U.S. Department of Energy
Energy Efficiency and Renewable Energy

High Performance Schools in Humid and Cool Climates: A Design Overview

Presented by:
Doug Sacra, LEED AP
HMFH Architects, Inc.

High Performance Green Facilities

- Improved Learning and Working Environment
- Costs less to maintain and operate
- Sensitive to the Environment

Improved Learning Environment

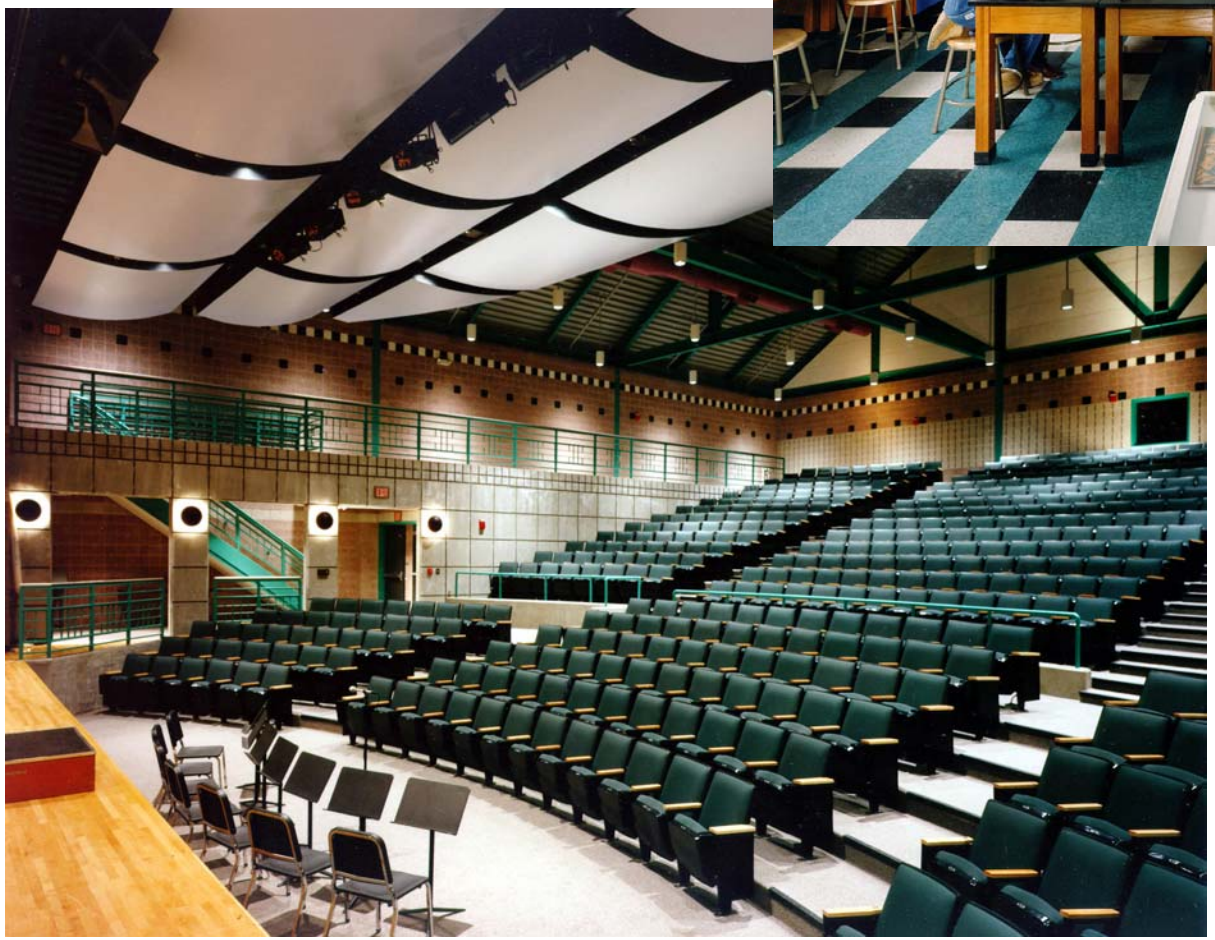
Daylighting

Capuano School
Somerville, MA – Classroom

Capuano School
Somerville, MA – Lobby

Burke Elementary School
Chelsea, MA - Art Classroom

Acoustics



Thermal Comfort

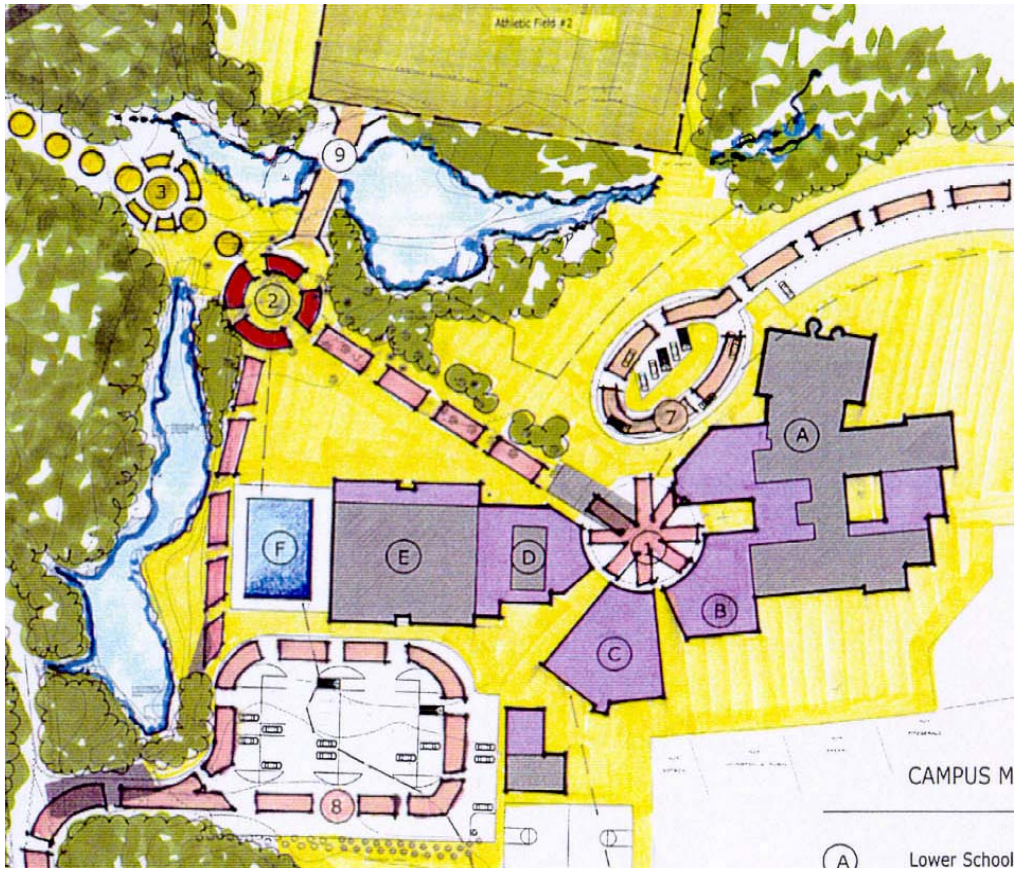
Indoor Environmental Quality

- HVAC Design
- Specify Materials to reduce off-gassing (VOC's, urea formaldehyde,…)
- Improve Air Barrier - Reduce air leakage & condensation that leads to mold and mildew
- Building Flush-out and Commissioning
- Regulate Construction Procedures

