High Performance School Construction Guidelines

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Introduction

- Schools spend $7.8 billion on energy per year: more than computers and textbooks combined
- EnergySmart Schools estimates energy bills could be reduced by 25%
- This afternoon…
  - Features of High Performance Schools
  - Review of Guidelines Format and Content
  - Examples from Districts Nationwide

ESS is Part of the Department of Energy's Office of Weatherization and Intergovernmental Rebuild America Program

Major DOE National Laboratories

National Nuclear Security Administration
Office of Science
Energy Efficiency and Renewable Energy
Office of Nuclear Energy
Fossil Energy

Major NREL Thrusts

Only National Lab Dedicated to RE and EE

Wind
- Large Scale
- Low Speed

Solar
- Photovoltaics
- Solar Thermal

Biomass
- Biorefineries
- Biosciences

Geothermal

Hydrogen
- Production
- Storage
- Delivery & End Use
- Systems Integration

Distributed Energy
- Distribution & Interconnection
- Thermal Systems
- Superconductivity

Vehicle Technologies
- Hybrid Vehicles
- Alternative Fuels Utilization

Building Technologies
- Building Efficiency
- Zero Energy Buildings

Federal Energy Management

Basic Energy Science
- New Materials
- Chemical & Biological Sciences

Analytical Studies

International

High Performance Schools mean High Performance Students

- Students with the most daylighting progressed
  - 20% faster on math tests,
  - And 26% faster on reading tests over a one year period

(Heschong Mahone Group 1999, 2003)

- Better teaching environment
- Cost savings
- Environmental savings

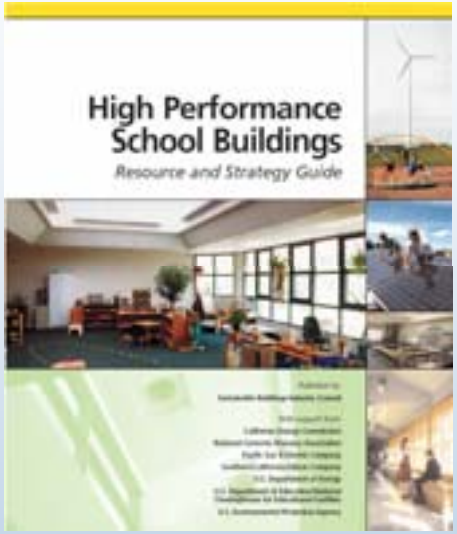
HPS Component: Teaching Resource

Energy Efficiency, Renewable Energy and Open Building Systems on Campus are effective ways to integrate math and science activities into daily study life

Many shades of green…

LEED

U.S. Green Building Council



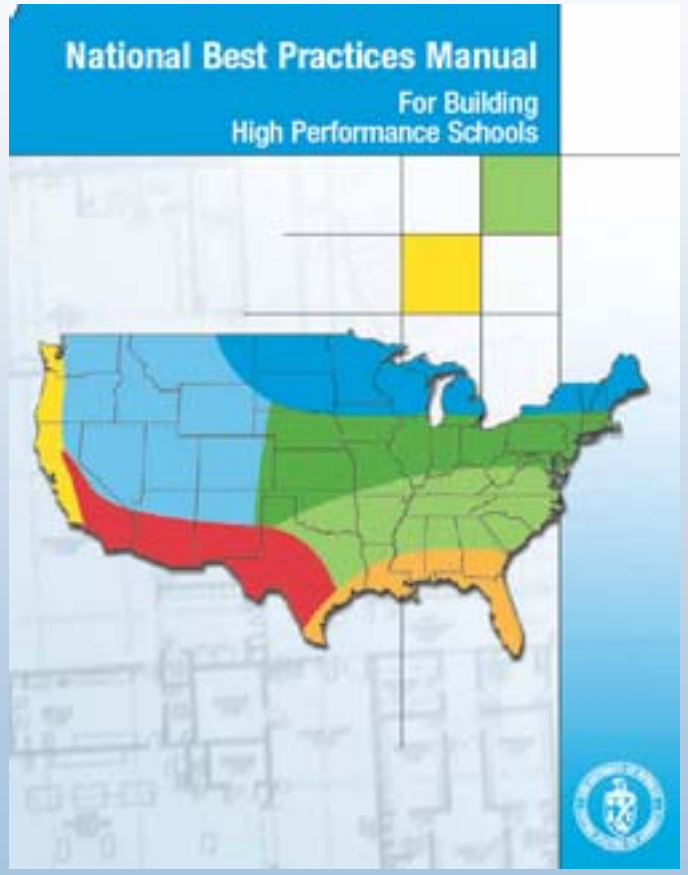
Sustainable Building Industry Council

American Society of Heating, Refrigerating, and Air-Conditioning Engineers

Energy Star for Buildings Award

DOE Guideline Documents

- National Best Practices Manual
  - Architects, Engineers, Project Managers
- Energy Design Guidelines for High Performance Schools
  - Architects, Engineers, Project Managers
  - Superintendents, Principals, schools boards, Administrative Staff



