Senior Thesis Capstone Project
Technical Assignment 1

ASHRAE Standard 62.1 Ventilation and Standard 90.1 Energy Design Evaluations

Interdisciplinary Science And Engineering Building

University of Delaware
Newark, DE 19716

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Executive Summary

This thesis technical report will be conducted on the University of Delaware's new Interdisciplinary Science and Engineering building (ISEB). The building will be built on university property, will be approximately 194,000 square feet, and is scheduled for completion in Fall 2013. This building will facilitate both research and education, each having its own wing of the building. The University of Delaware saw a need to connect their classroom curriculum with what is going on in their research facilities. This connection will allow for real life problem based learning to tackle such issues as renewable energy and sustainability.

The purpose of this report is to evaluate ISEB's mechanical, lighting, and electrical systems, as well as the building envelope, on the criteria set by the American Society of Heating, Refrigeration, and Air Conditioning Engineers in their standards 62.1 (sections 5 & 6) and 90.1. Standard 62.1 section 5 covers building issues such as, prevention of mold growth, measures to prevent re-entry of contaminated air, and particulate filtration. Section 6 of standard 62.1 lays out a procedure for calculating ventilation rates for each space in the building based on occupancy, floor area, and use. The prescriptive method of standard 90.1 contains minimum energy requirements for a buildings envelope and mechanical/electrical systems.

After evaluating ISEB based on Standard 62.1 section 5 it was concluded that it is fully compliant with all of the requirements in this section. Both the drawings and specifications indicate that the designers of ISEB consulted standard 5 when designing its ventilation, exhaust, and further HVAC systems. The mix use of laboratory and education of ISEB makes the need for proper ventilation and exhaust imperative.

The ventilation rate calculation procedure, set by Standard 62.1 section 6, was completed on all of the spaces throughout the building and the results were compared with the design supply airflow rates and outdoor airflow rates. After this analysis was completed it was concluded that every space and zone throughout the building meets, or surpasses, the requirements set by section 6.

When the MEP systems and building envelope were compared to ASHRAE standard 90.1 it became evident that energy conservation was at the forefront of ISEB's design. The building complied, or came close to complying, with almost every section of this standard. The fact that this building receives its heating and cooling from a central campus steam/chilled water plant makes compliance with 90.1 much easier because it alleviates a major portion of on site energy usage. Laboratory systems always pose problems for mechanical designers due to their complexity but they also breed some of the most innovative designs. From variable frequency drives, to DDC controls, and energy recovery systems, ISEB has made all of the right moves in order to be a energy conscience building. This building is going to cultivate many great minds and achievements in the field of sustainability, which is why the designers have gone to such great lengths to comply with standard 90.1 and make energy conservation a major identity of ISEB.

Mechanical Summary

The building receives steam and chilled water from the Campus Utilities Plant (CUP). The steam is converted to hot water in a steam-to-water heat exchanger, which provides the buildings heating requirements. Chilled water, from the University of Delaware's campus chilled water plant, is fed to a water-to-water flat plate heat exchanger that meets the buildings chilled water needs. An electric drive stand-by chiller is on site, in the basement mechanical room, and consists of 6 modules each sized at 50 tons (two of which incorporate hot gas bypass). The heat from this chiller will be recovered when possible and injected into the buildings heating/reheat loops. Two fluid coolers with a nominal cooling capacity of 240 tons are on site to provide to reject heat from the standby chiller if the heating/reheat loops do not need it.

There are ten total AHU's serving the building that are located in the fifth floor mechanical penthouses. Each of these seven AHU's fall into one of two system types, either recirculating or 100 percent outdoor air.

Air handling units 1, 2, & 10 are of the recirculating air system type. They serve the builds classrooms, offices, common spaces, and corridors. Pressure independent, Variable Air Volume (VAV) terminal units will be provided for each temperature control zone of the system. Each will be equipped with a hot water reheat coil to maintain space temperature. Because of the extreme variance in occupancy over a large span of operating hours in spaces served by this type of unit, the system will be designed to minimize energy consumption through unoccupied modes of operation. Supply fan volume control will be accomplished through the use of Variable Frequency Controllers (VFCs), which will modulate fan speed (and air flow) to maintain a constant duct static pressure.

