Senior Thesis

Final Report

An Evaluation of Water-Side Economics & Emissions

April 7, 2009

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Building Name: Sinai Hospital South Tower Vertical Expansion

Building Location: 2401 W. Belvedere Ave. | Baltimore, MD 21215

SINAI HOSPITAL

South Tower Vertical Expansion

2401 West Belvedere Avenue | Baltimore, Maryland

Project Team

› **Owner**	» Lifebridge Health
› **Architect**	» Hord Coplan Macht, Inc.
› **MEP**	» Leach Wallace Associates, Inc.
› **Civil**	» Rummel, Klepper & Kahl, LLP
› **Structural**	» Morabito Consultants
› **Interior Design**	» Arris, A Design Studio, Inc.
› **General Contractor**	» Whiting-Turner

Statistics

› **Size**	» 120,000 Square Feet
› **Total Levels**	» 3 Additional
› **Dates Of Construction**	» November 2007 – February 2009
› **Cost Of Work**	» $28,477,681

ARCHITECTURE

The South Tower Vertical Expansion at Sinai Hospital will add three stories onto the existing three-story tower, retaining the shape of the existing footprint. In addition, a six-story link enclosing a four-story atrium lobby will connect the South Tower to the North Tower. The exterior façade will consist of a water-managed exterior insulation finishing system (EIFS) and resemble the existing façade. Glazed aluminum framing will be used on part of the vertical expansion and on a majority of the link. Exterior glass will be double pane, low-e, and heat-strengthened. Roof construction will consist of a roof membrane on rigid insulation and metal decking. In addition, the fourth floor will have a green roof garden.

Anly Lor | MECHANICAL OPTION

MECHANICAL

Two new custom air handling units serve the expansion. A chilled water plant in the penthouse consisting of a 2,000 ton centrifugal chiller, cooling tower, and chilled and condenser water distribution pumps is required to provide additional infrastructure. Existing heating hot water, steam, domestic water, and medical gas mains are extended to the new air handling units. Air systems for both supply and return are variable air volume and medium pressure. Infectious isolation rooms have a dedicated isolation exhaust system.

LIGHTING / ELECTRICAL

The penthouse will house a double-ended 3,000 kVA, 13.2 kV 480Y/277V substation to provide power for the three additional levels of the vertical expansion. A 2,500 kVA 13.2 kV 480Y/277V substation serves the chiller and associated cooling tower and pumps. Normal power to each floor is distributed at 480V and steps down to 208Y/120V via dry-type transformers. All lighting fixtures are 120V, primarily fluorescent.

STRUCTURAL

The South Tower vertical expansion will be supported by the existing grade beam foundation system. The frame construction is concrete, consisting of post-tensioned beams, reinforced walls, and structural slabs. The link is also supported by a grade beam foundation system. Its frame is concrete as well with tendon support.

http://www.engr.psu.edu/ae/thesis/portfolios/2009/ail5002/

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Acknowledgements

▪ Lifebridge Health
▪ Leach Wallace Associates
▪ Hord, Coplan, Macht
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▪ Michael Schwarz, *KlingStubbins*
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  ➲ But still taking my mind off of it at the same time

Table of Contents

Executive Summary

The South Tower Vertical Expansion is a three-story addition under construction at Sinai Hospital of Baltimore, planned for completion and occupancy by the end of 2010. The addition adds space for over 120 more beds in an intensive care unit, traumatic brain injury care, and an intermediate care unit. The construction also links the South Tower to the North Tower, and a helipad has been added. With over 120,000 square feet of additional floor space, the demand in capacity for several mechanical systems increased substantially. Because hospitals are one of the greatest energy consumers, attempts were made to find alternatives to existing mechanical system designs which would reduce life-cycle costs as well as emissions of pollutants and greenhouse gases. The chilled water and domestic water systems were evaluated.

The primary objective of redesigning the chilled water plant was to reduce electric utility costs. By having the future chiller generate cooling capacity though an added thermal energy storage system, demand could be shifted from peak hours to off-peak hours, allowing the hospital to take advantage of time-of-use rates from Baltimore Gas & Electric. As a result of the redesign, the annual electric utility savings was over $51,000. This was equivalent to an electric utility rate savings of almost $0.03 per kilowatt-hour or an average savings of approximately $0.43 per square foot. However, a high initial cost of about $100 per ton-hour to install a storage tanks resulted in a simple payback period of 14.8 years. Although the length of time is fairly long, the system could prove viable.

Like the chilled water plant redesign, the proposal of using solar water heating in the domestic hot water system was in an effort to reduce electric utility costs. By utilizing renewable energy to heat domestic water, the existing steam-to-hot water converter would operate less, reducing the energy demand substantially. Following the study, it was determined that over $48,000 would be saved each year by using solar energy to provide all of the domestic hot water for the South Tower Vertical Expansion. However, with an average installed cost of $75 per square foot of solar collection area, the simple payback period was more than 22 years, a period too long to provide cost certainty in a volatile economic climate. In addition, another goal was to measure the amount of pollutants caused indirectly by the existing system. By installing a solar hot water heating system, up to 1.5 million pounds of carbon dioxide would be removed from the environment annually, an equivalent of 157 passenger vehicles driving 1,000 miles each month.

Overall, the alternative designs were feasible but required many years before a return on the investment was achieved. As energy costs continue to soar, these design methods will b explored more often, and economies of scale will allow them to become viable, cheaper, and cleaner options.

Existing Conditions

SITE

Sinai Hospital is part of Lifebridge Health, a regional healthcare organization located in northwest Baltimore, MD.

FIGURE 2.1

Sinai Hospital houses a variety of centers. These are illustrated in Figure 2.2.

ARCHITECTURE

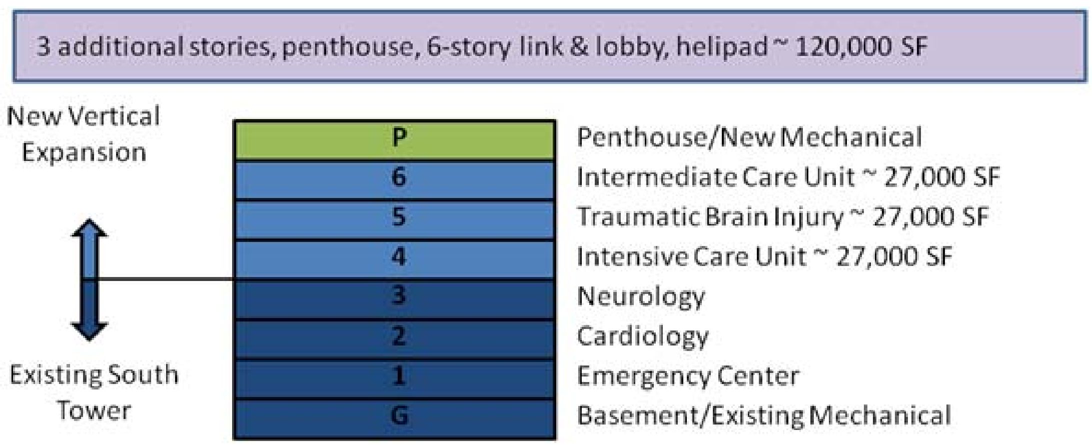


FIGURE 2.2

The Sinai Hospital South Tower Vertical Expansion is a three-story addition onto the existing three-story South Tower, retaining the shape of the existing footprint. In addition, a six-story link enclosing a four-story atrium lobby connects the existing North Tower to this brand new vertical expansion. A helipad and elevator tower round out the new construction. Each floor has its own unique function. The fourth floor houses the intensive care unit. The fifth floor will be the future home of traumatic brain injury care and sterile processing. Lastly, the intermediate care unit is on the sixth floor.

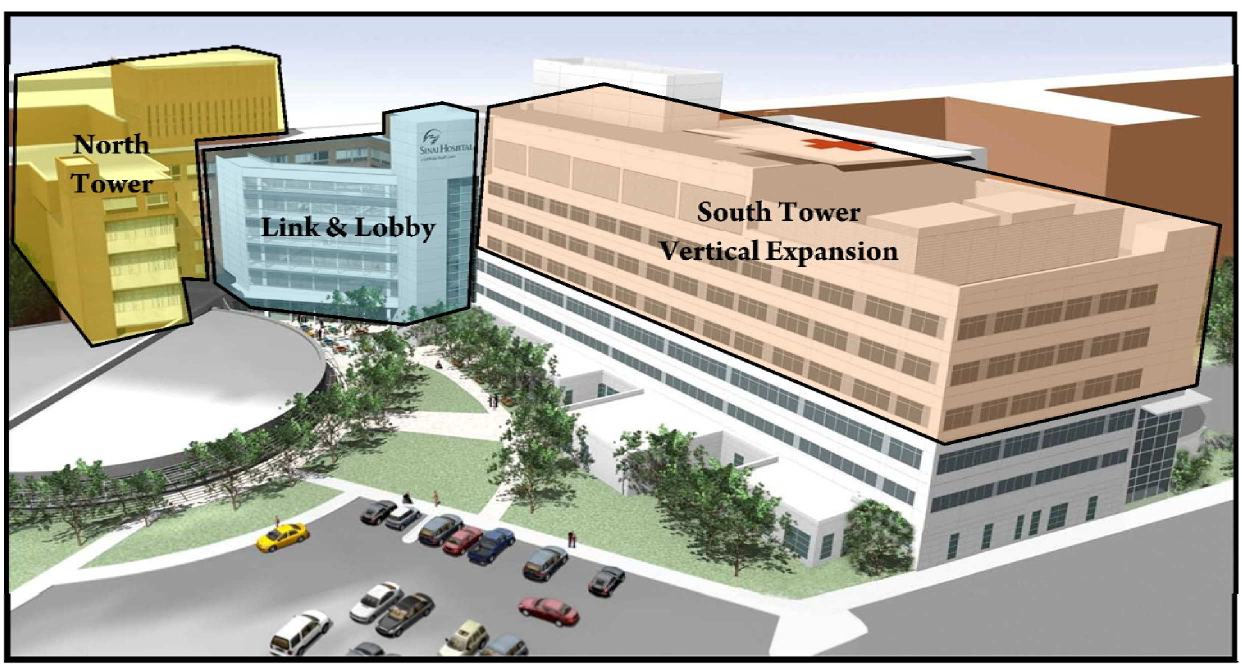


FIGURE 2.3

LAYOUT

Figure 2.4 shows how the patient rooms and the isolation rooms on the fourth and sixth floors of the South Tower are responsible for a majority of the building envelope, and consequently, a majority of the cooling load.

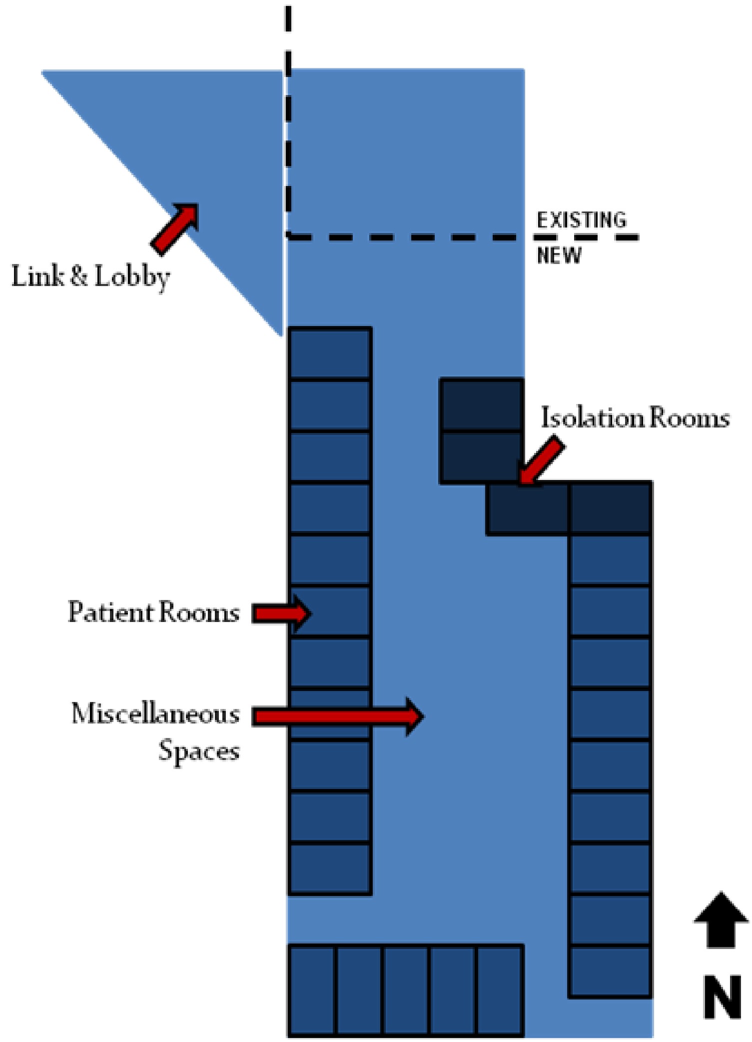


FIGURE 2.4

Table 2.1 describes the coverage of glazed aluminum framing.

	% Of Exterior Wall Area
Link & Lobby:	80
South Tower Vertical Expansion:	50

TABLE 2.1

BUILDING ENVELOPE

The exterior façade of the vertical expansion resembles the façade on the existing three-story tower. It consists of a water-managed exterior insulation finishing system (EIFS) with control joints. The EIFS is over glass-mat-faced gypsum sheathing on 6" structural metal studs with glass fiber batting insulation, vapor barrier, and gypsum wallboard. Glazed aluminum framing is used on part of the vertical expansion and on a majority of the link. Exterior glass (vision and spandrel) is double pane, low-e, and heat-strengthened. Roof construction consists of a roof membrane on rigid insulation and metal decking. In addition, the fourth floor has a green roof garden.

MECHANICAL SYSTEMS

The mechanical systems for the expansion include heating, ventilating & air conditioning, plumbing, fire protection, medical gases, and vacuum. A majority of the existing infrastructure is adequate to accommodate the additional loads.

AIR-SIDE

The supply and return air systems for the new medical/surgical patient room floors are medium pressure, variable air volume. The South Tower Vertical Expansion includes two new custom fabricated air handling units to provide additional capacity for the expansion. One air handling unit serves floors four, five, and six in the South Tower, and the other serves the six-story hospital link and four-story atrium lobby. The existing rooftop air handling units installed under the previous vertical expansion were relocated to the roof of the sixth floor, providing redundancy in the air distribution system. Ductwork is distributed from two mechanical shafts that extend down through each floor of the expansion from the penthouse. Infectious isolation rooms have a dedicated isolation exhaust system.

WATER-SIDE

A chilled water plant in the penthouse consisting of a 2,000 ton centrifugal chiller, cooling tower, and chilled and condenser water distribution pumps is required to provide additional infrastructure. Existing heating hot water, steam, domestic water, and medical gas mains are extended from the ground floor to the new air handling units.

Emergency power is provided for the equipment which allows for operation on all six floors in emergency situations.

DESIGN CONDITIONS

OUTDOOR

	Dry Bulb Temperature	Wet Bulb Temperature
Summer:	0°F	-
Winter:	95°F	79°F

TABLE 2.2

INDOOR

	Dry Bulb Temperature [°F]	% Relative Humidity
Nurse Stations, Work Rooms, & Ancillary Spaces:	70 -75	30-60
Patient Rooms:	70-75	30-60
Airborne Infection Isolation Rooms:	70-75	30-60
Offices, Conference Rooms, & Waiting Rooms:	72	30-60

TABLE 2.3

VENTILATION

	Volumetric Flow Rate [cfm]	% Outdoor Air
Link & Lobby:	0	0
Fourth Floor:	3,495	14.91
Sixth Floor:	3,056	13.33

TABLE 2.4

HEATING & COOLING

	Heating Load [tons]	Cooling Load [tons]
Link & Lobby:	15	31
Fourth Floor:	70	148
Sixth Floor:	70	148
Total:	155	327

TABLE 2.5

Only the fourth and sixth floors of the vertical expansion have been fit out. The layout of HVAC equipment has not yet been determined for the fifth floor. Heating loads include heat loss through the shell (28.6%) and reheat load (71.4%).

