CONSORTIUM for BUILDING ENERGY INNOVATION

FINDINGS

The Consortium for Building Energy Innovation

CBEI is focused on generating impact in the small and medium-sized commercial buildings (SMSCB) retrofit market. CBEI is comprised of 14 organizations including major research universities, global industrial firms, and national laboratories from across the United States who collaborate to develop and demonstrate solutions for 50% energy reduction in existing buildings by 2030. The CBEI *FINDINGS* series highlights important and actionable technical, application, operation and policy research results that will accelerate energy efficiency retrofits when applied by various market participants. CBEI views these FINDINGS as a portal for stakeholders to access resources and/or expertise to implement change.

Improving Energy Efficiency Through Integrated Systems

Is it possible to achieve a 50% improvement in system efficiency by integrating HVAC retrofits while remaining under a four-year payback? This is the task that CBEI researchers tackled, over the past couple of years, focusing on small and medium-sized existing buildings.

Due to a lack of experience and objective performance data, owners often make energy retrofit decisions based on their trusted contractor's personal preference or comfort level. If significant energy efficiency improvement in the existing building stock is necessary, then there is a growing need among owners in the architecture, engineering and construction (AEC) industry for objective data on the performance impacts of heating, ventilating and air conditioning (HVAC) components as integrated systems.

This CBEI research project focused on HVAC system design and equipment selection. Decisions in retrofits of small to medium-sized commercial buildings are typically made like-to-like without a detailed evaluation of the design alternatives. This is primarily a result of cost and schedule constraints but also is impacted by a lack of proper design and application guidelines, as well as, a desire to avoid comfort complaints on design days. CBEI research has demonstrated through simulation that, for selected building types over a range of climate zones, HVAC package solutions exist that have the potential to provide at least 50% HVAC energy savings with a simple payback of 4 years or less.

Research Findings: ***Integrated Systems***

Identified 66 packaged HVAC solutions - one package for each of the eleven building types and six selected climate zones.

Nine of thirty packaged HVAC measures met the greater than 50% HVAC efficiency reduction and also had paybacks less than 4 years.

Twelve more packaged HVAC measures have 25% to 49% HVAC efficiency reduction and also had paybacks less than 4 years.

CBEI work in using virtual energy audits and retrofits has identified cost effective deep HVAC energy retrofits and has contributed to the ease of modeling them through OpenStudio.

Typically, small and medium-sized commercial buildings have low HVAC energy cost relative to other business expenditures which impedes deep energy retrofit market uptake.

Deep energy retrofit of HVAC systems in existing buildings will be necessary to reduce the nation's energy intensity and carbon emissions. If properly focused, public policy centering on energy intensity and carbon emissions reduction will likely have a positive impact on uptake of HVAC deep energy retrofits.

Selecting Building Architypes, Climate Zones and Regions

Baseline buildings configurations were defined for 12 building types (Table 1) in 6 region/climate zone combinations (Figure 1 and Table 2). Baseline HVAC system configurations were defined based on analysis of eighty-five (85) dominant system characteristics using CBECS[1]-2003 database results.

Table 1: Building Types Assessed

- small size office building
- medium size office building
- stand-alone retail
- strip mall
- primary school
- quick service restaurants
- full service restaurants
- small hotels
- medium hotels
- supermarkets
- chain type convenience stores
- corner stores