The other seven AHU's (3, 4, 5, 6, 7, 8, & 9) are the 100% outdoor air units that serve the builds cleanroom, research, and instructional labs. These seven 100% outdoor air units all contain some form of energy recovery. Enthalpy wheels are used for spaces in which contamination of the supply air from the exhaust air is not critical and heat pipes for the units in which supply air contamination can not be risked (with the exception of AHU 9 which handles the clean room make-up air and has no energy recovery).

ASHRAE Standard 62.12007
Section 5: *Systems & Equipment*

Section 5.1 - Natural Ventilation

Natural ventilation is not incorporated into the design of this building; this section is not applicable.

Section 5.2 – Ventilation Air Distribution

Variable Volume supply air terminal units are implemented for the control of supply/ventilation air to each zone. These terminal units are controlled by occupancy sensors in each space and will throttle the amount of ventilation air to meet the critical space in that zone.

Section D3040B10d states, “The use of reheat will generally occur only after the terminal unit has reached its minimum air flow required for ventilation”.

Section 5.3 – Exhaust Duct Location

There are two types of exhaust in this building, laboratory exhaust (fume hoods) and general exhaust. Each fume hood will have a dedicated exhaust terminal unit, which will keep the exhaust ductwork negatively pressurized. General exhaust systems will also have exhaust terminal units.

Fume hood exhaust terminal units will modulate in relation to hood Sash position to maintain consistent 100 FPM sash face velocity. Supply and general exhaust terminal units will modulate as required to maintain lab negative pressure.

All general exhaust ductwork will be galvanized steel. Ductwork between each exhaust AHU and its exhaust terminal units will be medium pressure (SMACNA negative 4 inch water gauge construction). Ductwork between exhaust terminal units and hoods will be low pressure (SMACNA negative 2 inch water gauge construction).

Section 5.4 – Ventilation System Controls

Section D3010F16 states, “Occupancy sensors to control, lights and ventilation airflow”.

Section D3040B10j states, “The return fan, also equipped with a VFC, will be programmed to track supply fan speed with an appropriate flow offset to maintain minimum ventilation requirements and building pressurization”.

Section 5.5 – Airstream Surfaces

Exhaust duct mains will be galvanized steel. SMACNA 4" & 2" W.G. construction ductwork will be used for all ductwork between the supply AHU and the VAV supply air terminal unit.

Section 5.6 – Outdoor Air Intakes

There are two ventilation intakes in this buildings system:

1. There are two large ventilation louvers serving the basement mechanical rooms. These louvers are in the wall of basement mechanical room and sit in 22'x10' fresh air area ways. This keeps the ventilation air intake louvers roughly 15' below grade and well within the minimum distances specified in table 5-1 below.
2. All other ventilation air enters the rooftop penthouse and is ducted to each AHU from a large "hallway like" duct running around the inside perimeter of the penthouse. The only risks posed to this intake would be the exhaust system fans or the cooling tower intake/exhaust but this building does not have a cooling tower and the exhaust system utilizes high plume exhaust fans located well over 15' away from the ventilation intake louver.

TABLE 5-1 Air Intake Minimum Separation Distance

Object	Minimum Distance, ft (m)
Significantly contaminated exhaust (Note 1)	15 (5)
Noxious or dangerous exhaust (Notes 2 and 3)	30 (10)
Vents, chimneys, and flues from combustion appliances and equipment (Note 4)	15 (5)
Garage entry, automobile loading area, or drive-in queue (Note 5)	15 (5)
Truck loading area or dock, bus parking/idling area (Note 5)	25 (7.5)
Driveway, street, or parking place (Note 5)	5 (1.5)
Thoroughfare with high traffic volume	25 (7.5)
Roof, landscaped grade, or other surface directly below intake (Notes 6 and 7)	1 (0.30)
Garbage storage/pick-up area, dumpsters	15 (5)
Cooling tower intake or basin	15 (5)
Cooling tower exhaust	25 (7.5)

