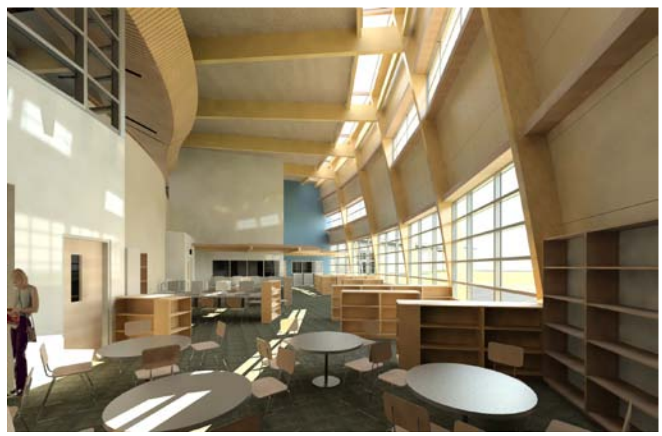
The Effect of Building Envelope Enhancements on the Energy Performance of Two New Elementary Schools

a White Paper produced by
NAC|Architecture Knowledge Institute in collaboration with Hargis Engineers
January 2010

Riverview Elementary School
Rendering by NAC|Architecture



Machias Elementary School
Rendering by NAC|Architecture

NAC | ARCHITECTURE

Greg Stack, AIA, LEED AP
Principal, NAC|Architecture

Matt Rumbaugh, AIA, LEED AP
Principal, NAC|Architecture

Philip Riedel, AIA, LEED AP
Associate Principal, NAC|Architecture

HARGIS

Brian Haugk, PE, LEED AP
Principal, Hargis Engineers

Joshua Robischon, PE, LEED AP
Senior Associate, Hargis Engineers

This paper documents building envelope enhancements that were part of an energy-saving strategy in the design of two new elementary schools. The benefits of the specific building envelope enhancements will be investigated through a comparison of their effects on a building simulated to meet Washington State Energy Code prescriptive requirements and the actual building design. Additionally, the applicability of these envelope enhancements to climates other than their designed climate of western Washington will be evaluated. Finally, the effect of the envelope enhancements on compliance with the AIA 2030 Commitment will be discussed. Readers of this paper should expect to understand the energy-saving effects and general applicability of high-performance building envelope enhancements as investigated as part of the design of two replacement elementary schools.

Riverview Elementary School
Rendering by NAC|Architecture

Two elementary schools, Machias and Riverview, were slated to be demolished and replaced as part of a capital improvement program in the Snohomish School District in western Washington, approximately 30 miles north of Seattle. The two demolished schools were originally constructed in the early '60s as almost identical buildings, both about 50,000 SF. The schools were constructed as single-wythe, un-insulated, load-bearing brick walls; single-pane, steel-framed windows; and a minimally insulated roof. The schools' space and domestic water heating source was propane boilers. Both schools were highly inefficient buildings and required significant ongoing maintenance. For example, the original Machias Elementary School building was the least energy-efficient elementary in the School District. For these reasons, the District decided to replace these schools rather than modernize them. The replacement schools would accommodate 600 students in approximately 72,000 SF. The program called for each school to have the same spaces and similar systems but still have their own identity and relationship to their respective sites.

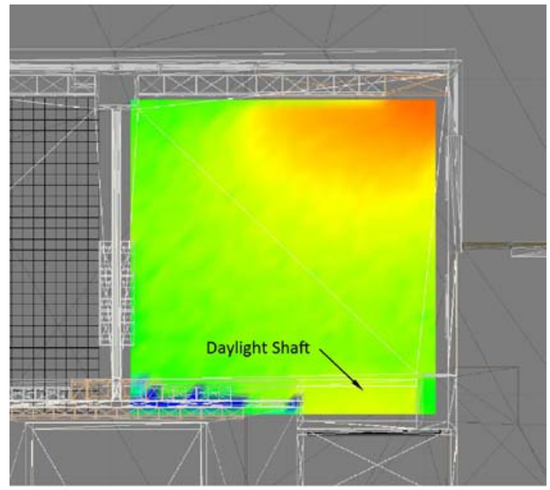
Integrating sustainability into the beginning of the design process for the architect, engineers, and client allowed us to more successfully design an energy-efficient building and site. Through early investigation of sustainable ideas, the design team was able to demonstrate to the owner creative, affordable, and easily constructible ways of achieving energy-saving results. Prior to discussing the building envelope, this paper will briefly identify the other sustainable features of the project that affect the overall energy-use profile of these schools.