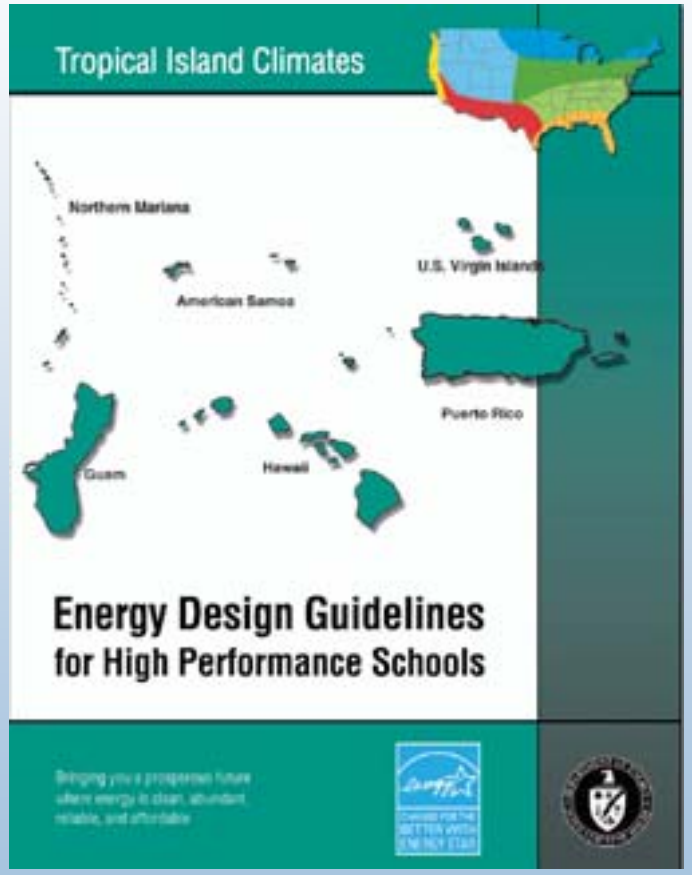
Climate Zone Specific

Accounts for climate – dependent variability in building needs and performance demands

Climate	Model City	Location	Summers	Winters
Hot and Humid	Orlando	Gulf Coast	Hot and humid, long	Mild, short
Temperate and Humid	Atlanta	Southeast	Hot and humid	Cold
Cool and Humid	Boston	Northeast, Mid-West, Southern Plains	Warm and humid	Cold snowy
Cold and Humid	Minneapolis	Northern Plains	Short in duration, but warm and humid	Long in duration, very cold
Hot and Dry	Phoenix	Southwest Desert	Hot and dry	Clear and mild
Cool and Dry	Denver	Western states	Warm and clear	Clear and cold
Temperate and Mixed	Seattle	Pacific Coast	Clear mild	Long, overcast and mild

Topics Covered Reflect Interaction of Building Components

- Site Design
- Daylighting and Windows
- Energy-Efficient Building Shell
- Lighting and Electrical
- Mechanical and Ventilation
- Renewable Energy
- Water Conservation
- Recycling Systems and Waste Management
- Transportation
- Resource Efficient Products
- Checklist
- Case Studies