Note 1: Significantly contaminated exhaust is exhaust air with significant contaminant concentration, significant sensory-irritation intensity, or offensive odor.
Note 2: Laboratory fume hood exhaust air outlets shall be in compliance with NFPA 45-1991[3] and ANSI/AIHA Z9.5-1992.[4]
Note 3: Noxious or dangerous exhaust is exhaust air with highly objectionable fumes or gases and/or exhaust air with potentially dangerous particles, bioaerosols, or gases at concentrations high enough to be considered harmful. Information on separation criteria for industrial environments can be found in the ACGIH Industrial Ventilation Manual [5] and in the *ASHRAE Handbook—HVAC Applications*.[6]
Note 4: Shorter separation distances are permitted when determined in accordance with (a) Chapter 7 of ANSI Z223.1/NFPA 54-2002[7] for fuel gas burning appliances and equipment, (b) Chapter 6 of NFPA 31-2001[8] for oil burning appliances and equipment, or (c) Chapter 7 of NFPA 211-2003[9] for other combustion appliances and equipment.
Note 5: Distance measured to closest place that vehicle exhaust is likely to be located.
Note 6: No minimum separation distance applies to surfaces that are sloped more than 45 degrees from horizontal or that are less than 1 in. (3 cm) wide.
Note 7: Where snow accumulation is expected, distance listed shall be increased by the expected average snow depth.

5.7 – Local Capture of Contaminants

ISEB utilizes "High Plume", roof mounted lab exhaust systems. Each system will have two (2) belt drive high plume dilution blowers, with integral bypass air inlets and dampers. Each blower will be sized at 50% capacity for partial redundancy. Other system components will include miscellaneous control and isolation dampers. Exhaust flow from the blowers will remain constant volume to maintain minimum stack exit velocity of 3,000 FPM, regardless of changes in building exhaust requirements. Bypass dampers on the intake plenum below the exhaust fans will induce outside air into the suction side of the exhaust fans to compensate for reduction in exhaust volume from the building. Exhaust systems will be located on the roof of the Instructional Lab wing penthouse, and on the roof of the Research Building penthouse. This will help separate the exhaust from outdoor air intakes by minimum 25 feet. Exhaust stacks (or the blowers themselves) will extend to a minimum height of 10 feet above the adjacent roof level in accordance with *ANSI/AIHA Standard Z9.5-1992 – American National Standard for Laboratory Ventilation.*

5.8 – Combustion Air

All heating applications are met by a steam to hot water heat exchanger in the basement mechanical room, no combustion takes place in ISEB. This section is not applicable.

5.9 – Particulate Matter Removal

Unit components will include a plenum type, centrifugal, supply fan, a centrifugal return air fan, chilled water cooling coils, hot water preheat coils, 30% efficient pre-filters, 95% efficient final filters.

5.10 – Dehumidification System

Generally, humidity will be controlled in occupied areas of the building to comply with ASHRAE Standard 55-1992 for occupant thermal comfort. However, in the core facilities of the Research Building, humidity will be controlled to comply with the stringent environmental requirements pertaining to these laboratories. Summer indoor relative humidity will be controlled via cooling/dehumidification of the supply air with chilled water cooling coils within air handling units. However, the Imaging/Microscopy core and the Advanced Materials Characterization core requiring desiccant wheels in the air handling units serving those areas. The design conditions for each space are listed in table 1.1 below.

Table 1.1: Design Air Conditions by Space Type

Space Design Tdb & %RH Conditions		
Space Type	T_{DB} (°F)	%RH
Cleanroom	68-72% (+/- 1°F)	45-55% (+/-1-%, min. 40%)
Classroom/Office		
Summer	75°	55%
Winter	72°	30%
Laboratory		
Summer	72°	55%
Winter	72°	30%

Section 5.11 - Drain Pans

Floor drains will be provided in each section of the unit. Part 23 7412 –12i of the AHU spec states, " Pans shall be sloped in all directions towards drain and downspouts", also "The main drain pan shall be piped through the unit perimeter base utilizing a 3 inch diameter copper drain pipe. The exterior drain pipe shall be provided with a trap as detailed and extended to point of discharge by the contractor as indicated."

Section 5.12 – Finned-Tube Coils & Heat Exchangers

"Each cooling coil shall have a 16 gauge, Type 304 stainless steel main condensate drain pan extending the entire length and at least 2" upstream and 12" downstream of the coil face. Drain pans shall be all welded construction."

All air handling units that use DX dehumidification are equipped with drain pans. Each coil is provided with at least 18" of intervening access space and therefore is compliant with section 5.12.

Section 5.13 – Humidifiers and Water Spray Systems

Humidifiers will be "clean steam" type. At each AHU (in various penthouses), a humidifier will be provided which uses campus steam in the tube side of a steam-to-steam heat exchanger/humidifier. Clean steam will be injected into the supply air streams at each AHU via dispersion manifolds. Water softeners will provide treated water for humidification.

