Brixham Montessori Friends School:

A Healthy, Energy Efficient and Cost Effective Learning Environment

BRIXHAM MONTESSORI FRIENDS SCHOOL

Ty Newell, PhD, PE (ty@buildequinox.com)

Build Equinox (buildequinox.com)

773-492-1893

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BUILD EQUINOX

Executive Summary

Brixham Montessori Friends School (BMFS) has achieved a hat trick with simultaneous improvement of indoor air quality, reduced annual utility costs, and increased environmentally friendly operation. The following summarizes BMFS decarbonizing conversion from propane furnace operation to high performance heat pumps and smart ventilation.

1) BMFS installed five CERV2 smart ventilation units that automatically maintain CO_2 and total VOC levels at 800ppm or less. Enhanced ventilation and air recirculation filtration are estimated to reduce absenteeism and staff sick days by 40% relative to standard building ventilation, or approximately 1 fewer sick days per person per year, or 90 fewer less sick days for the school's students and staff members. Assuming a cost of $500 per sick day, the value of improved indoor air quality is $45,000 per year spread across BMFS student and staff families.
2) Five heat pumps with nominal 10.5 tons of capacity (heating capacity 126,000Btu/h) replacing five propane fueled furnaces have:
    a. Reduced annual energy costs by $3000/year
    b. Reduced annual energy usage and site EUI (Energy Use Intensity) by 40%
    c. Reduced building carbon dioxide emissions by 13 to 15 tonnes per year

BMFS demonstrates the economic feasibility of creating healthy indoor environment coupled with conversion to environmentally sustainable building operation.

Brixham Montessori Friends School (BMFS) Introduction

Brixham Montessori Friends School (BMFS) is nestled in a quiet, wooded area in southern Maine. BMFS leadership undertook an aggressive conversion plan to simultaneously improve indoor air quality and convert their building from fossil fuel (propane) winter heat to high efficiency, electric driven heat pumps.

The BMFS project demonstrates a sensible approach to improving their indoor environment and converting building energy to non-carbon based operation. This report analyzes indoor air quality, energy usage, and utility cost of the BMFS project. Our goal is to provide BMFS Staff and Board with an assessment of the project, and to describe a road map for others to follow.

BMFS worked with Jeff St Pierre of Energy Efficient Homes (EEH) to install CERV 2 smart ventilation units coupled with conversion of the school building's propane furnaces to high efficiency heat pump comfort conditioning systems.

Improving air quality provides enhanced protection from current and future contagions. The school's leadership decided to simultaneously convert winter heating from propane furnaces to high efficiency heat pumps. The value of improved air quality is realized through reduced absenteeism and staff illness, and improved student and staff productivity. Conversion of propane furnaces to electric heat pumps can lower utility bills.

Figure 1 Heat pump outdoor units (ODUs) located on each end of the BMFS building.

Project Description

BMFS is located in a two story, 8100sqft building near York in southern Maine. York's winter "design-day" temperatures are similar to Portsmouth NH at 7.7F (99% DD) and 2.6F (99.6% DD), or approximately 5F colder than Boston and 5F warmer than Chicago. The cover sheet photo shows a front view of BMFS main entrance from the parking lot. Figure 2 photos show heat pump outdoor units that replaced propane fueled furnaces.

The school has a staff of 18 with a student enrollment of 78. Children range from 18 months to 11 years old, with the majority of students in 3 to 6 year old classes. Human respiration scales with age (size), as well as with gender and activity. Children in the 3 to 6 year old range weigh approximately 20% of adult weight. An adult's fresh air ventilation need during typical daytime activity levels is 40cfm/person (cubic feet per minute). Children in the 3 to 6 year old range require 8cfm/person assuming 20% of adult respiration. At this level of ventilation, carbon dioxide can be maintained at 800ppm (parts per million). A total fresh air flow capability of 1340cfm would maintain good air quality with full staff and classroom attendance.

Five CERV2 smart ventilation units were installed in the BMFS building to automatically manage fresh air ventilation and indoor air quality. The CERV2 units continuously monitor carbon dioxide (CO_2) and total VOC (Volatile Organic Compound) concentrations. When indoor CO_2 or VOC concentrations exceed 800ppm setpoints, fresh air is supplied to the building. Five CERV2 units can provide fresh air flow up to 1500cfm. The building has "normal" infiltration of 0.14ACH (air changes per hour) based on CERV2 carbon dioxide data trends, or 150cfm of infiltration air under normal (~5mph wind speed) for a total of 1650cfm of fresh air ventilation capability.

Figure 2 Five CERV2 units were integrated into existing ductwork for distribution of fresh air throughout the building. The left photo shows a heat pump air handler with CERV2 located in a mechanical closet on the first floor. Three CERV2 units were paired with ductwork from three inactive propane furnace units in the attic.

The building’s comfort conditioning system consisted of 5 propane furnaces with duct distribution into classrooms, activity rooms (eg, art room) and office areas. The furnaces were replaced by three 2.5 ton, one 2 ton, and one 1 ton cold temperature heat pumps, for a nominal heating capacity of 126,000Btu/h (note; by convention, heat pump sizing is based on air conditioning capacity; heating capacity generally exceeds AC capacity).

The downstairs furnaces were replaced with central AHU (Air Handling Unit) heat pumps with CERV2 connected to the return of the heat pump AHU (see Figure 2). Three CERV2 units located in the unfinished attic area are connected to return ducts of three propane furnaces. The three attic furnace circulation fans operate continuously in order to help circulate CERV2 fresh air throughout the school. Figure 2 shows a view in two CERV2 units in the attic.

BMFS Indoor Air Quality

Figure 3 is a series of 5 plots showing return air carbon dioxide (CO_2) and total VOC (Volatile Organic Compound) concentrations to the five CERV2 units over a three week period in April 2023. All five CERV2 units are set to ventilate when CO_2 exceeds 800ppm (ppm=parts per million; 1 ppm = 1 molecule of CO_2 per million air molecules). All five CERV2 units include a VOC (Volatile Organic Compound) sensor that triggers fresh air ventilation when a "correlated" 800ppm VOC setpoint level is exceeded. Correlated VOC concentration readings are VOC concentrations that correspond to a human's CO_2 respiration output. That is, if the only source of organic chemical vapors is from human metabolism, both CO_2 and VOC scales are the same. CERV2 units operate in recirculation and air filtration mode (MERV13 filters) whenever fresh air is not required.