Machias Elementary School
Rendering by NAC|Architecture

NON-ENVELOPE ENERGY-SAVING STRATEGIES

In order to optimize site layout, solar orientation and views were carefully considered to accommodate quality daylighting and to maximize the users' experience of the natural features on the site. Daylighting and electric lighting use were integrated to reduce energy use through the following strategies:

- Classrooms were arranged to have primarily north and south solar exposures and utilize high windows, skylights, and light shafts that bring light down to the first floor from skylights above.
- High-efficiency fluorescent fixtures with automatic dimming ballasts were integrated throughout the facility including classrooms, corridors and less conventional spaces such as the Gym and Commons.
- All site lighting is LED.
- 440 photovoltaic panels (100 Kw) on the roof are estimated to supply approximately 17% of the amount of total energy needed over the course of the year.



Classroom Daylight Study

We also knew that mechanical systems efficiencies and indoor air quality would be important features contributing to the success of our sustainability efforts. Over the past 5+ years, the design team pioneered in schools a hybrid displacement ventilation system with heat recovery that has proven very successful in terms of efficiency, indoor air quality, and acoustics. We knew that the Snohomish School District wanted to implement displacement ventilation at Machias and Riverview. In addition to displacement ventilation, we implemented the following mechanical energy-saving items:

- In lieu of using a fossil fuel source for heating we designed a ground loop heat exchanger system to serve the entire facility[1].
- Glycol heat recovery coils temper incoming air with heat from exhaust air.
- Variable-speed custom air-handling equipment uses fan-array technology.
- High-efficiency MERV 13 filters and CO_2 sensors ensure indoor air quality.

[1] The ground loop heat exchanger on these projects consists of piping installed in a series of deep bores that circulate a water-glycol solution to a water-water heat pump that provides heating and chilled water to air-handling unit coils. The fluid circulating through the piping system uses the ground as a heat source or sink as required for heating and cooling, utilizing the thermal energy stored within the earth as a renewable energy source to heat and cool the building.

OPERATIONAL FACTORS

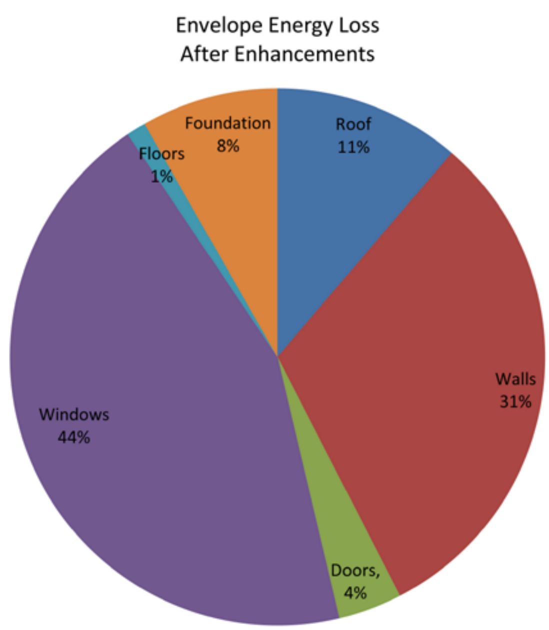
The success of energy-saving features and systems that are implemented in a building relies heavily on how the building is used and operated. There is a unique opportunity at schools to integrate student learning with the act of saving energy through conscientious use of the facility. We took advantage of this opportunity through multiple items:

- Separate sub-metering of energy consumption in each classroom wing so the various wings can compare energy use and compete to be the most efficient wing.
- Motorizing all classroom blinds to make it easy for the teacher to keep the blinds up during the day and only lower them for brief periods when low light is important to teaching.
- An interactive green touch-screen displays various aspects of the building's energy use, including on-site power generation.

These strategies encourage users of the building to actively engage in reducing energy use and help realize the savings we have simulated during design.