Indoor Environmental Quality

Safety and Security

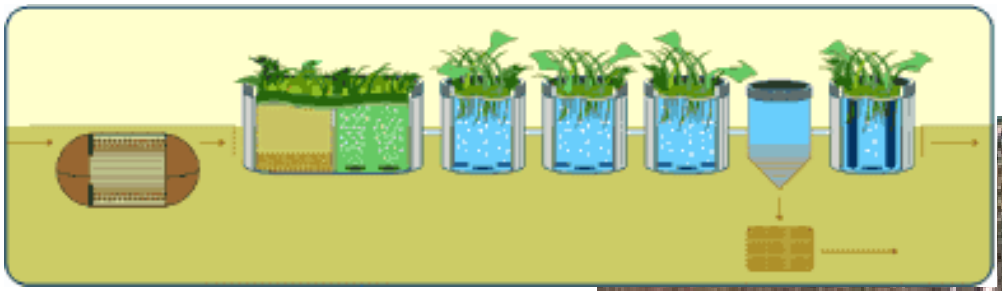
- Securing Building
- Securing Classrooms
- Site Lighting
- General design sensitivity for Visibility



Visual Comfort and Interest

Smith/Brooks Elementary Schools
Lincoln, MA - Library

Building as Sustainable Teacher



Costs Less to Operate and Maintain

- Energy Efficient – HVAC, Lighting
- Water Efficient – plumbing, irrigation
- Durable Materials – long life
- Easy to Maintain
- Robust Mechanical, Electrical, & Plumbing Systems
- Adaptable, Flexible

Lifecycle Cost / Owner Issues

- Consider entire cost to own: Initial cost, maintenance, energy, environmental
- Current norm: Consider initial cost only
- Private Schools: Increase competitiveness, giving
- Towns: Ideal "High Performance" Building Owners:
  - Own for life – bond for 20 years
  - Pay all maintenance, energy
  - Public School: portion of initial cost paid by state
  - H.P. features subsidized by utilities & renewable energy funds

Sensitive to the Environment

- Resource efficient construction – re-use existing buildings, materials, land, energy, capital
- Resource efficient operation – energy, water, sewage, maintenance labor and products, recycling
- Environmentally responsive site planning

➢ Outcome: Protects air, water, land quality

The Problem

- You want to do something new (something you have never done before)
- How do you find out the correct, best way to do it?
- How do you convince the design team and Owner that various upgrades makes sense?

Design Process

What is different between H.P. and normal design process?

- Client Education
- Present daylighting study with student performance results
- Review SBIC or other high performance user guide
- Review best design case studies - what are the possibilities?

Design Process – Client Education

School Building Committee Issues:

- Volunteers – not professionals
- Typical Success measured by maintaining budget & schedule
- Do not pay the energy bills – not part of their measurement of success
- May not be educators – importance of acoustics, daylight, IAQ

Outcome: Need total range of stakeholders

Need thorough process early

Design Process - Charrette

- Gather all key stakeholders: building committee, staff, students, parents, facilities staff, donors, architect, engineers, building inspector
- Determine all High Performance goals for project
- Prioritize goals
- Brainstorm around project concepts
- Build respect & relationships – understand each other's goals and viewpoints

Design Process

What is different between H.P. and normal design process?

- Integrated design team approach
- More options analysis up front (searching for best option, not just first acceptable one)
- Concentration on Lifecycle cost vs. Initial Construction Cost
- Review broadly early in project, more detail when appropriate

Design Process - ongoing

- Re-review goals at budget setting / cost cutting / funding review junctures
- Re-access / Revise goals as stakeholders increase understanding, awareness of opportunities

Provide Analysis for Intelligent Decisions

Define with client and design team:

- Daylight modeling
- Energy modeling:
  - -simple payback analysis
  - -manufacturer energy software analysis
  - -PowerDOE
- HVAC Systems Comparative Lifecycle Analysis
- LEED certification - provides measure of level of environmental performance

HVAC– Lifecycle Cost Analysis

Preliminary HVAC System Comparison example

- Multiple System Types, Cooling Equipment
- Construction Cost
- Energy Cost
- Maintenance Cost
- Life Cycle Cost

