Technical Report 3

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This document contains results from a previously conducted energy use analysis of Manassas Park Elementary School, as well as a mechanical system description and a total mechanical system cost. The results of the analysis were compared to the proposed design energy usage estimation created by professional design engineers at 2rw. Expected results from a comparable baseline building were also included in the analysis to clarify the estimated energy savings of Manassas Park Elementary School.

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Table of Contents

List of Tables

List of Figures

Building and System Design Objectives

“Good schools are a catalyst. Without good schools, people don’t want to come to the community”.
~Frank Jones, Mayer of Manassas Park

The traditional purpose of a buildings mechanical system is to provide a comfortable indoor environment for that building’s occupants’. Modern systems attempt to achieve this traditional purpose while minimizing the associated environmental impacts. The system objectives in Manassas Park Elementary School are no different; they were chosen as the best combination of minimized first cost and an ability to provide a comfortable indoor environment, all while minimizing the overall energy and associated resource consumption of the building.

Sustainability was a major consideration in the system selection, as the building was pre-determined to be the “poster child” of evolving environmental consciousness in the construction of educational facilities of northern Virginia. The school was designed with the philosophy that a good school can be the catalyst for an evolving and maturing community, and that a green school is unshakably a good school. This ideology was ultimately proven robust; Judges that selected MPES as a recipient of the *Citation of Excellence for outstanding educational facility design* in the 2009 edition of *Learning By Design*[1] have claimed that Manassas Park Elementary School is a “demonstration of how school design can transform the community”. According to Daniel L. Duke[2], “Manassas Park is a classic example of a school district leading its community out of the Doldrums”. Michael Birnbaum[3] continues to prove the claims by citing that “school performance is on the rise. The dropout rate has declined almost two-thirds since 1996, and 97 percent of third-graders last year passed state mathematics tests, a higher rate than anywhere else in Northern Virginia.” Mr. Birnbaum went on to say that “as schools have improved, residents and businesses have migrated into the city. In [Manassas Park’s] first years, the only businesses were in a strip mall. Now, construction workers are putting the final touches on a dense four-story complex of buildings that Mayer Frank Jones says he hopes will become a small downtown.” The community was *saved* by the design and construction of a LEED® Gold elementary school, and at a nominal elementary school cost.

Mechanical System Design

The building has a 75,000 gallon cistern used for grey water storage, light tubes that virtually eliminate artificial illumination requirements (on a sunny day), floors made out of recycled airplane tires (bonded together with a non-toxic adhesive, of course), motion sensors/automatic light meters, and a non-automated natural ventilation system[4]. Base mechanical heating and cooling is supplied to the building

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[1] *Learning By Design* is self-acclaimed as “the premier annual guide that showcases innovative school and university design and construction projects”.

[2] Daniel L. Duke is a professor at the University of Virginia who wrote a book about the transformation of the Manassas Park School System.

[3] Michael Birnbaum is a Washington Post Staff Writer.

[4] Teachers are expected to open and close windows as a corridor mounted green light turns on and off, respectively.

via distributed ground source heat pumps. These heat pumps utilize a 5 acre, 200 well variable primary geothermal system that is able to consistently supply water at 55 degrees Fahrenheit. In the geothermal system, variable primary pumps (P-1 and P-2 on schematic) work in a lead/lag configuration, and maintain a flexible differential pressure setpoint (at pressure sensor PS-1). Referenced system schematics can be viewed in Appendix A. According to Thomas DeBolt, the Manassas Park Schools Superintendent, the geothermal system is "bringing in water at the perfect temperature to make it warm or cold… It's the most practical and least expensive way to heat and cool a building[5]."

Table 1: Outdoor Air Unit Schedule[6]

Mark	Supply Air (CFM)	Supply Fan Power (HP)	Exhaust Fan Power (HP)	Enthalpy Wheel Power (HP)	Sensible Wheel Power (HP)	Cooling Coil Cap (MBH)	Gas Fired Cap (MBH)	Pre-Filter Efficiency
OAU-1,2,3	3360	5	3	0.25	0.25	128.5	123	30%
OAU-4	9330	15	7.5	0.5	0.25	365.3	341	30%
OAU-5	4650	7.5	3	0.25	0.25	188.3	170	30%

Before the building's air is supplied to the building occupants, it goes through one of 5 outside air units[7]. The specifications for the specific units can be seen in Table 1, above. In each one of thesis units, air goes through an enthalpy wheel, an air-cooled direct expansion coil[8], a sensible wheel, and an optional direct fire natural gas heater (in that order) to precondition the air to 72 degrees Fahrenheit and 50% relative humidity. From here, this 100% outside air is delivered to the distributed ground source heat pumps, which induce and mix room air with the 100% outside air. This mixed air is then conditioned to the supply temperature by an R-407c vapor compression cycle[9] that utilizes the 55 degree Fahrenheit geothermal water as a heat source or sync. Air is primarily exhausted[10] to the outside air units, where it provides supplemental conditioning to the intake air via the aforementioned sensible and enthalpy wheels.

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[5] The 55 degree Fahrenheit water is not further heated or cooled to be directly utilized in an airstream's coil (as is insinuated in the above quote), but rather is used as a heat source or sync to either reject heat to or take heat from by using a traditional vapor compression cycle. Thus the phrase, "we're bringing in water at the perfect temperature to make it warm or cold" is substantially incorrect, and in my opinion clearly represents the technical ignorance of most non-engineering professionals.

[6] The building ventilation requirements do not exceed 24,060 cubic feet per minute.

[7] See Appendix B for the Outside Air Unit Schematic taken directly from the construction documents as drawn by 2rw Consulting Engineers.

[8] OAU-1,2,3 have individual remote 2-compressor air-cooled condensing units. OAU-4 has a packaged 4-compressor air-cooled condensing unit, and OAU-5 has a packaged 2-compressor air-cooled condensing.

[9] Rooftop GSHP units utilize a 500W, 120V heater with a temperature stat set at 40 degrees Fahrenheit to precondition air. This is primarily used as freeze protection such that typical GSHP operation is possible.

[10] Areas including the mechanical rooms, penthouses, kitchens, data closets, and bathrooms are exhausted directly out of the building. A make-up air unit is used to balance the kitchen exhaust hood, and supplies a constant volume of air to the kitchen with optional direct fire heating.

Previous Research

MPES Technical Report I and Technical Report II contained much of the information that is required in this analysis, Technical Report III. Below is a summary of that information, taken directly from the aforementioned documents[11].

Weather Data

Indoor and outdoor air conditions for heating and cooling in Manassas, VA were used for the energy analysis conducted in Technical Report II. These values were taken from the 2005 ASHRAE Handbook of Fundamentals, and they represent the 0.4% and 99.6% values, respectively. Manassas is very close to Manassas Park, VA, and weather patterns are comparable. Table 2, below, shows the values used in the analysis[12].

Table 2: ASHRAE 2009 Weather Data – Manassas, VA

ASHRAE Values	Summer Design Cooling - 0.4%	Winter Design Heating - 99.6%
OA Dry Bulb (˚F)	92.7	10.6
OA Wet Bulb (˚F)	74.0	~
IA Dry Bulb (˚F)	74	70
Clearness Number	0.85	0.85
Ground Reflectance	0.2	0.2

Technical Report II Energy Analysis Results

Energy consumption results calculated in Technical Report II as part of the *whole building load and energy simulation analysis* are a reasonable representation of how much energy an average elementary school building should consume. Table 3, below, shows results of the analysis, and compares the results side by side to both the *building energy as estimated by the design engineers* (proposed building) and a *comparable baseline building*. The energy consumption values used for the proposed building were estimated by professional design engineers using eQuest.

