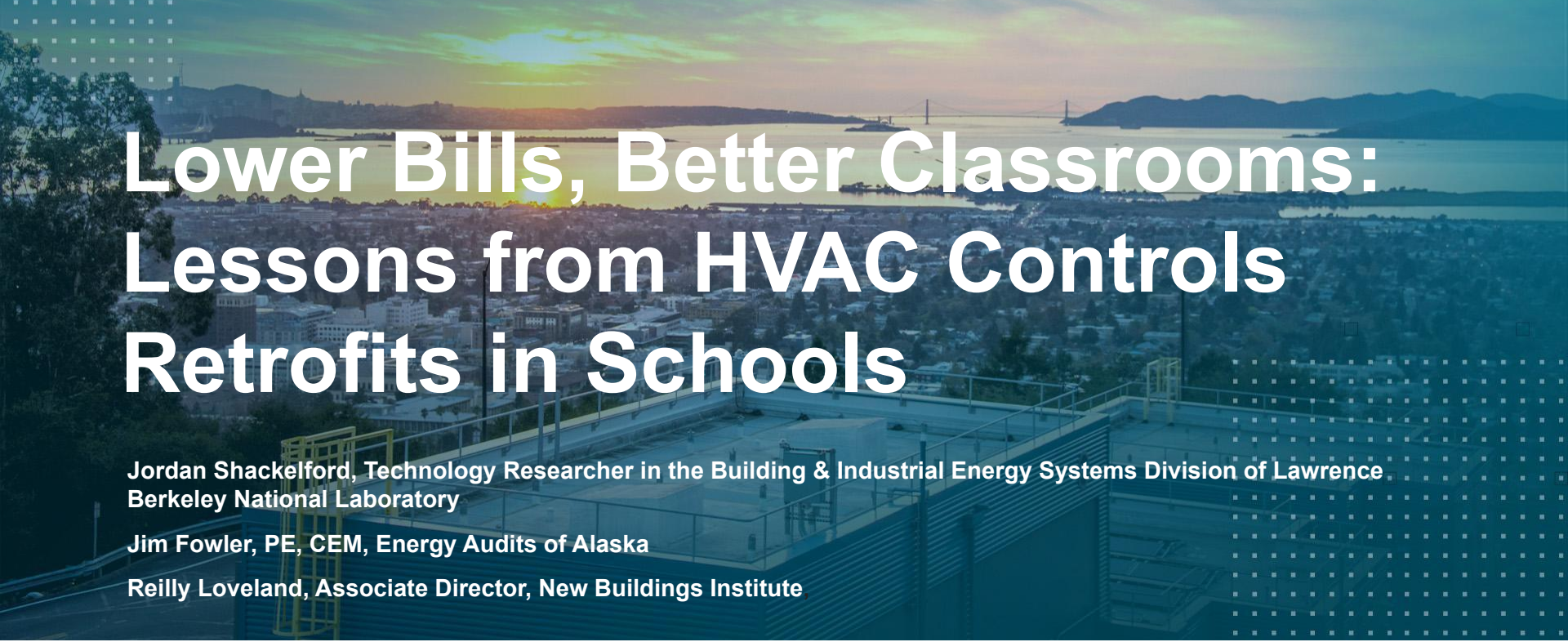


Lower Bills, Better Classrooms: Lessons from HVAC Controls Retrofits in Schools

Jordan Shackelford, Technology Researcher in the Building & Industrial Energy Systems Division of Lawrence Berkeley National Laboratory

Jim Fowler, PE, CEM, Energy Audits of Alaska

Reilly Loveland, Associate Director, New Buildings Institute

Energy Technologies Area
BERKELEY LAB

National Center on School Infrastructure

Presentation Outline

01 **School Infrastructure & Energy Challenges**
Overview of funding deficits, energy consumption, HVAC role in K-12 schools.

02 **Introducing the Project in Alaska**
Specific challenges in the state, and the selection process for the HVAC retrofit study locations.

03 **HVAC Retrofit Process**
Technical details and deployment process for the ventilation controls retrofits.

04 **Measurement & Verification**
The methodology and process used to monitor and verify performance of the ventilation retrofits.

05 **Retrofit Results & Impact**
Key findings: energy and cost savings, air quality improvements.

06 **Additional Studies & Resources**
Zooming out to other school HVAC retrofit studies and resources.

U.S. School Infrastructure & Energy Challenges

There are **100,000 public K-12 schools**.

U.S. schools earned a **D+** in a 2021 infrastructure report card

Infrastructure

Critical Facility Needs

- **Over 50%** of facilities require major upgrades to address unsatisfactory ventilation, heating, lighting, or security.
- **41% of districts** need HVAC upgrades in half or more of their schools.

Funding Deficits

Capital Shortfalls

- **$85 Billion** annual shortfall in maintenance and capital funding across U.S. school facilities.
- Deficits disproportionately impact high-poverty and rural communities.