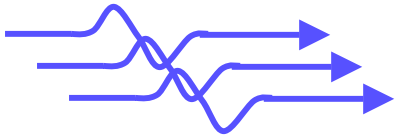
Also Need to evaluate Qualitatively

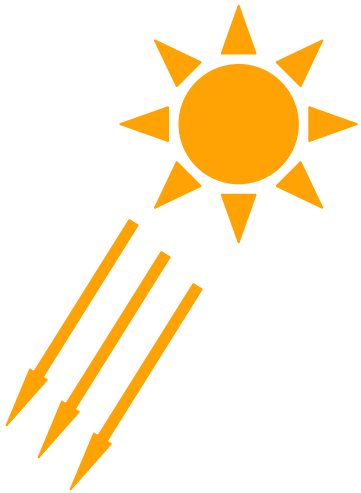
Natick High School

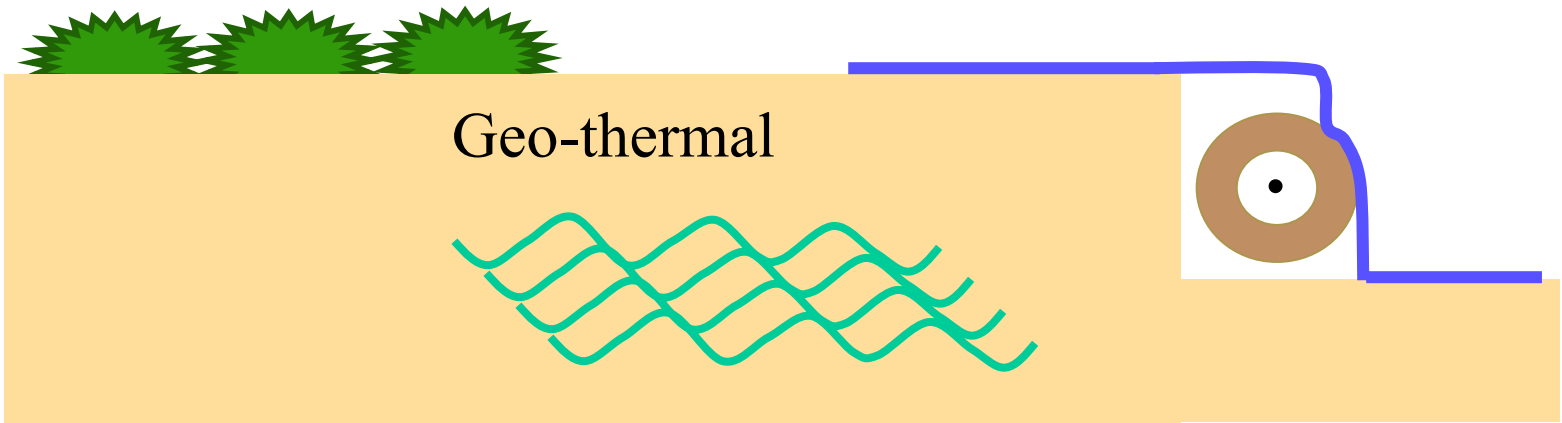
Preliminary HVAC System Comparison

Non-classrooms	Classrooms	Cooling Type	Construction	Annual Cost Energy	Annual Cost Maint	Life Cycle Cost
Air Handlers, package	All Air	DX	$ 5,227,000	$ 154,000	$ 60,000	$ 8,146,000
Air Handlers, package	All Air	Evap DX	$ 5,372,000	$ 147,000	$ 67,000	$ 8,289,000
Air Handlers, package	Fan Coils	DX	$ 4,429,000	$ 153,000	$ 69,000	$ 7,442,000
Air Handlers, package	Fan Coils	Evap DX	$ 4,501,000	$ 146,000	$ 76,000	$ 7,512,000
Air Handlers, package	Fan Coil with HR	DX	$ 4,574,000	$ 130,000	$ 70,000	$ 7,290,000
Air Handlers, package	Fan Coil with HR	Evap DX	$ 4,646,000	$ 124,000	$ 77,000	$ 7,380,000
Air Handlers, package	Unit Vents	DX	$ 4,138,000	$ 152,000	$ 72,000	$ 7,180,000
Air Handlers, package	Unit Vents	Evap DX	$ 4,211,000	$ 145,000	$ 79,000	$ 7,245,000
Air Handlers, chilled wtr	Unit Vents	WC chiller	$ 4,646,000	$ 143,000	$ 58,000	$ 7,379,000
Air Handlers, chilled wtr	Unit Vents	AC chiller	$ 4,211,000	$ 152,000	$ 66,000	$ 7,179,000
Air Handlers, chilled wtr	Unit Vents	Evap Chiller	$ 4,356,000	$ 145,000	$ 69,000	$ 7,265,000
Air Handlers, chilled wtr	Fan Coils	WC chiller	$ 4,937,000	$ 144,000	$ 56,000	$ 7,647,000
Air Handlers, chilled wtr	Fan Coils	AC chiller	$ 4,501,000	$ 153,000	$ 64,000	$ 7,441,000
Air Handlers, chilled wtr	Fan Coils	Evap Chiller	$ 4,646,000	$ 146,000	$ 67,000	$ 7,532,000
Air Handlers, chilled wtr	Fan Coil with HR	WC chiller	$ 5,227,000	$ 123,000	$ 57,000	$ 7,666,000
Air Handlers, chilled wtr	Fan Coil with HR	AC chiller	$ 4,792,000	$ 130,000	$ 59,000	$ 7,361,000
Air Handlers, chilled wtr	Fan Coil with HR	Evap Chiller	$ 4,937,000	$ 124,000	$ 61,000	$ 7,459,000

