, occupancy level, and schedules were changed to reflect current lifestyle complying with ASHRAE Standard 62.1-2013 (ASHRAE, 2013a) and 90.1-2013 (ASHRAE, 2013b). With the baseline pre-retrofit model, the annual energy consumption was compared with CBECS data to make sure that the baseline energy usage is close to the statistics from CBECS data.

Step 2. Develop Standard Retrofit Energy Models and Evaluate Its Energy Impact

The "standard retrofit" is defined as replacing the HVAC equipment in the pre-retrofit baseline with new equipment of the same style but with higher efficiency. The performance of the new equipment complies with ASHRAE Standard 90.1-2013. Compared with the pre-retrofit scenario, the standard retrofit would demonstrate some energy savings due to the higher efficiency equipment.

Step 3. Develop Integrated Retrofit Energy Models and Evaluate Energy Impact

In this step, the HVAC system configuration and performance from the baseline energy model is modified according to the measures listed in Table 4. The different measures were added until a packaged solution is completed. Then annual simulation is run to obtain the annual energy consumption for each package.

Step 4. Cost Estimation for Standard Retrofit and Integrated Retrofit Packages, Simple Payback Period Calculation, Iterate with Step 3 If Necessary

In this step, the cost to implement the standard retrofit and the other proposed integrated retrofit packages are estimated based on data provided in the RSMeans data book and cost information provided in DOE's P-Tool. Simple payback period is calculated based on the energy savings potential of the integrated retrofit package over the standard retrofit and their cost difference. The cost used for simple payback considers equipment, labor cost, and incentives. Engineer judgement was used to drop certain ineffective measures from the packaged to form a new package.

Table 5: Retrofit package evaluation results

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)	
Office	Small Office	PTHP (high effic.) DOAS with ERV		Fixed duct leakage RTU (high effic.) Gas Heater (high effic.)		VRF multi-split HP DOAS with ERV		VRF multi-split HP DOAS		Fixed duct leakage Economizer RTU (high effic.) Gas Heater (high effic.)		Fixed duct leakage RTU Economizer	
		51%	19	34%	6.5	50%	29.2	62%	71	31%	17.1	52%	2.9
	Medium Office	VRF multi-split HP ERV unit DCV		VRF multi-split HP ERV unit DCV		VRF multi-split HP DOAS DCV		Fixed duct leakage VAV RTU (high effic.) DCV		Fixed duct leakage Heat pump (ground source)		VRF multi-split HP ERV unit DCV	
		40%	34.7	58%	2.3	58%	0	61%	6.1	64%	125	49%	0
Mercantile	Stand-Alone Retail	AC unit (DX) Gas heat (core) Multi-split HP (others)		AC unit (DX) Gas heat (core) Multi-split HP (others)		AC unit (DX) Gas heat (core) Multi-split HP (others)		AC unit (DX) Gas heat (core) Multi-split HP (others)		AC unit (DX) Gas heat (core) Multi-split HP (others)		AC unit (DX) Gas heat (core) Multi-split HP (others)	
		48%	0	51%	0	50%	0.2	53%	0	48%	1	50%	0
	Strip Mall	Heat pump VFD supply fan 2 stage cooling coil		Heat pump VFD supply fan 2 stage cooling coil		Heat pump VFD supply fan 2 stage cooling coil		Heat pump VFD supply fan 2 stage cooling coil		VRF multi-split HP		Heat pump VFD supply fan 2 stage cooling coil	
		40%	0	30%	0.3	48%	0	30%	1.5	25%	0.3	52%	8
Education	Primary School	Heat pump (Water source) DOAS with ERV Boiler (gas fired)		VAV RTU (classroom) Enthalpy wheel CAV RTU (others) DOAS with ERV		VAV RTU (classroom) Enthalpy wheel CAV RTU (others) DOAS with ERV		VAV RTU (classroom) Enthalpy wheel CAV RTU (others) DOAS with ERV		VAV RTU (classroom) Enthalpy wheel CAV RTU (others) DOAS with ERV		RTU Economizer VFD supply fan	
		31%	0	47%	2.9	54%	2.6	51%	2.4	47%	3.1	40%	2

HVAC energy savings (first number); Simple payback (year) with incentives (second number)

- Green: Meet both energy savings and payback target
- Yellow: Meet only one of the energy savings or paback target
- Red: Neither targets are met

5. CONCLUSIONS

To assess HVAC retrofit solutions for SMSCB, prototypical building types and their features were developed. Mercantile (stand-alone retail and strip mall), office (small and medium office), and education (primary school) were selected as the baseline models for this study from among the principal building activities based on CBECS 2003 analysis. In addition, an energy model of these building types were upgraded with current lifestyle parameters to represent real existing energy buildings models. The modeling tool used was EnergyPlus.

Nine HVAC solutions were identified to meet the stated objectives, based on 5 building types (small office, medium office, stand-alone retail, strip mall, primary school) in 6 region & climate zone combinations (Table 5). For each of the 30 combinations the baseline standard HVAC retrofit and packaged retrofit solutions were evaluated for their energy savings potentials. Also, the first cost and simple payback of each retrofit were computed based on the incremental cost and annual HVAC energy cost savings of the packaged retrofit solutions over the standard retrofit. Standard retrofits are defined as replacing the old HVAC equipment with new equipment that meets current code efficiency requirements without changing the HVAC system configuration. For each building type and region & climate zone combination, 3-7 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. However, most of the packaged retrofit solutions did not achieve the payback target of 4 years or less. Therefore, existing incentives were applied based on the selected locations. These incentives are an important component to reduce the simple payback below the maximum acceptable to most commercial building owners and operators.

REFERENCES

ASHRAE. (1989). *Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings. ANSI/ASHRAE/IESNA Standard 90.1-1989.* Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASHRAE. (2001). *Energy Standard for Buildings Except Low-Rise Residential Buildings.* ANSI/ASHRAE/IESNA Standard 90.1-2001. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASHRAE. (2013). *Energy Standard for Buildings Except Low-Rise Residential Buildings.* ANSI/ASHRAE/IES Standard 90.1-2013. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASHRAE. (2013). *Ventilation for Acceptable Indoor Air Quality*. ANSI/ASHRAE Standard 62.1-2013. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

EIA. (2006). *2003 Commercial Buildings Energy Consumption Survey*. Energy Information Administration (EIA).

EIA. (2008). *Overview of Commercial Buildings, 2003.* Energy Information Administration (EIA).

IBE. (2011). *2011 Energy Efficiency Indicator: GLOBAL Results.* Institute for Building Efficiency

IBE. (2013). *Energy efficiency indicator - 2013 U.S. Results.* Institute for Building Efficiency

NREL. (2011). *U.S. Department of Energy Commercial Reference Building Models of the National Building Stock.* (NREL/TP-5500-46861). Golden, CO: National Renewable Energy Laboratory.

NREL. (2012). *A Tool to Prioritize Energy Efficiency Investments.* (NREL/TP-6A20-54799). Golden, CO: National Renewable Energy Laboratory.

PNNL. (2011). *Achieving the 30% Goal: Energy and Cost Savings Analysis of ASHRAE Standard 90.1-2010.* (PNNL-20405). Richland, WA: Pacific Northwest National Laboratory.

RSMeans. (2013). *RSMeans Square Foot Cost Data 2014.* Rockland, MA: RSMeans Publishers.

RSMeans. (2013). *RSMeans Green Building Cost Data 2014.* Rockland, MA: RSMeans Publishers.

RSMeans. (2013). *RSMeans Mechanical Cost Data 2014.* Rockland, MA: RSMeans Publishers.

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