Section 5.14 – Access for Inspection, Cleaning, and Maintenance

All air handling units are equipped with maintenance access panels or doors. Specification 23 7412-8 section 2.6A states, "Access doors and removable panels shall be provided as indicated on the plans conforming to the construction requirements and panel thickness of the unit housing hereinbefore specified. Provide access doors not less than size indicated on plans. Provide removable panels where indicated of size sufficient to remove coils and fans."

Section 5.15 – Building Envelope and Interior Surfaces

All exterior wall assemblies either incorporate weatherproofing on the interior face of the exterior sheeting or a vapor barrier on the warm side of the insulation to prevent moisture from entering the building.

Section 5.16 – Buildings with Attached Parking Garages

ISEB does not have a parking garage attached to it, therefore this section is not applicable.

Section 5.17 – Air Classifications and Recirculation

The ISEB lab exhaust air is under the table 5-2 (below) "laboratory hood" class 4 description. The lab exhaust (both general and fume hood exhaust) is not recirculated at any time. These units are 100% outdoor air (non-recirculation) units, which meets this sections requirements for class 4 air.

TABLE 5-2 Airstreams

Description	Air Class
Diazo printing equipment discharge	4
Commercial kitchen grease hoods	4
Commercial kitchen hoods other than grease	3
Laboratory hoods	4
Residential kitchen vented hoods	3

Section 5.18 – Requirements for Buildings Containing ETS Areas and ETS-Free Areas.

All buildings owned by the University of Delaware are "smoke-free" buildings, therefore this section does not apply to ISEB.

ASHRAE Standard 62.12007
Section 6: *Ven*tilation Rate Calculation Procedure

All zones and spaces were selected for the ventilation rate calculation procedure of section 6. This was done because the mixed use of this building makes each air handling unit and the zones it serves unique. After completing the analysis it was concluded that all of the spaces in the building are supplied with at least (in most cases more than) the required breathing zone outdoor airflow rates. When the mechanical engineer for this project performed these same calculations a zone air distribution effectiveness (E_z) value of 0.8 was used, which is why the design outdoor airflow rates are consistently higher than the calculated values in this report.

Sample Calculations:

$$V_{bz} = (R_p \times P_z) + (R_a \times A_z)$$

V_{bz} = Breathing zone outdoor airflow (cfm)

R_p = CFM outdoor air per occupant

P_z = Number of occupants in space

R_a = CFM outdoor air per ft^2

A_z = Zone floor are (ft^2)

$$E_z = 1 \quad \text{(Table 6-2)}$$

E_z = Zone air distribution effectiveness

$$V_{oz} = V_{bz} / E_z$$

$$Z_p = V_{oz} / V_{pz}$$

V_{oz} = Zone outdoor airflow (cfm)

V_{pz} = Zone primary airflow

Z_p = Zone outdoor air fraction

Table 1.2 (below) shows example results of the ventilation calculation procedure when conducted on all of the spaces served by AHU-1. The compliance column of table 1.2 illustrates that all of the spaces served by AHU-1 comply with Standard