The style chosen to represent these results roughly emulates the style used for the LEED-NC 2.2 Submittal Template for EA Credit 1: *Optimize Energy Performance*. The relevant portion of the LEED-NC 2.2 Submittal that was actually submitted for EA Credit 1: Optimize Energy Performance can be reviewed in Appendix C.

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[11] Some paraphrasing has been added to the information taken from Technical Reports I & II to increase the fluidity of this document.

[12] The actual weather data sheet used for this information can be reviewed in Appendix D.

Table 3: Energy Analysis Results Summary

End Use	Energy Type	Units	Analysis Building Results Estimation	Proposed Building Results	Baseline Building Results
Interior Lighting	Electricity	Energy Use (kWh)	105,321.0	119,320.0	311,811.0
		Demand (kW)	-	78.5	147.0
Exterior Lighting	Electricity	Energy Use (kWh)	10,000.0	9,854.0	24,110.0
		Demand (kW)	-	2.8	6.8
Space Heating	Electricity	Energy Use (kWh)	82,920.0	50,861.0	26,249.8
		Demand (kW)	-	116.8	25.8
Space Heating - Gas	Natural Gas	Energy Use (therms)	39,365.8	-	-
		Demand (MBH)	-	-	-
Space Cooling	Electricity	Energy Use (kWh)	152,526.0	71,690.0	402,868.2
		Demand (kW)	-	110.6	267.1
Pumps	Electricity	Energy Use (kWh)	-	41,199.0	5,954.3
		Demand (kW)	-	9.5	1.6
Heat Pump Supplemental	Electricity	Energy Use (kWh)	-	38.0	9,156.5
		Demand (kW)	-	1.5	61.1
Fans - Interior	Electricity	Energy Use (kWh)	84,805.0	266,200.0	101,162.0
		Demand (kW)	-	98.3	61.5
Space Heating - Gas	Natural Gas	Energy Use (therms)	-	5,556.0	36,942.5
		Demand (MBH)	-	630.0	3,550.0
Service Water Heating	Electricity	Energy Use (kWh)	-	23,134.0	23,163.8
		Demand (kW)	-	13.9	13.9
Receptacle Equipment	Electricity	Energy Use (kWh)	19,370.0	93,180.0	93,180.0
		Demand (kW)	-	40.2	40.2
Pumps/Auxiliary	Electricity	Energy Use (kWh)	142,605.0	-	-
		Demand (kW)	-	-	-
Refrigeration	Electricity	Energy Use (kWh)	-	49,932.0	49,932.0
		Demand (kW)	-	13.7	13.7
Service Water Heating - Gas	Natural Gas	Energy Use (therms)	-	3,148.0	3,858.5
		Demand (MBH)	-	320.0	390.0
Cooking	Electricity	Energy Use (kWh)	-	44,181.0	44,181.0
		Demand (kW)	-	35.0	35.0
Elevators and Escalators	Electricity	Energy Use (kWh)	-	9,839.0	9,839.0
		Demand (kW)	-	4.2	4.2
Cooking - Gas	Natural Gas	Energy Use (therms)	-	3,424.0	3,424.0
		Demand (MBH)	-	270.0	270.0
Total Corrected Gas Usage	Natural Gas	Energy Use (therms)	46,324.1	12,128.0	44,225.0
Total Corrected Electricity Usage	Electricity	Energy Use (kWh)	694,982.1	781,173.0	1,106,495.5
Total Corrected Energy Usage	~	mmbtu/year	7,003.7	3,878.2	8,197.9
Energy Usage as a Percent of Baseline	~	~	85.4%	47.3%	100.0%
Energy Usage as a Percent of Proposed	~	~	180.6%	100.0%	211.4%
Energy Usage as a Percent of Estimated	~	~	100.0%	55.4%	117.1%

Correction Factor: 1.18

The most notable values in comparing the building loads that were estimated as part of the Technical Report II analysis and the building loads that were estimated by the design engineers are those that are contained within the last 4 rows of the above table. Specifically, the summarized results in the above table show that the results for the building loads that were estimated as part of the previously conducted analysis are 180.6% of those that were estimated by the design engineers.

These results came as no surprise: A series of engineering decisions were made during the modeling process that were expected manipulate the results to values that are greater than the values that would be expected in a comparable tangible (as designed, not baseline) building. Most notably, natural ventilation and solar shading were designed to make a significant impact on the total energy consumption of Manassas Park Elementary School; these technologies were neglected[13] from the block energy analysis performed for Technical Report II, which should have driven the results of the analysis to much higher values than those presented by the professional design engineers. Contrariwise, roof surface area was neglected[14] from the block energy analysis performed for Technical Report II, which should have decreased the results of the analysis to values that are closer to (yet not in synergy with) the resulting values in the professional design engineers model (resulting directly from less total exterior surface area, which affects solar gain as well as convective and conductive heat transfer to and/or from the ambient outdoor air). This expected outcome is evident in the results of Technical Report II, presented above in Table 3. There exists the possibility that these two "assumptions" had a relatively equal but opposite effect on the energy model, with the terminal result on the model being tabulated as negligible. This unlikely yet plausible scenario could be used to show that there are indeed some modeling errors, even though the final results of the model were as expected.

Possible Errors

The myriad of possible error scenarios that existed throughout the execution of the Technical Report II energy analysis can be grouped in three main categories: modeler error, modeling software error, and miscommunication between the modeler and the modeling software.

The modeler that performed the energy analysis was relatively new to the program, and had never modeled a ground source heat pump system before[15]. There is a possibility that these infamiliarities could have led to many further errors; all of which with possible detrimental effects to the models end results.

Although it is a rare occurrence, modeling software packages may also contain intrinsic errors. They were ultimately created by humans, which are by no means perfect.

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[13] Natural ventilation and solar shading were neglected from the block building load and energy simulation analysis due to the analyzing engineer's unfamiliarity's with the load estimation software. Reasonable explanations of these estimation techniques were unsuccessfully investigated for the benefit of Technical Report II.

[14] Roof surface area was not utilized in the block building load and energy simulation analysis due to the initial assumption of building pod floor symmetries. One floor of pod 1 was analyzed, and the results of which were multiplied by nine to account for the remaining two floors of pod 1, as well as all three floors of pod 2 and pod 3.

[15] Rigorous attempts were made by the modeler to correctly model the systems of Manassas Park Elementary School; the Trane Trace 700 helpline was regularly used throughout the modeling process to efficiently increase the accuracy of the models end results.

Miscommunication between the modeler and the modeling software is also a possible source of error. If the modeling software perceives a specific building characteristic or system input differently than the modeler had initially intended, the results may become unfavorably skewed.

Operating Costs

The operating costs of the building were calculated in Technical Report II using an averaged rate structure. This rate was determined by taking averaged annual costs from the professional design engineers' cost analysis and dividing them by the average annual energy totals from the professional design engineers' energy analysis. The resultant number obtained from this calculation was in the form of *dollars per unit of energy*, and can be reviewed below in Table 4.

Table 4: Averaged Energy Costs

Energy Type	Averaged Energy Cost	Units
Electricity	0.075911308	dollars/kWh
Natural Gas	1.313679057	dollars/therm

Manassas Park Elementary Schools annual energy costs were calculated using these averaged energy rates, and the results can be found in Table 5, below. This table shows the results for the building energy cost estimation performed in the Technical Report II energy analysis, the results for the building energy cost estimation performed by the professional design engineers, and the value of a typical building energy cost for a comparable baseline building.