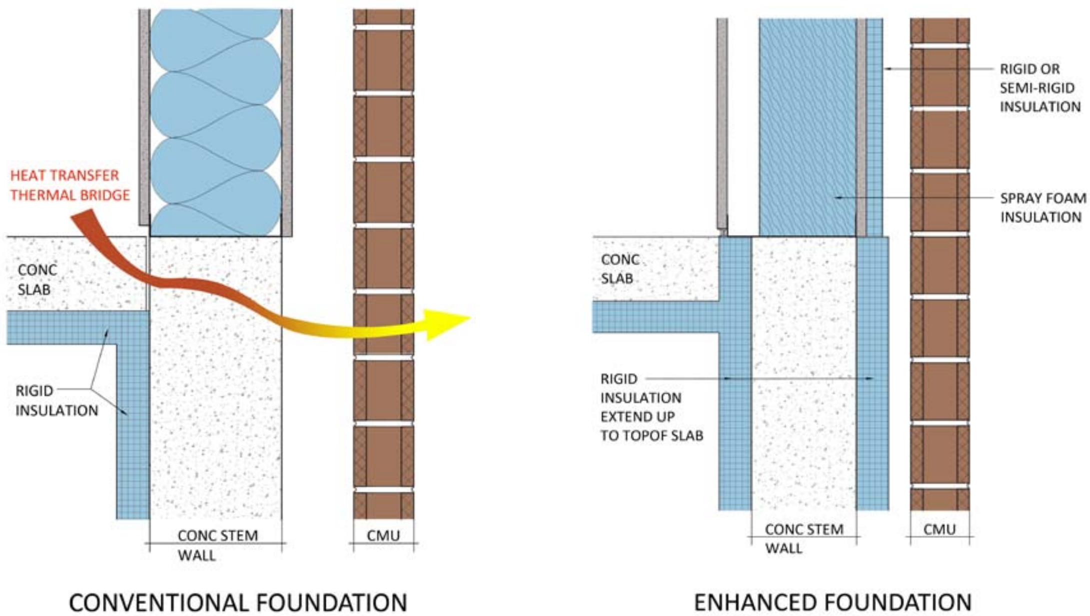
ENVELOPE

To complement the aforementioned energy-efficiency strategies, we investigated further energy savings through an enhanced envelope design. We focused on how such improvements could reduce the size/cost of the mechanical systems by reducing energy loss through the envelope, creating the best-performing envelope we could afford to build. For the Machias and Riverview buildings, energy losses through the envelope are distributed between elements as shown in the adjacent "Envelope Energy Loss" chart. We pursued energy savings associated with all the major envelope components: foundation, wall, window, and roof.



FOUNDATION

In conventional foundation construction with insulation adjacent to the interior of the stem wall and below the perimeter of the slab on grade, heat travels from the warm concrete slab out through the concrete stem wall, creating a continuous thermal bridge around the perimeter of the building. This assembly provides an F-value of .54[2]. Where possible in these projects, the thermal bridge is completely eliminated by running the full 1.5” of insulation to the top of the slab. This is accomplished by offsetting the stud framing from the stem wall so that the interior face of stud overhangs the interior face of stem wall, covering what would otherwise be exposed insulation. To account for the reduction in thermal bridging at the enhanced foundation the F-value is estimated at .45.



WALLS

Metal-stud framing is needed for exterior non-combustible wall construction. The biggest problem with metal-stud wall construction is that the highly conductive metal, although only a small portion of the wall area, creates a significant thermal bridge between inside and outside of the wall, thereby reducing the effectiveness of the wall insulation between the studs. For example, in standard construction with studs spaced 16” o.c., the effective R-value of a wall assembly will be only about one-third the nominal R-value (R-19 insulation translates to R-7.1 effective wall R-value[3]). The thermal bridge can be reduced by increasing stud spacing to 24” on center. For metal-stud framing with R-19 insulation, changing from 16” spacing to 24” increases the effective wall R-value from R-7.1 to R-8.6, a 21% improvement.

[2] F-value is a heat loss coefficient utilized by the Washington State Energy Code (WSEC), Table 10-2, page 41

[3] WSEC, page 50

To enhance the wall insulation and maximize R-value per inch, we specified 6” of spray-applied closed-cell polyurethane foam insulation in lieu of batt insulation. Spray foam provides a substantially higher insulation value and reduces losses due to infiltration and exfiltration through the envelope. The minimum specified aged R-value is 6.4 per inch of spray foam, bringing the nominal R-value for 6” to R-38.4. After applying the de-rating to account for the thermal bridge of metal-stud framing at 24” spacing and a decrease in effectiveness of R-value as the insulation gets thicker, the effective cavity R-value is R-13.5.

