EFFICIENT AND HEALTHY SCHOOLS

Roof-top Unit (RTU) Replacement Package

Performance Requirements, Savings and Costs

Version 1.2

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Disclaimer

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1. Introduction

Infrastructure upgrades in schools are a prime opportunity to implement energy efficiency and decarbonization measures that can reduce costs, improve indoor environmental quality, and lower greenhouse gas emissions.

This guide describes a package of efficiency measures that can be incorporated with a roof-top unit (RTU) replacement. In addition to a high efficiency RTU, the package includes several complementary measures that provide deeper savings and allied benefits.

Primary measure	High efficiency RTU
Complementary measures	Networked thermostats
	Networked thermostats with CO_2 sensors and economizer controller
	High capacity, Low pressure drop filters
	Variable flow fan (typically using VFDs)
	Economizer commissioning
	Supply air temperature reset

This guide includes information on:

- Performance requirements for energy efficiency
- Energy savings
- Implementation costs

The guide is primarily intended for school facilities staff involved with the planning, design and specification of infrastructure upgrades. It may also be useful for allied stakeholders such as designers, energy consultants and service providers.

How to use this guide:

- Read the package overview section and identify which complementary measures are in scope for your project.
- Use the performance requirements (section 2) as a template to develop project requirements and modify them as appropriate for your project. (However, note that the language here is not written as a specification that can be directly used as-is in a contractual technical document).

- The energy savings data are based on an energy simulation analysis of the DOE prototype models for primary schools. The actual savings for your site will vary based on your site characteristics. These savings data can be used for planning purposes and for presenting the value proposition to the school board and other stakeholders, prior to conducting detailed savings calculations.
- The cost effectiveness data may be used to get a "first order" estimate of the cost of the package for planning purposes, prior to conducting a more detailed cost estimate.

2. Performance Requirements

2.1 High Efficiency RTU

2.1.1 Introduction

Roof-top units (RTUs), i.e. packaged or unitary HVAC units that provide cooling and/or heating air, are self-contained and are commonly sold "off the shelf," either as a single packaged unit or as a split system. High-efficiency unitary air-conditioning units provide the same reliable space cooling as standard efficiency models, but they incorporate a number of features to reduce energy use. These features include larger condensers, condenser fans that are efficient at full and part load, reduced pressure drops across filter banks and cooling coils, reliable economizer designs less prone to failure, high efficiency air foil fan blades to reduce ventilation energy, and improved compressor efficiencies at part loads.

2.1.2 Guidelines

Use ASHRAE Fundamentals procedures to calculate the design heating and cooling load in the spaces served by these units. Properly sized RTUs can result in as much as a 50% efficiency increase when compared with oversized units[1].

Units should meet or exceed the efficiency levels of Consortium for Energy Efficiency (CEE) Tier 2[2] performance specifications, as shown in Tables 1-3. Unitary air conditioners with furnace sections for heating should have a thermal efficiency of 80% or higher. However, school districts are strongly encouraged to consider all-electric replacements, with heat pump RTUs instead of furnace-based heating. For example, California's Title 24 code

[1] Guidelines for Energy Efficient Commercial Unitary HVAC Systems, Consortium for Energy Efficiency (CEE)
[2] Units in high CEE Tier are also heavier.

requires all-electric replacements for packaged units depending on size and location, starting January 2023.

When decommissioning existing units, school districts should reclaim refrigerant on-site. Refrigerants are potent greenhouse gasses and harmful for the ozone layer, and recycling centers don't always use proper reclaiming procedures for HVAC equipment.

