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Getting Beyond Widgets: Performance of Efficient Indoor Air Quality System Retrofit Packages for Schools

A report on the modeled energy, greenhouse gas, and cost savings of several multi-measure retrofit packages for energy efficiency and indoor air quality in primary schools

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Abstract

School facilities are often underfunded with aging and poorly maintained HVAC and lighting systems. Most existing school buildings stand to benefit significantly from retrofits in terms of energy, cost, and emissions savings. Ventilation and indoor air quality (IAQ), which are important aspects of a healthy and productive learning environment, can also be enhanced by some energy efficiency measures (EEMs). Packaging energy efficiency and IAQ systems retrofits may represent a golden opportunity to improve performance in this critical building sector.

Retrofit projects and utility incentive programs typically emphasize only energy savings and are often component-based, targeting upgrades of one piece of equipment or control sequence at a time. The Beyond Widgets program, which addresses barriers to systems-based retrofit approaches, developed retrofit packages for schools with energy and IAQ benefits, combining EEMs vetted with a utility partner based on technical readiness, market availability, ease of implementation, energy savings potential, and other factors. EEMs included occupancy-based ventilation strategies, efficient lighting and controls, efficient supply air filtration, HVAC sequence improvements, retuning, and scheduling, as well as HVAC equipment upgrades. EEMs were combined into ten distinct packages representing a range of likely implementation costs and complexities, with the aim of packaging measures to improve overall cost-effectiveness and energy reduction impact versus performance of the individual EEMs.

Integrated system packages were evaluated for two climate zones - northern California (representative location: San Jose) and North Carolina (representative location: Charlotte) by comparing baseline and retrofit whole-building annual energy simulation results to derive annual energy and demand savings, utility cost savings, as well as carbon emission reductions. Energy savings were valued according to local utility rates. Generally, energy and carbon emissions savings were greater for the higher-cost, more comprehensive retrofit packages (i.e. packages involving more building systems and trades). Retrofit impacts ranged from 14% to 36% energy savings relative to the existing building baseline in the California case, and 13% to 36% savings in the North Carolina case. Simple payback results, calculated from modeled annual energy cost savings and estimated project implementation costs, ranged from around 6 to 11 years for early replacement scenarios and 1 to 5 years for normal replacement scenarios (only considering the incremental measure cost above code-compliant alternatives).

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1.1 Beyond Widgets Program Background

Most building energy retrofits are component-based, typically involving upgrades to only one piece of equipment or control sequence at a time. Utility incentive programs are an important channel to support energy efficiency upgrades in buildings, but utility programs normally target single-component strategies (Regnier, 2020). Case studies demonstrate that integrated systems and strategies can achieve deeper whole building energy savings, combining multiple equipment and control sequence upgrades often resulting in energy savings greater than the sum of their parts (Regnier, 2018). With the potential for deeper energy savings through multi-component packages, utilities can be motivated to shift program focus to systems-level and integrated strategies[1], although uptake in the utility program space is limited to-date. A challenge is that the systems-based approach requires a more rigorous design and savings assessment effort, as well as greater resources for installation and commissioning.

The Beyond Widgets program addresses barriers to systems-based retrofit approaches by developing, testing, and validating integrated packages of efficiency retrofits and creating streamlined approaches to implementation. The main objective of developing these integrated retrofit packages is to help decision makers in the real world move from ‘widget-based’ thinking to systems-level actions, by simplifying integrated package identification, assessment of suitability for implementation of packages per building, and eventual application in buildings that chose to move forward. Proven systems, if adopted by utility companies in customer energy efficiency programs, may also benefit from access to incentives to help reduce implementation costs.

1.2 Energy Efficiency System Packages to Improve Indoor Air Quality

School operators stand to gain significant energy, cost, and emissions reductions from efficiency retrofits, and are also increasingly aware of the importance of good ventilation and indoor air quality (IAQ) to support a healthy and productive learning environment for their students and staff. Studies have shown a correlation between good IAQ and student performance (Vakalis, 2020). Improved ventilation and effective filtration helps to manage the potential health and productivity impacts that may be experienced from exposure to outdoor and indoor-generated air pollutants. Emerging challenges such as wildfire smoke and concerns about airborne infection transmissions are putting a spotlight on the urgent need for better indoor air quality in schools.

Improving filtration is not only a recommended approach to mitigate airborne transmission risk of infection, it is also important to reduce occupant exposure to fine particulate matter (PM2.5) from sources such as vehicle exhausts, which poses a significant health burden particularly in

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[1] See Mass Save’s *Deep Energy Retrofit* offering for an example of a commercial retrofit program that targets upgrades across systems and end uses (e.g. ventilation, building shell, HVAC equipment electrification), at https://www.masssave.com/business/programs-and-services/deep-energy-retrofit

underserved communities. In particular, buildings with improved filtration are more likely to maintain acceptable indoor air quality during periods of heavy wildfire smoke. There are many buildings that are still using air filters with low Minimum Efficiency Rate Value (MERV). By upgrading the filter rack to accommodate deeper (e.g. 4 inch) air filters with higher removal efficiency (e.g. MERV 14 or better), the improved filtration performance is expected to benefit occupant health in a number of ways (Fisk and Chan, 2017).

The need to improve ventilation and filtration to support better IAQ can be an opportunity for school districts to also upgrade their heating, ventilation, and air conditioning (HVAC) systems. The system packages developed herein aim to improve energy efficiency as well as building IAQ, through measures such as CO_2-based demand controlled ventilation (DCV). This measure ensures that CO_2 concentrations, an indicator of air quality, do not exceed defined limits, as well as providing school building operators with CO_2 data to determine whether ventilation performance is adequate to meet ASHRAE standard 62.1. Energy efficiency measures also include outside air economizer retuning to ensure proper operation, so that buildings can appropriately benefit from outdoor air ventilation when conditions are right for free cooling (Pistochini, 2022).

Other HVAC control measures in the packages assessed include several from ASHRAE Guideline 36: High-Performance Sequences Of Operation For HVAC Systems (hereinafter Guideline 36), including variable air volume (VAV) terminal unit (also known as VAV box) minimum flow retuning, supply air temperature trim and respond (resetting within 55°F to 65°F range based on outside air temperature), and occupied standby conditioning setpoint setbacks. These measures have been demonstrated in field studies to result in thermal comfort improvements by avoiding over-cooling (Arens, 2018). While saving HVAC energy, the measures also prioritize maintaining ventilation rates that meet minimum requirements.

HVAC equipment upgrades include replacing rooftop unit (RTU) air conditioning that uses gas furnace heating with air source heat pumps (ASHPs) that use electricity to efficiently heat and cool air. Additionally, equipment retrofits include fixing and tuning economizer operation to take better advantage of free cooling opportunities, adding energy recovery ventilators that harvest thermal energy from exhaust air in order to precondition outdoor air supply, and replacing fan motors with premium efficiency motors.

Along with HVAC upgrades, the system packages incorporate LED lighting retrofits to replace existing lighting systems, as well as efficient lighting controls upgrades (e.g., occupancy and daylighting controls). The light source change to LEDs is expected to result in a 50% reduction in lighting power density, with further energy reductions achieved by controls in relevant zones (daylit areas and areas where occupancy-based control is feasible).

1.3 Audience

The packages developed here are meant to be applicable to school buildings, with school districts as the target audience for this effort, including stakeholders such as facility managers and superintendents. This work may be used by schools stakeholders to identify potential packages of technologies that can save energy while improving IAQ. The opportunity to save energy by retrofitting HVAC controls to include occupancy-based sensing is also motivated by the reality that many buildings including schools now operate at partial capacity due to the pandemic. The focus on schools is driven by the critical need to support safe in-person instruction. There is also an increase in investments, such as from federal stimulus and infrastructure funding, to support schools in upgrading their HVAC systems and for other facility improvements.

Another intended audience for the packages discussed here is investor owned and publicly-owned utilities with commercial Demand Side Management (DSM) programs, as a goal of this work is to facilitate utility DSM programs in providing incentive programs for system packages of retrofit technologies for efficiency and IAQ. Utility incentive programs are a highly effective means of deploying technologies at scale, and in a targeted manner. This research is intended to facilitate the launch of energy efficiency incentive programs for the IAQ system packages by at least two utilities partners, with validated energy savings and program materials to facilitate development, management, and administration. For packages selected by utility partners for development into an incentive program through the Beyond Widgets program, a System Package Program Manual is prepared to support program development and implementation, (including package description, specified baselines for energy savings analysis, implementation requirements, normalized units of performance, program eligibility criteria and exclusions, measurement and verification requirements, and more). Utility program materials are outside the scope of this report however, which is focused on describing the system retrofit packages and their modeled energy, cost and greenhouse gas (GHG) savings benefits.