CHILLED WATER PLANT SCHEMATICS

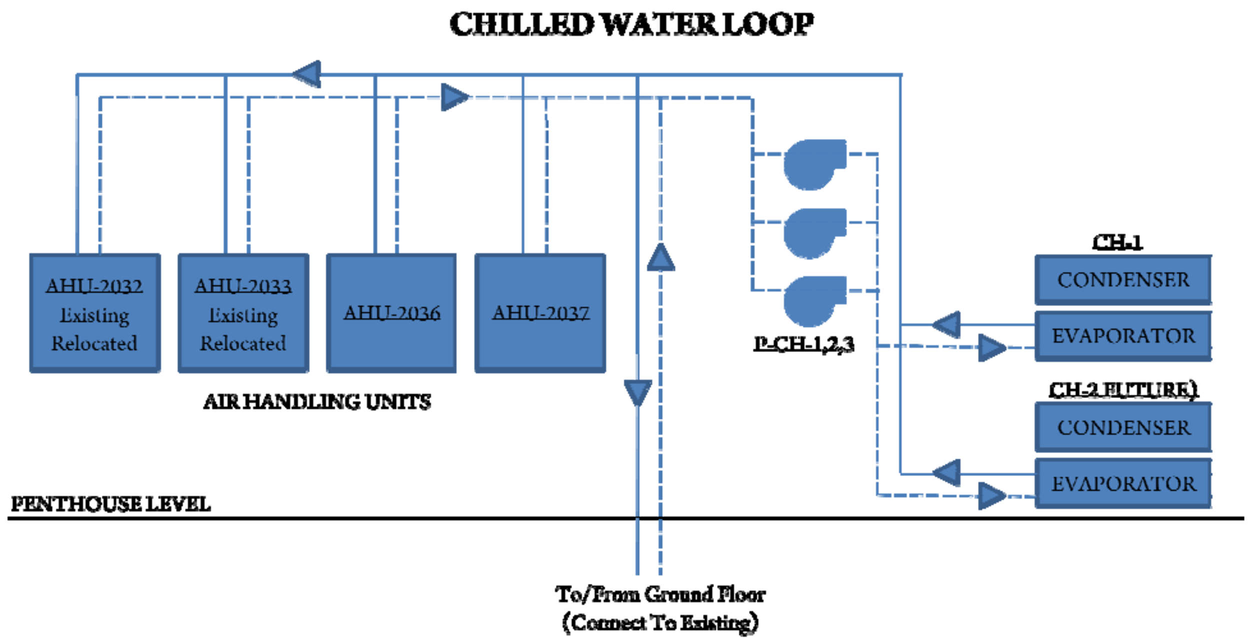


FIGURE 2.5

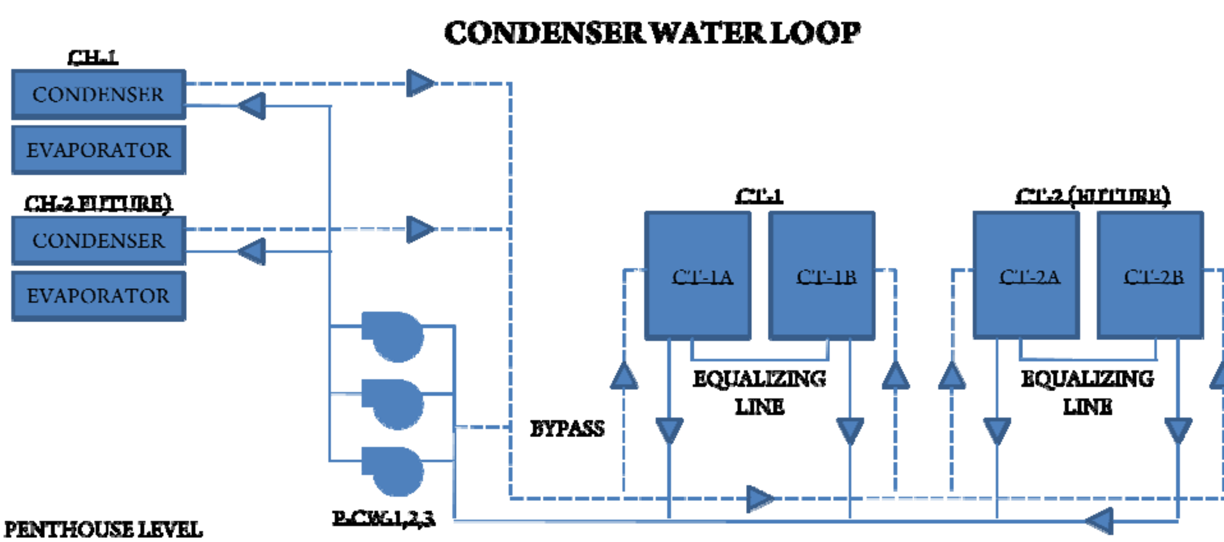


FIGURE 2.6

ASHRAE STANDARD 62.1 EVALUATION

5.1 Natural Ventilation

Not applicable.

5.2 Ventilation Air Distribution

Each patient room is provided with an individual, digitally controlled variable air volume supply air terminal unit. Up to ten of these units are contained in individual zones, each which have supply and return airflow monitoring.

All air distribution systems including supply, return, outdoor air, and exhaust ductwork is tested and balanced.

5.3 Exhaust Duct Location

Airborne infectious isolation rooms on the fourth, fifth, and sixth floors are negatively pressurized and have a dedicated isolation exhaust system. Standard patient rooms have a neutral pressure relationship.

5.4 Ventilation System Controls

Custom indoor air handling units are digitally controlled with pneumatic actuation, each having outside air sections with minimum and maximum dampers and actuators. An automatic temperature control system is provided and is an extension of the existing Johnson Metasys direct digital control system in the lower three levels. Supply, return, and exhaust air terminal units are all digitally controlled.

5.5 Airstream Surfaces

Ductwork is constructed of prime, first quality galvanized steel and is resistant to mold growth and erosion.

5.6 Outdoor Air Intakes

The air handling unit's outdoor air intake (located in the penthouse, not susceptible to rain or snow entrainment) is at a sufficient distance from contaminated exhaust, vents, and the cooling tower.

5.7 Local Capture of Contaminants

All exhaust air is discharged directly to the outdoors.

5.8 Combustion Air

Not Applicable.

5.9 Particulate Matter Removal

The air handlings units have pre-filter, intermediate filter, and final filter sections installed. A 30% efficient, 2” pre-filter is followed by a 65% efficient, 12” cartridge intermediate filter. A 95% efficient 12” cartridge final filter mounted in 24” x 24” HEPA holding frames finish the capture of contaminants. This also provides the capability of installing HEPA filters in the future.

5.10 Dehumidification Systems

Nurse stations, work rooms, ancillary spaces, patient rooms, airborne infectious isolation rooms, offices, and conference and waiting rooms are all provided with conditioned air with a relative humidity between 30% and 60%.

5.11 Drain Pans

Drain pans are provided under coil and fan sections. They are constructed of welded galvanized steel with a bitumastic coating and are insulated with 1”, 3PCF fiberglass insulation at the bottom.

5.12 Finned-Tube Coils & Heat Exchangers

Coils have adequate intervening access space.

5.13 Humidifiers & Water-Sprayed Systems

Humidifiers in the air handling units are of the direct discharge type. Steam is provided from existing steam lines and boilers to be injected into the air for humidification. Each humidifier consists of multiple, vertical steam discharge pipes to provide optimum steam to air contact while minimizing pressure drop.

5.14 Access for Inspection, Cleaning, & Maintenance

All rectangular ductwork including outside air, return air, and exhaust air provided on the project conform to SMACNA standards (Sheet Metal and Air Conditioning Contractors National Association, Inc.), which includes providing insulated access doors at a minimum size of 12” x 12” to allow convenient and unobstructed access, cleaning, and routine maintenance of air distribution components.

5.15 Building Envelope & Interior Surfaces

An exterior insulation and finish system provides thermal and moisture protection for the building envelope. The installation includes a complete drainage board system, which includes a rolled on waterproof layer on back-up substrate. The substrate consists of a flashing membrane applied over glass mat faced gypsum. Self-adhering sheet waterproofing or hot fluid-applied rubberized asphalt waterproofing is used to treat joints, cracks, deck drains, corners, and penetrations.

An adhered membrane roofing system, vapor retarder, and roof insulation prohibit the passage of water and resist specified uplift pressures, thermally induced movement, and exposure to weather.

Domestic water, chilled water, heating hot water, steam supply, steam condensate, and condenser water piping are insulated. Air conditioning condensate, and supply, outside air, and return ductwork are insulated. Linear supply air diffusers, generator exhaust, air separators, and chilled water pumps are also insulated.

5.16 Buildings with Attached Parking Garages

Not applicable.

5.17 Air Classification & Recirculation

Isolation exhaust may be classified as class 4 with potentially dangerous particles. All other exhaust may be classified as class 3. Air in patient rooms, offices, common areas, and utilities is re-circulated and can be classified as class 1.

5.18 Requirements for Buildings Containing ETS Areas and Non-ETS Areas

Not Applicable.

ASHRAE STANDARD 90.1 EVALUATION

Building Envelope

Baltimore, MD is in climate zone 4A.

	Assembly Maximum	Design	Compliance
Roof, Insulation Above Deck	U-0.048	U-0.100	No
Walls Above Grade, Mass	U-0.123	U-0.100	Yes
Floors, Mass	U-0.107	U-0.100	Yes
Opaque Doors, Swinging	U-0.70	U-0.100	No
Vertical Glazing, Metal Framing	U-0.60	U-0.100	No
	SHGC-0.25	SGHC-0.67	No

TABLE 2.6

Safe design values were utilized in the Sinai Hospital South Tower Vertical Expansion in order to be conservative when selecting mechanical system components. Only the U-values for walls above grade and floors complied with the assembly maximum for zone 4A in ASHRAE Standard 90.1.

HVAC Systems

The building complies with section 6 of ASHRAE standard 90.1. Minimum equipment efficiencies are verified and labeled, design loads for sizing systems and equipment were determined, and each zone is individually thermostatically controlled. Duct construction conforms to SMACNA standards. Ductwork is insulated and required to undergo leakage tests. Grilles, registers, and diffusers are adjusted to within 10% of design quantities.

Service Water Heating

Not applicable.

Power, Lighting, & Electric Motor Efficiency

The building complies with section 8 and 9 of ASHRAE standard 90.1.

Chilled Water Plant Redesign

OVERVIEW

The chilled water plant redesign includes the addition of a thermal energy storage system. This allows for economic and operational benefits for the facility by storing cooling capacity. The ability to shift loads will reduce peak demand and offer electric utility savings. Although hospitals have 24-hour operation, the majority of use in patient rooms typically occurs in the daytime, which represent a large amount of floor space, lighting, and equipment use at Sinai Hospital. The electric load profile can be shifted by generating cooling capacity at night when the building's electric load is at a minimum and employing it in the afternoon when it is at its peak. Additionally, less stress is placed on the chiller at night due to lower outdoor ambient conditions.

Furthermore, with the proposed future addition of a 2,000-ton electric centrifugal chiller, retrofitting the chilled water plant will be substantially simpler and offer more savings. The storage system can be sized to accommodate both current and future capacity needs.

OBJECTIVES

- Shift loads during peak hours of operation to off-peak hours
- Achieve economical benefits by taking advantage of time-of-use rates
- Increase plant flexibility by utilizing the future chiller to generate capacity through storage and directly
- Perform a feasibility study of locating storage equipment on-site
- Attain a reasonable payback period

**Note: This depth study satisfies the*

Integrated Program (M.A.E/B.A.E) requirements.

DESIGN

The first step in adding a thermal energy storage system to the existing chilled water plant is to determine the amount of storage needed for the hospital. This requires generating a load profile which depicts the amount of cooling, electricity use, and time per day at which the plant operates. Because the hospital has not yet been occupied, a load profile or any utilization data for the South Tower Vertical Expansion is unavailable. Trane's Trace software will be used to simulate the facility's operation history. This will dictate the size of the tank, whether water or ice storage will be implemented, and the location and arrangement of the system.

The chilled water plant was designed to not only support the three additional floors of the South Tower Vertical Expansion but also provide more cooling capacity for the ground and first floors of the emergency center (ER-7), the second and third floors, and the cafeteria. However, the expansion will be treated as its own building, and therefore, thermal energy storage will only be evaluated for floors four, five, and six, and the link and lobby. For analysis purposes, the fourth floor will be duplicated to also represent the fifth floor since the fifth floor layout has not yet been completed; both floors offer similar services.

INPUT DATA (TRACE 700)

Weather Information:	Baltimore, MD
Internal Loads:	<u>People</u> 250 BTU/hr sensible 200 BTU/hr latent <u>Lighting</u> 2 W/ft^2 <u>Miscellaneous Loads</u> 2 W/ ft^2 ▪ See Appendix A
Ventilation:	5 cfm/person 0.06 cfm/ft^2
Infiltration:	0.6 air changes/hr
Thermostat:	<u>Cooling</u> 75°F dry bulb, 50% relative humidity <u>Heating</u> 70°F dry bulb, 50% relative humidity

TABLE 3.1

EQUIPMENT DEMAND

Figure 3.1 depicts the daily electrical demand of the South Tower Vertical Expansion's cooling equipment (chiller, compressor, pumps, fans), miscellaneous equipment (computer, kitchen, medical, etc.), and lighting. Peak demand in the year occurs in the month of July.

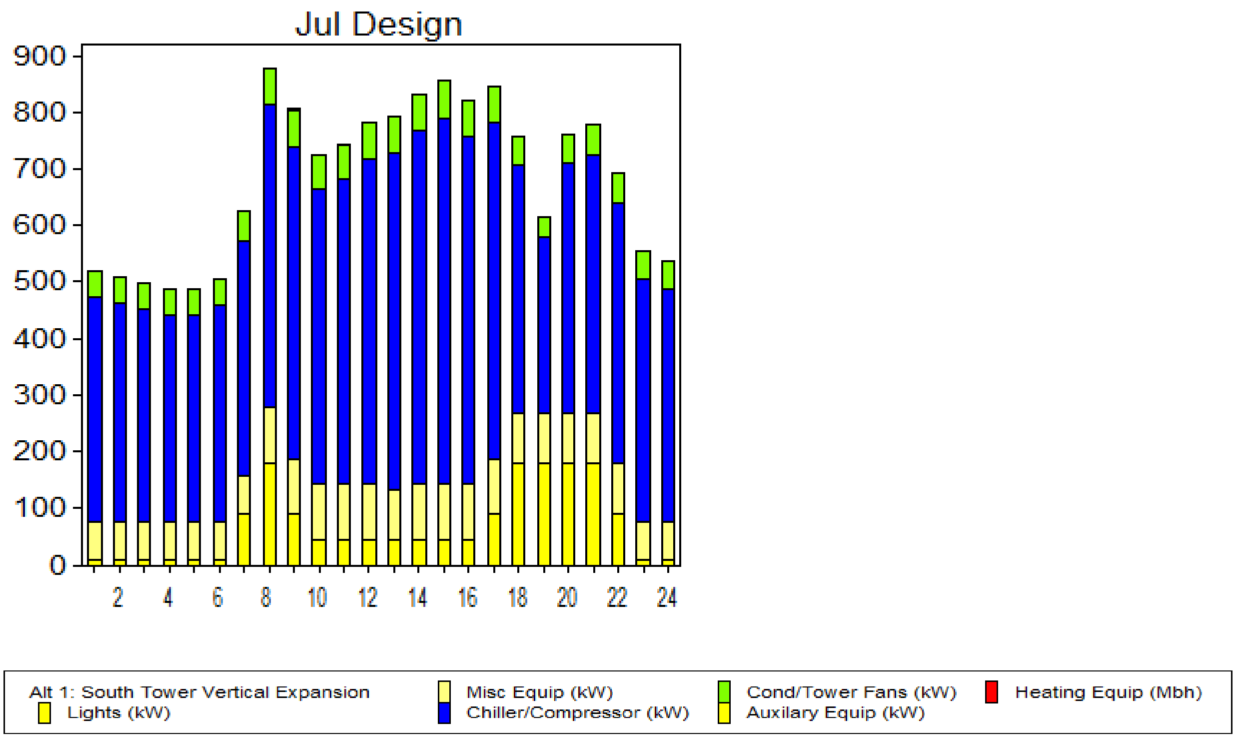


FIGURE 3.1

Based on this graphic, the peak electrical demand for the South Tower Vertical Expansion occurs at approximately 3 PM in the afternoon. The fairly sharp curvature of the profile shows the potential to shift a substantial load from the middle of the day to the evening and night hours. Since the greatest portion of the electrical demand is a result of the cooling equipment, generating cooling capacity during those low peak times will provide a measurable electric utility cost savings.

THERMAL ENERGY STORAGE DEMAND

Figure 3.2 represents the cooling load required during each hour for the cooling design day in July. The peak load from this figure is approximately 600 tons. More detailed values will be determined in the following sections of this report. In order to simplify the redesign, it will be assumed that the load profile for the remaining spaces (the ground and first floors of the emergency center (ER-7), the second and third floors, and the cafeteria) is flat, and the capacity allocated to those spaces is around 1,300 tons. This means that thermal energy storage can only be applied to the South Tower Vertical Expansion.

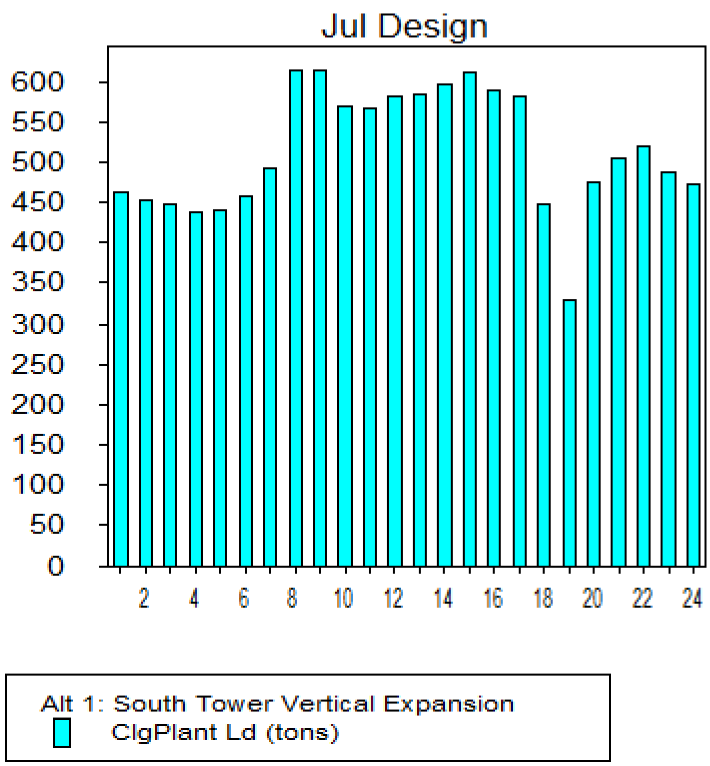


FIGURE 3.2

From Figure 3.2, it will be possible to create a smooth load profile to determine the average load, peak load, and total load. Based on these values, the amount and type of storage needed can be determined.

