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A Framework to Improve Energy Usage and Reduce the Environmental Footprints in Commercial Buildings

Jeffrey M Molavi¹, Kevin J Prag²

Professor, Department of Technology, University of Maryland Eastern Shore, USA¹

Construction Professional, GMB Engineering Group, Salisbury, Maryland, USA²

ABSTRACT: The construction industry is constantly searching for new methods and materials to comply with environmental requirements, reduce construction and operational costs, and make a comfortable space for occupants. The most efficient way to reduce the operating costs of a building is to cut down energy costs. Two systems that perform this objective the best are solar panel technology and geothermal heating system, as renewable energy, satisfy the environmental protection requirement. There are several methods available to become more energy efficient, including the green building technologies of increased envelope insulation and passive design, alternative energy through geothermal heating and solar panel technology. This paper will investigate the following systems: namely the energy performance of a typical building and the proposed protocol compared to the cost and environmental foot-print of a standard high performance building model. Furthermore, an analysis can be performed to see how well our prototype that uses these strategies measures up to the LEED standards. The calculations for energy performance and analysis will all be based on the performance baseline established by ANSI/ ASHRAE/ IESNA Standard 90.1-2007. This study provides a baseline for further investigations in building performance and lifecycle cost analysis of buildings.

KEYWORDS: Energy Performance, LEED, Geothermal Heat Pump, Building Envelope

I. INTRODUCTION AND HEATING METHODS

Although decreasing in the U.S., typical commercial stores use an induced draft furnace system to heat a building but the prototype building will utilize a geothermal system. Although a simpler heat pump system may be used, geothermal offers greater energy savings and LEED credit benefits for any building. Average operational costs for a geothermal system use 1 kWh of electricity to heat 10.24 MBtu (Marques, Bohorquez, & Melgar, 2016, p. 2).

Geothermal, as a heating, ventilation, and air conditioning (HVAC) system works by drawing heat from or depositing heat in underground soil layers. According to Coastal Comfort (ND), a geothermal well is simply underground pipes connected to a heat pump. A heat pump is a machine that uses a “heat exchanger [to transfer] heat between refrigerant and an antifreeze solution.” This function serves to condition air that is in a buildings ductwork, whether outside air or a mixture of outside air and inside air, to control the temperature in a building. One may be familiar with the exterior air conditioning unit attached to the majority of single-family residences and many commercial buildings; those models use the large fan(s) on top to circulate outside air to the heat exchanger. Instead of moving outside air, a heat pump may circulate a liquid or gas through an underground pipe network. In the warmer days of the year, the system will circulate heated liquid or gas to transfer heat into the ground, therefore cooling the liquid; in cooler days, the circulation is reversed.

The pipe network configuration may vary depending on the soil quality present at a building site. Coastal Comfort (ND) describer’s two network options: close loop and vertical loop. The close loop is a relatively shallow configuration. “[T]wo or more wells” are dug and each pipe run will lay horizontally. A vertical loop will extend to a depth between 100 feet and 400 feet and loop back up. Both networks are closed and rely on the transfer of heat from the pumped

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liquid or gas, through the pipe material to the ground or vice versa. As indicated in the study by Cho, Nam, and Kim, a well may be open ended so that the heat exchange fluid is the water from an aquifer. Regardless, the functionality of the system requires the exchange of thermal energy in the earth. Furthermore, the heat production of a geothermal system (Q) is related to the thermal transfer properties of the system. This can be modelled by: $Q = C_p \times mw \times \Delta T$

where C_p is the specific heat of the pumped fluid, mw is the flow rate of the pumped fluid in cubic feet per minute (cfm), and ΔT is the temperature difference of the ground at the bottom of the loop (Cho, Nam, & Kim, 2016). This equation alongside a soil study yields the heat production ability of the system.

The efficiency of a geothermal system is directly related to the soil temperature and the soil thermal diffusivity. In the study by Márques, Bohórquez and Melgar (2016), the thermal change is variable for the first 15m (~49.2 ft.) then changes to a constant increase of 3°C for every 100m depth (~37.4°F / 328 ft.) or 0.114 °F/ft.) (Marques, Bohorquez, & Melgar, 2016). The first 49.2 ft. is referred to as the stable layer and the swings/ variations result from solar radiation and rainfall. The researchers Cho, Nam, and Kim (2016) disagree and write ΔT is the only factor the soil contributes to a geothermal systems heat production; they do not provide a mathematical proof for this assertion. For the purposes of this report, the soil analysis, as it relates to the production of thermal energy, will only consider a theoretical mean soil temperature in the stable layer. Furthermore, an average ground temperature for the Delmarva Peninsula is 57°F (Coastal Comfort, ND); this will be assumed as the mean annual ground temperature in the stable layer.

