Building & Plant Energy Analysis Report

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William & Mary
Virginia Institute of Marine Science
Marine Research Building Complex
Seawater Research Laboratory

Gloucester Point, VA

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1.0 Executive Summary

This report investigates the Seawater Research Laboratory's compliance with the ASHRAE Standard 90.1 and LEED-NCv2.2. The LEED Certification system was defined but, the building was not rated for because the building is a laboratory and not a commercial office building. The Seawater Research Laboratory does, however, utilize some green features such as an energy recovery loop, and utilizes a DDC control system to monitor and control the available minimum conditions that the mechanical systems can operate at. The building envelope is compliant with the ASHRAE Standard 90.1, with all of the building wall types meeting the minimum requirements.

The electrical systems of the Seawater Research Laboratory were also analyzed for compliance with the ASHRAE Standard 90.1. The power system was analyzed through calculation of the percent of voltage drop through the feeders and branch circuits. The requirements for the power system compliance are 2% voltage drop per feeders, and 3% power drop per branch circuits. The design documents state that both the feeders and the branch circuits were to be sized to accommodate a maximum percent voltage drop to be 3%. This value could not be confirmed with the amount of information that is present at the time. The lighting power load was also calculated to confirm the compliance of the building to the ASHRAE Standard 90.1.

The mechanical systems of the Seawater Research Laboratory were another component of the building that was analyzed for compliance with the ASHRAE Standard 90.1. The efficiencies, unit size, energy consumed, space lost due to the mechanical systems, and operation cost were taken from the design data or from the drawing set. Lack of information prevented all the required components minimum efficiencies from being analyzed but, all of the equipment that was analyzed was compliant with the ASHRAE Standard 90.1. The equipment that wasn't evaluated can be once the proper information of the equipment is known. The energy consumed and the HVAC loads were estimated using HAPv4.2, which generated a reasonable energy cost of \$1.95/ft^2 for operation of the HVAC systems. This number would be higher if more of the Seawater Research Laboratory was supplied with cool air. The total initial cost of the mechanical systems was found to be \$1,681,744, which is 23.8% of the total building cost. For a building this size that is a high value, mostly because the building is a laboratory with 100% outdoor air requiring a control system the isn't necessary in most other buildings.

2.0 LEED-NC v2.2

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System is the accepted national standard in the design, construction, and operation of sustainable buildings. Sustainability is the ability to facilitate the needs of the present without reducing the ability of facilitating to the needs of the future. A building that is sustainable uses building materials, systems, construction processes, and operating procedures that generate a better environmental quality, economic vitality, and social benefit. The system is a voluntary, consensus-based standard.

The LEED Green Building Rating System was created by the U.S. Green Building Council, which is composed of leaders representing all segments of the building industry. The U.S. Green Building Council divided the LEED Green Building Rating System into 6 major categories: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, and Innovation and Design Process.

Each of the major categories consists of various requirements that are assigned point values. For a building to become LEED approved it must attain a minimum number of total points from all categories. There are a total of 69 possible points that a building can get. There are four levels of certification in the LEED rating system, LEED Certified (26-23 points), Silver (33-38 points), Gold (39-51 points), and Platinum (52-69 points).

Since the Seawater Research Laboratory is a science lab and not a commercial office building, the LEED Rating System doesn't really apply to the building. The Seawater Research Laboratory doesn't have too much in the way of conserving energy, in fact for the most part the building is a energy pig. However, there is an air to air energy recovery loop that is the heat source for the preheat coil of AHU-1. Another feature of the Seawater Research Laboratory is the DDC control network for the HVAC system. It controls the dampers, fan motors, boilers, chillers, and VAV terminal units, to maintain the indoor air quality and control space and duct pressurization to prevent potentially dangerous leaks.

3.0 ASHRAE Standard 90.1

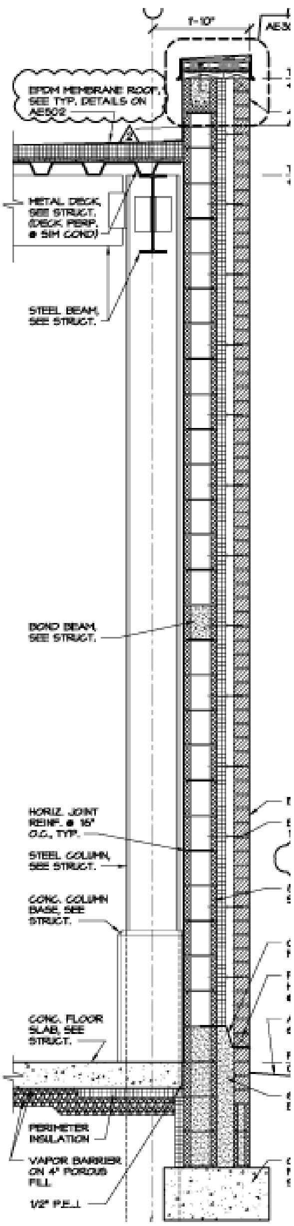
ASHRAE Standard 90.1 provides regulating guidelines and requirements for economical and safe design, construction, operation, and maintenance of mechanical systems. This report is to check the compliance of the Seawater Research Laboratory's building envelope, power distribution efficiency, lighting system, service water heating, and HVAC system efficiencies. The data requirements are found in ASHRAE Standard 90.1 Section 5 for building envelope, Section 8 for power, Section 9 for lighting, Section 6 for HVAC systems, and Section 7 for service water heating.