Through prior Beyond Widgets efforts, three other system packages have also been developed for a target commercial building market: (1) automated shading integrated with daylight dimming lighting control, (2) integrated workstation-specific lighting with daylight dimming, and (3) integrated task/ambient lighting with occupancy-based plug load controls. Further information on the Beyond Widgets program and support of utility incentive program development can be found at the project website.[2]

1.4 Approach

Working with our utility partners, we identified energy efficiency measures (EEMs) that are capable of delivering significant energy savings, and paired well with the opportunity to improve IAQ. EEMs were then combined into appropriate system packages, with the aim of improving overall cost-effectiveness and energy reduction impact versus performance of the individual EEMs. We evaluated the development of ventilation and IAQ integrated system packages for two climate zones - northern California (representative location: San Jose) and North Carolina (representative location: Charlotte)

Packages were prioritized to also make best use of the trades necessary to implement / install the measures (e.g. packaging measures implemented by the same trade together). Energy

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[2] https://buildings.lbl.gov/cbs/getting-beyond-widgets-enabling-utility-incentive

savings for packages of EEMs were derived from whole building annual energy simulations, leading to selection of packages according to the above prioritization as well as energy performance. Prior work in the Beyond Widgets program has employed this same process to estimate energy savings, demand reductions, and cost-effectiveness for over 30 systems retrofit packages in six utility service territories, finding 5-22% whole building annual energy savings and 13-22% annual energy costs savings (Regnier, 2022).

1.4.1 Ventilation and IAQ in Schools

It is well documented that there has been underinvestment in school HVAC systems across the U.S., and that many of these systems need to be replaced entirely. In many cases, even newly installed systems are not fit for purpose and do not guarantee adequate ventilation due to poor specification, installation, and commissioning practices, insufficient maintenance, and an absence of systems performance monitoring (Pistochini, 2020). This long-term problem has been exacerbated by a tendency to do like-for-like replacements of equipment, and to focus on low first-cost options that can be installed in large volumes.

Upgrading or replacing school HVAC systems can improve ventilation and IAQ, while also saving energy, and can help unlock the technical potential for large-scale demand response (DR). Facility participation in utility DR programs can provide cost savings through utility incentives and beneficial rate structures. Improved ventilation and filtration supports safe in-person instruction and delivers greater resilience for school buildings (for example in increasingly common wildfire events that impact outdoor air quality as well as during periods of elevated pathogen transmission when indoor air quality is paramount) , reducing health risks, thereby improving attendance rates and productivity. The specific IAQ benefits of some of the EEMs discussed in more detail later are listed in Table 1 below. In addition to these EEMs, others with potential IAQ benefits that were considered but were excluded from this project due to limitations of energy model include duct sealing, which improves air distribution and thermal comfort and ensures ventilation air reaches the occupied spaces of the building.

Table 1. ***IAQ Benefits from Selected Measures***

Measure	**IAQ Benefits**
Demand controlled ventilation (DCV), with CO_2 sensors	● Provides data to track and confirm if spaces have sufficient ventilation to maintain CO_2 below setpoint ● CO_2 setpoints can be adjusted according to needs, e.g., lower setpoint for COVID-19 risk mitigation
Economizer control retuning	● Improves performance of economizer to bring in more outside air for ventilation when also effective for space cooling

Measure	**IAQ Benefits**
Select Guideline 36 measures	● Measures include VAV terminal unit minimum flow retuning, supply air temperature trim and respond (from 55°F when outside air is 70°F and above, proportionally up to 65°F when outside air is 60°F and below), and standby heating and cooling setpoint setbacks based on occupant sensors ● Measures meet minimum ventilation requirements while avoiding overcooling and improving thermal comfort
Upgrade to 4” low pressure-drop MERV 14 air filters	● Many existing buildings have ineffective filtration from using low MERV air filters and high filter bypass. Upgrading filter rack to accommodate 4” MERV 14 air filters can lower indoor particulate matter (PM) concentrations, with no significant impact on fan energy use
Relief damper control	● Maintain positive building pressure, reducing air infiltration and the introduction of outdoor air pollutants

2. Selecting and Packaging Measures

The project team conducted a broad review of HVAC and lighting EEMs and IAQ measures with potential for applicability in the buildings of interest. Measures were drawn from sources including scientific literature and technical publications, utility program Technical Resource Manuals (TRMs)[3], publicly-available EEM databases and websites, and consultation with utility energy efficiency incentive program implementers. As one goal of the Beyond Widgets program is to encourage utilities to develop incentive programs for multi-measure retrofit packages, and a key factor in program acceptance is cost effectiveness, measure selection emphasized shorter project paybacks when possible.

We undertook a process of vetting EEMs based on technical readiness, market availability, ease of implementation, energy savings potential, and other factors to down-select from an initial list, arriving at a final set of EEMs to model for whole building energy analysis. EEMs were then grouped into various potential integrated package combinations. All packages have lighting or lighting plus lighting controls elements, as LED lighting EEMs are a relatively mature utility program offering with broad applicability, good cost effectiveness and high savings potential (note that lighting energy savings only apply to facilities that have not already undergone an LED retrofit). A range of HVAC measures were selected to reflect a range of implementation considerations (from less to more complex and disruptive), number of trades involved in implementation, and expected energy savings. Two ‘high intervention’ packages were developed in which replacement of large HVAC equipment was included.

Each of the EEMs selected for the systems packages was assumed to be nominally cost effective from a utility program perspective by virtue of the EEM’s inclusion in utility rebate incentive programs and / or the TRM or utility program databases. Each selected EEM is extensively documented and well understood. The selected EEMs are described in Table 2 below. Table 3 then shows the retrofit packages, which include various combinations of the selected EEMs in Table 2. Package 0 is simply the pairing of lower-wattage LED lighting technology (saving an estimated 50% on installed lighting power density) with occupancy sensors and daylight dimming controls. Package 0 was included as a comparison against other packages to understand the relative benefits of selecting packages with deeper interventions beyond lighting. Package 1 was included as a low-cost, low intervention option, comprised of a simple lighting fixture upgrade (without lighting controls upgrades), DCV, and air filter upgrades. Packages 2 - 10 all incorporated the Package 0 measures (lighting and lighting controls upgrades) along with various HVAC and IAQ measures, with the higher numbered packages corresponding to an increased quantity of measures and overall package complexity. Packages 7B - 10 include equipment upgrades such as high efficiency fan motor replacement (7B), energy recovery ventilator (ERV) (8 and10) and air source heat pump (9 and 10). Package 10 was the most capital intensive with the greatest number of interventions, resulting in higher savings but also the greatest number of trades required to conduct the retrofit.

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[3] Technical Resource Manuals provide standardized EEM descriptions, assumptions and calculation methodologies for measure-level energy and demand savings for state regulators, utilities, and program administrators and implementers, see https://emp.lbl.gov/publications/technical-reference-manuals-trms

Table 2. ***Summary of IAQ System Package Modeling – Individual Measure Descriptions***

