

Energy Performance
of the
Green Modular Classroom

Produced by NRB Modular Building Specialists

Analysis by Mark E. Kelley, III, PE

The Hickory Consortium

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Introduction:

The energy performance of the Green, Relocatable Modular Classroom, as designed and produced by NRB Modular Building Specialists, is far better than would be expected for a similar building built to meet the Massachusetts Energy Code or the ASHRAE 91-2004 Standard. Due to better insulation, windows, daylighting, CO₂ controlled energy recovery ventilation, and higher efficiency equipment, this building will save approximately 56% of the energy cost in comparison to the stricter ASHRAE 90.1 – 2004 standard. At current energy prices, this would save over \$2118 per year out of a potential \$3990 cost for electricity.

Approach:

The best way to see how a building performs is to compare it to a typical building, one that has the same characteristics and uses, but which is built without consideration for performance. In this analysis, we have made several such comparisons, since different tools reveal distinct aspects of performance. For example, the Energy 10 analysis software can easily model the performance of a schematic phase building and provide information on what measures will save the most energy or cost: daylighting, infiltration control, equipment, glazing, etc. The RemDesign tool provides component buy component performance comparison, and shows the impact at the detailed envelope level. Visual DOE2 combines the most comprehensive hourly analysis with the ability to model daylighting savings and detailed systems and equipment performance.

We compared the Green Classroom to a similar building that just meets the Massachusetts Energy Code and also to a building that meets the ASHRAE 91.1-2004 Standard. These hypothetical base case building wouldn't have daylighting or lighting controls, but it would have allowable classroom standard lighting of 1.6 watts per square foot. For the Mass. Code base case, the equipment is the code minimum: an Energy Efficiency Ratio (EER) of 8.9 is now the minimum for this type of system, with a Coefficient of Performance (COP) of 2.7 at high outdoor temperatures and 1.8 at 17 degrees F. Insulation and windows would be code minimum, with R-15 roof, R-12 (approximate) walls, and windows with U=.68, SHGC of .39 are allowed by code.

Features of the Green Classroom:

Insulation and windows are significantly better than code requirements, with R-30 roof, R-18 walls (overall R-value is R-22 considering other wall components and reflective layer), R-19 floor, and thermally broken aluminum windows with U=.53, SHGC of .52. Air sealing is much better than typical, and ventilation is the same as required by code, but heat recovery, part of the HVAC equipment, will save up to 80% of the energy in the exhaust air stream and deliver it to the incoming fresh air.

The Green Classroom has 8 daylighting light tubes (Velux SunTunnels), and daylighting controls, it has installed lighting at a very low .57 watts per square foot. Side windows have interior light shelves to reflect light deeper into the building, and lighting systems are controlled by daylight sensors, which dim the lights when adequate daylight is available.