A good HVAC system is only half of the design consideration because when one generates heat, one must retain the heat as long as possible to maintain a desired temperature. The consideration of the walls of the prototype building must involve assessing the resistance to heat transfer in the external wall materials. This is done by analyzing the thermal resistivity of the layered materials that are assembled to construct the building envelope.

Most heat transfer is mitigated by the insulation within the walls. However, the wall must be able to hold the weight of the roof, the weight of wind pressing against the sides and snow loads on top of the roof using structural studs; studs, whether aluminium, wood or another material, act as a “thermal bridge” and thereby reduce the thermal resistance per linear foot relative to their prevalence within the construction of the exterior wall (Wujek & Dagostino, 2010, p. 44). The calculation for the prototype building will consider a standard construction framing structure of studs placed along the center of the wall at 16 inches on-center. The framing material for all comparative buildings will be 2x6 wood studs because the material is easily accessible in the U.S. and the thermal bridge effect is the least among common construction materials.

This paper will focus on one insulation type: aerogel is the best insulation available that is highly rated for environmentally friendly design. Aerogel is the most environmentally friendly insulative material that may be used in a building envelope on the market currently. The material is produced by removing liquid contents from silica and replacing the liquid contents with air under high pressure and temperature. Aerogel is purchased as a blanket in commercial markets and are form fitted by a worker. As the liquid expands into a foam, it fills and conforms to a wall cavity. The material has a thermal resistivity of R10.3 per inch and can be installed for \$2 per linear foot and comes in 57” sheets by 1.5” thick. The building prototype will have a calculated material cost based on volume fill required between studs and an assumed labor cost of \$6.03 per square foot of wall area and \$8.01 per square foot of ceiling area based on typical labor rates for the installation of high quality insulative blankets (Plotner et al, 2016, p. 225).

II. RELATED WORK

Research was conducted to investigate whether there had been any previous papers were written that analyzed building cost and energy usage with regard to LEED building guidelines; There was only one other paper that could be found. However, studies on geothermal design and efficiency were found and a study on solar panel design and efficiency was found; this gathered information for this paper in parts but are applied to form a whole model.

Cho, Nam and Kim (2016) investigated the efficiency and production capability of a deep well geothermal system with an open loop configuration. The experiment was conducted on a scale model and a working commercial building in

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South Korea. By monitoring the Btu output as compared to the circulation speed in the system they tabulated the heat generation as well as the cyclical heat reduction over the course of a year [1].

Márques, Bohórquez and Melgar (2016) analyzed how soil temperatures can affect the thermal output of a geothermal system. The focus was on soil diffusivity: it is the ability of a soil to transfer heat relative to its density and chemical composition. They also developed an equation for measuring the ground temperature swings within the stable layer relative the mean ground temperature for a given area. They found that as the depth increases, the effect of solar and precipitous temperature change decreased up to about 50 feet [3].

Molavi, and Barrall (2014) conducted a similar research project from which the fundamental structure, assumptions and baselines will be mimicked in this paper. The authors investigated a theoretical commercial building with environmentally friendly modifications as compared to a baseline commercial building pursuant to Standard 90.1-2007. The buildings' heat loads, components' construction prices, and electrical generation to calculate a payback period.[4]

Molavi, and Prag (2017) conducted a following study with the same parameters as Molavi, and Barrall (2014). The information analysed the components to compare the efficiencies in a newer market for materials and fuel. The results from the portion of the data regarding the efficiency of aerogel will be used in the Revit simulation. Furthermore, the model developed for the paper will be revised to be more accurate to a real retail store. Refer to Appendix A for the building layout.

Molavi, and McDaniel (2016) investigated the geothermal heat pump systems in retail building. Although, the concept of geothermal is not new and it has been around since 1940s, the interest and favourability of this systems have remained modest. Researches on feasibility of the systems and the technological advancement on one hand and the environmental concerns and regulations on the other together have shown the viability of geothermal systems in 21th century [13].