Table 1. Minimum efficiency requirement for RTUs: Air Conditioners, Air Cooled (Cooling Mode)

Size Category	Heating Section Type	Subcategory	CEE Tier II
65,000 Btu/h	All	Split system	16 SEER 13 EER
		Single package	16 SEER 12 EER
>= 65,000 Btu/h to <135,000 Btu/h	Electric Resistance or None	Split System and Single Package	12.2 EER 14.8 IEER
	All Other	Split System and Single Package	12 EER 14.6 IEER
>= 135,000 Btu/h and <240,000 Btu/h	Electric Resistance or None	Split System and Single Package	12.2 EER 14.2 IEER
	All Other	Split System and Single Package	12 EER 14 IEER
>= 240,000 Btu/h and < 760,000 Btu/h	Electric Resistance or None	Split System and Single Package	10.8 EER 13.2 IEER
	All Other	Split System and Single Package	10.6 EER 13 IEER
>= 760,000 Btu/h	Electric Resistance or None	Split System and Single Package	10.4 EER 12.3 IEER
	All Other	Split System and Single Package	10.2 EER 12.1 IEER

Table 2. Minimum efficiency requirement for RTUs: Heat pump, air cooled (cooling mode)

Size Category	Heating Section Type	Subcategory	CEE Tier I	CEE Tier II
65,000 Btu/h	All	Split system	N/A	16 SEER
			N/A	13 EER
		Single package	N/A	16 SEER
			N/A	12 EER

>= 65,000 Btu/h to <135,000 Btu/h	Electric Resistance or None	Split System and Single Package	11.8 EER	N/A
			13.6 IEER	N/A
	All Other	Split System and Single Package	11.6 EER	N/A
			13.4 IEER	N/A
>= 135,000 Btu/h and <240,000 Btu/h	Electric Resistance or None	Split System and Single Package	10.9 EER	N/A
			12.8 IEER	N/A
	All Other	Split System and Single Package	10.7 EER	N/A
			12.6 IEER	N/A
>= 240,000 Btu/h and < 760,000 Btu/h	Electric Resistance or None	Split System and Single Package	10.3 EER	N/A
			11.8 IEER	N/A
	All Other	Split System and Single Package	10.1 EER	N/A
			11.6 IEER	N/A

Table 3. Minimum efficiency requirement for RTUs: Heat pump, air cooled (heating mode)

Size Category	Heating Section Type	Subcategory	CEE Tier I	CEE Tier II
< 65,000 Btu/h	-	Split system	N/A	9.0 HSPF
		Single package	N/A	8.2 HSPF
>= 65,000 Btu/h to <135,000 Btu/h	-	47°F db/43°F wb Outdoor Air	3.4 COP	N/A
		17°F db/15°F wb Outdoor Air	2.4 COP	N/A
>= 135,000 Btu/h and <240,000 Btu/h	-	Split System and Single Package	3.3 COP	N/A
		Split System and Single Package	2.1 COP	N/A

2.2 Complementary Measures

2.2.1. Networked thermostats

Replace existing unconnected zone level thermostats with an energy management system utilizing wireless communication with cloud-based servers for all packaged units, with the following features:

- Internet programmable thermostat should be capable of modulating following setpoints:
  - Temperature setpoints.
  - System mode (Heat, Cool, Auto, Off).
  - Fan mode (Auto, On).
- The web-based configuration of the thermostat should include following options:
  - Naming of the thermostat.
  - Grouping of the thermostat.
  - System type: Heat pump or conventional (DX-cooling, furnace-heating).
  - Energy and power metrics (kW, Btu, ton, or watts)
- The web-based app (app) should be able to control the following settings on the thermostats in real time:
  - Space temperature.
  - System mode (Heat, Auto, Off).
  - Fan mode (Auto, On).
  - Current setpoint.
  - Relay status (Heat and Fan).
  - Historical trend graphs.
  - Scheduling (see below for further details).
  - Lock/unlock entire thermostat keypad.
  - Lock/unlock thermostats fan mode setting only.
- Web based graphical user interface (GUI)
  - The app should be able to run on any computer that uses Microsoft Edge, Safari, Chrome, Firefox, or any other web browser that meets these browsers' functionality.
  - The web-based app platform should be able to run on any Internet Accessible Smartphone and/or Tablet.
  - The app should allow up to a minimum of 10 simultaneous users/clients to access the Energy Management System.
- Schedules
  - The app should provide the user with access to setting schedules for each thermostat. At least 6 schedule periods per day should be available for each thermostat.
  - Schedules should be available as Weekly (7-day), Daily, or Weekday/Weekend (5-2)
  - The app should provide the user with the ability to:

        - View schedules.
        - Add/modify schedules.
        - Assign the thermostat to a group schedule.
        - Delete schedules.