Renewable Energy Sources

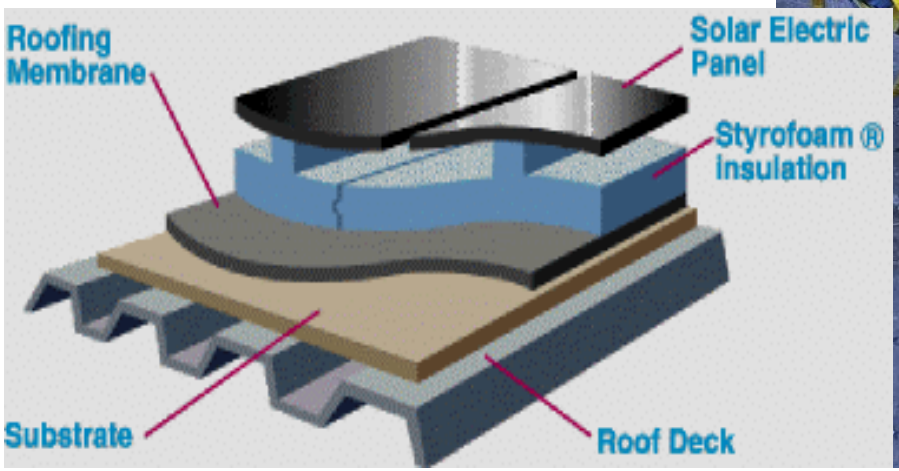




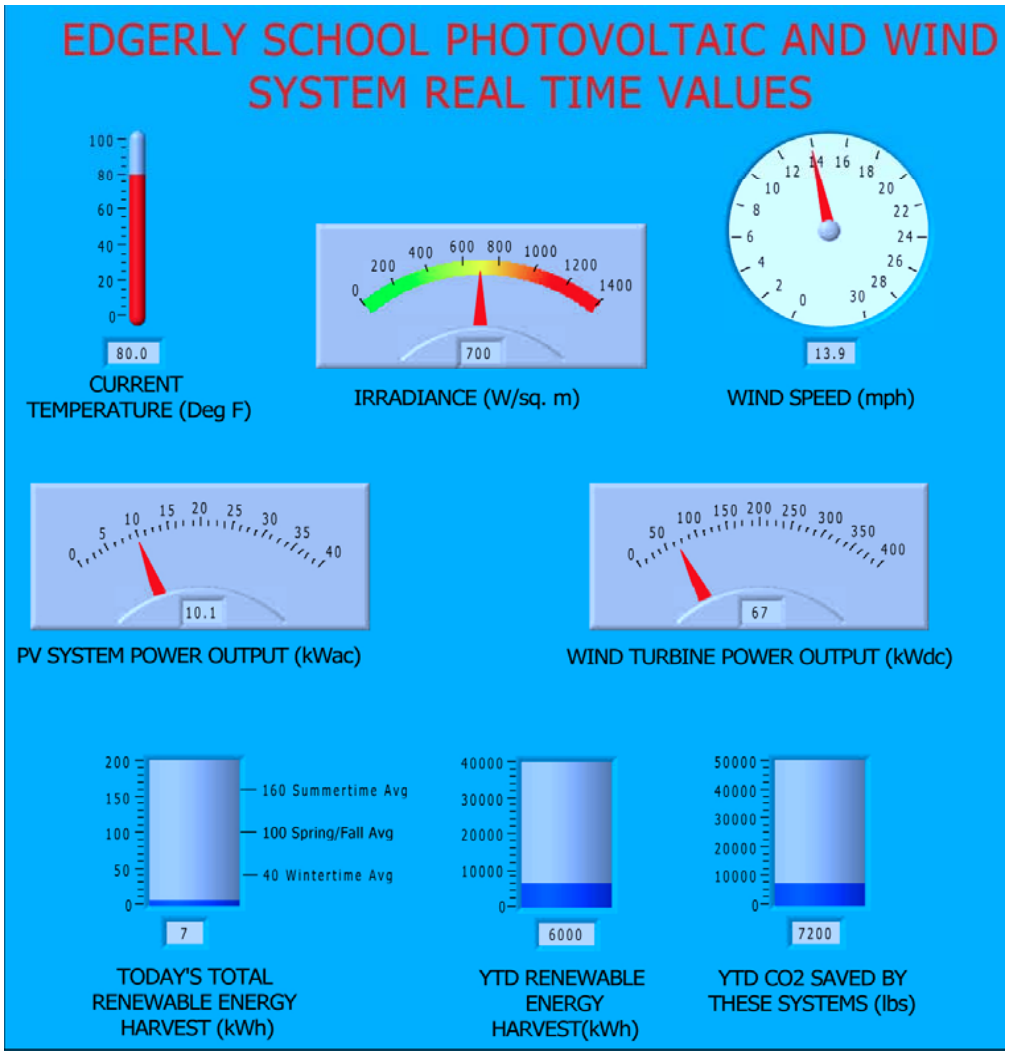


Renewable Energy / Distributed Generation

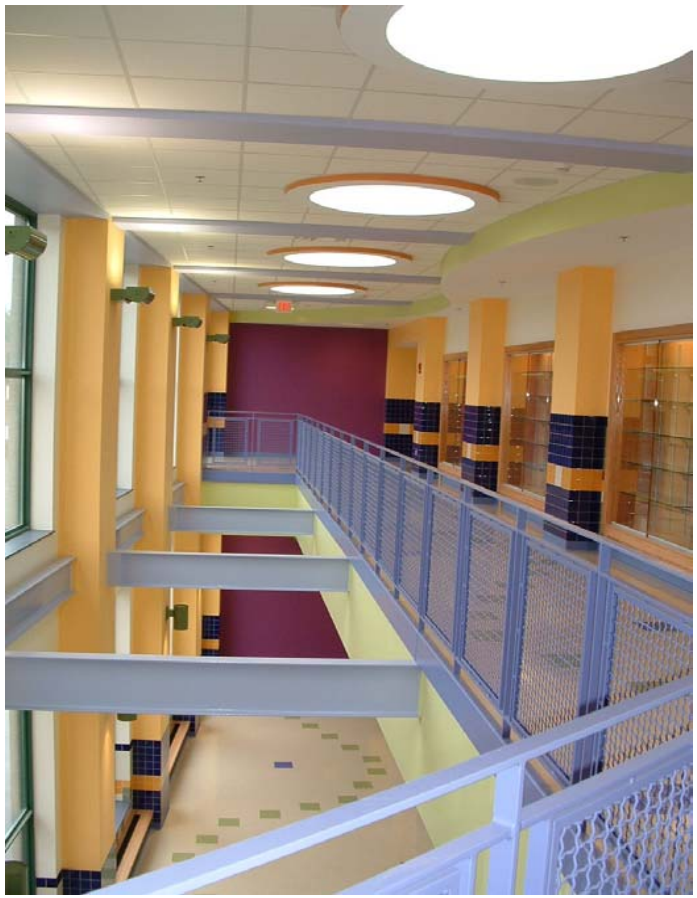
- Photovoltaic Systems
- Solar Hot Water
- Wind Turbines
- Wood Chip Gassification
- Combined heat and power
- Environmental Curriculum



Web Based Data Acquisition System



Capuano Early Childhood Center Somerville, MA



- Grades Pre-K to 1
- 80,000 square feet, 2 story
- 400 students
- Fully air conditioned
- MTC Green School Program
- LEED Registered
- Occupied September 2003
- AASA Walter Taylor Award
- 9% electricity from PV
- 39% less energy use

Edgerly Early Childhood Development Center
Somerville, Massachusetts
COMMUNITY GARDENS
HARD SURFACE PLAY AREA
SWINGS & PLAY EQUIPMENT
PARKING (14 SPACES)
BUS DROP OFF
SOCCER FIELDS
PARKING (12 SPACES)
BASKETBALL COURT
COMMUNITY GARDENS
MAIN ENTRY
FIRE LANE
PROPOSED SCHOOL
ENTRY
SERVICE AREA
PARKING (12 SPACES)
OLIVER STREET
KNOWLTON STREET
FRANKLIN STREET
GLEN STREET
DELL STREET
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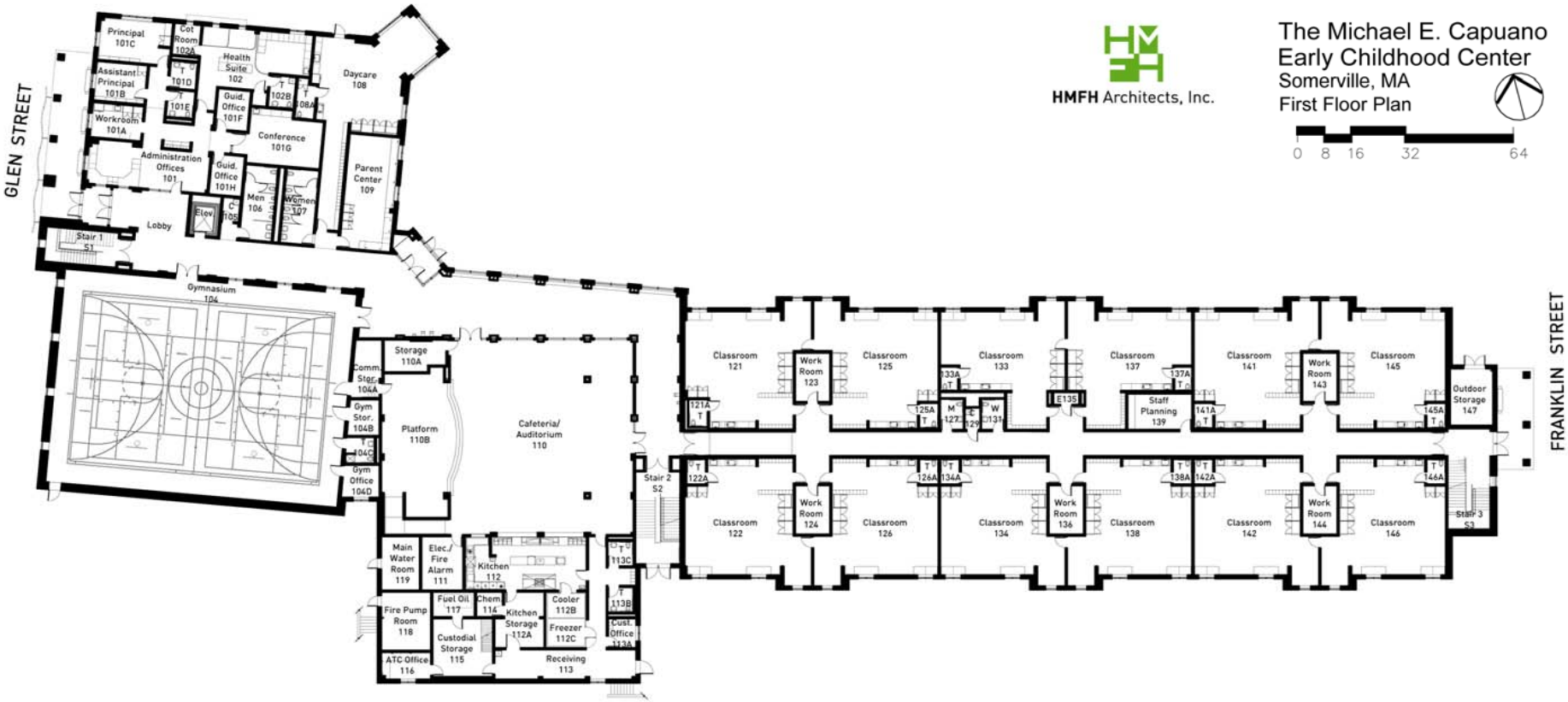
The Michael E. Capuano
Early Childhood Center
Somerville, MA
First Floor Plan

0 8 16 32 64



Design Process - In the beginning

Green for non-green clients

- Improve the learning environment
- Decrease maintenance
- Decrease energy usage

Shhh - Don't use the word "Green"

Design Process

Edgerly original client H. P. goals:

- Maximize daylighting in teaching spaces
- Reduce energy usage if payback reasonable
- Deliver fully functioning HVAC system
- Use materials that reduce maintenance/replacement

Sensitive to the Environment

Furnace Slag or Fly Ash in Concrete

Capuano School Concrete:

- 3,500 cubic yards
- 30% cement replaced with furnace slag
- 160 cy slag = 311 tons
- Avoids 311 tons virgin cement
- Avoids use of 11,000 gallons of oil
- Avoids 466 tons CO_2 emissions
- Stronger Concrete

480’ tall 3’x3’ tower waste avoided

How Much Does It Cost?