The Seawater Research Laboratory is located in Gloucester Point, VA. The closest location listed in ASHRAE Standard 90.1 is Norfolk, VA which is approximately 43 miles from Gloucester Point. Table D-1 of Appendix D lists the weather data for Norfolk, VA where the outdoor cooling design temperature is 91db/76wb, and the outdoor heating design temperature is 20db. Gloucester Point is also located in Climate Zone 4A according to Table B-1 of Appendix B in the ASHRAE Standard 90.1.

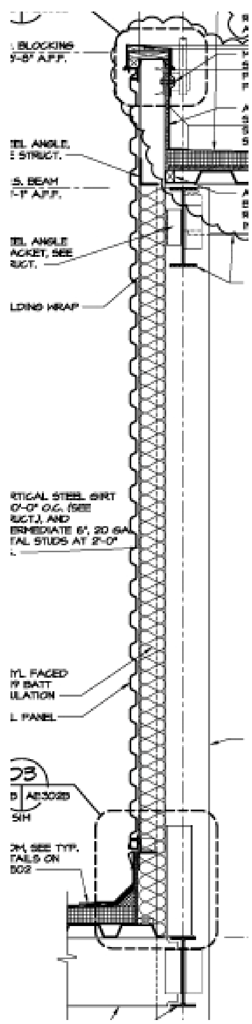
The use of this standard was in conjunction with the use of the ASHRAE Fundamentals 2001 Handbook. Mostly in cases where required values were not known and a typical value from ASHRAE was able to be used.

3.1 Building Envelope Compliance to ASHRAE Standard 90.1

The Seawater Research Laboratory has two different wall types, one that is descriptive of the lower masonry wall and the other one is descriptive of the upper metal panel wall that encloses the high bay portion of the multi-purpose lab. The materials of the two wall types were taken from the typical exterior wall sections of the architectural drawings shown below.

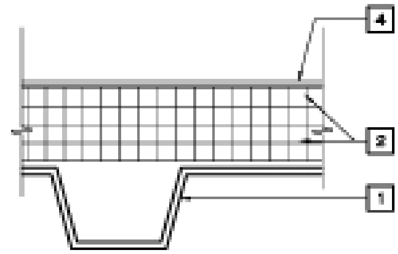


Typical Masonry Wall



Typical Metal Panel Wall

The Seawater Research Laboratory has only one roof type. The materials of the roof were taken from the building sections and typical roof details of the architectural drawings shown below.



Typical Roof

The R-Values listed in the tables below were either specified in the architectural drawings or they were taken from Table-4 of the 2001 ASHRAE Fundamentals Handbook. The R-Values of each particular wall type and roof type were summed together to find the total R-Value of each individual wall type or roof type. The U-Values were calculated using the following equation:

$$\text{U-Value} = \frac{1}{\sum \text{(R-Values)}}$$

The U-Values of the exterior walls and roof were calculated as follows:

Table 1

Masonry Wall		
Material	R-Value	
Inside Surface Still Air	0.68	**Total R-Value = 15.76**
8" CMU	0.97	
4" Brick Veneer	0.44	
2" Rigid Insulation	12.5	
1.5" Air Space	1	**Total U-Value = .0635**
Outside Surface 15 mph wind	0.17	

Table 2

Metal Panel Wall		
Material	R-Value	
Inside Surface Still Air	0.68	Total R-Value = 21.05
6" 20 ga. Metal Studs w/ 2' Spacing O.C.	1.2	
Batt Insulation	19	
Metal Panels	neg.	Total U-Value = .0475
Outside Surface 15 mph wind	0.17	

Table 3

Roof Type I		
Material	R-Value	
Inside Surface Still Air	0.68	Total R-Value = 20.85
Ethylene Propylene Diene Monomer	neg.	
Rigid Insulation	20	
Metal Decking	neg.	Total U-Value = .0480
Outside Surface 15 mph wind	0.17	

The U-Value is the overall heat transfer coefficient measured in Btu/h·ft2·ºF. The lower the U-Value the better the insulating properties of that wall or roof type. The metal panel wall type has the lower U-Value (U-Value = .0475) of the two different wall types, and the roof had a U-Value of .0480.