Table 5: Technical Report II Energy Cost Analysis Results Summary

Energy Type	Analysis Building Results			Proposed Building Results			Baseline Building Results		
	Energy Use	Units	Cost	Energy Use	Units	Cost	Energy Use	Units	Cost
Electricity	694,982.1	kWh	$ 52,757	781,173.0	kWh	$ 59,182	1,106,495.5	kWh	$ 84,163
Natural Gas	46,324.1	therms	$ 60,855	12,128.0	therms	$ 16,244	44,224.0	therms	$ 56,960
Total	7,003.7	mmbtu	$ 113,612	3,878.2	mmbtu	$ 75,426	8,197.9	mmbtu	$ 141,123
Energy Price as a Percent of Baseline	~	%	80.5%	~	%	53.4%	~	%	100.0%
Energy Usage as a Percent of Proposed	~	%	150.6%	~	%	100.0%	~	%	187.1%
Energy Usage as a Percent of Estimated	~	%	100.0%	~	%	66.4%	~	%	124.2%

Mechanical System Direct Cost Breakdown

Table 6: Financial Breakdown of the Mechanical Systems

Description of Work	Scheduled Value
Mobilization	$ 66,000.00
Bond	$ 133,000.00
Submittals	$ 66,000.00
Coordination Drawings	$ 60,000.00
U/G Sanitary & Storm - Material	$ 163,000.00
U/G Sanitary & Storm - Labor	$ 270,000.00
Sleeving -Materials	$ 5,000.00
SIeeving - Labor	$ 20,000.00
A/G Sanitary & Storm - Material	$ 210,000.00
A/G Sanitary & Storm - Labor	$ 225,500.00
Domestic & NPW Water Piping - Material	$ 232,000.00
Domestic & NPW Water Piping - Labor	$ 193,000.00
Gas Piping - Materials	$ 20,000.00
Gas Piping - Labor	$ 15,000.00
Plumbing Fixtures - Materials	$ 176,500.00
Plumbing Fixtures - Labor	$ 48,000.00
Domestic Hot Water Heaters - Material	$ 65,000.00
Drains & Carriers - Material	$ 60,000.00
Plumbing Pumps -Material	$ 133,000.00
Cistern Plumbing - Materials	$ 28,000.00
Cistern Plumbing - Labor	$ 22,000.00
Cistern Equipment - Materials	$ 113,000.00
HVAC Piping Mains - Materials	$ 125,000.00
HVAC Piping Mains - Labor	$ 135,000.00
HVAC Equipment Trim & Piping - Material	$ 28,000.00
HVAC Equipment Trim & Piping - Labor	$ 20,000.00
GSHP - Material	$ 550,000.00
OAU's - Material	$ 450,000.00
ERV's - Material	$ 28,500.00
Fans - Material	$ 57,500.00
HVAC Pumps & Accessories	$ 50,000.00
VFD's - Material	$ 25,000.00
Set P/HVAC Equipment- Pre-K	$ 5,000.00
Set P/HVAC Equipment - Boiler Room	$ 10,000.00
SCI P/11VAC Equipment - Stage Mech	$ 8,000.00
Set P/HVAC Equipment - Pod #1 Roof	$ 5,000.00
Set P/HVAC Equipment - Pod #2 Roof	$ 8,000.00
Set P/HVAC Equipment - Pod #3 Roof	$ 8,000.00
Plumbing Piping -Material	$ 20,000.00
Plumbing Piping - Labor	$ 29,000.00
HVAC Piping -Material	$ 19,000.00
HVAC Piping - Labor	$ 27,000.00
HVAC Ductwork - Material	$ 92,000.00
HVAC Ductwork - Labor	$ 138,000.00
Submittals & Mobilization	$ 25,000.00
Sheet Metal Coordination Drawings	$ 65,500.00
Pre-K Duct Work - Furnish	$ 92,000.00
Pre-K Duct Work - Install	$ 50,000.00
1st Floor Duct Work - Furnish	$ 234,000.00
1st Floor Duct Work -Install	$ 124,000.00
2nd Floor Duct Work - Furnish	$ 265,000.00
2nd Floor Duct Work - Install	$ 143,000.00
3rd Floor Duct Work - Furnish	$ 127,500.00
3rd Floor Duct Work - Install	$ 69,000.00
Roof Level Duct Work - Furnish	$ 138,000.00
Roof Level Duct Work - Install	$ 75,000.00
Fire Dampers - Furnish	$ 10,000.00
Registers, Grills & Diffusers - Furnish	$ 72,000.00
Registers, Grills & Diffusers -Install	$ 58,000.00
Engineering/Submittals	$ 49,000.00
Programming/Graphics	$ 10,000.00
Panel Fabrication	$ 5,000.00
Electrical Install	$ 291,000.00
Automation Materials	$ 200,000.00
Electrical Materials	$ 48,000.00
Valves	$ 74,500.00
Dampers	$ 29,500.00
Checkout Labor	$ 88,000.00
System Demonstration/framing	$ 32,000.00
Testing & Balancing	$ 28,224.00
Contract Allowances	$ 6,565,224.00
Geothermal Fields and Wells	$ 2,221,219.00
CO #1- VE Credit	$ 408,850.00
CO #2 - Cistern Dewatering	$ 34,841.00
CO #3 - Duct Changes	$ 104,118.00
Grand Total	$ 8,516,552.00

This grand total[16] can be divided by the total building area to get a mechanical system cost of $69.24 per square foot. That number represents almost 26% of the total building cost; an extremely high relative mechanical system cost.

Additional Indirect Costs due to Mechanical Area Allocations

The mechanical system has an associated indirect cost which comes from floor space and vertical shaft space requirements. Because this space is in a school building and thus not considered leasable space, the indirect cost will be in terms of construction costs per square foot, and not leasable cost per pay period.

The main ductwork system in Manassas Park Elementary School is only used to transport the minimum required outside air as specified by ASHRAE Standard 62.1. This represents the minimum sized ductwork that could be used for this building design, independent of the mechanical system selection in the building. Because of this, vertical shaft area can be neglected in this analysis as it consumes the least amount of space of any comparable system.

The heating and cooling load requirements of the building are met via a hydronic system, which takes advantage of the high thermal capacity of water to minimize wall and ceiling space consumption. This type of system is also able to provide a relatively high level of flexibility to the design team. Hydronic piping volume will be ignored in this analysis, as it can be considered negligible with respect to volume requirements of a comparable all-air design.

This leaves mechanical room and penthouse space to be considered in this study. Penthouse space requirements can be held responsible for approximately 7,350 square feet of the building's rooftop space. Because this is unconditioned space located on the building roof, it would be inaccurate to assume that this space costs the same as a comparable area of furnished and conditioned interior space. Instead, the structure of the building was analyzed to determine indirect costs of the mechanical penthouse. Currently, the areas of the roof that do not hold any of the mechanical equipment are made up of 1 ½ inch deck supported by W12 X 16 beams. The portion of the roof that supports the structural load of the mechanical penthouses is made up of 4 inch normal weight concrete on $^{9}/_{16}$" X 28 gage metal deck, supported by beams up to W24 X 55 in size.

Without needing to support the total penthouse area of 7,350 square feet, the roof would have used 18,375 less cubic feet of concrete, and would have been able to size down beams from W24X55 to W12X16. That would account for a savings of 39 pounds of steel per foot of beam used on the roofing system[17]. Additional savings would come from reduced column sizes and reduced reinforcing bar requirements.

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[16] On a typical high efficiency design, the design team or owner will work to decrease the total cost of the mechanical system by trying to obtain some type of government rebate or tax relief. It has been reported by Manassas Park City Schools Superintendent Thomas DeBolt that although many incentives were looked into, only one $50,000 grant was obtained.

[17] The total weight of the penthouse associated structural steel was not calculated in this study.

Mechanical rooms on the first floor, second floor, and under the stage can be held responsible for approximately 2,005 square feet of interior building space. At an average floor area cost of $268.29 per square foot, it can be roughly estimated that the inclusion of this mechanical space cost the building owner $537,930. This number is not a major factor in the total building value, as it only represents approximately 1.63% of the total building cost.