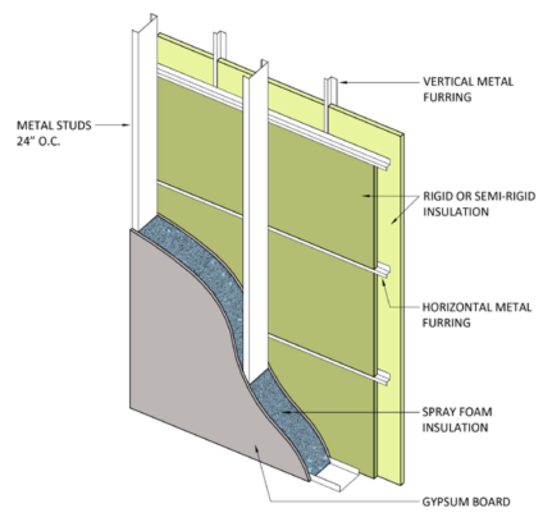
TABLE A: INSULATION EFFECTIVENESS IN FRAMED WALL ASSEMBLIES					
Insulation Type	Depth	Nominal R-Value	Effective R-Value		Improvement due to increased stud spacing
			Metal Studs 16” o.c.	Metal Studs 24” o.c.	
Batt	4”	11	5.5*	6.6*	20%
Batt	6”	19	7.1*	8.6*	21%
Spray Foam	6”	38.4	10.4**	13.5**	23%

* *Washington State Energy Code (WSEC), page 50*

** *Calculated based on interpolation of WSEC tables*

Given the significant effect of thermal bridging by metal studs in the wall cavity, the best way to increase insulation in non-combustible construction is with a layer of rigid or semi-rigid insulation on the outside of the wall beneath the siding, which functions as a “blanket” to create a thermal break. This strategy will add the full R-value of the exterior insulation to the overall R-value of the wall assembly.

Chapter 26 of the International Building Code places restrictions on use of foam plastic, particularly in multi-story non-combustible construction. These requirements include standards for labeling, flame spread, smoke development, ignition, potential heat, and separation with gypsum board. Careful attention to code requirements is needed when selecting spray foam and rigid/semi-rigid insulation products. On the subject projects, we used 1” of polyisocyanurate rigid insulation with an R-value of 6.7 where the exterior cladding is masonry veneer. This veneer protects the insulation from ignition. Where the exterior cladding is fiber-cement panels, metal siding or other thin material, we specified 2” of mineral wool semi-rigid boards, which provide R-4.2 per inch for a total of R-8.4. Both the mineral wool and polyisocyanurate insulation are resistant to moisture and can be used on the wet side of the building wrap, within the rainscreen cavity behind cladding materials.

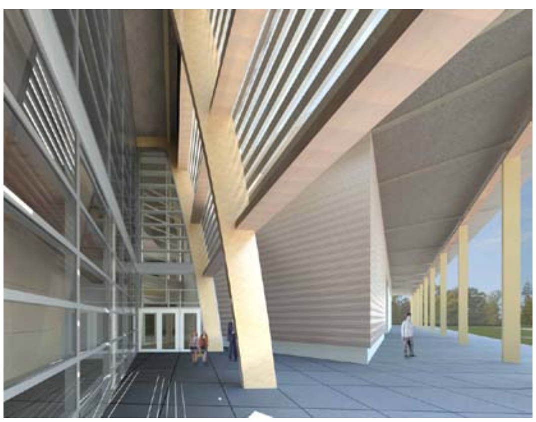


ENHANCED WALL AXONOMETRIC

In addition to the building insulation, additional R-value is provided by the gypsum wallboard, siding and the physical properties of air film. Contributions of each component to the overall R-value for typical walls at these elementary schools are as follows:

TABLE B: TYPICAL ENHANCED WALL EFFECTIVE R-VALUE	
Interior Air Film	0.68
5/8" Interior Gypsum Wallboard	0.56
2x8 Metal Framing at 24"OC, 6" Spray Foam Insulation	13.5
Exterior 5/8" Gypsum Wall Sheathing	0.56
Building Wrap	0.05
2" Semi-Rigid Mineral Wool Board Insulation	8.4
Air Space	0.91
Cement Fiber Board Siding	0.2
Exterior Air Film	0.17
OVERALL R-VALUE FOR WALL ASSEMBLY	**25.03**

WINDOWS



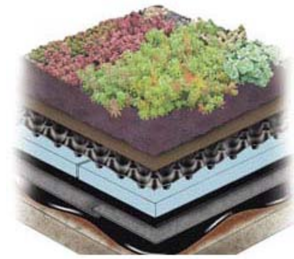
In order to achieve the goals for daylighting, experience of views, and a highly efficient envelope, glazing must be optimized, especially since, for these schools, 26% of the wall area is glazing.

