Domestic Hot Water System Redesign

OVERVIEW

The domestic hot water system redesign includes the use of solar collectors to assist in hot water heating. Because the amount of domestic hot water used in a hospital is typically very large, the operating cost of the system can be significantly decreased. However, the first cost of a solar collection system is typically very high, and therefore, methods to mitigate this expense such as rebates or other incentives must be explored. Although this redesign may not be substantially beneficial economically due to the length of the payback period, the use of renewable energy will reduce fossil fuel consumption, paving the way towards lower emissions to help slow down climate change.

OBJECTIVES

- Reduce domestic water heating costs
- Indirectly reduce greenhouse gas emissions
- Maintain existing comfort level
- Attain a reasonable payback period

DESIGN

Determining the amount of domestic hot water used in the South Tower Vertical Expansion that could be supported by solar water heating is the first step in the redesign process. Similar to the chilled water plant redesign, only the floors of the expansion will be analyzed, which includes floors four, five, and six and the link and lobby. To simplify the design process, values obtained from fourth floor will also represent the fifth and sixth floors as all three floors offer similar services.

HOT WATER DEMAND

The hot water demand for the South Tower Vertical Expansion will be determined using the 2007 ASHRAE Handbook, HVAC Applications. The number of fixtures on the fourth floor will be tallied and multiplied by the hot water demand per fixture. See Appendix B for these calculations.

After completing these calculations, the hot water demand was found to be 290 gallons per hour (GPH) per floor. After factoring in a demand factor or 0.25 and three floors, the total hot water demand for the entire expansion is 3.625 gallons per minute (GPM). Knowing the volumetric flow rate, the amount of heat input required to raise the water temperature 80°F can be determined, assuming a cold water supply temperature of 60°F and a final hot water distribution temperature of 140°F:

$$Q = 500\left[\frac{min \cdot BTU}{hr \cdot gal \cdot °F}\right] \times GPM \left[\frac{gal}{min}\right] \times \Delta T\ [°F]$$

$$Q = 500\left[\frac{min \cdot BTU}{hr \cdot gal \cdot °F}\right] \times 3.625 \left[\frac{gal}{min}\right] \times 80\ [°F]$$

$$Q = 145{,}000\ [BTU/hr]$$

$$Q = 104{,}400{,}000\ [BTU/month]$$

$$Q = 1{,}270{,}200{,}000\ [BTU/year]$$

Based on these heat input values, the amount of solar energy that needs to be collected can be determined.

SOLAR STUDY

The orientation of solar collectors is critical to a solar water heating system. Table 4.1 displays the sun's altitude and azimuth range during the winter and summer solstices for Baltimore, MD when the strength of solar energy is at its weakest and at its strongest, respectively.

	Winter Solstice	Summer Solstice
Date:	December 21, 2009	June 21, 2009
Altitude Range:	-11.9° to 27.3°	-11.5° to 74.1°
Average Altitude:	7.7°	31.3°
Azimuth Range:	110.7° to 249.3°	46.2° to 312.6°
Average Azimuth:	180°	179.4°

TABLE 4.1

Because the average azimuth is exactly 180°, the most optimal orientation for the solar collectors is directly facing south. The tilt of the solar collectors should be at a medium where the maximum amount of solar energy can be collected throughout each day and throughout the year. Manufacturer Heliodyne recommends a tilt at latitude minus five degrees.

Latitude (Baltimore, MD):	39°N
Recommended Tilt:	34°

TABLE 4.2

SOLAR INTENSITY

The amount of solar energy reaching the surface of the solar collectors is a variable value due to the constantly changing weather conditions and panel efficiency. The amount of energy absorbed is affected by ambient temperature, clouds, fog, and pollution, which cannot be accurately predicted. Therefore, average solar intensities will be used, which will provide a reasonable estimate of solar energy collected. These values can be used to determine how many solar collectors are needed.

SOLAR COLLECTORS

Heliodyne solar flat-plate collectors will be used for the domestic hot water system redesign. These collectors operate at an optimal efficiency with 95% absorption and 5% emission. The collectors with the blue sputtered coating and high selective surface are suitable for all regions. See Appendix D for product specifications.