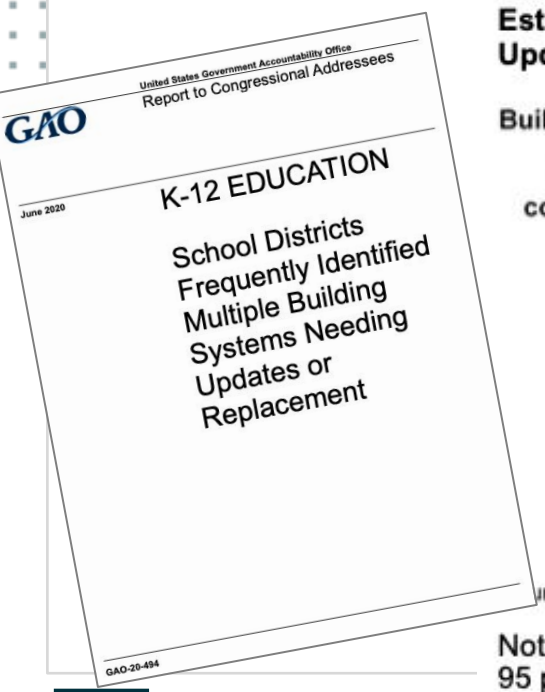
Energy & HVAC

High Consumption

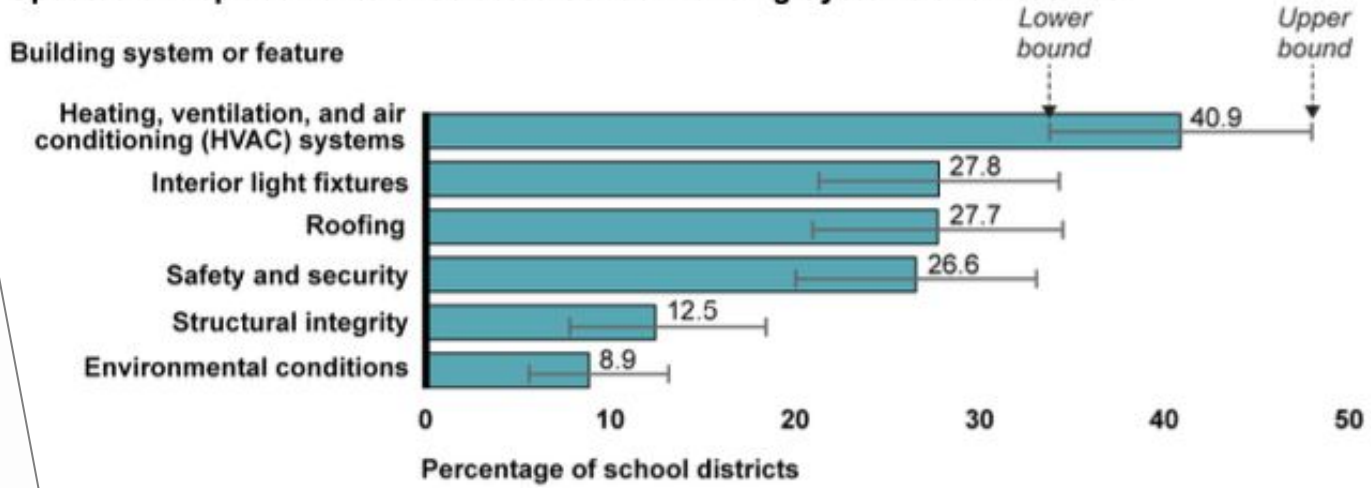
- K-12 sector is the **2nd-largest electricity consumer** in commercial buildings and the largest natural gas consumer.
- Energy is typically the **2nd highest** operational expense.
- HVAC systems account for the **vast majority of energy use**.

Sources: 2021 *State of Our Schools Report*, ASCE Infrastructure Report Card, GAO study

U.S. School Infrastructure & Energy Challenges



Estimated Percentage of Public School Districts in Which at Least Half the Schools Need Updates or Replacements of Selected School Building Systems and Features



urce: GAO analysis of school district survey data. | GAO-20-494

Note: GAO administered the survey from August to October 2019. Thin bars in the chart display the 95 percent confidence interval for each estimate.

HVAC Upgrades: Context & Needs

01

Multi-Benefit Impact

Well-designed HVAC upgrades contribute to ongoing cost savings, health, comfort, and learning benefits, and keeping schools open during adverse air quality events.

02

The Guidance Gap

While the energy-health-education nexus is clear, there is limited guidance on replicable retrofit approaches adapted to unique local district needs and budgets.

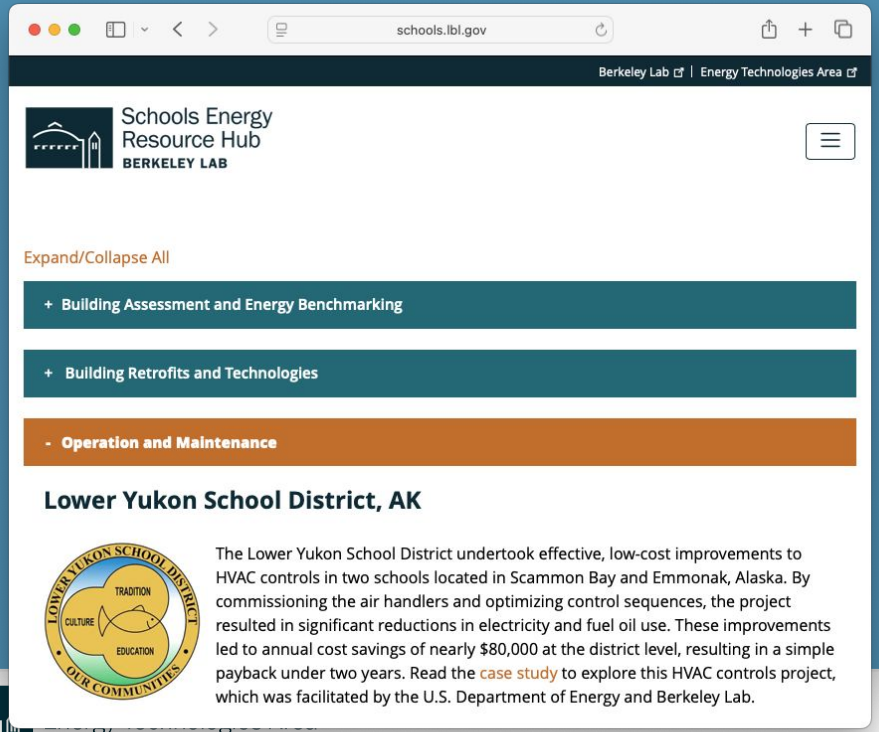
03

Critical Need

There is a critical need to document broadly applicable retrofit approaches and rigorously evaluate their real-world impacts.