School districts typically prefer aluminum window frames for their durability and low maintenance; however, aluminum conducts heat well and therefore has relatively poor thermal performance. This can be partially mitigated by choosing thermally broken aluminum frames. Typical U-values for thermally broken aluminum windows with 1” double-pane insulated glazing are around 0.50. For the two Snohomish elementary school projects, we increased the insulation of the windows by using 1 ½” thick, triple-pane insulated glazing with low-E coatings on two surfaces, improving the composite window U-value to 0.39, a 22% improvement.

Typical school construction in western Washington utilizes storefront systems for large areas of glass at entries, corridors and libraries, with a composite U-value around 0.55. For these schools, we are instead using a high-performance gasketed curtainwall system with 2” thick triple-pane insulated glazing, achieving a remarkable overall composite U-value of 0.19. Thus, at the large glazed areas susceptible to significant energy loss through the building envelope, we raised the insulation value from approximately R-2 to R-5, a 250% increase.

ROOF

Typical roof construction on new schools in western Washington incorporates R-30 rigid insulation applied over a metal-deck roof structure. The advantage of applying rigid insulation over the deck is that no structure penetrates the insulation, so the insulation effectiveness is the full R-value of the insulation. For these elementary school projects, we increased the rigid insulation at roofs to R-45, including the portion of roof that is a vegetated roof (green roof).



American Hydrotech Inc.

The daylighting strategy for these projects includes abundant use of skylights, both clear glass units and diffusing fiberglass panels. At the glass skylights, we are using triple-pane 2" insulated glazing similar to the curtainwall locations. The translucent panels consist of exterior and interior fiberglass face sheets with batt insulation between them, supported by thermally broken aluminum frames, with a composite U-value of 0.29.

ENERGY SIMULATION

We wanted to understand which of the envelope enhancements described above would have the largest effect on overall energy savings for the building. To investigate this, we analyzed and estimated energy use and compared that with estimated construction costs. For our analysis of the energy use for the buildings, we used the program "E-Quest" by the Department of Energy (DOE).

The energy simulations require detailed assumptions about how the building will be used and these assumptions significantly affect the predicted energy use of the facility. Among many other assumptions, these simulations are based on the following:

- When school is in session the building will be occupied from 6 a.m. to 5 p.m. with modest use outside of those time periods.
- School will not be in session from mid-June through the end of August although the administrative area will be occupied all summer.
- The occupied temperature set point during heating season is 70 degrees F and cooling season is 75 degrees F.
- Exterior lighting turns on at dusk and off at dawn.

In order to understand the energy savings associated with our enhanced envelope design in the context of the Washington State Energy Code (WSEC), we created two separate building energy simulations. One of the simulated buildings was based strictly on meeting the minimum WSEC requirements (called: "Code Minimum Building") and the second was based on the Riverview[4] design without enhanced envelope improvements (called: "Riverview Baseline"). This allows us to compare the benefits of the proposed envelope enhancements to the WSEC minimum building and to the actual Riverview school

[4] For the purposes of this paper, we are primarily discussing the Riverview energy simulation, although the results found on Machias are similar.

design prior to making envelope enhancements. Below is a description of the two buildings used for simulation.

- “Code Minimum Building” – This building is designed to comply with the minimum requirements of the Washington State Energy Code (WSEC). This means that the envelope, lighting, electrical systems, and mechanical systems are all designed only to comply with the minimum code requirements. For example, in lieu of the ground loop heat exchange mechanical system used on these schools, the code minimum building assumes rooftop, gas-fired air-handling units. The size, shape and orientation of the code minimum building, including items such as wall, window, and roof areas, are identical to the actual designs for the Machias and Riverview elementary schools. The envelope design for the code minimum baseline building includes R-21 insulation at the roof, metal-stud walls with R-19 batt insulation, and double-pane windows. The code minimum building is estimated to use the equivalent of 4,378 MBtu annually.