III. SUSTAINABLE OPPORTUNITY

For this building analysis, the standard grading system for a building's environmental impact will be the Leadership in Energy and Environmental Design (LEED) standards produced by the United States Green Building Council (USGBC). The standards offer ways to appraise any building; this is typically done on a point scale that will give a range of value depending on the item being assessed and the comparative advantage the item has over similar items. When presented in this paper, the buildings will be given a range of total LEED point's available (worst case scenario to best case scenario) [7].

For the building envelope, LEED offers points in the categories for the insulation in the materials category and in the energy conservation category. The materials category includes both how the material is manufactured and how well the insulation reduces. For up to two points, the insulation must exceed the building code requirement by 10% for one point and 20% for two points (The US Green Building Council, 2014). Another two points can be achieved if the insulation doesn't fail at completely filling the area requiring insulation up to 2% of the total exterior wall area (The US Green Building Council, 2014) [8]. In the energy conservation category three points are possible for building design if the total glass area on the southern side of a building is 50% greater than the combined area of both the east and the west facing, exterior walls. (The US Green Building Council, 2014). While this list is not exhaustive, a basic credit summary is proposed here [9].

LEED lists geothermal heating and cooling under its energy conservation category as well as solar panels. For a geothermal system, a total of 4 points will be awarded if the system has a COP rating of 4.0 or greater and an EER rating of 17 or greater (The US Green Building Council, 2014).¹ Solar panels are given up to 3 points depending on the percentage of the building's electrical cost is covered: 5% = 1 point, 12.5% = 2 points, and 20% = 3 points (The US

¹ This assumes the building's location is in climate zone 4.

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Green Building Council, 2014). While geothermal does appear alongside the solar panel point description, the assumption there is that the geothermal system is generating electricity; in this paper it will not [10].

A model building will be assessed by a simulation based on the materials and equipment used, ability to retain heat and relative cost of operation. The analysis will utilize the design recommendations and procedures for calculating heat loss and heat load as prescribed by chapters 2 through 5 in the textbook by Wujek and Dagostino (2010) [1]. The calculations are broken down into 5 categories, heat loss through transmission through the building envelope, through infiltration and ventilation, through the perimeter of the slab on grade and gains from solar radiation through the south facing curtain wall.

IV. ENERGY PERFORMANCE ANALYSIS FOR PROPOSAL

A model building will be assessed by a simulation based on the materials and equipment used, ability to retain heat and relative cost of operation. The analysis will utilize the design recommendations and procedures for calculating heat loss and heat load as prescribed by chapters 2 through 5 in the textbook by Wujek and Dagostino (2010) [13]. The calculations are broken down into 5 categories, heat loss through transmission through the building envelope, through infiltration and ventilation, through the perimeter of the slab on grade and gains from solar radiation through the south facing curtain wall.

V. HEATING LOAD ANALYSIS

For the model analysis, the location of the building was chosen to be in Princess Anne, Maryland; the heating degree day's value was chosen from the meteorological data for Princess Anne from ClimaTemps.com. The model does not need a specific address to complete a calculation but does need the building's orientation. To create a best-case scenario, the building front is assumed to be facing due south. For a baseline model, the building will consist of 3 stud walls, 1 glass curtain wall, 1 rear overhead door and 1 rear window. To remain consistent with the previous work by Molavi, and Barrall (2014), the building's dimensions will also be 80' x 100' x 14' [4] as shown in the next page appendix A.