Mechanical Sustainability Assessment - LEED® v2.2

The United States Green Building Council (USGBC) has famously developed the Leadership in Energy and Environmental Design green building certification program (LEED®). Although there have been criticisms on the individual category weightings in the LEED rating system[18], it has proven to be a robust and comprehensive assessment of a sustainable building. Specific levels of LEED certification are currently required in many local building codes throughout the country, and LEED certification requirements have also been included in some United States federal mandates. The LEED rating system is currently the most widely used green building certification program in the country.

The LEED rating system "addresses all building types and emphasizes state-of-the-art strategies in five areas: *sustainable site development, water savings, energy efficiency, materials and resources selection, and indoor environmental quality*" (http://www.usgbc.org/). Of these five categories, a buildings credit score in *energy efficiency* and *indoor environmental quality* are most dependant on that buildings mechanical system.

Energy & Atmosphere

In the energy efficiency category[19] of the LEED rating system, Manassas Park Elementary School achieved all three of the required prerequisites, as well as 8 out of the 17 possible credits.

The intent of E&A Prerequisite 1, *Fundamental Commissioning of the Building Energy Systems*, is to "verify that the buildings energy related systems are installed, calibrated, and perform according to the owner's project requirements, basis of design, and construction documents"[20]. This intent was achieved through a contract with Sebesta Blomberg[21], who provided the commissioning services on the project.

The intent of E&A Prerequisite 2, *Minimum Energy Performance*, is to "establish the minimum level of energy efficiency for the proposed building and systems". To satisfy this intent, the engineer of record

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[18] In the past, the LEED rating system has had controversial category weightings that have not "sufficiently stressed the importance of energy efficiency", claim some environmental critics. Newer versions of the LEED rating system have reconsidered category weightings, and have put a higher importance on the energy efficiency and overall conservation of an applicable building.

[19] The energy efficiency category of the LEED rating system is officially titled *Energy & Atmosphere* (E&A).

[20] The intents of individual prerequisites and credits that are shown in quotations were taken directly from the LEED-NC Version 2.2 Reference Guide.

[21] Sebesta Blomberg is a Minneapolis, MN based company with an extensive history of commissioning building systems. The design team worked directly with the Alrington, VA office to achieve many of the commissioning related credits in the LEED rating system.

designed the building to comply with all mandatory provisions[22] as well as the prescriptive requirements[23] of ASHRAE Standard 90.1-2004 (without amendments).

The intent of E&A Prerequisite 3, *Fundamental Refrigerant Management*, is to "reduce ozone depletion". To satisfy this intent, the engineer of record specified heating, ventilating, air-conditioning and refrigeration equipment that did not use any chlorofluorocarbon-based refrigerants.

Manassas Park Elementary School achieved 7 out of the 10 possible credits for E&A Credit 1, *Optimize Energy Performance*. The intent of this credit is to "achieve increasing levels of energy performance above the baseline in the prerequisite standard to reduce environmental and economic impacts associated with excessive energy use". To satisfy this intent, the design team worked as an integrated entity to create a building that had a designed energy consumption equaling less than 68.5% of the energy that a comparable baseline building would consume. The comparable baseline energy consumption used in this analysis was calculated in accordance to the Building Performance Rating Method in Appendix G of ASHRAE Standard 90.1-2004. Major factors that contributed to this building energy use reduction include (but are not limited to) an efficient daylighting design that minimizes artificial illumination requirements, hydronic thermal transport between conditioning systems and the spaces being conditioned, and the use of a variable primary geothermal system to produce an approximately constant temperature heat source/sync for efficient space conditioning via a series of decentralized heat pumps.

The school was also able to achieve E&A Credit 5, *Measurement & Verification*. The intent of Credit 5 is to "provide for the ongoing accountability of building energy consumption over time". Achieving this credit is imperative for a publically owned building, as it can be used to *prove* substantial energy savings[24] that may or may not be the result of an increased first cost, financed by the paying public[25].

Indoor Environmental Quality

In the indoor environmental quality (IEQ) category of the LEED rating system, Manassas Park Elementary School achieved both of the required prerequisites, as well as 11 out of the 15 possible credits.

The intent of IEQ Prerequisite 1, *Minimum IAQ Performance*, is to "establish minimum indoor air quality performance to enhance indoor air quality in buildings, thus contributing to the comfort and well-being of the occupants". To satisfy this intent, the engineer of record designed the building to comply with Sections 4 through 7 of ASHRAE Standard 62.1-2004, *Ventilation for Acceptable Indoor Air Quality*.

The intent of IEQ Prerequisite 2, *Environmental Tobacco Smoke (ETS) Control*, is to "minimize exposure of building occupants, indoor surfaces, and ventilation air distribution systems to Environmental

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[22] Mandatory provisions of ASHRAE Standard 90.1-2004 can be found in Sections 5.4, 6.4, 7.4, 8.4, 9.4, and 10.4.

[23] Prescriptive requirements of ASHRAE Standard 90.1-2004 can be found in Sections 5.5, 6.5, 7.5, and 9.5.

[24] Without achieving E&A Credit 5, *Measurement & Verification*, a design team could potentially manipulate energy modeling results (knowingly or not) to obtain values indicative of a high performance building. These results could be used to undeservingly receive credit for an energy efficient building, as the energy efficiency of the constructed building could potentially be less than what was shown in the respective energy model.

[25] Some residents have been known to argue against energy saving measures in public buildings due to the potentially increased first costs of design (which is likely passed on to the respective tax payers).

Tobacco Smoke”. To satisfy this intent, the entire building site was designated as a tobacco free school zone. This completely eliminates[26] all noticeable amounts of ETS from the building’s interior and exterior air.

IEQ Credit 2, *Increased Ventilation*, was not attempted or achieved by the MPES design team. Discussion on other non-achieved credits has been neglected from this analysis; however, due to the controversial nature of this credit, a short insight has been included. ASHRAE Standard 62.1, *Ventilation for Acceptable Indoor Air Quality*, has been under development for over 100 years. It is based on the results from experiments conducted by numerous design professionals and accredited institutions that have become famous within the industry as leading sources of experimentally proven information. The standard provides specific ventilation rates for different area types, with final ventilation values dependant on the affiliated amount of area and the occupancy levels of those areas. The USGBC has created IEQ Credit 2, which rewards a design team for specifying ventilation values that are 30% above the suggested values of ASHRAE Standard 62.1. This increased ventilation comes at a premium energy cost, and does not provide any proven advantages over a typical system that is compliant with ASHRAE Standard 62.1. According to Joseph Lstiburek[27], design teams should strive to “Build tight, ventilate right. Tight is [defined as] 0.39 cfm/ft2 [(or less) airflow when the building is pressurized to] 0.3 inches of water column. Right is [a design that is compliant with] Standard 62.1” (J. Lstiburek, *Why Green Can Be Wash*, ASHARE Journal, November 2008). IEQ Credit 2 directly opposes this philosophy—according to Dr. Lstriburek and like minded professionals, it was a technically vigorous decision on the part of the mechanical designers of Manassas Park Elementary School not to attempt this credit.[28]

The intent of IEQ Credit 3.1, *Construction IAQ Management Plan, During Construction*, is to “reduce indoor air quality problems resulting from the construction/renovation process in order to help sustain the comfort and well-being of construction workers and building occupants”. To achieve the intent of this credit, the General Contractor implemented an indoor air quality management plan for the construction and pre-occupancy phases of the project. This plan helped to ensure that absorptive material stored or installed on site was protected from moisture damage, and that filtration media with a MERV rating of 8 or higher was used at each return air grille of the AHU’s that were operated during the construction phase of the project (among other things).

IEQ Credit’s 4.1 through 4.4 were all achieved for this project. These credits all reference the installation or use of low-emitting materials in the building; more specifically: adhesives & sealants, paints & coatings, carpet systems, and composite wood & agrifiber products, respectively. The generalized intent of these credits is to minimize the “quantity of indoor air contaminants that are odorous, irritating,

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[26] Exterior air that is in close proximity to the tobacco free school zones boundaries may contain noticeable traces of ETS.