- “Riverview Baseline Building” – This simulated building has an envelope design that meets only the minimum requirements of the WSEC, but the simulation overall substantially exceeds the WSEC minimums because it includes all the high-efficiency systems such as the ground loop heat exchange mechanical system, the efficient lighting and electrical systems, and other energy-saving systems incorporated into the actual Riverview building design. It doesn’t include the enhanced building envelope improvements. This building simulation is estimated to use the equivalent of 1,847 MBtu annually (57.8% less than the “Code Minimum Building”) without accounting for the on-site energy generation associated with the photovoltaic panels.

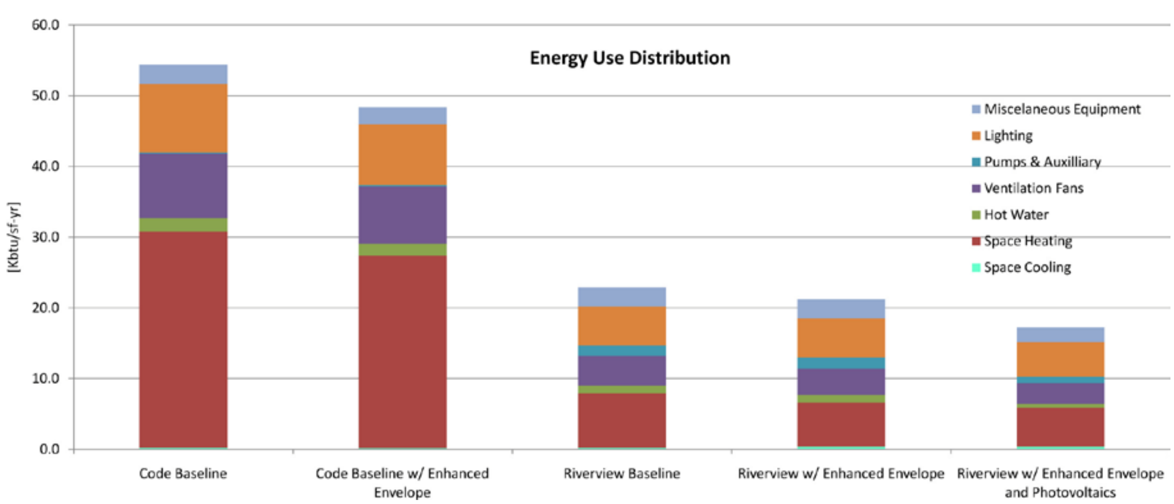
To be able to individually understand the impact of each proposed building envelope improvement, both building simulations (the “Code Minimum Building” and the “Riverview Baseline Building”) were simulated repeatedly, changing only one envelope improvement at a time. After analyzing each improvement individually, we then analyzed all improvements together to determine the total energy savings associated with the envelope enhancements.   The total sum of each individual item does not equal the total energy saved. Since the totals are expressed as a percentage of energy savings compared to baselines when all other variables are held constant, they are not additive. Their cumulative effect compared to the baselines must be calculated separately in a final building model simulation. This is because building energy use is dynamic due to the many factors contributing to the energy-use profile of the facility interacting together. When a change is made to one element, it will impact how another item performs in relation to the entire building energy-use profile and savings.

TABLE C: ENERGY SAVINGS ANALYSIS SUMMARY				
Building Envelope Component	CODE BASELINE BLDG		RIVERVIEW BASELINE	
	Energy Use [MBtu/yr]	Energy Savings %	Energy Use [MBtu/yr]	Energy Savings %
2006 WSEC Code Baseline Envelope	**4378**		**1847**	**57.8%***
Triple-Pane Glass / Curtainwall Upgrades	4172	4.7%	1794	2.9%
Increased Wall Insulation(R-36+Rigid)	4200	4.1%	1800	2.5%
Increase Roof Insulation (R-45)	4170	4.7%	1817	1.6%
Foundation Insulation (F=0.45)	4361	0.4%	1840	0.4%
Total With All Enhanced Envelope Improvements	**3893**	**11.1%**	**1711**	**7.4%****
100kW PV System Effect			-325	17.6%
Total with PV System Included			1386	**25.0%**

* *reduction from code minimum building due to mechanical/lighting systems*

** *does not include savings from onsite energy generation through Photovoltaic (PV) Panels*

The analysis summarized above demonstrates that some envelope enhancements have a greater effect than others on total energy use and that the enhancements have a larger relative effect on the "Code Minimum Building" than the "Riverview Baseline Building." The effect of the envelope enhancements is greater in the "Code Minimum Building" because there is more energy to be saved by the building envelope due to the less efficient baseline mechanical and lighting systems. Essentially, because the baseline building consumes more energy, the envelope improvements can have a larger impact on the overall energy-use profile. The highly efficient mechanical and electrical systems included in the "Riverview Baseline Building" (57.8% more efficient) make it difficult to capture higher magnitudes of additional savings with envelope enhancements. Nevertheless, the total building energy savings of 7.4% is substantial enough to make it worth implementing. The data suggests that the single most effective building envelope upgrade to maximize energy savings is to increase the U-value of glazing assemblies through the use of triple glazing and highly efficient curtainwall frames. Increasing the wall insulation is a close second. When costs are considered along with energy efficiency, increasing wall insulation would be the first recommended approach.