The Building Envelope Requirements of Table 5.5-4 of the ASHRAE Standard 90.1 were used to determine if the calculated U-Values of the Seawater Research Laboratory are compliant with the ASHRAE Standard 90.1. The following table compares the calculated U-Values of the Seawater Research Laboratory with the ASHRAE Standard 90.1 maximum U-Values.

Table 4

Compliance Check Type	Calculated U-Value	Maximum U-Value From ASHRAE Std. 90.1	Compliant to ASHRAE Std. 90.1?
Masonry Wall	0.0635	0.151	**YES**
Metal Panel Wall	0.0475	0.113	**YES**
Roof Type I	0.048	0.063	**YES**

The vertical fenestration of the Seawater Research Laboratory is/isn't compliant with the ASHRAE Standard 90.1. The vertical wall fixed glazing covers 6.8% of the total wall area. The design documents state the U-Value to be .57 and the SHGC to be .39. The maximum values specified in the ASHRAE Standard 90.1 are U-Value = .57 and SHGC = .39. The design of the building was to use the ASHRAE Standard 90.1 values. So the vertical glazing of the Seawater Research Laboratory is compliant to the ASHRAE Standard 90.1.

3.2 Building HVAC Systems Compliance to ASHRAE Standard 90.1

The Seawater Research Laboratory's mechanical systems check of compliance is described in Sections 6.1, 6.2, 6.4, and 6.5 of the ASHRAE Standard 90.1. The categories of building mechanical system compliance cover:

- Equipment Efficiencies
- HVAC System Construction and Insulation
- Simultaneous Heating and Cooling
- Air System Design And control
- Exhaust & Fume Hoods
- System Controls
- Economizers
- Heat Rejection Equipment
- Energy Recovery
- Radiant Heating Systems

Not all of these categories were able to be checked for compliance, due to the limited information that was available. Of the categories that were not able to be checked or were not applicable to the Seawater Research Laboratory were: HVAC System Construction and Insulation, Economizers, Simultaneous Heating and Cooling, and Heat Rejection Equipment.

The equipment that was able to be checked for minimum efficiency were: Air Handler Units, Boilers, Chillers, Fume Hoods, and System Controls. Table 5 shows the Air Handler Unit efficiencies and their status of compliance. Tables 6 and 7 show the efficiencies of the boilers and chillers respectively along with their status of compliance.

Table 5

Unit	Supply Air Volume	Hp	Unit Hp/1000cfm	ASHRAE Hp/1000cfm	Compliance
AHU-1	18,425	25	1.36	1.7	**yes**
AHU-2	3,295	5	1.52	1.7	**yes**
MAU-1	13,100	10	0.76	1.7	**yes**
MAU-2	21,960	15	0.68	1.7	**yes**
MAU-3	9,940	7.5	0.76	1.7	**yes**
MAU-4	6,985	7.5	1.07	1.7	**yes**

Table 6

Unit	Input	Efficiency	ASHRAE Efficiency	Compliant?
Boiler 1	2000 MBtuh	88%	75%	**yes**
Boiler 2	2000 Mbtuh	88%	75%	**yes**