- 3,500 c.y.
- 3,000 PSI Concrete
- $76/cy with 100% cement
- $73/cy with 70% cement, 30% furnace slag
- Net savings $3.00/c.y.
- Total Savings $10,500 + markup
- For typical project – no related extra costs

Improving The Learning & Working Environment

Example: Daylighting

- Light from the sun
- But **No Direct Beam** Light

Potential of Daylighting

Heschong Mahone Group Study - 1999

Students with the most daylighting in their classrooms (compared to least in classrooms):

- progressed 20% faster in math tests
- progressed 26% faster on reading tests

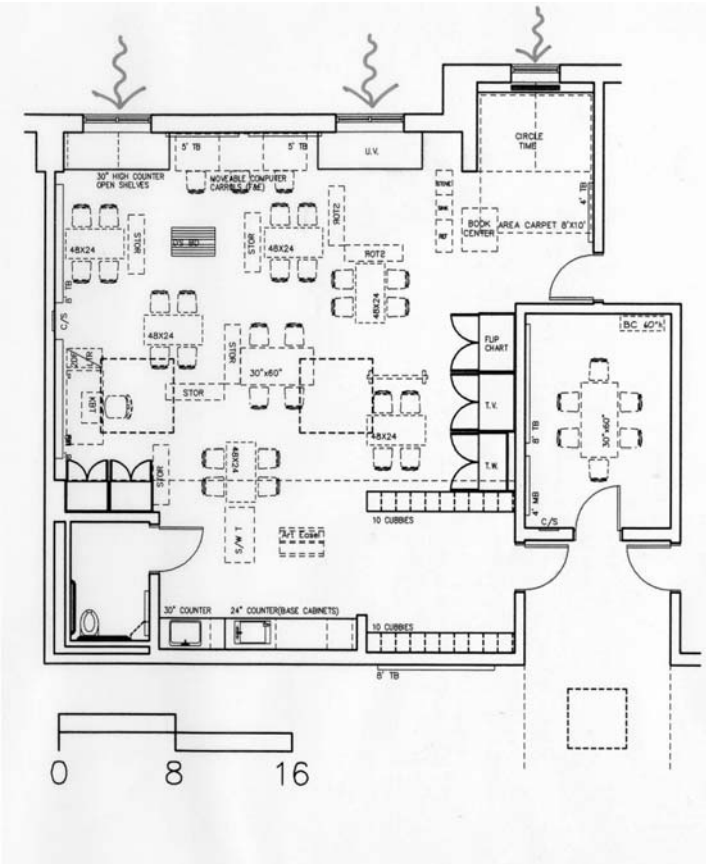
Students with poorly designed daylighting in classrooms:

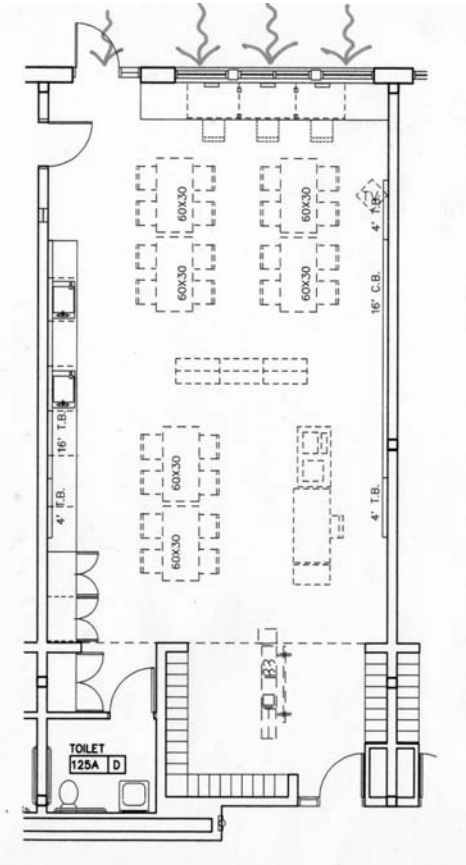
- declined 21% on reading tests

Goals for good daylighting

- Distribute light evenly
- Maximum Contrast ratio across room of 3:1 - 5:1
- Eliminate Glare
- Combine with view windows to connect with the landscape – feel changing natural light conditions
- Aim for best overall energy performance