- Trending
    - The app should provide real-time trend information on the following parameters:
        - Space temperature.
        - Space temperature setpoint.
        - Current call for heat, and/or fan.
        - Call for economization.
        - If the evaporator fan is variable speed, the fan percent speed or VFD frequency.

2.2.2. Networked thermostats with CO2 sensors and economizer controller

Replace existing unconnected zone level thermostats with an energy management system utilizing wireless communication with cloud-based servers for all packaged units. The replacement thermostats should also include zone level carbon dioxide (CO_2) sensors and advanced economizer diagnostics for packaged HVAC units with economizers. In addition to all the features described in section 2.2.1, it should include the following additional features:

- Carbon dioxide (CO_2) monitoring
    - The sensor should monitor indoor CO_2, detecting values between 0 and 2000 parts per million (ppm).
    - The CO_2 monitor should work in conjunction with the economizer controller to modulate the outdoor air and return air damper to maintain the indoor CO_2 concentration under 800 ppm or until the system is operating on 100% outside air.
    - All units selected for an economizer controller must have a thermostat with CO_2 monitoring.

- Internet enabled economizer (for units with an active economizer)

- The application must be able to record and provide data on:
    - Calls for economization.
    - Outside air damper position.
    - Supply and outdoor air temperature.
    - Settings for 0-10VDC output for outside air damper actuator control.

  - 0-10VDC input for outside air damper position feedback.
  - Demand control ventilation, including maintained zone CO2 concentration.

- The application should be capable of forwarding the economizer fault and diagnostic codes to the software application, email addresses, and/or text messages.
- The economizer controller should include the installation of a discharge air temperature sensor, a return air temperature sensor, and an outside air temperature sensor.

2.2.3. High capacity, Low pressure drop filters

RTUs use air filters to remove particulates from the air stream. This reduces the amount of dirt left on heat transfer surfaces inside the unit (e.g. on coils) and reduces the amount of dirt brought into the building. Air filters have an energy cost associated with their use, as they create a pressure drop that the fan must work against. High capacity filters can save energy due to their greater surface area (more pleats). They take longer to fill up with dirt than regular filters, which significantly increases pressure drop. The result is much less pressure drop over the installed period, provided they're replaced at the same interval as regular filters.

2.2.4. Variable flow fan (typically via variable frequency drives (VFDs))

Select RTUs with variable flow capability, which is often standard on high efficiency RTUs. Fan rotational speed adjustments are the most efficient means of controlling fan flow. Variable frequency drives (VFDs) are a common and efficient means of controlling the fan speed. As fan speed is reduced, the air flow drops about proportionately; however fan power falls much faster (exponentially, to the power of about 2.4 in practice). For example, a fan slowed to 75% speed provides about 75% the airflow, but uses only about half the power of full speed operation.

Controls guidelines:

- Many RTUs have built-on controls for fan variable speed, integrated with cooling and other controls.
- For large units, the controls may be set by the BMS. The supply (evaporator) fan should use the VFD to vary the air volume supplied to the zone(s). If the fan serves multiple zones with terminal boxes, the fan should continuously vary the speed based on a duct static pressure setpoint and reset. If the fan serves a single zone, the fan speed should be controlled based on the current heating, cooling, or ventilation stage.

2.2.5. Commissioning of the economizer

Economizer systems take advantage of favorable weather conditions to reduce mechanical cooling loads by introducing cool outdoor air into a building. The term "free cooling" is used to describe savings achieved from a properly working economizer. An economizer consists of air dampers, sensors, actuators, linkages and controls that work together to determine how much outside air to bring into a building. In mild climates, economizers save energy by using outside air to supplement mechanical cooling equipment to cool the building. When economizers are properly installed and maintained, they can significantly reduce mechanical cooling in certain climates. Economizers not only save energy, they also decrease wear on air conditioning equipment and improve indoor air quality.