Measure Name	**Measure Description**
Lighting Power Density (LPD) Reduction	Light source replacement (e.g. efficient LED fixtures) to reduce installed lighting power density (watts/ft^2) by 50%, to an average of 0.6 W/ft^2
LPD Reduction + Lighting Controls	Efficient LED fixtures with lighting controls upgrade (occupancy control and daylight dimming)
Demand Controlled Ventilation (DCV)	CO_2 based DCV control to maintain indoor CO_2 levels below 1,100 PPM; includes installation of CO_2 sensors in each HVAC zone
Outside Air Scheduling	Shorter schedule for outdoor air supply (two hour morning delay relative to baseline) to reduce conditioning of outside air when not occupied
Economizer Retuning	The economizer, which provides "free cooling" when outside air conditions are appropriate, is considered faulty in the baseline assumption (common in existing buildings, modifications to economizer operation in the reference model were made to reflect this); retuning it restores normal operation. The high limit temperature at which outside air intake is cut off is also raised from 65°F to 75°F, increasing free cooling opportunity.
Guideline 36 Economizer control	Based on differential dry bulb, when outdoor air temperature > return air temperature, economizer switches off.
Guideline 36 Occupied Standby	When zone is unoccupied during workday, setback heating 1°F and setup cooling 1°F. Also provide minimum ventilation air when unoccupied.
Guideline 36 Supply Air Temperature (SAT) Trim and Respond	When occupied and outside air is between 60 - 70°F, SAT reset proportionally within the range of 55 - 65°F
Guideline 36 Optimal Start	Heating or cooling in advance of occupancy to achieve setpoint when first occupants arrive. Pre-heating or pre-cooling start time and duration varies according to outside air temperature.
Guideline 36 VAV minimum retuning	Reset minimum damper position setting at VAV terminal unit from the factory setting (~30%) to a lower minimum (15%).
Fan Motor Replacement	From base fan motor efficiency (85.5%) to premium motor efficiency (93%) based on typical motor size.
Energy Recovery Ventilation (ERV)	Rotary wheel-based heat exchanger on air handler operates when heat recovery is available from exhaust air to precondition outdoor air supply.
Air Source Heat Pump (ASHP)	Rated performance of 10.9 energy efficiency ratio (EER) for cooling mode and 3.3 Coefficient of Performance (COP) for heating mode.

Measure Name	Measure Description
MERV 14 Air Filters*	Upgrade to high-efficiency MERV 14 (min. 4") filters on supply air, resistance pressure <= 0.35 inches of water gauge (w.g.)
Relief Damper Control*	Set damper for neutral / minor positive building pressurization

* These measures were included in some of the IAQ system packages, but energy impacts were not modeled due to limitations of the simulation software.

Table 3. ***Summary of IAQ System Package Modeling – Package Descriptions***

Package Reference	Package Measures	Trades Involved in Implementation
Package 0	LPD reduction of 50% with lighting controls upgrade	Electrical, HVAC Controls
Package 1	LPD reduction of 50%, DCV with CO_2 sensors, outdoor air scheduling, MERV 14 filters	
Package 2	50% LPD reduction with lighting controls upgrade, DCV with CO_2 sensors, outside air scheduling, MERV 14 filters	
Package 5	50% LPD reduction with lighting controls upgrade, DCV with CO_2 sensors, retune economizer, outside air scheduling, MERV 14 filters	Electrical, HVAC Controls, HVAC, Testing and Balancing (TAB)
Package 6	50% LPD reduction with lighting controls upgrade, DCV with CO_2 sensors, Guideline 36 VAV min retune, Guideline 36 economizer, outside air scheduling, MERV 14 filters	
Package 7	50% LPD reduction with lighting controls upgrade, DCV with CO_2 sensors, Guideline 36 VAV min. retune, Guideline 36 economizer, outside air scheduling, MERV 14 filters, relief damper control	
Package 7B	50% LPD reduction with lighting controls upgrade, DCV with CO_2 sensors, Guideline 36 VAV min. retune, Guideline 36 economizer, outside air scheduling, replace fan motor, MERV 14 filters, relief damper control	Electrical, HVAC Controls, HVAC TAB, HVAC Equipment Installer
Package 8	50% LPD reduction with lighting controls upgrade, DCV with CO_2 sensors, Guideline 36 VAV min. retune, Guideline 36 economizer, outside air scheduling, MERV 14 filters, relief damper control, ERV on air handlers	
Package 9	50% LPD reduction with lighting controls upgrade, DCV with CO_2 sensors, Guideline 36 VAV min. retune, Guideline 36 economizer, Guideline 36 occ. standby, Guideline 36 SAT trim & respond, G 36 optimal start, outside air scheduling, MERV 14 filters, relief damper control, ASHP	

Package Reference	**Package Measures**	**Trades Involved in Implementation**
Package 10	50% LPD reduction with lighting controls upgrade, DCV with CO_2 sensors, Guideline 36 VAV min. retune, Guideline 36 economizer, Guideline 36 occ. standby, Guideline 36 SAT trim & respond, G 36 optimal start, outside air scheduling, MERV 14 filters, relief damper control, ERV, ASHP	Electrical, HVAC Controls, HVAC Balancing, HVAC Equipment Installer

* Packages 3 and 4 were developed but not modeled as it was determined that package performance would not be not significantly different from other developed packages.

3. Energy Simulations

Whole building annual energy usage was simulated with EnergyPlus using Department of Energy (DOE) reference models. Baseline school building performance was simulated as well as building performance with the IAQ packages implemented in order to determine the whole building energy impacts of the retrofit packages. Simulated energy usage for the building models is affected by building vintage, construction details, equipment efficiency assumptions, and other parameters, which vary for existing building models and code-compliant models in different regions, in turn affecting EEM energy savings potential. Note that savings results calculated against more energy-efficient baselines (e.g. newer, more restrictive building codes) will be lower, as will results for service territories with milder climates.

3.1 Climate Zones and Baseline Model Conditions

Results are presented for both northern California (San Jose, CA chosen as the representative regional location) and North Carolina (Charlotte) locations. The energy model was set up for an existing building energy performance baseline (details on the building characteristics in the section below). Each retrofit package was modeled for comparison to existing building baseline performance for energy savings analysis. Envelope and construction characteristics were held constant in simulations at the existing building performance levels since the package retrofits do not impact these features. For example, in the building envelope, structure and fabric (including insulation) are unchanged, as are the windows. This is also true for most HVAC system elements, including the central plant, except for retrofit packages that include equipment upgrades. As the system packages also do not include retrofits to interior equipment or domestic hot water elements, energy for these use types remain the same across the baseline and retrofit simulations.

3.2 Primary School Model

To simulate school building annual energy usage without and with the efficient retrofit packages, we used the DOE prototype building models for primary school buildings.[4] The primary school model is a one story, 73,932 ft^2 building. The daily and seasonal occupant loads and plug loads follow the standard schedules for the ASHRAE 90.1 prototype school models as well. Facility occupancy varies based on a presumed school-year calendar, with around 3,400 hours per year of partial or full occupancy in the classrooms and much lower hours of occupancy in less frequently used space types.[5]

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[4] The DOE / ASHRAE prototype model comes from ASHRAE 90.1 prototype from https://www.energycodes.gov/prototype-building-models. For California's Title 24 baseline, a 2019 large school model is not available, so the ASHRAE model was used for California as well.

[5] The assumed annual operating hours for school facilities are lower than many other commercial building types, which affects overall annual energy usage rates and therefore payback potential of EEMs. Fewer baseline operating hours and less baseline energy usage results in lower overall cost savings potential from EEM energy savings and longer paybacks, everything else equal, relative to facilities with more annua operating hours (e.g. offices, hospitals, food service, etc.).

The pre-1980 model includes 25 total conditioned zones, and a typical HVAC system for the building vintage, with heating, ventilation, and cooling supplied by RTUs and VAV systems for the classrooms and office space, and three constant volume packaged single zone air conditioners (PSZ-ACs) for the gymnasium, kitchen, and cafeteria. The VAV systems have outside air economizers but the PSZ-AC systems, which are much smaller in capacity, do not. Natural gas boilers provide hot water to the air handler heating coils and to reheat coils in the zone VAV terminal units. Heating for the packaged single zone units is via direct-fired natural gas furnaces. Cooling is provided via direct expansion in each of the RTUs and PSZ units. Domestic hot water is provided via dedicated natural gas-fired water heaters. Details on the school model's HVAC system are given in Table 4, and the building footprint and space types are illustrated in Figure 1 below.