Daylighting - Classroom Layout

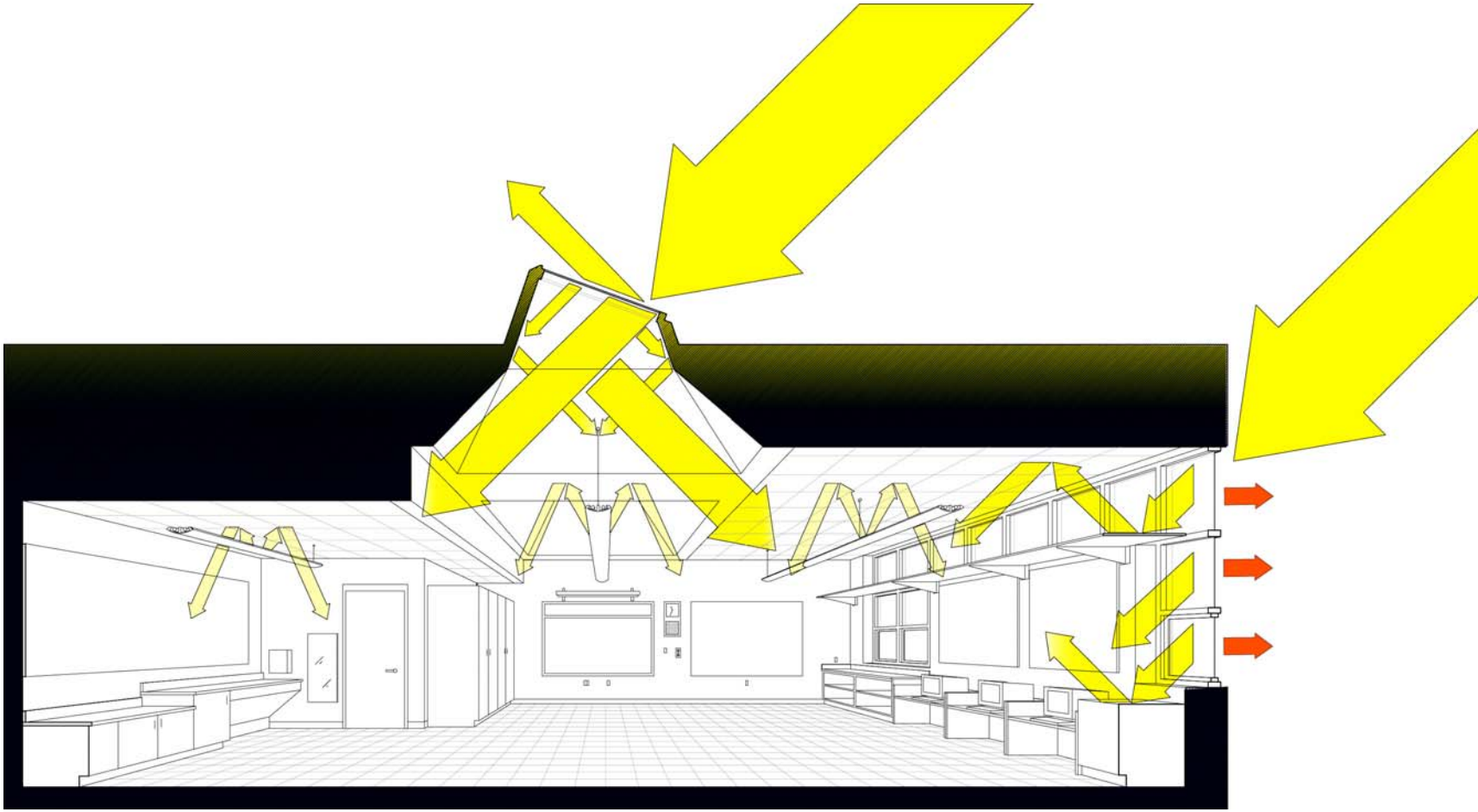




Capuano School Classroom Plan

Healey School Classroom Plan

Daylighting



Capuano School Classroom Section

Daylighting - Physical Model

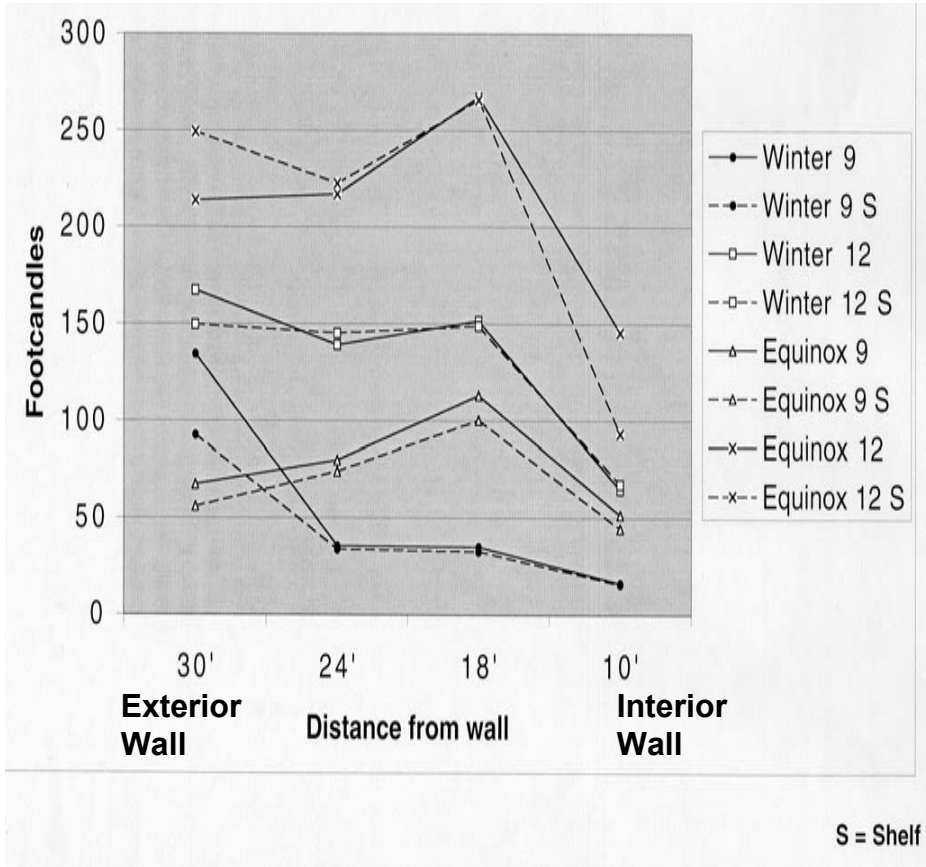
Up on the roof - testing the model

Daylighting – skylights

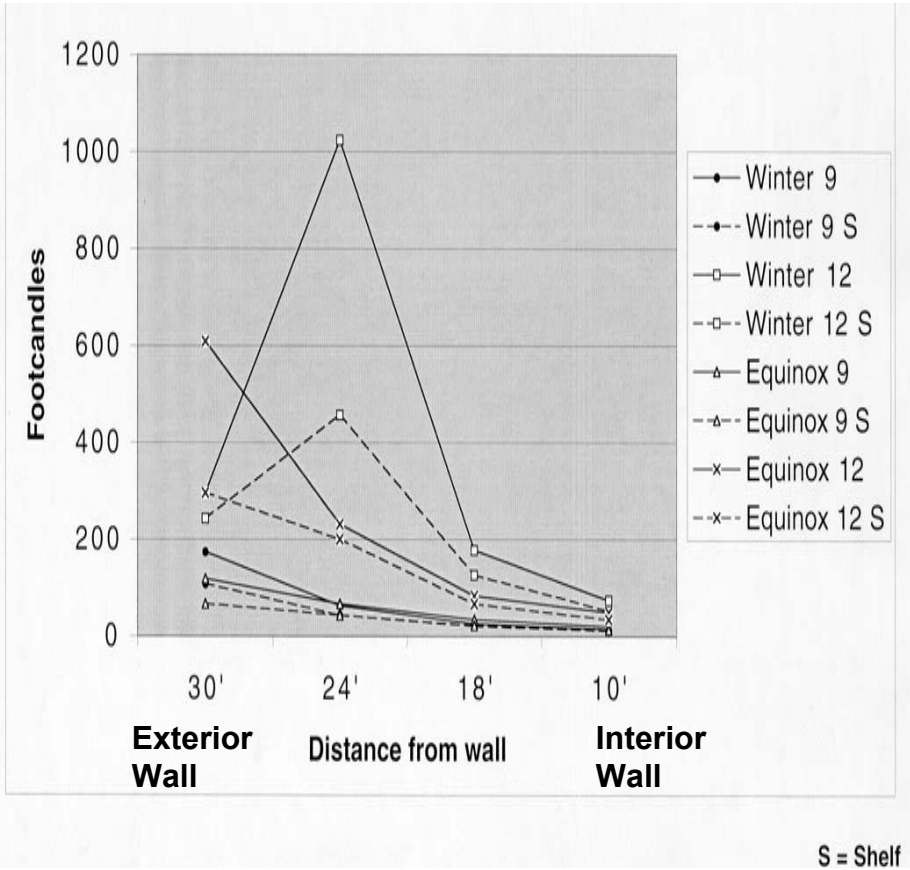
2nd floor - without skylights
Equinox at noon - south side