LOAD PROFILE

Representing cooling loads from Figure 3.2 as data points, a trend line can be produced to portray the chilled water plant cooling design day operation. This is illustrated in Figure 3.3.

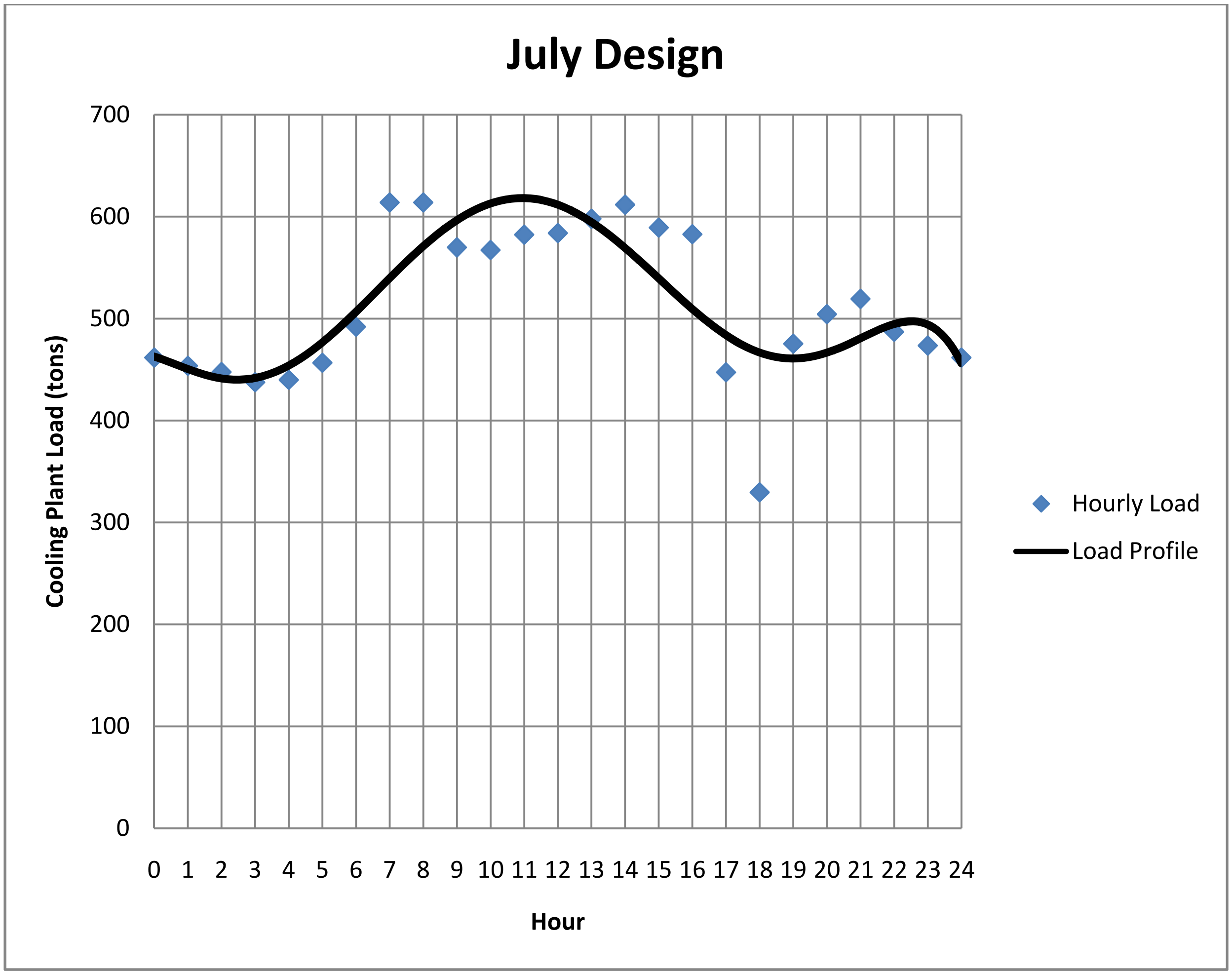


FIGURE 3.3

Trend Line Equation
$y = -0.000214849198201697x^6 + 0.0139792112743158x^5 - 0.313622180670263x^4 + 2.64550027413572x^3 - 4.39777417477859x^2 - 10.2315167506266x + 462.741019309213$

TABLE 3.2

The trend line given in Table 3.2 can be used to calculate the total cooling plant load required for the hospital's cooling design day through integration.

COOLING PLANT LOAD

Total Plant Load:	12,345 ton-hr
Minimum Hourly Plant Load:	441 tons
Average Hourly Plant Load:	515 tons
Peak Hourly Plant Load:	619 tons
Load Factor:	83.2%

TABLE 3.3

From Figure 3.3, the load factor for the Sinai Hospital South Tower Vertical Expansion was determined to be 83.2%. Because a future chiller has been proposed, it will be utilized to generate storage capacity at night in order to fulfill chilled water capacity needs during the day. This will maximize the time-of-use savings. Therefore, full storage will be applied.

FULL STORAGE

ADVANTAGES

- Minimize costs by generating cooling capacity only during the night
- Favorable payback
- Maximize efficiency

DISADVANTAGES

- Size of storage equipment

Based on time-of-use electric utility rates from Baltimore Gas & Electricity, the cheapest time to operate equipment is between 9 PM and 7 AM. To maximize payback, thermal energy storage would need to be generated during this time. To do so, the plant load must be determined by calculating the area under the curve in Figure 3.3. This procedure is performed in Figure 3.4. Further economic analysis will be provided later in the report.

CHARGING & DISCHARGING

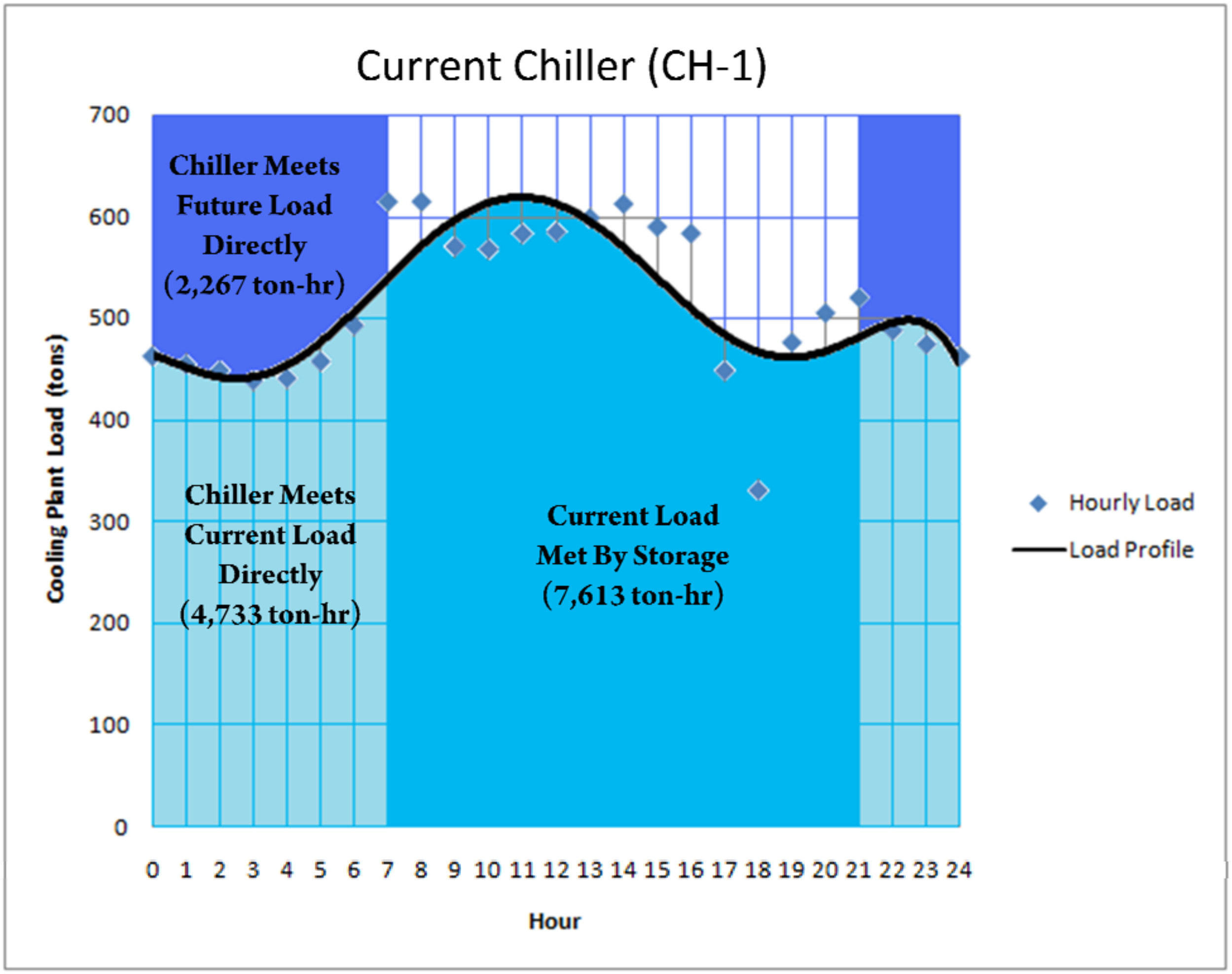


FIGURE 3.4

Table 3.4 breaks down the hours when loads are met directly by the chiller and the hours when loads are met by storage.

Hours	Plant Load
0-7 (12 AM - 7 AM)	3,269 ton-hr
7-21(7 AM - 9 PM)	7,613 ton-hr
21-24 (9 PM - 12 AM)	1,464 ton-hr

TABLE 3.4

Based on values from Table 3.4, the thermal energy storage required to meet peak cooling demand for the South Tower Vertical Expansion is 7,613 ton-hr. This requires an hourly generation during off-peak hours of:

$$\frac{7{,}613\ [ton - hr]}{10\ [hr]} = 762\ [tons]$$

FUTURE OPERATION

The additional 2,000-ton chiller was proposed to meet any future capacity. No determination has been made as to what the additional loads will be. To accommodate for future needs, nighttime capacity will be provided by any remaining capacity on both the current and future chillers during off-peak hours. Daytime capacity will be provided by the future chiller directly during peak hours. If more capacity is still required, the current chiller will also have to operate during peak hours.

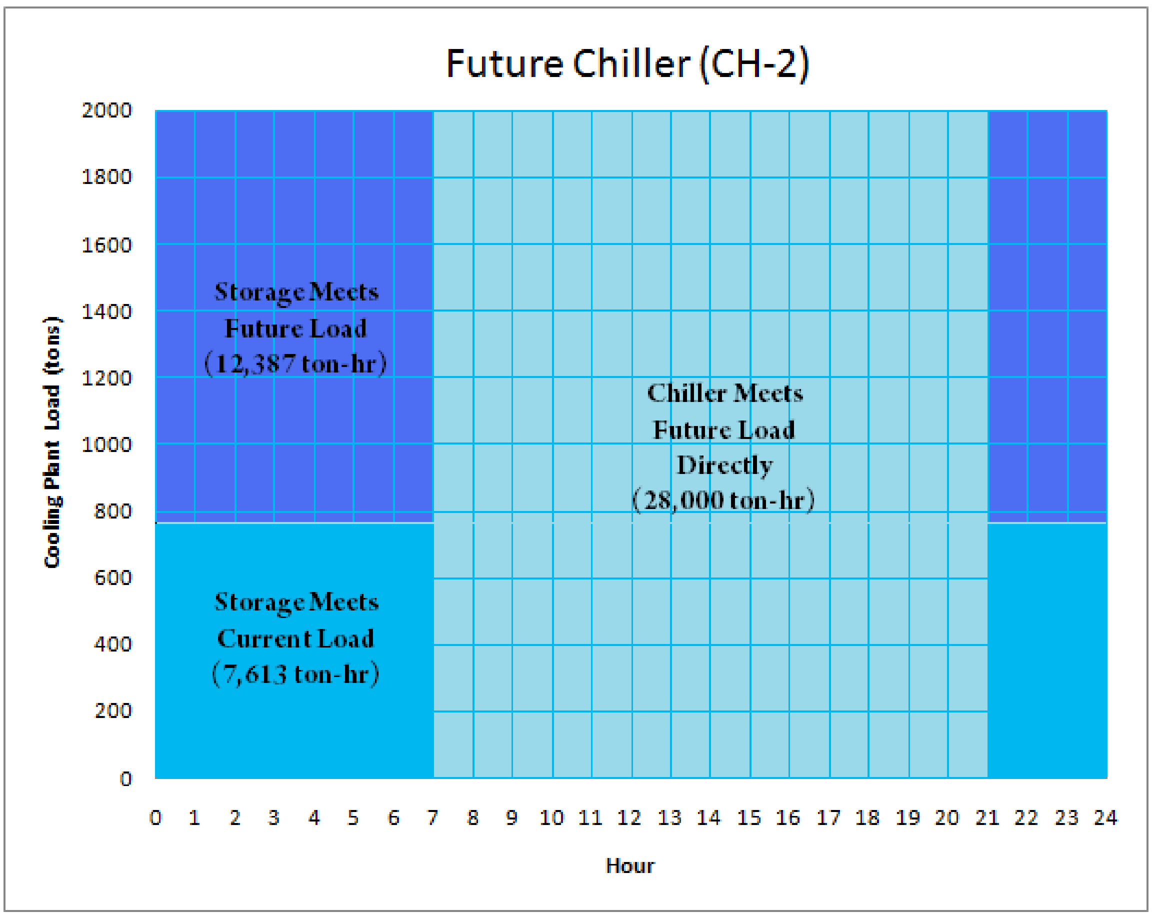


FIGURE 3.5

Available future capacity is indicated on Figure 3.5. Table 3.5 will summarize those values.

	Chiller	Hours	Capacity	Per Hour
Nighttime: (Met By Chiller Directly)	Current (CH-1)	9 PM - 7 AM	2,267 ton-hr	227 tons
Nighttime: (Met By Storage)	Future (CH-2)	9 PM - 7 AM	12,387 ton-hr	1,284 tons
Daytime: (Met By Chiller Directly)	Future (CH-2)	7 AM - 9 PM	28,000 ton-hr	2,000 tons
Total:			42,654 ton-hr	1,778 tons

TABLE 3.5

TOTAL STORAGE

The amount of storage required by the South Tower Vertical Expansion is 7,613 ton-hr between 9 PM and 7 AM. In addition, the remaining capacity of the chiller allows for 12,387 ton-hr of storage for the future.

Current Storage:	7,613 ton-hr
Future Storage:	12,387 ton-hr
Total Storage:	20,000 ton-hr

TABLE 3.6

Based on this quantity, there are several important factors that will determine whether water or ice storage is utilized.

SYSTEM CONSIDERATIONS

- Tank size
- Available space
- Required modifications to existing chilled water equipment

TANK SIZE

The size of the storage tank is critical to overall system design. If the tank is small enough, it would be able to be located on the roof. Otherwise, it would have to be located on the ground or underground. Having the tank or tanks closer to the chiller will reduce piping and pumping costs.

For water storage (sensible thermal energy storage), the required tank volume would be:

$$V = \frac{1{,}440 \times S\ [ton - hr]}{FOM \times \Delta T [°F]}$$

$$V = \frac{1{,}440 \times 20{,}000\ [ton - hr]}{0.85 \times 21\ [°F]}$$

$$V = 1{,}613{,}446\ [gal] = 215{,}687\ [ft^3]$$

Assumptions:	▪ Naturally stratified tank ▪ ΔT = 21°F ▪ Figure Of Merit = 0.85 (worst-case scenario)

TABLE 3.7

For ice storage (latent thermal energy storage), (47) 162 ton-hr CALMAC Ice Banks would be required to meet current storage needs. Up to 77 more tanks can be added to meet future storage needs. Each tank has a dimension of 89 in x 101 in (O.D. x H) for a volume of 364 ft^3. See Appendix D for tank specifications.

Storage Capacity	# Of Tanks	Tank Volume
162 ton-hr	1	364 ft^3
7,613 ton-hr (current)	47	17,108 ft^3
12,387 ton-hr (future)	77	28,028 ft^3
20,000 ton-hr (total)	124	45,136 ft^3

TABLE 3.8

WATER & ICE COMPARISON

Figure 3.6 illustrates the ratio of the required tank size using water storage and ice storage.