Emphasis on the Whole Building as a System

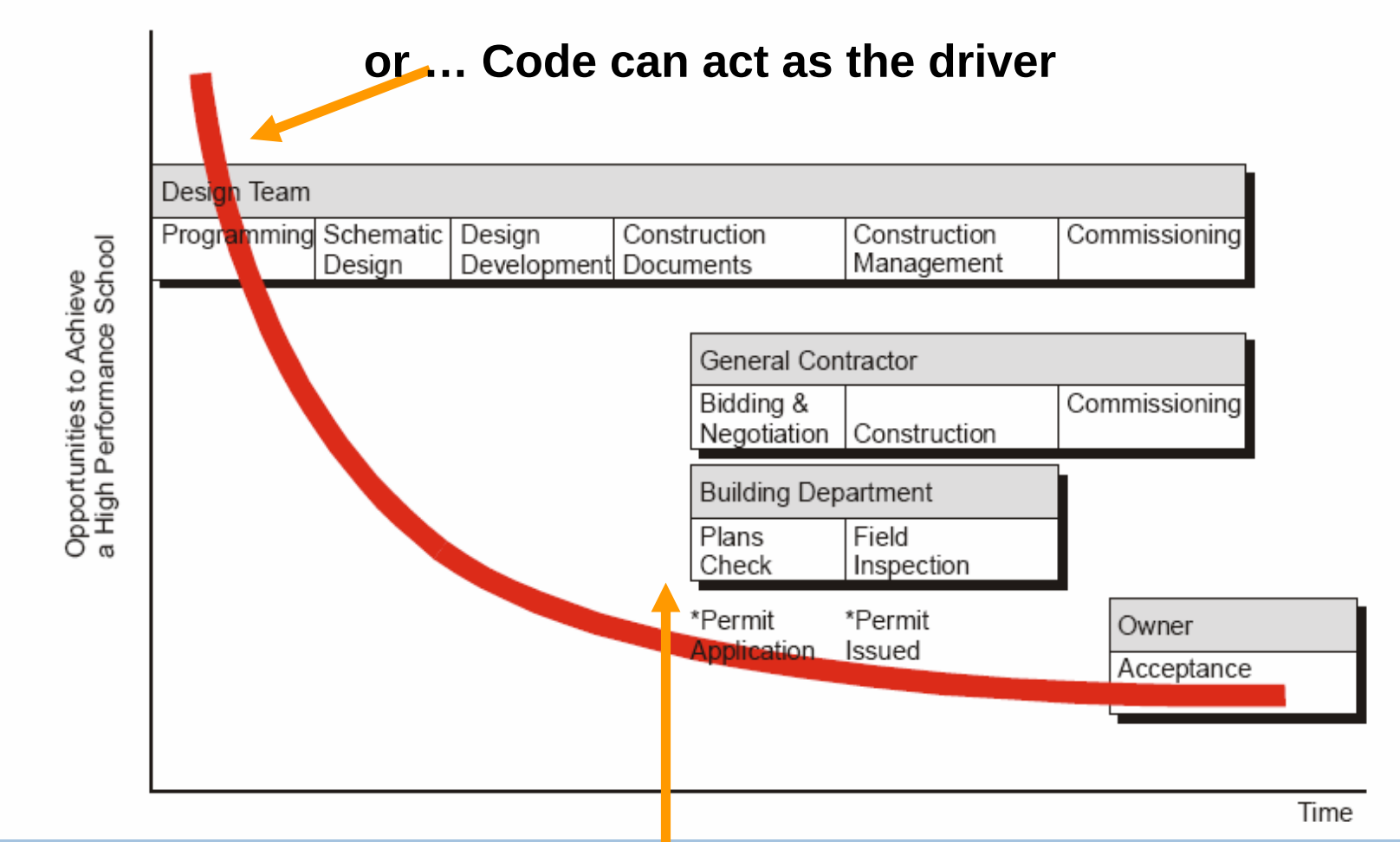
Evaluate a wide range of energy-efficient strategies, *working together*

Passive solar heating
Shading
High Efficiency HVAC
Daylighting
Better HVAC Controls
Better windows
Economizer cycle
Energy efficient lights and ballasts
Reduced infiltration
Lighting controls
Reduced duct leakage
Insulation
Photovoltaics
Thermal mass
Distributed Generation
Combined Heat and Power

Cross-Cutting Issues

Technical Chapters	Goals/Cross-Cutting Issues									
	Health and IAQ	Thermal Comfort	Visual Comfort	Acoustic Comfort	Security and Safety	Ecosystem Protection	Energy Efficiency	Water Efficiency	Materials Efficiency	Building as a Teaching Tool
Site Design	●	●	●	●	●	●	●	●	●	●
Daylighting and Windows		●	●		●		●		●	●
Energy-Efficient Building Shell		●		●			●		●	●
Lighting and Electrical Systems		●	●				●			●
Mechanical and Ventilation Systems	●	●		●	●		●	●	●	●
Renewable Energy Systems		●					●			●
Water Conservation								●		●
Recycling Systems and Waste Management						●			●	●
Transportation					●	●	●			
Resource-Efficient Building Products	●			●		●	●		●	●

Opportunities in the Design Process



Code phase can be here

National Best Practices Manual Comprehensive Format

- Recommendation:
  - How to apply the high performance design concept or technology
- Description
  - Detailed information on the strategy or technology
- Applicability Chart
  - Indicates applicability to particular spaces, climate zones and design process steps
- Integrated Design Implications
  - Describes the implications the design strategy or technology may have on other building systems
- Cost Effectiveness
  - Cost/Benefits of the design strategy on a system and overall project basis

National Best Practices Manual Format

- Benefits
  - Expected benefits from the implementation of HP design strategies and technologies
- Design Tools
  - Applicable design tools including software that determine benefits and costs
- Design Details
  - Rules of thumb, Specifications, Schematics
- O&M Issues
  - Potential O&M concerns and strategies
- **Commissioning**
  - Outlines need for calibration, functional tests, static tests
- References
  - Sampling of documents, websites etc….