The contractor should:

- Functionally test the outdoor air, return air, and exhaust air dampers. The functional testing should include fully stroking the dampers and actuators. If a damper or actuator cannot smoothly move through the normal range of motion, the device should be serviced (e.g. cleaned, lubricated, or otherwise maintained) to the point where it functions as intended. If the damper or actuator cannot be made to function, the device should be replaced;
- Set the minimum OA damper position to supply required ventilation.
- Calibrate the OAT, MAT, RAT and SAT temperature sensors;
- Test and trend operation to ensure that proper sequence is followed, as described above.

2.2.6. Supply air temperature reset (single zone unit)

When possible, select RTUs with supply air temperature resets, which is often common on high efficiency RTUs. The supply air temperature from RTUs can be modulated, often based on demand for cooling (e.g. second stage of cooling), so that the coldest temperature air is only used when maximum cooling is needed. During less demanding conditions, a more moderate air temperature is used. The exact control strategy will vary by manufacturer and model and will be pre-programmed into the unit. ASHRAE Guideline 36 has a programmable control sequence for implementing supply air temperature reset for RTUs, but specifying that sequence is only recommended if part of a broader controls programming initiative.

3. Energy and GHG Savings

Energy savings for the package will vary depending on location, existing building systems and operating characteristics. We calculated the energy savings for the package using the DOE prototype models for primary schools (figure 1), representative of post-1980 construction, generally conforming to ASHRAE Standard 90.1-1989. Table 3 shows the key characteristics of the model.

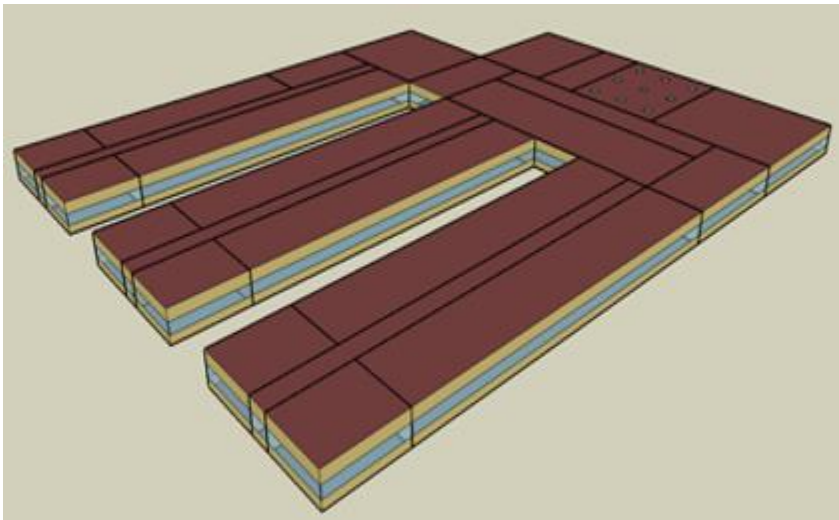

Figure 1. Primary school - DOE prototype model geometry

Table 3. DOE prototype model characteristics

Characteristic	Primary School
Floor area	73,959 sq.ft
Number of floors	1
Window to wall ratio	0.35
Floor-to-ceiling height	13.1 ft
Roof type	Built-up flat roof, insulation entirely above deck. Insulation varies by location
Wall type	Steel frame with batt insulation (varies by location)
HVAC system type	MZ VAV with hot water reheat, PSZ-AC (gym, kitchen, cafeteria)
Heating type	Boiler, gas furnace (gym, kitchen, & cafeteria)
Cooling type	Two speed DX unit, PACU (gym, kitchen, & cafeteria)

Fan control	Variable, constant (gym, aux gym, kitchen, & cafeteria)
Service water type	Gas, storage tank

The retrofit scenario that was modeled included a high efficiency RTU and all the complementary measures in the package.