[27] Joseph W. Lstiburek, Ph. D., P.Eng., is a principal of Building Science Corporation in Westford, MA, as well as an ASHRAE Fellow. He has twenty-five years of experience in building science research, design, and construction, and is considered by many to be an international authority on indoor air quality, moisture, and condensation in buildings.

[28] Alas, I digress.

and/or harmful to the comfort and well-being of installers and occupants”. This intent was achieved by specifying all products that can be classified within the aforementioned categories to have Volatile Organic Compound (VOC) emission rate less than or equal to the maximum emission rate specified in the LEED-NC Version 2.2 Reference Guide. The successful achievement of these credits is especially imperative for an elementary school project, as young children may be more susceptible to the negative effects of VOC emissions than adults.

IEQ Credits 6.1 and 6.2 reference a building occupant’s ability to control the lighting and thermal comfort systems of occupied spaces, respectively. The generalized intent of these credits is to provide a high level of indoor environmental control “to promote the productivity, comfort, and well-being of building occupants”. The intent of these credits was achieved by the design team, who provided individual lighting controls for over 90% of the building occupants and individual comfort controls for over 50% of the building occupants. The design team also provided individual lighting and comfort system controllability in all shared multi-occupant spaces, assuring that each individual could manipulate their indoor environment to achieve comfort.

The design for Manassas Park Elementary School also achieved IEQ Credits 7.1 and 7.2. These credits reference the design and verification of a thermally comfortable environment for building occupants. The generalized intent of these credits is similar to that of Credit 6.2 (above); however, Credit 7.2 specifically requires an occupant assessment of the thermal conditions of the building after a specified period of time (6-18 months after occupancy) to ensure that the buildings thermal systems are operating as designed. To achieve the intent of these credits, the engineer of record complied with ASHRAE Standard 55-2004, *Thermal Comfort Conditions for Human Occupancy*, and the building owner agreed to administer a thermal comfort survey within the required time period[29].

IEQ Credits 8.1 and 8.2, *Daylight and Views*, were both achieved for this project. The generalized intent of these credits is to “provide for the building occupants a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building”. The intent of these credits was achieved by the architectural team, who completed a glazing factor calculation that proved that the required glazing factor of 2% was exceeded for over 75% of the buildings regularly occupied areas. Figure 1, below, shows the methodology for completing glazing factor calculations. The architectural design team also provided a direct line of sight to the outdoors to over 90% of the building occupants to further solidify their daily connection with nature.

$$\text{Glazing Factor} = \frac{\text{Window Area [SF]}}{\text{Floor Area [SF]}} \times \text{Window Geometry Factor} \times \frac{\text{Actual } T_{vis}}{\text{Minimum } T_{vis}} \times \text{Window Height Factor}$$

Figure 1: Glazing Factor Calculation Methodology

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[29] The required thermal comfort survey has not yet been administered to the building occupants; however, the building owner reports minimal occupant dissatisfaction with the thermal quality of the indoor environment.

The last mechanical design and/or energy consumption related credit that the design team was able to achieve cannot be found in the Energy & Atmosphere or the Indoor Environmental Quality categories of the LEED rating system, but rather in the Innovation & Design Process category[30]. Credit was given to the design team for their efforts to educate the buildings occupants on *how* the building was able to achieve the fundamental space and program requirements of an elementary school while decreasing the associated environmental toll. The design team discusses many of the design decisions through an easily comprehendible language on many plaques, placed throughout the building. These plaques discuss the effects of building orientation, daylight utilization, mechanical system design, material choice (and etcetera) on the overall stress that the building imposes on the environment. It was thought that if students learned and became accustomed to the technologies and methodologies implemented by the MPES design team, they would grow to appreciate and even request similar technologies on future building designs over which they had influence.

To defend the design team's decision to spend the extra time, effort, and money[31] on educating the building occupants, let's theorize the potential results of the successful communication of these building traits to just one student who becomes a successful property manager. The school holds over 500 students every year. If just 10% of these students are positively influenced by the sustainable traits of this building each year, than that means around 50 students each year will feel some sort of connection with the sustainable built environment. If after 10 years, only 1 out of the 500 influenced students becomes a successful property owner/manager, then the added time, effort, and money spent on educating the building's occupants will become negligible compared to the end result; perhaps hundreds of thousands of square feet of building area, built in an environmentally conscious manor and thus saving inconceivable amounts of energy and primary resources.

Conclusion

Overall, the building was able to achieve a certification of LEED Gold, with almost half of the earned credits being a direct result of the energy efficiency or mechanical systems of the school. While I must disagree with the Manassas Park City Schools Superintendent who was quoted saying that "LEED certification is not an easy thing to achieve", I must admit that a LEED Gold building certification proves that a strong effort was made by the design team to mitigate the detrimental effects that a new building has on our environment. This design team, along with others that share a similar mission, should be applauded for their continued efforts.

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[30] This category was not included in the initial breakdown of the LEED rating system because it is designed to give credit to ambiguous sustainable design traits of a project that do not fit within the traditional 5 categories.
[31] The educational signs were completely financed by the $50,000 grant, previously discussed in footnote 16.

Resources:

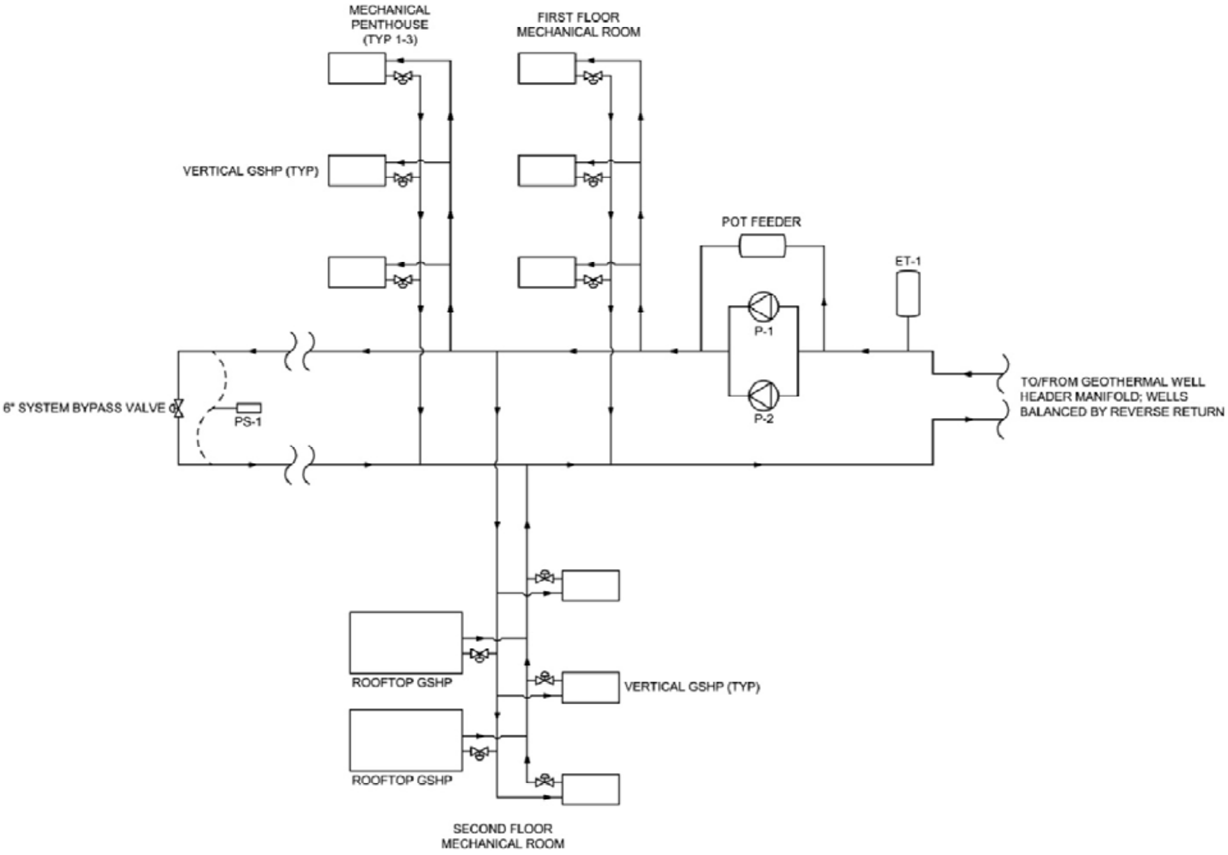
ASHRAE Journal
ASHRAE Standard 62.1-2004
ASHRAE Standard 62.1-2007
ASHRAE Standard 62.1-2004 Users Manual
ASHRAE Standard 90.1-2004
ASHRAE Standard 90.1-2007
ASHRAE Standard 90.1-2004 Users Manual
ASHRAE Handbook of Fundamentals
ASHRAE Handbook of HVAC Systems and Equipment
Source Energy and Emission Factors for Energy Use in Buildings – M. Deru and P. Torcellini (2007)
LEED-NC Version 2.2 Reference Guide