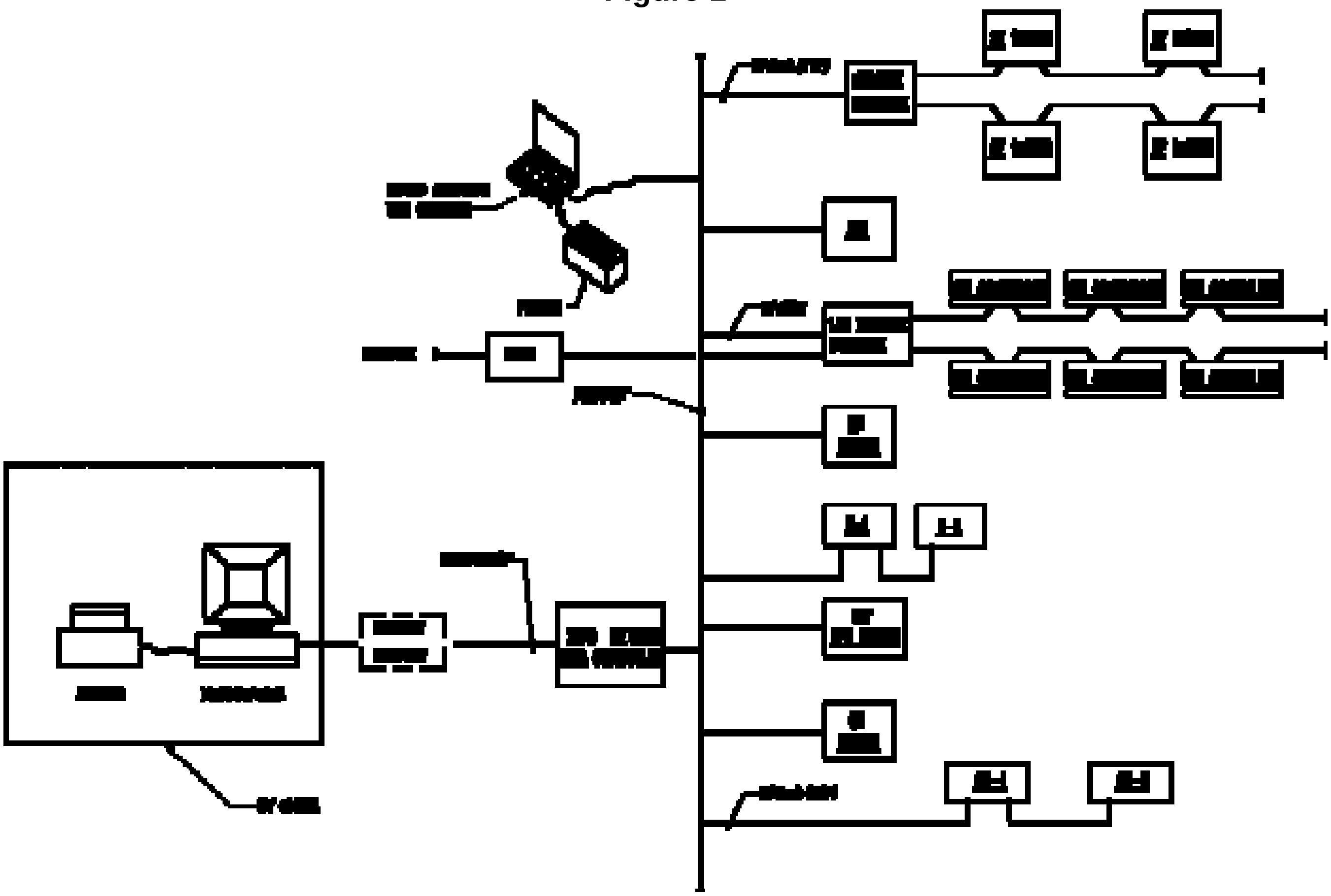
Table 7

Unit	GPM/Ton	NPLV	AHSRAE NPLV	Compliant?
Chiller 1	2.29	12.3	5.74	**yes**
Chiller 2	2.29	12.3	5.74	**yes**

The provisions for fume hoods are specified in the ASHRAE Standard 90.1 Section 6.5.7.2. The total exhaust rate of the fume hood systems is 35,530 cfm, which is greater than 15,000 cfm. All the fume hoods are variable air volume control system interlocked with the variable air volume supply system. The Seawater Research Laboratory utilizes a air to air coil energy recovery loop that provides a heating source for the preheat coil of Air Handling Unit 1. Also the Makeup Air Units are capable of providing over 100% of the exhaust flow air rate that is provided by the fume hoods. However, the design of the laboratory spaces is that, they are to be negatively pressurized to prevent potentially dangerous leaks.

The Seawater Research Laboratory HVAC system is controlled by a DDC energy management and control system shown in Figure 1. This system passes all the mandatory provisions of ASHRAE Standard 90.1 Section 6.4.3.