ABSORBTION

To determine the amount of solar radiation absorbed by the collectors, data must be obtained which describe average solar radiation in Baltimore, MD on a daily, monthly, or yearly basis. For this report, the values will come from the National Solar Radiation Database, which contains thirty years of meteorological data. They represent the amount of solar radiation absorbed by collectors mounted facing south and tilted at an angle of 39°, which is more conservative than the actual tilt of 34°. This is illustrated in Table 4.3.

	Average Solar Radiation	
Month	BTU/ft²/day	BTU/ft²/month
January	658	20,407
February	908	25,415
March	1,230	38,128
April	1,555	46,662
May	1,778	55,129
June	1,954	58,612
July	1,909	59,190
August	1,686	52,279
September	1,392	41,748
October	1,046	32,429
November	707	21,207
December	561	17,393
Total		468,598

TABLE 4.3

COLLECTOR EFFICIENCY

Although the average solar radiation absorbed by the collectors has been calculated, the efficiency of a Heliodyne solar flat-plate collector must be taken into account. Its efficiency plot has been provided.

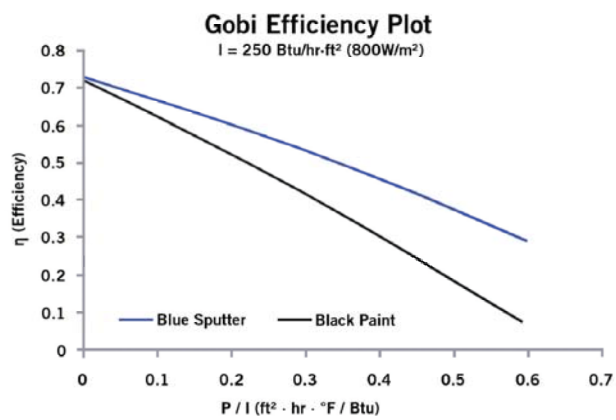

FIGURE 4.1

**Assume the average fluid temperature within the collectors is 145°F*

Month	Max Solar Radiation [BTU/ft²/month]	Average Ambient T [°F]	Efficiency	Actual Solar Radiation [BTU/ft²/month]
1	20,407	31.8	0.372	7,602
2	25,415	34.8	0.382	9,712
3	38,128	44.1	0.412	15,713
4	46,662	53.4	0.442	20,627
5	55,129	63.4	0.474	26,145
6	58,612	72.5	0.504	29,514
7	59,190	77.0	0.518	30,663
8	52,279	75.6	0.514	26,847
9	41,748	68.5	0.491	20,485
10	32,429	56.6	0.452	14,669
11	21,207	46.8	0.421	8,924
12	17,393	36.7	0.388	6,753
Total				217,653

TABLE 4.4

SOLAR COLLECTION AREA

In order to meet the energy requirements of heating the domestic water, a large amount of surface area must be available. To calculate the minimum required surface area, the month with the least amount of solar radiation available must be considered, which is December with a monthly solar radiation of 6,753 BTU/ft^2. The minimum required surface area on the collectors must be:

$$Surface\ Area = \frac{104{,}400{,}000\ [BTU/month]}{6{,}753\ [\frac{BTU}{ft^2}/month]}$$

$$Surface\ Area = 15{,}460\ [ft^2]$$

Each Heliodyne solar flat-plate collector (model GOBI 410) has net surface area of 37.47 ft^2. The minimum number of collectors required for hot water heating in December would then be:

$$\#\ Of\ Collectors = \frac{15{,}460\ [ft^2]}{37.47\ [ft^2]}$$

$$\#\ Of\ Collectors = 413$$

As a comparison, the minimum number of collectors required during the month with the greatest amount of solar radiation available, July, is 91, which is roughly 22% of the solar collectors required in December. Because space may not be available to locate 413 solar collectors, solar water heating may have to be only a partial energy source. For now, 413 collectors are assumed to be installed, and the effects of partial heating (and a lower fluid temperature in the collectors) will be evaluated in later in this report.

SYSTEM MODIFICATIONS

The added solar water heating system will be used in conjunction with the existing steam-to-hot water converter. The heat exchanger will act as a backup and provide redundancy to maintain a hot water temperature of 140°F at all times, which is required to prevent bacteria growth when solar absorption is low. Additionally, it could also partially heat the water to increase the performance and efficiency of the solar collectors. Figure 4.2 is a flow diagram for the entire system operating within the Sinai Hospital South Tower.