Table 1.2: Ventilation Calculation Procedure. AHU-1 Results

AHU-1 62.1 VENTILATION CALCULATIONS									
	Az	Ra	Pz	Rp	Vbz (= Voz)	Design Supply	Zp	Zone Design	Compliance?
	ft^2	CFM / SF	# People	cfm / person	CFM OA	CFM	% O.A	O.A. CFM	
209 Group Study	714	0.06	7	5	77.84	1,173	**7**	**97.0**	**YES**
207 Classroom	1,069	0.12	41	10	538.28	1,585	**34**	**672.0**	**YES**
205 Classroom	1,025	0.12	41	10	533	1,584	**34**	**665.0**	**YES**
202 Classroom	1,019	0.12	41	10	532.28	1,607	**34**	**665.0**	**YES**
204 Storage	76	0.12	0	0	9.12	60	**16**	**9.1**	**YES**
201 Group Study	368	0.06	4	5	42.08	2,036	**3**	**52.0**	**YES**
206 Electric Room	86	0.06	0	0	5.16	165	**4**	**6.5**	**YES**
208 Copy/Print	118	0.06	0	0	7.08	127	**6**	**8.9**	**YES**
101 Lobby	170	0.06	0	5	10.2	1,320	**1**	**12.8**	**YES**
309 Group Study	704	0.06	7	5	77.24	1,380	**6**	**96.6**	**YES**
307 Classroom	1,070	0.12	41	10	538.4	1,585	**34**	**673.0**	**YES**
305 Classroom	1,025	0.12	41	10	533	1,584	**34**	**665.0**	**YES**
302 Classroom	1,025	0.12	41	10	533	1,598	**34**	**678.0**	**YES**
304 Storage	76	0.12	0	0	9.12	60	**16**	**9.1**	**YES**
301 Group Study	368	0.06	4	5	42.08	2,038	**3**	**53.0**	**YES**
306 Electric Room	86	0.06	0	0	5.16	173	**3**	**7.0**	**YES**
308 Copy/Print	197	0.06	0	0	11.82	133	**9**	**15.0**	**YES**
404 Reception/Huddle	439	0.06	2	5	36.34	2,013	**2**	**45.0**	**YES**
402H Director	191	0.06	1	5	16.46	264	**7**	**21.0**	**YES**
402G Faculty Office	161	0.06	1	5	14.66	244	**7**	**18.0**	**YES**
402F Faculty Office	164	0.06	1	5	14.84	245	**7**	**18.0**	**YES**
402E Meeting	158	0.06	6	5	39.48	301	**14**	**50.0**	**YES**
402D Faculty Office	160	0.06	1	5	14.6	244	**6**	**18.0**	**YES**
402C Faculty Office	165	0.06	1	5	14.9	245	**7**	**18.0**	**YES**
402B CITA	158	0.06	1	5	14.48	243	**6**	**18.0**	**YES**
402A Conference	232	0.06	12	5	73.92	515	**15**	**92.0**	**YES**
TA (x6)	282	0.06	6	5	46.92	1,005	**5**	**47.0**	**YES**
Circulation/Common Area	1,142	0.06	0	0	68.52	541	**13**	**69.0**	**YES**
402L Huddle	163	0.06	6	5	39.78	100	**40**	**40.0**	**YES**
TA (x2)	98	0.06	2	5	15.88	100	**16**	**13.0**	**YES**
TA (x4)	196	0.06	4	5	31.76	516	**7**	**32.0**	**YES**
402J Copy/Work Room	118	0.06	0	0	7.08	163	**5**	**9.0**	**YES**
403 Electric Room	141	0.06	0	0	8.46	180	**5**	**11.0**	**YES**
401 Group Study	368	0.06	4	5	42.08	2,046	**3**	**53.0**	**YES**
402K Coffee/BreakRoom	119	0.06	2	5	17.14	268	**7**	**21.0**	**YES**
300B Corridor	170	0.06	0	0	10.2	800	**2**	**13.0**	**YES**
	13,821				**4,032**	**28,241**		**4,991**	

= Max Z_P

62.1 section 6. Not only does every space comply with section 6 calculations, but the design outside airflow rates for the majority of the spaces exceed the rates required by this section.

ASHRAE 62.1 Conclusions:

After evaluating ISEB based on the criteria of both section 5 and 6 of ASHRAE Standard 62.1 it is clear that it meets all of the requirements. The fact that this building is both a laboratory and educational facility means that the designers had to take extreme care and consult these sections of Standard 62.1 when designing the supply, ventilation, and exhaust air systems for this building. The high occupancy densities of the classrooms and need for 100% outdoor air for the laboratories purposed a complex problem for the mechanical designers but after evaluating the current design, it is apparent that ISEB will be a clean, healthy, and well ventilated building.

ASHRAE Standard 90.12009

Section 5: *Building Envelope*

For this section of standard 90.1 the building climate location must be determined before any building envelope requirements may be evaluated. ISEB is located on the University of Delaware campus in Newark Delaware, which is in ASHRAE climate zone 4a.This climate zone is depicted in figure 1 below, in yellow. Climate zone 4a buildings are referred to table 5.5-4 (appendix B) for building envelope requirements.