Table 4. ***Building Model Summary***

Systems	**Areas Served**	**Details**	**Rated Performance**
4 rooftop units (RTU) ● Direct expansion cooling ● Natural gas boiler for heating	3 serve classroom wings and 1 serves office, lobby, corridor, bathroom, and library	● VAV air handler supply fans ● no exhaust fans ● hydronic heating and cooling coils (two speed) ● Economizers for each RTU operating on differential dry bulb temperature control	● 17 to 23 tons of cooling each ● Cooling COP: 2.63 ● Heating efficiency: 0.74
VAV terminal units ● Served by RTUs ● Include reheat coils, gas boiler for reheat at zone	22 zones; 5 in each classroom wing and 7 for other spaces (office, lobby, corridor, bathroom, and library)	Minimum flow fraction set to 0.3 of design peak (existing building standard practice)	
3 packaged single zone air conditioners (PSZ-ACs) ● Direct expansion cooling ● Natural gas heating	Gym, auditorium, cafeteria, kitchen	● Constant volume supply fans ● Economizers on the two larger units operating on differential dry bulb temperature control	● 5 to 9 tons of cooling each ● Cooling COP: 3.8 to 4.12 ● Heating efficiency of 0.78
Ventilation	Throughout building	Ventilation rates during occupied hours based on floor area requirement for outdoor air per person (no DCV). No ventilation requirement after-hours.	
Domestic hot water	Bathrooms, kitchen	● Dedicated hot water heaters, natural gas-fired	● 140°F supply temperature

Systems	**Areas Served**	**Details**	**Rated Performance**
Envelope	Throughout building	● Wall construction: steel frame, stucco with gypsum board and cavity insulation ● Roof construction: membrane, insulation, metal decking ● Window type: climate zone-dependent ● Window to wall ratio: 35%	● Roof U-value 0.637 W/m^2-K ● Wall U-value 1.57 W/m^2-K ● Window U-value 5.835 W/m^2-K ● Window SHGC 0.54
Lighting	Throughout building	● Lighting power density basis, consistent with 3-lamp T8 fixtures for classrooms	● 1.2 W/ft^2 average lighting power

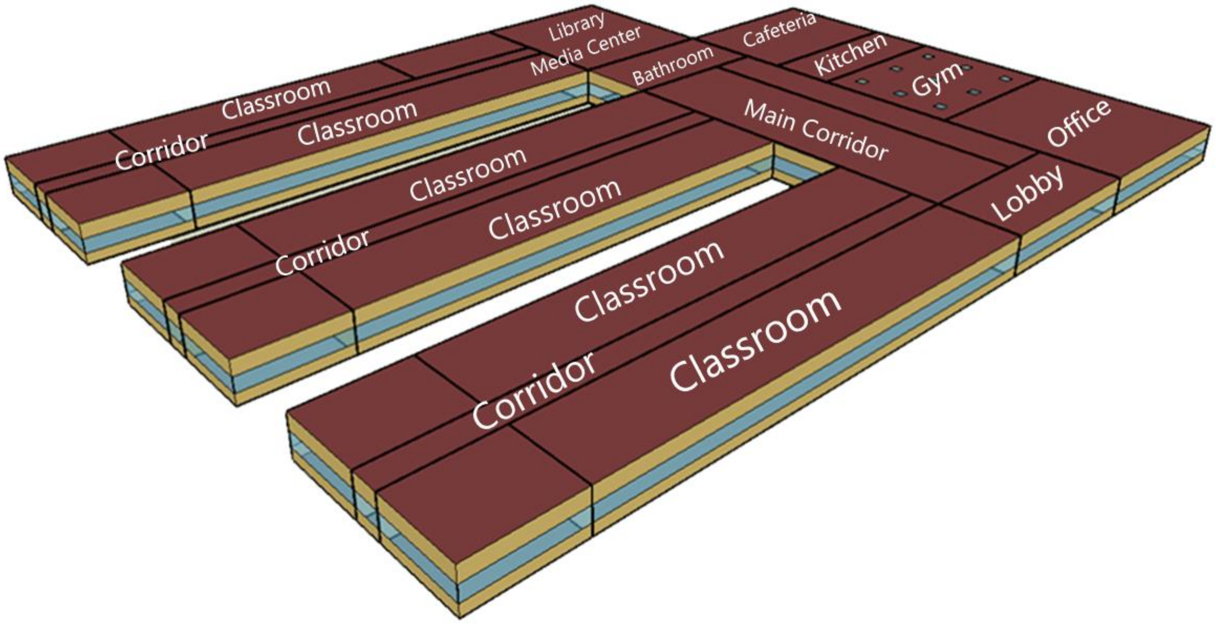

Figure 1. ***Primary School Building Model***

The baseline lighting system power density was modified from pre-1980 existing building assumptions in order to reflect that older buildings will typically have upgraded lighting systems from earlier T12 fluorescent lighting systems, which had very high lighting power densities that may not be an appropriate baseline from which to calculate measure energy savings. Baseline lighting power was adapted to the DOE reference model primary school values for ASHRAE 90.1 2004 code vintage, averaging 1.2 W/ft^2 of lighting power for the whole building (area weighted average) and generally corresponds to 3-lamp T8 fixtures on 8' by 8' spacing, with no daylighting control or occupancy sensing.

3.3 Emissions Inputs

For all climate zones and utility service territories modeled, the energy cost savings results include the impacts of using respective regional time-of-use (TOU) rates as well as demand charge savings impacts. CO_2 emissions savings were also modeled, which for electricity-based CO_2 reductions were derived from EPA's AVERT (AVoided Emissions and geneRation Tool) database input files which include hourly grid emissions rates for the year for modeled geographies, reflecting grid carbon intensity variation with time. AVERT[6] was created by EPA's State and Local Climate and Energy Program to help evaluate county, state, and regional emissions displaced on the grid by energy efficiency and renewable energy policies and programs. AVERT uses public data that is accessible and auditable. From the entire year of simulated energy data (8,760 hours) from the EnergyPlus model, emissions associated with each hour of electricity consumption of the prototype school building are determined. Onsite natural gas carbon impacts (from domestic water heating, re-heat water heating, and gas-fired PSZ-ACs) were modeled with a single emissions factor for gas combustion.

4. Results

4.1 Energy and Carbon Savings

4.1.1 California

Table 5 and Figure 2 show the range of modeled site energy savings from the systems packages in the northern California climate zone and illustrate how site energy is utilized by each end use category (lighting, HVAC, interior equipment, domestic hot water). There was a wide range of savings across the packages - site energy savings ranged from 14% to 36% (combining the electricity and gas savings) from packages 0 through 10, around 175,000 to 440,000 kWh/year of site energy savings. Please refer back to Table 3 for the detailed differences in retrofit measures per package.

As expected, the systems packages comprising more energy efficiency measures showed greater energy savings. For all packages, the majority of savings come on the electrical side, which reflects the prevalence of electrical loads over gas loads in the building generally (electricity to gas energy needs are >2:1). Of EEMs that result in natural gas savings, DCV, VAV minimum retuning (packages 6 - 10), Guideline 36 optimal start (package 9 and 10), and efficient air source heat pumps (also packages 9 and 10) are the largest contributors. Note the HVAC energy results for package 0, the lighting package option, which illustrate the impact of efficient lighting on interior loads; the package incurs a natural gas penalty that reflects a slight need for increased space heating due to the loss of the heat generated by the less efficient lighting system.

Carbon emissions savings occurred as a result of a reduction in consumption of electricity and natural gas for the proposed system packages, with the majority of reductions associated with the lighting upgrade (see Package 0 carbon savings bar in Figure 2 below). This also reflects

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[6] https://www.epa.gov/avert/avert-web-edition

the greater carbon intensity per unit of grid electricity compared with natural gas.

Table 5. ***Summary of Package Savings - California (Reference Location San Jose)***

Package ID	Energy Savings	Electricity Savings	Gas Savings	CO$_2$ Savings
Package 0	14.3%	25.5%	-9.4%	20.1%
Package 1	15.0%	18.4%	7.8%	16.8%
Package 2	19.1%	25.1%	6.4%	22.2%
Package 5	19.5%	25.7%	6.4%	22.8%
Package 6, 7*	30.1%	28.6%	33.2%	29.3%
Package 7b	30.1%	28.6%	33.2%	29.4%
Package 8	30.8%	28.9%	34.7%	29.8%
Package 9	35.1%	28.9%	48.1%	32.0%
Package 10	36.0%	30.2%	48.1%	33.1%

*Relief air damper control, the difference between package 6 and 7, could not be modeled in EnergyPlus, so energy savings and any implementation costs for this measure are not estimated here. Therefore the two packages, otherwise identical, have the same energy, cost, and payback outcomes.