Human CO_2 output correlates to human size (weight), gender, age, and activity level. "Mets" or Metabolic units are used to describe human physical activity. Average-size adults at office level activity are 1.2 to 1.4 Mets, a sleeping adult is 0.7 Mets while vigorous exercise and physical activity can reach 7 Mets. Human CO_2 output described by these variables does not widely vary, with an adult male at sedentary (office work) activity of 1.2 to 1.4 Met releasing 0.03kg-CO_2/hour-person.

VOCs, unlike CO_2, display a wider variation among people of the same age, size, gender and activity level. Some VOCs are from respiration while others are released from skin. Ozone, from indoor and outdoor sources, increases human VOCs by converting skin oils into vaporous chemicals. Diet impacts human-related VOC releases as does hygiene, personal care products, and natural variations among people.

All return air CO_2 and VOC concentrations in Figure 3 plots from school building offices and classrooms are consistently maintained at excellent IAQ levels. Fresh air ventilation (denoted by green vertical bar regions in Figure 3 plots) is triggered whenever CO_2 or VOCs exceed 800ppm. Both CO_2 and VOCs regularly trigger fresh air ventilation, which indicates a good balance between human generated CO_2 and human-sourced VOCs.

CO_2 will exceed VOCs in buildings with indoor combustion sources such as gas cooking and unvented fuel combustion heaters. VOCs dominate fresh air ventilation needs when non-human chemical pollution sources are significant. Return air quality from all areas of BMFS show a good balance of CO_2 and VOCs, indicating IAQ is primarily from human sources.

The three week monitoring data in Figure 3 includes a weekend (Saturday and Sunday, April 8 and 9) and spring vacation (Saturday, April 15 through Sunday, April 23). CO_2 concentrations are very low during the weekend and holiday periods, with some CO_2 variations from periodic occupant activities (eg, teacher, staff and maintenance visits).

VOC concentration levels continue to show elevated concentrations during low occupancy weekend and vacation week periods. VOCs, unlike CO_2, readily absorbs into and adsorbs onto surfaces throughout a building. These condensed VOCs, often called SVOCs (semi-VOCs) are re-released when temperatures increase. Thermostat setback, diurnal outdoor temperature variations, and daytime solar heating in windowed rooms are some heat sources that elevate a room's temperature during daytime hours, causing re-release of VOCs. These VOCs can again be re-absorbed and adsorbed, and then re-released each day. Nightime reduction of VOCs to very low levels (400ppm on the CO_2 correlated scale) during low occupancy periods indicates there are no other significant sources of chemical pollutants in addition to human VOC production. That is, BMFS is a very healthy building!

ASHRAE, the engineering society that formulates building ventilation standards, recently released a draft ventilation standard "ASHRAE 241P", that calls for doubling today's minimal, odor-based ventilation standard during times when an airborne disease is detected. The new standard's objective is defining air quality that reduces airborne disease transmission. ASHRAE 241P ventilation level for schools results in CO_2 concentrations of 800ppm or less. As expressed by Professor Joseph Allen, Harvard TH Chan School of Public Health, this new ventilation standard should become the regular ventilation standard. Figure 3 demonstrates that BMFS air quality already meets ASHRAE's new 241P healthy air standard.

ASHRAE 241P ventilation is expected to reduce sick days and absenteeism by 40% relative to today's (minimum) ventilation standard (ASHRAE 62.1). A recent study of school absenteeism confirms the relation between fresh air ventilation, airborne particulate concentration and absenteeism in schools. A reduction of sick days by 40% is 1 less sick day per year (average sick days per year in US assumed to be 2.5 days/person). With BMFS student and staff population of approximately 90 people, 90 less sick days per year are expected with an estimated value of $45,000, assuming $500/sick day per person (includes loss wages, medical treatment, medicines, loss productivity and substitute worker wages). Note that while children do not lose wages, their caretakers will generally lose workdays for childcare.

Maintaining excellent air quality also results in improved student and teacher productivity and cognition performance. Placing a value on improved cognition and productivity is difficult. Creating indoor environments that enhance student comprehension and performance benefits society as students transform into productive adults.

Figure 3; Unit #1 (downstairs)

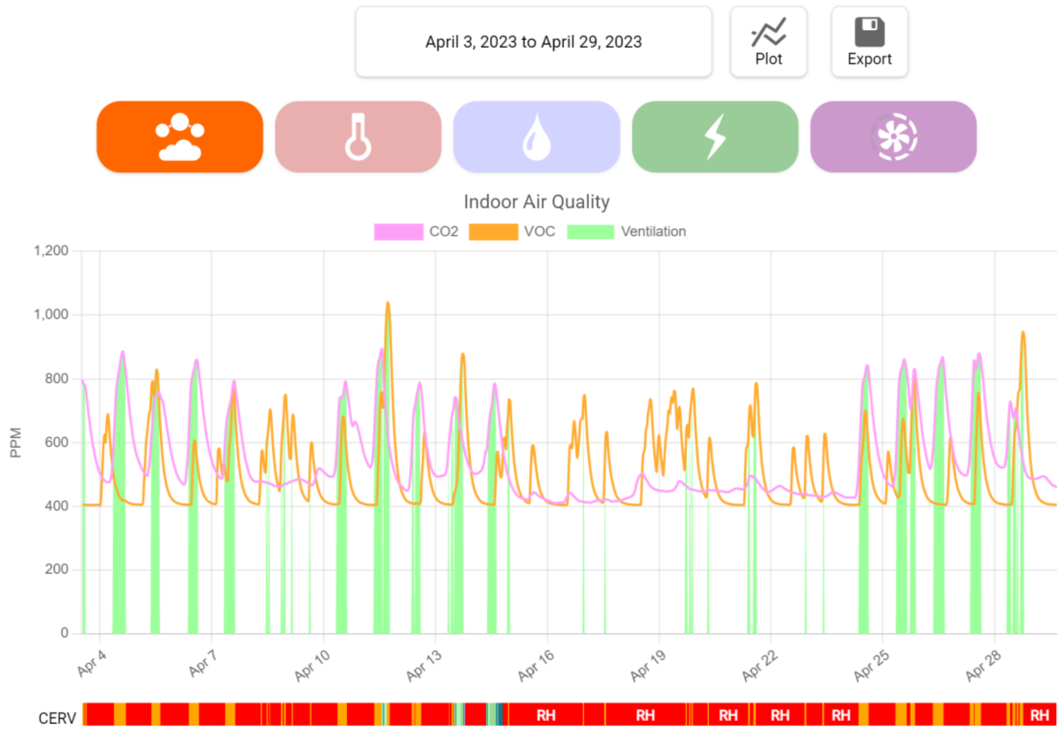

Figure 3; Unit #2 (downstairs)