VMDO Architects; news articles – http://vmdo.com

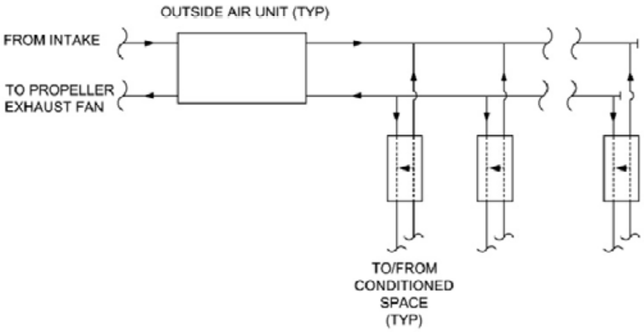
Gregory Smithmyer
James Gawthrop
Justin Herzing

Appendix A: System Schematics

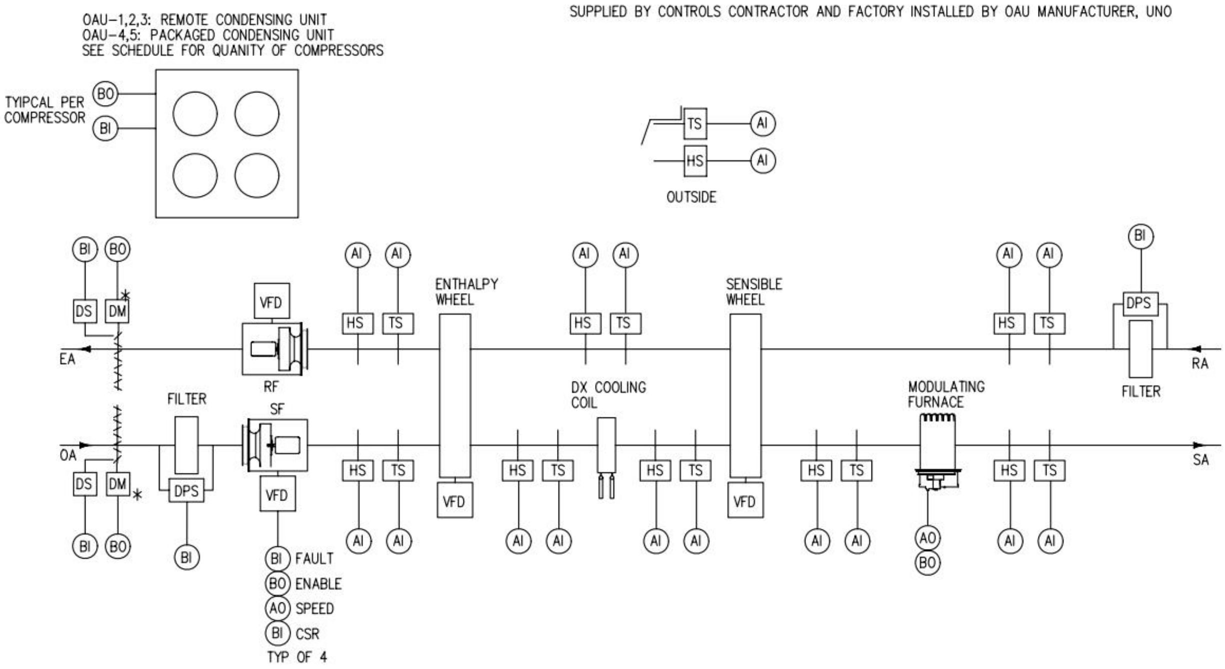
Water Side System Schematic



Air Side System Schematic



Appendix B: Outside Air Unit Schematic



Appendix C: LEED 2.2 Submittal – EA Credit 1

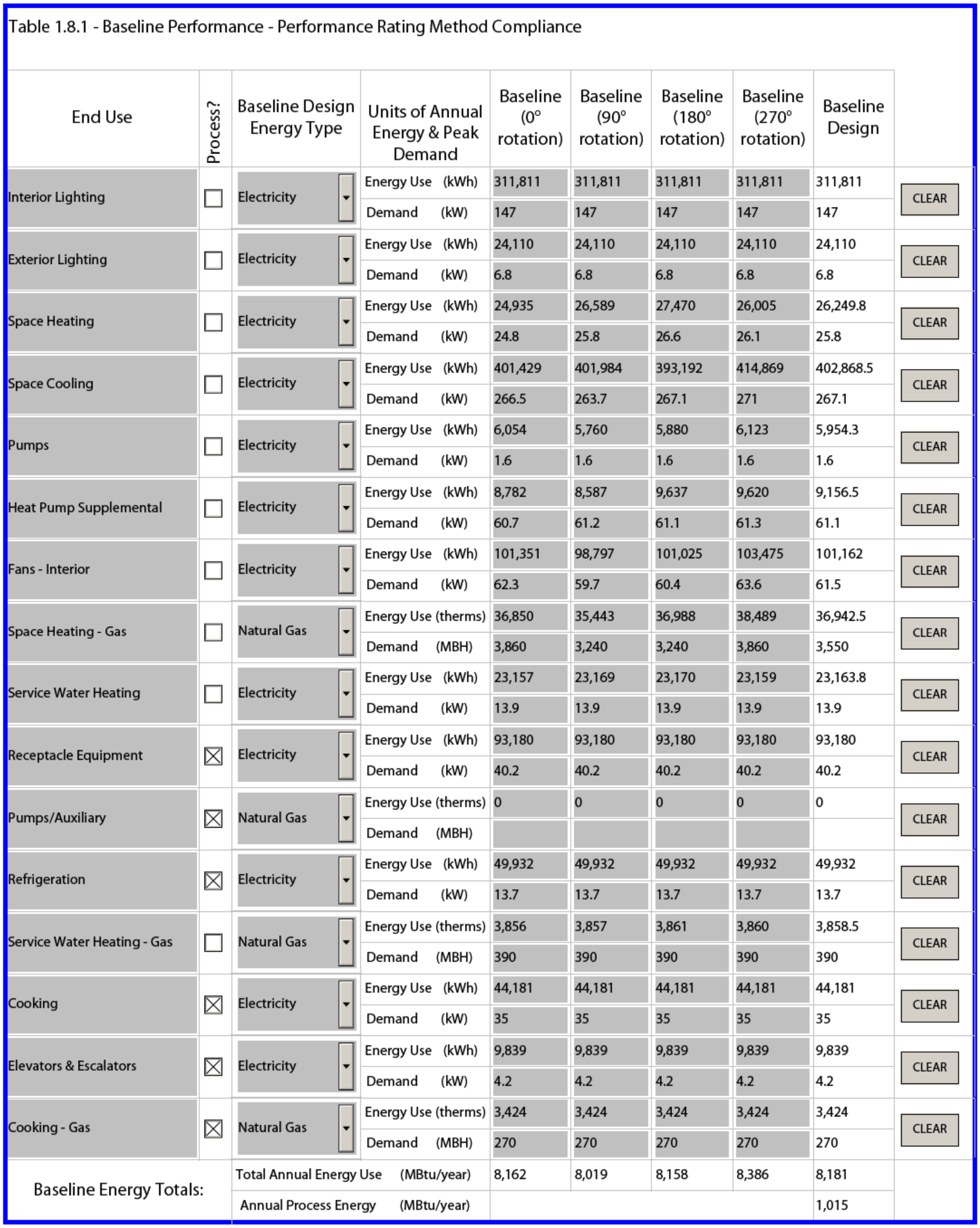
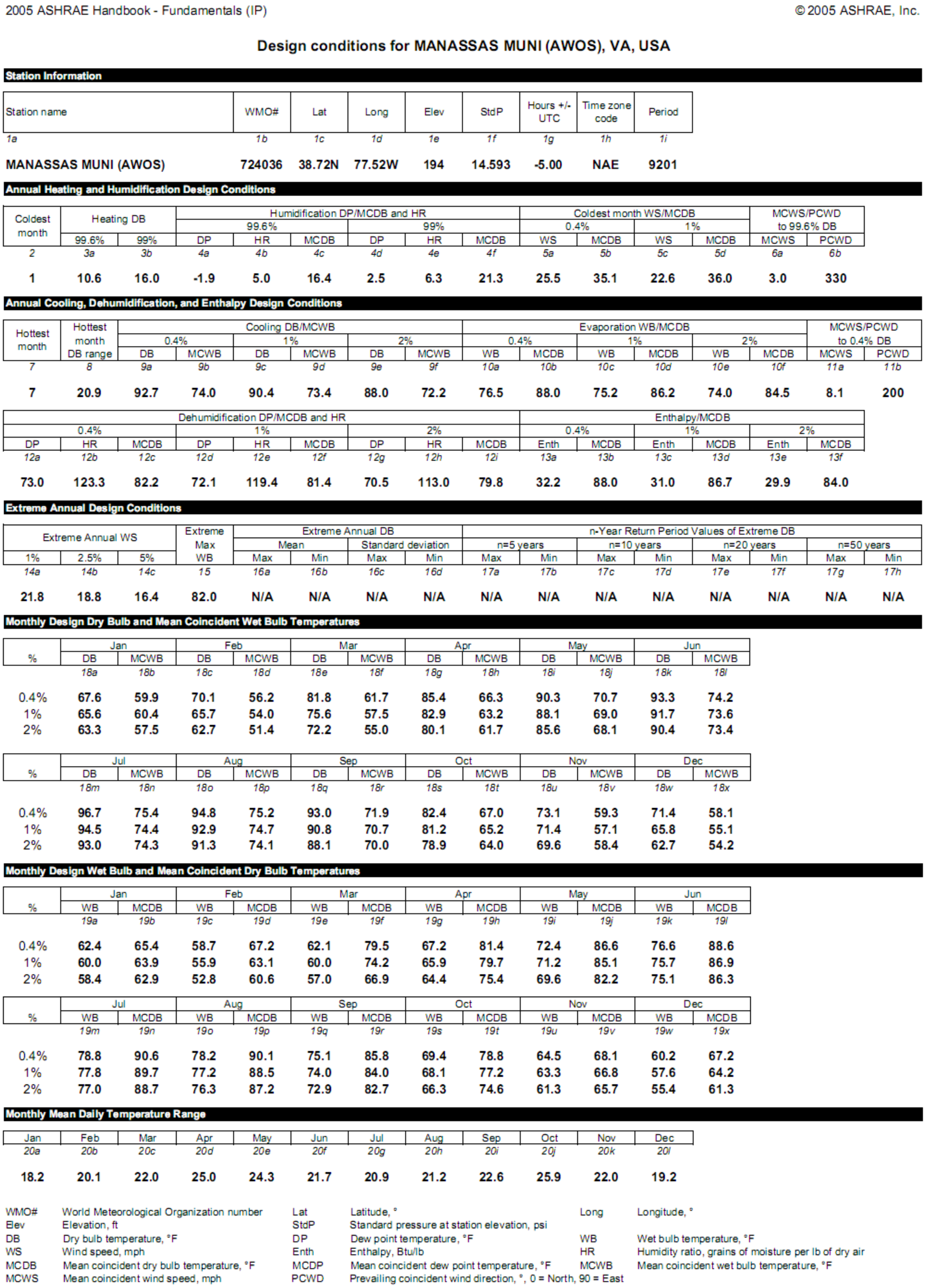


Table 1.8.1 - Baseline Performance - Performance Rating Method Compliance

End Use	Process?	Baseline Design Energy Type	Units of Annual Energy & Peak Demand	Baseline (0° rotation)	Baseline (90° rotation)	Baseline (180° rotation)	Baseline (270° rotation)	Baseline Design	
Interior Lighting	☐	Electricity	Energy Use (kWh)	311,811	311,811	311,811	311,811	311,811	CLEAR
			Demand (kW)	147	147	147	147	147	
Exterior Lighting	☐	Electricity	Energy Use (kWh)	24,110	24,110	24,110	24,110	24,110	CLEAR
			Demand (kW)	6.8	6.8	6.8	6.8	6.8	
Space Heating	☐	Electricity	Energy Use (kWh)	24,935	26,589	27,470	26,005	26,249.8	CLEAR
			Demand (kW)	24.8	25.8	26.6	26.1	25.8	
Space Cooling	☐	Electricity	Energy Use (kWh)	401,429	401,984	393,192	414,869	402,868.5	CLEAR
			Demand (kW)	266.5	263.7	267.1	271	267.1	
Pumps	☐	Electricity	Energy Use (kWh)	6,054	5,760	5,880	6,123	5,954.3	CLEAR
			Demand (kW)	1.6	1.6	1.6	1.6	1.6	
Heat Pump Supplemental	☐	Electricity	Energy Use (kWh)	8,782	8,587	9,637	9,620	9,156.5	CLEAR