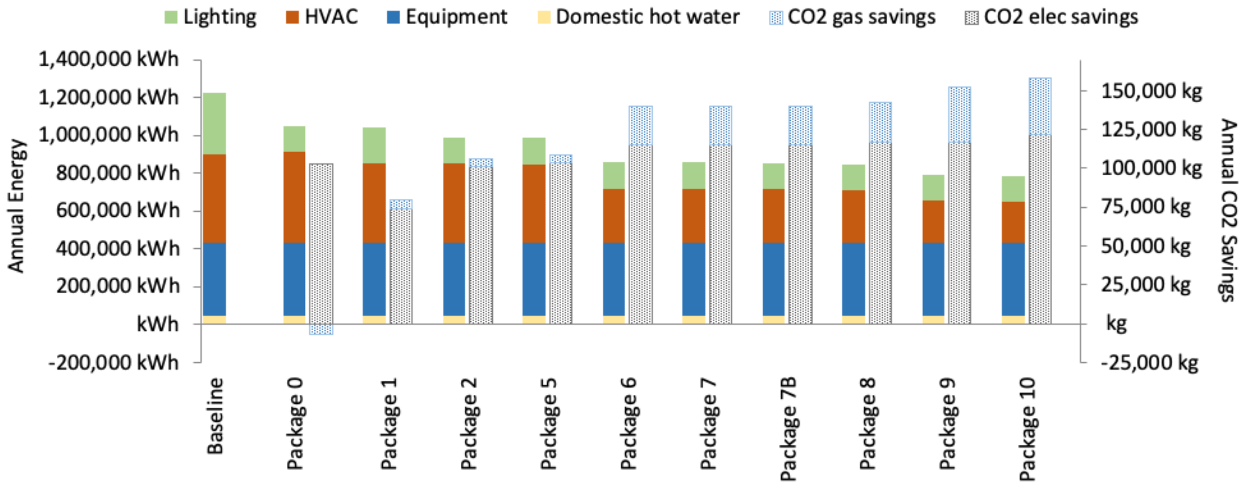

Figure 2. ***Whole Building Annual Energy Usage for Baseline and Packages, and Carbon Reductions from Packages - California (Reference Location San Jose)***

4.1.2 North Carolina

Table 6 and Figure 4 show the range of site energy savings for systems packages in the North Carolina location. Again, there was a wide range of savings across the packages - from 13% to 36% (electricity and gas), equal to around 183,000 to 534,000 kWh per year, from packages 0 through 10. Relative savings per package (in % terms) are similar to the results from California described above, but absolute savings are somewhat higher due to a higher energy intensity in the baseline building in North Carolina. As with the California cases, the systems packages comprising more energy efficiency measures result in greater energy savings. For all packages, lighting and lighting controls had the biggest single impact for all packages, and incurred only a small heating penalty due to the relatively warm climate. For natural gas savings, DCV and outdoor air scheduling, VAV minimum retuning (packages 6-10), and installation of ASHPs (package 9 and 10) had the largest impacts. The majority of emissions savings are associated with the lighting and lighting controls upgrade (see package 0 results in Figure 3). Note that the carbon intensity of grid electricity in North Carolina is higher than in California, so emission savings per unit of electricity are greater in North Carolina.

Table 6. ***Summary of Package Savings - North Carolina (Reference Location Charlotte)***

Package ID	Energy Savings	Electricity Savings	Gas Savings	CO_2 Savings
Package 0	12.5%	23.0%	-7.1%	19.5%
Package 1	15.5%	18.2%	10.4%	17.3%
Package 2	19.3%	24.3%	9.9%	22.6%
Package 5	19.4%	24.4%	9.9%	22.7%
Package 6, 7*	29.5%	27.7%	33.0%	28.3%
Package 7b	29.6%	27.7%	33.0%	28.4%
Package 8	32.1%	29.5%	36.9%	30.5%
Package 9	34.1%	27.3%	46.6%	29.7%
Package 10	36.4%	30.9%	46.6%	33.0%

*Relief air damper control, the difference between package 6 and 7, could not be modeled in EnergyPlus, so energy savings and any implementation costs for this measure are not estimated here. Therefore the two packages, otherwise identical, have the same energy, cost, and payback outcomes.

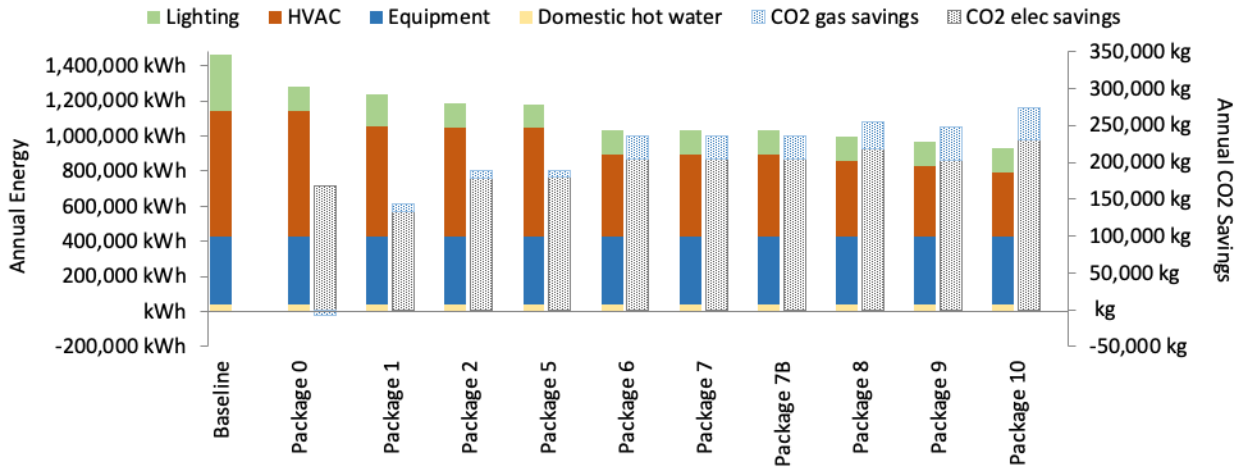

Figure 3. ***Whole Building Annual Energy Usage for Baseline and Packages, and Carbon Reductions from Packages – North Carolina (Reference Location Charlotte)***

4.2 Cost Effectiveness

Simple payback calculations (time in years it takes for energy cost savings to equal package implementation costs) have been developed to provide guidance on and context for package selection for further incentive program development and support. Simple payback is a helpful metric from the customer's perspective as well, giving the customer a sense of maximum benefit per dollar for energy efficiency investment at their site.

For costing of measures and packages we relied on a variety of sources, including utility TRMs and other utility program cost documentation, construction industry cost estimate database for regional cost adjustment factors (RSMeans Online, n.d.), online cost estimation sites (HVAC Direct, n.d.), industry reports on costs of measures such as LED lighting with integrated controls (NEEA, 2020), market information from energy efficiency and program implementation experts (Rocky Mountain Institute, TRC Companies), other published sources of measure cost information, and ground-up estimates of cost for implementation of some controls measures. Where multiple cost information sources were found, estimates were compared and a reasonable combined cost was used.

Retrofit costs depend on whether a project is considered an “early replacement” or a “normal replacement.” The early replacement case, sometimes called early retirement, is a retrofit of a given technology or system during its useful life in order to upgrade functioning equipment to more efficient equipment. For early replacement package costing, the total cost of equipment and labor for implementing measures and packages is included; the alternative being “take no action”. A normal replacement case on the other hand, sometimes called replacement on burnout (ROB), is project implementation at the end of the useful life of prior equipment. Costing in this case includes only the incremental cost of the efficiency measures compared to ‘standard’ option that would otherwise be implemented; the “business as usual” alternative.

For package cost estimates, installation totals are a function of estimated number of units installed for each measure included in the package, based on project floor area and density of units per area, or number of zones or affected pieces of equipment per building and devices per zone or affected equipment, and estimated cost per unit (materials and installation labor). See Table A-1.2 Cost Input Data in the appendix for cost information per measure used to determine package costs. Costs for each system package reflects the sum of bottom-up calculation of costs for each measure included in the package. For both equipment and labor costs, there are regional variations that must be reflected in the bottom-up cost totals. We referred to RS Means data for regional adjustment factors. The impact of these is particularly significant on the labor side, where rates vary significantly across the U.S. Appendix Table A3 provides the regional cost adjustment factors used here.

4.2.1 California

The range of retrofit package annual energy cost savings relative to the existing building annual energy usage baseline was $47K to $88K. These cost savings are a function of the package energy savings and the retail energy and demand rates for the regional utility. For the California case, energy rates are time-of-use dependent, and utility costs also include demand charges. For the annual simulations, demand charges comprised around 21% of total utility costs. Utility energy costs, per kWh, including time of use variability, averaged $0.26/kWh. Adding annual demand charge and energy cost totals and dividing by annual energy usage, costs averaged 0.33/kWh. Natural gas charges were around $0.80/therm.