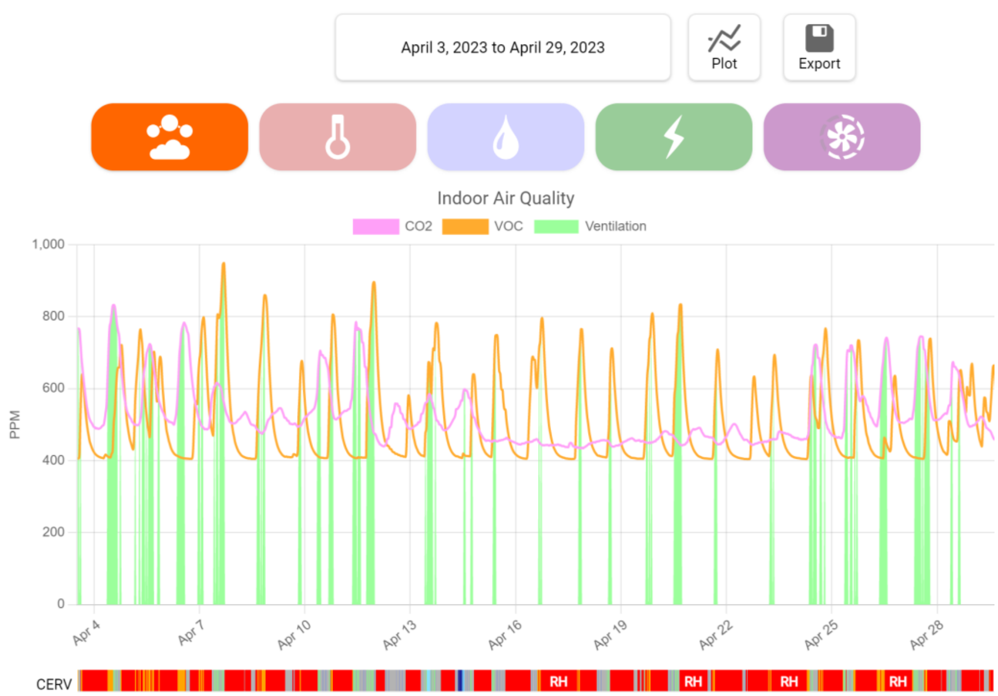

Figure 3; Unit #3 (attic)

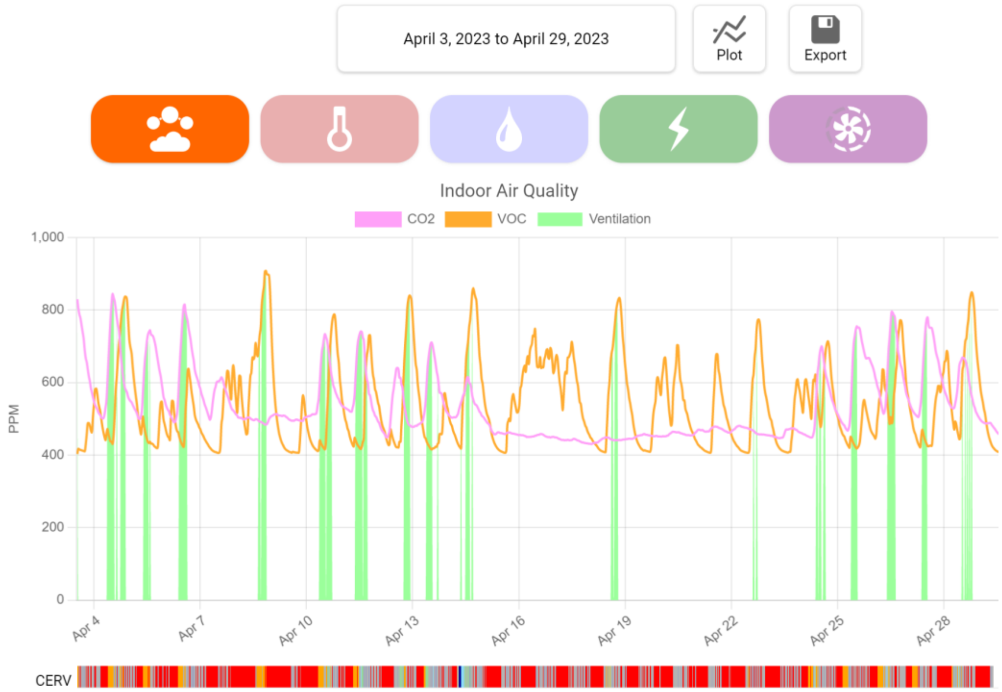

Figure 3; Unit #4 (attic)

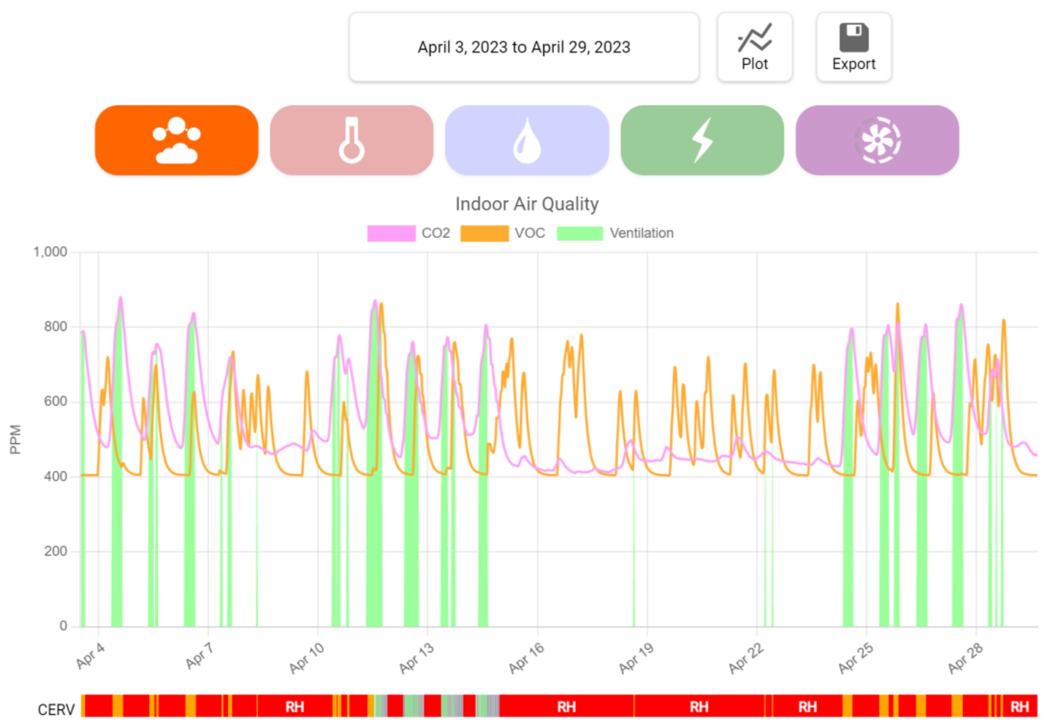

Figure 3; Unit #5 (attic)