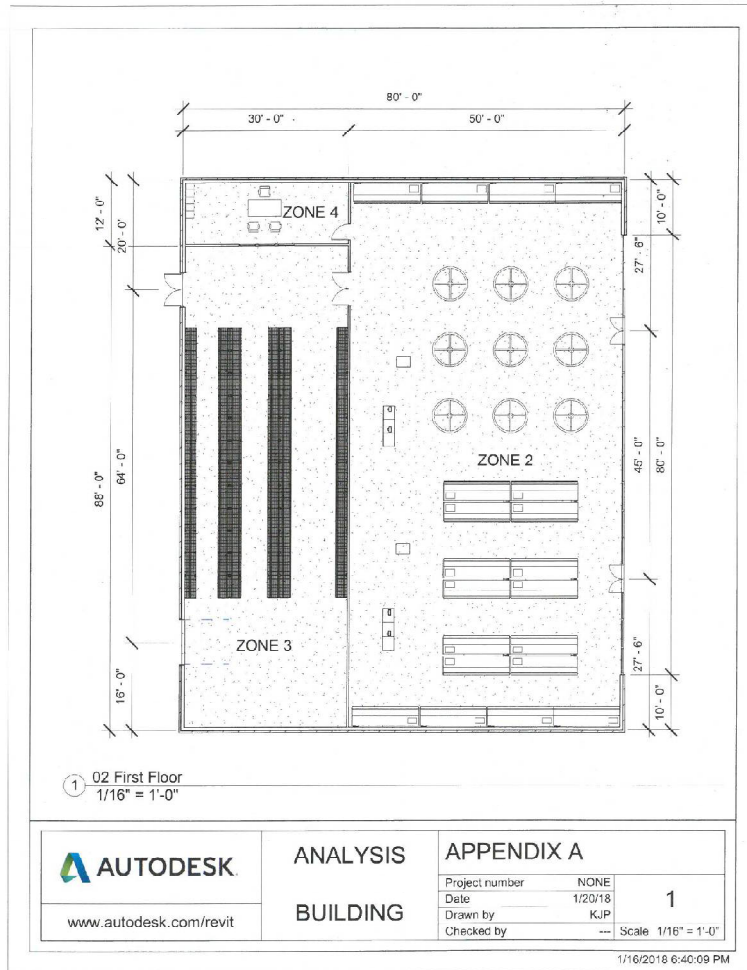
APPENDIX B								11
Heat Loss Table								
Month	Base Temperature	Average Temperature	Heat Loss				Solar Gain	
			Wall	Garage Door	Rear Door	Front Curtain Wall		
January	70	35	56,866	8,467	16,582	329,280	-523,044	
February	70	37	53,616	7,983	15,634	310,464	-581,160	
March	70	46	38,994	5,806	11,370	225,792	-639,276	
April	70	54	25,996	3,871	7,580	150,528	-697,392	
May	70	64	9,748	1,452	2,843	56,448	-755,508	
June	70	72	-3,249	-484	-948	-18,816	-813,624	
July	74	76	-3,249	-484	-948	-18,816	-755,508	
August	74	75	-1,625	-242	-474	-9,408	-697,392	
September	70	69	1,625	242	474	9,408	-639,276	
October	70	58	19,497	2,903	5,685	112,896	-581,160	
November	70	49	34,120	5,080	9,949	197,568	-523,044	
December	70	40	48,742	7,258	14,213	282,240	-464,928	
Month	Base Temperature	Average Temperature	Heat Loss				Total	
			Floor	Roof	Infiltration	Ventilation		
January	70	35	12,096,000	93,489	846,720	2,217,600	15,141,959	
February	70	37	11,404,800	88,146	798,336	2,090,880	14,188,700	
March	70	46	8,294,400	64,106	580,608	1,520,640	10,102,441	
April	70	54	5,529,600	42,738	387,072	1,013,760	6,463,752	
May	70	64	2,073,600	16,027	145,152	380,160	1,929,921	
June	70	72	-691,200	-5,342	-48,384	-126,720	-1,708,767	
July	74	76	-691,200	-5,342	-48,384	-126,720	-1,650,651	
August	74	75	-345,600	-2,671	-24,192	-63,360	-1,144,964	
September	70	69	345,600	2,671	24,192	63,360	-191,704	
October	70	58	4,147,200	32,053	290,304	760,320	4,789,698	
November	70	49	7,257,600	56,093	508,032	1,330,560	8,875,958	
December	70	40	10,368,000	80,133	725,760	1,900,800	12,962,218	
APPENDIX B								12
Heat Loss Graph								

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VI. INFILTRATION AND VENTILATION LOSSES

Heat loss through air gaps in the buildings' constructions will be calculated through the Revit analysis program. Typically in an infiltration heat loss calculation, the three factors that determine how much heat escapes are the air changes per hour, the volume of the space and the temperature difference between the inside and the outside of the building. The focus will be on the air changes per hour which is an estimated value (0.5) which dictates how many times the entire air volume of a space is changed with outside air in one hour (Wujek & Dagostino, 2010, p. 96) [13].