Ventilation Controls Retrofits in Lower Yukon School District, Alaska

Just published!
At: schools.lbl.gov/school-case-studies





BERKELEY LAB

Unique challenges for AK Schools

55 school districts in Alaska and 504 schools, of which 294 schools are designated as Title 1

Extremes

- Weather
- Lack of road access
- Fuel Cost: $7-$8/gal (vs. $3.53 US avg) during study, over $14/gallon today
- Power: >$0.50/kWh (vs. $0.18 US avg) during study, now >$1.00/kWh

Resource Limitations

- Extremely limited human resources
- Cost per student very high
- No economic base in rural villages
- High staff turnover
- “Bandaids” to keep equipment operating

Ventilation Controls Project Goals

RETROFIT TARGETING

Highest need, poorest energy performing, Title 1 schools

Low-touch, lower-cost retrofits

DEMONSTRATE VALUE

Tangible results = cost savings and trained staff, reducing district operating expenses and ensuring persistence of results

IMPROVE CLASSROOM COMFORT

Enhance learning conditions and comfort by correcting ventilation issues.

Identifying Highest Need Schools

Engagement with State Department of Education

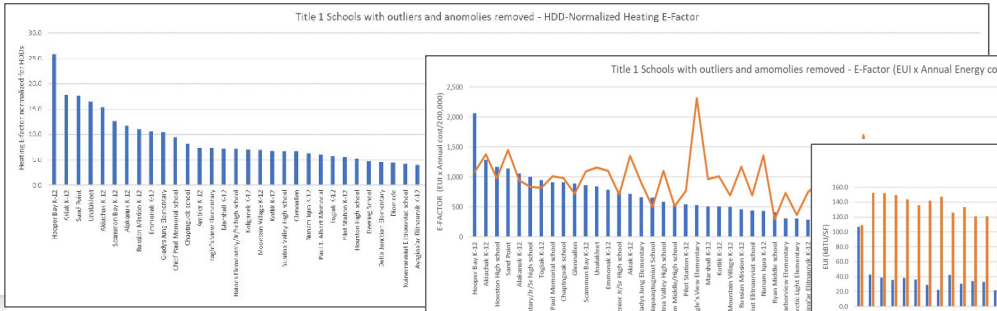
Director of Facilities connected us to the **State Retro-Commissioning (RCx) Program for schools**

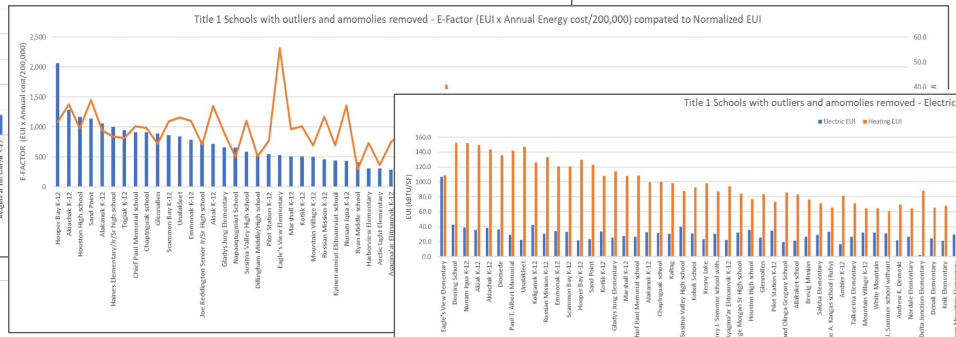
- For school size > 5000 ft^2
- For school buildings that are “salvageable” vs needing total replacement
- 33 districts with 260 schools qualified
- Source Energy Data: schools required to provide annual electric, heating oil, biomass BTUs, waste heat BTUs, natural gas from 2015 - 2019
- **94 Title 1 schools** included in group - these were investigated further

School Selection Process

Analyze Energy & Performance Parameters

- **EUI** (kBTU/ft^2/yr) normalized by dividing by heating degree days (HDDs).
- Further break down total EUI into electric and heating EUI
  - Electric EUIs provide minimal information
- **ECI** analyzes the energy cost per square foot, not very helpful when energy costs vary widely
- **E-factor** combines EUI and annual energy costs, again normalized by HDDs
- Final ranking by weather normalized heating EUIs x annual energy costs





School Selection Process

Down-select & Outreach

Facilities managers contacted in each school district for 10 schools with highest need.