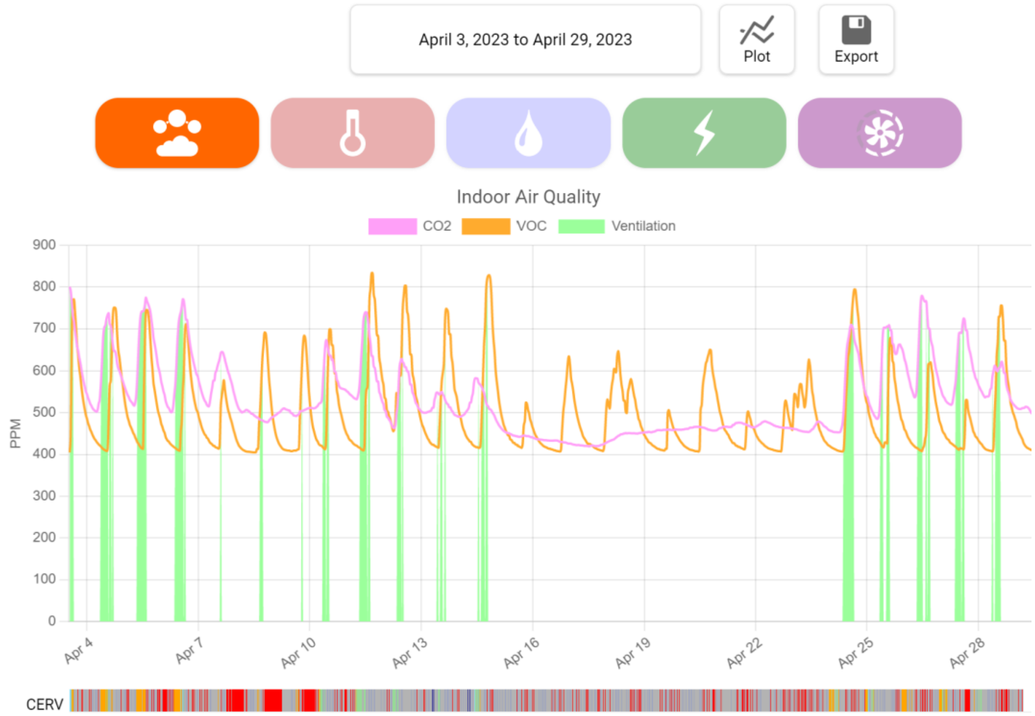

Figure 3 Three week plots of CO_2 and total VOC data from Brixham Montessori Friends School's 5 CERV2 smart ventilation units. Green regions denote active fresh air ventilation triggered by either CO_2 or VOC levels exceeding the CERV2 800ppm setpoint.

Building Energy Use Characteristics Before and After Conversion from Propane Furnaces to Heat Pumps

Conversion of BMFS building from propane furnaces to heat pumps for comfort conditioning has reduced the building's energy usage, decreased the building's EUI (Energy Use Intensity) factor, and eliminated carbon dioxide produced from propane furnace operation.

Utility data from 2019 to April 2023 is used to characterize the building's energy usage. Propane furnace usage occurred until 2022. Electric heat pumps were installed in 2022 to replace propane furnace usage. Winter 2023 (January – March) utility data is based on all-electric comfort conditioning. Figures 4 and 5 plot electric display utility energy usage and power demand data, respectively, for 2019 to 2023. Tables 1 and 2 include data used for plotting Figures 4 and 5.

The pandemic impacted school operation and energy use characteristics beginning in the spring of 2020, continuing into 2021. Base energy usage (non-comfort conditioning energy) for 2020 is 25% lower than other years indicating reduced occupancy and occupant activity. Utility data for 2019, 2021 and 2022 are used for building energy usage analysis. Propane heating and electric utility data from 2020 is excluded from the analyses but included in data tables and plots.

Figure 4 shows daily average electric energy usage for each month using BMFS 2019 to 2023 utility data. The data is plotted versus the monthly average temperature. At temperatures above 55F, the relatively flat daily energy usage indicates very little, if any, air conditioning usage occurs. If significant air conditioning usage occurs, daily energy usage would increase as temperatures increase above 55F. Maine's relatively cool summer season for the years assessed had average temperatures below 75F. Notice the lower base energy load for 2020 pandemic year in Figure 4.

Figure 5 is a plot of the BMFS electric power demand for 2021, 22, and 23. Central Maine Power includes a "demand charge" for transmission of electricity in addition to a charge for the amount of electric energy usage. The demand charge is approximately $16 to $18 per kW (kilowatt) of power demand over a 15 minute period for a given month. The new heat pump system has increased the power draw during cold weather months by 6 to 8kW, or about $100 per month in addition to elevating electric energy usage. Power demand impact of the heat pumps in addition to increased electric energy usage is included in the next section's utility cost analyses.

Red and green lines drawn on Figure 4 characterize daily winter electric energy requirements for propane furnace operation (red line) and heat pump operation (green line). Increased electric energy usage during propane furnace operation is due to furnace fan energy. Colder outside temperatures require longer furnace operation and fan operation. Heat pumps also increase electric energy usage as outdoor temperature decreases. The difference between the red and green lines represents heat pump electric energy that is pumping "heat" into the building for comfort conditioning.

Heat pumps "pump" heat from colder outdoor ambient environments to higher temperatures that can heat buildings. For building heat pumps in BMFS climate, approximately 3 units of heat are delivered to the building for every 1 unit of electric energy used. Propane furnaces deliver a fraction of the chemical energy released by combustion as heat to a building, with 90% furnace efficiency assumed for the present analyses. Table 3 is an estimate of propane energy required for furnace operation based on the electric energy difference between the red and green lines in Figure 3, and assuming the heat pumps' coefficient of performances are 3 and a propane furnace efficiency of 90%.