2nd floor - with skylights
Equinox at noon - south side

Daylighting - Analysis Graphs

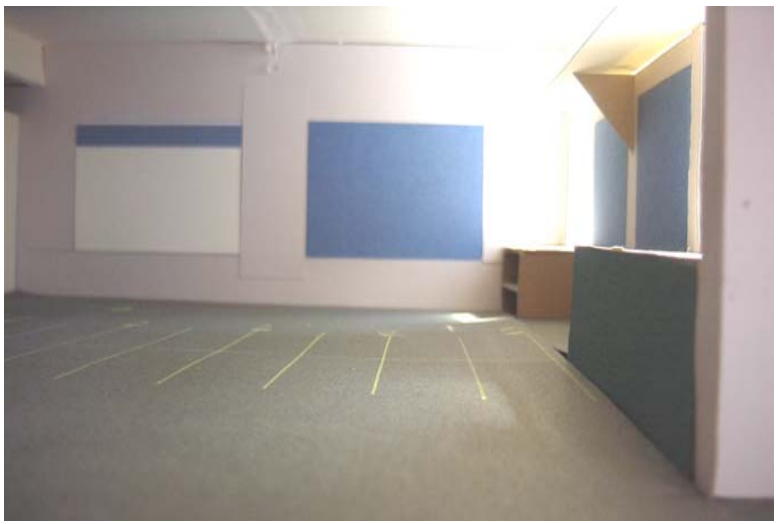


2nd floor - with skylights south side



2nd floor - without skylights south side

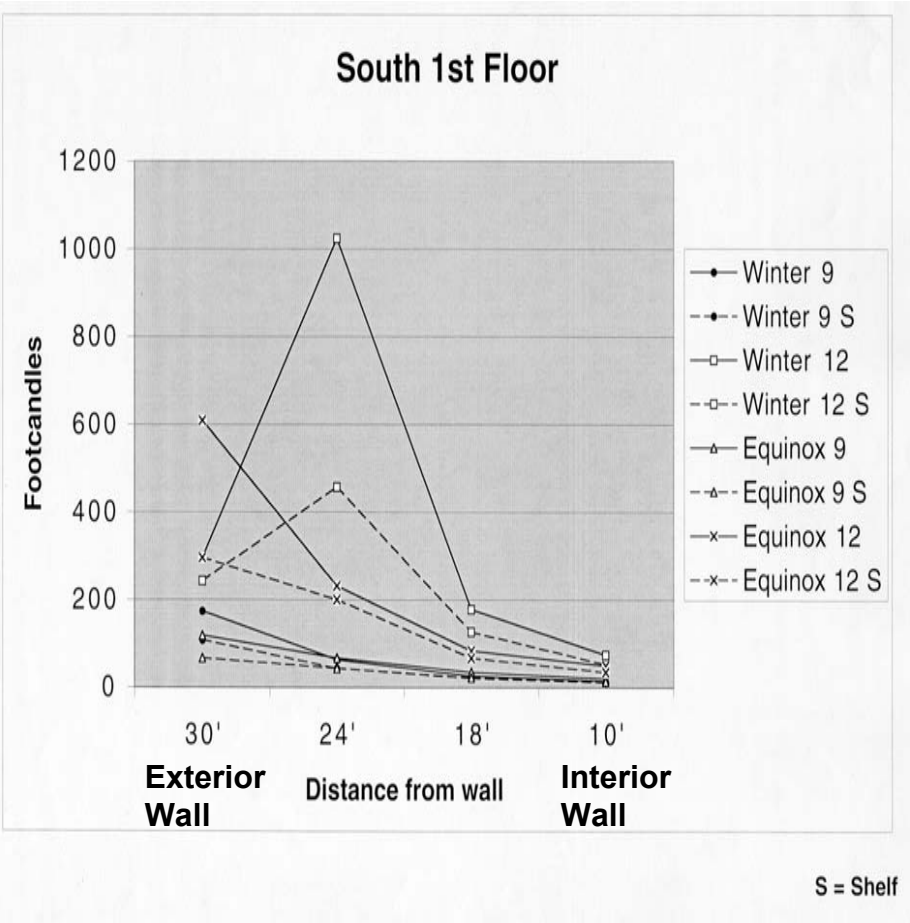
Daylighting - Light Shelf



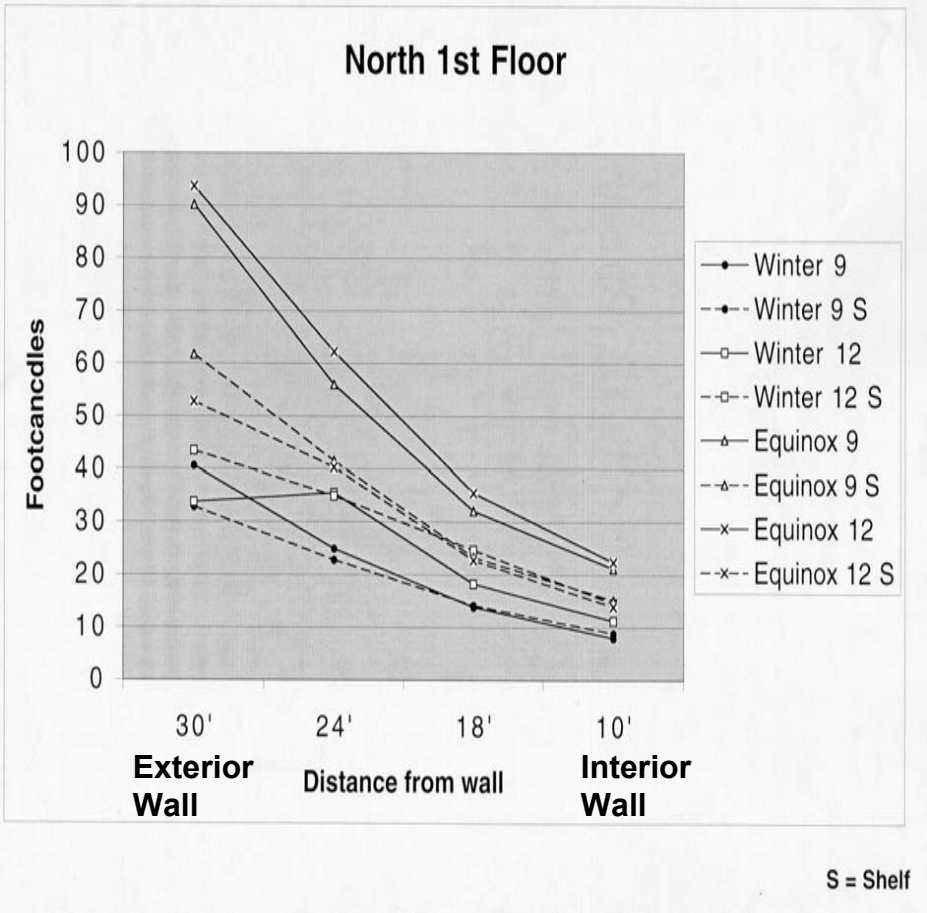
1st floor - with light shelf
south side

1st floor - without light shelf
south side

Daylighting - Analysis Graphs



1st floor south side



1st floor north side

High Performance Electric Lighting Goals

- Provide high quality, high efficiency artificial lighting
- Shut off or dim lights when:

  - People aren't there
  - People don't want them
  - People don't need them - sufficient daylight (daylight harvesting)

ECM-4: Daylight Dimming Control

Strategy:

- Dim lights near windows and skylights & then shut them off when daylight is sufficient

Base Case:

- Lights on in rooms whenever occupied

Upgrade:

- Add photocell at windows, skylights
- Add dimming ballasts to linear fluorescents
- Assumes extra daylighting provided - skylights, clerestories, light shelves….