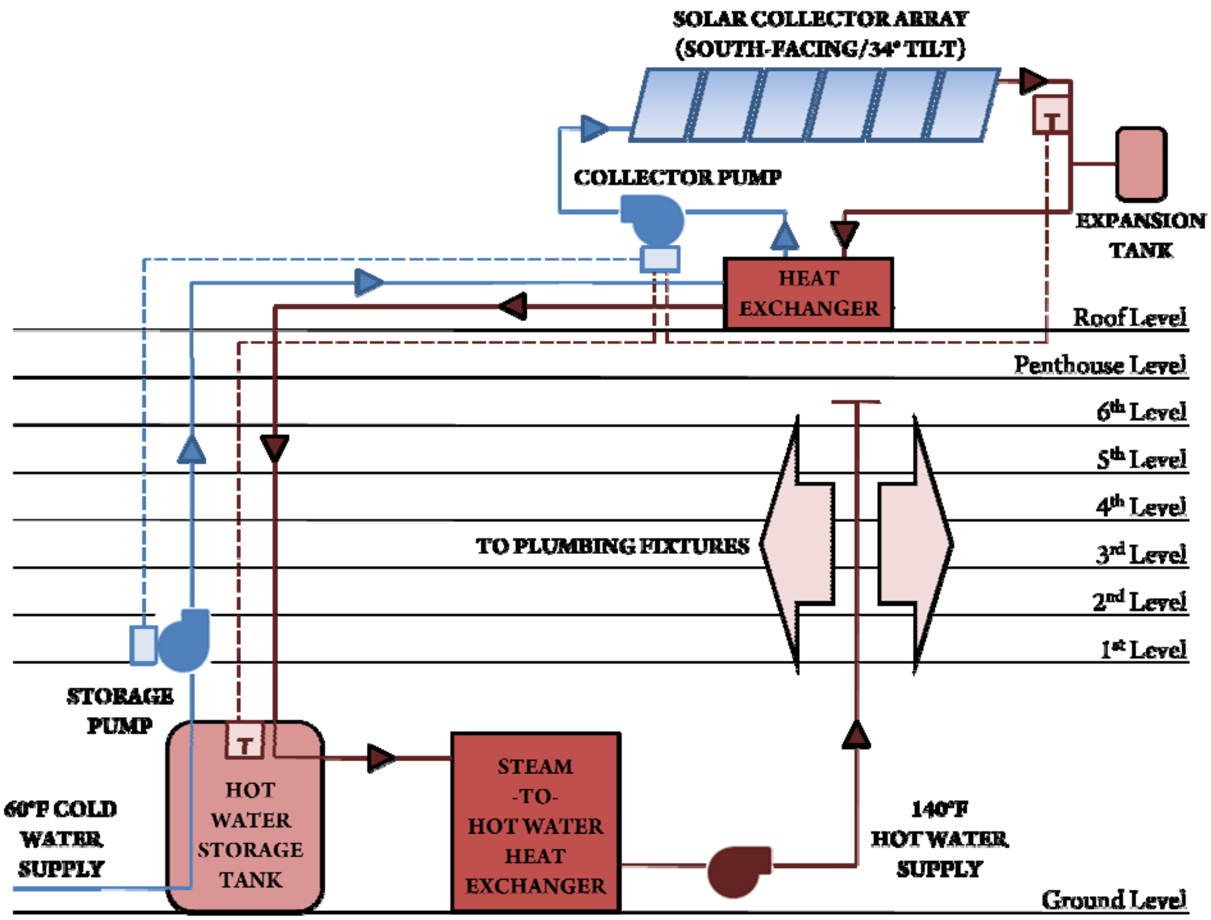

FIGURE 4.2

FLUID

The fluid that will be used in the solar collectors is a high temperature Dyn-O-Flo HD propylene glycol with inhibitors in a 50/50 solution with water. This is to prevent the water from freezing and protect the equipment.

STORAGE

Heliodyne recommends having 1.5 to 2 gallons of storage per square foot of solar collector surface area. Table 4.5 summarizes the number of collectors at various fluid temperatures within the solar collectors and the recommended storage for the associated surface area. Appendix C contains calculations which show how the number of collectors was determined based on fluid temperature.