COMPARATIVE EFFECT OF CLIMATE

Machias and Riverview elementary schools were designed for the relatively moderate climate of the Puget Sound region of western Washington. The summers are cool and comparatively dry, with the average maximum temperature in the mid to high 70s. Temperatures exceed 80 degrees F for only 0.4% of the year. The winters are mild and wet, and typically range between 28 to 45 degrees F. Temperatures in the winter drop below 27 degrees F for only 0.4% of the year. There are 5,151 heating degree days and 68 cooling degree days, assuming a base temperature of 65 degrees F[5]. We wanted to determine if the envelope enhancements that were incorporated into these two schools would be beneficial in a very different climate such as the dry and relatively warm climate of Pomona, California. To investigate this we simulated the same building, with the same solar orientation, systems, and envelope enhancements as the final Riverview Elementary School design, but located in Pomona. We found that the envelope improvements are not useful in Pomona and actually increase energy use for a building in the cooling-dominated climate of Southern California. The envelope enhancements to the "Riverview Baseline Building" located in Pomona would increase energy use by 3.6%, while these enhancements in western Washington reduce energy use by 7.4%. This is due to the fact that the highly insulated envelope in a climatic environment such as California does not allow internal loads from solar heat gain, occupants, computers, and lighting to dissipate through the building envelope when heat loss to the outdoor environment could be effectively utilized, thereby increasing the mechanical cooling requirements. This investigation confirms that climate-specific responses to envelope enhancements are critical.

AIA 2030 COMMITMENT

Our final inquiry was to determine how these energy-saving measures would rank the schools relative to the requirements of the AIA 2030 Commitment. The 2030 Commitment requires gradually increasing reductions in energy use over the energy use of average buildings for a given building type, using 2003 as a baseline year. It requires a reduction of 60% in 2010. The required reduction increases by 10% every 5 years to carbon-neutral buildings in 2030. Based on the ENERGY STAR® Target Finder[6] results, Riverview Elementary will be 54% more efficient than the 2003 average school building before including the on-site energy generation from photovoltiacs. After including the photovoltaics, the building will be 62% more efficient than the 2003 baseline and therefore will meet the 2010 goal of 60% reduction in energy use. As previously discussed, these schools incorporate a significant number of energy-saving strategies, including ground loop heat exchangers, enhanced envelope, and on-site energy generation, and they still only slightly exceed the 2010 requirement of the 2030 Commitment. This demonstrates how difficult it will be for designers to meet the 2030 Commitment and that even its current goals require photovoltaics or other on-site energy generation.

[5] 2009 ASHRAE Fundamentals Ch 14.

[6] The ENERGY STAR Target Finder is used to determine compliance with the 2030 Commitment.

CONCLUSIONS

These two elementary schools have many features that make them very energy-efficient buildings. The evaluation of the envelope enhancements incorporated into the buildings demonstrates a definite and beneficial effect on reducing energy use for the buildings.

- The envelope enhancements for the Riverview building are estimated to save 11.1% over the Code Minimum Building requirements and reduced energy use by 7.4% over the Riverview Baseline Building.

- The regional climate plays a substantial role in determining which envelope strategies are the most effective for reducing overall building energy use. The envelope enhancements discussed in this paper are beneficial in a heating-dominated climate like western Washington but are detrimental (increase energy use) in a cooling-dominated region like Southern California.

- For those attempting to meet the AIA 2030 Commitment, this data suggests that it is rather difficult to achieve even the 2010 goals of the Commitment. Therefore, all measures to reduce energy use, including envelope enhancements, will be required.

The envelope enhancements described in this paper suggest that the improvements definitively improve energy efficiency in buildings and are an important, if not crucial, part of the design arsenal needed to comply with the AIA 2030 Commitment.

Riverview Elementary School
Rendering by NAC|Architecture