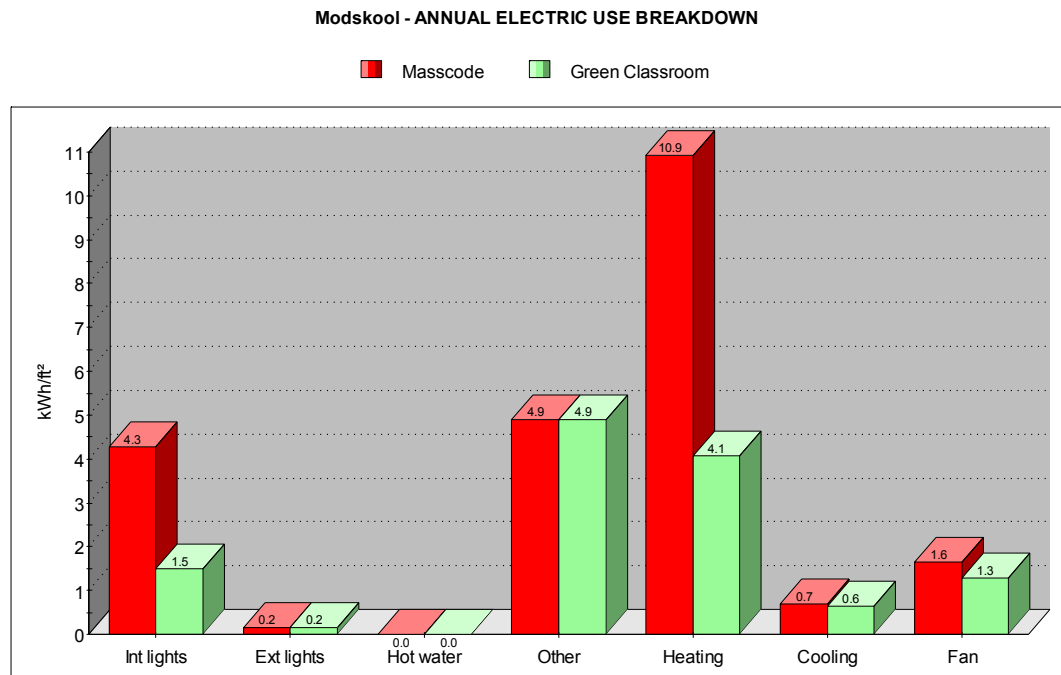
The advanced classroom will have the Bard high efficiency Stepped Heatpump, which also has the Green Refrigerant R-410A, which is not on the phase-out list for the Montréal Protocol because of its low environmental impact. The new stepped version of the heatpump has two stages of heating and cooling for both the indoor and outdoor units. This Bard ultra high efficiency heatpump, has a SEER of 13.5 and an HSPF of 8. The 3 ton unit will step down to

lower output when the load is less (when it isn't too hot) or when it's not too cold in the heating season. This will provide better efficiency and dehumidification.

Two of these heat pumps will be used, one for the smaller module at 1.5 tons (18,000 BTU/hr) and the other at 3 tons for the larger two modules. These two stage heat pumps will be provided with CO₂ controls to vary the input of fresh air according to demand based on occupancy. In addition, energy recovery equipment is integrated into the Bard heat pump to reduce the energy load for heating and cooling the fresh air supply. The equipment is the Bard CH3S1 with an Energy Efficiency Ratio (EER) of 10.2 BTU/watt and an Integrated Part Load Value of 14.2 BTU/watt, which tells us that in the cooling season, the unit will produce on average over 4 watts of cooling for every one watt purchased. Heating season performance is also very good, with a low temperature Coefficient of Performance (COP) of 2 while at higher outdoor temperatures the COP can be as high as 3.2, or 3.2 times as many watts output as input (compare to baseboard electric at a COP of 1 – 1 output of heat for every 1 watt purchased).

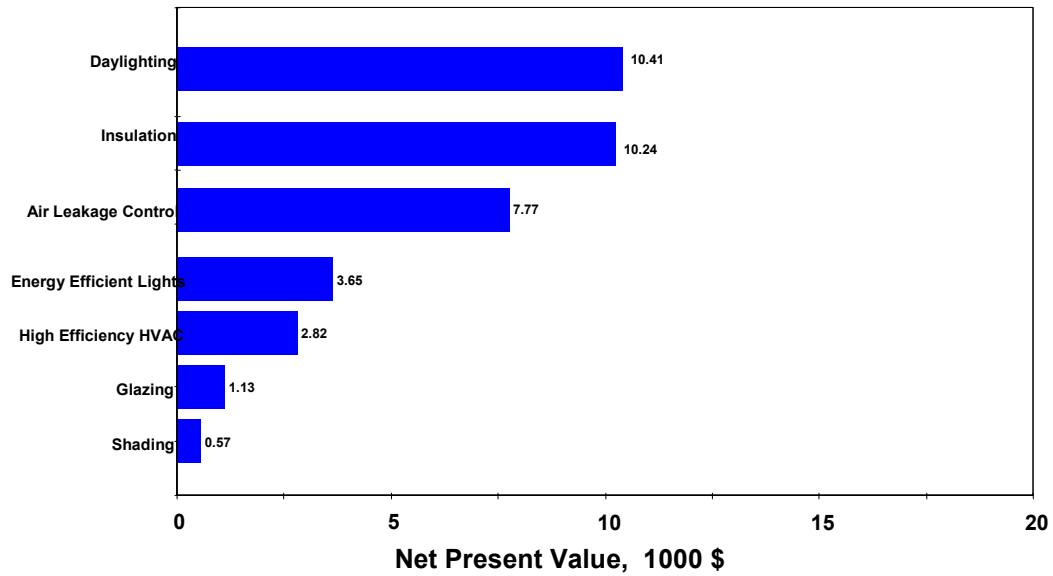
Modeling process:

Given all the above assumptions, we have used three separate modeling tools to get a good idea of the performance. Since they include different energy uses (e.g. one includes “other” for equipment use in the classroom, the other doesn't), the results are slightly different. I have included the output from the RemDesign tool, which gives a more accurate estimate of energy use costs on a component by component basis. Energy 10- is most useful for showing where to place emphasis in choosing energy conserving techniques. The chart below shows where the Green classroom saves energy relative to the Mass. Code base case.



An example of the ranking of energy saving measures is below:

RANKING OF ENERGY-EFFICIENT STRATEGIES



Finally, we have used the Visual DOE2 program to have greater flexibility in modeling equipment, daylighting, and schedules for use of the building. This program has the benefit of allowing detailed modeling of the envelope, lighting, and equipment energy consumption as well as utility costs.

More detailed daylighting results are also available from the DOE2 program used to calculate LEED energy cost savings. These results show that the lighting savings for this building are nearly 80%, with 15% coming from daylighting, and 65% from controls and energy efficient lighting fixtures and ballasts.

Results:

Using RemDesign, we are able to look at the impact of improving envelope elements, to see where the most savings are generated. The table below compares the Green Classroom to a similar building built to meet the Massachusetts Commercial Energy Code.

	LEED Classroom	Sup HP Classroom	DIFF	% DIFF
HEATING SEASON (BTU/ft²/yr)				
Ceiling R-10	7.4	2.0	4.5	60.5%
R-10 Bal. Deck	2.2	0.0		
Exterior Glazing	5.5	4.3	1.2	21.7%
Exterior Walls	7.7	0.0		
Doors	1.1	0.6	0.5	45.5%
Window Glazing	10.1	5.7	4.4	44.1%
Frame Glazing	8.5	3.0	5.5	64.7%
Door Glazing (1/4" Air)	2.0	0.0		
Slab Glazing	0.0	0.0		
Infiltration	1.4	0.7	0.8	56.9%
Mechanical Ventilation	1.5	0.5	1.0	66.7%
Ducts	2.1	0.0	2.1	100.0%
Architectural	2.2	0.0		
Summer	7.7	0.0		
Interior Gain	1.7	0.2	1.5	87.9%
Total	42.7	15.4	27.3	64.0%

The Figure below shows the comparison between the Green Classroom and the ASHRAE 90.1 – 2004 Standard:

	ASHRAE Classroom	Step II Classroom	DIFF	% DIFF
HEATING SEASON (kBtu/yr)				
Ceiling/Roof	7.4	2.5	4.9	66.2%
Floor/Slab	0.0	0.0		
Area Outside Walls	10.6	7.5	3.1	29.2%
Foundation Walls	0.0	0.0		
Doors	1.5	0.8	0.7	46.7%
Windows/Sliding Glass	10.9	3.0	7.9	71.5%
Frame/Floors	10.4	3.0	7.4	70.8%
Case/Storage Unit/Bank	0.0	0.0		
Sub Floor	0.0	0.0		
Partitions	14.3	7.7	6.6	46.2%
Mechanical Ventilation	22.2	13.4	8.8	39.6%
Leakage	1.0	0.1	0.9	90.0%
Active Solar	0.0	0.0		
Subtotal	0.0	0.0		
Internal Gains	13.0	7.7	5.3	40.8%
Total	51.1	25.5	25.6	50.1%

Note that these figures show heating energy consumption and savings. The Mass. Code building is not quite as efficient as the ASHRAE 91.1 building, so less energy is saved for the latter comparison.