GUIDELINE SD1: OPTIMUM BUILDING ORIENTATION

Recommendation

When site conditions permit, orient buildings so that major windows face either north or south. Position classrooms so that light and air can be introduced from two sides. Solar orientation should guide the placement of building and site features. Reduce the impact of exterior noise sources by locating noise sensitive areas, such as classrooms, away from noise producers, like roadways, train tracks, etc.

Orientation plays a key role in the landscaping and daylighting design. NREL/PIX09704

Description

Space heating and cooling accounts for nearly 20% of all energy consumption in the U.S. Optimal orientation of the building creates opportunities to utilize the potential contributions of the sun, topography, and existing vegetation for increased energy efficiency by maximizing heat gain (or minimizing heat loss) in winter and minimizing heat gain in summer. In the case of existing buildings, arrangement of interior spaces, strategic landscaping, and modifications to the building envelope can mitigate unfavorable orientation.

Applicable Climates

Applicable Spaces	When to Consider
Classrooms	Programming
Library	Schematic
Multi-Purpose	Design Dev.
Gym	Contract Docs.
Corridors	Construction
Administration	Commissioning
Toilets	Operation
Other	

Applicability

All climates. Primarily for new buildings and site planning, with some applicability to retrofitting existing buildings for greater efficiency.

Integrated Design Implications

Knowledge of the existing site soils, vegetation, and microclimate are critical to understanding how to best arrange site elements to create the least disruption to the site and orient structures and spaces appropriately. Integrate existing site features; proposed landscape design; orientation, height, and finish of walls; architectural design; impervious surfaces; location of heating and cooling equipment. Refer to guideline: SD2: Landscaping to Provide Shade to HVAC Systems, Buildings, and Paved Areas and TR2: Safe and Energy-Efficient Transportation.

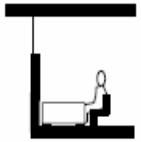
Cost Effectiveness

Cost implications exist mainly in the design phase. Resulting cost savings will be demonstrated during building operation with lowered heating and cooling requirements.

Benefits

Reduced energy consumption will result in cost savings for year-round heating and cooling. The arrangement of interior and outdoor spaces with thoughtful solar orientation allows optimal natural lighting and user-friendly spaces. Studies have shown that students in classrooms with the most daylighting have

GUIDELINE DL2: HIGH SIDELIGHTING—CLERESTORY



Clerestory windows provide a more uniform distribution of daylight across the space. NREL/PIX 11404

Recommendation

Use high clerestories in perimeter walls to increase daylight delivery deeper in classrooms, offices, libraries, multipurpose rooms, gymnasiums, and administrative areas.

Description

High sidelighting clerestories are vertical glazing in an exterior wall above eye level (usually above 7 ft). Because the penetration of daylight from vertical glazing is about two times the window head height, moving the window higher in the wall increases daylight penetration in the space.

Applicable climates:

Applicable Spaces	When to Consider
Classrooms	Programming
Library	Schematic
Multi-Purpose	Design Dev.
Gym	Contract Docs.
Corridors	Construction
Administration	Commissioning
Toilets	Operation

Applicability

High clerestory windows can be used in all school spaces to provide deep penetration of daylight. They are applicable to all climate regions and should be planned in the schematic design phase.

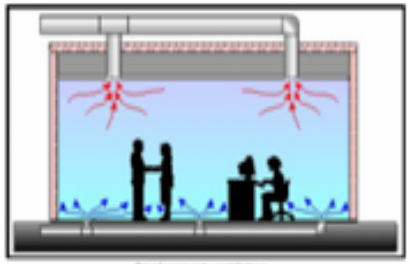
Integrated Design Implications

- **Design phase.** High sidelighting requires high ceilings and perimeter walls. North and (shaded) south orientations are preferable, although east, and west orientations can be acceptable if diffusing glazing is used, or if low-angle sun penetration will not be bothersome in the space. High sidelighting is most appropriate for open plan interior layouts that allow unobstructed daylight penetration. It should be considered in the early schematic design phase.
- **Balance with other daylight needs.** Applied to one wall, this approach creates a decreasing gradient of useable daylight about two times the clerestory head height into the space. Spaces of 20 ft to 40 ft in width (classrooms, etc.) can be balanced with a daylighting scheme on the opposite wall to provide even lighting across the entire space. View windows should also be provided. The total glazing area should be apportioned among these needs.