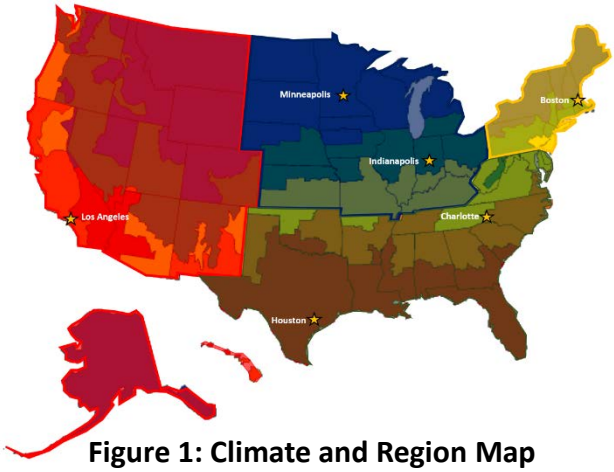


Figure 1: Climate and Region Map

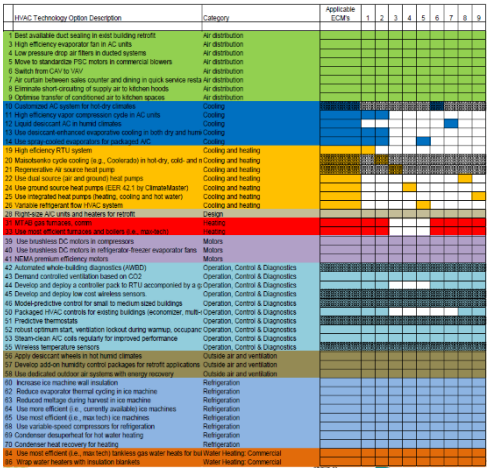
Table 2: Regions and Climate Zones

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

Retrofit Package Selection

Retrofit options selected for the building type and climate zone were assessed based on the applicability of each option compared to the baseline building configuration including its HVAC system. The compatibility of each technology with the other options was also assessed. This allowed all the possible compatible retrofit options applied to each package to be compared. The result for the quick service restaurant (QSR) case is a total of nine retrofit packages (Table 3), which are mostly determined by the type of Cooling/Cooling and Heating system selected since typically there can only be one or two of these. In practice, many of the technologies in each package will not be cost effective enough to warrant inclusion. The cost effectiveness of each package element was determined by using EnergyPlus models to calculate the reduction in energy savings as each retrofit option is removed sequentially from the overall retrofit package. This information was used to construct packages that minimize payback while achieving the target energy savings.

Table 3: Retrofit Packages



QSR Retrofit Packaged HVAC Baseline Performance and Potential HVAC

Based on a CBECS database analysis, heating and cooling systems were determined by building type and climate zone. Based on these results, Table 4 shows the baseline HVAC system type used for QSRs. Baseline equipment efficiencies were derived from the minimum performance requirements of ASHRAE 90.1-1989 as this is assumed to be the applicable standard when most of these buildings were constructed and of the equipment that would now need to be updated during a retrofit. Table 4 also shows the potential HVAC Energy savings assuming a 50% reduction.

Table 4 QSR Baseline Performance and Potential HVAC

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)
Baseline						
Heating	Pkg. Unit	Furnace	Pkg. Unit	Furnace	Furnace	Furnace
Cooling	Pkg. Unit	Pkg. Unit	Pkg. Unit	Pkg. Unit	Pkg. Unit	Pkg. Unit
Potential Savings (Trillion Btu)						
Total Energy	55.59	22.62	46.6	7.45	7.41	2.69
HVAC Energy	14.82	7.89	11.12	2.45	2.74	0.35
Savings-50% Potential	7.41	3.94	5.56	1.22	1.37	0.18

Retrofit Packaged HVAC Systems Evaluation

Four modeling steps were undertaken to evaluate the energy performance of the Retrofit Packaged HVAC Systems and determine the retrofit cost. Step 1: Develop pre-retrofit building and HVAC system models based on DOE Commercial Reference Building Models, validate with CBECS data. Step 2: Apply standard retrofit and evaluate its energy impact. Step 3: Implement integrated retrofit measure packages[2] and evaluate energy impact. Step 4: Cost estimation for standard retrofit and integrated retrofit measure packages, simple payback period calculation, iterate with step 3 if necessary.

Results

Table 5 presents the results showing that certain building HVAC systems can achieve a 50% or greater energy savings and deliver economics yielding less that a four-year payback (Green cells in Table 5). Note that many of the yellow cells (indicating whether less than a 50% energy reduction or greater than a four-year payback) yield significant energy reduction which are often under the four-year payback threshold.