Fluid Temperature	Number Of Collectors	Surface Area [ft^2]	Storage [gal]
145	413	15,549	31,098
135	333	12,491	24,982
125	265	9,945	19,890
115	206	7,737	15,474
105	155	5,804	11,608
95	109	4,098	8,196
85	69	2,581	5,162
75	33	1,223	2,446

TABLE 4.5

With limited space available, the size of the storage tank may need to be strongly considered when moving forward with the installation of the Heliodyne solar flat-plate collectors. A 31,098-gallon tank would require almost 4,200 ft^3 of space.

CONTROLS

Temperature sensors located downstream of the solar collector array outlet and in the storage tank manage the pumps. When the sensor located in the array loop indicates a temperature difference of 18°F or greater than the storage sensor, the pumps activate. When the temperature difference drops below 5°F, the pumps disengage. This prevents wasting energy when little heat transfer is occurring.

COST ANALYSIS

CURRENT DESIGN

Currently, domestic hot water is produced by a steam-to-hot water converter located in the mechanical room on the ground floor of the South Tower. To calculate the projected savings and payback period of utilizing solar water heating, the cost of running the heating equipment in the current design must be calculated.

Heating Demand:	145,000 BTU/hr	
Boiler Efficiency:	80%	
Energy Consumption:	53.12 kW	
	Winter (October-May)	Summer (June-September)
Operating Hours:	5,840	2,920
Electric Demand:	310,221 kWh	155,111 kWh
Electric Utility Rate:	9.945¢/kWh	11.526¢/kWh
Seasonal Operating Cost:	$30,851	$17,879
Annual Operating Cost:	**$48,730**	

TABLE 4.6

REDESIGN

According to Heliodyne, the installed cost of solar flat-plate collectors is approximately $75/ft^2, which includes storage, piping, and pumping, both material and labor. Therefore, the cost to install one collector is:

$$Installed\ Cost\ Of\ One\ Collector = 37.47\ [ft^2] \times \frac{\$75}{ft^2}$$

$$Installed\ Cost\ Of\ One\ Collector = \$2{,}811$$

Consequently, to install the maximum requirement of 413 solar flat-plate collectors for domestic hot water heating in December, it would cost:

$$Installed\ Cost\ Of\ 413\ Collectors = \frac{\$2{,}811}{collector} \times 413\ collectors$$

= **$1,160,943**

INCENTIVES

The state of Maryland offers a $3,000 grant for commercial solar water heating systems. The federal government offers $0.60/ft^2 in tax deductions for measures affecting heating systems, which results in a savings of $72,000 for 120,000 ft^2. The final cost of the solar water heating system is $1,085,943.

SIMPLE PAYBACK PERIOD

$$Simple\ Payback\ Period = \frac{\$1{,}085{,}943}{\$48{,}730}$$

$$\boldsymbol{Simple\ Payback\ Period = 22.3\ years}$$

The payback period represents complete domestic water heating by the solar collectors. Because of this, the temperature of the fluid circulating through the collectors must be around the temperature of the hot water. This lowers the efficiency of the absorption of solar radiation. Figure 4.3 illustrates the payback period as function of the fluid temperature. Anything lower than 145°F requires the current steam-to-hot water converter to work in conjunction with the solar water heating system. However, the payback period is shortened as the fluid temperature decreases.