GUIDELINE MV6: DISPLACEMENT VENTILATION SYSTEM

Description

Displacement ventilation systems are different from most other HVAC systems for schools and offer a number of advantages. With displacement systems, air is delivered near the floor, at a low velocity, and at a temperature from 63ºF to 65ºF (compared to around 55ºF for conventional air distribution cooling). The goal of displacement systems is not to cool the space, but to cool the occupants. Cool air flows along the floor until it finds warm bodies. As the air is warmed, it rises around occupants, bathing them in cool fresh air. Air quality improves because contaminants from occupants and other sources tend to rise out of the breathing zone rather than being mixed in the space. Similarly, cooling loads decrease significantly because much of the heat generated by occupants, lights, and computer equipment rises directly out of the occupied zone and is exhausted from the space. This is especially true in classrooms designed for 100% outside air with total energy recovery.



Displacement ventilation.

Ventilation system.
(source: http://www.advancedbuildings.org)

Applicable Climates

Applicable Spaces	
Classrooms	■
Library	■
Multi-Purpose	■
Gym	■
Corridors	□
Administration	■
Toilets	□
Other	□

When to Consider	
Programming	■
Schematic	■
Design Dev.	□
Contract Docs.	□
Construction	□
Commissioning	□
Operation	□

Variations and Options

There are several supply air distribution options:

- Access floor.
- Low wall outlets.
- Infloor outlets.

The best cooling source for a displacement ventilation system is a chilled water coil. The control valve in a hydronic system allows supply of constant 63ºF to 65ºF air. A typical direct exchange (DX) system is designed to provide colder 50ºF to 55ºF air while the compressor is running and cycles on and off to meet space loads. This lower temperature and temperature fluctuations would create a comfort problem in displacement ventilation when it comes in contact with occupants. However, larger DX systems with several compressors and temperature reset capabilities can be used as an alternative to a chilled water system. For example, a packaged rooftop VAV system serving 10 or more classrooms should be able to provide the necessary supply air temperature control.

Evaporative cooling is also a potential source because it typically produces higher air temperature than a DX system.

Applicability

Displacement ventilation is most appropriate for spaces with ceiling height of at least 10 ft to permit stratification. Systems that utilize 100% outside air design with enthalpy energy recovery are very suitable for high occupant density areas like classrooms and auditoriums. This distribution type is also a great choice where raised access floors are desired for flexibility of power and communication wiring (although access floors are not required for displacement ventilation).

Integrated Design Implications

Supply air outlets must be coordinated with the location of furnishings and space usage. The outlets may be integrated with cabinets or seating.

There is an excellent opportunity to integrate electrical and communication wiring with the air distribution either under the floor or along the baseboard.

A displacement system can eliminate the need for a suspended ceiling and allow the ceiling to be clear of supply diffusers.

If the ceiling is high enough, displacement ventilation can be integrated into portable classroom design, where space for ducting exists in the crawlspace beneath the floor.

Slab floors may be designed with integral ducts or troughs for air distribution.

Consider using variable-speed heating and cooling sources to minimize the on-off cycling and variations in supply air temperature.

Ceiling fans are not recommended with displacement ventilation because they are designed to mix air in a space and will disrupt the stratification created by the displacement ventilation system.

Cost Effectiveness

There is not a great deal of experience with displacement ventilation in classrooms, but it is growing in popularity for new commercial buildings. For the near future, costs are likely to be higher than standard overhead air distribution.

A displacement ventilation system will probably not provide a short payback based on energy savings alone. However, the system provides additional comfort and air quality benefits.

Costs	L	M	H
L			
M			
H			■

Benefits

Benefits

Advantages

- Significantly lower cooling loads (1/3 lower) result from thermal stratification.
- Significantly low system capacities will be needed if enthalpy energy recovery is used in combination with this vertical displacement approach.
- Air quality will improve per cfm moved compared to systems that mix space air.
- Can provide equal or better air quality with less outdoor air due to stratification.
- Lower fan energy with lower static pressure may result (depends on distribution type and outlet type).
- Ceiling remains clear of supply registers, except for exhaust/return grills.
- Raised access floor systems are typically made up of 1-in. to 1.5-in.-thick concrete sections. This provides advantages from the standpoint of controlling duct noise breakout and/or radiated noise from VAV or fan powered boxes.

Disadvantages

- Heating performance may be worse than systems providing air at greater velocities. Mixing (i.e., destratification) is desirable for heating.
- First cost may be higher with raised floor systems.
- Some floor area or low wall area is required for supply air outlets.