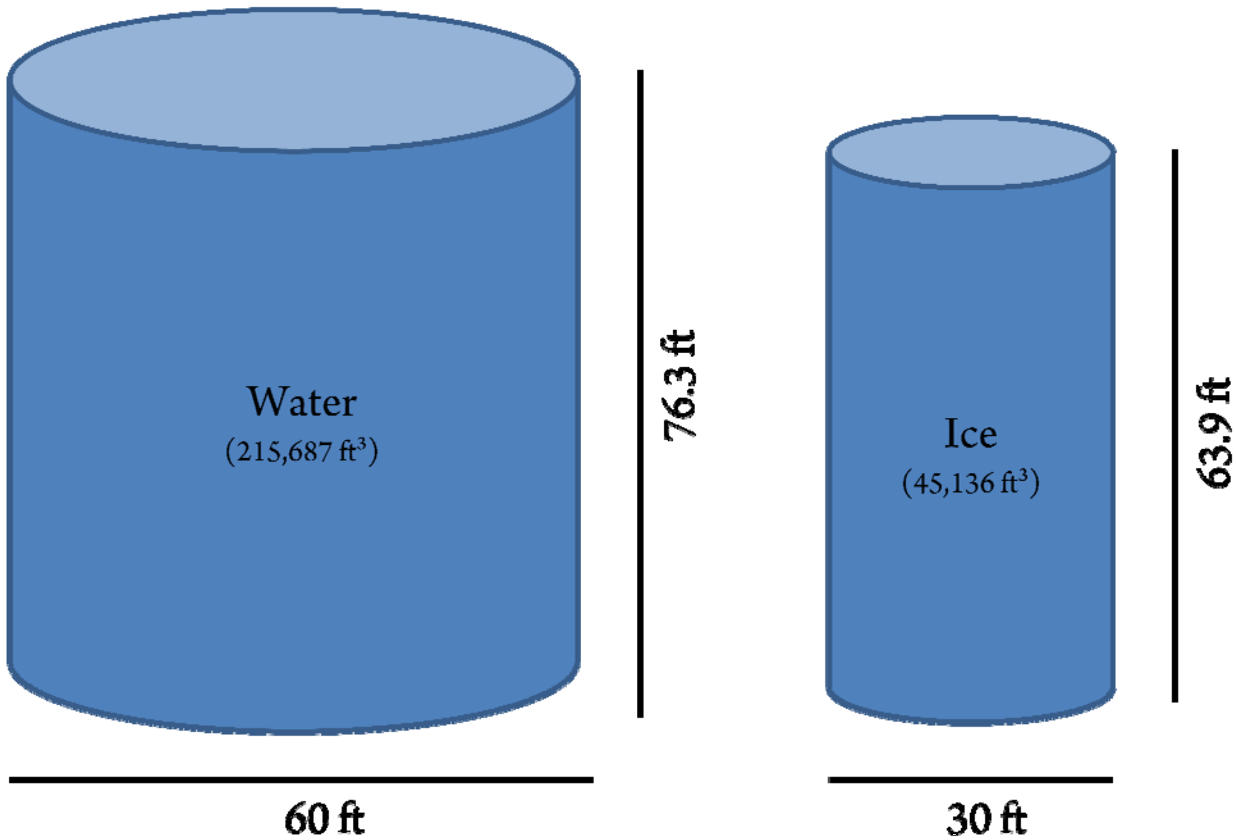


FIGURE 3.6

AVAILABLE SPACE

Because space is at a premium at Sinai Hospital, the best decision is to use latent thermal energy storage and ice tanks, where the required storage is 21% of the required storage using sensible thermal energy storage.

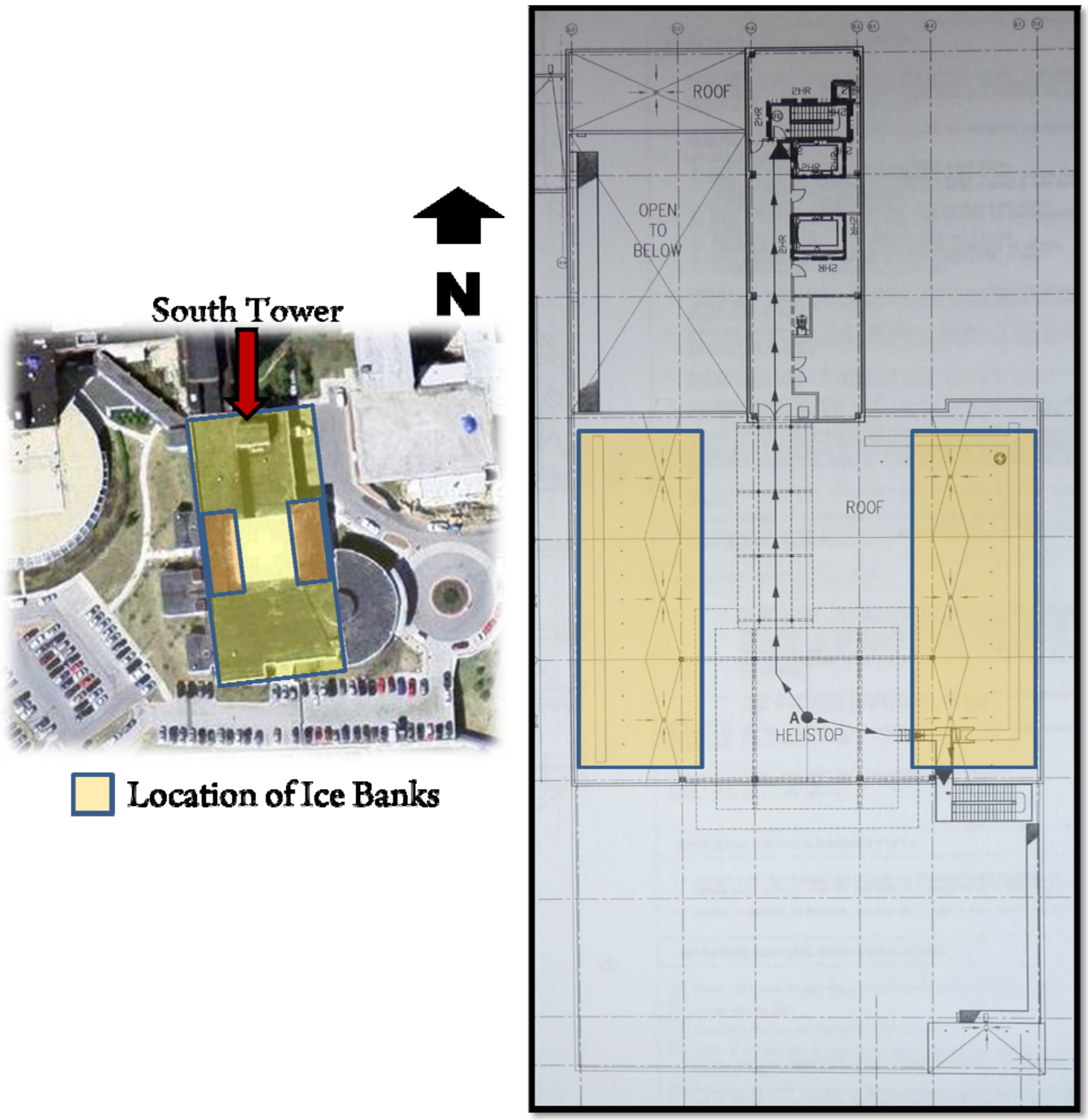


FIGURE 3.7

The best place available to locate the ice tanks is on the west and east sides of the South Tower roof adjacent to the helipad and above the penthouse. See Figure 3.7 for details. The storage tanks will be closer to the chillers and pumps located in the penthouse, reducing piping and pumping costs.

The footprint of the available roof space is 88 ft x 32 ft (L x W) on each side for a total area of 5,632 ft^2. In order to install all of the ice tanks, they must be stacked above one another on two separate levels. Structural support must be provided to accommodate the weight. In addition, a screen will be needed to hide the ice tanks from pedestrian view. These issues will be explored in the breadth sections later in this report. The setup will be described next.

SETUP

There will two levels of ice tanks on each side. Each level will support 30 ice tanks each (3 rows x 10 columns/22.7 ft x 75.6 ft). Figure 3.8 shows the typical arrangement for one level. The required height of each level is 11.5 ft (8.5 ft for the ice tanks and 3 ft of clearance), requiring a total height of 20 ft. For current storage needs, only 47 ice tanks need to be installed.

FIGURE 3.8

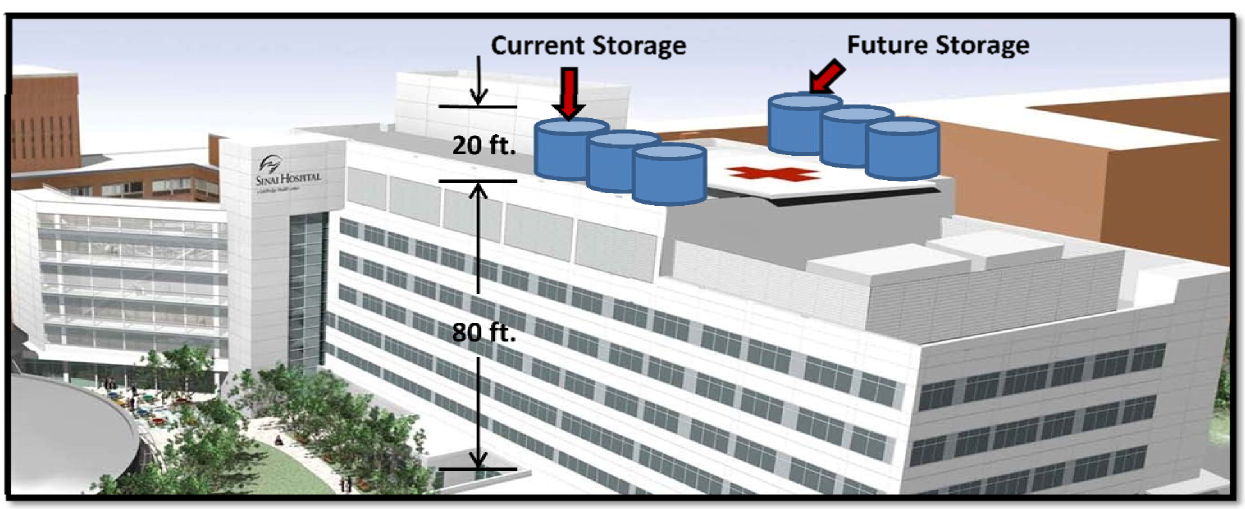


FIGURE 3.9

CHILLED WATER FLOW DIAGRAM

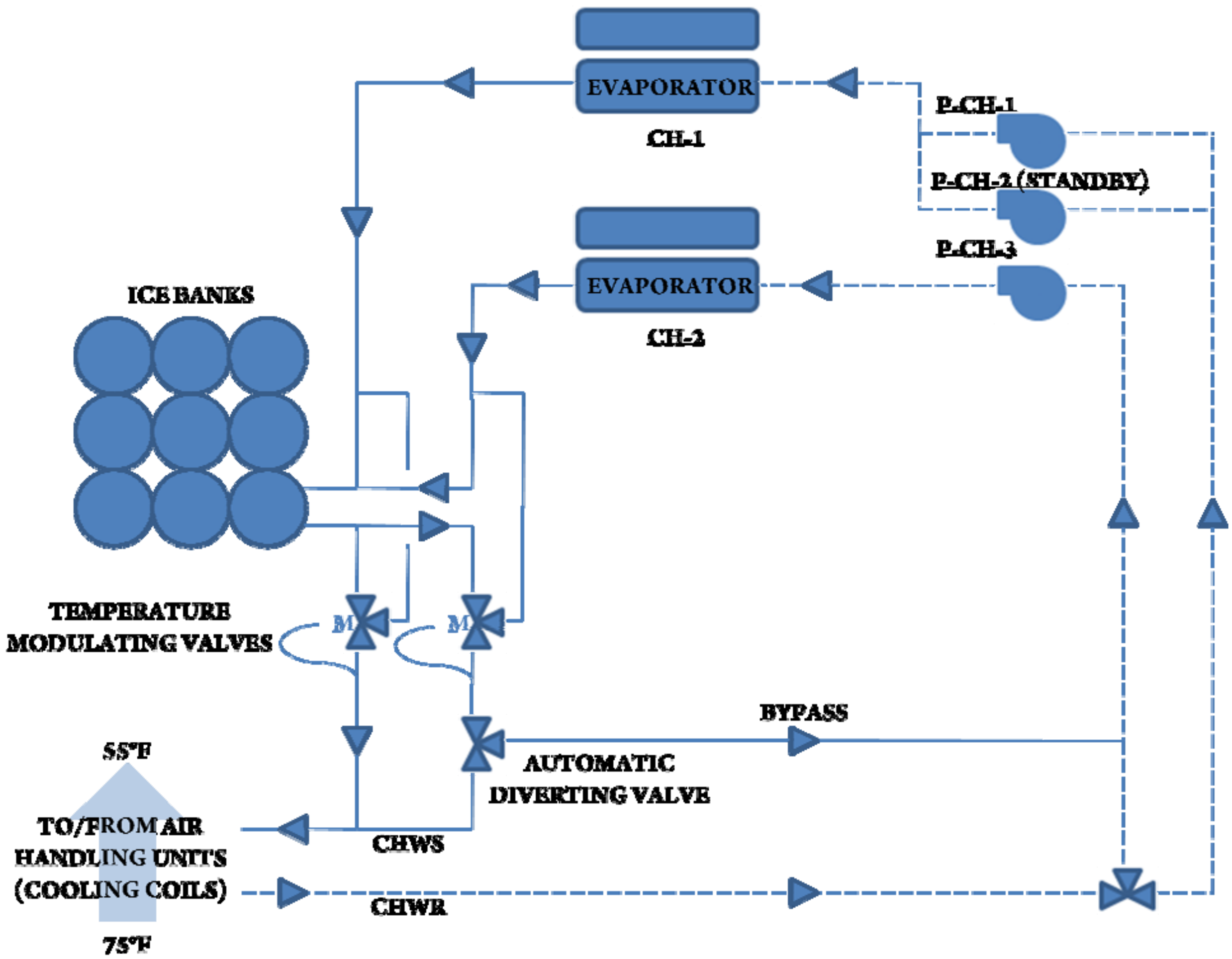


FIGURE 3.10

SYSTEM MODIFICATIONS

Because the model of the chiller, McQuay WDC126, has been designed for use in a thermal energy storage system, the modifications to the chilled water plant should be less complicated. For normal air-conditioning conditions, the entering water temperature at the evaporator is 57°F and the leaving water temperature is 42°F. When ice is being produced during off-peak hours in the future chiller, however, the leaving fluid temperature must be between 22°F and 26°F. Therefore, in order to accommodate such low temperatures, a water-glycol solution must be utilized.

FLUID

The solution that will be used is an ethylene glycol-based industrial coolant. Because this fluid inhibits corrosion, it can be used in standard pumps, air handling unit coils, and seals. This permits the current installed chiller, CH-1, to use the solution with damaging any equipment.

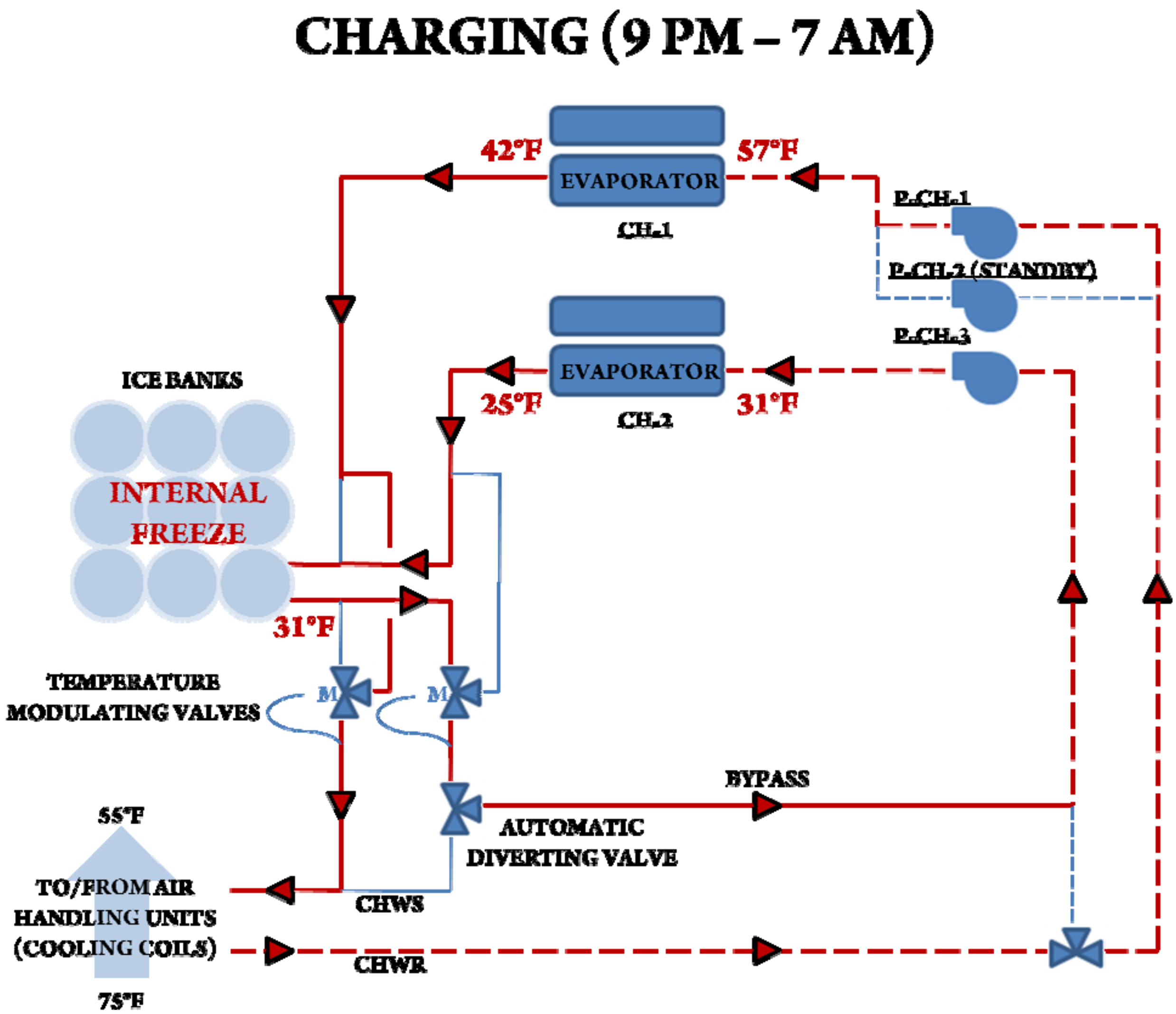


FIGURE 3.11

OPERATION

The added thermal energy storage system will operate in conjunction with the existing chilled water plant distribution. Future chiller CH-2 cycles water through the ice tanks during off-peak hours, internally freezing the water inside the tanks. Current chiller CH-1 provides cooling capacity directly to the hospital at this time. During peak hours, between 7 AM and 9 PM, future chiller CH-2 shuts down. Current chiller CH-1 then utilizes the charged ice tanks to provide cooling capacity to the hospital by internally melting the ice.