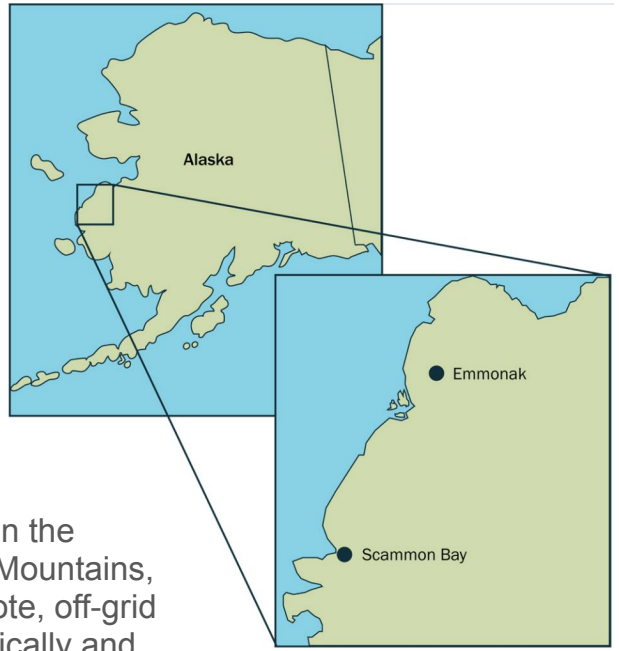
Key Upgrades Underway

Lower Yukon SD had ventilation equipment upgrades funded and underway for Emmonak and Scammon Bay, but lacked budget for controls optimization or commissioning.

School District	School
Lower Yukon	**Hooper Bay K-12**
Yupiit	**Akiak K-12**
Aleutians East	**Sand Point**
Bering Strait	**Unalakleet**
Yupiit	**Akiachak K-12**
Lower Yukon	**Scammon Bay K-12**
Lower Yukon	**Alakanuk K-12**
Lower Yukon	**Russian Mission K-12**
Lower Yukon	**Emmonak K-12**
Lower Kuskokwim	**Gladys Jung Elementary**

Lower Yukon Schools Ventilation Controls Retrofit



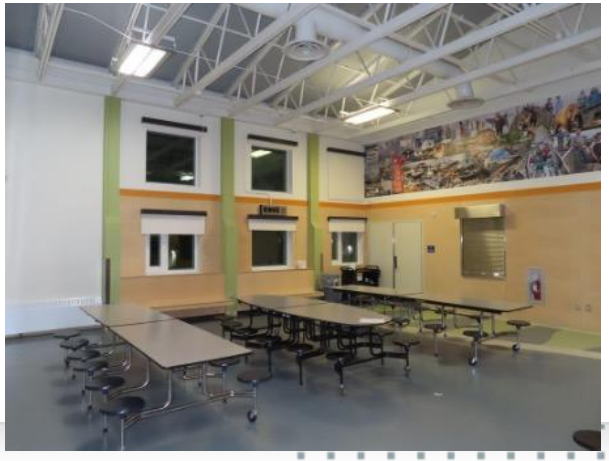


Emmonak and Scammon Bay are remote, off-grid communities located in the Yukon-Kuskokwim Delta. Scammon Bay lies at the base of the Askinuk Mountains, while Emmonak is located near the mouth of the Yukon River. Both remote, off-grid communities are deeply rooted in Yup'ik Eskimo culture, relying economically and culturally on subsistence harvesting, fishing and hunting, and local tribal governance.

Lower Yukon Schools Ventilation Controls Retrofit

Location	**Scammon Bay, AK** (Population 610)	**Emmonak, AK** (Population 848)
School type	K-12	
School size	**43,000 ft²** — 246 students, 15 teachers	**44,000 ft²** — 236 students, 14 teachers





HVAC and Ventilation Issues

- Pneumatic controls
- No access or training on DDC controls (missing laptops)
- Outdated DDC controls no longer supported
- No remote access to controls
- Manual override control sequences
  - Exhaust from diesels
  - Freeze up
- Air filters
- Failed CO_2 sensors
- Failed field devices (actuators, control valves, thermostats)
- High turnover
- Lack of local knowledge and resources





Equipment and Controls Upgrades

Emmonak School Equipment Upgrades

$1.3M Retrofit

Replaced air handler, upgraded all filters, upgraded DDC hardware/software, and enabled remote DDC access and data monitoring.

Scammon Bay Equipment Upgrades

$1.8M Retrofit

Replaced AHU fan wheels and motors, upgraded filters, upgraded DDC hardware/software, and enabled remote DDC access and data monitoring.

Commissioning and Controls Optimization

$97,000 Cost

Funded the project's design engineers, controls contractor and the testing and balancing engineers to commission Emmonak controls and optimize Emmonak and Scammon Bay controls sequences.





Equipment and Controls Upgrades: Details

Facility	Equipment Upgrades	Controls Improvements
Emmonak	Upgrade AHU filters to MERV 13	Ventilation system commissioning AHU 1 and 2 fan motor scheduling Provided training to maintenance staff regarding using temporary “event” schedule features to prevent permanent overrides
	New constant volume AHU 1 installed with supply fan variable frequency drive (VFD)	
	New VFD; supply fan motor on AHU-2	
	Replace DDC front end to permit remote access; update DDC software	DDC sequence optimizations including supply fan scheduling and speed control, supply air temperature resets, relief damper and outside air damper modulation for CO_2 based, minimum code ventilation and building static pressure.
Scammon Bay	Upgrade AHU filters to MERV 13	DDC sequence optimizations including supply fan scheduling and speed control, relief and outside air damper modulation to maintain code minimum ventilation and building static pressure.
	Replace AHU-1 and 2 fan wheel and motor	
	Replace DDC front end to permit remote access; update DDC software	

Equipment and Controls Upgrades: Stages

PROJECT STAGES

01. Original Conditions

State of school facilities prior to any of the HVAC upgrades or interventions.

02. Equipment Retrofit

Physical installation of new HVAC hardware and controls systems.

Our study's baseline performance period

03. Post-Equipment Installation, original control sequences, no commissioning

Equipment upgrades fully complete, but sequence optimizations and controls tuning not yet implemented.