Site Design and Selection

- Optimum Building Orientation
- Landscaping Design
- Impervious Surfaces
- Integrated Weed and Pest Control
- IAQ during Construction

Site design can create opportunities for outdoor classrooms and environmental learning projects. NREL/PIX 02682

Daylighting and Windows

- View Windows
- High Sidelighting-Clerestory
- Classroom Daylighting
- Central Toplighting
- Linear Toplighting
- Tubular Skylights

Clerestory windows provide a more uniform distribution of daylight across the space. NREL/PIX 11404

Grid of skylights provide even illumination across the space. NREL/PIX 11434

Energy Efficiency Building Shell

- Wall Insulation
- Roof Insulation
- Cool Roofs
- Radiant Barriers
- Air Barriers
- Concrete Masonry

Because solar gain on roofs is a significant component of heat gain, using materials that have a high reflectance can significantly reduce the load. NREL/PIX 03510

Lighting and Electrical

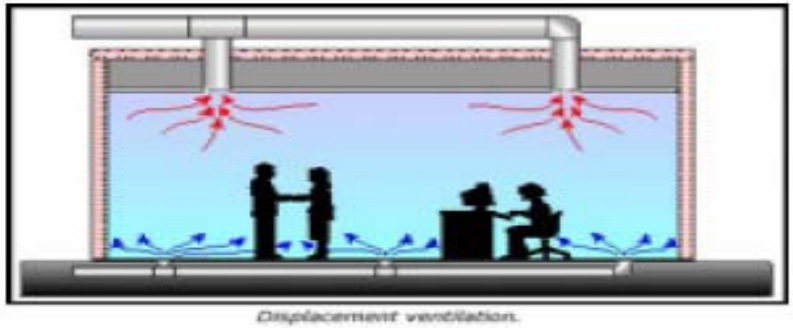
- Pendant Mounted Lighting
- Troffer Lighting
- Gym Lighting
- Corridor Lighting
- Lighting for Office, Library and Classroom
- Outdoor Lighting

Light sensors, like the one being tested here, can dramatically affect both energy use and usability.

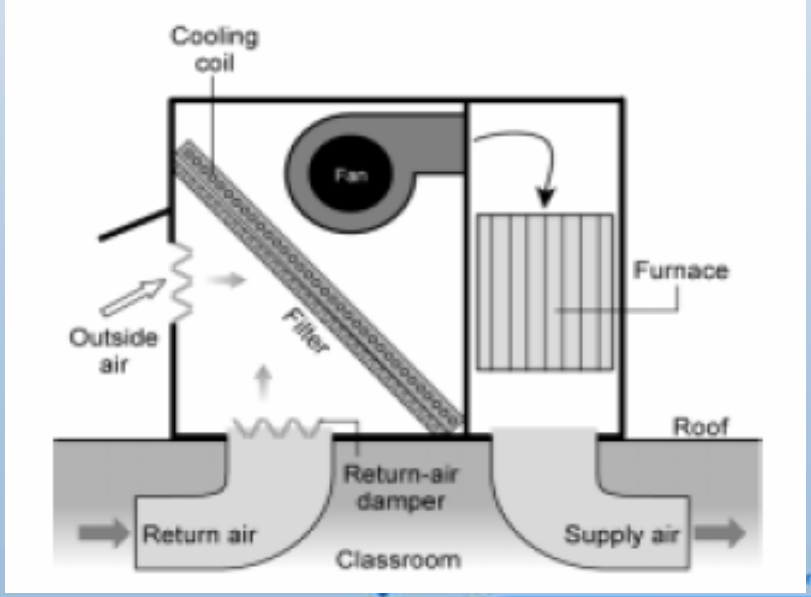
NREL/PIX 05171

Mechanical and Ventilation

- Cross & Stack Ventilation
- Ceiling Fans
- Packaged Rooftop
- Radiant Slab
- Evaporative Cooling
- Economizers
- Boilers
- CO Sensors
- Heat Pumps



Ventilation system.
(source: http://www.advancedbuildings.org)



Renewable Energy Systems

- Passive Heating & Cooling
- Solar Thermal
- Solar Pool Heating
- Wind
- Geothermal (GSHP)
- Photovoltaics

A solar heating system requires very little or no maintenance since it has no burners or moving parts. NREL/PIX08590

Photovoltaics are most cost effective in remote locations that are at a distance from an electrical grid, but they have zero environmental costs. NREL/PIX00006

Water Conservation

- Water Efficient Irrigation
- Stormwater Manageent
- Rainwater Collection
- Gray Water
- Efficient Terminal Devices

Low-flow devices will reduce water consumption by 15% to 20%, resulting in lower environmental costs and reduced load on wastewater treatment plants. NREL/PIX00653