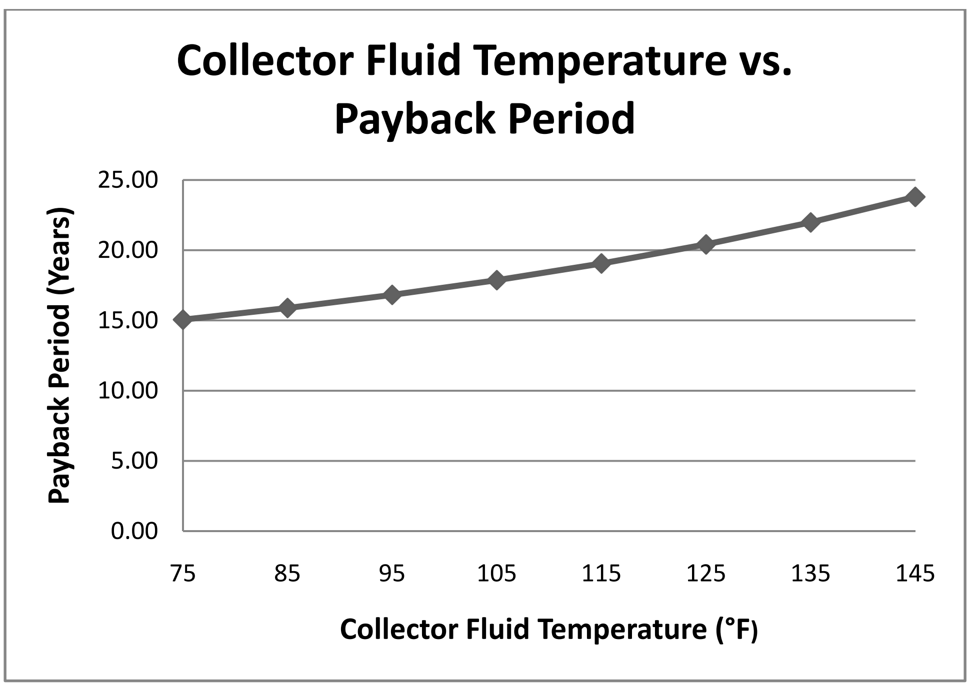

FIGURE 4.3

EMISSIONS ANALYSIS

Utilizing renewable energy is not only economically beneficial but also environmentally sound. By using solar energy to heat the domestic water, less electricity is used, and the distribution, transmission, and generation of electricity decreases. Consequently, fewer fossil fuels are burned and the solar water heating system indirectly reduces greenhouse gas emissions.

According to the National Renewable Energy Laboratory, 2.528 kWh of fossil fuel energy is consumed during generation for every kWh of electricity that is delivered in the Eastern United States. In addition, losses caused by transmission and distribution of electricity are close to 10%. For the Sinai Hospital South Tower Vertical Expansion, 465,322 kWh are consumed each year to meet domestic hot water demands. Table 4.7 illustrates the fossil fuel energy consumed each year.

Electricity Consumed Annually:	465,322 kWh
Transmission & Distribution Losses	9.6%
Fossil Fuel Energy Factor:	2.528
Fossil Fuel Energy Consumed:	1,289,263 kWh

TABLE 4.7

As seen in Table 4.7, it takes almost three times the energy to generate the same amount of electricity. As a result, emissions from the combustion and pre-combustion (extraction, procession, and transportation) of fossil fuels are very high. The amount of emissions for several pollutants is indicated in Table 4.8.

Pollutants	Pounds Per kWh Of Electricity	Pounds Per Year
Carbon Dioxide Equivalent	1.67	777,087
Carbon Dioxide	1.57	730,556
Methane	0.00371	1,728
Nitrous Oxide	0.0000373	18
Nitrogen Oxides	0.00276	1,285
Sulfur Oxides	0.00836	3,891
Carbon Monoxide	0.000805	375
Total Non-Methane Organic Carbon	0.0000713	34
Lead	0.000000131	<1
Mercury	0.0000000305	<1
Particulate Matter (<10μm)	0.0000916	43
Solid Waster	0.190	88,412

TABLE 4.8

As seen in Table 4.8, the most prominent pollutant is carbon dioxide and carbon dioxide equivalents. Over the course of one year, heating 3.625 GPM of domestic water generates over one-and-a-half million pounds of carbon dioxide and carbon dioxide equivalent. That is the equivalent of:

- ➲ 75,000 gallons of gasoline burned
- ➲ 1,875,000 miles driven (25 mpg)
- ➲ 750 round-trip cross-country flights

If 413 solar collectors were installed, those emissions would be eliminated. However, as discussed earlier in the report, installing so many collectors may not be practical. Figure 4.4 plots the reduction of carbon dioxide and carbon dioxide equivalent emissions as a function of solar collectors installed.