Fig. 1: ASHRAE Climate Zone Map

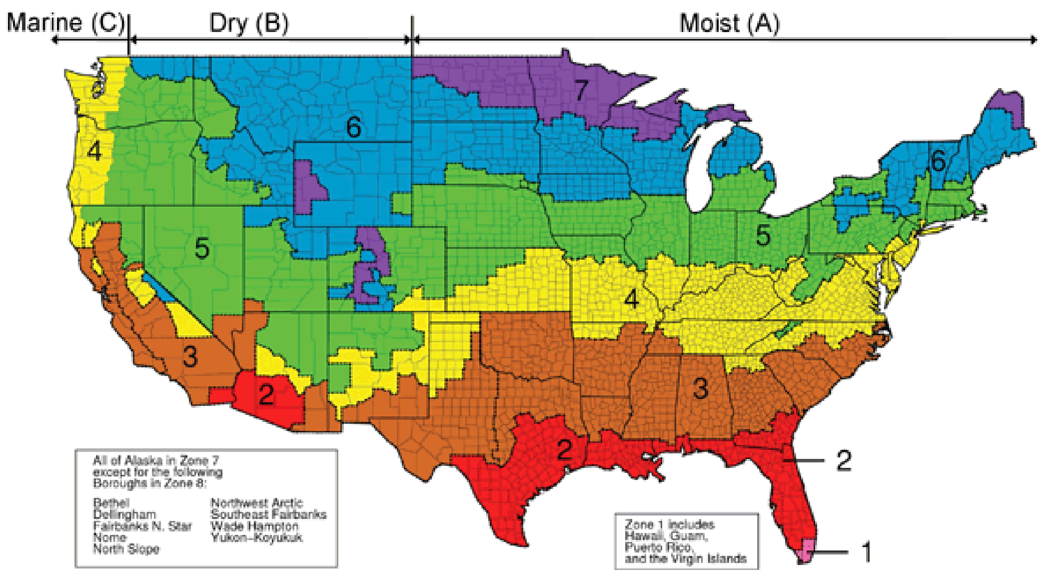

Table 2.1: Building Envelope Criteria

Building Envelope Requirements Zone 4a			
	Maximum	**ISEB**	
Opaque Elements	U-Value	U-Value	**Compliant?**
Roof (Insul. above deck)	0.048	0.059	No
Walls (above grade)	0.064	0.053	Yes
Walls (below grade)	1.14	0.624	Yes
Floors	0.087	0.078	Yes
Opaque Doors	0.7	0.96	No
Fenestrations	**Maximum**	**ISEB**	**Compliant?**
Vertical Glazing	0.5	0.49	Yes

Section 6: *Heating, Ventilations, Air Conditioning*

6.5.1 Economizers

Although this building resides in climate zone 4a, which does not require the use of air economizers, it does take advantage of economizers for free cooling in the recirculating type systems. “To reduce chilled water usage, outdoor air economizer will be utilized at air handling units when outside air temperatures are below 50ºF.” These economizers will implement low leakage dampers and will be controlled through the building’s DDC system to utilize outside air for free cooling when ambient conditions allow.

6.5.2 Simultaneous Heating and Cooling

The use of reheat at the zone level will be minimized through control sequences, and generally will occur only after the terminal unit has reached its minimum airflow required for ventilation. Space temperature sensors, through the DDC system, will modulate automatic temperature control valves on hot water reheat coils at each supply air terminal unit. Although most of the AHU’s in this building utilize desicant dehumidification, which is compliant with this section of 90.1, AHU-9 uses DX dehumidification of incoming air with hydronic reheat coils which is not compliant.

6.5.3 Air Systems Design and Control

6.5.3.1 Fan System Power Limitation:

The only systems that must be checked for compliance with this section are the recirculating type (AHU 1,2, &10), all laboratory 100% OA units are exempt from this criteria. The criteria for compliance of the supply and return fans for these units are show in table 3 below. All of these fans are variable volume fans.

Table3: Section 6.5.3 Fan Efficiency Criteria

TABLE 6.5.3.1.1A Fan Power Limitation[a]

	Limit	Constant Volume	Variable Volume
Option 1: Fan System Motor Nameplate hp	Allowable Nameplate Motor hp	$hp \le CFM_S \cdot 0.0011$	$hp \le CFM_S \cdot 0.0015$
Option 2: Fan System bhp	Allowable Fan System bhp	$bhp \le CFM_S \cdot 0.00094 + A$	$bhp \le CFM_S \cdot 0.0013 + A$

[a] where

CFM_S = the maximum design supply airflow rate to conditioned spaces served by the system in cubic feet per minute
hp = the maximum combined motor nameplate horsepower
bhp = the maximum combined fan brake horsepower
A = sum of $(PD \times CFM_D/4131)$

where

PD = each applicable pressure drop adjustment from Table 6.5.3.1.1B in in. w.c.
CFM_D = the design airflow through each applicable device from Table 6.5.3.1.1B in cubic feet per minute

Table 4 below, shows that no all of the fans comply with this standard.