Recycling Systems and Waste Management

- Paper, Plastics, Glass and Aluminum
- Composting
- Construction & Demolition

A well-coordinated school recycling plan requires minimal costs and can be more than offset by a reduction in waste pickup costs. NREL/PIX 11337

Transportation

- Alternative Fuels
- Transportation and Site Design
- Alternative Fuel Vehicles

Designing bike and pedestrian paths and facilities for shared vehicle transportation helps to reduce morning traffic congestion at schools. NREL/PIX 09075

Resource Efficient Building Products

- Carpeting
- Resilient Flooring
- Ceramic Tile
- Concrete, Wood and Bamboo Flooring
- Acoustical Panels
- Casework and Trim

Formaldehyde-free acoustical panels with recycled content are considered a material efficient, low-volatile organic compound product, promoting healthy indoor air.

Commissioning & Maintenance

- Commissioning Approaches
- Benefits of Commissioning
- Costs of Commissioning
- The Commissioning Team
- Commissioning Phases

Figure 1 – How to Pay for Commissioning-One Option

Shift 2% of total project costs to the commissioning provider and 3% to the design team.[6]

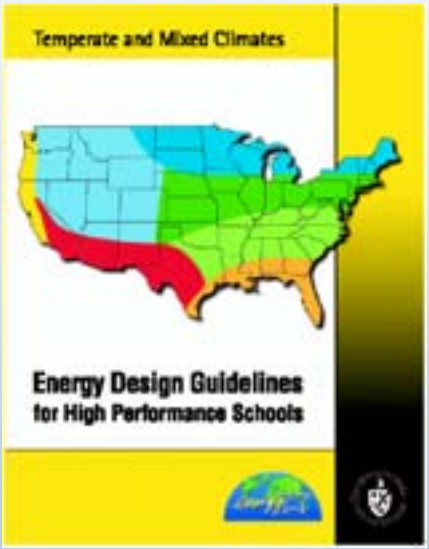
Table 1 — Estimated Commissioning Costs for New Equipment[4]

Commissioning Scope	Estimated Cost Range
Whole building (controls, electrical, mechanical) Commissioning from design through warranty	0.5% to 3% of total construction cost
HVAC and automated controls system only	1.5% to 2.5% of mechanical contract
Electrical system only	1% to 1.5% of electrical contract

Temperate and Mixed Climates

Corvallis School District 509J, Corvallis, Oregon

- 6850 students in 12 schools
- $1.5 million saved 1999-2004:
  - reduced energy use in off-peak hours
  - turning off lights and computers
- New middle school and new high school use energy efficient measures as well:
  - estimated **35% energy savings** for high school and **30%** for middle school
  - applying for **LEED Silver ratings**



www.nrel.gov/docs/fy02osti/29986.pdf

Corvallis, Oregon

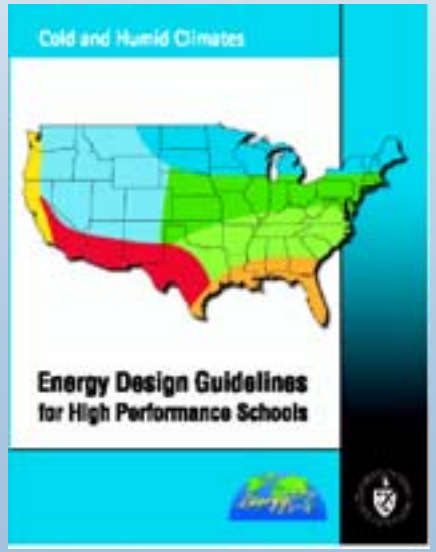
- Technologies used across the district:
  - T-8 lighting
  - digitally controlled HVAC
  - energy-efficient boilers
- $5200 reimbursement from the local utility funded cafeteria lighting upgrade
- $24,000 rebate and Business Energy Tax Credit (BETC) funded a gym lighting retrofit

The new Corvallis High School

Cold and Humid Climates

Elk River School District #728, Elk River, Minnesota

- 11,000 students in 17 buildings
- Rogers High School:
  - New school; completed 2003
  - First high performance school in the state
  - 850 students and 257,000 ft²
  - 25% less energy over code-built
  - $175,000 annual savings
  - $32 million project cost



www.nrel.gov/docs/fy02osti/29107.pdf

Elk River, Minnesota

- Westwood Elementary:
  - Also completed 2003
  - 74,000 ft² and 475 students
  - Expected savings of $65-75,000 annually over code-built schools
  - Project cost was $11.5 million

- Expected to receive LEED Silver Certification
- The first elementary in the state to have this distinction

Elk River, Minnesota

- In Westwood Elementary, there have been days in winter when it costs nothing to heat the school,