04. Commissioning and Controls Optimization

Period after updated DDC sequences and full controls tuning completed.

Our study's retrofit performance period

Measurement and Verification (M&V)

Energy Monitoring Equipment

Installed on mechanical systems serving classrooms. AHU electricity (kWh) was measured directly.

Heating fuel usage calculated. from outside air dampers, fan speed, discharge temp, boiler hours.

Controls Trending

Trend points were successfully configured in the DDC systems.

Air Sensors & Loggers

Distributed throughout classrooms and common areas.

M&V Constraints

Due to equipment operation challenges during various phases, savings from equipment upgrades alone could not be calculated.

M&V savings were computed for controls optimizations relative to new equipment operating without them

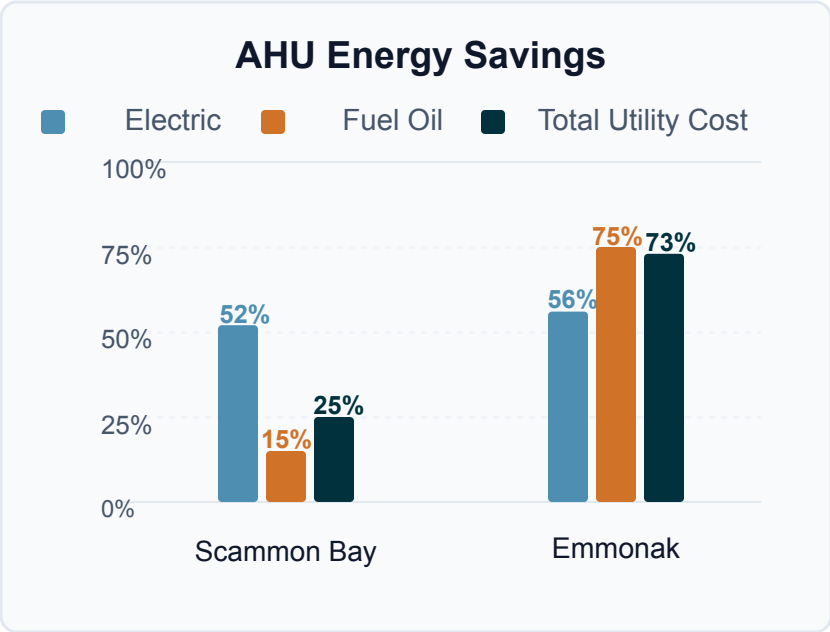
Field Hardware

Loggers and current transformers installed on site.





Project Impact



$80,000 / year

Combined District Utility Savings

< 2 Years payback

Rapid Recovery of Investment

Whole Building Energy Picture

Estimated Building-Level Savings

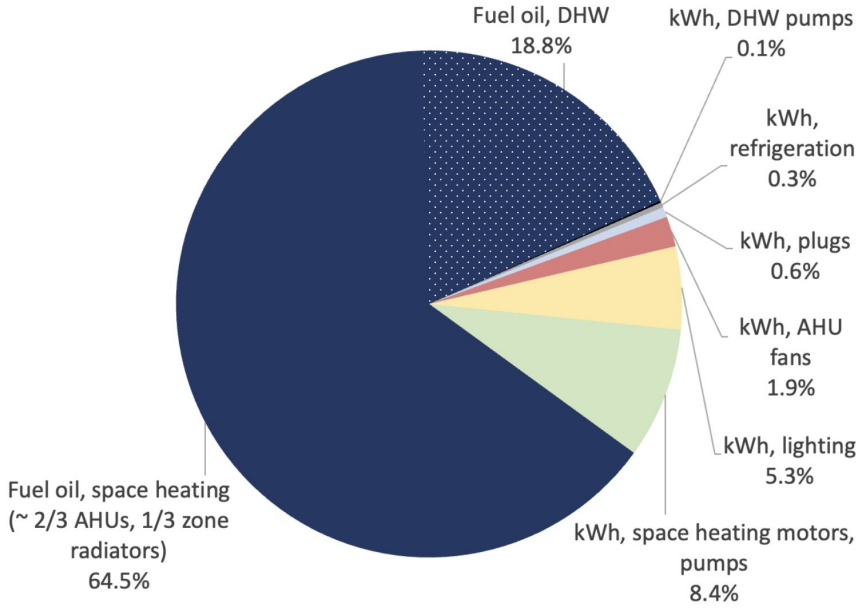
5.1% at Scammon Bay and **15.0% at Emmonak**.

Energy Budget Proportion

AHU electricity and fuel oil constitute only a portion of total energy budget (a small fraction of electricity, and a large amount of total fuel oil usage)

Other Major End Uses

Radiator water heating, domestic hot water, lighting, plug loads, and distribution pumps