Table 4 is a conversion of Table 3 propane energy into propane fuel usage (gallons per day). A sum of annual propane usage is included at the bottom of Table 4. For the non-pandemic years (2019/21/22), propane usage is estimated to be 2200 to 2600 gallons per year. Propane fuel usage data is difficult to assess because of the irregularity of propane tank filling. BMFS Staff reported annual propane usage to be 2692 (2020) and 1936 gallons (2021). Only 979 gallons of propane was purchased in 2022 and 235 gallons of propane was purchased for 2023 as the switch from propane furnaces to heat pumps occurred.

Propane usage for 2019 and 2020 are reflected by 2020 and 2021 propane tank filling. Later propane tank fillings include pandemic effects and transition to heat pumps in 2022. Estimated propane usage in Table 4 is similar to the 2020 and 2021 propane tank filling data, indicating that the energy modeling predictions for propane and electrical energy usage are reasonable. This allows utility cost comparisons between propane and all-electric operation for the school to be performed.

Table 4 also shows annual carbon dioxide production has been reduced by 13 to 15 tonnes per year (1 metric tonne = 2200 pounds = 1.1 ton). Domestic hot water (DHW) is produced with an "instantaneous" propane water heater, which may total approximately 200 gallons per year based on current propane usage. Conversion of propane water heating to electric heat pump water heating will be discussed in a later section.

Table 5 compares BMFS energy usage between propane comfort conditioning and heat pump comfort conditioning. Monthly "site" energy for each case is shown in Table 4. Site energy does not distinguish between electrical energy and fossil fuel energy. "Source" energy is a metric that distinguishes between the two forms of energy. We use site energy here because the conversion difference between fossil fuel and electric energy will disappear as renewable energy powers the entire electric grid.

BMFS is using 40% less site energy with heat pump comfort conditioning. The school has a "site EUI" of 32 kBtu/sqft (annual site energy usage in kilo Btus per floor plan area of 8100sqft) in relation to 55 kBtu/sqft before the conversion to heat pumps. This is an excellent EUI for a school building.

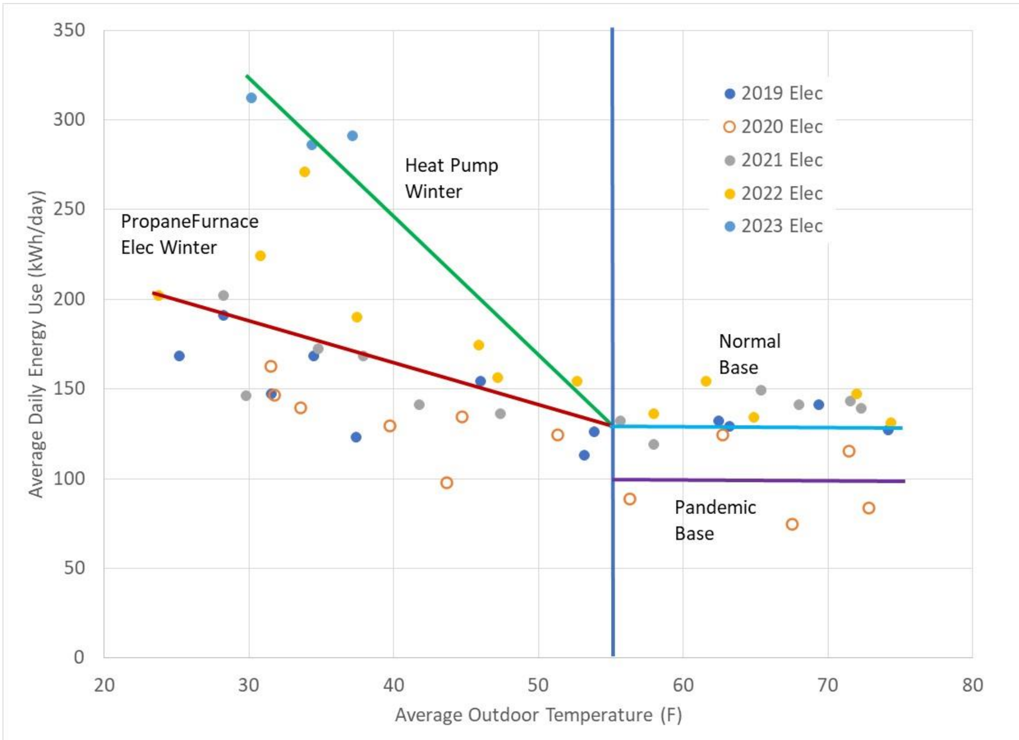

Figure 4 Plot showing BMFS electric energy usage from 2019 to April 2023.

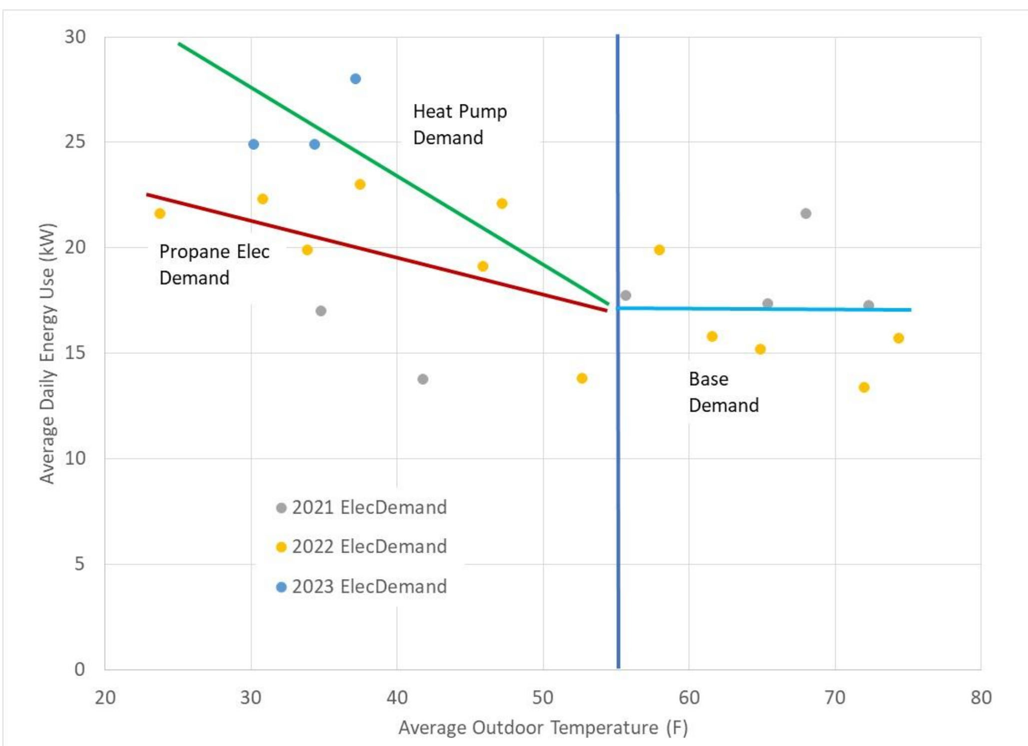

Figure 5 Plot showing electricity power demand for BMFS from 2021 to April 2023.