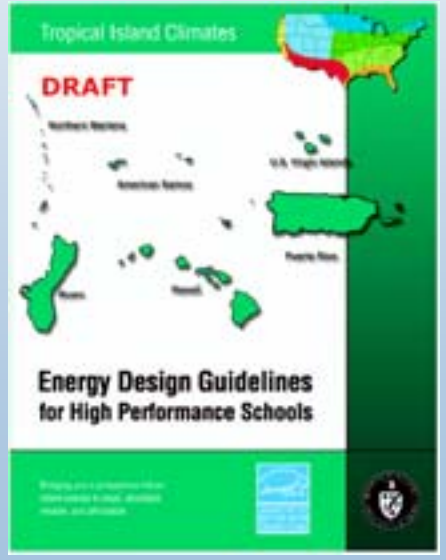
"The building maintained its desired temperature even with a constant flow of fresh air coming in."

Ron Bratlie,
Director of Special Projects

Tropical Island Climates

Chiefess Kamakahelei Middle School, Lihue, Kauai, Hawaii

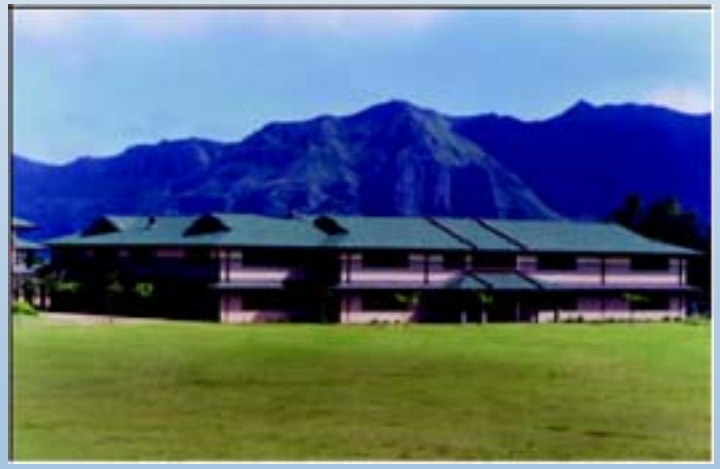
- 1064 students
- 134,000 ft² building oriented on east-west axis
  - Maximize exposure to daylight
  - Capture northeast trade winds for natural ventilation
- Variable-air-volume systems with variable-speed drives to ventilate library and music buildings



www.rebuild.org/attachments/SolutionCenter/34274draft.pdf

Lihue, Kauai, Hawaii

- Heat recovery unit converts heat of the refrigerant to supplement the hot water system
- High performance shell
  - Tinted, low-e windows
  - R-19 roof insulation

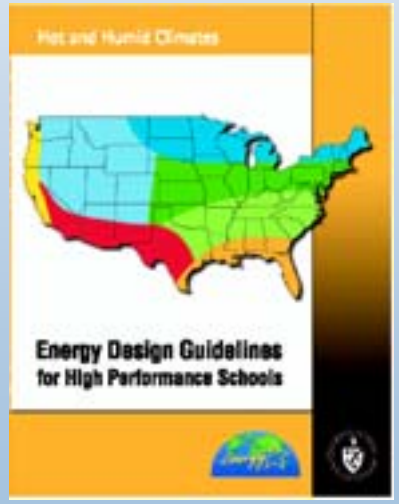


Chiefess Kamakahelei Middle School
Photo by Mitsunaga & Associates

- Daylighting strategies used to design most classrooms
- Lighting includes T-8 lamps and electronic ballasts

Energy Design Guidelines for High Performance Schools

- Department of Energy's Rebuild America program
- Specially targeted to nine climate zones



- Outline high performance principles for the new or retrofit design of K-12 schools

To order hardcopies:

www.rebuild.org/sectors/sectorpages/ess_guidelines.asp

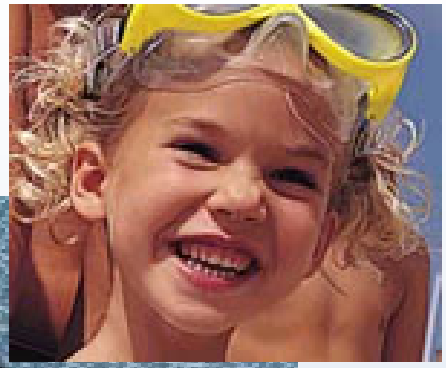
National Best Practices Manual

Key technical knowledge for architects, engineers and code officials

Available at: www.rebuild.gov

Conclusion

- High performance design allows for energy savings as well as better learning environment
- Building Codes can be used to drive a high performance process and push the envelope
- Integrated design and planning is essential
- Code inspectors can encourage beyond code practices



Bluffsview Elementary
Official Partner