Simulated school building annual energy end uses in Lower Yukon

Ventilation Performance

Scammon Bay

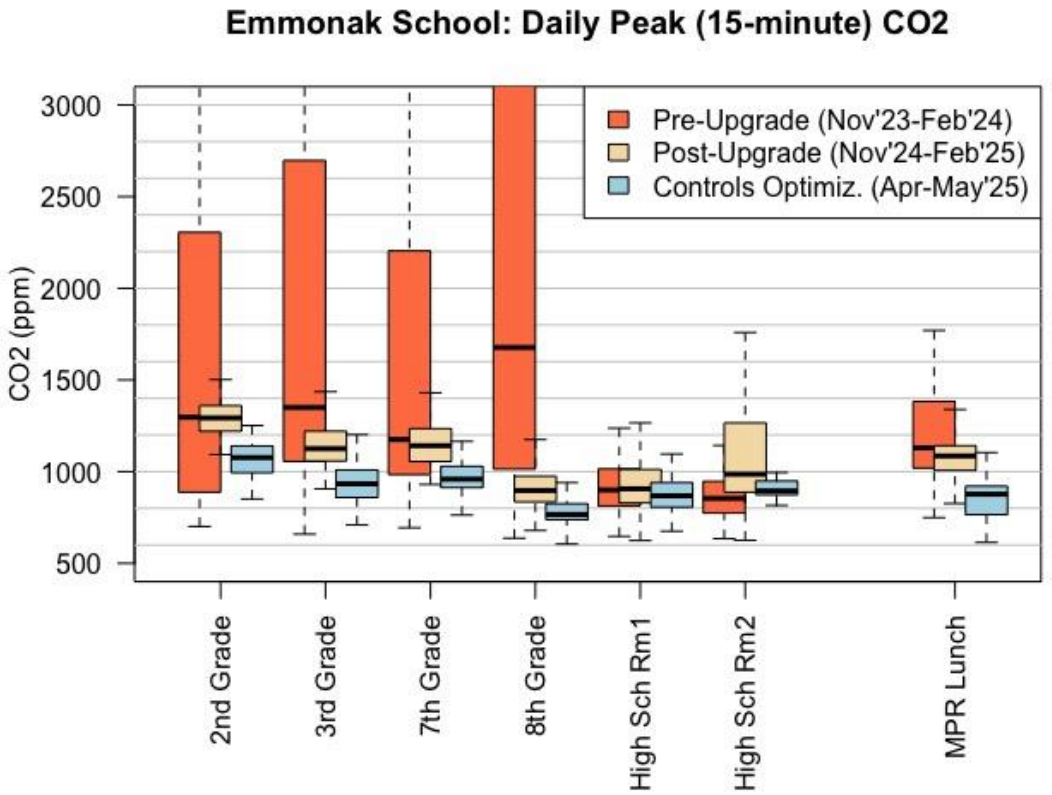
Ventilation rates good before and after retrofits.

Emmonak Classrooms

- **Pre-Upgrade:** Routinely under-ventilated.
- **Post-Equipment Upgrade:** Substantial improvements.
- **Controls Optimization:** Adequate ventilation fully achieved

***CO_2 as indicator for ventilation:**

Levels of **1,000 ppm** or less expected in classrooms with adequate ventilation.



Conclusions

- **Successful Demonstration of Concept:** Targeted ventilation controls improvements at Emmonak and Scammon Bay schools achieved significant benefits.
- **Substantial Financial Savings:** Generated **almost $80,000 in annual energy cost savings** for the school district, recovering the commissioning and optimization costs of **roughly $97,000** in just over a year.
- **Staff Training**: ensuring effectiveness and longevity of the ventilation improvements

Building on Success in Alaska Schools

Renew America's Schools Alaska Project

Mitigating geographic isolation, energy costs through structured ECMs, including controls commissioning, across 11 school facilities.

Key Regional Profiles:

- **Metropolitan District:** Up to 1,100 students in major urban centers; focusing on complex HVAC sequences and baseline benchmarking.
- **Remote Island District:** Isolated sites (some with independent generation) serving 12 to 30+ students. Urgent need: eliminate diesel reliance.
- **Fly-In Only District:** 16 to 300 students per school; extreme supply chain vulnerability, saving energy the highest economic multiplier.

CORE ECM & CONTROLS OPPORTUNITIES

Update and Optimize Controls: Re-commission field devices, optimize settings in new DDC systems and provide staff training, proper equipment and temperature scheduling and DCV.

Hydronic Tuning: Replacing constant-speed pumps with variable-speed units to optimize biomass loop efficiency.

COMMUNITY & ECONOMIC IMPACT

Emergency Shelters & Cultural Hubs: Audited schools serve as critical community centers, hosting enrichment programs and tribal activities.

The Fuel Multiplier: Minimizing heating dollar outflows keeps more resources in the community, offsets severe supply chain vulnerabilities, and fosters regional resilience.

What This Means for Other Districts

- **Retrocommissioning of systems** can help save money, energy, and maintenance capacity
- Simple, **low-cost ventilation controls retrofits deliver high-value results** (even in the most demanding environments)
- **Staff training is critical** to long term success
- Involving staff across departments helps significantly with knowledge retention and turnover

What can you do so this knowledge doesn't walk out the door?

Additional School HVAC Retrofit Resources and Research

THE HVAC CHANGE LAB

The HVAC Change Lab is a collaborative initiative designed to address the root causes of the challenges that schools face in upgrading heating, ventilation, and air conditioning (HVAC) systems.



Center for Green Schools

National Center on School Infrastructure

nbi new buildings institute

https://school-infrastructure.org/about-us/hvac-change-lab/

1) Tools at LBNL School Energy Resource Hub

AVAILABLE NOW!



Scope of Work (SOW) Template for Commissioning Projects

- Template SOW for commissioning services for school projects, includes specific sections, tasks, and procedures with examples throughout.
    - Ensure projects operate as intended, meeting design specs, checks on equipment functionality and control sequences, and saving energy, in comprehensive process managed by a CxA.



Commissioning (Cx) / Retro-Commissioning (RCx) Request for Proposal (RFP) Template

- Solicit bids for commissioning / retro-commissioning services
    - Select / modify applicable sections of template for your project
    - May be used in conjunction with SOW to describe scope and requirements for commissioning services.

https://schools.lbl.gov/commissioning-cx-retrocommissioning-rcx

2) Operational Excellence Study



Core Objective

Shift operational practices from episodic, failure-driven interventions to continuous, data-driven, systematic improved management practices.