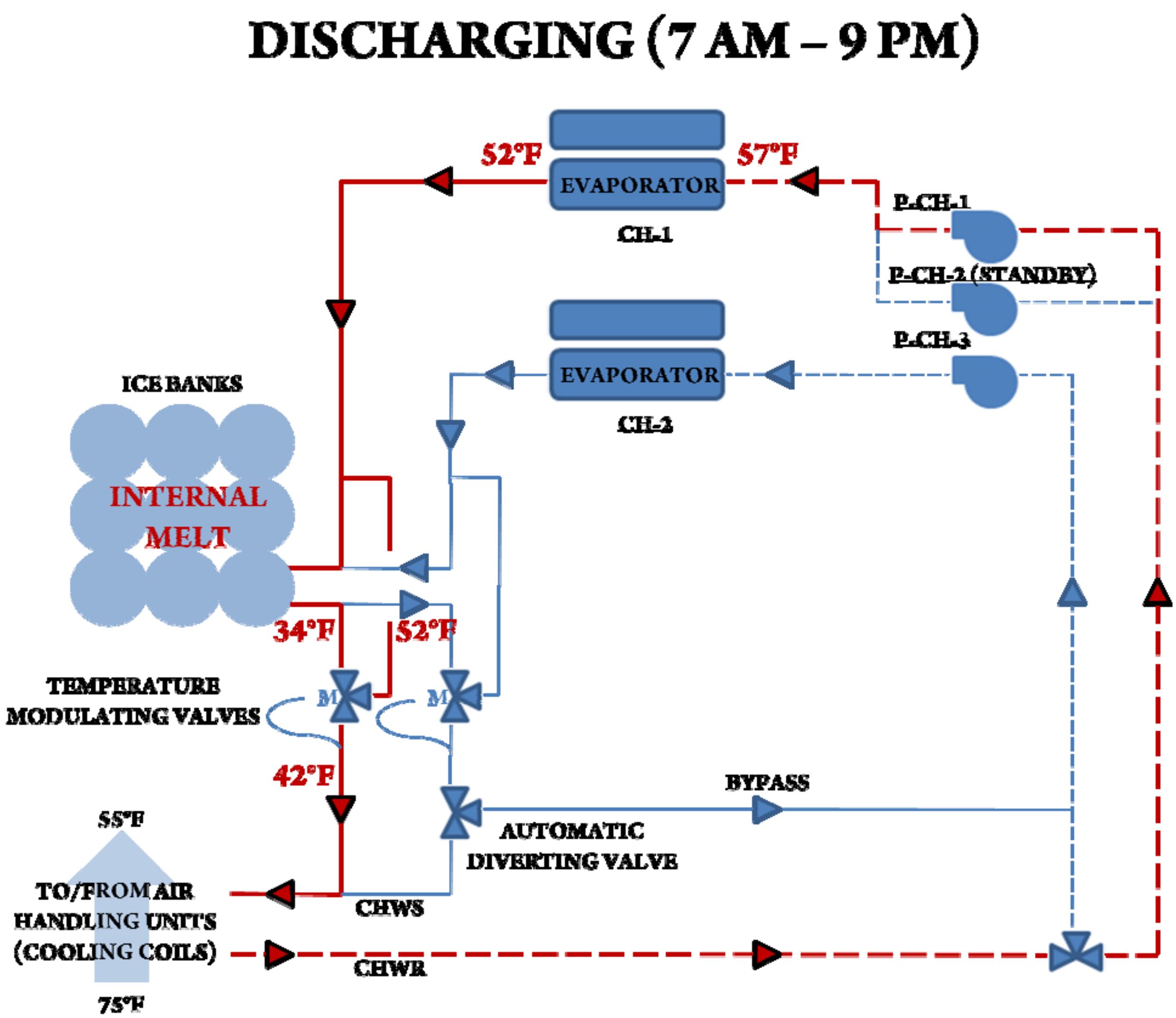


FIGURE 3.12

When future loads are added and more capacity is needed, future chiller CH-2 will have to operate during peak hours. Figure 3.13 illustrates how both chillers operate at this time, working in parallel.

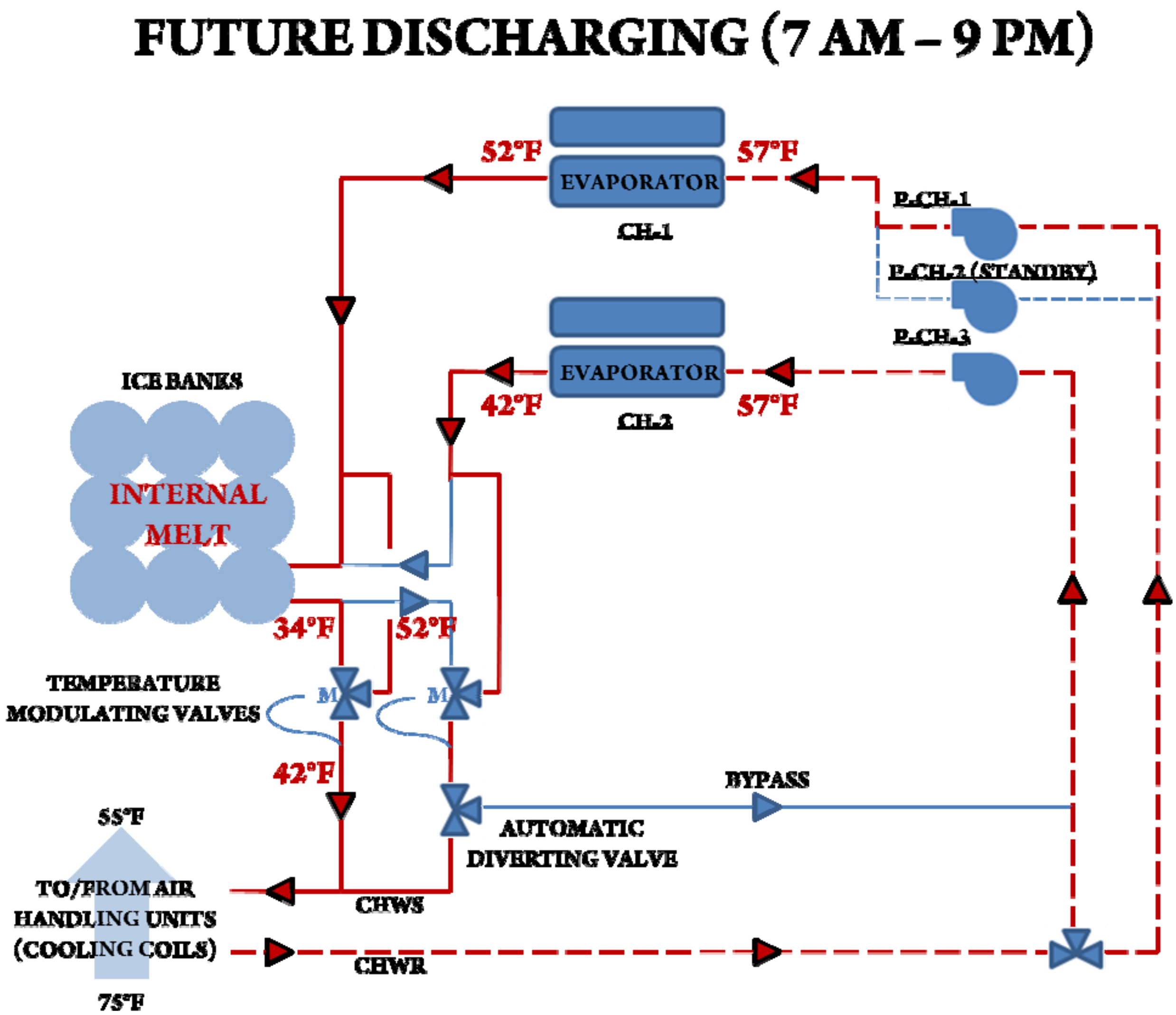


FIGURE 3.13

COST ANALYSIS

The main benefit of thermal energy storage is to operate equipment during off-peak hours when electric utility rates are low. The chiller specified for the South Tower Vertical Expansion operates at 1,255 kW at full load, so shifting loads will significantly reduce costs.

Using cooling load profiles from TRACE 700, it is possible to determine part load ratios for each month, and consequently, the chiller's average energy consumption. Once again, this procedure will only evaluate the three additional floors and the link and lobby of the South Tower Vertical Expansion.

Full Load Kilowatts =	1,255
Maximum Cooling Capacity/Month [ton-hr] =	1,440,000

Month	Cooling Capacity [ton-hr]	Part Load Ratio	Hourly Part Load Kilowatts
1	38,909	0.0270	33.91
2	32,167	0.0223	28.03
3	88,668	0.0616	77.28
4	129,875	0.0902	113.19
5	215,357	0.1496	187.69
6	278,891	0.1937	243.06
7	336,441	0.2336	293.22
8	295,990	0.2055	257.96
9	233,580	0.1622	203.57
10	141,332	0.0981	123.18
11	110,467	0.0767	96.27
12	70,351	0.0489	61.31

TABLE 3.9

The part load kilowatts for each month do not accurately represent the daily variations in energy consumption. However, they will be used to simplify the economic analysis while remaining on the conservative end for estimates. For example, the part load kilowatts is around 400 during off-peak hours while being close to 550 kW during peak hours on the cooling design day rather than a consistent value for the entire day.

TIME-OF-USE ELECTRIC UTILITY RATES

Electricity is provided to the South Tower Vertical Expansion from Baltimore Gas & Electric. They offer rate discounts based on time of electricity use. Figure 3.14 summarizes those rates.

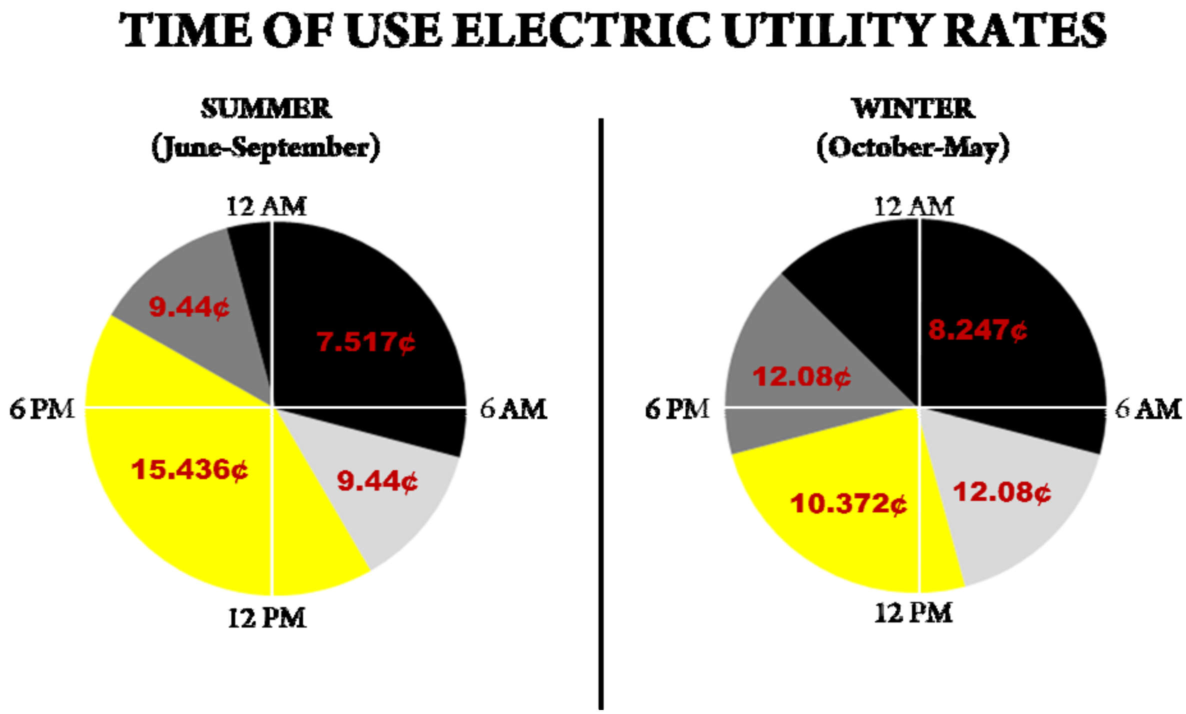


FIGURE 3.14

These rates compare to non-time-of-use rates, which do not fluctuate during the day. Those rates are given in Table 3.10.

Summer Non-TOU Rate:	11.526¢/kWh
Winter Non-TOU Rate:	9.945¢/kWh

TABLE 3.10

ELECTRIC UITLITY SAVINGS

CURRENT DESIGN

Using the part load kilowatts required for chiller operation listed in Table 3.9, it is possible to estimate the electric utility costs for the cooling equipment.

**Assume 720 operating hours per month*

Month	Hourly Part Load Kilowatts	kWh	Rate	Cost
1	33.91	24,415	$0.09945	$2,428
2	28.03	20,185	$0.09945	$2,007
3	77.28	55,639	$0.09945	$5,533
4	113.19	81,497	$0.09945	$8,105
5	187.69	135,137	$0.09945	$13,439
6	243.06	175,004	$0.11526	$20,171
7	293.22	211,117	$0.11526	$24,333
8	257.96	185,734	$0.11526	$21,408
9	203.57	146,571	$0.11526	$16,894
10	123.18	88,686	$0.09945	$8,820
11	96.27	69,318	$0.09945	$6,894
12	61.31	44,146	$0.09945	$4,390

$134,423

TABLE 3.11

Without thermal energy storage, the cost to operate the chiller annually for the South Tower Vertical Expansion is $134,423.

REDESIGN

The same procedure will be performed for the redesign's cost analysis with thermal energy storage being accounted for. This is shown in Table 3.12.

**For capacity met by chilled water directly, assume 300 operating hours per month (by CH-1)*
**For capacity met by thermal energy storage, assume 300 operating hours per month (by CH-2)*

Month	Hourly Part Load Kilowatts	Hours	kWh	Rate	Cost
1-CHW	33.91	9 PM - 7 AM	10,173	$0.08247	$839
1-TES		9 PM - 7 AM	10,173	$0.08247	$839
2-CHW	28.03	9 PM - 7 AM	8,410	$0.08247	$694
2-TES		9 PM - 7 AM	8,410	$0.08247	$694
3-CHW	77.28	9 PM - 7 AM	23,183	$0.08247	$1,912
3-TES		9 PM - 7 AM	23,183	$0.08247	$1,912
4-CHW	113.19	9 PM - 7 AM	33,957	$0.08247	$2,800
4-TES		9 PM - 7 AM	33,957	$0.08247	$2,800
5-CHW	187.69	9 PM - 7 AM	56,307	$0.08247	$4,644
5-TES		9 PM - 7 AM	56,307	$0.08247	$4,644
6-CHW	243.06	9 PM - 11 PM	14,584	$0.09440	$1,377
		11 PM - 7 AM	58,335	$0.07517	$4,385
6-TES		9 PM - 11 PM	14,584	$0.09440	$1,377
		11 PM - 7 AM	58,335	$0.07517	$4,385
7-CHW	293.22	9 PM - 11 PM	17,593	$0.09440	$1,661
		11 PM - 7 AM	70,372	$0.07517	$5,290
7-TES		9 PM - 11 PM	17,593	$0.09440	$1,661
		11 PM - 7 AM	70,372	$0.07517	$5,290
8-CHW	257.96	9 PM - 11 PM	15,478	$0.09440	$1,461
		11 PM - 7 AM	61,911	$0.07517	$4,654
8-TES		9 PM - 11 PM	15,478	$0.09440	$1,461
		11 PM - 7 AM	61,911	$0.07517	$4,654

**For capacity met by chilled water directly, assume 300 operating hours per month (by CH-1)*
**For capacity met by thermal energy storage, assume 300 operating hours per month (by CH-2)*

Month	Hourly Part Load Kilowatts	Hours	kWh	Rate	Cost
9-CHW	203.57	9 PM - 11 PM	12,214	$0.09440	$1,153
		11 PM - 7 AM	48,857	$0.07517	$3,673
9-TES		9 PM - 11 PM	12,214	$0.09440	$1,153
		11 PM - 7 AM	48,857	$0.07517	$3,673
10-CHW	123.18	9 PM - 7 AM	36,953	$0.08247	$3,047
10-TES		9 PM - 7 AM	36,953	$0.08247	$3,047
11-CHW	96.27	9 PM - 7 AM	28,882	$0.08247	$2,382
11-TES		9 PM - 7 AM	28,882	$0.08247	$2,382
12-CHW	61.31	9 PM - 7 AM	18,394	$0.08247	$1,517
12-TES		9 PM - 7 AM	18,394	$0.08247	$1,517

$82,976

TABLE 3.12

Figure 3.15 shows the difference in annual electricity costs.