Solar panels may also increase the amount of savings for a particular building because it can generate electricity over the course of the day by converting sunlight into electricity. Modern solar panels cover about 12 square feet of area and produce 280 watts (Paradise Energy Solutions Representative, 2017) [5]. Typically, they are priced according to the energy generation desired by the client; this makes construction pricing unique in the construction industry. In order to be consistent with the data provided by Molavi, and Barrall, a 2% inflation rate and 2,004 square feet of solar panels as Shown below under appendix B [4].

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APPENDIX B					
Geothermal Heating and Cooling Demand Table					
Month	Heat Load	Btu/ KWhr.	KWhr.	Average Daily Cost	Total with Solar
January	15,141,959	10,240	1,479	\$147.87	\$144.04
February	14,188,700	"	1,386	\$138.56	\$134.31
March	10,102,441	"	987	\$98.66	\$93.98
April	6,463,752	"	631	\$63.12	\$58.02
May	1,929,921	"	188	\$18.85	\$13.32
June	-1,708,767	"	167	\$16.69	\$10.74
July	-1,650,651	"	161	\$16.12	\$10.59
August	-1,144,964	"	112	\$11.18	\$6.08
September	-191,704	"	19	\$1.87	-\$2.80
October	4,789,698	"	468	\$46.77	\$42.52
November	8,875,958	"	867	\$86.68	\$82.85
December	12,962,218	"	1,266	\$126.58	\$123.18

APPENDIX B					
Solar Production Table					
Month	Average Sunlight Hours	Proposed Number of Panels	Electrical Generation	Total Wattage	Cost Savings
January	9	167	280	38,258	\$3.83
February	10	"	"	42,509	\$4.25
March	11	"	"	46,760	\$4.68
April	12	"	"	51,011	\$5.10
May	13	"	"	55,262	\$5.53
June	14	"	"	59,513	\$5.95
July	13	"	"	55,262	\$5.53
August	12	"	"	51,011	\$5.10
September	11	"	"	46,760	\$4.68
October	10	"	"	42,509	\$4.25
November	9	"	"	38,258	\$3.83
December	8	"	"	34,007	\$3.40

VII. COST EFFECTIVENESS

As seen in Appendix B, the heat gain is the primary concern for the building with respect to the efficiency of the building. The highest spikes in January through February are indicative of the natural progression of temperatures during the Earth's orbit. A similar note could be made of the solar panel generation rates. Regardless, the aerogel insulation is dramatically reducing the daily heating cost which never exceeds \$150 on any given day.