Five Key Interdependent Practices

- **Energy Management Planning** (EMP)
- **Improved Operations & Maintenance** (O&M)
- **Energy Audits**
- **Performance Benchmarking**
- **Existing Building Commissioning** (EBCx)

Strategic Recommendations

- **Total Cost of Ownership:** Move toward preventive and predictive maintenance.
- **Integrate Practices:** Cycle interdependent elements through energy planning.
- **Workforce Capacity:** Empower / train staff, and develop "energy champions."
- **Building Commissioning:** Implement existing building commissioning and consider ongoing, monitoring-based commissioning.

2) Operational Excellence Study

Literature review on costs and benefits of practice areas:

Practice Area	Reported Costs ($/ft^2)	Reported Energy Savings	Reported Financial Benefits
Energy Management Planning (EMP)	$0.42	n/a	n/a
Improved O&M (planning, Preventative Maintenance)	$0.33 to $0.43	5% to 20%	Payback: 0.3-2 yrs Ben./Cost: 3.8 ROI: 545% IRR: 98%
Performance Benchmarking	$0.01 to $0.02	1.6% to 14% Avg: 2.4%	Paybacks not specifically given
Building Energy Audits	$0.05 to over $0.50 (depending on audit level)	n/a	n/a
Existing Building Commissioning (RCx, MBCx)	$0.26 to $0.30.	Avg: 6% to 16%	Payback: 1.7 avg. 5-yr ROI: 450% Cash-on-cash return: 91%

2) Operational Excellence Study

01 **Benchmarking**
Establish performance baselines to identify underperforming properties and prioritize them for deeper analysis.

02 **Audits & Diagnostics**
Deep dive to diagnose energy waste, discover energy-saving retrofits, and quantify financial returns.

03 **Tuning, RCx & Retrofits**
Action phase: execute low-cost/no-cost operational and controls tuning measures, and retrofits if recommended, to turn potential into realized returns.



3) Modeled Retrofit Packages for Schools

AVAILABLE NOW!

Simulation Overview

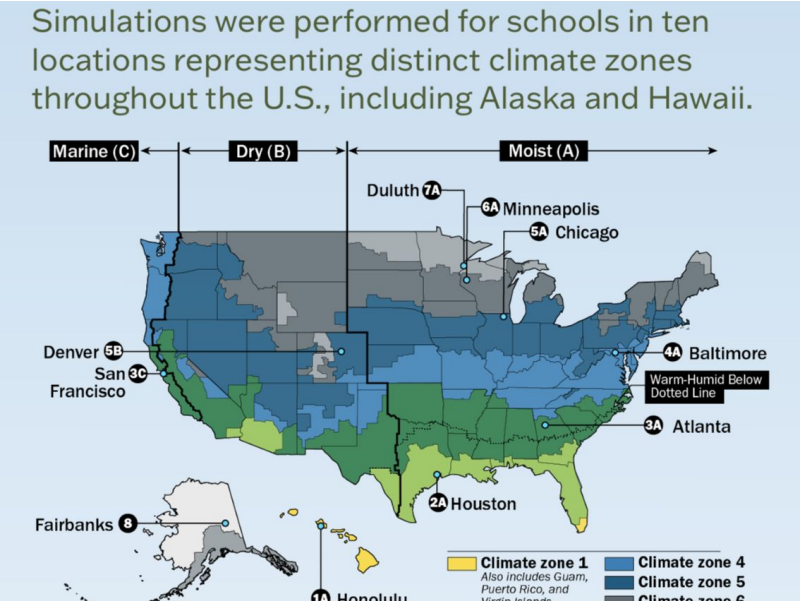
Computer Simulations

Predict energy and utility savings for elementary and secondary schools across urban and rural areas and diverse climate zones for 8 different retrofit packages.

Key Outcomes

Estimates of project costs and paybacks, alongside detailed descriptions of health and safety benefits.

https://schools.lbl.gov/guides-and-packages



3) Modeled Retrofit Packages for Schools

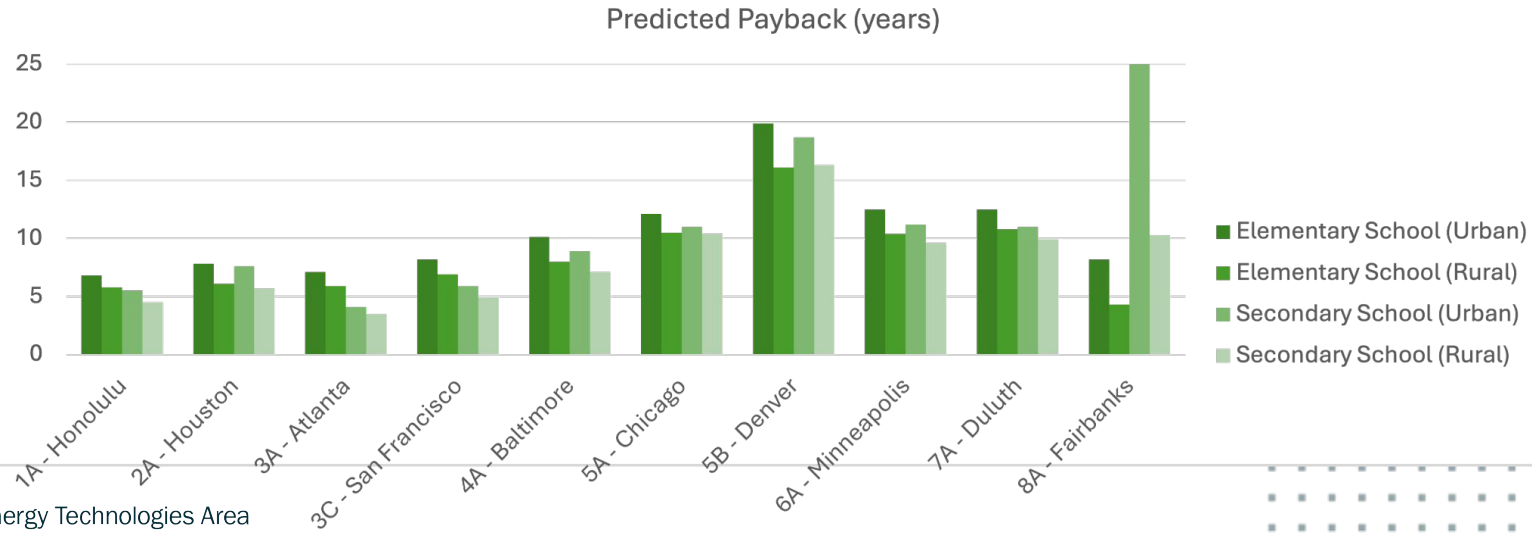
Example Package (#5)