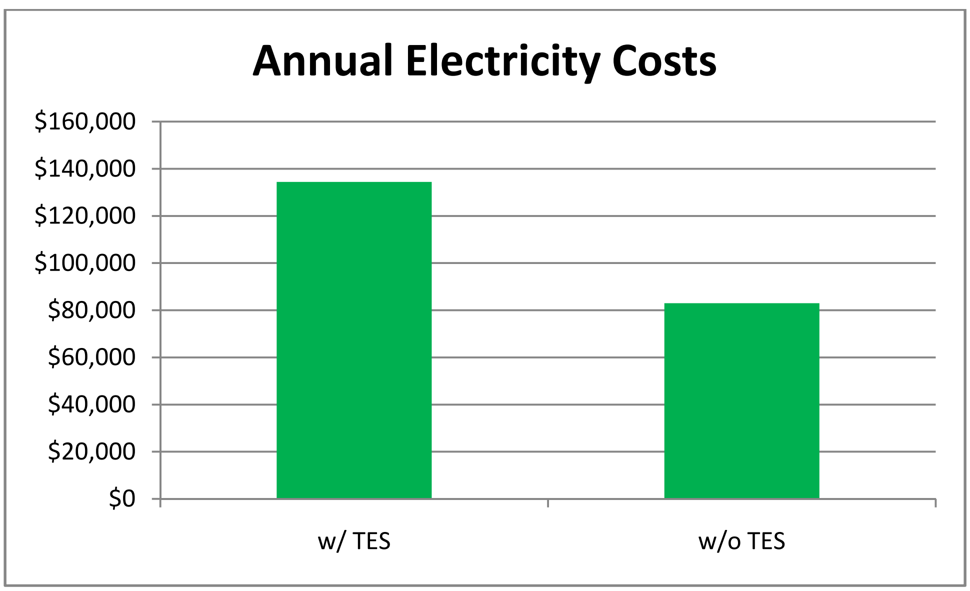


FIGURE 3.15

SAVINGS

Table 3.13 summarizes the annual savings by dollars per year, dollars per square foot, and dollars per kWh.

w/ TES	w/o TES	Annual Difference
$134,423	$82,976	**$51,447**
$1.12/ ft^2	$0.69/ft^2	**$0.43/ft^2**
$0.10863/kWh	$0.08046/kWh	**$0.02817/kWh**

TABLE 3.13

SIMPLE PAYBACK PERIOD

According to CALMAC, the installed cost of thermal energy storage is around $100/ton-hour. This figure will be used to determine the payback period of the system. The storage capacity required for the South Tower Vertical Expansion is 7,613 ton-hr. Future storage will not be evaluated. In addition, the cost of the future chiller and associated equipment will not be taken into account; they have already been proposed.

$$Simple\ Payback\ Period = \frac{\frac{\$100}{ton - hr} \times 7{,}613[ton - hr]}{\$51{,}447}$$

$$\boldsymbol{Simple\ Payback\ Period = 14.8\ years}$$

CONCLUSIONS

Objective 1: Shift loads during peak hours of operation to off-peak hours ✓

As displayed in Figure 3.4, full storage was implemented, and 7,613 ton-hr of cooling capacity was shifted from peak hours in the current chiller to off-peak hours in the future chiller.

Objective 2: Achieve economical benefits ✓

As a result of load shifting, economical benefits were achieved. Baltimore Gas & Electric offers lower electric utility rates during off-peak hours, and because both chillers generate cooling capacity only during those times, there was a savings of approximately $0.03 per kWh. This resulted in an annual electric utility savings of $51,447.

Objective 3: Increase plant flexibility ✓

By using the future chiller for thermal energy storage applications, flexibility in the chilled water plant increased. Both chillers can meet current and future loads while still taking advantage of off-peak time-of-use rates. Furthermore, the future chiller could potentially be downsized by implementing partial storage for any additional loads.

Objective 4: Perform a feasibility study of locating storage equipment on-site ✓

The storage required to support the shifted cooling capacity for current loads would be a feasible amount. 7,613 ton-hr of cooling capacity would need approximately 17,000 ft^3 of space, which is available on the roof. However, the addition of 77 ice tanks for future storage may be more difficult to locate since it requires an additional 28,000 ft^3 of space.

Objective 5: Attain a reasonable payback period ✓

After performing the redesign and cost analysis, it was determined that the payback period of the thermal energy storage addition would be 14.8 years. This is a fairly long length of time, but the system still remains a viable option. CALMAC Ice Banks require very little maintenance and come with a 10-year warranty, so achieving reimbursement of the initial investment seems very likely, especially with a hospital lifespan of at least 30 years.

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	$BTU/ft^2/day$	$BTU/ft^2/month$
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.

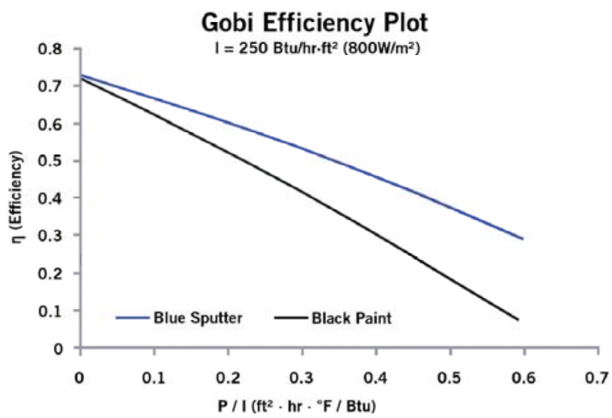


FIGURE 4.1

**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.

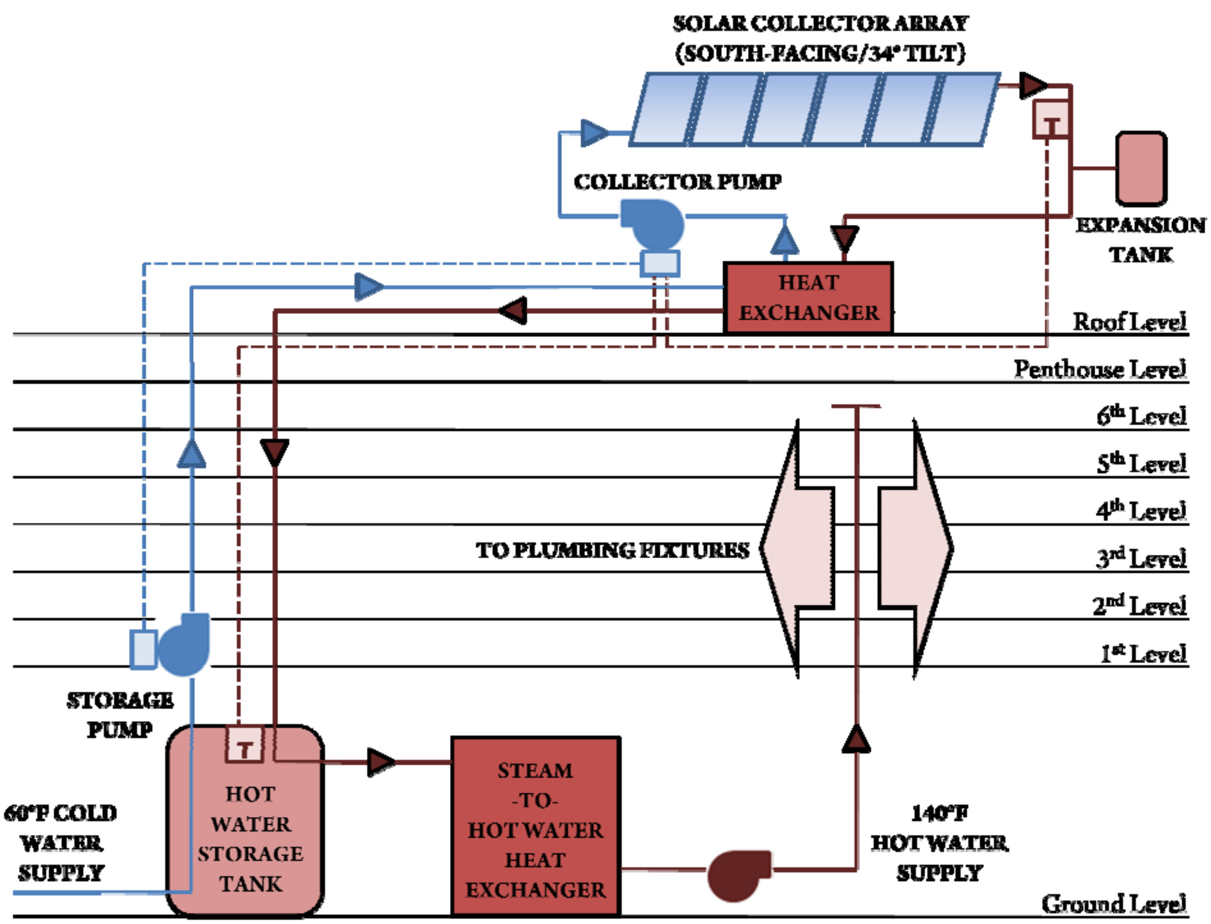


FIGURE 4.2

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:

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

$$= \mathbf{\$1{,}160{,}943}$$

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.

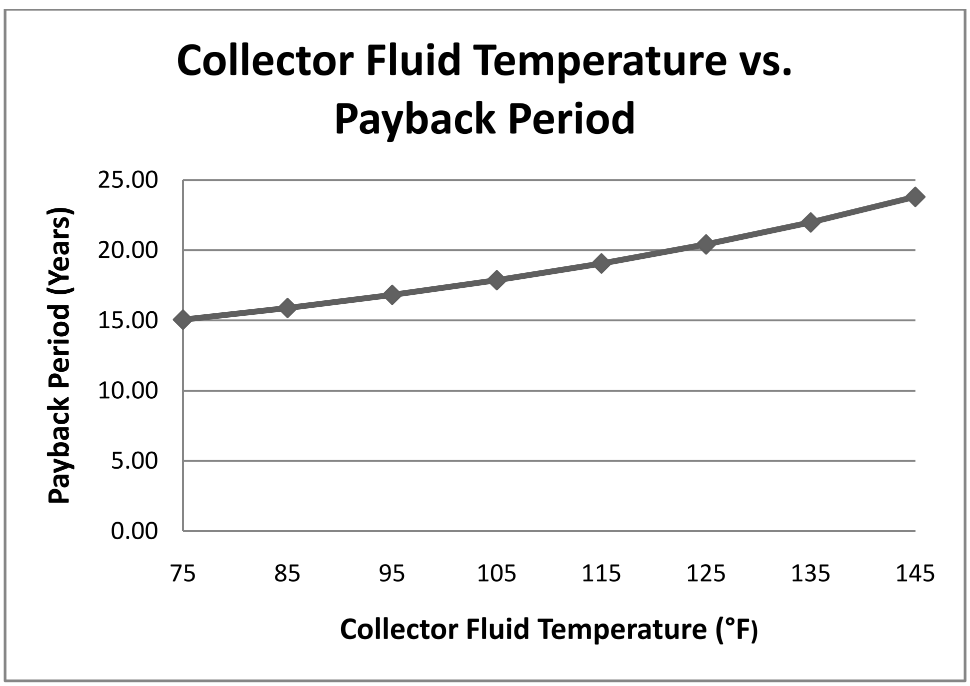


FIGURE 4.3

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.

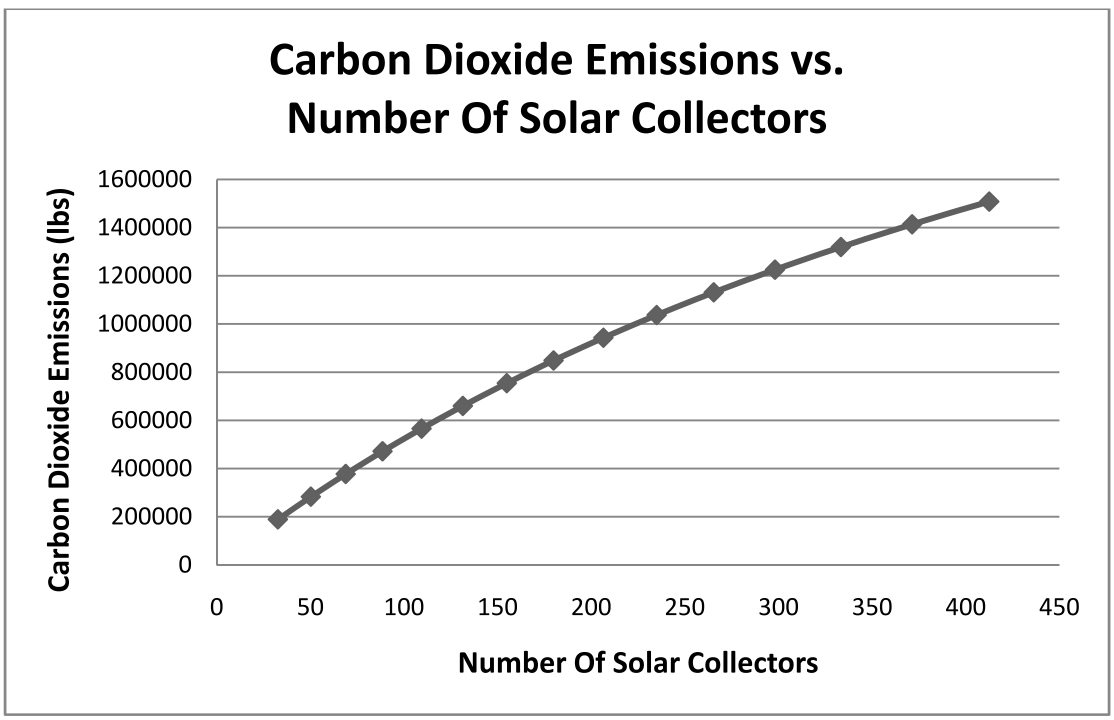


FIGURE 4.4

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.

Structural Breadth

With the weight of several ice tanks located on the roof, a structural analysis must be performed to ensure that installing the thermal energy storage system does not affect the structural integrity of the building.

As previously calculated, 47 ice tanks are proposed to be installed in the chilled water plant redesign to meet cooling capacity for current loads. An additional 77 ice tanks are required to meet cooling capacity for future loads. The weight of this equipment is illustrated below in Table 5.1.

# Of Tanks	Filled Weight [kips]	Floor Loading [psf]
1	16.77	388
47	788.19	776 (2 stacks)
77	1,291.29	776
124	2,079.48	776

TABLE 5.1

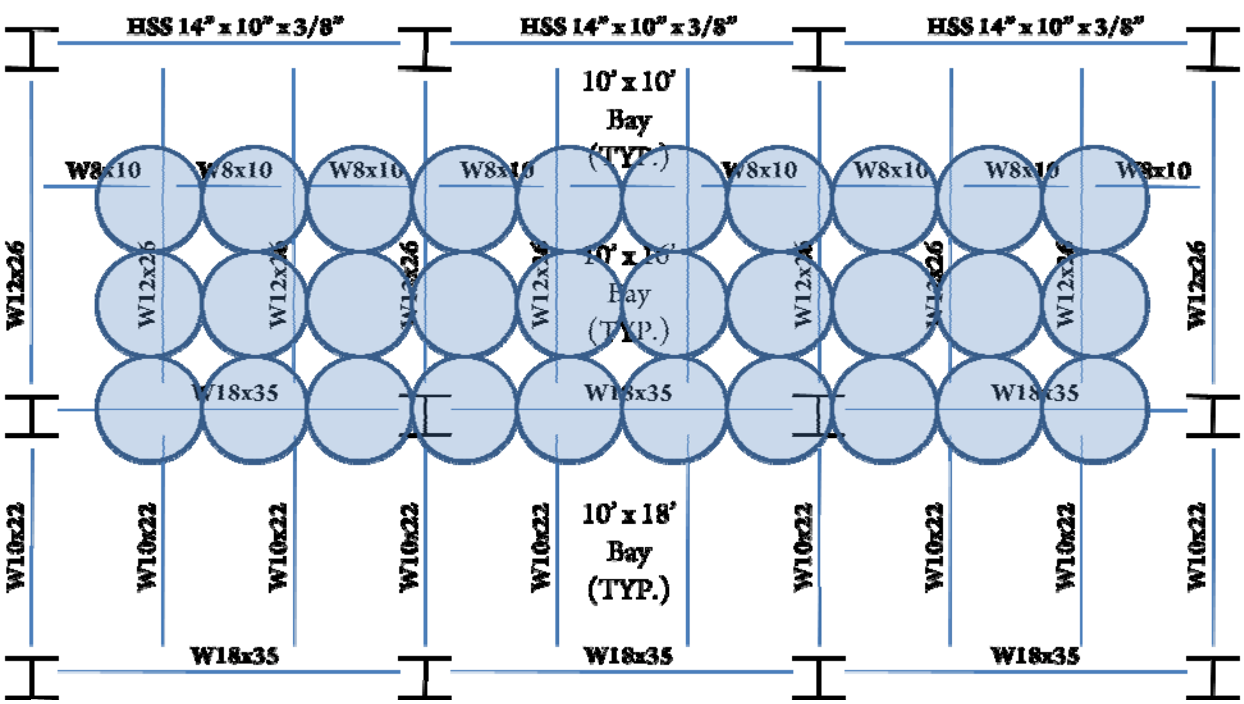


FIGURE 5.1

Figure 5.1 details the framing plan of one side of the roof where the ice tanks will be situated. This will determine whether or not measures need to be taken in order to support the ice tanks. The other existing roof loads to consider are the live load, the dead load of the structure, and the snow load. Table 5.2 summarizes all the loads.

Ice Tank Load:	770 psf
Live Load:	40 psf
Structure Dead Load:	15 psf
Snow Load (Baltimore, MD):	25 psf
Total Load:	850 psf

TABLE 5.2

The slab thickness of the roof is 5”. Figure 5.2 shows the wall section of the roof area in discussed previously.