Savings were also calculated relative to a "business-as-usual" (BAU) equipment replacement. The BAU replacement assumes the existing RTU is replaced with a new RTU that meets code and does not include any of the additional complementary measures of the ISP. Therefore, the savings represent the marginal benefits of upgrading a code-compliant RTU to a higher-efficiency RTU with the additional ISP measures.

Table 4 shows the site energy, electricity, natural gas and GHG (CO2e) percentage savings relative to the two baselines, i.e., existing building and BAU equipment replacement. The savings are shown for seven locations representing IECC climate zones[3] 2A (hot humid), 3A (warm humid), 3C (warm marine), 4A (mixed humid), 5A (cool humid), 5B (cool dry), 6A (cold humid). Emissions factors for grid electricity and fuels are based on DOE guidelines, which are generally consistent with ENERGY STAR calculation methods.

Table 4. Site energy, electricity, natural gas and GHG (CO2e) savings relative to existing building and BAU equipment replacement

	% Savings Relative to Existing Building Baseline				% Savings Relative to Business-as-Usual Replacement			
Location (IECC climate zone)	**Total Site Energy**	**Total Site Electricity**	**Total Site Nat. Gas**	**Total GHG**	**Total Site Energy**	**Total Site Electricity**	**Total Site Nat. Gas**	**Total GHG**
Houston, TX (2A)	9.5%	6.4%	28.0%	8.2%	8.2%	4.9%	28.0%	6.7%
Atlanta, GA (3A)	11.7%	5.0%	31.7%	9.2%	10.2%	3.0%	31.7%	7.6%
San Francisco, CA (3C)	10.7%	2.3%	37.3%	9.7%	10.2%	1.6%	37.3%	9.1%
Baltimore, MD (4A)	12.7%	3.6%	32.6%	10.2%	11.8%	2.3%	32.6%	9.1%
Chicago, IL (5A)	14.1%	2.9%	30.5%	8.3%	13.5%	1.9%	30.5%	7.5%
Denver, CO (5B)	12.3%	2.4%	33.0%	6.4%	11.9%	2.0%	33.0%	6.0%
Minneapolis, MN (6A)	14.5%	1.8%	30.8%	9.5%	14.1%	1.2%	30.8%	9.1%

[3] https://codes.iccsafe.org/content/IECC2021P1/chapter-3-ce-general-requirements#IECC2021P1_CE_Ch03_SecC301

4. Cost effectiveness

The implementation cost for the package will depend on the size and specific characteristics of each building and location. Unit costs for various components of the RTU package were estimated from RSMeans[4] and selected other sources. The unit cost data were then used to calculate the incremental cost of the package relative to a BAU replacement for the DOE prototype model for the seven locations mentioned earlier. The incremental energy cost savings were calculated using average electricity and natural gas prices from the Energy Information Administration[5]. Table 5 shows the simple payback of the package, relative to a BAU replacement. Since cost data can vary widely based on site characteristics, these simple payback data below should be considered as indicative only.

Table 5. Simple payback of the RTU package relative to a BAU replacement. Also shown are the electricity and natural gas prices used for the calculation.

Location (IECC climate zone)	Simple Payback (yrs)	Elec Price $/kWh	Gas Price $/MCF
Houston, TX (2A)	6.6	$ 0.08	$ 6.52
Atlanta, GA (3A)	8.7	$ 0.10	$ 7.71
San Francisco, CA (3C)	14.0	$ 0.18	$9.78
Baltimore, MD (4A)	6.7	$ 0.11	$10.62
Chicago, IL (5A)	10.2	$0.10	$6.84
Denver, CO (5B)	9.2	$0.10	$6.23
Minneapolis, MN (6A)	10.2	$ 0.11	$ 6.39

Note: Electricity and natural gas prices are annualized data by state, from the Energy Information Administration. The data are for 2020 (latest year for which a complete dataset was available).

[4] https://www.rsmeans.com/
[5] Using annual data for 2020 (latest complete set available as of this analysis).
Electricity prices: https://www.eia.gov/electricity/state/;
Natural gas prices: https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm