Zero Net Energy-Ready School Design Guideline

Consumers Energy Zero Net Energy (ZNE) Pilot Program

July 2020

Consumers Energy
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Executive Summary

During these unprecedented times, we want you to know we're in this together and here to help our Michigan schools. We are proud to serve and support Michigan, you can count on Consumers Energy to help you lower your energy bills while increasing your sustainability. This design guideline provides a detailed step by step pathway to renovating an existing school into a Zero Net Energy (ZNE) ready building in the Michigan climate. The intent of this document is to be used as an accompanying handbook to assist the building owner and design team in achieving high performance design and if feasible, an all-electric solution for their school project. Additionally, the purpose of the guide is to serve as a resource for customers by providing referrals and recommendations to other Consumers Energy Business Energy Efficiency Program offerings to maximize their energy efficiency opportunities.

The baseline design is a 20+ year old existing school building in the Grand Rapids area that is in significant need of a major renovation. A total of 10 energy conservation measures (ECM) are recommended with at least one measure per building category (building envelope, lighting, HVAC and service hot water).

A "right steps-right order" approach through an iterative modeling analysis is suggested for any whole building energy efficiency upgrade. The first three energy conservation measures recommended (ECM 1, 2 & 3) in this design guideline focus on improving the thermal performance of the passive building components/systems in order to reduce the cooling and heating loads. Once these passive strategies are implemented, additional energy savings can be achieved by increasing the performance efficiency and reducing the run time of the active systems installed (ECM 4 through 9).

There were two paths investigated for HVAC system upgrade and replacement; a dual fuel HVAC system upgrade (ECM 8a) and an all-electric system replacement (ECM 8b). The purpose in analyzing both options was to ensure that for projects where a full HVAC system replacement and electrification was not possible, an energy efficiency pathway for dual fuel HVAC system was still provided.

An annual Energy Use Intensity (EUI) is used to compare the energy performance of each of the proposed ECMs. An EUI represents an engineer unit of one thousand British Thermal Units (Btu) per square foot of building area per year, or kBtu/sf-year.

Pathway 1

The first pathway was developed as an actionable dual fuel solution to achieving significant building energy savings in both electric and natural gas.

With the implementation of ECM 1 – 8a, the annual energy use intensity of the school is reduced from 78.5 kBtu/ft^2 to **55 kBtu/ft^2 (savings of 30%)**.

	Energy Use Intensity (kBtu/ft^2)	Annual Cumulative Energy Savings (%)
BASELINE – EXISTING SCHOOL	**78.5**	**0%**
ECM 1 – ROOF INSULATION	**72.6**	**7.5%**
ECM 2 – EXTERIOR WALL INSULATION	**71.0**	**9.6%**
ECM 3 - INFILTRATION	**65.0**	**17.1%**
ECM 4 – INT. & EXT. LIGHTING	**61.5**	**21.6%**
ECM 5 – DAYLIGHTING CONTROLS	**61.4**	**21.8%**
ECM 6 – PLUG LOAD EFFICIENCY	**60.9**	**22.4%**
ECM 7 – SERVICE HOT WATER	**59.8**	**23.8%**
ECM 8a – RETRO-COMMISSIONING	**55.0**	**31.0%**

Pathway 2

The second solution that is presented in this design guideline results in an all-electric, high performing school building. To eliminate natural gas use entirely, ECM 1 – 7, ECM 8b and ECM 9 are recommended, which achieves an annual energy use intensity of **24.3 kBtu/ft^2 (savings of 69%)** for the school.

	Energy Use Intensity (kBtu/ft^2)	Annual Cumulative Energy Savings (%)
BASELINE – EXISTING SCHOOL	**78.5**	**0%**
ECM 1 – ROOF INSULATION	**72.6**	**7.5%**
ECM 2 – EXTERIOR WALL INSULATION	**71.0**	**9.6%**
ECM 3 - INFILTRATION	**65.0**	**17.1%**
ECM 4 – INT. & EXT. LIGHTING	**61.5**	**21.6%**
ECM 5 – DAYLIGHTING CONTROLS	**61.4**	**21.8%**
ECM 6 – PLUG LOAD EFFICIENCY	**60.9**	**22.4%**
ECM 7 – SERVICE HOT WATER	**59.8**	**23.8%**
ECM 8b – GROUND SOURCE HEAT PUMP SYSTEM	**26.3**	**66.4%**
ECM 9 – NATURAL VENTILATION	**24.3**	**69.1%**

For purposes of this report we have utilized a simple payback metric for the financial analysis. This metric considers the resulting annual energy cost savings compared to the initial capital cost for the implementation of each of the energy conservation measure iterations. The ECM, or collection of ECMs may be considered cost-feasible when the payback falls into reasonable periods. The Summary of Results section lists the cumulative payback for each of the ECMs. The intent of including cost information in this guidebook is to aid in the decision making for other projects. It is assumed that each building owner has a definition of reasonable payback based on their situation.

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Introduction

This document presents the approach, results and recommendations for an existing school building seeking to achieve significant energy savings and enhance the indoor environment for its occupants. First, the report provides an overview of the benefits of designing a ZNE school. Next, details of the methodology and modeling analysis adopted to represent the existing school conditions and the proposed, renovated design are presented. Finally, two pathway solutions are prepared based upon the optimization of the recommended energy conservation measures.

Why ZNE Schools?

ZNE schools provide many additional benefits beyond reducing operational costs and lessening the energy footprint for the building. Other benefits include:

Better education: Schools that have heathier indoor environments have been shown to create better learning environments for students increasing retention rates and test scores, while reducing absenteeism.

Teaching tools: Schools that integrate sustainability elements into the design extend the learning opportunities outside the traditional classroom.

Students as ZNE champions: Students can promote gamification by championing the measurement and monitoring of classroom/school's energy and carbon performance, which can further reduce energy and carbon emissions.

Owner occupied facilities: School districts and Building Authorities have long-term ownership interests that encourages them to consider utility expenses, capital improvement projects and longer returns of investments (ROI) than non-owner-occupied facilities.

Generation of investment dollars: Schools districts and Building Authorities can access bond measures for school improvements providing them access to large sources of funding.

Renewable energy opportunities: School facilities typically have large building footprints, which create large areas that can be used for solar photovoltaic arrays.

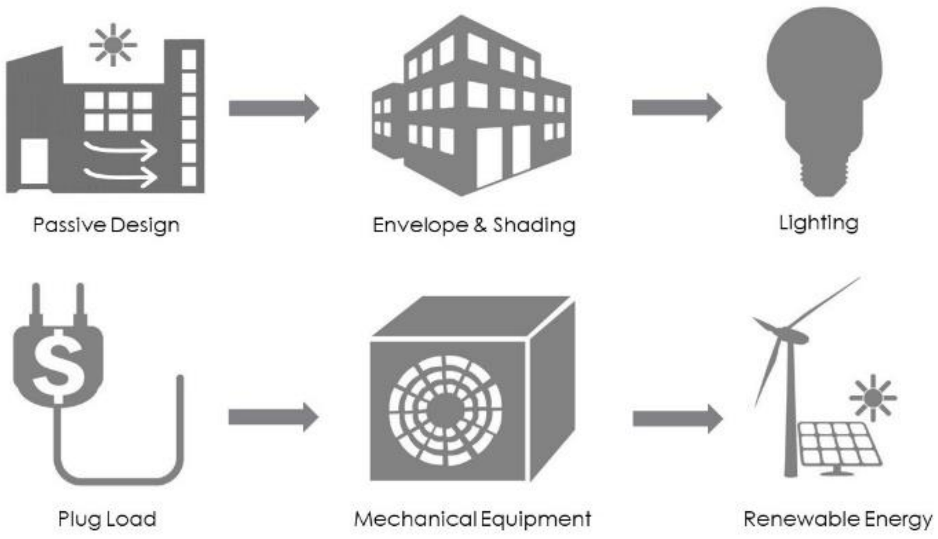
Objectives

This design guideline is intended to be used as a reference for building owners and their design teams seeking to achieve an all-electric, zero net energy school project.

The guideline provides a pathway for Consumers Energy customers to achieve this level of high performance by:

- Identifying baselines and performance targets for schools in the Consumers Energy territory.
- Evaluating energy and cost savings for design strategies and processes.
- Recommending holistic energy efficiency measures that collectively meet the ZNE-ready goal for a school.

- Providing additional referrals and recommendations to Consumers Energy Pilot and Specialty programs and other program offerings to maximize the opportunity on behalf of the customer.



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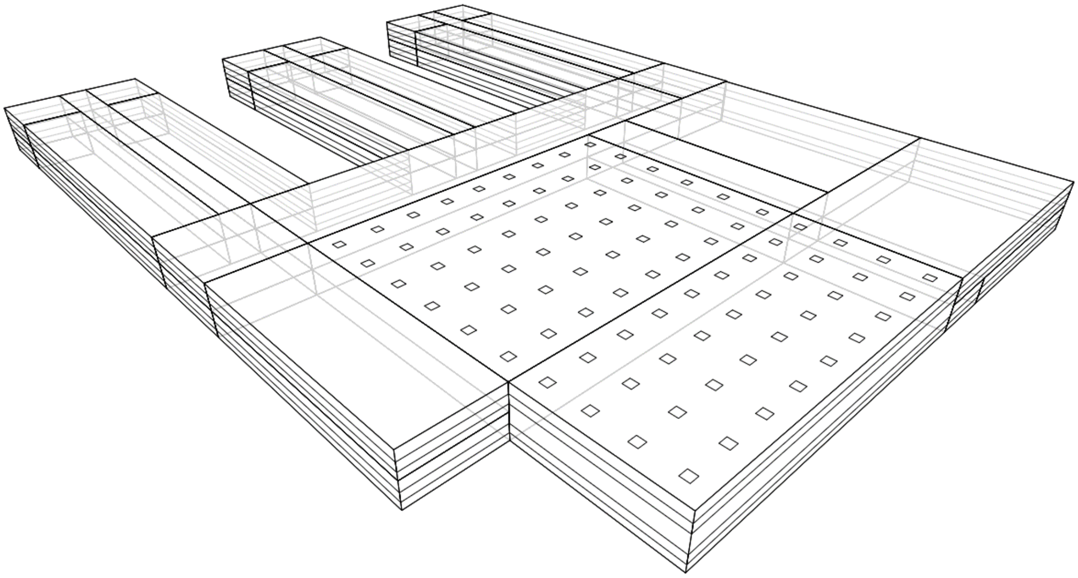


Source: DNV GL

Methodology

Energy Modeling Software

Virtual Environment (VE) 2019 was used as the modeling software to conduct the energy calculations for this design guide. The VE software suite was chosen as it allows for full consideration of dynamic thermal performance and offers a wide variety of outputs. Included within the thermal model are:

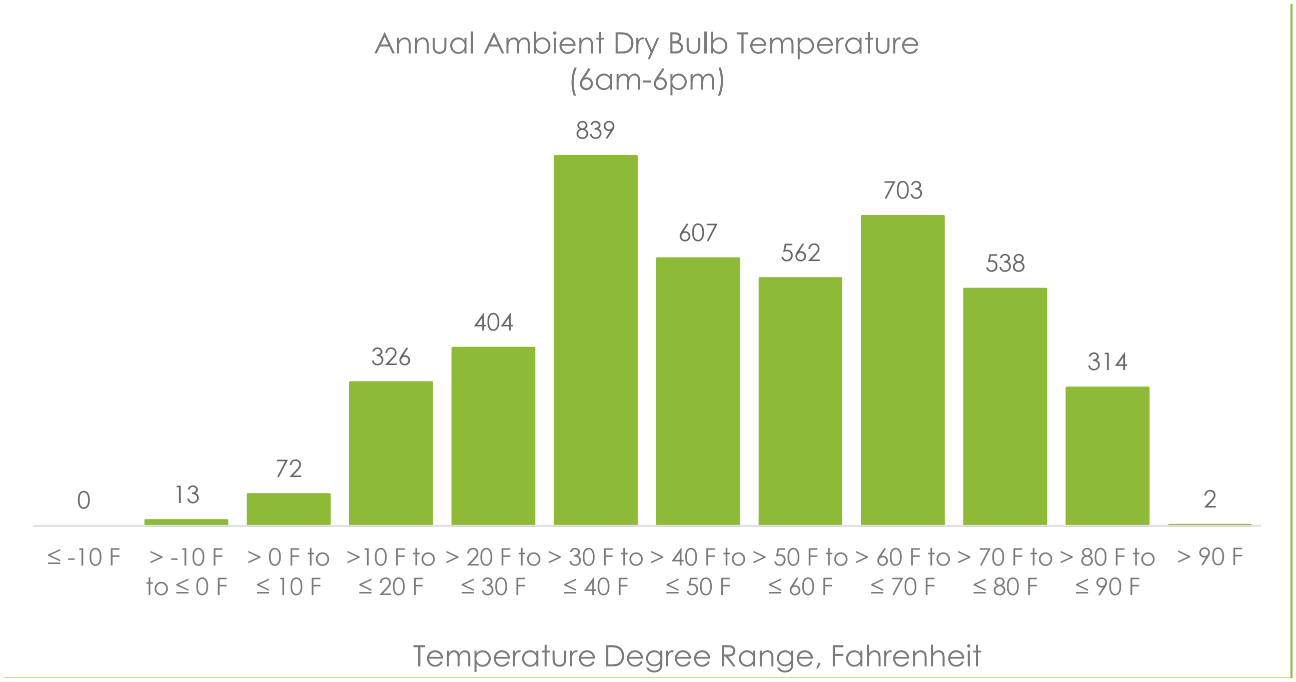
- All material constructions.
- All internal diversified load profiles for people, lights and equipment.
- All schedules for internal loads, external loads and HVAC system components.
- The shading and overshadowing for each hour of the day for each day of the year.

Weather

The Grand Rapids weather station was selected as a representative climate zone for Consumers Energy territory. Hourly-recorded weather data for Gerald R. Ford International Airport, Grand Rapids, Michigan was used in the simulation to accurately model the dynamic nature of building thermal response. This weather data contains records on solar radiation, temperature, humidity, sunshine duration and wind speed and direction. The energy model uses the normalized weather data for its annual simulation that informs climate-specific energy efficiency recommendations.

The following table is an overview of the ambient temperature conditions experienced in Grand Rapids, Michigan over the course of one year.

Figure 1: Annual Ambient Dry Bulb Temperature for Grand Rapids



Cost Benefit Analysis

For purposes of this report we have utilized a simple payback metric, which considers annual energy cost savings compared to the initial capital cost for the measure. A measure, or collection of measures, may be considered cost-feasible when the payback falls into reasonable periods - each building owner will have their own definition of reasonable payback.

This guidebook presents a simplified look at cost benefit analysis using project construction cost data derived from RSMeans and other sources as noted. RSMeans is a source of construction and maintenance cost pricing that includes a collection of data points actively monitored by experienced cost engineers using market data. RSMeans data is used by construction professionals to create budgets, estimate projects, validate their own cost data and plan for ongoing facilities maintenance. Other data sets include Consumers Energy incentive programs and department of energy references on energy conservation measure costs.

This guidebook references a retrofit project for a 200,000+ square foot high school facility in Grand Rapids, Michigan. The cost data are intended to be illustrative of the conditions of the hypothetical project. The energy rates assumed for the cost calculations are virtual rates based on normalized energy tariffs for commercial buildings in Consumers Energy territory:

- Electricity: $0.10 per kWh (kilowatt per hour)
- Natural gas: $10/Mcf (thousand cubic feet)

Specific analyses may be needed for unique project considerations. The intent of including cost information in this guidebook is to aid in the decision making for other projects.

Baseline Conditions

A 'Baseline' energy model was developed as a representation of the existing school building of 20+ year vintage. A major lighting upgrade was performed in 2007, however, no other major retrofits have occurred at the school. Due to degradation in equipment, ongoing maintenance issues and the desire to reduce operating costs, the school district has assigned capital improvement funds to the school to undergo a major renovation of its components and systems.

Table 1: Existing Building Assumptions

BUILDING ENVELOPE	• Roof: a singly-ply membrane roof over insulation on metal deck with 4" of R12 Insulation • Exterior walls: steel frame with CMU block and board insulation • Infiltration: 0.2 Air Changes/Hour (ACH) • Glazing: Double pane, U value = 0.55, SHGC = 0.32
LIGHTING & CONTROLS	• LPD: space-by-space ASHRAE 90.1 – 2004 code minimum lighting power densities • Occupancy controls: none • Daylighting controls: none
HVAC	• Air distribution system: Multi-zone air-handling units • Cooling system: Water-cooled chiller with a COP of 3.0 full load efficiency • Heating system: Natural gas-fired boiler with 70% thermal efficiency • Natural ventilation: No natural ventilation strategy employed for thermal comfort • Domestic hot water: Natural gas-fired boiler with 75% thermal efficiency

Each of these improvements, referred to as energy conservation measures (ECMs), have been modeled as cumulative iterations to the Baseline model.

As the school building was constructed over 20 years ago it was assumed that some basic level of energy efficiency was considered in its design and equipment selection, however, there was not a statewide regulated energy code being followed. As part of the lighting retrofit in 2007, it was assumed that all fixtures were upgraded to meet 2006 International Energy Conservation Code (ASHRAE 90.1 2004) minimum lighting power densities.

The existing HVAC equipment was modeled with a full load operational performance equivalent to the ASHRAE 90.1 – 2004 code minimum efficiency requirements (as a proxy reference standard for modeling inputs), with some additional losses in efficiency assumed due to 20+ years of operation.

Energy Conservation Measures

To align with the 2020 ZNE Companion Program energy targets, the energy performance of the Proposed school design is targeting the following criteria:

- Annual energy use intensity (EUI) of 25 kBtu/ft^2 and at least a 20% energy savings reduction, or if 25 kBtu/ft^2 EUI cannot be reached; at least a 30% energy savings reduction.
- The proposed project must use 100% electricity (i.e., no natural gas, district heating, etc. used onsite).
- New construction, major renovation, or a deep retrofit project upgrading a minimum of two whole building energy systems.

The ECMs identified are specific to the Consumers Energy territory and incorporate strategies that reduce the building's energy use. There were two paths investigated for HVAC system upgrade and replacement; a dual fuel HVAC system upgrade (ECM 8a) and an all-electric system replacement (ECM 8b). The purpose in analyzing both options was to ensure that projects where a full HVAC system replacement and electrification was not possible, an ECM alternative recommendation for dual fuel HVAC system was still provided. It was further assumed that natural ventilation would only be incorporated for projects that were undergoing HVAC replacement due to operational and cost implications. Therefore, the performance of ECM 9 was applied in addition to the ECM 8b pathway:

Figure 2: Recommended Energy Reduction Pathways

ECM 1 – ROOF INSULATION	Replaced 4" of R-12 board insulation with R-30 board insulation for the roof construction
ECM 2 – EXTERIOR WALL INSULATION	Added 2" of board insulation to the interior side of the exterior walls
ECM 3 - INFILTRATION	Reduced infiltration gain for perimeter spaces by 30%
ECM 4 – INTERIOR & EXTERIOR LIGHTING	Reduced interior lighting densities in all school spaces to exceed code minimum requirements and applied occupancy controls in applicable spaces
ECM 5 – DAYLIGHTING CONTROLS	Reduced classroom interior lighting power density by 30%
ECM 6 – PLUG LOAD EFFICIENCY	Reduced interior equipment power densities by 20% for applicable areas
ECM 7 – SERVICE HOT WATER	Upgraded the natural gas fired water heater to an all-electric air sourced heat pump water heater system

HVAC OPTION 1: NON-ELECTRIC HEATING	
ECM 8a Retro-commissioning	To represent the implementation of retro-commissioning activities, the efficiency of the central plant equipment was improved by 20%.

HVAC OPTION 2: ELECTRIC HEATING	
ECM 8b GSHP System	Upgraded existing HVAC system to a GSHP system with heat recovery.
ECM 9 Natural Ventilation	Incorporated mixed-mode ventilation for both heating and cooling seasons.

In 2017, Michigan adopted the 2015 International Energy Conservation Code (IECC) and ASHRAE 90.1 2013 as it's governing state-wide building energy codes. For the purpose of this design guideline, we assumed that any new work will at a minimum meet ASHRAE 2013 prescriptive requirements. For cases where the building component or system is recommended to exceed ASHRAE 90.1 2013 level performance, the increase in percentage or factor is noted.

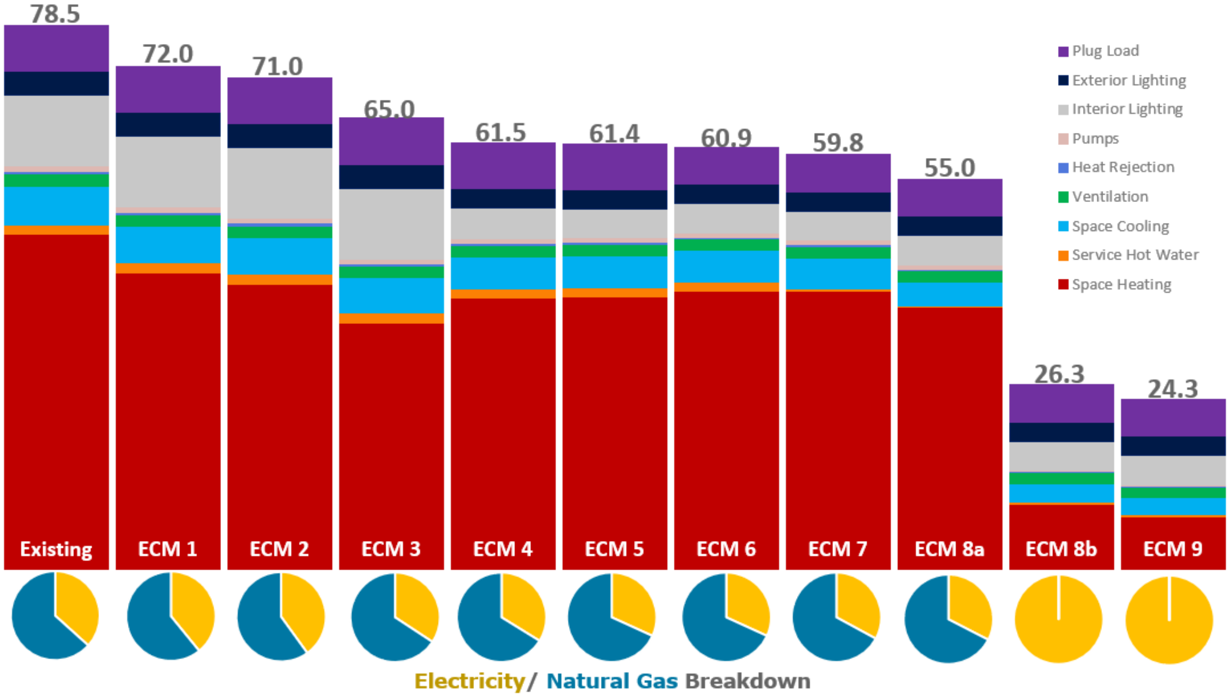
Summary of Results

The following section lists the predicted annual energy use intensity (kBtu/ft^2) and energy savings for the school through cumulative implementation of the recommended energy conservation measures. The results demonstrate that if Pathway 1 is followed, the projected annual energy use intensity is 55 kBtu/ft^2 which results in total annual energy savings of 31% when compared to the existing school's energy use.

If Pathway 2 is chosen, and a full all-electric solution is achieved, then the resulting energy use intensity is approximately 24.3 kBtu/ft^2/year, which equals an energy reduction of 69% when compared to the existing school.

The chart included below further illustrates the annual energy use intensity and cumulative reduction as a result of implementing the recommended ECMs. An additional graphic of the fuel source is shown for each of the iterations to indicate the total natural gas versus electricity breakdown for the school building. It should be noted that only complete electrification is achieved if Pathway 2 is followed and the existing HVAC system is upgraded to a ground source heat pump system.

Figure 3: Energy Use Intensity by Energy Conservation Measure and End-Use



As mentioned in the methodology section of this report, for the financial analysis, the cumulative payback for each measure was calculated. This metric considers the cumulative energy cost savings compared to the total cumulative capital costs of the preceding ECMs.

The following table demonstrates the cumulative payback for each of the ECMs recommended for the school.

Table 2: Cumulative Simple Payback by Energy Conservation Measure

	Cumulative Simple Payback (years)
ECM 1 – ROOF INSULATION	15.0
ECM 2 – EXTERIOR WALL INSULATION	18.0
ECM 3 – INFILTRATION	11.7
ECM 4 – INTERIOR & EXTERIOR LIGHTING	10.9
ECM 5 – DAYLIGHTING CONTROLS	11.2
ECM 6 – PLUG LOAD EFFICIENCY	10.4
ECM 7 – SERVICE HOT WATER	10.7
ECM 8a – RETRO-COMMISSIONING	10.0
ECM 8b – GROUND SOURCE HEAT PUMP SYSTEM	23.2
ECM 9 – NATURAL VENTILATION	24.4

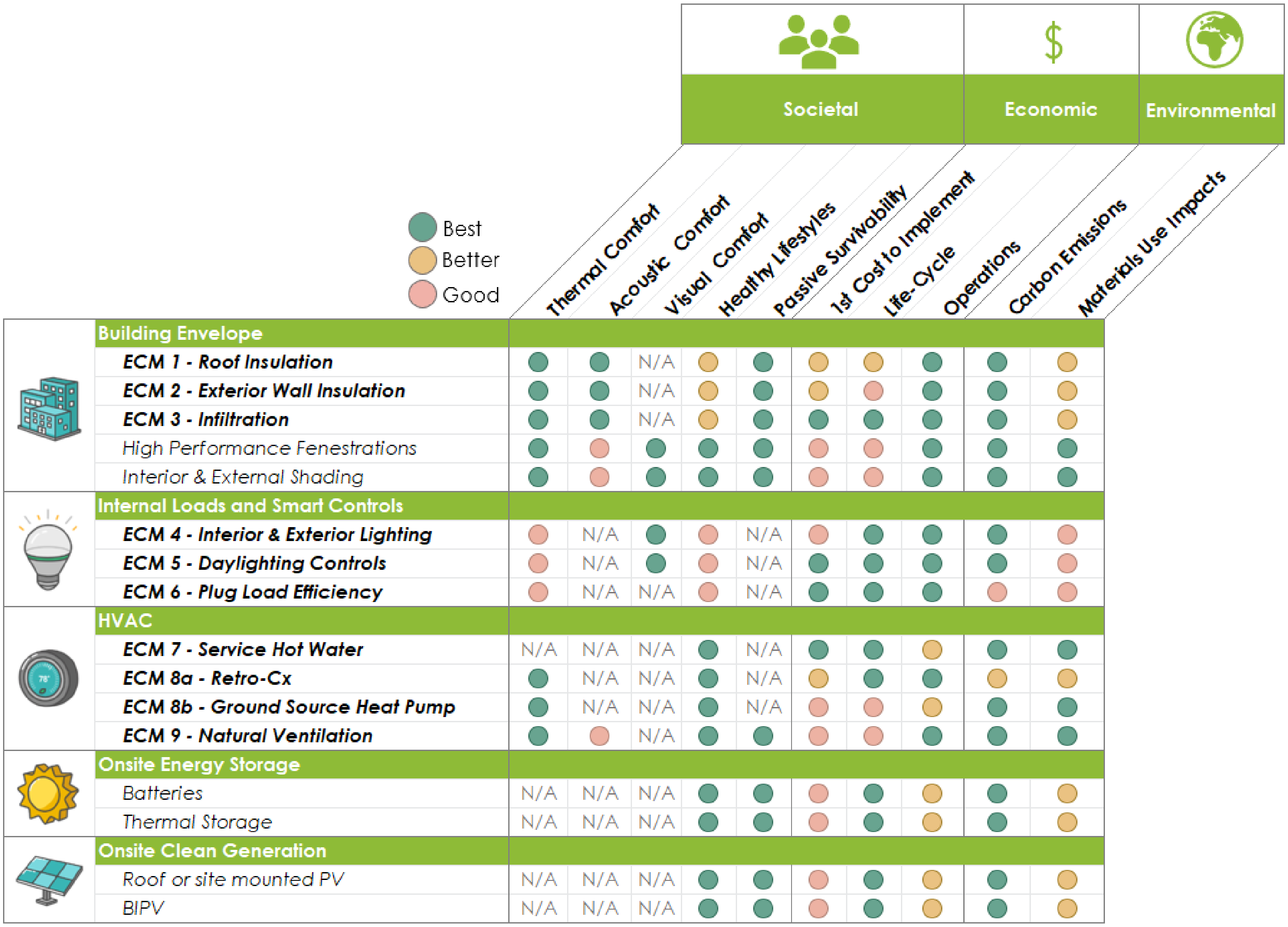
The results show that for each of the measures, the cumulative payback calculated is not greater than the individual measure life. Further, if the first pathway (ECM 1 through 8a) is followed and this package of measures are implemented in the project, the cumulative payback will be 10 years.

The envelope measures (ECM 1 & 2) have a higher payback when compared to ECM 3 through 8a (cumulative payback of less than 12 years). Adding insulation to an existing building envelope construction can be costly with a minimum energy efficiency impact in comparison (although this is highly dependent on the climate, building type and construction). However, a building's skin has a life expectancy of approximately 50 years and, ultimately, improving it extends the life of the building by reducing operational and maintenance costs.

Adopting pathway 2 (ECM 1 through 7, ECM 8b and 9) should be a non-economic based solution for building owners and project teams that are seeking to decarbonize their building's energy footprint. A complete upgrade to a ground source heat pump system coupled with mixed-mode ventilation will result in a cumulative payback of approximately 24 years. The first costs associated with the procurement, construction and installation of a ground source heat pump system are a significant investment for an existing building and requires a long-term commitment from the owner that is not just focused on costs.

The following diagram provides a preliminary, high-level ranking of the societal, economic and environmental non-energy benefits for each of the recommended ECMs for the school. It demonstrates that regardless of the energy use impact, the implementation of each of the ECMs enhances the indoor and outdoor environment for the occupants.

Figure 4: Non-Energy Benefits Matrix



🟢 Best
🟡 Better
🔴 Good

	Societal					Economic			Environmental	
	Thermal Comfort	Acoustic Comfort	Visual Comfort	Healthy Lifestyles	Passive Survivability	1st Cost to Implement	Life-Cycle	Operations	Carbon Emissions	Materials Use Impacts
Building Envelope										
ECM 1 - Roof Insulation	🟢	🟢	N/A	🟡	🟢	🟡	🟡	🟢	🟢	🟡
ECM 2 - Exterior Wall Insulation	🟢	🟢	N/A	🟡	🟢	🟡	🔴	🟢	🟢	🟡
ECM 3 - Infiltration	🟢	🟢	N/A	🟡	🟢	🟢	🟢	🟢	🟢	🟡
High Performance Fenestrations	🟢	🔴	🟢	🟢	🟢	🔴	🔴	🟢	🟢	🟢
Interior & External Shading	🟢	🔴	🟢	🟢	🟢	🔴	🔴	🟢	🟢	🟢
Internal Loads and Smart Controls										
ECM 4 - Interior & Exterior Lighting	🔴	N/A	🟢	🔴	N/A	🔴	🟢	🟢	🟢	🔴
ECM 5 - Daylighting Controls	🔴	N/A	🟢	🔴	N/A	🟢	🟢	🟢	🟢	🔴
ECM 6 - Plug Load Efficiency	🔴	N/A	N/A	🔴	N/A	🟢	🟢	🟢	🔴	🔴
HVAC										
ECM 7 - Service Hot Water	N/A	N/A	N/A	🟢	N/A	🟢	🟢	🟡	🟢	🟢
ECM 8a - Retro-Cx	🟢	N/A	N/A	🟢	N/A	🟡	🟢	🟢	🟡	🟡
ECM 8b - Ground Source Heat Pump	🟢	N/A	N/A	🟢	N/A	🔴	🔴	🟡	🟢	🟢
ECM 9 - Natural Ventilation	🟢	🔴	N/A	🟢	🟢	🔴	🔴	🟢	🟢	🟢
Onsite Energy Storage										
Batteries	N/A	N/A	N/A	🟢	🟢	🔴	🟢	🟡	🟢	🟡
Thermal Storage	N/A	N/A	N/A	🟢	🟢	🔴	🟢	🟡	🟢	🟡
Onsite Clean Generation										
Roof or site mounted PV	N/A	N/A	N/A	🟢	🟢	🔴	🟢	🟡	🟢	🟡
BIPV	N/A	N/A	N/A	🟢	🟢	🔴	🟢	🟡	🟢	🟡

In the next section, each of the recommended measures are discussed in detail and information on the following is provided:

- Baseline condition for that building component/system.
- Proposed upgrade and modification made in the energy model.
- Resulting energy performance and calculated costs of implementing the measure.

ECM 1: Roof Insulation

Reducing the building energy loads by creating an efficient envelope can reduce heating and cooling needs of the building which has a major impact on energy use. The following table presents a summary of the incremental energy reduction and cumulative payback when roof insulation is improved.

ASSUMPTIONS AND SAVINGS	
Model	Baseline + ECM 1
Baseline Input	A singly-ply membrane roof over insulation on metal deck with 4" of R12 Insulation
Proposed Measure	Improved the thermal performance of the roof construction by adding 4" of insulation above the roof deck
Component Modification	Construction U value/R value modification
Incremental Energy Reduction	*5.9 kBtu/ft^2/yr* (7.5%)
Cumulative Savings	7.5%
EUI	72.6 *kBtu/ft^2/yr*
Incremental ECM Cost	\$2-\$3/ft^2 of roof area
Cumulative Payback without Incentives	15 years*

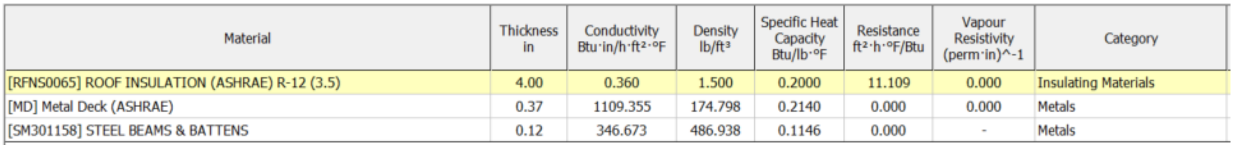
** Measure qualifies for ZNE Companion & C&I Program Rebates which provide additional payback benefit.*

Insulation installed at the roof level of existing building is typically provided by adding rigid foam board to the outside of the structural roof deck and above a continuous air and water membrane installed directly to the roof sheathing. This measure provides the ideal amount of insulation that should be added to the roof layer in order to maximize both cost effectiveness and energy efficiency.

Baseline Roof Construction

Typically, a school of pre 2000 vintage in Grand Rapids area would likely have a singly-ply membrane roof over insulation on metal deck. The insulation assumed in the baseline model is 4-inch average thickness. This type of construction is built with individual layers (outside to inside) in the energy model with the following thicknesses and thermal parameters:

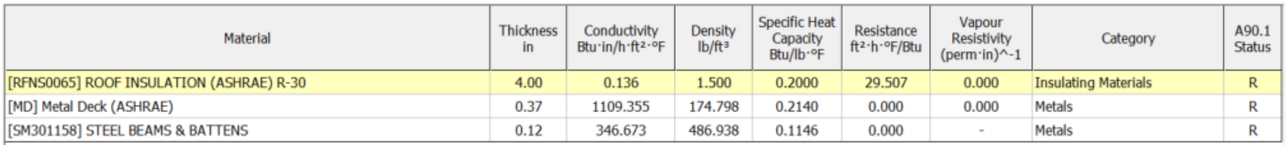
The total Baseline roof construction had an overall thermal conductivity (U value) of 0.084 Btu/hr.ft^2.F and equivalent R value of 11.1 ft^2·h·°F/Btu.



Material	Thickness in	Conductivity Btu·in/h·ft²·°F	Density lb/ft³	Specific Heat Capacity Btu/lb·°F	Resistance ft²·h·°F/Btu	Vapour Resistivity (perm·in)^-1	Category
[RFNS0065] ROOF INSULATION (ASHRAE) R-12 (3.5)	4.00	0.360	1.500	0.2000	11.109	0.000	Insulating Materials
[MD] Metal Deck (ASHRAE)	0.37	1109.355	174.798	0.2140	0.000	0.000	Metals
[SM301158] STEEL BEAMS & BATTENS	0.12	346.673	486.938	0.1146	0.000	-	Metals

Proposed Roof Construction

For the proposed roof construction, the 4" of R12 insulation above the metal deck was replaced with R30 rated insulation which decreases the overall thermal conductivity of the construction to a U value of 0.033 Btu/hr.ft^2.F and increases the R value to 29.5 ft^2·h·F/Btu, thus, improving the energy performance. The resulting roof construction that is modeled is shown in the screenshot below:



Material	Thickness in	Conductivity Btu·in/h·ft^2·°F	Density lb/ft^3	Specific Heat Capacity Btu/lb·°F	Resistance ft^2·h·°F/Btu	Vapour Resistivity (perm·in)^-1	Category	A90.1 Status
[RFNS0065] ROOF INSULATION (ASHRAE) R-30	4.00	0.136	1.500	0.2000	29.507	0.000	Insulating Materials	R
[MD] Metal Deck (ASHRAE)	0.37	1109.355	174.798	0.2140	0.000	0.000	Metals	R
[SM301158] STEEL BEAMS & BATTENS	0.12	346.673	486.938	0.1146	0.000	-	Metals	R

Costs and Payback

Similar to most measures, the cost to add increased roof insulation is driven by the adjacent and associated work. For example, in a situation where the roof membrane is at the end of its life, or prone to leaking; the associated work would necessarily include all adjacent costs. Therefore, we have included only the added cost of additional insulation which, based on RSMeans data is $2-3 per square foot of roof area. This is because the contractor would be mobilized to complete adjacent roof replacement work including removal, roof membrane replacement, base-levels of insulation and associated work. The energy benefits of this added insulation yield a simple payback of approximately 12 years, which is less than the measure life. Consumers Energy offers incentives to increase the roof insulation on the projects, the incentive value varies based on your condition. Please contact Consumers Energy for more information.

ECM 2: Exterior Wall Insulation

Similarly, to improving the thermal resistance of the roof, adding insulation to the walls is a cost-effective solution to increasing energy performance. For wall improvements, the feasibility of installing additional insulation to the existing structure and the ability to access the required areas of the envelope to do so will need to be assessed. The following table presents a summary of the incremental energy reduction and cumulative payback when this measure is implemented in conjunction with the roof insulation upgrade described in ECM 1.

ASSUMPTIONS AND SAVINGS	
Model	Baseline + ECM 1-2
Baseline Input	Steel frame walls with CMU block and board insulation
Proposed Measure	Added 2" of board insulation to the interior side of the exterior walls
Component Modification	*Construction U value/R value modification & addition*
Incremental Annual Energy Reduction	*1.6 kBtu/ft^2/yr* (2.1%)
Cumulative Savings	9.6%
EUI	71.0 *kBtu/ft^2/yr*
Incremental ECM Cost	\$1,6 - \$2.4/ft^2 of wall area
Cumulative Payback without Incentives	18 years*

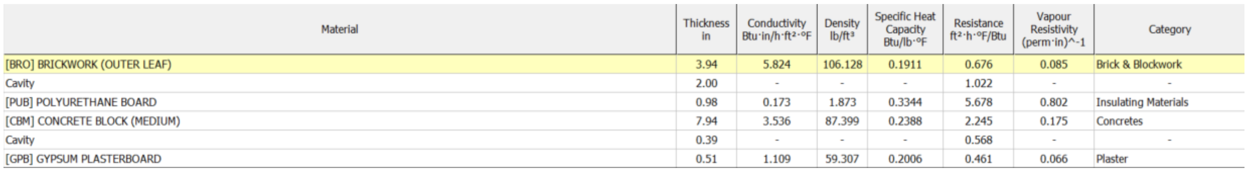
**Measure qualifies for ZNE Companion & C&I Program Rebates which could provide additional payback benefit.*

For ECM 2, it is assumed that additional rigid insulation board can be added directly to the CMU block for the entire perimeter of the school building. The type of rigid insulation recommended would be polyurethane board that has a high rated R-value per inch of thickness added benefit as a vapor retarder. When evaluating the type and quantity of insulation that should be added to the building envelope, cost, constructability, and location are all considerations that should be accounted for in the decision-making process.

Baseline Wall Construction

The Baseline school envelope construction is based on building data obtained through Consumers Energy Schools program. Typically, a school of pre 2000 vintage in Grand Rapids area would be steel frame with CMU block and board insulation type.

This type of construction is built with individual layers (outside to inside) in the energy model with the following thicknesses and thermal parameters:



Material	Thickness in	Conductivity Btu·in/h·ft²·°F	Density lb/ft³	Specific Heat Capacity Btu/lb·°F	Resistance ft²·h·°F/Btu	Vapour Resistivity (perm·in)^-1	Category
[BRO] BRICKWORK (OUTER LEAF)	3.94	5.824	106.128	0.1911	0.676	0.085	Brick & Blockwork
Cavity	2.00	-	-	-	1.022	-	-
[PUB] POLYURETHANE BOARD	0.98	0.173	1.873	0.3344	5.678	0.802	Insulating Materials
[CBM] CONCRETE BLOCK (MEDIUM)	7.94	3.536	87.399	0.2388	2.245	0.175	Concretes
Cavity	0.39	-	-	-	0.568	-	-
[GPB] GYPSUM PLASTERBOARD	0.51	1.109	59.307	0.2006	0.461	0.066	Plaster

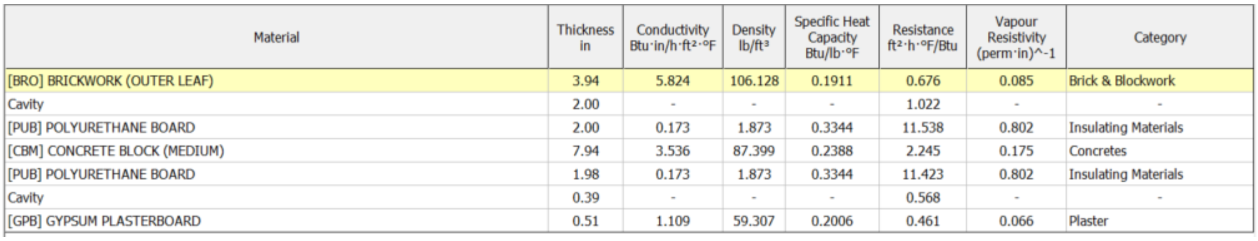
The Baseline wall construction is modeled with a total assembly U value of 0.086 Btu/hr/ft^2/°F (R-value of 10.7 ft$^{2\cdot}$ h·°F/Btu).

Proposed Wall Construction

For the proposed wall construction, adding polyurethane board insulation interior to the concrete block was the recommended improvement. In the model, two changes were made to the Baseline wall construction in order to represent this:

- Two inches of insulating board (polyurethane board) was added to the interior of the concrete block.
- An additional 1" of polyurethane board was modeled on the outside of the concrete block. Increasing the insulating layers to 2".

The figure below shows the new wall construction with the board insulation added. The Proposed wall assembly U value is 0.035 Btu/hr/ft^2/°F (R-value of 27.9 ft^2·h·°F/Btu).



Material	Thickness in	Conductivity Btu·in/h·ft^2·°F	Density lb/ft^3	Specific Heat Capacity Btu/lb·°F	Resistance ft^2·h·°F/Btu	Vapour Resistivity (perm·in)^-1	Category
[BRO] BRICKWORK (OUTER LEAF)	3.94	5.824	106.128	0.1911	0.676	0.085	Brick & Blockwork
Cavity	2.00	-	-	-	1.022	-	-
[PUB] POLYURETHANE BOARD	2.00	0.173	1.873	0.3344	11.538	0.802	Insulating Materials
[CBM] CONCRETE BLOCK (MEDIUM)	7.94	3.536	87.399	0.2388	2.245	0.175	Concretes
[PUB] POLYURETHANE BOARD	1.98	0.173	1.873	0.3344	11.423	0.802	Insulating Materials
Cavity	0.39	-	-	-	0.568	-	-
[GPB] GYPSUM PLASTERBOARD	0.51	1.109	59.307	0.2006	0.461	0.066	Plaster

Costs and Payback

Adding exterior wall insulation can be a challenging retrofit activity. If no adjacent work is scoped, then it is unlikely that insulation could be added. The analysis for the case presented here assumed that the exterior walls would need to be enhanced. The cost differential for this ECM assumed that adjacent work would occur to the exterior walls, therefore, we have included only the added cost of additional wall insulation, which based on RSMeans data is $1.60-2.40 per square foot of wall area. The energy benefits of this added insulation provide an approximate annual savings yielding a simple payback for this measure of approximately 18 years, which is less than the installed energy conservation measure life. Additional benefits from reduced air leakage are included in ECM 3. Consumers Energy offers incentives to increase the wall insulation on retrofit projects, the incentive value reduces the payback period into a shorter time frame.

ECM 3: Infiltration

The unintentional introduction of outside air into a building is known as infiltration. There can be an increase in infiltration especially in existing buildings as a result of building spaces being over or under pressurized, ductwork sealing deteriorating or the existing envelope decaying due to exposure to natural elements over time. Sealing air leaks in any building can make it more comfortable and efficient. For existing buildings, infiltration can often be the biggest envelope energy driver. The following table presents a summary of the incremental energy reduction and cumulative payback when this measure is implemented in addition with ECM 1 & 2.

ASSUMPTIONS AND SAVINGS	
Model	Baseline + ECM 1-3
Baseline Input	Leaky existing building (0.2 ACH)
Proposed Measure	Modeled the effect of implementing an air-sealing improvement procedure for all exterior walls by reducing infiltration gain for perimeter spaces by 30%
Component Modification	Modified infiltration gain in building
Incremental Annual Energy Reduction	7.0 kBtu/ft^2/yr (7.5%)
Cumulative Savings	17%
EUI	65.0 kBtu/ft^2/yr
Incremental ECM Cost	\$0.50 - \$1.0/ft^2 of exterior wall surface area
Cumulative Payback without Incentives*	12 years

**Measure qualifies for ZNE Companion & C&I Program Rebates which could provide additional payback benefit.*

To improve infiltration in an existing school building, it is recommended that a comprehensive air-sealing improvement procedure is conducted that uses spray foam to seal off any of the air leaks in the envelope. It is recommended that this type of air-sealing process is conducted in conjunction with roof and wall upgrades (ECM 1 & ECM 2) as both these strategies ensure that there will be a continuous air and thermal barrier in the construction.

In order to model the energy impact of infiltration, a standardized modeling approach for estimating air change rates for each building zone was followed. The 2017 ASHRAE Fundamentals handbook was used to establish an air change rate that was representative of standard building envelope tightness measured through field pressurization tests.

Baseline Infiltration

The Baseline infiltration rate was inputted based on the typical commercial building air leakage value per unit wall area of 0.30 cfm/ft^2 for an average 'leaky' wall (ASHRAE Fundamentals, 2017).

Proposed Infiltration

Performing an air-sealing improvement procedure as recommended above would reduce the leakiness of the building's envelope. To accurately represent this result in the energy model, the ECM 3 modeling iteration reduced the Baseline's infiltration rate to 0.20 cfm/ft^2.

Costs and Payback

Building on the work of ECM 1 and ECM 2; ECM 3 offers increased energy savings through air-sealing improvements. The cost differential for this ECM builds on the added insulation in the exterior walls with an incremental cost of $0.50-$1.00/ft^2 of exterior wall surface area. The energy benefits of the added air sealing yield an approximate annual savings that have a very short payback period of less than 3 years. When considered together, the simple payback of ECM 1, ECM 2, and ECM 3 is approximately 12 years without incentives.

ECM 4: Interior & Exterior Lighting

Energy efficient indoor and outdoor lighting design focuses on ways to improve both the quality and efficiency of lighting. Intelligent lighting design includes the consideration of both light quality and quantity, matching the amount and quality of light to the performed function and using task lighting to reduce the amount of ambient light elsewhere. The main advantages of improved lighting design are energy savings, reduced light pollution and improved working conditions and productivity for building occupants.

The following table presents a summary of the incremental energy reduction and cumulative payback when a lighting upgrade is undergone in addition to the implementation of ECM 1 – 3.

ASSUMPTIONS AND SAVINGS	
Model	Baseline + ECM 1-4
Baseline Input	ASHRAE 90.1 – 2004 code minimum space-by-space W/sf values with no occupancy or daylighting controls
Proposed Measure	Reduced interior lighting power densities in all school spaces to exceed code minimum requirements and applied occupancy controls in applicable spaces
Component Modification	Reduced interior and exterior lighting power densities
Annual Incremental Energy Reduction	3.5 kBtu/ft^2/yr (4.5%)
Cumulative Savings	21.6%
EUI	61.5 kBtu/ft^2/yr
Incremental ECM Cost	\$2.0 - \$2.5/ft^2 of building floor area
Cumulative Payback without Incentives	11 years*

**Measure qualifies for ZNE Companion & C&I Program Rebates which could provide additional payback benefit.*

For this measure, it was assumed that the school building would undergo a complete interior and exterior lighting fixture retrofit which includes upgrading all lamps to LEDs (or similar lamp in terms of energy efficiency) and installing occupancy controls where required by code.

Baseline Lighting Power Densities

The existing lighting design for the school was assumed to be equivalent to ASHRAE 90.1 2004 Building Energy Efficiency Standards performance. The interior and exterior lighting power densities that are required by the ASHRAE 90.1 2004 standard and are representative of the Baseline case are shown in the tables below. No occupancy controls have been assumed to be installed in the existing school building.

Table 3: Baseline Interior Lighting Power Densities

INTERIOR SPACE TYPES	LIGHTING POWER DENSITIES
AUDIENCE/SEATING AREA – AUDITORIUM	0.9 W/ft^2
CLASSROOM/LECTURE/TRAINING	1.4 W/ft^2
CORRIDOR/TRANSITION	0.5 W/ft^2
DINING AREA – CAFETERIA OR FAST FOOD	0.9 W/ft^2
ELECTRICAL/MECHANICAL	1.5 W/ft^2
FOOD PREPARATION	1.2 W/ft^2
GYM – EXERCISE AREA	0.9 W/ft^2
GYM – PLAYING AREA	1.4 W/ft^2
LIBRARY – READING AREA	1.2 W/ft^2
LOBBY	1.3 W/ft^2
OFFICE - ENCLOSED	1.1 W/ft^2
RESTROOMS	0.9 W/ft^2

Table 4: Baseline Exterior Lighting Power Densities

EXTERIOR SPACE CATEGORIES	END USE	LIGHTING POWER
UNCOVERED PARKING AREAS	Parking Areas and Drives	1,500 W
BUILDING GROUNDS	Walkways less than 10 ft wide	5,432 W
	Walkways 10 ft wide or greater	2,024 W
BUILDING ENTRANCES & EXITS	Main entries	21,420 W
	Other doors	10,560 W
CANOPIES & OVERHANGS	Canopies	3,515 W
OUTDOOR SALES	Illuminated wall or surface	975 W

Proposed Lighting Power Densities

For the interior and exterior lighting upgrades to the school, it is recommended that the replacement lighting fixtures use 20% less energy than the recommended hardwired power levels in the ASHRAE 90.1 2013 standard. Additionally, for the classroom spaces a level lighting power density of 0.3 W/ft^2 is recommended. The level of lighting performance chosen for Proposed design is based on extensive experience in the lighting analysis of classroom spaces in schools.

For the spaces in the school building where occupancy controls are required by the ASHRAE 90.1 2013 standard, the lighting power densities modeled were reduced by additional 10%. Occupancy controls were modeled in the following spaces: corridors, dining area, gymnasium and restrooms.

The following tables show the proposed lighting power densities for interior and exterior spaces and categories.

Table 5: Proposed Interior Lighting Power Densities

INTERIOR SPACE TYPES	PROPOSED LIGHTING POWER DENSITIES
AUDIENCE/SEATING AREA – AUDITORIUM	0.5 W/ft^2
CLASSROOM/LECTURE/TRAINING	0.3 W/ft^2
CORRIDOR/TRANSITION	0.46 W/ft^2
DINING AREA – CAFETERIA OR FAST FOOD	0.46 W/ft^2
ELECTRICAL/MECHANICAL	0.34 W/ft^2
FOOD PREPARATION	0.96 W/ft^2
GYM – EXERCISE AREA	0.5 W/ft^2
GYM – PLAYING AREA	0.84 W/ft^2
LIBRARY – READING AREA	0.76 W/ft^2
LOBBY	0.72 W/ft^2
OFFICE - ENCLOSED	0.76 W/ft^2
RESTROOMS	0.63 W/ft^2

Table 6: Proposed Exterior Lighting Power Densities

EXTERIOR SPACE CATEGORIES	END USE	LIGHTING POWER
UNCOVERED PARKING AREAS	Parking Areas and Drives	1,200 W
BUILDING GROUNDS	Walkways less than 10 ft wide	4,345 W
	Walkways 10 ft wide or greater	1,620 W
BUILDING ENTRANCES & EXITS	Main entries	17,136 W
	Other doors	8,448 W
CANOPIES & OVERHANGS	Canopies	2,812 W
OUTDOOR SALES	Illuminated wall or surface	975 W

Costs and Payback

The main drivers of costs to upgrade lighting are fixture density, building area, and controls and sensors. As expected, project costs decrease significantly as project size increases. Based on Department of Energy data, for the example project of a 200,000+ square foot building, the material and labor cost to retrofit lighting is expected to be $2.00-2.50 per square foot. The interior and exterior savings are significant and lighting retrofit has an expected simple payback of approximately 9 years. Consumers Energy offers many incentives for lighting retrofits, that can make the payback period much shorter. The cumulative payback for all ECMs including ECM 4 is around 11 years without incentives.

ECM 5: Daylighting Controls

Incorporating daylighting into an existing building's design is a way of enhancing daylighting performance of the interior spaces to minimize the use of artificial light, maximize daylight contributions, and provide overall quality daylighting. Advantages of daylighting include energy savings through reduced need for lighting, improved aesthetics and improved occupant productivity and comfort. Implementing daylighting strategies for existing buildings can be limited due to the costs involved in moving or upgrading the building envelope and program. However, for a building type such as a school the benefits of natural light for student alertness and productivity are so great that the opportunity to incorporate daylighting into the design at any level is strongly encouraged. The following table presents a summary of the incremental energy reduction and cumulative payback when daylight controls are installed in addition to the implementation of ECM 1 – 4.

ASSUMPTIONS AND SAVINGS	
Model	Baseline + ECM 1-5
Baseline Input	**none**
Proposed Measure	Reduced classroom interior lighting power density by 30%
Component Modification	Applied 30% daylight reduction to applicable areas
Annual Incremental Energy Reduction	0.1 kBtu/ft^2/yr (0.2%)
Cumulative Savings	21.8%
EUI	61.4 kBtu/ft^2/yr
Incremental ECM Cost	\$1/ ft^2 of daylighted space
Cumulative Payback without Incentives	11 years*

**Measure qualifies for ZNE Companion Program Incentives which could provide additional payback benefit.*

A daylighting analysis will evaluate existing conditions, testing for lighting levels and glare conditions. Based on these results, recommendations will be made to optimize daylighting, while mitigating glare and unwanted heat gain. These results (paired with daylight sensors) will then be used to reduce the lighting load and schedules in the energy model.

For this energy conservation measure it is assumed that daylighting controls are installed in the classroom spaces. Daylighting sensors read available light and send a signal to the control system to adjust lighting levels. Daylight responsive controls should be installed in classrooms within daylighting zones (20 feet from windows and under skylights). These controls typically include a photo sensor in the circuit with the luminaires and may employ bi-level switching, step-dimming ballasts or continuous dimming.

Baseline Lighting Controls

The existing school building was modeled with a lighting design equivalent to ASHRAE 90.1 2004 prescriptive lighting power densities (see Table 3: Baseline Interior Lighting Power Densities). No daylighting controls were modeled in the existing school.

Proposed Lighting Controls

For ECM 5, the lighting power density in the classroom spaces was reduced by an additional 30% to account for the installation of daylighting controls in the form of photosensors.

Table 7: Classroom Lighting Power Density Reduction

INTERIOR SPACE TYPES	BASELINE LIGHTING POWER DENSITY	ECM 4: LIGHTING POWER DENSITY	ECM 5: LIGHTING POWER DENSITY
CLASSROOM/LECTURE/TRAINING	1.4 W/ft^2	0.30 W/ft^2	0.21 W/ft^2

Costs and Benefits

Lighting controls offer reasonable payback when coupled with appropriate daylighting strategies for building spaces on the perimeter of the building. The cost of dimming controls is based on the system's ability to produce a cost-effective reduction in lighting energy. The installed cost of the lighting controls should be less than $1.00 per square foot of daylighted space, which results in a typical payback period of three to four years for this ECM. The cumulative payback for all ECMs including ECM 5 is modelled to be under 11 years without incentives.

ECM 6: Plug Load Efficiency

Plug load efficiency is an important component to be considered when analyzing a building's energy use as the energy use and power load for this end-use can vary greatly depending the activity and operation. Plug or receptacle load equipment is not currently regulated by the building energy codes, which means that the equipment's power draw and energy efficiency is not mandated. As a result, this end-use can be one of the major drivers in a building's annual energy use and strategies should be employed to reduce where possible. The following table presents a summary of the incremental energy reduction and cumulative payback when energy efficiency electrical appliances are used in the school in addition to the implementation of ECM 1 – 5.

ASSUMPTIONS AND SAVINGS	
Model	Baseline + ECM 1-6
Baseline Input	No ENERGY STAR® equipment
Proposed Measure	Reduced interior equipment power densities by 20% for applicable areas
Component Modification	Reduced receptacle power density values
Annual Incremental Energy Reduction	0.5 kBtu/ft^2/yr (0.7%)
Cumulative Savings	22.4%
EUI	60.9 kBtu/ft^2/yr
Incremental ECM Cost	$20,000 - $40,000 lump sum
Cumulative Payback without incentives	10 years*

* *Measure qualifies for ZNE Companion Program Incentives which could provide additional payback benefit.*

Examples of common plug equipment and other electronics that fall into this category:

- Computers, monitors and servers
- Copiers, printers, scanners, faxes and multifunction devices
- Power strips and surge suppressors
- Classroom whiteboards, projectors and other electronics
- Cold beverage vending machines
- Break room refrigerator, water coolers and large coffee machines
- Kitchen cooking and refrigeration equipment (i.e., commercial convection oven, fryers, ranges, steamers and hot walk-in coolers and freezers)

Many plug load appliances and products will have an ENERGY STAR rating, which means they meet the energy efficiency requirements set forth in ENERGY STAR product specifications. These certified products must deliver the features and performance demanded by consumers, in addition to increased energy efficiency.

Baseline Plug Load

For the existing school it was assumed that the plug load and receptacle levels were equal to the ASHRAE 90.1 2004 User Manual guidelines for that specific building type. These are specified in the table below.

Table 8: Baseline Interior Equipment Power Densities

INTERIOR SPACE TYPES	BASELINE INTERIOR EQUIPMENT POWER DENSITIES
AUDIENCE/SEATING AREA – AUDITORIUM	1.0 W/ft^2
CLASSROOM/LECTURE/TRAINING	1.0 W/ft^2
CORRIDOR/TRANSITION	0.2 W/ft^2
DINING AREA – CAFETERIA OR FAST FOOD	0.5 W/ft^2
ELECTRICAL/MECHANICAL	0.2 W/ft^2
FOOD PREPARATION	1.5 W/ft^2
GYM – EXERCISE AREA	0.5 W/ft^2
GYM – PLAYING AREA	0.5 W/ft^2
LIBRARY – READING AREA	1.5 W/ft^2
LOBBY	0.5 W/ft^2
OFFICE - ENCLOSED	1.0 W/ft^2
RESTROOMS	0.5 W/ft^2

Proposed Plug Load

For this energy conservation measure, it was assumed that plug load efficiency strategies were employed that reduced the equipment's power draw. Strategies such as replacing equipment and appliances with equivalent, ENERGY STAR certified products and having smart power strips that can turn off a group of appliances at the power outlet when not in use. These efficiency measures are assumed to reduce the equipment power density by 20% and are illustrated in the table below.

Table 9: Proposed Interior Equipment Power Densities

INTERIOR SPACE TYPES	PROPOSED INTERIOR EQUIPMENT POWER DENSITIES
AUDIENCE/SEATING AREA – AUDITORIUM	0.8 W/ft^2
CLASSROOM/LECTURE/TRAINING	0.8 W/ft^2
CORRIDOR/TRANSITION	0.16 W/ft^2
DINING AREA – CAFETERIA OR FAST FOOD	0.4 W/ft^2
ELECTRICAL/MECHANICAL	0.16 W/ft^2
FOOD PREPARATION	1.2 W/ft^2
GYM – EXERCISE AREA	0.4 W/ft^2
GYM – PLAYING AREA	0.4 W/ft^2
LIBRARY – READING AREA	1.2 W/ft^2
LOBBY	0.4 W/ft^2
OFFICE - ENCLOSED	0.8 W/ft^2
RESTROOMS	0.4 W/ft^2

Costs and Benefits

The use of ENERGY STAR appliances throughout the facility has energy benefits of 10-20 percent of the plug and process loads. The cost premium of this equipment can vary depending on the application. For example, commercial kitchen equipment in schools may add a small premium for certain appliances like dishwashers, but many other products are cost neutral—even when all-electric appliances are selected. According to ENERGY STAR, the simple payback periods for most equipment is within 3 years, which makes ENERGY STAR appliances a common ECM in retrofit situations. The cumulative payback for all ECMs including ECM 6 is modelled to be approximately 10 years without any applied incentives.

ECM 7: Service Hot Water

Schools usually have a high hot water demand with spaces such as gymnasium locker rooms and cafeterias necessitating general purpose and sanitizing hot water systems. Typical service hot water systems for commercial and residential buildings include an electric or natural gas water heater with an expansion tank that incurs standby losses and less than 1.0 thermal efficiency. Heat pump water heaters (HPWH) are an emerging technology that extracts heat from air to heat the water. Their efficiency is 3-4x as efficient as their natural gas or standard electric counterparts. The following table presents a summary of the incremental energy reduction and cumulative payback when the service hot water system in the existing school is replaced with a heat pump hot water system. This measure is recommended in addition to the implementation of ECM 1 – 6.

ASSUMPTIONS AND SAVINGS	
Model	Baseline + ECM 1-7
Baseline Input	Natural gas-fired water heater
Proposed Measure	Upgraded the natural gas fired water heater to an all-electric air sourced heat pump water heater system
Component Modification	Change of domestic hot water system
Annual Incremental Energy Reduction	0.5 kBtu/ft^2/yr (0.7%)
Cumulative Savings	25%
EUI	59 kBtu/ft^2/yr
Incremental ECM Cost	$30,000 - $50,000 equipment cost
Cumulative Payback without incentives	10 years*

**Measure qualifies for ZNE Companion & C&I Program Rebates which could provide additional payback benefit.*

HPWHs use the same basic technology as air source heat pumps, using electricity to transfer heat from the surrounding air to heat water in the tank.

Unitary systems are the most common type of HPHW heater with a variety of UL listed models available. HPWHs require air from which to draw heat which can be provided one of two ways:

1. 100 ft^2 of closet space from which to draw heat, otherwise the room will get too cold and the system will not operate.
2. A very small room can be outfitted with a simple louvered door to allow airflow as one would see when stacked washer-dryers are installed in a closet.

Baseline Hot Water System

The hot water system assumed for the school building is equivalent to the service hot water system type and efficiency specified in ASHRAE 90.1 2004 standard. The Baseline system is a natural gas storage water heating system with input size category of greater than 75,000 Btu/hr with 75% thermal efficiency.

Proposed Hot Water System

This energy efficiency measure (ECM 7) replaces the existing hot water system at the school with a heat pump hot water heater (HPWH) system that has an efficiency COP of 3.5.

Costs and Benefits

Heat pump hot water heaters often are 3-4 times more efficient than natural gas fired water heaters, however, the relative energy costs between natural gas and electricity can extend simple payback past the useful life of the equipment. We have included this ECM to illustrate an all-electric design solution for distributed hot water heating. The relatively small cost of hot water heating in a school, however, make the cumulative payback for all ECMs is modeled to be slightly above 10 years without any applied incentives.

ECM 8a: Retro-Commissioning

A systematic process that optimizes equipment energy performance as well as reduces maintenance and operation costs for existing buildings is known as retro-commissioning (RCx). Most buildings have equipment installed that is not working correctly when the building is turned over to the owner at the beginning of occupancy. Unfortunately, construction is driven by schedule and costs so correct equipment installation and control set up is not often checked unless a formal commissioning process has been followed. Additionally, it is very common for the control sequences for equipment to be adjusted as part of operation and maintenance procedures over time.

The combination of all these actions means that there are always opportunities to improve the performance of existing HVAC systems. The following table presents a summary of the incremental energy reduction and cumulative payback when the energy performance of the existing HVAC system is improved by implementing this retro-commissioning measure. The resulting energy and costs are reflective of the implementation of ECM 8a in addition to the preceding measures, ECM 1 – 7.

ASSUMPTIONS AND SAVINGS	
Model	Baseline + ECM 1-7 + ECM 8a
Baseline Input	Water cooled chilled water system COP: 3.0 The hot water boiler thermal efficiency: 70%
Proposed Measure	Increased the efficiency of the central plant equipment: Water cooled chilled water system COP: 4.0 The hot water boiler thermal efficiency: 85%
Component Modification	Chiller and boiler efficiency metric
Annual Incremental Energy Reduction	3.6 kBtu/ft²/yr (4.5%)
Cumulative Savings	31.0%
EUI	55.0 kBtu/ft²/yr
Incremental ECM Cost	\$0.50 - \$0.80/ft² of building floor area
Cumulative Payback without incentives	10 years*

**Measure qualifies for Retro-Commissioning Program Rebate which could provide additional payback benefit.*

By conducting an RCx investigation and analysis of the current HVAC systems in a building, the interaction between the equipment and their controls can be assessed and improved.

Examples of some corrective actions that can result from a retro-commissioning process that improve the efficiency of the chilled water and hot water systems in a building are as follows:

- Chilled water set point temperature reset adjustment
- Upgrade chiller plant control system
- Optimization of cooling tower
- Adjustment of chiller sequencing
- Adjust combustion efficiency of boiler

For the case of this measure, it was assumed that as a result of the retro-commissioning actions listed, the combined efficiency of Baseline chilled water and hot water systems were improved by 20% overall. To replicate the effect of performing a retro-commissioning procedure for the existing school building in the energy model, the Baseline chiller and hot water boiler efficiency of performances were improved to a COP of 4.0 and thermal efficiency of 90% respectively.

Baseline HVAC Efficiency

For the existing school, it is assumed that the central plant has experienced efficiency degradation over its lifetime due to lack of or poor maintenance procedures.

As a representation of this, the Baseline HVAC system consists of a water-cooled chiller with COP of 3.0 and a hot water boiler has a thermal efficiency of 70%.

Proposed HVAC Efficiency

For ECM 8a, the chiller's coefficient of performance was increased to 4.0 (25% increase in efficiency) and the hot water boiler's thermal efficiency was increased to 90%.

Costs and Benefits

Based on industry date, retro-commissioning in buildings is estimated to cost between $0.50 and $0.80 per square foot. As a result, this ECM adds high value to the overall efficiency package and is recommended for projects that have useful life remaining on existing equipment—especially equipment used for heating, cooling and ventilation. The estimated payback of this measure is approximately 10 years bringing the cumulative total of ECMs 1-8a to under 10 years.

ECM 8b: Ground Source Heat Pump System

Commonly called “geothermal,” ground source heat pumps utilize the consistent temperature of the earth to provide a source for heating and cooling of a building. Because the earth’s temperature remains relatively constant across the seasons, ground source heat pumps are effective and reliable ways to transfer heat in cold climates.

However, the installation of a ground source heat pump system is expensive. Holes are bored into the ground up to 300 feet deep and piping is inserted into the holes, which pumps a water-glycol solution to-and-from the heat pump unit. The large land requirements and excavation costs can make ground-source heat pumps unrealistic at scale. The following table presents a summary of the incremental energy reduction and cumulative payback when this measure is implemented in addition with ECM 1 – 7.

ASSUMPTIONS AND SAVINGS	
Model	Baseline + ECM 1-7 + ECM 8b
Baseline Input	Chilled water system, natural gas-fired boiler, VAV fan control
Proposed Measure	Upgraded existing HVAC system to a GSHP system with heat recovery
Component Modification	Changing HVAC system
Annual Incremental Energy Reduction	29.7 kBtu/ft^2/yr (37.9%)
Cumulative Savings	66.4%
EUI	26.3 kBtu/ft^2/yr
Incremental ECM Cost	$4,500 - $8,000/tonnage of cooling (~420 tons total capacity for the school)
Cumulative Payback without incentives	20+ years*

**Measure qualifies for ZNE Companion & C&I Program Rebates which could provide additional payback benefit.*

Baseline HVAC System

The HVAC system in the existing school was modeled as chilled water system with hot water reheat supplied by a natural gas fired boiler.

Proposed GSHP System

Michigan’s cold climate can be an issue for some commercial-scale air-cooled heat pump systems. By utilizing a heat pump system on the site, the school can provide high efficiency heating and cooling without concerns that low outdoor air temperatures will diminish the effectiveness of the heating system. The recommended design makes it possible for the school to maintain their existing air handling unit and ducting design, saving substantial capital.

The following part load efficiency curve was modeled for the GSHP system in the IES-VE modeling software.

Figure 5: Part Load Efficiency Curve for the Ground Source Heat Pump System

Load (kBtu/h)	Efficiency (%)
724	430
1,448	410
2,172	390
2,896	370
3,620	350

Costs and Benefits

Ground source heat pumps offer significant energy savings in humid climate of Michigan; however, this comes at significant first cost. This makes the inclusion of ground source heat pumps a challenge for many projects.

Without incentives, transitioning to a ground source heat pump for space conditioning would have a payback that exceeds the life of the equipment. This affects overall ECM cost-effectiveness as well, pushing the simple payback to 20 plus years for all measures 1-7 and ECM 8b.

ECM 9: Natural Ventilation

ASSUMPTIONS AND SAVINGS	
Model	Baseline + ECM 1-7 + ECM 8b + ECM 9
Baseline Input	No operable windows
Proposed Measure	Incorporated mixed-mode ventilation for heating and cooling seasons
Component Modification	Thermal comfort analysis of hourly weather data to inform reduction to HVAC system annual operation
Annual Incremental Energy Reduction	2.1 kBtu/ft^2/yr (2.6%)
Cumulative Savings	69.1%
EUI	24,3 kBtu/ft^2/yr
Incremental ECM Cost	$23.50 - $30/ft of window surface area (from fixed to operable windows)
Cumulative Payback without incentives	20+ years

Reintegrating natural ventilation into the built environment is one sustainable practice that has increased in popularity within the past decade. Fresh air, like fresh water, is a fundamental human need. People are healthier, work more effectively and are more engaged when their places of work or habitation are naturally ventilated.

To promote good thermal comfort and access to nature for students and teachers, operable windows in a school are encouraged as the number one source of ventilation. Schools are almost always driven by their internal load. A large group of students in conjunction with lighting and computer loads expel an enormous amount of heat to the space. Furthermore, classrooms typically only have windows on one façade so the amount of openable area to incorporate 'cross' or 'stack' type natural ventilation is even of greater importance. Hence, with the right number of openings, and therefore incorporating natural ventilation, the classroom has comfortable conditions for the students and teachers. For classrooms on the second floor, the room temperature does reach higher temperatures (this is expected due to stratification). If the openable area is increased, however, the temperatures drop to a more comfortable level.

Unfortunately, for a lot of existing schools the size of opening or quantity can be limited or even nonexistent.

Baseline Natural Ventilation

For the existing school building, it was assumed that the operable windows were not adequate in opening size and quantity to provide the natural ventilation needed for acceptable thermal comfort for the occupants.

Proposed Natural Ventilation

For this energy conservation measure it was assumed that the existing windows would be replaced with windows that can be manually or automatically operated. A bin analysis of Grand Rapids weather data was performed to calculate the number of hours that the ambient dry bulb temperature lies between acceptable thermal comfort ranges for natural ventilation.

The acceptable outdoor temperature range for natural ventilation was determined to be between 65°F and 75°F. In the Proposed energy model, the HVAC system was adjusted to run in 'standby mode' when outdoor temperatures were within this range. The HVAC system would only turn on during this time if the space it was serving was at peak heating or cooling load.

It should be acknowledged that thermal comfort is not based solely on air temperature and an individual's perception of temperature is based on a combination of factors. However, for this specific study, only temperature was analyzed and therefore the associated energy savings should be considered conservative.

Costs and Benefits

The capital cost for natural ventilation include the incremental difference between operable and fixed windows as well as the HVAC integration to achieve the energy savings. The simple payback period for integrated natural ventilation is less than the installed life of the façade and can be considered by projects wanting to improve the occupant experience and comfort of the space. The cumulative payback for ECMs 1 – 7, 8b and 9 exceeds 25 years.

Additional Measures

Through an integrated, holistic building design process the building owner and design team should consider all available passive and active strategies in order to achieve the optimal energy performance for their project. The following measures are recommended as additional options to further reducing building's energy use. Although they were not considered part of the detailed energy analysis for this design guideline, strategies to improving the thermal performance of these components have been provided below.

Insulating the Foundation

Thermal heat transfer through the foundation can be regulated by providing insulation between the interior and exterior environment. However, in some existing buildings insulation below the foundation may not exist. Insulating existing foundations can be an expensive and time-consuming process that involves locating existing utilities, excavating around the foundation perimeter, adding perimeter drainage, installing waterproofing membranes, installing rigid insulation along the perimeter walls and footings.

For this reason, this guideline does not recommend insulating existing foundations as an energy efficiency measure to target zero net energy. Instead, the recommendation is to evaluate improving the thermal resistance of the walls and roof of the existing building.

High Performance Glazing

Windows often represent the largest sources of heat loss, condensation and discomfort in buildings. Several studies have shown that health, comfort and productivity are improved in building with increased ventilation and access to natural light. Heat gain and loss through windows and doors of existing buildings can have significant cost impacts on the energy used for space heating and cooling. When evaluating an existing building for energy efficiency measures, high performance windows and doors are often an expensive alternative. It is for this reason that a specific ECM for improving glazing performance is not recommended for this study. However, regardless of cost, several key factors on glazing design are provided below to assist the team in the decision-making process:

- **U-factor:** Glazing systems are measured for thermal performance using a factor to represent the measure of a thermal conductance of a building assembly. The U-factor is the inverse of thermal resistance (R-value) of an assembly. $U = 1/R$. The lower the value, the better performing the product.
- **Solar Heat Gain Coefficient (SHGC):** The fraction of solar radiation allowed through a window, door, or skylight, that is released into a building. The lower the SHGC value, the less heat transmitted and the greater the shading ability.
- **Visible Light Transmittance (VLT):** A measure of the amount of light in the visible portion of the spectrum that passes through a glazing material. Expressed as a percentage from 0 to 1, the higher the VLT value the more daylight passes through the glazing component.

Replacing the glazing components of existing buildings can be a costly exercise but given their potential to increase energy efficiency, this measure should be considered when evaluating options to improve building performance. Although omitted from this specific analysis for the school, if a glazing upgrade is being considered it is recommended the window replacement occurs when wall systems are exposed and access to the structural components is available,

Shading

The use of shading devices can significantly reduce the amount of solar heat gain through openings in the building envelope. By intercepting sunlight before it reaches the walls and windows, shading devices can reduce the amount of cooling required by mechanical systems and improve the light quality of the indoor environment. Carefully designed sun control devices can allow solar radiation during the winter season when sunlight is desired to passively heat a building. Exterior shading is also used to control glare in interior spaces which can result in increased visual comfort and productivity. Additionally, shading devices can be used as design features to increase the visual appeal of building facades and provide additional mounting locations for solar photovoltaic panels.

Although not considered a specific ECM for this study, exterior and interior shading design is recommended as an effective strategy to improve the thermal performance of the building's envelope and therefore reducing a building's energy use overall. Additionally, it can improve the visual comfort for the occupants by blocking direct light and reducing glare conditions on work surfaces. It is recommended that design teams perform a solar shading analysis using daylight (or equivalent façade) modeling software so that the sun's position at various times of the day for each orientation can be assessed and the optimal solution for shading each façade is achieved.

Conclusion

This design guideline provides a detailed roadmap to renovating an existing school into a zero net energy ready building in the Michigan climate. A suite of energy conservation measures is recommended that if implemented as a packaged design solution can significantly reduce the energy footprint of the school building. The design guideline presents two different approaches for the building owner and the design team. The first approach is a duel fuel, high performance design solution for projects where complete natural gas mitigation is not feasible. The second approach is for projects seeking to achieve an all-electric solution.

Recommendations

The results demonstrate that if Pathway 1 is followed, the projected annual energy use intensity is 55 kBtu/ft^2 which results in total annual energy savings of 31% when compared to the existing school's energy use. Additionally, if this package of measures were to be implemented in the project, the cumulative payback would be approximately 10 years. To eliminate natural gas use entirely, Pathway 2 is recommended (ECM 1 through 7, ECM 8b and ECM 9, which results in an annual energy use intensity of 24.3 kBtu/ft^2 (savings of 69%)) for the school. Taking this second approach should be considered a long-term commitment to energy and carbon reduction for the project.

All recommendations listed in this design guideline encourage a healthy and relatively comfortable place for school occupants. The incorporation of these design elements into the project's design and construction will help in assuring that the building will not only be enjoyed by the teachers and students but by the whole school community.

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