Measures	HVAC Controls + Lighting + IEQ
HVAC Controls	Improved HVAC controls, consistent with BMS upgrade or significant tuning of BMS, economizer repairs, supply air temp. reset, static pressure reset; installation of supply fan VFD; heating water pump VFD and temp. reset
Lighting	LED retrofit indoors and outdoors; occupancy sensor controls on indoor and outdoor lighting; daylighting controls on indoor lighting
IAQ	Upgrade air filters from 2” MERV 8 to 4” MERV 13; networked thermostats and sensors for DCV

3) Modeled Retrofit Packages for Schools

Package 5: Key Finding

- HVAC controls + lighting + IEQ package shows good paybacks overall, with relatively low implementation costs and good energy savings

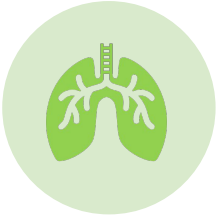


3) Modeled Retrofit Packages for Schools

Benefits Beyond Energy and Cost Savings



- Improve the likelihood of thermal comfort being maintained
- Lower background noise to support learning in classroom



- Improve ventilation
- Enhance removal of particulate matter for cleaner indoor air



- Improve indoor lighting quality
- Improve site security by improving outdoor light distribution

4) FLEXLAB School Retrofit Packages Project

AVAILABLE NOW!

Goal: High Energy Savings & IAQ Retrofits

Develop school retrofit packages capable of delivering significant energy savings and IAQ benefits. Address system-level barriers by testing integrated packages.

Approach: Packaged Solutions

Recognize needs for energy savings and IAQ.

System package included **occupancy-based ventilation controls**, **lighting + controls**, **improved air filters**, and **HVAC scheduling**

Motivation: Focus on IAQ

School facilities are often poorly maintained and fail to guarantee adequate ventilation. Target opportunities for school districts to upgrade heating, ventilation, and air filtration.

Performance Validation: Simulate & Test

Evaluated annual energy & cost savings through whole-building energy simulations. Selected top packages for physical testing at LBNL's FLEXLAB facility.

4) FLEXLAB School Retrofit Packages Project



Whole Building Annual Energy Simulations

Predicted **14% to 36%** site energy savings for elementary schools in CA and NC.

Simple payback: **1 to 5** years (replace on failure) **6 to 11 years** (early replacement)

FLEXLAB Testing

Validated smart lighting/controls, demand controlled ventilation, economizer retuning, outside air scheduling, and MERV 14 supply air filters.

Key Measurements

Analyzed real-world energy performance, task illuminance, thermal comfort, and $PM_{2.5}$ leves.

4) FLEXLAB School Retrofit Packages Project

Comfort & Indoor Air Quality

- **Comfort maintained** (lighting performance and thermal comfort analyzed)
- MERV 14 air filter reduced indoor $PM_{2.5}$ by **95% on average** compared to baseline



Retrofit package validation in LBNL's FLEXLAB. Occupant emulators and programmable plug loads are shown at desks in a classroom configuration.

https://eta.lbl.gov/publications/getting-beyond-widgets-performance

More Resources

Smarter Small Buildings

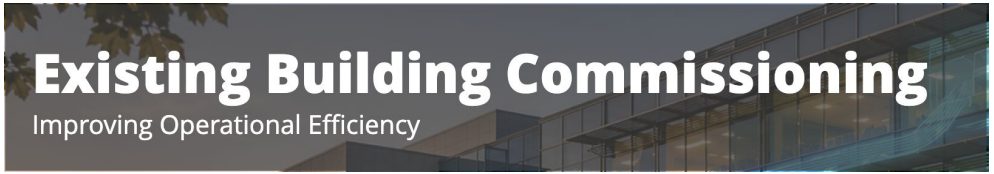
https://smartersmallbuildings.lbl.gov/guidance-documents

National Center on School Infrastructure

https://school-infrastructure.org/

Schools Energy Resource Hub
BERKELEY LAB

https://schools.lbl.gov/



https://bies.lbl.gov/existing-building-commissioning

Questions and Answers

Use the Q and A feature to ask questions

Thank you!

- Please complete a quick survey!
- Visit school-infrastructure.org and schools.lbl.gov

National Center on School Infrastructure