Figure 1

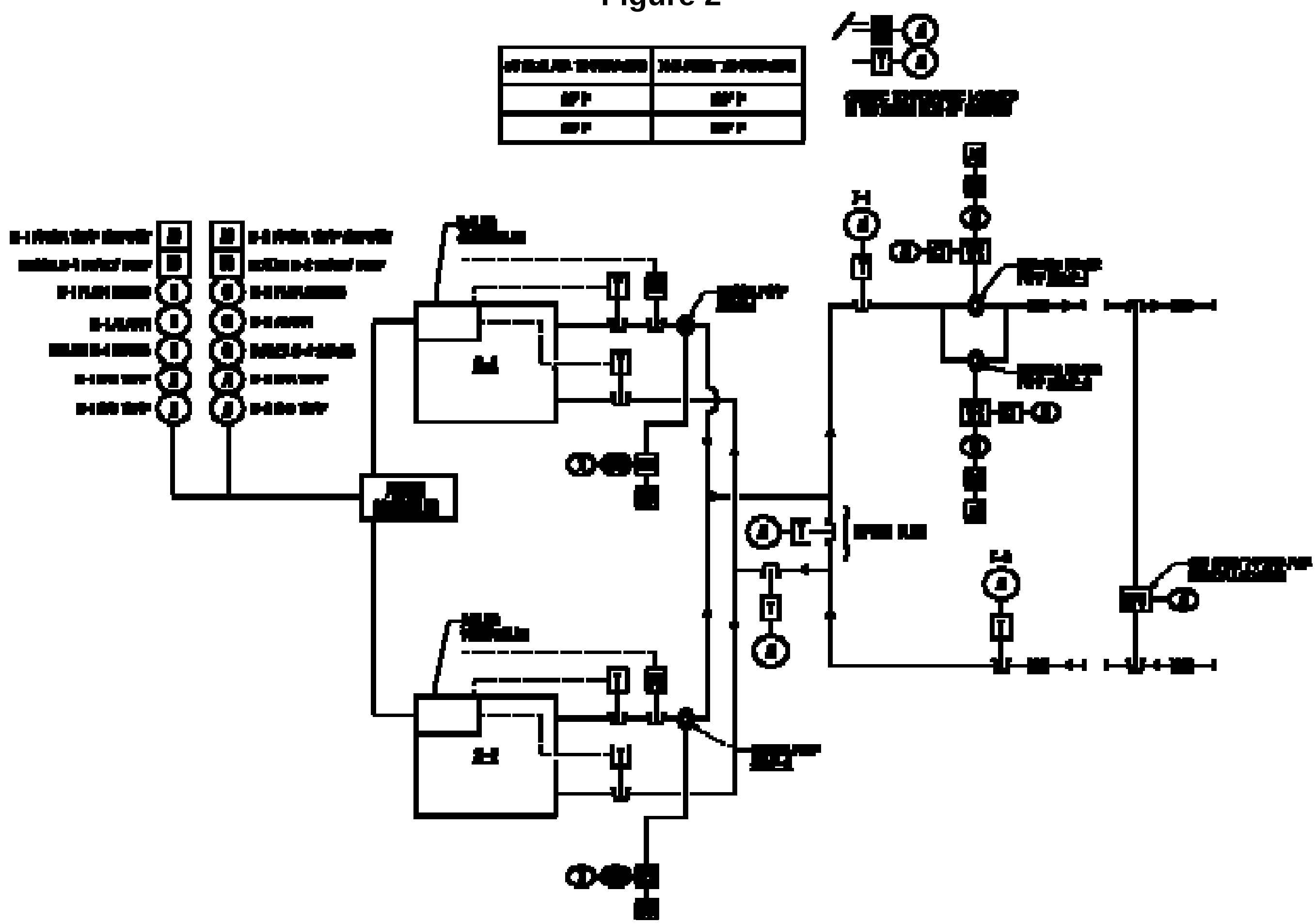


3.3 Building Service Water Heating Compliance to ASHRAE Standard 90.1

The Seawater Research Laboratory uses two propane fired boilers for heating the incoming service water and to supply required amount of heat to the hot water coils of both air handling units and for all makeup air units. The ASHRAE Standard 90.1 describes proper boiler application and control in Section 7.4 and 7.5.

The ASHRAE Standard 90.1 requires that the boiler control that maintain at minimum the maximum temperature that is required for use. The DDC system manages the boiler operation with temperature sensors, modulating the operation time of the boiler. The boiler controls system schematic is shown in Figure 2. Since the boiler system serves heating for both water service and HVAC application, with an input greater than 150,000 Btu/hr, the system isn't compliant with ASHRAE Standard 90.1.

Figure 2



3.4 Building Power System Compliance to ASHRAE Standard 90.1

The Seawater Research Laboratory electrical power system's compliance check with ASHRAE Standard 90.1 is described in Section 8.4. For the Seawater Research Laboratory to be compliant with ASHRAE Standard 90.1, it must have a feeder voltage drop of not more than 2% and a branch circuit voltage drop of no more than 3%.

The Seawater Research Laboratory's power system cannot be checked for compliance with ASHRAE Standard 90.1, because of incomplete information required. The percent voltage drop calculation involves conductor length, phase angle, voltage, number of phases, current load, power factor, number of conductors, conduit material, and ambient temperature. The conductor lengths could not be determined and an estimated number would be pointless, because of the fact that the electrical systems contractor can for the most part layout the conduit however he/she sees fit. The procedure for the voltage drop calculation was taken from, Electrical Systems in Buildings (S. David Hughes, 1988), which also contains Table 11.5 of voltage drops per 1000 ampere-feet. The procedure is outlined as the following:

V_{L-N} = Voltage Drop From Line to Neutral

ϕ = Phase Angle

V_{L-L} = Voltage Drop From Line to Line

Ampere-feet = Amps x Length of Conductor = Number of Amps per 1000ft

V_{L-N} = Number of Amps per 1000ft x Voltage Drop per 1000ft

$V_{L-L} = \tan(\phi) \times VL\text{-}N$

$$\%\ \text{Voltage Drop} = \frac{V_{L-L}}{V}$$

The design documents state that the maximum allowable percent voltage drop for both the feeders and the branch circuits is to be 3%. This maximum on the feeders is not compliant with the ASHRAE Standard 90.1, however, the branch circuits are compliant. This is a maximum so it does not mean that the voltage drop is designed to be 3%, it means that the 3% cannot be exceeded. This means that only the feeders that exceed the 2% are not compliant. Again once the feeder lengths are known the percent voltage drop can be calculated.

3.5 Building Lighting System Compliance to ASHRAE Standard 90.1

The Space by Space Method of ASHRAE Standard 90.1 Section 9.6 was use in determining if the lighting power allowance of the Seawater Research Laboratory is compliant with ASHRAE Standard 90.1. The procedure of the Space by Space Method is specified in Section 9.6.1. The light fixture types were taken from the lighting fixture schedule in the architectural drawings and then compared with similar fixtures in Table 2 of Chapter 29 in the ASHRAE Fundamentals 2001 to get the fixture watts.

The space types used in the Seawater Research Laboratory were: office-enclosed, conference, lobby, lounge, laboratory, restrooms, corridor, equipment room, active storage, electrical/mechanical. The results of the compliance check are shown in Table 8. The spaces that are not compliant with the ASHRAE Standard 90.1 are: Women's Toilet, Men's Toilet, Engineer's Office, Building Manager's Office, Necropsy Lab, Janitor's Closet, Corridor Vestibule, Corridor, and BSL electrical room. These values were then used in the modeling of the building using the HAPv4.2 program.

The required light to strike the work plane surface for a laboratory is higher for the fact that the tasks that are being done are considered very important. Also the lighting was designed to meet the owner's needs. Which are the major factors that contribute to some of the spaces not being compliant with ASHRAE Standard 90.1

