LINNEAN Solutions

Carbon Accounting for Martin Luther King Jr. School Design Options

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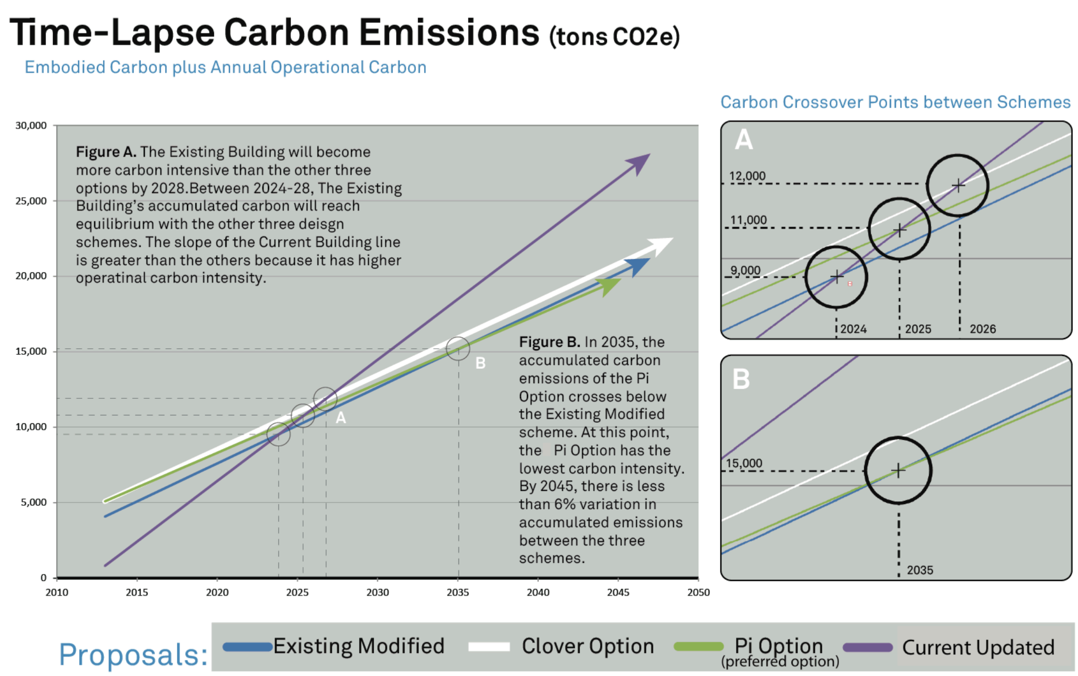
Conclusions

This study looks at the embodied carbon and the operational carbon emissions in the three proposed design options against the current Martin Luther King Jr. School (MLK) building upgraded to use approximately 30% less energy than the current building.

The upgraded current MLK building is estimated to surpass all three of the proposed design options in total emitted carbon dioxide equivalent emissions after 15 years of expected operation.



This graph shows the total accumulated carbon equivalent emissions for each of the three building options, as well as for the existing building with energy use upgrades. The upgraded current building surpasses the total carbon emissions for the three design options after approximately 15 years of operation. The three design options are essentially equivalent over time.

Figure 1
Total combined carbon equivalent emissions comparison for the three design options and the current building, upgraded for energy efficiency.

Introduction to Carbon Analysis

This study looks at the actions related to materials manufacture, transport, construction, operation and the demolition and disposal of building materials and the building assemblies that they make up for the proposed options for the Martin Luther King Jr. School in Cambridge. This study provides comparisons expressed in terms of carbon equivalent emissions that many scientists and policy makers suggest are related to climate change. This framework enables a look at how building life span and building operating energy efficiency may affect the decision to reuse buildings versus build new.

The goal of this study is to provide an embodied energy and embodied carbon analysis for the Martin Luther King, Jr. School Project in Cambridge, MA.

Becoming aware of environmental issues and actively participating in reducing Cambridge's carbon footprint is crucial work towards restoring the Earth's natural systems on a local level. While the effects of any carbon reduction strategies undertaken on this project won't be instantaneous, this report recognizes our responsibility to reduce carbon emissions resulting from our activities over time.

This is a preliminary analysis of the building options. The calculations are based on information provided by Perkins Eastman and their subcontractors, and the City of Cambridge. Energy use characteristics of both the existing building and the design options are estimates and have not been verified. The information about the building design options and energy reduction strategies for the existing building are also preliminary, and thus, should not be considered as exact and definitive, but rather, useful for comparison.

Introduction to Embodied Carbon

Embodied energy is required to produce a building. It includes the up-front energy investment for extraction of natural resources, manufacturing, transportation, installation, and disposal of materials, referred to as initial embodied energy.

Embodied carbon represents the carbon emitted by the fossil fuel used to extract, manufacture, transport, and dispose of the materials used to produce a building. Since different materials use different types and amounts of energy, determining the embodied carbon for each material, or in this case, each set of materials that make up parts of the building (called "building assemblies") is a complex process. For this study, Linnean has used several carefully researched databases of material and assembly carbon values, including:

- The Athena Sustainable Materials Institute's Impact Estimator and EcoImpact Calculator,
- The Inventory of Carbon and Energy (ICE) from University of Bath, UK,
- Boston Community Greenhouse Gas Inventories, portion of the 2009 City of Boston Climate Action Plan,

- The City of Cambridge Climate Protection Plan,
- The Greenest Building, a recent study from Preservation Green Lab, and
- The Influence of Construction Materials on Life-Cycle Energy Use and Carbon Dioxide Emissions, a thesis submitted to Victoria University of Wellington, New Zealand.

This study uses the "Avoided Impacts" methodology, as described in The Greenest Building study of building Life Cycle Assessment.

> The Avoided Impacts methodology considers any building or equipment already in place as having no environmental impact. Impacts can be "avoided" by re-using materials and systems. Only newly constructed materials and systems are counted as having an embodied energy and CO2e impact in this study.

Building Options Data and Analysis

Analysis Scope

The current building, with some updates, and the three building design options were analyzed for embodied carbon equivalent emissions and embodied fossil fuel energy. Operational energy characteristics for the three design options were based on the energy modeling report provided by in:posse.

This study considers energy and carbon effects over a projected 50-year life for the MLK School building.

The energy and carbon analysis includes materials and activities associated with constructing the three building options and updating of the current (or "existing") building. Some activities and materials that are projected to be the same for all 3 options were not included in this preliminary analysis – such as walkway and parking lot materials and site-work, playgrounds, installed kitchen equipment, woodshop equipment, etc. This carbon analysis is based on materials listed in the Feasibility Study Cost Estimate prepared by Davis Langdon.

The energy use of the current MLK building is based on information provided by the City of Cambridge.

This analysis was done using the Athena EcoCalculator to look at building assemblies, the ICE Carbon Database to look at specific materials, and the Retroficiency Automated Energy Analysis to look at the energy and carbon emissions of the existing building.

The *current building* option (also called the "current updated" building to distinguish it from the design options) assumes that systems and infrastructure for the building are updated to provide lower operating energy, and that changes are made to the interior and exterior finishes of the building to both help with energy improvements and upgrade the building, in general.

Proposed Changes:

- Updated plumbing systems and fixtures
- New heating and cooling equipment and systems
- Updated fire and IT infrastructure
- Added insulation to the foundation and exterior
- Replacement of up to 30% of interior walls and fittings
- Replacement of all interior paint, flooring and surfaces
- Other minor changes

Effects of these changes to the operational energy and carbon emissions of the existing building were modeled using the Retroficiency Automated Energy Audit software system. Results of that audit are in the appendix. Changes and updates to the building that do not affect the building energy performance were not modeled.

The embodied energy and carbon associated with these changes were modeled using the Athena EcoCalculator and the ICE database.

Catogory	Tons CO2e
Building Systems	256.0
Insulation	33.2
Equip (incl. Kitchen)	150.0
Interior Finish	591
Casework	50.0
Misc.	270.0
Total	1350.3

Table 1

Embodied CO2e accounting for upgrades to the current updated building.

The *Existing Modified* option assumes that some portion of the existing building is demolished, the rest of the existing building is stripped to the structure, and the new building is constructed with a mix of new and re-used structure, as described in the Perkins Eastman documents.

The operational energy of the *Existing Modified* option was modeled by in:posse for Perkins Eastman. Operational carbon emissions were modeled using the Boston Community Greenhouse Gas Emissions data, by Linnean.

The embodied energy and carbon associated with the *Existing Modified* option was modeled using the Athena EcoCalculator and the ICE database.

The *Clover and Pi* options assume that all of the existing building is demolished except a portion of the foundation, to be replaced with new construction.

The operational energy of the *Clover and Pi* options were modeled by in:posse for Perkins Eastman. Operational carbon emissions were modeled using the Boston Community Greenhouse Gas Emissions data, by Linnean.

The embodied energy and carbon associated with the *Existing Modified* option was modeled using the Athena EcoCalculator and the ICE database.

Embodied and Operational Energy and Carbon

Operating energy is a prime factor in evaluating building-related energy and CO2e impacts. Analyses of building operating energy and related impacts have become common, as concern about resource depletion and climate change have grown. The operating energy of buildings varies greatly, due to differences in building envelope and system performance, as well as building management and maintenance, occupant behavior and building life span. Thus, the ratio of buildings' annual operating energy to total embodied energy can diverge substantially – between 5:1 and 30:1.

According to The Greenest Building study, schools typically have a lower ratio of embodied to operational energy. In other words, schools use a lot of energy relative to the energy to make the building. This study cites their research showing that school buildings in cold climates (like Cambridge's) take only 10 to 15 years of operational efficiency to pay back the embodied energy in a new building.

Year Of Carbon Equivalency For Existing Building Reuse Versus New Construction

This study finds that it takes between 10 to 80 years for a new building that is 30 percent more efficient than an average-performing existing building to overcome, through efficient operations, the negative climate change impacts related to the construction process. This table illustrates the numbers of years required for new, energy efficient new buildings to overcome impacts.

Building Type	Chicago	Portland
Urban Village Mixed Use	42 years	80 years
Single-Family Residential	38 years	50 years
Commercial Office	25 years	42 years
Warehouse-to-Office Conversion	12 years	19 years
Multifamily Residential	16 years	20 years
Elementary School	10 years	16 years
Warehouse-to-Residential Conversion*	Never	Never

*The warehouse-to-multifamily conversion (which operates at an average level of efficiency) does not offer a climate change impact savings compared to new construction that is 30 percent more efficient. These results are driven by the amount and kind of materials used in this particular building conversion. As evidenced by the study's summary of results, as shown on page VII, the warehouse-to-residential conversion does offer a climate change advantage when energy performance for the new and existing building scenarios are assumed to be the same. This suggests that it may be especially important to retrofit warehouse buildings for improved energy performance, and that care should be taken to select materials that will maximize environmental savings.

Table 2

From The Greenest Building, a Life Cycle Assessment study of building re-use by Preservation Green Lab, 2012.

As noted above, embodied carbon is determined by the fuel types and amounts used in materials and construction of the building, whereas operational carbon is calculated from the energy types and amounts used to operate the building.

Preliminary Comparisons

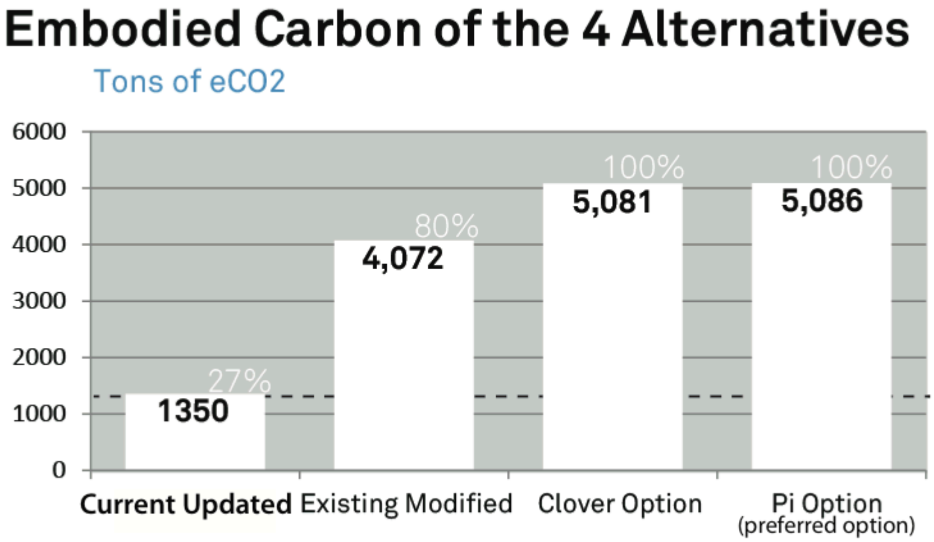


Figure 2
This figure shows the scale of the relative carbon dioxide equivalents (CO2e) embodied in updating the existing building and building each of the three design options. The embodied CO2e for the existing building upgrades is substantially lower than that for the other options because this option does not include new construction, only new systems, finishes, and some interior walls.

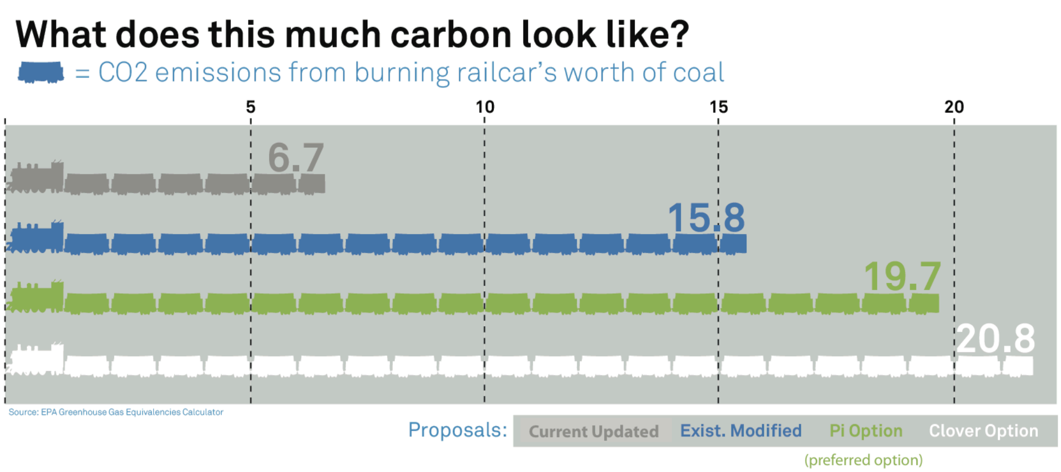


Figure 3
This figure provides a way to understand how much CO2e each building option embodies.

Carbon Equivalents Embodied in Constructing the 4 Building Options

The CO2e embodied in the updating of the current updated building is substantially lower than any of the three building design options. This reflects the fact that much less work and materials go into updating the existing building than in constructing the design options.

Of the design options, the *Existing Modified* option embodies less CO2e than the *Clover* and *Pi* options, due to the re-use of substantial structure in the *Existing Modified* option.

Annual Carbon Equivalent Emissions from Building Operations

The annual CO2e emissions from operating each of the four building options are shown below. This analysis includes the operational CO2e reductions from proposed photovoltaic electricity production on the *Existing Modified, Clover*, and *Pi* design options. Even with updating to reduce the operating energy of the existing building, it performs substantially worse than the design building options.

	EUI	Total KWh	Solar Contribution	Operational CO2e	
Current Updated	44.0	2,049,810	-	804	tons
Existing Modified	30.9	1,430,110	328,310	504	tons
Clover Option	30.2	1,392,980	316,125	492	tons
Pi (preferred) Option	30.7	1,405,980	403,473	458	tons

Table 3

This table show the Solar PV contribution to operational energy for the four building options, and the operational CO2e in tons. All forms of operational energy have been converted to KWh for this table.

Note also that carbon emissions from electricity use are higher per unit of energy used at the existing building, due to electricity transmission losses. This is factored in to the CO2e figures.

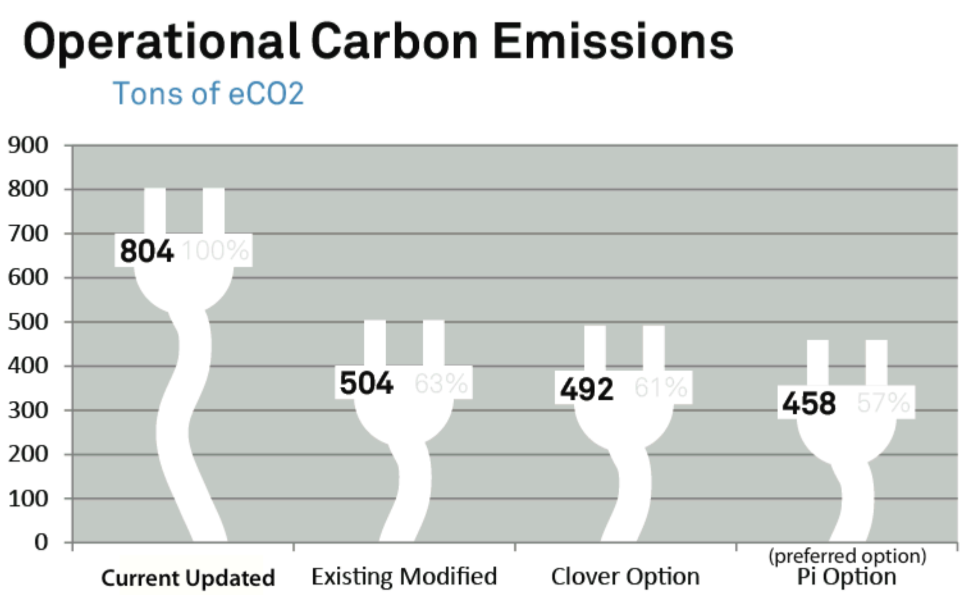


Figure 4

This figure shows the estimated CO2e emissions from the annual operations of the four building options: the current updated building, the *Existing Modified* option, the *Clover* option, and the *Pi* (preferred) option.

Embodied and Annual Operational Energy for the Four Options (in KBtu)

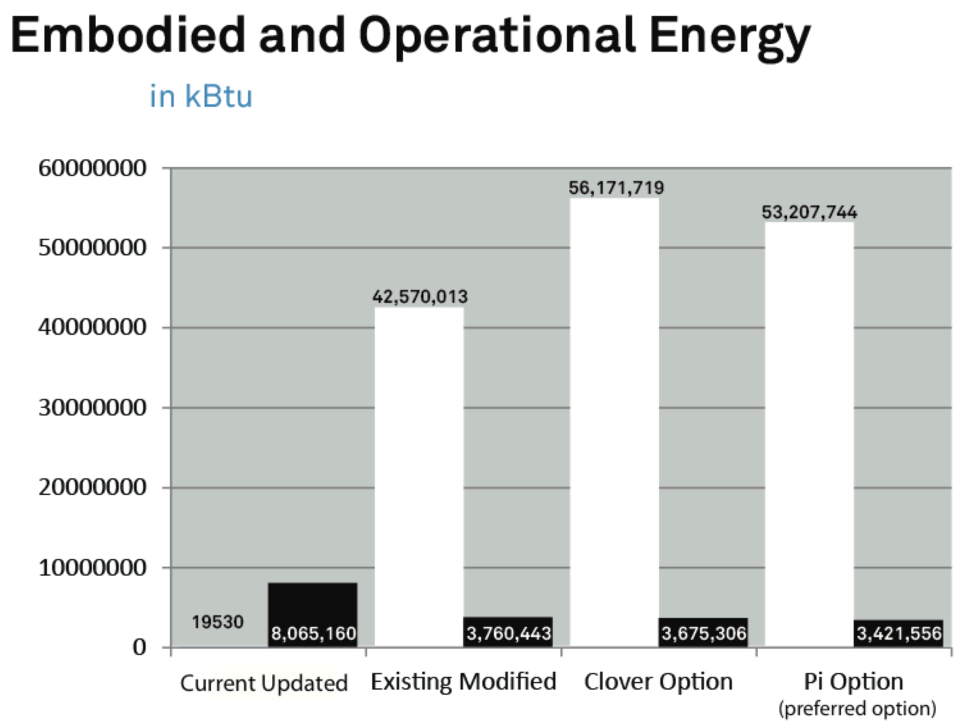


Figure 5
This figure shows the estimated embodied and operational energy for each building option: the current updated building, the *Existing Modified* option, the *Clover* option, and the *Pi* (preferred) option. Energy and CO2e emissions are equivalent, because of differences in carbon emissions from different energy sources.

Distributions of CO2e Emissions for Each Building Option

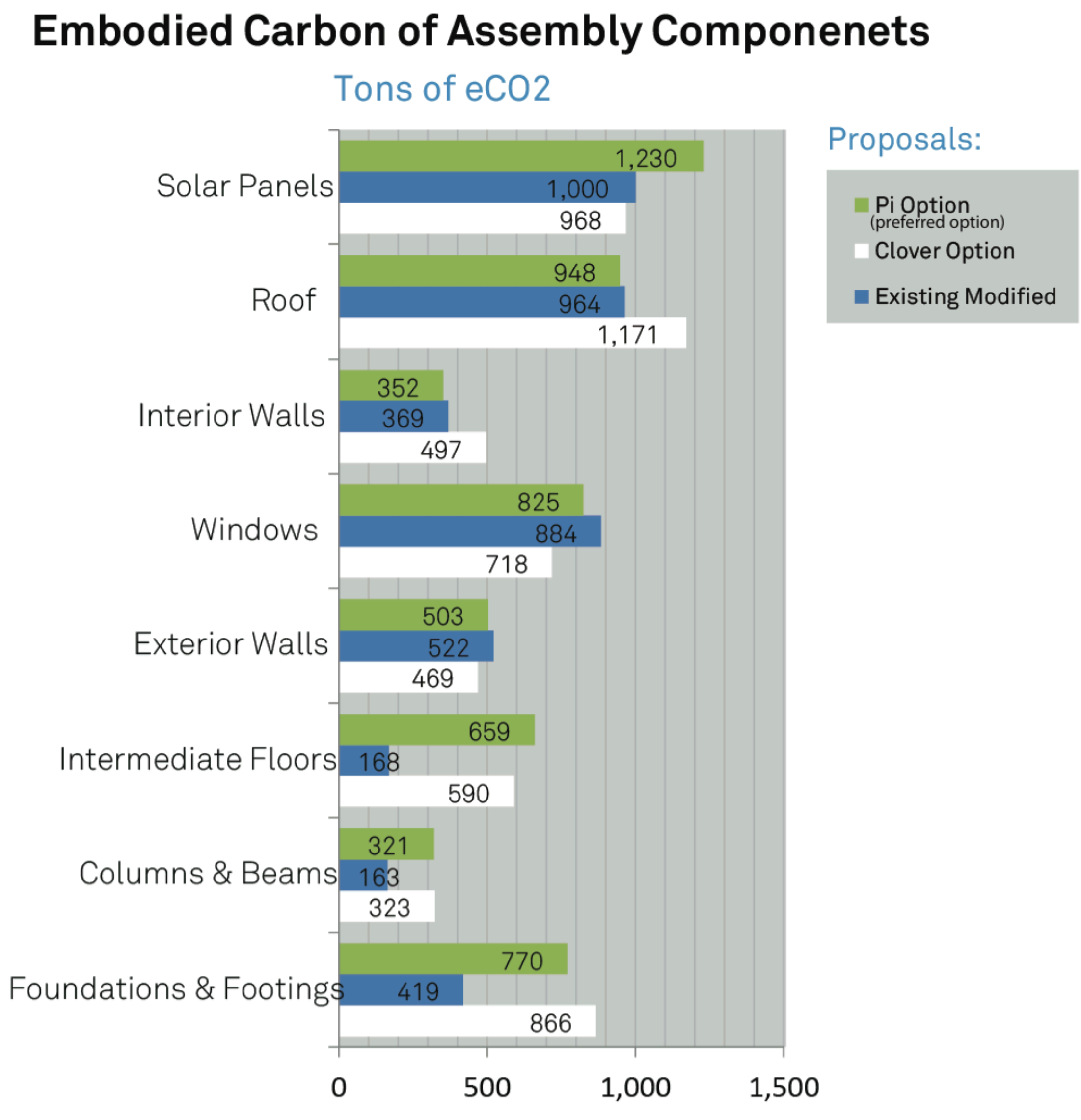


Figure 6
This figure shows the relative estimated contribution of 8 building assemblies to the estimated embodied CO2e emissions for the three building design options: the *Existing Modified* option, the *Clover* option, and the *Pi* (preferred) option.

Appendix A

Energy Analysis of the Existing Building

Linnean Solutions calculated the Energy Use Intensity (EUI) of the existing Martin Luther King Jr. School (MLK) building by examining the energy record for the building for the previous 10 months and then adjusting the data for a standard weather year. (The heating load was low due to a warm winter and the cooling load was approximately right.) A modeling study was done to determine the possibility of improving the energy performance of the existing MLK building by 30%. The energy improvements suggested by this study are shown here. The goal of the study was to test the feasibility of gaining a 30% reduction in energy use, and not to consider the cost of doing so.

Energy Use Intensity Comparison Kbtu per Square Foot						
Current Building (as is)	Current Updated	TCB Unaltered	TGB Updated	Existing Modified	Clover	Pi (preferred)
61	**44**	**80**	**56**	30.7	30.2	30.4
		Solar PV Contribution		-6.9	-6.9	-8.5
		Design Option Totals		**23.8**	**23.3**	**21.9**

Table 4

This table shows a comparison of Energy Use Intensities (EUI) for the current MLK building and the current building with 30% reduction in EUI (Current Updated), compared to an un-improved and an updated building in a similar cold climate (Chicago) from The Greenest Building (TGB) study, as well as the three proposed design options for MLK. The estimated reductions in EUI from the proposed solar arrays for the proposed design options are shown, as well.

It proved difficult in the study to get greater than a 30% energy use reduction in the current MLK building. Greater levels of insulation did not yield greater savings, primarily due to the overall energy load structure of the school operations.

Potential Kitchen Energy Use	
Cooking (gas)	337,400
Washing (hot water)	420,000
Equipment (elec)	269,968
Total Kbtu	**1,027,368**
% Current	10.6%
% Current Updated	14.7%
% Exist. Modified	27.3%
% Clover	28.0%
% Pi (preferred option)	30.0%

Table 5

This table shows the estimated energy load from the existing kitchen operations at the MLK School. These loads are likely to stay approximately the same under any of the design scenarios. The table show what proportion of the EUI these loads represent under the different scenarios. The percentages do not reflect energy use effects of the proposed solar arrays.