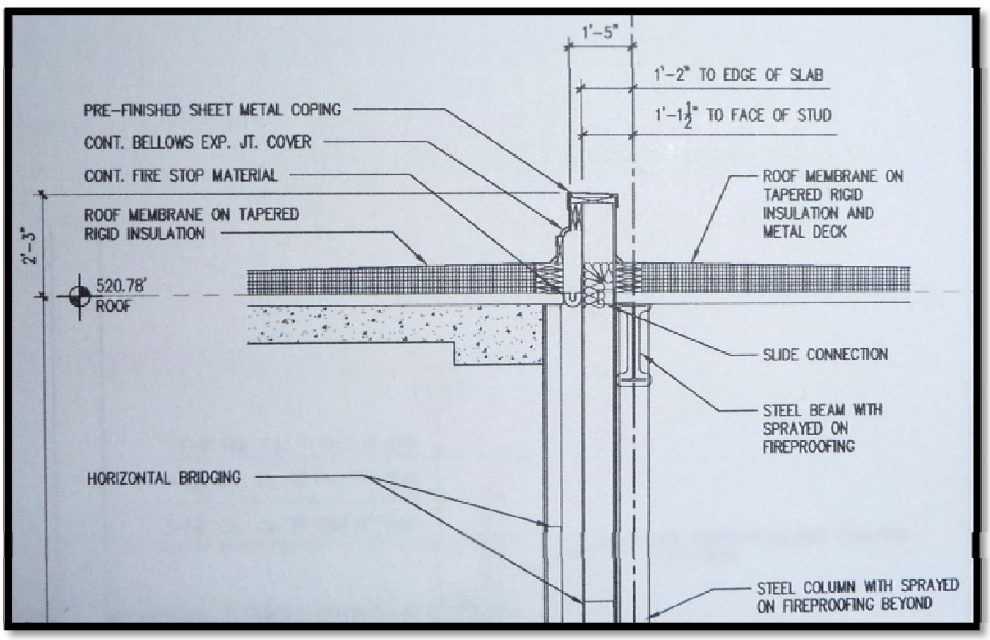


FIGURE 5.2

From Figure 5.1, most of the loading occurs on the central W12x26 and W18x35 beams. Each W12x26 beam takes the load of about two ice tanks while each W18x35 beam takes the load of about three ice tanks. Table5.3 summarizes each beam’s load (2 stacks) and the associated tributary area.

Beam	Load [psf]	Tributary Area [ft^2]	Total Load [kips]
W12x26	850	80	68
W18x35	850	150	127.5

TABLE 5.3

Using the figures from Table 5.1, the total load (including dead, snow, and tank) on each W12x26 beam is 64.8 kips and on each W18x35 is 121.5 kips.

CALCULATIONS

Assumptions:	▪ Loaded in middle ▪ Beam fixed at both ends ▪ A36 steel

TABLE 5.4

W12x26

$$Maximum\ Bending\ Moment = \frac{68\ [kips] \times 26\ [ft]}{8}$$

$$Maximum\ Bending\ Moment = 221\ [kips - ft]$$

$$Section\ Modulus = \frac{221\ [kips - ft] \times 1{,}000\ \left[\frac{lbs}{kips}\right] \times 12\ [\frac{in}{ft}]}{36{,}000\ psi \times 0.55\ (yield)}$$

$$Section\ Modulus = 134\ [in^3]$$

$$Allowable\ Deflection = \frac{312\ [in]}{240}$$

$$Allowable\ Deflection = 1.3\ [in]$$

$$Moment\ Of\ Inertia = \frac{2 \times 68{,}000\ [lbs] \times 312\ [in]^3}{48 \times 30{,}000{,}000\ [psi] \times 1.3\ [in]}$$

$$Moment\ Of\ Inertia = 2{,}207\ [in^4]$$

W18x35

$$Maximum\ Bending\ Moment = \frac{127.5\ [kips] \times 30\ [ft]}{8}$$

$$Maximum\ Bending\ Moment = 479\ [kips - ft]$$

$$Section\ Modulus = \frac{479\ [kips - ft] \times 1{,}000\ \left[\frac{lbs}{kips}\right] \times 12\ [\frac{in}{ft}]}{36{,}000\ psi \times 0.55\ (yield)}$$

$$Section\ Modulus = 291\ [in^3]$$

$$Allowable\ Deflection = \frac{360\ [in]}{240}$$

$$Allowable\ Deflection = 1.5\ [in]$$

$$Moment\ Of\ Inertia = \frac{2 \times 127{,}500\ [lbs] \times 360\ [in]^3}{48 \times 30{,}000{,}000\ [psi] \times 1.5\ [in]}$$

$$Moment\ Of\ Inertia = 5{,}508\ [in^4]$$

Table 5.5 summarizes the calculation results and shows whether or not the current beams are appropriately sized to meet the additional loads of the ice tanks.

	Actual Property Values		Required Property Values	
	Section Modulus [in^3]	Moment Of Inertia [in^4]	Section Modulus [in^3]	Moment Of Inertia [in^4]
W12x26:	33.4	204	134	2,207
W18x35:	57.6	510	291	5,508

TABLE 5.5

As seen in Table 5.5, the beams are incredibly undersized. If the load bearing capacity of the beams is not increased, the structural integrity of the building would be severely compromised. Table 5.6 recommends beams which would be able to support the ice tanks.

Recommended Beam	Section Modulus [in^3]	Moment Of Inertia [in^4]
W24x84	196	2,370
W27x146	411	5,630

TABLE 5.6

Architectural Breadth

Locating the ice tanks on the roof will create a variation in the appearance of the west façade. Pedestrians will see the ice tanks from ground level and the look of those tanks do not match seamlessly with South Tower architecture.

Therefore, a screen will need to be provided to mask the view of the tanks from street level. The same type of screen used to hide the air handling units will be used to hide the storage tanks. See Figure 6.1 for existing details. See Figure 6.2 for proposed changes.

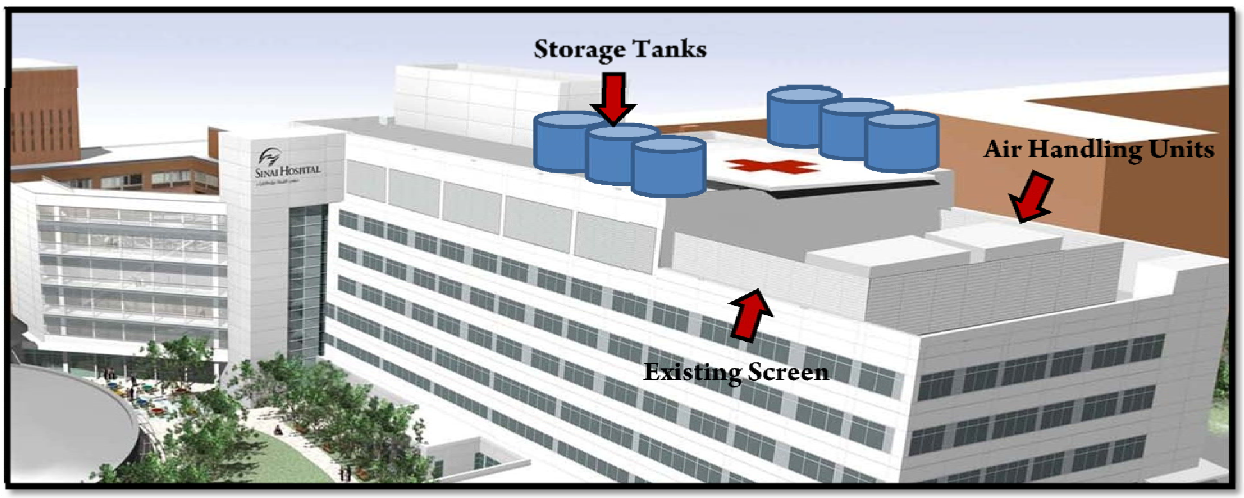


FIGURE 6.1

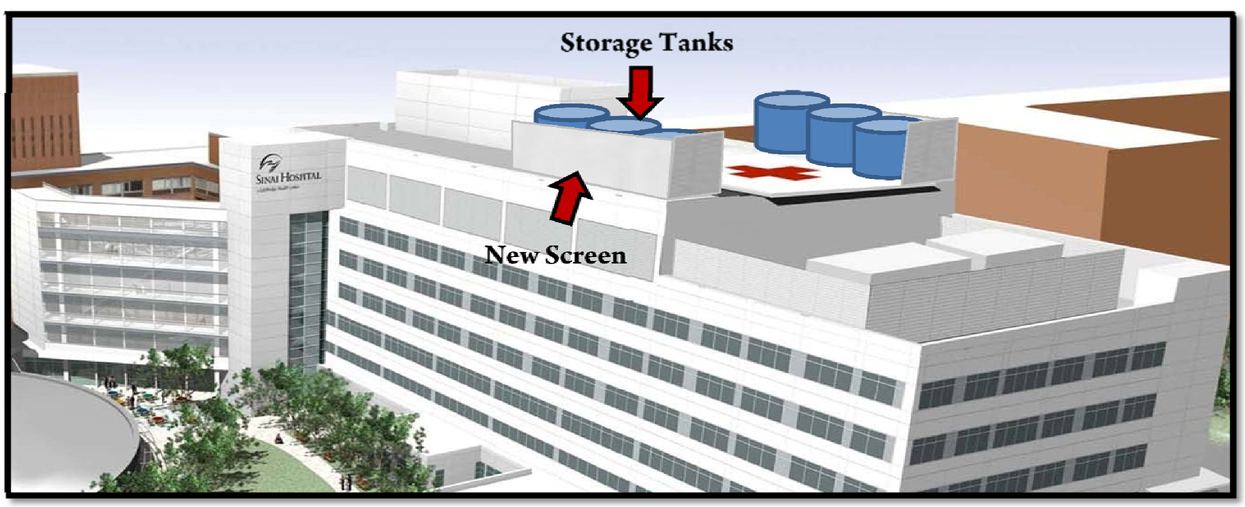


FIGURE 6.2

References

Astronomical Applications Department. “Sun or Moon Altitude/Azimuth Table.” http://aa.usno.navy.mil/data/docs/AltAz.php.

Bahnfleth, William. “A E 557 Lecture Notes.”

Baltimore Gas & Electric. “Time of Use.” http://www.bge.com/portal/site/bge/menuitem.44ea3fa837dc1a5d6b737213747176a0/gHref;.

CALMAC. “A Technical Introduction to Thermal Energy Storage Commercial Applications.”

Commercial Energy Advisor. “Managing Energy Costs in Hospitals.”

Energy Star. “Federal Tax Credits for Energy Efficiency.” http://www.energystar.gov/index.cfm?c=products.pr_tax_credits#s4.

Energistic Systems. “Solar Collector Efficiency.”

Environmental Process Systems, Limited. “Plus-ICE Phase Change Materials (PCM) Thermal Energy Storage (TES) Design Guide."

Federal Energy Management Program. “Thermal Energy Storage for Space Cooling.”

Frankenfield, Guy. “Thermal Energy Storage Makes Good Sense.”

Hess, Mike, and Ari Tinkoff. “Confronting Climate Change in the Healthcare Market.”

Institute of Hospital Engineering, Australia. “Application Notes for Energy Saving: Solar Domestic Hot Water.”

MacCracken, Mark. “Thermal Energy Storage and Peak Load Reduction.”

MacCracken, Mark. “Thermal Energy Storage in Sustainable Buildings.”

Maryland Incentives for Renewables and Efficiency. “Solar Energy Grant Program.” http://www.dsireusa.org/library/includes/incentive2.cfm?Incentive_Code=MD14F&state=MD&CurrentPageID=1&RE=1&EE=1.

Naguib, Ramez. "Hybrid Ice Thermal Energy Storage: All-in-one Innovative New System Concept."

National Renewable Energy Laboratory. "Source Energy and Emission Factors for Energy Use in Buildings."

National Solar Radiation Data Base. "The Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors."
http://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/redbook/.

Platts Research & Consulting. "Managing Energy Costs in the Hospital/Healthcare Sectors."

Sullivan, C.C. "Thermal Energy Storage Brings Operational Efficiency."
http://www.allbusiness.com/construction/construction-buildings/490293-1.html.

The Engineering Toolbox. "American Wide Flange Beams."
http://www.engineeringtoolbox.com/american-wide-flange-steel-beams-d_1319.html.

Turpin, Joanna. "Thermal Storage and Perpetual Savings."
http://findarticles.com/p/articles/mi_m0BPR/is_7_19/ai_89490488/pg_2/?tag=artBody;col1.

U.S. Department of Energy. "Solar Hot Water."
http://www.eere.energy.gov/de/solar_hotwater.html.

Washington State University Energy Program. "Thermal Energy Storage."

Whole Building Design Guide. "Solar Water Heating."
http://www.wbdg.org/resources/swheating.php.

Appendix A: Input Data (TRACE 700)

Fourth/Fifth Floor					
			From Design Documents:		
Room	Quantity	Area [ft²]	Occupancy	OA Ventilation Rate [cfm]	Load Sources
Ante Room 1	1	65	1	0	computers
Ante Room 2	1	65	1	0	computers
Clean Utility 1	1	87	0	0	none
Clean Utility 2	1	168	0	0	none
Clean Utility 3	1	128	0	0	none
Clinical Leaders	1	253	3	0	computers
CR Reader	1	80	0	0	none
Director's Office 1	1	148	3	0	computers
Director's Office 2	1	147	3	0	computers
Electrical Closet 1	1	50	0	0	elec. equip.
Electrical Closet 2	1	128	0	0	elec. equip.
Elevator Lobby	1	378	11	0	none
Equipment Storage	1	363	0	0	none
Family Consultant	1	108	2	0	computers
Housekeeping	1	50	0	0	none
ICU Patient Room 01	1	419	5	130	med. equip.
ICU Patient Room 02	1	399	5	120	med. equip.
ICU Patient Room 03	1	399	5	120	med. equip.
ICU Patient Room 04	1	399	5	120	med. equip.
ICU Patient Room 05	1	399	5	120	med. equip.
ICU Patient Room 06	1	399	5	120	med. equip.
ICU Patient Room 07	1	399	5	120	med. equip.
ICU Patient Room 08	1	399	5	120	med. equip.
ICU Patient Room 09	1	399	5	120	med. equip.
ICU Patient Room 10	1	400	5	120	med. equip.
ICU Patient Room 11	1	399	5	120	med. equip.
ICU Patient Room 12	1	379	5	115	med. equip.

Room	Quantity	Area [ft^2]	Occupancy	OA Ventilation Rate [cfm]	Load Sources
ICU Patient Room 13	1	339	5	105	med. equip.
ICU Patient Room 14	1	411	5	125	med. equip.
ICU Patient Room 15	1	366	5	110	med. equip.
ICU Patient Room 16	1	363	5	110	med. equip.
ICU Patient Room 17	1	366	5	110	med. equip.
ICU Patient Room 18	1	434	5	135	med. equip.
ICU Patient Room 19	1	399	5	120	med. equip.
ICU Patient Room 20	1	399	5	120	med. equip.
ICU Patient Room 21	1	399	5	120	med. equip.
ICU Patient Room 22	1	399	5	120	med. equip.
ICU Patient Room 23	1	399	5	120	med. equip.
ICU Patient Room 24	1	399	5	120	med. equip.
ICU Patient Room 25	1	399	5	120	med. equip.
Isolation Room 1	1	398	5	120	med. equip.
Isolation Room 2	1	369	5	115	med. equip.
Isolation Room 3	1	454	5	140	med. equip.
Isolation Room 4	1	454	5	140	med. equip.
Medication 1	1	88	0	0	computers
Medication 2	1	81	0	0	computers
Meds Room	1	77	0	0	computers
Mid Level Providers	1	150	2	0	computers
Nourishment 1	1	131	0	0	none
Nourishment 2	1	74	0	0	none
Nurse Manager	1	110	4	0	computers
Nurse Station 1	1	198	4	0	computers
Nurse Station 2	1	202	4	0	computers
Nurse Station 3	1	202	4	0	computers
Nurse Station 4	1	150	4	0	computers
On Call Room 1	1	62	1	0	computers
On Call Room 2	1	63	1	0	computers
On Call Room 3	1	68	1	0	computers
On Call Room 4	1	65	1	0	computers

Room	Quantity	Area [ft²]	Occupancy	OA Ventilation Rate [cfm]	Load Sources
Patient Corridor	1	4400	0	0	none
Public Toilet	1	59	0	0	none
Reception	1	119	1	0	computers
Security	1	104	1	0	computers
Social Worker	1	75	2	0	computers
Soiled Utility	1	100	0	0	none
Staff Conference Room	1	292	10	0	tv
Staff Lockers	1	271	1	0	none
Staff Lounge	1	290	12	0	tv, refrigerator
Staff Toilet 1	1	66	0	0	none
Staff Toilet 2	1	42	0	0	none
Staff Toilet 3	1	62	0	0	none
Storage 1	1	365	0	0	none
Storage 2	1	45	0	0	none
Viewing	1	222	9	0	tv, computers
Waiting Room	1	930	26	0	tv
Work Alcove	13	40	1	0	computers

Sixth Floor					
			From Design Documents:		
Room	Quantity	Area [ft²]	Occupancy	OA Ventilation Rate [cfm]	Load Sources
Ante Room 1	1	69	1	0	computers
Ante Room 2	1	139	1	0	computers
Charting	1	46	1	0	computers
Clean Utility 1	1	120	0	0	none
Clean Utility 2	1	120	0	0	none
Clean Utility 3	1	147	0	0	none
Clinical Coach	1	86	2	0	computers
Clinical Leaders	1	310	4	0	computers
Conference	1	240	8	0	computers
Consulting	1	133	4	0	computers
Corridor 1	2	2275	0	0	none
Corridor 2	1	1533	0	0	none
Corridor 3	1	303	0	0	none
Corridor 4	1	220	0	0	none
Corridor 5	1	355	0	0	none
Corridor 5A	1	200	0	0	none
E Patient Room	11	300	5	85	med. equip.
E Patient Room Toilet	11	35	0	0	none
Electrical Room	1	156	0	0	elec. equip.
Elevator Lobby	2	80	5	0	none
Equipment	1	242	0	0	none
Family Waiting	1	138	7	0	none
Isolation Room 1	1	331	5	94	med. equip.
Isolation Room 2	1	373	5	106	med. equip.
Isolation Room 3	1	50	5	15	med. equip.
Isolation Room 4	1	50	5	15	med. equip.
Isolation Room 5	1	347	5	99	med. equip.
Isolation Room 6	1	343	5	98	med. equip.
Janitor 1	1	51	0	0	none
Janitor 2	1	63	0	0	none