Table 5 Five Building Architype Resulting Energy Savings and Payback

U. S. Census Regions and Divisions		Northeast	South	South	Midwest	West	Midwest
U. S. Climate Zones for 2003 CBECS		Zone 2	Zone 4	Zone 5	Zone 2	Zone 4	Zone 1
Representative City (ASHRAE Climate Zone)		Boston	Charlotte	Houston	Indianapolis	Los Angeles	Minneapolis
Small Office	% Reduction	62%	51%	50%	34%	52%	31%
	Payback	71	19	29.2	6.5	2.9	17.1
Medium Office	% Reduction	61%	40%	58%	58%	49%	64%
	Payback	6.1	34.7	0	2.3	0	125
Stand-Alone Retail	% Reduction	53%	48%	50%	51%	50%	48%
	Payback	0	0	0.2	0	0	1
Strip Mall	% Reduction	30%	40%	48%	30%	52%	25%
	Payback	1.5	0	0	0.3	8	0.3
Primary School	% Reduction	51%	31%	54%	47%	40%	47%
	Payback	2.4	0	2.6	2.9	2	3

[1] http://www.eia.gov/consumption/commercial/

[2] Many of the integrated system packages included moving from constant speed devices to variable speed devices and/or utilized mini/multi-split systems (some with variable refrigerant flow). For more information, see the final report at www.cbei.psu.edu

Lessons Learned

Achieving 50% HVAC energy savings with under a four-year payback, in the existing small and medium sized building stock, is challenging but achievable. Table 5 shows that 30 percent of the integrated systems in five applications met both criteria. An additional 40% of the integrated systems in Table 5 achieved 25 to 49% efficiency improvement with under a four-year payback.

CBEI research also confirms the following as essential tools in successful HVAC deep energy retrofits:

1. **Obtain building owner buy-in.** The more they know about and participate in the planning and design process, the better they will be able to help achieve the design retrofit efficiency.
2. **Assemble an experienced team.** The team achieves 50% HVAC energy savings by creating a building that minimizes heating, and cooling loads; and has highly efficient lighting and HVAC systems.
3. **Adopt an integrated HVAC design process.** Cost-effective, energy-efficient design requires tradeoffs among potential energy-saving features.
4. **Consider energy modeling.** CBEI researchers have added advanced integrated retrofit measures to the OpenStudio[2] measure library, so that users will be able to apply them quickly and easily to their building models.
5. **Use building commissioning.** CBEI research has verified that building HVAC systems are very often improperly installed or set up and do not operate as efficiently as expected. The 50% goal can best be achieved through building commissioning.

Moving Forward

Commercial buildings account for almost 20% of the total U.S. energy consumption. Small to medium sized commercial building HVAC systems use ~1.95 Quads site energy annually.

Acceptable retrofit cost needs to be low to achieve the 4-year payback target.

Typical small/medium sized commercial buildings have HVAC energy cost – usually less than $1.5/ft^2/year.

Energy efficiency incentives may be necessary to drive substantial uptake of energy efficient HVAC retrofits.

Opportunities to develop and apply these optimized HVAC package solutions will likely require utility and public policy engagement. Identifying potential stakeholders (policy makers, utilities, building owners) and developing opportunities for demonstration projects should be pursued.

Current simulation tools have gaps in simulation of new and near future HVAC technologies. This work has naturally led to the development of advanced integrated retrofit measures to the OpenStudio measure library. These algorithms and tools should be widely disseminated throughout the HVAC industry.

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CBEI is a research and demonstration center that works in close partnership with DOE's Building Technologies Office.

[2] OpenStudio allows building researchers and software developers to quickly get started through its multiple entry levels. Users can leverage the Ruby interface to create OpenStudio Measures that can be easily shared and applied to OpenStudio Models. https://www.openstudio.net/

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