Table 1 BMFS Electric usage data (2020 Pandemic year; 2019/20/21/22 Propane Furnace; 2023 Heat Pump)

	2019		2020		2021		2022		2023	
Month	**kWh**	**Temp (F)**	**kWh**	**Temp(F)**	**kWh**	**Temp(F)**	**kWh**	**Temp(F)**	**kWh**	**Temp(F)**
January	168	25.2	146	31.8	146	29.8	202	23.8	286	34.4
February	191	28.3	162	31.6	202	28.3	224	30.8	312	30.2
March	168	34.5	129	39.8	168	37.9	190	37.5	291	37.2
April	154	46	97	43.7	136	47.4	156	47.2		
May	126	53.9	88	56.4	119	58	136	58		
June	129	63.2	74	67.6	143	71.6	134	64.9		
July	127	74.2	83	72.9	141	68	131	74.4		
August	141	69.4	115	71.5	139	72.3	147	72		
September	132	62.5	124	62.8	149	65.4	154	61.6		
October	113	53.2	124	51.4	132	55.7	154	52.7		
November	123	37.4	134	44.8	141	41.8	174	45.9		
December	147	31.6	139	33.6	172	34.8	271	33.9		

Table 2 BMFS Electric power demand data (transmission charge ~ $16-18 per kW 15 minute power demand)

Demand	2019		2020		2021		2022		2023	
Month	**kW**	**Temp (F)**	**kW**	**Temp(F)**	**kW**	**Temp(F)**	**kW**	**Temp(F)**	**kW**	**Temp(F)**
January		25.2		31.8		29.8	21.6	23.8	24.9	34.4
February		28.3		31.6		28.3	22.3	30.8	24.9	30.2
March		34.5		39.8		37.9	23	37.5	28	37.2
April		46		43.7		47.4	22.1	47.2		
May		53.9		56.4		58	19.9	58		
June		63.2		67.6		71.6	15.2	64.9		
July		74.2		72.9	21.6	68	15.7	74.4		
August		69.4		71.5	17.25	72.3	13.4	72		
September		62.5		62.8	17.34	65.4	15.8	61.6		
October		53.2		51.4	17.73	55.7	13.8	52.7		
November		37.4		44.8	13.77	41.8	19.1	45.9		
December		31.6		33.6	17	34.8	19.9	33.9		

Table 3 Propane thermal energy usage for comfort heating estimated from heat pump comfort heating electric energy assuming heat pump COP=3 and propane furnace efficiency = 90%.

Propane Use (kWh_thermal/day)										
Usage	**2019**		**2020**		**2021**		**2022**		**2023**	
Month	**kWh_therm**	**Temp (F)**	**kWh_therm**	**Temp(F)**	**kWh_therm**	**Temp(F)**	**kWh_therm**	**Temp(F)**	**kWh_therm**	**Temp(F)**
January	550	25.2		31.8	465	29.8	576	23.8		34.4
February	493	28.3		31.6	493	28.3	447	30.8		30.2
March	379	34.5		39.8	316	37.9	323	37.5		37.2
April	166	46		43.7	140	47.4	144	47.2		
May	20	53.9		56.4	0	58	0	58		
June	0	63.2		67.6	0	71.6	0	64.9		
July	0	74.2		72.9	0	68	0	74.4		
August	0	69.4		71.5	0	72.3	0	72		
September	0	62.5		62.8	0	65.4	0	61.6		
October	33	53.2		51.4	0	55.7	42	52.7		
November	325	37.4		44.8	244	41.8	168	45.9		
December	432	31.6		33.6	373	34.8	390	33.9		

Table 4 Estimated propane fuel usage and annual carbon dioxide production based on Table 3 propane thermal energy results.

Propane Comfort Heating Use (gal/day); 50340kJ/kg, 14kWh/kg, 91,500Btu/gal, 21,550Btu/#, 4.25#/gal										
Usage	**2019**		**2020**		**2021**		**2022**		**2023**	
Month	**gal/day**	**Temp (F)**	**gal/day**	**Temp(F)**	**gal/day**	**Temp(F)**	**gal/day**	**Temp(F)**	**gal/day**	**Temp(F)**
January	20.4	25.2		31.8	17.2	29.8	21.3	23.8		34.4
February	18.3	28.3		31.6	18.3	28.3	16.5	30.8		30.2
March	14.0	34.5		39.8	11.7	37.9	12.0	37.5		37.2
April	6.2	46		43.7	5.2	47.4	5.3	47.2		
May	0.8	53.9		56.4	0.0	58	0.0	58		
June	0.0	63.2		67.6	0.0	71.6	0.0	64.9		
July	0.0	74.2		72.9	0.0	68	0.0	74.4		
August	0.0	69.4		71.5	0.0	72.3	0.0	72		
September	0.0	62.5		62.8	0.0	65.4	0.0	61.6		
October	1.2	53.2		51.4	0.0	55.7	1.6	52.7		
November	12.0	37.4		44.8	9.0	41.8	6.2	45.9		
December	16.0	31.6		33.6	13.8	34.8	14.4	33.9		
Total gal	2708				2294		2360		0	
Total CO2 (tonnes)	15.4				13.1		13.5		0	

Table 5 Comparison of total building energy usage and building "site" EUI (Energy Use Intensity) for an average weather year for Brixham Montessori Friends School, York Maine.

Average Year Energy Usage							
	York ME	**Propane & Electric**				**Heat Pump & Electric**	
Month	**Ave Temp (F)**	**Propane kWh**	**Elec kWh**	**Total kWh**	**Total kBtu**	**Total kWh**	**Total kBtu**
January	27	17480	5992	23472	80474	10800	37030
February	29	13953	5285	19239	65961	9318	31949
March	36	12086	5361	17447	59818	8624	29569
April	46	4986	4510	9496	32558	6006	20592
May	55	0	4030	4030	13817	4030	13817
June	64	0	3900	3900	13371	3900	13371
July	70	0	4030	4030	13817	4030	13817
August	69	0	4030	4030	13817	4030	13817
September	62	0	3900	3900	13371	3900	13371
October	51	517	4310	4827	16549	4997	17133
November	42	10790	4781	15571	53388	6942	23801
December	32	13489	5641	19131	65590	9591	32885
				Total kBtu/y	**442533**	**Total kBtu/y**	**261153**
			"Site"	**EUI (kBtu/sqft)**	**55**	**EUI (kBtu/sqft)**	**32**
Brixham Montessori Friends School = 8100sqft							

Utility Cost

A comparison of current BMFS utility cost with all electric operation and its previous utility cost before conversion to heat pumps shows an annual utility savings of $3000 per year. The comparison requires some analysis because the price of both propane and electricity in Maine have changed significantly since 2019. Propane cost was $2.4/gallon in 2019 and is now $3.4/gallon. Electricity has likewise increased, however, electricity has an annual cost fluctuation layered onto an overall utility cost increase. Also, a significant fraction of electricity cost is the "demand" charge based on the power (energy rate) capacity drawn by the building.