Payback results ranged from around 6 to 11 years for the early replacement case, generally with longer paybacks for the higher-touch, more complex packages (i.e. more EEMs / package). For the normal replacement case, only the incremental measure cost above code-compliant alternatives were considered, resulting in much lower total package costs, ranging from 1 to 5 years, again with higher – touch packages with higher incremental costs generally having longer paybacks. From the customer perspective (e.g. school district or facility responsible for utility bill payment) the energy savings relative to the existing building performance is the same for normal or early replacement cases, though for utility EE programs, energy savings in normal replacement analysis are only those savings above a minimum code-compliant alternative.

Table 7. ***Summary of Package Implementation Costs, Annual Energy Cost Savings, and Simple Paybacks - California (reference location San Jose)***

Package ID	CA – Early Replacement (Full Cost Basis)			CA – Normal Replacement / ROB (Incremental Cost Basis)		
	Total Capital Costs (full project cost)	Annual Utility Cost Savings	Simple Payback (yrs)	Total Capital Costs (incremental project cost)	Annual Utility Cost Savings	Simple Payback (yrs)
Package 0	$380,581	$63,300	6.0 years	$152,085	$63,300	2.4 years
Package 1	$283,265	$47,413	6.0 years	$54,769	$47,413	1.2 years

Package ID	CA – Early Replacement (Full Cost Basis)			CA – Normal Replacement / ROB (Incremental Cost Basis)		
	Total Capital Costs (full project cost)	Annual Utility Cost Savings	Simple Payback (yrs)	Total Capital Costs (incremental project cost)	Annual Utility Cost Savings	Simple Payback (yrs)
Package 2	$408,781	$65,049	6.3 years	$180,285	$65,049	2.8 years
Package 5	$413,461	$66,783	6.2 years	$182,245	$66,783	2.7 years
Package 6, 7*	$438,407	$77,208	5.7 years	$209,911	$77,208	2.7 years
Package 7b	$450,189	$77,271	5.8 years	$210,727	$77,271	2.7 years
Package 8	$610,657	$80,424	7.6 years	$382,161	$80,424	4.8 years
Package 9	$815,106	$84,221	9.7 years	$288,530	$84,221	3.4 years
Package 10	$987,356	$88,447	11.2 years	$460,780	$84,447	5.2 years

*Relief air damper control, the difference between package 6 and 7, could not be modeled in EnergyPlus, so energy savings and any implementation costs for this measure are not estimated here. Therefore the two packages, otherwise identical, have the same energy, cost, and payback outcomes.

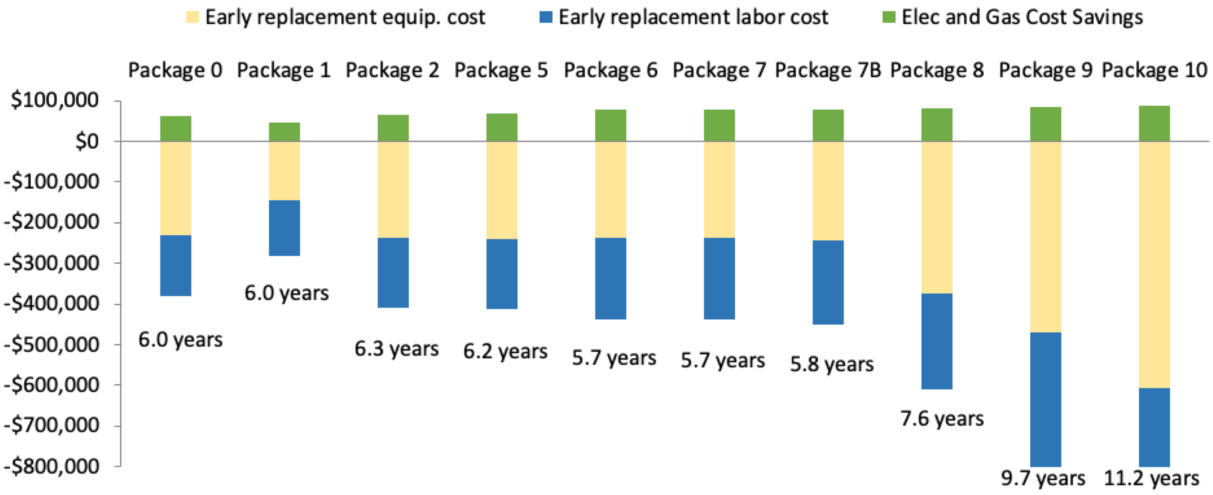

Figure 4. ***Package Costs, Savings, and Paybacks - CA Early Replacement Case***

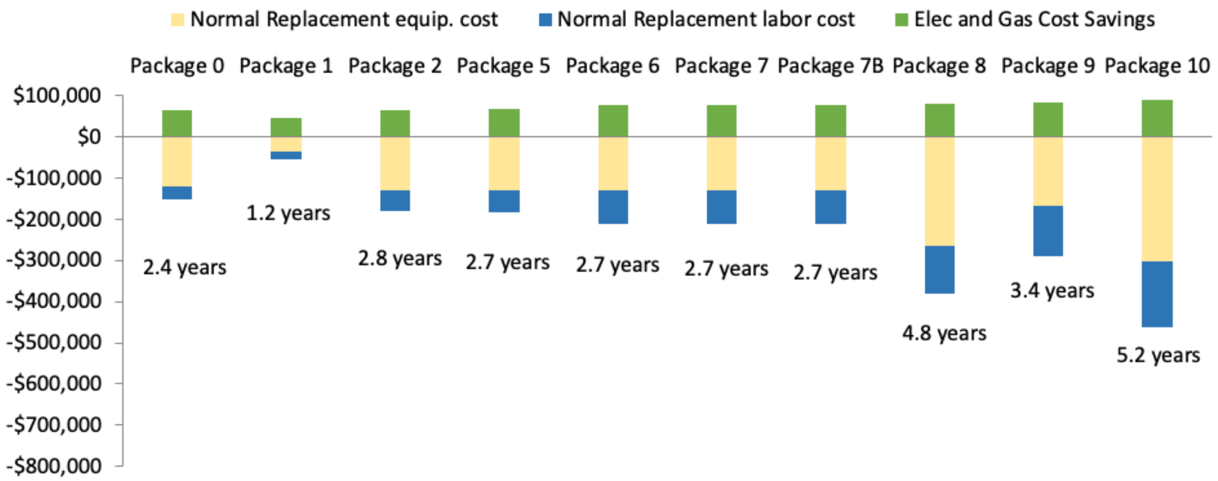

Figure 5. ***Package Costs, Savings, and Paybacks - CA Normal Replacement Case***

4.2.2 North Carolina

For the North Carolina case, cost effectiveness was also evaluated on the basis of early replacement (full cost) and normal replacement (incremental cost) retrofit scenarios, with energy savings calculated against the existing building energy baseline. Annual energy cost savings are the same in both cases. The baseline energy usage in the North Carolina regional model, at almost 1.5 million kWh annually, was higher than the California model, around 1.2 million kWh. The difference between existing building baselines is due largely to climate factors, with North Carolina having more seasonal variation in temperature. It follows then that the energy savings impacts of the HVAC measures were somewhat greater. On the other hand, regional utility retail rates for electric energy ($/kWh) and demand charges ($/kW maximum per billing cycle) were lower for the North Carolina case; kWh costs averaged $0.06/kWh. Demand charges made up18% of utility bills and if annual demand charge costs were added to kWh costs, costs in kWh terms averaged $0.08/kWh. Natural gas costs were around $1.20/therm.

With the lower utility rates, even at the higher energy savings, considerably lower total annual cost savings resulted ($14K to $33K range) compared to the California case ($47K to $88K). Retrofit paybacks on a full cost basis, e.g. early replacement, were therefore higher, ranging from 13 years to 26 years. On an incremental cost basis (normal replacement), paybacks were much more favorable relative to the early replacement case, from 3 year to around 13 years.