Energy Use Reduction Strategies

Suggested energy use reduction strategies include a number of options. The information below includes changes to the current MLK building that affect the energy use of the building. They do not include any analysis of necessary upgrades to the building that do not affect the energy use or CO2e emissions of the building.

Suggested Current Building Load Reduction	
Heating System	6.5%
Cooling System	1.0%
Lighting Systems	1.7%
Insulation	12.0%
Hot Water	5.9%
Ventilation	0.5%
Total Reduction	**27.5%**

Table 6

This table shows the percentage of load reduction in each category, from the suggested energy use upgrades to the current MLK building. The total load reduction from the suggested upgrades is 27.5%.

The recommendations in this study are estimated to reduce overall energy usage from 9,699 MMBtu to 6,996 MMBtu, a savings of about 27.5%.

Suggested energy upgrades to the current MLK building include the following Energy Conservation Measures for lowering energy use. The modeling process also takes into account the interactive effects of multiple measure, such as the way in which lowering the lighting load in the building will also lower the cooling load and increase the heating load.

Hot Water	Replace existing water heater with electric water heater with R-24 insulation, insulate pipe near tank, aerators
The existing distillate oil water heater consumes 4,055 gal of distillate oil per year. A electric water heater with r-24 insulation, insulate pipe near tank, aerators will consume 14,377 kwh of electricity per year. (combined with faucet aerators and additional insulation on piping).	
CO2 Equivalent Reduction	4%
Annual Energy Savings	5.9%

Heating	Replace distillate oil conventional boiler with new gas boiler
The distillate oil conventional boiler consumes 42,374 gal of distillate oil per year. A gas boiler with a 84% combustion efficiency will consume only 55,907 therms of natural gas per year.	
CO_2 Equivalent Reduction	12%
Annual Energy Savings	3%

Lights	Upgrade to new Super T8 fluorescent lighting with electronic ballasts
A T12 fixture with 4 40-watt lamps and electronic ballasts consumes 124 watts. Converting to Super T8 fixture with 3 30-watt lamps and electronic ballasts reduces the electricity consumption to 78 watts.	
CO_2 Equivalent Reduction	8%
Annual Energy Savings	2%

Lights	Upgrade to new 0.35-watt electroluminescent exit sign retrofit kits
The existing 40-watt incandescent exit signs will consume 18,923 kWh per year. Converting to 0.35-watt electroluminescent exit signs reduces the electricity consumption to 166 kWh per year.	
CO_2 Equivalent Reduction	< 1%
Annual Energy Savings	< 1%

Roof	Insulate built-up roof surface and re-roof
	Insulating the built-up roof with R-20 insulation and re-roofing will increase the existing roof insulation R-value from 5 to 25.

CO_2 Equivalent Reduction	11%
Annual Energy Savings	10%

Floor	Insulate perimeter of slab on grade with R-15 insulation
Adding insulation to the perimeter of the slab on grade will increase the existing floor insulation R-value from 0 to 15.	
CO_2 Equivalent Reduction	< 1%
Annual Energy Savings	< 1%

Wall	Add interior masonry surface insulation
Adding R-12.4 insulation to the interior masonry surface will increase the existing wall insulation R-value from 5.5 to 17.9.	
CO_2 Equivalent Reduction	2%
Annual Energy Savings	2%

Cooling	Upgrade to a new ultra high efficiency water-cooled centrifugal electric chiller
Replacing the electric water-cooled centrifugal chiller with a COP of 6 with a water-cooled centrifugal electric chiller having a COP of 7.37 will decrease cooling energy consumption by 1,875 kWh of electricity annually.	
CO_2 Equivalent Reduction	< 1%
Annual Energy Savings	< 1%