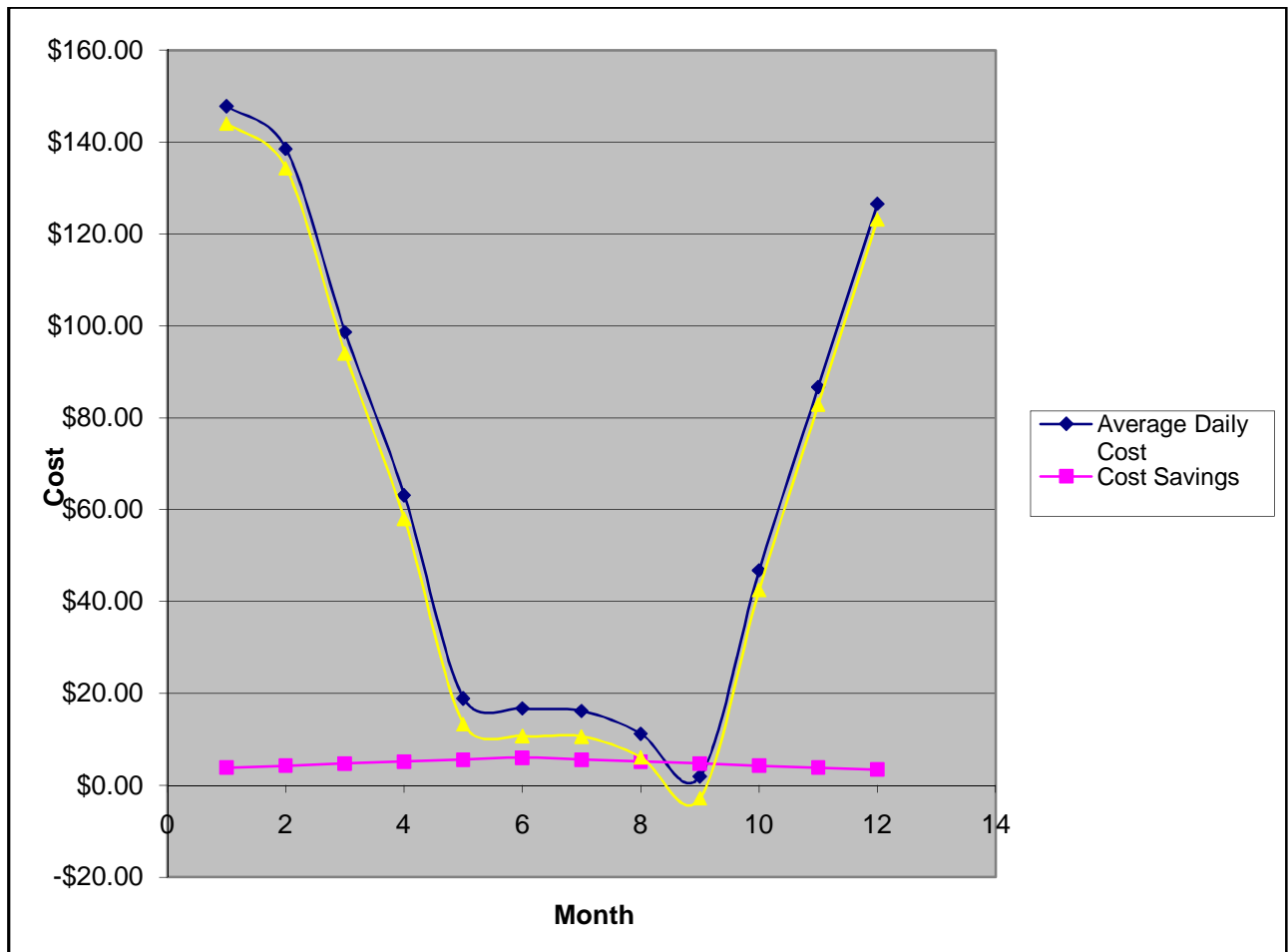
The cooling load is marginal in comparison as the cost lowers to a negative value in September; a point at which, the building could be advertised as earning money through normal operation. These values could be higher. The main divergence of the graph between the cost and the total cost with solar is in the summer months. As solar panel technology becomes more efficient, the cost gap between the two figures will inevitable widen. The following graph shows the cost saving using this method.

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VIII. CONCLUSION AND FUTURE STUDY

The optimized building, would benefit the owner by increasing the LEED points for the evaluation from five to fourteen points. On the higher end, these improvements account for 17.5% of the points necessary for the basic LEED certification². While that might not result in a large portion of the LEED grading requirements being fulfilled, other marginal improvements an owner may make will add up to the higher LEED certifications. With the popularity of green initiatives on the rise, building owners are offered and advertising opportunity to capitalize on their building's environmental friendliness.

Future models and investigations should include a more complex breakdown of building sizes and their relative environments. This study focused on an 8,000 square foot retail building in an open area. Other studies should make a distinction based on a greater variety of square footage break downs. For example, three buildings, with differing square footages and number of stories, would be evaluated against each other based on the impact of energy saving and environmentally friendly improvements has on the economic viability of each building; This could be measured in payback periods and percentage of cost addition. Another investigation could be on regional economies: Maybe the commercial building' economic viability could be gauged in a regional zone of the Delmarva Peninsula; how much is the construction of each element (insulation, geothermal, or solar)? Finally, geotechnical testing could yield more

² See www.usgbc.com for more information on the LEED rating system.

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valuable data for measuring geothermal efficiency and meteorological testing could yield more valuable data on the efficiency of solar panels.

As it pertains to an optimized energy performance building, the investment is valuable because the net value of the operational expense in the late summer or early fall is negative. The investigation into the costs related to the economic and environmental benefits shows that future buildings will be more energy efficient by adopting better insulative construction, HVAC equipment and implementing on-site energy production capabilities. This study will help to improve baseline modeling for future investigations into the new technology implementation as it relates to energy conservation.

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