Room	Quantity	Area [ft^2]	Occupancy	OA Ventilation Rate [cfm]	Load Sources
Locker	1	207	1	0	none
Managerial Assistant	1	88	3	0	computers
Medication	1	120	0	0	computers
Nourishment 1	1	81	0	0	none
Nourishment 2	1	81	0	0	none
Nurse Manager	1	145	6	0	computers
Nurse's Station 1	1	641	6	0	computers
Nurse's Station 2	1	534	6	0	computers
Office	1	123	3	0	computers
Patient Room	1	336	5	96	med. equip.
Patient Support	1	115	1	0	computers
Repertory Storage	1	395	0	0	none
Repertory Therapy	1	360	6	0	computers
S Patient Room	5	290	5	83	med. equip.
S Patient Room Toilet	5	35	0	0	none
S Patient Room Toilet 1	1	35	0	0	none
S Patient Room Toilet 2	1	35	0	0	none
S Patient Room Toilet 3	1	35	0	0	none
Soiled Utility	1	147	0	0	none
Soiled Holding	1	70	0	0	none
Staff Lounge	1	318	12	0	refrigerator
Staff Toilet	1	78	0	0	none
Storage	1	170	0	0	none
SW Case Management	1	148	2	0	computers
Trash Room	1	80	0	0	none
Vending	1	64	3	0	none
W Patient Room	13	320	5	91	med. equip.
W Patient Room Toilet	13	35	0	0	none

Link & Lobby					
			From Design Documents:		
Room	Quantity	Area [ft²]	Occupancy	OA Ventilation Rate [cfm]	Load Sources
First Floor Walkway & Lobby	1	7580	0	0	none
Second Floor Walkway	1	2100	0	0	none
Third Floor Walkway	1	2100	0	0	none
Fourth Floor Walkway	1	2100	0	0	none
Fifth Floor Walkway	1	2100	0	0	none
Sixth Floor Walkway	1	2100	0	0	none
Women's Toilet	1	400	0	0	none
Men's Toilet	1	420	0	0	none
Corridor	1	240	0	0	none

Appendix B: Domestic Hot Water Demand

	Quantity	Basins	Other Fixtures	GPH/fixture	Total GPH	Notes
Patient Room	25	2	-	2	100	
Isolation Room	4	2	-	2	16	
Staff Conference Room	1	1	-	6	6	
Staff Toilet	4	1	-	6	24	
Staff Lounge	1	1	-	6	6	
On-Call Toilet	1	1	-	6	6	
	1	-	1	10	10	Shower
Public Toilet	1	1	-	6	6	
Soiled Utility	1	1	-	6	6	
	1	-	1	28	28	Laundry
House Keeping	2	1	-	20	40	
Nourishment	2	1	-	6	12	
Ante Room	2	1	-	6	12	
Medication	2	1	-	6	12	
Meds Room	1	1	-	6	6	

GPH/floor =	290	
Demand Factor =	0.25	
Floors =	3	
Total GPH =	217.5	

OR

Total GPM =	3.625	
Storage Capacity Factor =	0.6	
Storage Tank Volume =	130.5	[gal]

OR

Storage Tank Volume =	17.44785	[ft³]

Appendix C: Payback Calculations

**Values are for the month of December*

Collector T	Ambient T	ΔT	ΔT/I	Efficiency	Max Solar Rad	Actual Solar Rad	BTU/hr
145	36.7	108.3	0.43	0.39	17393	6753	145000
135	36.7	98.3	0.39	0.42	17393	7313	126875
125	36.7	88.3	0.35	0.45	17393	7873	108750
115	36.7	78.3	0.31	0.48	17393	8433	90625
105	36.7	68.3	0.27	0.52	17393	8993	72500
95	36.7	58.3	0.23	0.55	17393	9554	54375
85	36.7	48.3	0.19	0.58	17393	10114	36250
75	36.7	38.3	0.15	0.61	17393	10674	18125

Collector T	kW	$ Boiler	BTU/month	ft^2 Of Collectors	# Of Collectors	$ Collectors	Payback
145	53.12	48733	1.04E+08	15459	413	1159442	23.79
135	46.48	42642	91350000	12491	333	936820	21.97
125	39.84	36550	78300000	9945	265	745870	20.41
115	33.20	30458	65250000	7737	206	580281	19.05
105	26.56	24367	52200000	5804	155	435316	17.87
95	19.92	18275	39150000	4098	109	307347	16.82
85	13.28	12183	26100000	2581	69	193552	15.89
75	6.64	6092	13050000	1223	33	91698	15.05

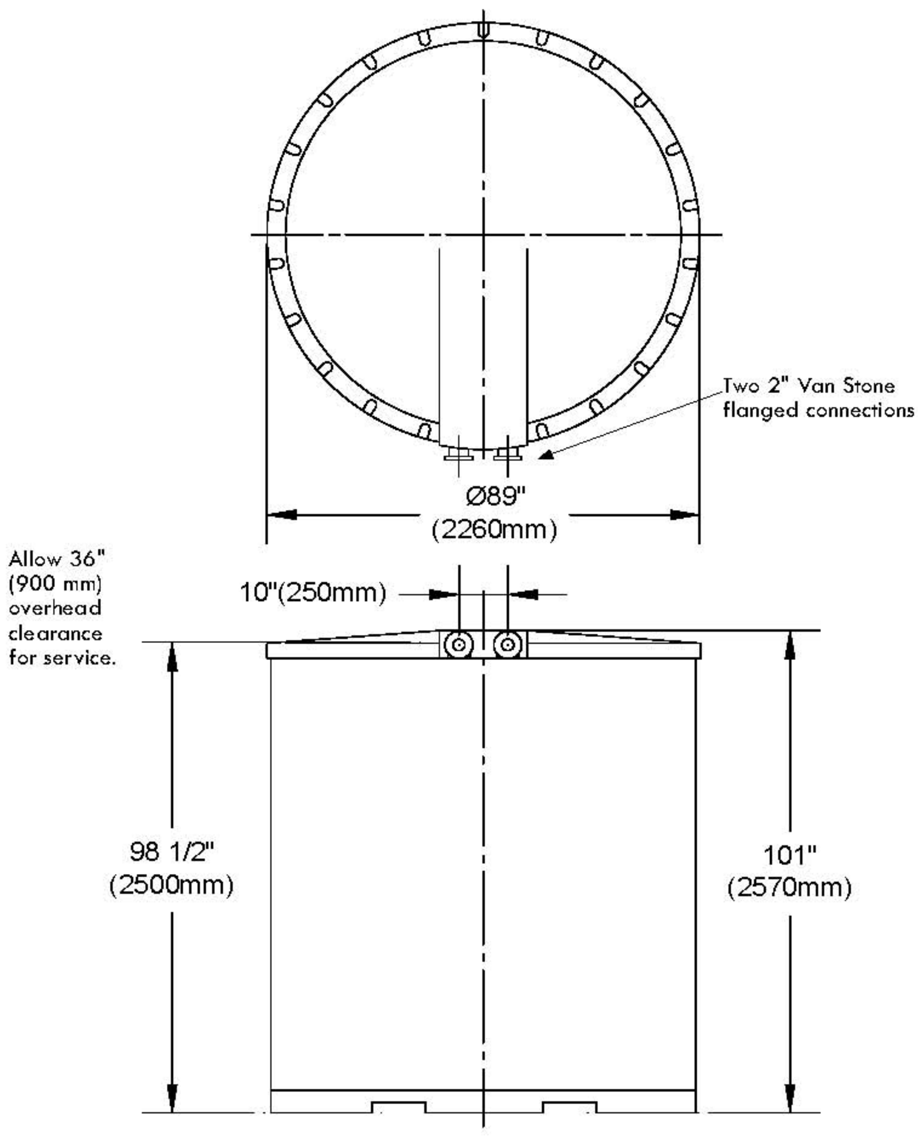
Appendix D:

Product Specifications

CALMAC **IceBank**®
THERMAL ENERGY STORAGE

DRAWING
Model 1190A
August 2007
CS-5

CALMAC Manufacturing Corp. 3-00 Banta Place Fair Lawn, NJ 07410 Tel (201) 797-1511 www.Calmac.com

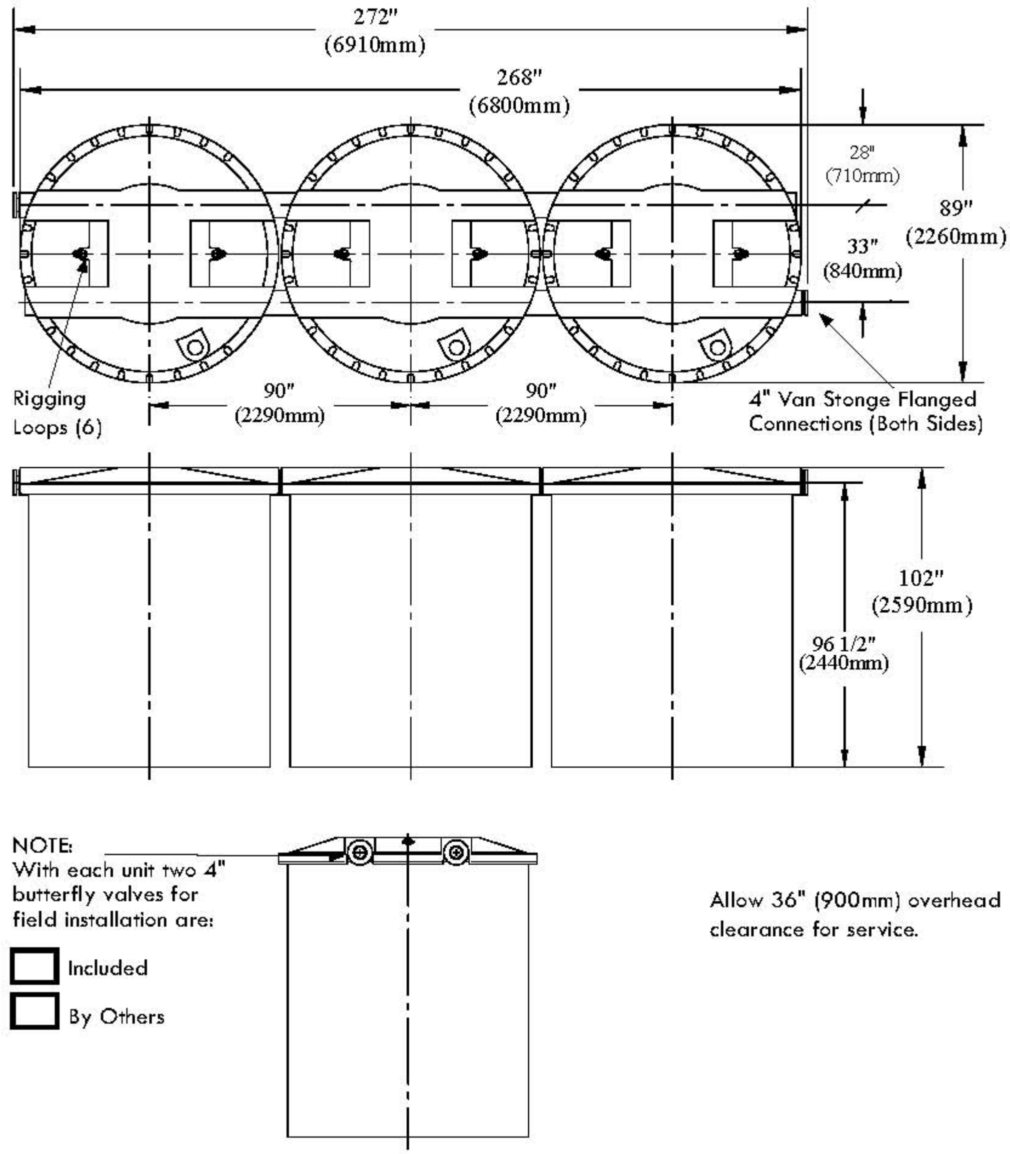


NOTE: Tolerance for all dimensions is ± 1/2" (12.5 mm)

CALMAC **IceBank®**
THERMAL ENERGY STORAGE

DRAWING
Model 1500CRF
August 2007
CS-50

CALMAC Manufacturing Corp. 3-00 Banta Place Fair Lawn, NJ 07410 Tel (201) 797-1511 www.Calmac.com



NOTE: Overall length ±1", Tolerance for all other dimensions is ±1/2" (12.5 mm)

heliodyne
SOLAR HOT WATER

SOLAR COLLECTORS

The GOBI line of solar flat-plate collectors is one of the industry's highest-rated. Over 30 years of design and engineering refinement have gone into making it a world-class performer for heat output, efficiency, and durability. The collector is available in three sizes, with two surface types to choose from (blue sputtered and black paint), making it suitable for all types of solar heating applications.

OG100 CERTIFIED

DOS unions are included to connect collectors

Features

- Low-profile tapered design for a subtle rooftop presence
- Optimal heat absorption and overall efficiency
- Certified to withstand a windload of 50 lbs per square foot
- Anodized aluminum frame improves durability & rigidity
- No-solder connections with factory installed DYN-O-SEAL unions
- Rated by SRCC and IAPMO as one of the industry's best-performing collectors

ABSORBER SURFACES

Blue sputtered coating (Variant 001)

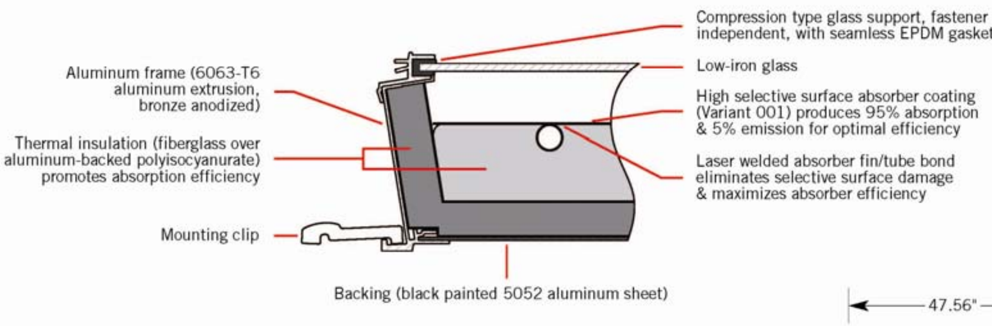
- Optimal heat absorption with minimal emission
- Suitable for all installations & regions
- Recommended for cool climates

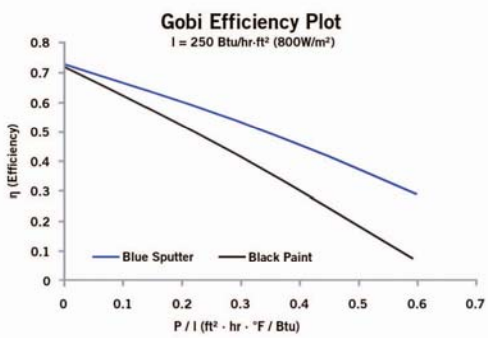
Black paint coating (Variant 002)

- An economical choice
- Adequate heat absorption in ideal climate regions
- Best for warm climates with ample solar radiation

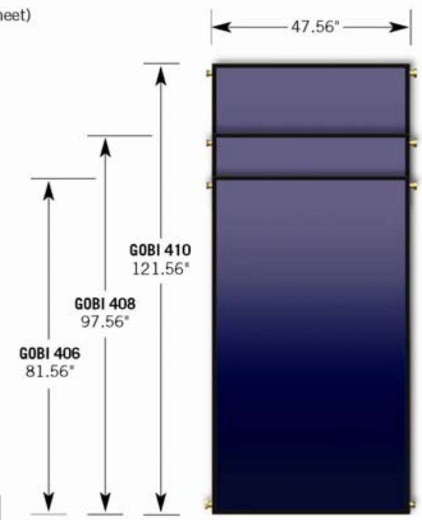
EXCELLENCE BY DESIGN

TECHNICAL SPECIFICATIONS





Gross Area Efficiency Curve



REFERENCE AREA	BLACK PAINT GROSS	BLACK PAINT NET	BLUE SPUTTER GROSS	BLUE SPUTTER NET
C_0 (-)	0.7190	0.7783	0.7300	0.7902
C_1 (BTU / HR FT^2 °F)	0.9358	1.0130	0.6006	0.6501
C_2 (BTU / HR FT^2 °F)	0.0010	0.0011	0.0010	0.0011

Note: GOBIs all have a depth of 3.9"

PRODUCT CODE	GOBI 406	GOBI 408	GOBI 410
Dimensions, Weights, Capacities			
Gross Area	26.94 ft²	32.22 ft²	40.15 ft²
Net Area	24.90 ft²	29.93 ft²	37.47 ft²
Dry Weight	102 lbs	126 lbs	153 lbs
Fluid Capacity	1 gal	1.14 gal	1.34 gal
Ratings & Certifications			
Maximum Operating Pressure	150 psi (10.34 Bar)	150 psi (10.34 Bar)	150 psi (10.34 Bar)
Wind Load Certification	50 psf (2.39 kPa)	50 psf (2.39 kPa)	50 psf (2.39 kPa)

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