ECM	Savings Per Year				Increm't'l	U.Payback	NSTAR	Cost After	Util. Inc.	Owner	Include in
No.	kWh	MMBtu	Utility $	Owner $	Cost	w/out Inc.	Incentive	Incentive	Payback	Payback	Project
4	41,404	(83)	$2,744	$6,002	$16,740	6.1	$11,691	$5,049	1.8	0.8	Yes

Energy Conservation Measures (ECM)

Examples:

- Architectural Enclosure
- Electrical
- Mechanical

Icynene Expanding Foam Insulation

First large commercial building to use it

- 3” applied, R3.6/in.
- Fills all gaps, holes
- Never falls down
- No odor – CO_2 only
- ~$.80 - $1.00/s.f.
- Reduces leakage – need for pressurization

➢ **Be cutting edge but Do your homework**

Energy Efficiency Measures Chart

Edgerly School Energy Efficiency Measures		Electrical Usage Reduct'n (kWh/yr)	Gas Usage Reduction (MMBTU/yr)	Utility Co. Energy Savings per year[1]	Owner Energy Savings per year[1]	Increment'l Construct'n Cost	Payback without Incentive (Years)	Projected Utility Incentive	Construct'n Cost After Incentive
ECM No.	Efficiency Measure								
	Architectural Envelope Upgrades								
1	high performance glazing	866	(5.00)	$33	$101	$512	5.1	$384	$128
12	extra wall insulation	(53)	169.00	$1,263	$1,259	$22,649	18.0	$11,325	$11,325
13	extra roof insulation	1,295	44.00	$435	$537	$37,445	69.7	$0	$37,445
	Electrical Upgrades								
2	Light occupancy sensors	16,951	(56.00)	$958	$2,292	$11,160	4.9	$8,370	$2,790
4	Daylight Dimming Control	41,404	(83.00)	$2,744	$6,002	$16,740	2.8	$11,691	$5,049
7	Multi-circuit switching controls	13,611	(9.00)	$1,039	$2,110	$3,861	1.8	$2,201	$1,660
18	Prescriptive Lighting Rebates							$20,970	
	HVAC Upgrades								
3	premium efficiency motors	6,215	(1.00)	$498	$987	$3,366	3.4	$905	$2,461
5	Evaporatively Cooled Chiller	33,447	0.00	$2,719	$5,352	$39,402	7.4	$0	$39,402
6	Variable Frequency Drives on RTU-1	22,168	(40.00)	$1,502	$3,247	$9,337	2.9	$6,634	$2,703
8	Two-speed Fan Control on AHU-1 and AHU-2	70,514	(3.00)	$5,710	$11,260	$21,867	1.9	$13,268	$8,599
9	Expanded DDC System with optimization controls	102,192	164.00	$9,538	$17,581	$17,889	1.0	$5,427	$12,462
16	DAT Reset on AHUs (modeled in ECM-9)								
10	Unit Vent Fresh Air Damper Control	620	19.00	$193	$242	$26,000	107.6	$0	$26,000
11	Occupancy Controlled Outdoor Air Quantities at AHU's	13,993	148.00	$2,248	$3,349	$4,118	1.2	$2,059	$2,059
15	Advanced Boiler Combustion Controls	0	787.00	$5,903	$5,903	$12,000	2.0	$6,000	$6,000
14	Condensing Lead Boiler, full modulation burner control[4]	240	937.00	$7,047	$7,066	$40,728	5.8	$20,364	$20,364
17	Auto Boiler Isolation Valves & HW pump VFDs	26,695	(23.00)	$1,998	$4,099	$10,291	2.5	$7,036	$3,255
	Simple Total Of All Recommended Measures	314,796	1,198	$34,578	$59,352	$162,518		$110,634	$72,855
	Total Elec. Interactive, custom measures, estimated	250,731	89	$21,048	$67,196	$91,657		$71,273	
	Prescriptive electric incentive:							$21,875	
	Gas incentives:							$33,748	
	Grand Total all Rebates:					$162,518		$126,896	

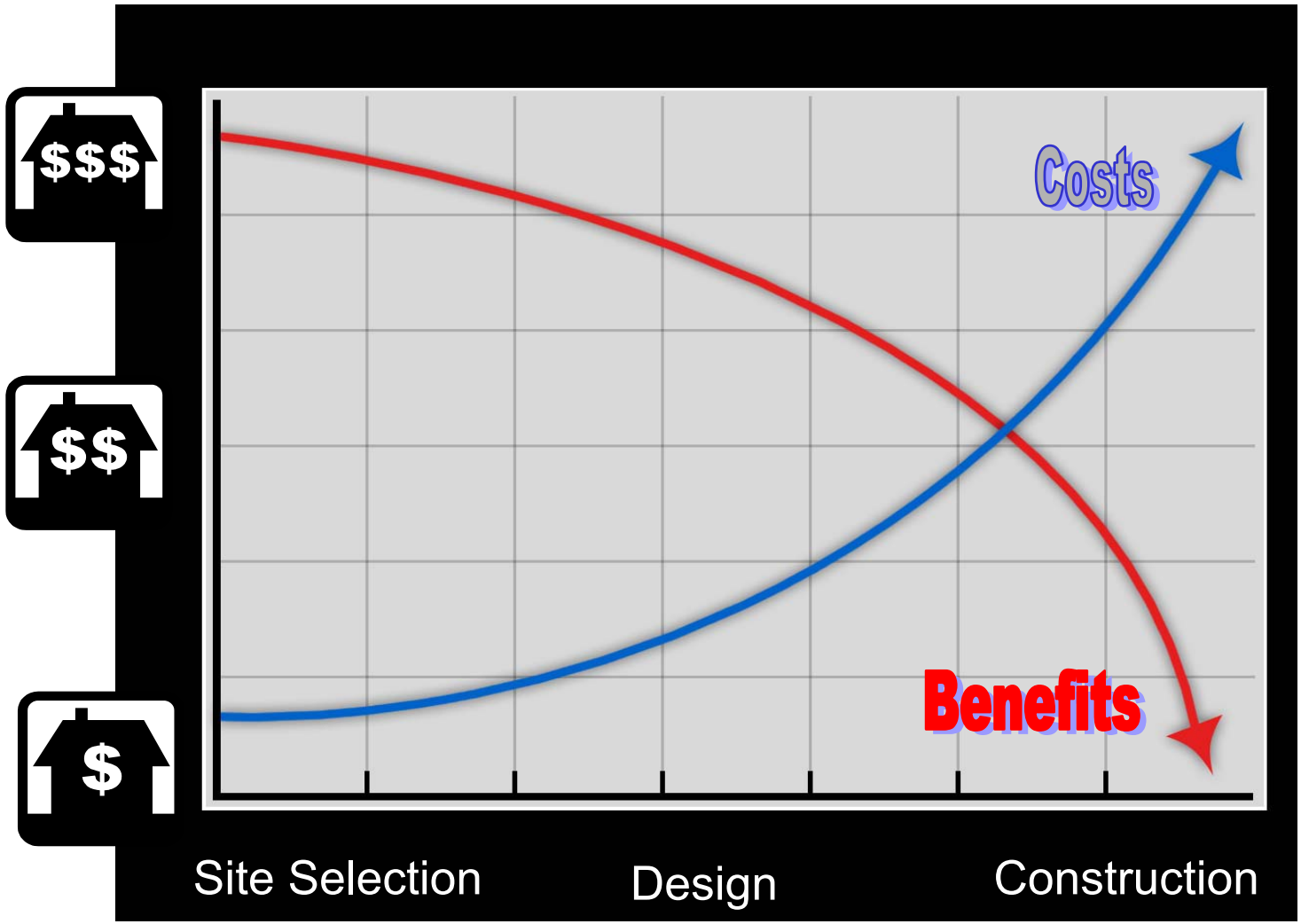
How Much Energy Do We Save?

Final Metrics

Total Energy	Base Case (ASHRAE 90.1-99)	Projected	% Reduction from base
Electricity (kWh)	719,907	445,175	38%
Electricity Production	0	37,058	
Natural Gas (MMBTU)	4,595	3439	24%

How Much Energy/Money Do We Save?

Edgerly School

Total Energy Cost	Base Case (ASHRAE 90.1-99)	Projected	% Reduction
Electricity Use	$115,185	$71,228	38.2%
Electricity Production	$0	($5,929)	
Green Attributes	$0	($0)	
Natural Gas Use	$34,462	$26,288	23.7%
Total	$149,648	$91,587	38.8%

What about cost?