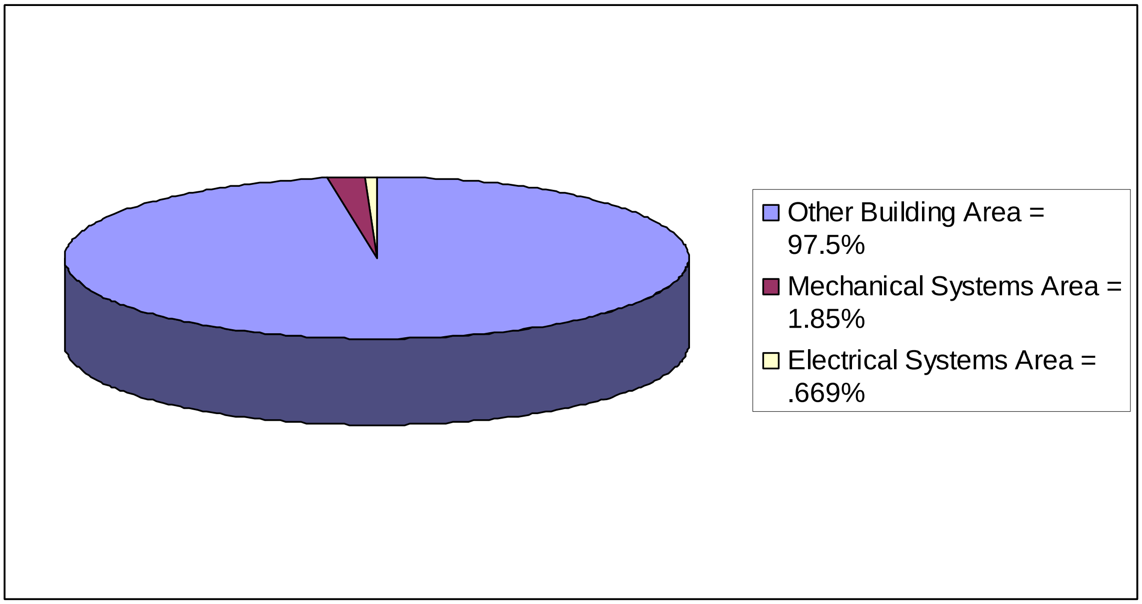
Table 8

Space	Fixture Type	Watts/Fixture	Number of Fixtures	Area (Sq. Ft.)	Watts/Sq. Ft.	ASHRAE Watts/Sq.	Compliance
Main Entry Vestibule	D1	50	2	231	0.433	0.5	**yes**
Observation	D1	50	14	788	0.888	1.3	**yes**
Conference Room	P5	85	4	287	1.18	1.3	**yes**
Exposure Lab I	A3	93	6	488	1.14	1.4	**yes**
Exposure Lab II	A3	93	12	952	1.17	1.4	**yes**
Toxicology Lab	V4	120	9	3830	0.708	1.4	**yes**
	V8	68	24				
Tel./Comm.	S1	60	2	134	0.896	1.2	**yes**
Women's Toilet	D1	50	4	232	1.12	0.9	**no**
	R2	60	1				
Men's Toilet	D1	50	4	227	1.15	0.9	**no**
	R2	60	1				
Kitchen	A2	60	1	109	0.771	1.2	**yes**
	U1	24	1				
Fax/Copy Room	A2	60	1	79	0.759	1.2	**yes**
Engineer's Office	A3	93	2	123	1.45	1.1	**no**
Building Manager's Office	A3	93	2	148	1.26	1.1	**no**
Lab A	A3	93	10	921	1.01	1.4	**yes**
Lab B	A3	93	3	223	1.25	1.4	**yes**
Necropsy Lab	A3	93	3	231	1.48	1.4	**no**
	V1	60	1				
Janitor's Closet	B3	50	1	37	1.35	0.8	**no**
Lounge/Vending/Coffee	D1	50	3	186	0.806	1.2	**yes**
Corridor Vestibule	D1	50	1	80	0.625	0.5	**no**
Corridor	A2	60	6	670	0.537	0.5	**no**
Coral Reef Lab	V8	68	4	231	1.18	1.4	**yes**
Multi-Purpose Lab	H2	85	12	17484	0.97	1.4	**yes**
	H6	340	24				
	V4	120	32				
	V8	68	58				
BSL 1/2	V4	120	8	6781	0.643	1.4	**yes**
	V8	68	50				
BSL 3	V2	60	16	900	1.07	1.4	**yes**
BSL 3 Prep	A6	60	5	403	0.893	1.4	**yes**
	V2	60	1				
Gowning Room	V2	60	2	121	0.992	1.4	**yes**
BSL 3 Entry	A2	60	2	117	1.03	1.4	**yes**
BSL 3 Support	V2	60	4	394	0.609	1.4	**yes**
Shop	V2	60	5	256	1.17	1.9	**yes**
Radiation I	V2	60	6	323	1.11	1.4	**yes**
Radiation II	V2	60	6	307	1.17	1.4	**yes**
Mechanical	V2	60	8	784	0.612	1.5	**yes**
Electrical	V2	60	2	151	0.795	1.5	**yes**
Toilet	B1	24	1	61	0.393	0.9	**yes**
Toxicology Electrical	S1	60	1	60	1	1.5	**yes**
BSL Electrical	S1	60	2	72	1.67	1.5	**no**
Exterior Colonnade	D8	50	1	1695	0.637	1.25	**yes**
	H1	128	8				
Exterior Walls	W1	138	5	12560	0.172	0.2	**yes**
	W2	295	4				
Building Total	Watts =		37004	Area =	52676	Density =	0.702483104

4.0 Lost Rentable Space Due To Mechanical Systems

The total building area of the Seawater Water Research Laboratory is 42,333 square feet. An area of 784ft² was taken from the architectural drawings, as space lost to the mechanical systems, which is the area of the mechanical room. The area lost amounts to 1.85% of the total building area. Figure 3 provides a breakdown of the lost space of the Seawater Research Laboratory.

Figure 3



The Seawater Research Laboratory is a one story building with the majority of the mechanical systems are located either outside in the service yard or mounted on the roof with the ductwork and piping running in the ceiling cavity and dropping down through to distribute the air or water exactly where it needs to be, so that the use of chases are not a necessity. This layout provides for a greater use of the floor area of the building. Since the building purpose is a laboratory the concealment of the mechanical systems for aesthetic purposes is not necessary.

5.0 Mechanical System First Cost

The building cost of the Seawater Research Laboratory was calculated by U.S. Cost Inc. The cost report was divided into the major building systems that include:

Foundations	Slab-on-Grade	Structural Frame
Supported Floor	Roof Structure	Roofing
Stairs	Elevators	Exterior Walls
Interior Walls	Interior Finishes	Doors & Hardware
Windows & Glazed Walls	Specialties	Plumbing
HVAC System	Fire Protection	Power
Lighting	Special Electrical	Special Systems

The cost report also included additional costs of:

Overhead & Fees:	18%
Bonds/Insurance:	1%
Escalation:	2.12%
Design Contingency:	10%

The mechanical system cost consists of Plumbing, HVAC, and Fire Protection Systems. The Aquaculture System was not included in the mechanical systems cost, for the fact that it is a process that occurs within the building and is not required for building operation. The total mechanical system first cost amounted to $1,681,744, which is 23.8% of the overall building initial costs. The total mechanical system first cost and its cost per square foot is summarized in Table 9.