Figures 6 and 7 show recent propane and electric utility costs since 2019. Figure 6 shows electricity rates peak during January, February and March. During 2023, peak electricity rates were three times summer rates in comparison to 2019 when winter peak rates were less than twice summer time rates. Propane does not display a monthly cost variation, but instead tends to periodically jump in price. Figure 7 shows a high step increase in propane cost during the spring of 2022 when Russia invaded Ukraine, causing significant uncertainty in petroleum prices. Since 2019, propane has increased from $2.4/gallon to $3.4 per gallon.

Tables 6 and 7 show annual BMFS utility cost comparisons between propane and heat pump operation for 2019 and 2023. Note that Central Maine Power has projected it utility cost through 2023. Included in electric cost but not shown explicitly in Tables 6 and 7 cost is the demand charge for each month. Demand charge is based on the highest 15 minute power requirement with a slightly varying rate of $14-$18 per kW. Although winter months have higher power demand than summer months, higher electric usage during winter levels the demand charge such that on an energy usage basis the demand charge is equivalent to an extra $0.06/kWh. Therefore, electric utility rates in Tables 6 and 7 have $0.06/kWh added to the utility's energy rate.

Comparing Table 6 annual utility costs for propane and electricity with Table 7 annual utility cost for electric-only shows an annual utility increase from $15,140/year for propane and electricity in 2019 to a projected $19,248/year for 2023, or a $5000/year utility cost increase. Table 6, however, shows that if the school were converted to heat pump comfort conditioning in 2019 that all-electric operation would have cost $12,138, or $3000 less per year than propane heating. Similarly for 2023, if the school were using propane, projected utility cost would be $22,486 per year, or $3000 more per year than heat pump operation. Price variations of propane and electricity cannot be accurately predicted, but the present analysis indicates a beneficial utility bill savings due to conversion to heat pump operation.

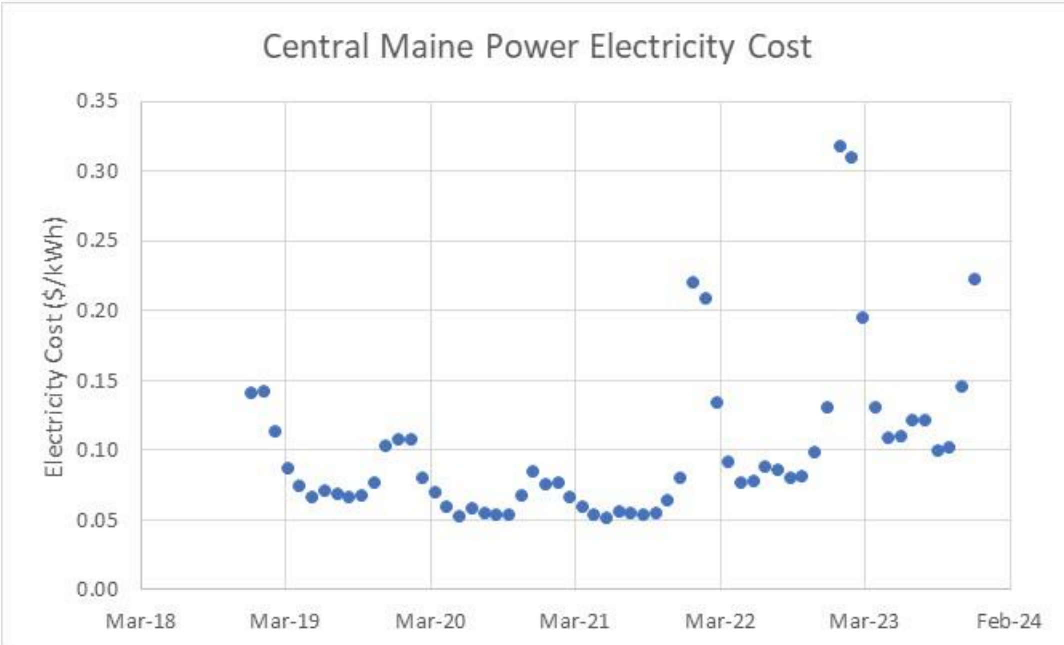

Figure 6 Central Maine Power utility electricity rates since 2018.