			Demand (kW)	60.7	61.2	61.1	61.3	61.1	
Fans - Interior	☐	Electricity	Energy Use (kWh)	101,351	98,797	101,025	103,475	101,162	CLEAR
			Demand (kW)	62.3	59.7	60.4	63.6	61.5	
Space Heating - Gas	☐	Natural Gas	Energy Use (therms)	36,850	35,443	36,988	38,489	36,942.5	CLEAR
			Demand (MBH)	3,860	3,240	3,240	3,860	3,550	
Service Water Heating	☐	Electricity	Energy Use (kWh)	23,157	23,169	23,170	23,159	23,163.8	CLEAR
			Demand (kW)	13.9	13.9	13.9	13.9	13.9	
Receptacle Equipment	☒	Electricity	Energy Use (kWh)	93,180	93,180	93,180	93,180	93,180	CLEAR
			Demand (kW)	40.2	40.2	40.2	40.2	40.2	
Pumps/Auxiliary	☒	Natural Gas	Energy Use (therms)	0	0	0	0	0	CLEAR
			Demand (MBH)						
Refrigeration	☒	Electricity	Energy Use (kWh)	49,932	49,932	49,932	49,932	49,932	CLEAR
			Demand (kW)	13.7	13.7	13.7	13.7	13.7	
Service Water Heating - Gas	☐	Natural Gas	Energy Use (therms)	3,856	3,857	3,861	3,860	3,858.5	CLEAR
			Demand (MBH)	390	390	390	390	390	
Cooking	☒	Electricity	Energy Use (kWh)	44,181	44,181	44,181	44,181	44,181	CLEAR
			Demand (kW)	35	35	35	35	35	
Elevators & Escalators	☒	Electricity	Energy Use (kWh)	9,839	9,839	9,839	9,839	9,839	CLEAR
			Demand (kW)	4.2	4.2	4.2	4.2	4.2	
Cooking - Gas	☒	Natural Gas	Energy Use (therms)	3,424	3,424	3,424	3,424	3,424	CLEAR
			Demand (MBH)	270	270	270	270	270	
Baseline Energy Totals:		Total Annual Energy Use	(MBtu/year)	8,162	8,019	8,158	8,386	8,181	
		Annual Process Energy	(MBtu/year)					1,015	