Table 9

System	Total Cost	Cost per ft^2
Plumbing	$358,893	$8.93/ft^2$
HVAC	$1,143,347	$28.44/ft^2$
Fire Protection	$179,504	$4.47/ft^2$

6.0 Load And Energy Estimates

The design load estimation was calculated using HAPv4.2. There were several assumptions of the input values that were used to perform the analysis, which included:

The lighting loads that were used were the loads that were calculated in the Lighting System Compliance of ASHRAE Standard 90.1 section of this report.

The weather data was based on Norfolk, VA.

All space and building materials and property values were taken form ASHRAE Fundamentals 2001.

All space and building dimensions and construction types were taken from the architectural drawings.

Space occupancies were taken form the design documents.

The results from the HAP model are summarized in Table 10.

Table 10

System	Cooling Capacity MBH	Heating Capacity MBH	Tons of Cooling	Supply Airflow CFM	Ventilation Airflow CFM	Percent OA	Cooling ft^2/Ton	Supply cfm/ft^2	Ventilation cfm/ft^2
AHU-1	846.3	289.9	70.5	18,402	18,450	100%	94.4	2.76	2.76
AHU-2	201.8	88.6	16.8	3,295	3,295	100%	88	2.23	2.23
MAU-1		3.3		5,706	5,706	100%		0.8	0.8
MAU-2		5.1		9,757	9,757	100%		0.8	0.8
MAU-3		2.6		5,440	5,440	100%		0.99	0.99
MAU-4		3		3,105	3,105	100%		0.8	0.8

7.0 Annual Energy Consumption and Operating Costs

The HAPv4.2 model of the Seawater Research Laboratory also provided results of annual energy consumption and operation costs. The results showed that the HVAC energy costs and consumption is a very small part of the energy used, both electric and propane, for the entire building. The results of the annual energy consumption are summarized in Table 13, and the results of the annual operating costs are summarized in Table 14 and Figure 4. The results show that the HVAC system doesn't account for much of the energy use but, the bulk of the energy is consumed by the laboratory equipment and equipment for building process.

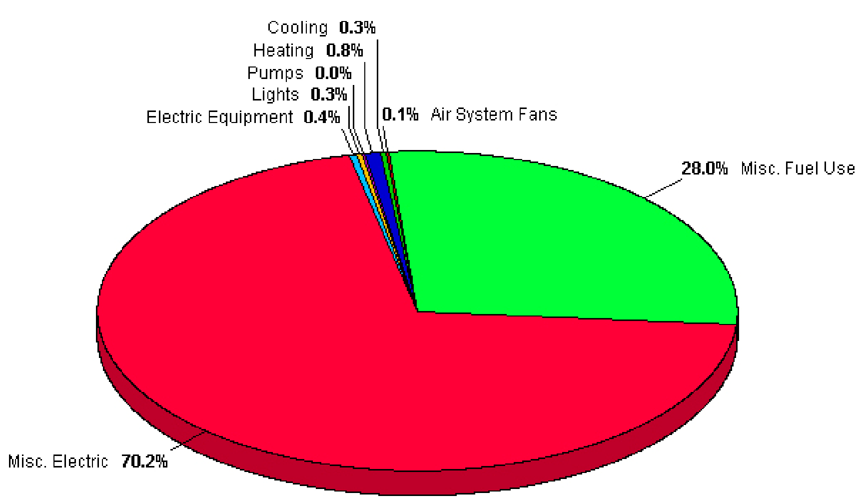
Table 13

HVAC Components	
Electric (kWh)	580,093
Propane (Therms)	39,337
Non-HVAC Components	
Electric (kWh)	86,605,740
Propane (Therms)	1,401,600

Table 14

Component	Annual Cost	Cost/ft^2
Air System Fans	$4,256	$0.13
Cooling	$16,615	$0.52
Heating	$38,862	$1.22
Pumps	$2,284	$0.07
HVAC Total	$62,017	$1.95
Lights	$12,455	$0.39
Electric Equipment	$17,852	$0.56
Misc. Electric	$3,457,408	$108.71
Misc. Fuel	$1,377,913	$43.33
Non-HVAC Total	$4,865,628	$152.99
Grand Total	$4,927,645	$154.94

Figure 4



8.0 References

ASHRAE Fundamentals 2001 I-P Edition

Green Building Rating System for New Construction & Major Renovations (LEED-NC) Version 2.2, October 2005

LEED online: http://www.usgbc.org/leed