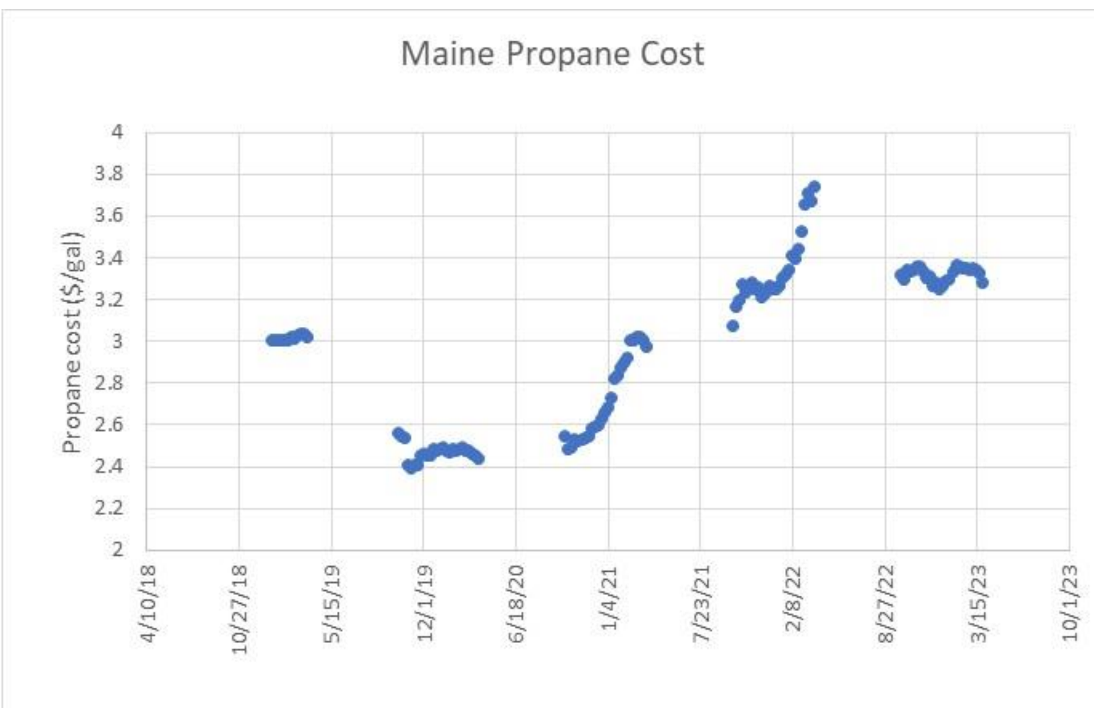

Figure 7 Propane cost for southern Maine since 2018.

Table 6 Comparison of annual utility cost between propane and heat pump operation for BMFS using 2019 electricity cost and propane cost.

2019 Utility Costs						
Month	**Maine Fuel Oil (propane) $/gal**	**Central Maine Pow $/kWh**	**Propane Cost $**	**Electric Cost $**	**Total Elec & Propane $**	**HP Electric Cost $**
January	2.4	0.201	1572	1204	2776	2170
February	2.4	0.202	1255	1068	2323	1883
March	2.4	0.173	1087	927	2014	1492
April	2.4	0.146	448	660	1109	879
May	2.4	0.134	0	541	541	541
June	2.4	0.126	0	492	492	492
July	2.4	0.130	0	526	526	526
August	2.4	0.129	0	519	519	519
September	2.4	0.126	0	491	491	491
October	2.4	0.127	46	548	594	635
November	2.4	0.136	970	653	1623	947
December	2.4	0.163	1213	919	2132	1562
Total					**15140**	**12138**

Table 7 Comparison of annual utility cost between propane and heat pump operation for BMFS using 2023 electricity cost and propane cost.

2023 Utility Costs (projected)						
Month	**Maine Fuel Oil (propane) $/gal**	**Central Maine Pow $/kWh**	**Propane Cost $**	**Electric Cost $**	**Total Elec & Propane $**	**HP Electric Cost $**
January	3.4	0.378	2227	2266	4493	4085
February	3.4	0.370	1778	1956	3733	3448
March	3.4	0.255	1540	1369	2908	2202
April	3.4	0.190	635	857	1492	1141
May	3.4	0.169	0	681	681	681
June	3.4	0.170	0	663	663	663
July	3.4	0.182	0	732	732	732
August	3.4	0.181	0	729	729	729
September	3.4	0.159	0	620	620	620
October	3.4	0.162	66	696	762	807
November	3.4	0.206	1375	984	2359	1429
December	3.4	0.283	1719	1594	3313	2711
Total					**22486**	**19248**

Summary and Future Considerations

Brixham Montessori Friends School administration and school board commitment to improving their school has significantly improved air quality, energy efficiency and environmental sustainability of their 8100sqft school building. They have completed a hat trick of building renovation that significantly improves student and staff health, reduces utility bills, and reduces the school's carbon footprint.

CERV2 smart ventilation systems efficiently and reliably maintain healthy indoor air. During weekends, vacation periods, nighttime and other low occupancy periods, the five CERV2 units automatically detect reduced need for fresh air and adjust accordingly. BMFS indoor air quality meets ASHRAE's new 241P indoor air quality standard for reducing airborne disease transmission. The difference between today's ASHRAE "minimum" ventilation standard (62.1) and the new 241P standard is a 40% reduction absenteeism (1 sick day per year per building occupant) with an estimated value of $45,000. The estimated savings are based on ventilation studies examining correlation between sick days and ventilation rates. Even a more modest sick day reduction of 10% (1/4 sick day savings per occupant per year) has an estimated value of $10,000/year.

Conversion of the BMFS building from propane furnace heating to heat pumps for comfort conditioning has eliminated an estimated 13 to 15 tons of carbon dioxide production per year, reduced the building's site EUI (Energy Use Intensity) by 40%, from 55kBtu/sqft to 32kBtu/sqft, and reduced annual utility bills by $3000 per year. Significant changes in both propane cost and electric utility rates have occurred over the past few years, however all-electric operation is likely to continue to maintain significant annual savings relative to propane heating.

Four areas for future energy savings and cost reduction are discussed below:

1) Additional roof insulation: The school building attic insulation can be improved. Foam insulation and sealing of the roof structure would further reduce winter heating costs. Building energy modeling can estimate the value of the energy savings relative to insulation cost to determine return-on-investment.
2) Reduction/elimination of furnace fan and attic exhaust fan operation: although propane is no longer used for winter heating, the propane furnaces remain in place with the duct circulation fans operating to help distribute ventilation air from the CERV2 units. Some modification to the duct distribution system could eliminate the need for furnace fan operation. The modifications are minor (blocking air flow in the furnace return ducts), but should be conducted in a manner to ensure CERV2 ventilation units are able to provide bulk air movement throughout the school building. Return air quality to the CERV2 units provides data needed to assess the necessity of furnace fan operation. Furnace fan power measurement data should also be collected to assess energy savings value. The attic area includes an exhaust fan that appears to continually operate. This fan's operation and necessity should also be evaluated.
3) Domestic Hot Water (DHW) conversion from propane to heat pump water heating: current DHW is from an instantaneous hot water heater using propane. Assuming last year's propane usage (235gal) is due to hot water energy usage, and assuming a gas water heater efficiency of 80%, daily hot water usage for the building is estimated to be 75 gallons per day, or slightly less than 1 gallon per person per day. The gas water heater could be replaced with a high efficiency heat pump water heater (HPWH), also called a "hybrid" water heater, with a COP (Coefficient of

Performance) of 3. At current propane and electricity utility rates, propane heated water costs $800 per year. HPWH would reduce hot water cost by 25%, or $200 per year.

4) Demand load reduction: electric utility data shows the building's average power draw is 1/2 to 1/3 of the peak 15 minute power draw. Monitoring electric distribution circuits would provide data for understanding sources of power demand, and suggest methods for "flattening" power demand. For example, thermostat setback of the building might result in a high power draw at the beginning of the school day coupled with other building power demands such as lighting. A reduction of 5kW in peak power demand would be an electric utility bill reduction of $80 to $100 per month.