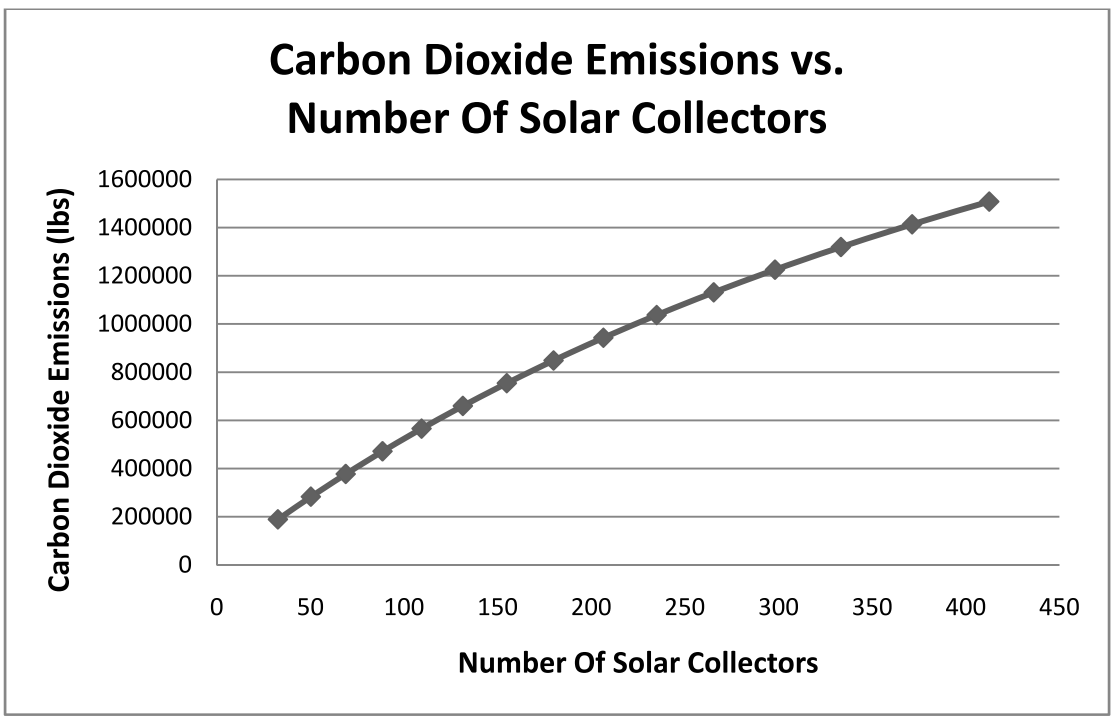

FIGURE 4.4

Whatever number of collectors are installed, the fact is that using renewable energy has significant impacts on the environment by eliminating pollutants.

CONCLUSIONS

Objective 1: Reduce domestic water heating costs ✓

After the redesign of the domestic hot water system, it was determined that installing 413 Heliodyne solar flat-plate collectors would save close to $50,000 annually. This was due to the elimination of electricity required by the steam-to-hot water converter to raise the cold water supply by 80°F. Although installing as many as 413 solar collectors may not be feasible, installing a smaller number would still be economically advantageous as depicted in Figure 4.3.

Objective 2: Indirectly reduce greenhouse gas emissions ✓

The use of solar energy is a great way to reduce pollutants indirectly, especially greenhouse gases which are contributing to climate change. By decreasing electricity consumption, fewer fossil fuels are burned, and consequently, there is less impact on the environment. Figure 4.4 shows how even a minimal number of solar collectors can have a positive effect on the environment.

Objective 3: Maintain existing comfort level ✓

By putting the solar hot water storage tank in series with the existing steam-to-hot water converter, comfort is maintained. During times when solar energy is low or unavailable, the steam-to-hot water converter works in conjunction with the solar water heating system to provide continuous 140°F domestic hot water. This prevents bacterium growth and maintains the high temperature of the water.

Objective 4: Attain a reasonable payback period ✘

By installing the maximum number of 413 solar collectors, the payback period for the redesign was 22.3 years, which is a very large amount of time. Although hospitals have a minimum lifespan of 30 to 50 years, waiting over 22 years before the initial investment is reimbursed provides too much cost uncertainty, especially in a volatile economic climate. By installing fewer solar collectors, the payback period can be reduced to as low as 15 years. Even then, more detailed feasibility studies would need to be performed in order to determine how beneficial the solar water heating system would be.

Overall, when the first cost of solar energy equipment falls to a viable level for a building's region and climate, solar water heating is a fantastic option , providing operating costs close to zero while reducing pollutants and greenhouse gas emissions which negatively impact the environment.