Note: Process Cost accounts for 18% of Baseline Performance. Process cost must equal at least 25% of Baseline Performance, or the narrative at the end of this form must document why this building's process costs are less than 25%

Appendix D: ASHRAE Weather Data



2005 ASHRAE Handbook - Fundamentals (IP)

Design conditions for MANASSAS MUNI (AWOS), VA, USA

Station Information

Station name	WMO#	Lat	Long	Elev	StdP	Hours +/- UTC	Time zone code	Period
1a	*1b*	*1c*	*1d*	*1e*	*1f*	*1g*	*1h*	*1i*
MANASSAS MUNI (AWOS)	**724036**	**38.72N**	**77.52W**	**194**	**14.593**	**-5.00**	**NAE**	**9201**

Annual Heating and Humidification Design Conditions

Coldest month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB	
			99.6%			99%			0.4%		1%			
	99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD
2	*3a*	*3b*	*4a*	*4b*	*4c*	*4d*	*4e*	*4f*	*5a*	*5b*	*5c*	*5d*	*6a*	*6b*
1	**10.6**	**16.0**	**-1.9**	**5.0**	**16.4**	**2.5**	**6.3**	**21.3**	**25.5**	**35.1**	**22.6**	**36.0**	**3.0**	**330**

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

Hottest month	Hottest month DB range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB	
		0.4%		1%		2%		0.4%		1%		2%			
		DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD
7	*8*	*9a*	*9b*	*9c*	*9d*	*9e*	*9f*	*10a*	*10b*	*10c*	*10d*	*10e*	*10f*	*11a*	*11b*
7	**20.9**	**92.7**	**74.0**	**90.4**	**73.4**	**88.0**	**72.2**	**76.5**	**88.0**	**75.2**	**86.2**	**74.0**	**84.5**	**8.1**	**200**

Dehumidification DP/MCDB and HR									Enthalpy/MCDB					
0.4%			1%			2%			0.4%		1%		2%	
DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB
12a	*12b*	*12c*	*12d*	*12e*	*12f*	*12g*	*12h*	*12i*	*13a*	*13b*	*13c*	*13d*	*13e*	*13f*
73.0	**123.3**	**82.2**	**72.1**	**119.4**	**81.4**	**70.5**	**113.0**	**79.8**	**32.2**	**88.0**	**31.0**	**86.7**	**29.9**	**84.0**

Extreme Annual Design Conditions

Extreme Annual WS			Extreme Max WB	Extreme Annual DB				n-Year Return Period Values of Extreme DB							
				Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years	
1%	2.5%	5%		Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
14a	*14b*	*14c*	*15*	*16a*	*16b*	*16c*	*16d*	*17a*	*17b*	*17c*	*17d*	*17e*	*17f*	*17g*	*17h*
21.8	**18.8**	**16.4**	**82.0**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**

Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures

%	Jan		Feb		Mar		Apr		May		Jun	
	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB
	18a	*18b*	*18c*	*18d*	*18e*	*18f*	*18g*	*18h*	*18i*	*18j*	*18k*	*18l*
0.4%	**67.6**	**59.9**	**70.1**	**56.2**	**81.8**	**61.7**	**85.4**	**66.3**	**90.3**	**70.7**	**93.3**	**74.2**
1%	**65.6**	**60.4**	**65.7**	**54.0**	**75.6**	**57.5**	**82.9**	**63.2**	**88.1**	**69.0**	**91.7**	**73.6**
2%	**63.3**	**57.5**	**62.7**	**51.4**	**72.2**	**55.0**	**80.1**	**61.7**	**85.6**	**68.1**	**90.4**	**73.4**

%	Jul		Aug		Sep		Oct		Nov		Dec	
	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB
	18m	*18n*	*18o*	*18p*	*18q*	*18r*	*18s*	*18t*	*18u*	*18v*	*18w*	*18x*
0.4%	**96.7**	**75.4**	**94.8**	**75.2**	**93.0**	**71.9**	**82.4**	**67.0**	**73.1**	**59.3**	**71.4**	**58.1**
1%	**94.5**	**74.4**	**92.9**	**74.7**	**90.8**	**70.7**	**81.2**	**65.2**	**71.4**	**57.1**	**65.8**	**55.1**
2%	**93.0**	**74.3**	**91.3**	**74.1**	**88.1**	**70.0**	**78.9**	**64.0**	**69.6**	**58.4**	**62.7**	**54.2**

Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures

%	Jan		Feb		Mar		Apr		May		Jun	
	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB
	19a	*19b*	*19c*	*19d*	*19e*	*19f*	*19g*	*19h*	*19i*	*19j*	*19k*	*19l*
0.4%	**62.4**	**65.4**	**58.7**	**67.2**	**62.1**	**79.5**	**67.2**	**81.4**	**72.4**	**86.6**	**76.6**	**88.6**
1%	**60.0**	**63.9**	**55.9**	**63.1**	**60.0**	**74.2**	**65.9**	**79.7**	**71.2**	**85.1**	**75.7**	**86.9**
2%	**58.4**	**62.9**	**52.8**	**60.6**	**57.0**	**66.9**	**64.4**	**75.4**	**69.6**	**82.2**	**75.1**	**86.3**

%	Jul		Aug		Sep		Oct		Nov		Dec	
	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB
	19m	*19n*	*19o*	*19p*	*19q*	*19r*	*19s*	*19t*	*19u*	*19v*	*19w*	*19x*
0.4%	**78.8**	**90.6**	**78.2**	**90.1**	**75.1**	**85.8**	**69.4**	**78.8**	**64.5**	**68.1**	**60.2**	**67.2**
1%	**77.8**	**89.7**	**77.2**	**88.5**	**74.0**	**84.0**	**68.1**	**77.2**	**63.3**	**66.8**	**57.6**	**64.2**
2%	**77.0**	**88.7**	**76.3**	**87.2**	**72.9**	**82.7**	**66.3**	**74.6**	**61.3**	**65.7**	**55.4**	**61.3**

Monthly Mean Daily Temperature Range

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
20a	*20b*	*20c*	*20d*	*20e*	*20f*	*20g*	*20h*	*20i*	*20j*	*20k*	*20l*
18.2	**20.1**	**22.0**	**25.0**	**24.3**	**21.7**	**20.9**	**21.2**	**22.6**	**25.9**	**22.0**	**19.2**

WMO#	World Meteorological Organization number	Lat	Latitude, °	Long	Longitude, °
Elev	Elevation, ft	StdP	Standard pressure at station elevation, psi		
DB	Dry bulb temperature, °F	DP	Dew point temperature, °F	WB	Wet bulb temperature, °F
WS	Wind speed, mph	Enth	Enthalpy, Btu/lb	HR	Humidity ratio, grains of moisture per lb of dry air
MCDB	Mean coincident dry bulb temperature, °F	MCDP	Mean coincident dew point temperature, °F	MCWB	Mean coincident wet bulb temperature, °F
MCWS	Mean coincident wind speed, mph	PCWD	Prevailing coincident wind direction, °, 0 = North, 90 = East		

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