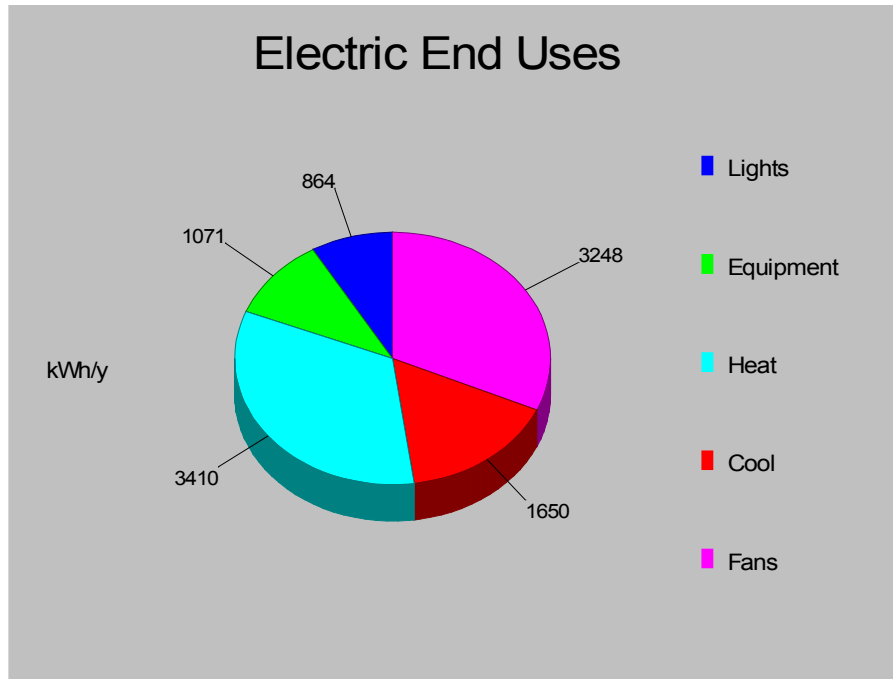
Similar results are shown for cooling with the comparison to the Mass. Code saving 56% of cooling energy and the comparison to ASHRAE, saving 77%, shown below:

	ASHRAE Classroom	Step II Classroom	DIFF	% DIFF
COOLING SEASON (kBtu/yr)				
Ceiling/Roof	0.0	0.0	0.0	0.0%
Floor/Slab	0.0	0.0		
Area Outside Walls	0.0	0.0	0.0	0.0%
Foundation Walls	0.0	0.0		
Doors	4.0	4.0	-0.1	-2.5%
Windows/Sliding Glass	0.1	4.0	3.9	100.0%
Frame/Floors	4.4	4.2	-0.2	-4.5%
Case/Storage Unit/Bank	0.0	0.0		
Sub Floor	0.0	0.0		
Partitions	4.0	4.0	-0.1	-2.5%
Mechanical Ventilation	1.1	4.0	2.9	100.0%
Leakage	0.0	0.0	0.0	0.0%
Active Solar	0.0	0.0		
Subtotal	0.0	0.0		
Internal Gains	7.1	2.2	4.9	69.0%
Mechanical Ventilation	0.0	0.0		
Total	6.1	1.4	4.7	77.0%

Overall Performance:

To get the most comprehensive comparison, we used Visual DOE2. The performance of the advanced classroom building is 56% better than the code building in terms of energy costs. This is based on current Massachusetts electric rates. Other areas have different costs, but the percentage savings will be the same. The estimated cost to heat, cool, and light the code building is \$3990, while the Green Classroom costs only \$1872 per year.

Looking a bit closer, there is also a 68% reduction in heating energy consumption, and a 49% reduction in cooling energy. Lighting energy is reduced by 80% relative to the code building



The energy savings described above result in a total electricity savings of 12287 kWh out of 23530 kWh, a savings of 53%. For LEED, only the cost saving for energy counts, but here we are doing even better, with cost savings of 56% using the NGRID G-1 electric rate for small businesses. We will regard these figures as the official energy and cost savings numbers, since they may differ slightly from the RemDesign and Energy 10 figures. Thus, the overall savings are as described above and shown on the last line of the table, and the heating savings are 68% and the cooling savings are 49% (100% - Proposed/Budget%). Interior lighting saves 80% from combined efficiency, daylighting and controls.