Table 8. ***Summary of Package Implementation Costs, Annual Energy Cost Savings, and Simple Paybacks - North Carolina (reference location Charlotte)***

Package ID	**NC – Early Replacement (Full Cost Basis)**			**NC – Normal Replacement / ROB (Incremental Cost Basis)**		
	Total Capital Costs (full project cost)	**Annual Utility Cost Savings**	**Simple Payback (yrs)**	**Total Capital Costs (incremental project cost)**	**Annual Utility Cost Savings)**	**Simple Payback (yrs)**
Package 0	$313,786	$14,316	21.9 years	$124,327	$14,316	9.8 years
Package 1	$216,516	$14,798	14.6 years	$35,066	$14,798	2.9 years
Package 2	$329,481	$19,062	17.3 years	$132,027	$19,062	8.2 years
Package 5	$332,965	$19,167	17.4 years	$132,027	$19,167	8.2 years
Packages 6, 7*	$341,035	$25,752	13.2 years	$132,027	$25,752	6.5 years
Package 7b	$348,902	$25,793	13.5 years	$132,838	$25,793	6.5 years
Package 8	$491,473	$28,696	17.1 years	$268,806	$28,696	11.1 years
Package 9	$702,242	$29,394	23.9 years	$220,844	$29,394	9.8 years
Package 10	$852,681	$32,678	26.1 years	$357,624	$32,678	13.4 years

*Relief air damper control, the difference between package 6 and 7, could not be modeled in EnergyPlus, so energy savings and any implementation costs for this measure are not estimated here. Therefore the two packages, otherwise identical, have the same energy, cost, and payback outcomes.

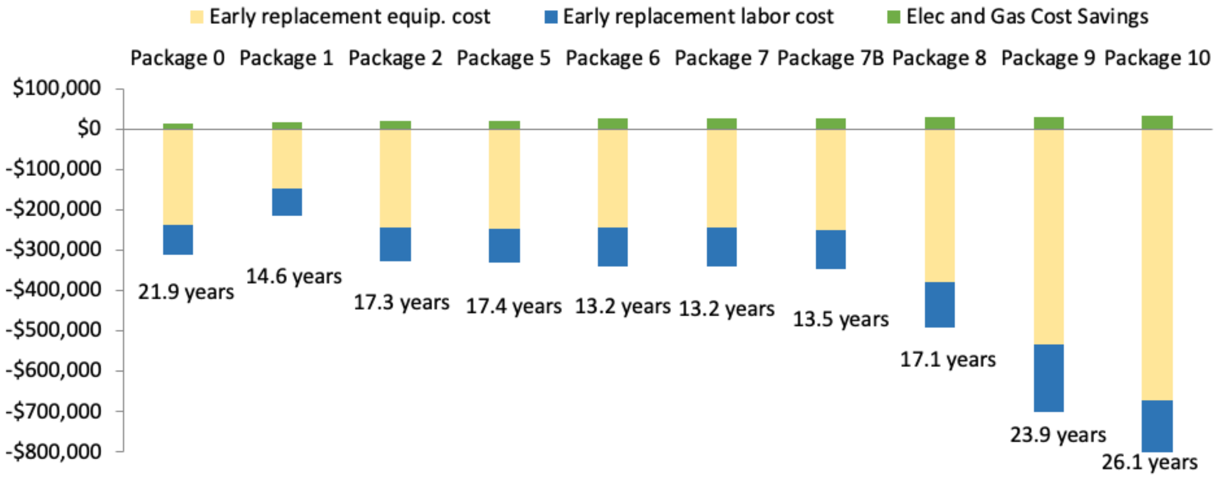

Figure 6. ***Package Costs, Savings, and Paybacks - NC Early Replacement Case***

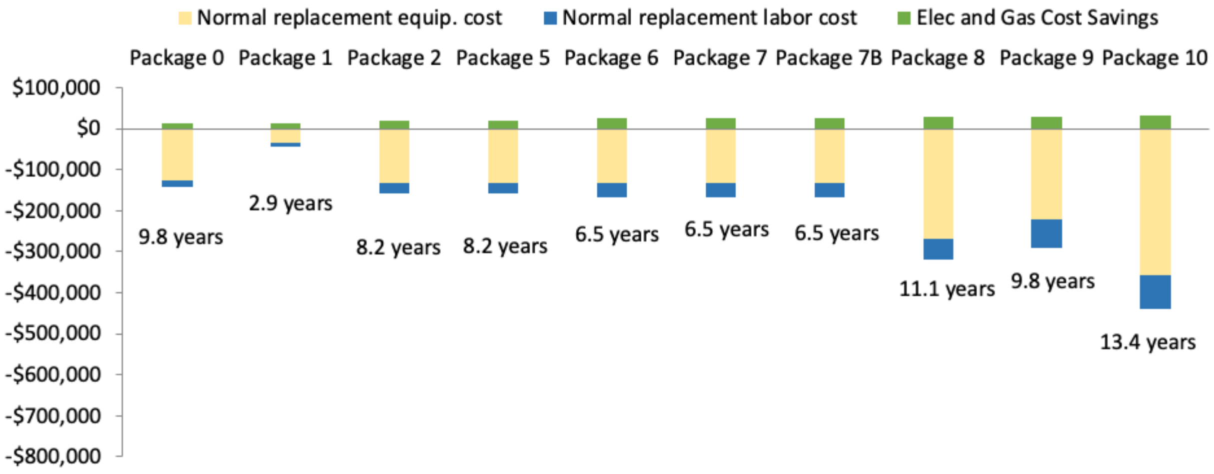

Figure 7. ***Package Costs, Savings, and Paybacks - NC Normal Replacement Case***

4.2.3 A Note on IAQ Measure Implementation Costs

IAQ-only measures like filter upgrades do not necessarily result in energy cost savings themselves. Also, non-energy benefits such as IAQ improvements (Fisk and Chan, 2017, Pistochini, 2022) are notoriously difficult to quantify in dollar figures. In this study we did not attempt to quantify the benefits of improvements in indoor air quality in dollar terms. Accordingly, the costs of implementing the IAQ-only measures were excluded from package cost totals and the cost - benefit analysis.

Nonetheless, some general context on the cost of IAQ measure implementation was collected during the project. For filter upgrades to MERV 14 (minimum of 4" thickness) with maximum pressure drop / resistance no greater than 0.35" water-gauge, we estimate that the first-year upgrade costs would be in the range of $4,000 to serve the four RTUs ($1,000 per RTU) in the school model. This cost is attributable to filter rack upsizing on each of the RTUs, as a MERV 14 upgrade will often require this step. There will then be an ongoing O&M cost difference due to the periodic replacement of the higher-cost filter.

5. Recap and Discussion

5.1 Package Savings

To determine the annual energy savings and evaluate package potential in different regions and utility service territories, whole building annual energy simulations for an existing school building model were performed for two distinct climate zones. Annual energy use was simulated using the EnergyPlus DOE primary school reference model; a one-story building just over 70,000 ft^2 with 25 total conditioned zones. Baseline and retrofit simulation results were compared in order to derive annual energy and demand savings as well as carbon emission reductions. Energy savings were valued according to local retail energy rates, including demand charges, for commercial customers in the specific utility territories evaluated.

Generally, energy and carbon emissions savings were greater for the higher-cost, more complex retrofit packages (i.e. packages involving more building systems and trades). In other words, the more involved, comprehensive packages did in most cases save more energy. Impacts ranged from 14% to 36% energy savings relative to the existing building baseline in the California case, and 13% to 36% savings in the North Carolina case. The modeled school buildings use much more electric energy than gas energy (a ratio of >2:1), and the majority of package energy savings are reductions in electricity usage, with a significant impact from the efficient lighting measures. For natural gas energy savings, the main contributing measures are DCV, VAV minimum retuning (packages 6 - 10), and Guideline 36 optimal start (package 9 and 10), along with gas heating energy savings for ASHP packages.

As discussed in section 3.2 on energy simulations, generally energy savings from retrofits in schools can be a challenge because annual operating hours are typically lower than in other commercial buildings such as offices. Vacancy or partial-occupancy during the summer also means that summer peak savings can be lower. Energy savings potential is further limited in the CA location where the modeled climate is relatively mild and energy usage for space conditioning is already low.