The LEED system only considers cost and only the cost for “Regulated energy”, which means that the energy for miscellaneous uses and exterior lighting is not included. In the table below, the energy performance is shown at the top, and both energy and the cost of energy are shown in the lower area, with the final LEED cost savings percentage at the lower right.

In the right hand column, the percentage shown is the energy use of the Green Classroom divided by the energy use of the base case. To get the savings percent, we subtract this number from 100%.

Results of Visual
DOE2 LEED Analysis
Energy Summary By End
Use

End Use	Energy Type	Proposed Building Energy (MBTU/yr)	Proposed Building Peak (but/h)	Budget Building Energy (MBTU/yr)	Budget Building Peak (but/h)	Proposed / Budget Energy (%)
Lighting - interior	Electricity	2.9	2	14.7	6.5	20%
Lighting - exterior	Elec-unregulated	0	0	0	0	n.a.
Space heating (1)	Electricity	11.6	60.4	36.4	74.4	32%
Space heating (2)	Fuel	0	0	0	0	n.a.
Space cooling	Electricity	5.6	9.9	11	20.5	51%
Pumps	Electricity	0	2.7	0	2.7	n.a.
Heat Rejection	Electricity	0	0	0	0	n.a.
Fans	Electricity	11.1	2.4	11.1	2.4	100%
Service water heating	Fuel	0	0	0	0	n.a.
Misc Equipment	Elec-unregulated	3.7	0.7	3.7	0.7	100%
Total Building Consumption		34.9		76.9		45%

Regulated Energy Use and Cost Summary By
Fuel Type

	Proposed Building Energy (MBTU/yr)	Proposed Building Cost (\$/yr)	Budget Building Energy (MBTU/yr)	Budget Building Cost (\$/yr)	Proposed / Budget Energy (%)	Proposed / Budget Cost (%)
Electricity	31.2	1674	73.2	3798	43%	44.10%
Fuel						
Other fossil fuel						
Total nonsolar	31.2	167.4	73.2	3798		
Solar or site recovered						
Total including Solar						

LEED Cost Savings: 55.90%

LEED energy cost savings performance:

The LEED certification system gives up to 10 points for energy performance, and up to three more for using renewable energy generating equipment to provide 5, 10 and 20% of the energy used by the building. Given the sterling performance of 56% energy savings, this building qualifies for all 10 energy efficiency points. If the site permits the application of the one kilowatt photovoltaic array the has been sized for this building, the 1431 kilowatt hours of electricity produced each year would provide nearly 14% of the energy needed by the building, qualifying for two additional points.

This gives us an idea of the impact of the energy use on LEED certification. If we were to actually pursue LEED certification, there would be some additional documentation including the LEED Template for energy, a building description, design narrative for the systems, and a comparison line-by-line with the ASHRAE standard.

11	5	1	Energy & Atmosphere	17 Points
Y			Prereq 1 Fundamental Commissioning of the Building Energy Systems	Required
Y			Prereq 2 Minimum Energy Performance	Required
Y			Prereq 3 Fundamental Refrigerant Management	Required
10			Credit 1 Optimize Energy Performance	1 to 10
	3		Credit 2 On-Site Renewable Energy	1 to 3
	1		Credit 3 Enhanced Commissioning	1
1			Credit 4 Enhanced Refrigerant Management	1
	1		Credit 5 Measurement & Verification	1
		1	Credit 6 Green Power	1

Given the previous estimates of energy cost performance e, there are several other LEED points in the Energy and Atmosphere category that this building would attain. The environmentally friendly refrigerant in the heat pump is good for one prerequisite and one additional point. The building will certainly qualify for the Minimum Energy Performance prerequisite, and if a commissioning agent is hired to check out the systems after installation, the Fundamental Building Commissioning requirement can be met. Enhanced commissioning requires the commissioning agent to review designs early in the process before construction, so that is probably not possible. Several other points are within grasp: green power requires the owner to buy at least 20% renewable produced electricity, and measurement and verification requires either monitoring of energy or analysis of energy bills for a number of years.

In summary, the Green Classroom has all the attributes of a well integrated design, which considers materials, energy, and the environment. For a modular commercial school building, this attention to detail and multiple operational characteristics promises to produce remarkable energy, health, and environmental performance.