Carbon emissions savings for the packages reflect a) a higher proportion of energy savings for electric end uses than gas use as noted above, and b) a higher carbon intensity for grid electricity than natural gas combustion onsite.[7] Fuel switching from gas to electricity, via electrification of heating with heat pump technology (e.g. packages 9 and 10), involves reducing gas usage but increasing electricity usage, which could have negative carbon emissions consequences. However, the coefficient of performance (COP) of heat pumps (heating energy service delivered/heating energy input) can result in electric space- and water-

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[7] For example, electricity generated using natural gas as the primary fuel typically has an electrical conversion efficiency of 35-40% (assuming a power station utilizing single cycle gas turbine technology). Once transmission and distribution losses are taken into account (assumed at ~10%), one kWh of electricity supplied to the customer has a carbon intensity 2-3X greater than that of natural gas, which is typically converted into heat or hot water onsite at efficiencies of 75-90%. Grid electricity in California is currently less carbon intensive than in North Carolina (averaging 0.49 kg. CO_2/kWh vs. 0.77 kg. CO_2/kWh respectively in this analysis) compared to 0.17 kg. CO_2/kWh for natural gas.

heating at a lower carbon intensity than gas heating,[8] although this varies by COP, grid fuel mix, and climate zone. As the electric grid continues to onboard renewable generation capacity and large-scale battery storage, and retires older, less efficient power generation assets, the difference in carbon intensity between electricity and natural gas supplied to the site boundary will narrow and fuel switching to grid electricity for heat pump technologies should result in carbon savings.

5.2 Simple Paybacks

For cost effectiveness analysis, the equipment and labor costs of implementing the constituent measures were summed for each package. Simple paybacks, in years, were determined as total cost of implementation ($) divided by annual benefit in terms of energy cost savings ($/year). The packaging of measures with different ranges of paybacks can affect overall retrofit cost effectiveness. Combining known shorter payback measures such as the HVAC controls changes that are lower-cost to implement can improve paybacks of packages that also include measures with longer payback horizons due higher capital expenditures, such as lighting and HVAC equipment replacements. Note that from the utility cost-effectiveness standpoint, measure selection included cross-referencing the selected measures with utility EE programs and TRM databases to ensure that the measures were already accepted in the utility framework and had been deemed nominally cost effective from the utility's perspective.

Findings here indicated that paying back the cost of package implementation with energy cost savings alone may require a longer timeframe than may be acceptable in a typical commercial project (e.g. a 3 to 5 year range). However public institutions like school districts, which hold facilities for decades, not years, often take a longer view on infrastructure investments and may be willing to consider projects with longer payback horizons; ten years or even longer.[9] Under those criteria, many of the retrofit packages evaluated here could be attractive investments for schools. However, the more complex and expensive packages, while achieving greater savings, often incurred longer overall paybacks that may fall outside of an acceptable range even for public institutions so consideration for implementing these packages may need to be broader than simple payback from energy savings alone (see non-energy benefits discussion below). Our analysis also did not include the utility cost reduction impacts of DR strategies (DR rate structures or incentives) or the inclusion of potential utility incentives to buy down package installation costs. Simple payback calculations reflect only the current electricity prices and do not take into account important lifecycle cost variables such as energy price escalation, cost of capital, discount rates, financing costs, etc.

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[8] For the heat pump COP of 3.3 in packages 9 and 10, the switch from gas to electric energy for heating, at the gid electricity carbon intensities above, would result in lower carbon intensity for heating in CA and roughly equivalent carbon intensity in NC, depending on assumed onsite combustion efficiency.

[9] Per the Advanced Energy Retrofit Guide: Practical Ways to Improve Energy Performance of K–12 Schools, "[m]ost school districts can expect to use their facilities for at least 40 years, so they have the flexibility to take full consideration of life cycle costs… schools may accept payback periods of 5 years, 10 years, or longer." https://www.nrel.gov/docs/fy14osti/60913.pdf

5.3 Non-Energy Benefits

For IAQ measures without specific energy savings ramifications (e.g. higher efficiency supply air filtration), it is important to recognize that the non-energy benefits might still be very high. However these are notoriously difficult to quantify in dollar terms. As the indoor environment, including air quality, is closely tied to both teacher and student performance and health, IAQ measures included in the packages are considered essential based on the overarching goal of the package development; school retrofits with energy and IAQ benefits in schools. Nonetheless, because monetization of the IAQ benefits is not possible within the scope of this analysis, neither the costs nor the savings of the IAQ-only measures are quantified and included in the payback calculations here.

5.4 Summary Conclusions

School system package retrofits for energy efficiency that include IAQ benefits represent a golden opportunity to improve building performance in a sector that has been chronically underfunded. Projects implementing these packages can save substantial energy and related costs and significantly improve the learning environment for students and staff in terms of factors such as air quality, thermal comfort, and visual comfort.

Typical energy retrofits target single pieces of energy-consuming equipment in a building, or individual processes or controls sequences. However, integrated solutions that combine multiple components, systems, and energy-saving measures have higher savings potential and can achieve project efficiencies by implementing measures together. Recognizing the need for streamlined and validated packages of retrofit measures, the Beyond Widgets team developed package combinations designed to work in school facility retrofit processes. To address the known need for improved indoor air quality and equipment performance in aging schools infrastructure, which often have poorly maintained mechanical systems, the packages included an HVAC, lighting, and IAQ focus. Packages combined HVAC controls sequences for more efficient operation, as well as enhanced ventilation and air filtration, along with LED lighting upgrades to improve the indoor lighting environment / conditions and lighting performance. In light of the proven energy savings potential of the packages along with the IAQ and other indoor environment benefits, districts and schools engaged in facility upgrade planning and investment may do well to consider the retrofit packages developed and analyzed here.

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Appendix A.

A.1 Measure and Package Cost Information

Table A-1.1 ***Measure Cost References***

Measure	**Sources**
DCV	Itron (2014). Report: 2010-2012 Ex Ante Measure Cost Study Report, for California Public Utilities Commission Minnesota Commerce Department (2021). State of Minnesota Technical Reference Manual for Energy Conservation Improvement Programs, v. 3.2, Effective 2022
Economizer re-tune	Itron (2014). Report: 2010-2012 Ex Ante Measure Cost Study Report, for California Public Utilities Commission
Air source heat pump	
Fan motor replacement	
LPD reduction	NEEA (2021) 2020 Luminaire Level Lighting Controls Incremental Cost Study, 2021 TRC retrofit project data
Networked Lighting Controls	
VAV Min. retune	Rocky Mountain Institute (RMI), LBNL estimates from industry contacts Feng and Cheng (2018) Comparison of construction and energy costs for radiant vs. VAV systems in the CA Bay Area. 2018
Morning preconditioning	RMI, LBNL estimates from industry contacts
Supply air temp. reset	
Guideline 36: Economizer	TRC retrofit project data
Guideline 36: Occupied standby mode	
Guideline 36: Trim and Respond	
ERV	NREL Database Retrofit Measures for Mechanical Ventilation Texas A&M University Analysis of Energy Recovery Ventilator Savings, 2009 Vendor cost quote (Lifebreath Commercial ERV Energy Recovery Ventilators)

Table A-1.2 ***Cost Input Data***

Measure	**Base Cost Region**	**Base Cost - Equipment**	**Base Cost - Labor**	**Factor Multiplier**
DCV	CA	$350	$850	# of treated zones
Economizer re-tune	CA	$680	$490	# of air handling units
Air source heat pump	CA	Range of Costs	Range of Costs	Multiple Variables
Fan motor replacement	US Average	$1,317	$948	# of air handling units
LPD reduction	CA	$1.84	$1.61	\$/ft^2 treated floor area
Networked Lighting Controls	CA	$1.73	$0.58	\$/ft^2 treated floor area
VAV Min. retune	CA	$0	$150	# of treated zones
Morning preconditioning	CA	$0	$42	# of treated zones
Supply air temp. reset	CA	$0	$600	# of air handling units
Guideline 36: Economizer	CA	$0	$0.35	\$/ft^2 treated floor area
Guideline 36: Occupied standby	CA	$0	$150	# of zones
Guideline 36: Trim and Respond	CA	$0	$200	# of zones
ERV	US Average	$5.40	$0.82	Per peak CFM ventilation air

Table A-1.3 ***Regional Cost Adjustment Factors (CA=1)***

Service	**Cost Type**	**US Average**	**NC**
Lighting	Equipment	0.98	1.03
	Labor	0.58	0.51
HVAC	Equipment	0.99	1
	Labor	0.59	0.39