Table 4: Fan Efficiency Calculations

Fan Power Limitations					
	HP	CFMs	Multiplier	CFMs x Mult.	Compliance?
F-RA1	20	18000	0.0015	27	YES
F-SA1	50	24000	0.0015	36	NO
F-RA2	10	17000	0.0015	25.5	YES
F-SA2	30	20000	0.0015	30	YES
F-RA10a	15	16000	0.0015	24	YES
F-RA10b	15	16000	0.0015	24	YES
F-SA10a	50	21000	0.0015	31.5	NO
F-SA10b	50	21000	0.0015	31.5	NO

6.5.3.2 VAV Fan Control :
This part of section 6.5 is only for VAV fans with motors of 10HP or larger. The air terminal units in this building do not include fans, only dampers to throttle the flow from the air handling units, therefore this section does not apply.

6.5.3.3 Setpoint Reset:
Fan static pressure and discharge air temperature reset controls will be used for non-laboratory central air handling systems to minimize energy during periods of reduced load.
Supply fan volume control will be accomplished through the use of Variable Frequency Controllers (VFCs) which will modulate fan speed (and air flow) to maintain a constant duct static pressure. The return fan, also equipped with a VFC, will be programmed to track supply fan speed with an appropriate flow offset to maintain minimum ventilation requirements and building pressurization.

6.5.4 Hydronic System Design and Control

6.5.4.1 Hydronic Variable Flow Systems:
The hydronic systems of this building are in compliance with this section of 90.1.The ISEB heating water system will utilize variable flow pumping and the chilled water distribution within the building will be variable flow. Control valves will be twoway modulating type. Pumps shall be selected so that the operating point on the selected impeller curve will be at or to the left of, and not more than 5 percent below the point of maximum efficiency.

6.5.4.2 Pump Isolation:
This section is only relevant for buildings with more than one chiller and more than one boiler. ISEB contains only one (backup) chiller and no boilers, therefore this section is not applicable to this building.

6.5.4.3 Chilled and Hot Water Temp. Reset Controls:

This section requires the reset of chilled and hot water temperatures based on either building loads or outdoor air temperature. This system will have controls to reset the supply water temperature based on outside air temperature. In mild weather, the supply water temperature will be reduced for energy savings and controllability. It will be allowable to de-energize this system during the summer, when there is no heating load on the building from the outside.
Although the chilled water hydronic system is not reset, because supply chilled water from the campus chilled water plant is at a constant 44°F, it is still within this sections compliance because it utilizes variable flow pumps to reduce pumping energy.

6.5.4.4 Hydronic Heat Pump Systems:

ISEB does not contain any hydronic heat pump systems, therefore this section is not applicable.

6.5.5 Heat Rejection Equipment

6.5.5.1 Hydronic Heat Pump Systems:

Section 6.5.5 applies only to heat rejection equipment used in comfort cooling systems such as air-cooled condensers, open cooling towers, closed circuit cooling towers, and evaporative condensers. ISEB does utilize two fluid cooler units but this equipment only serves process equipment, not comfort cooling, therefore this section is not applicable.

6.5.6 Heat Recovery

6.5.6.1 Exhaust Air Energy Recovery:

This section requires energy recovery with a minimum of 50% recovery effectiveness, for systems that have a supply air capacity of at least 5,000 CFM and a minimum outdoor air supply of 70% or greater of the design supply air quantity. The only spaces that exceed 70% outdoor air quantities are the lab spaces, which are exempt from this section because these systems utilize exhaust air terminal units that are capable or reducing exhaust air volume to 50% or less of design values.

6.5.6.2 Heat Recovery For Service Water Heating:

ISEB does not operate 24 hrs. a day and does not have condensers on site for heat rejection because it is served by the East Campus Utilities Plant (ECUP), therefore this section does not apply to ISEB. However, it should be noted that heating water may be supplied from the ECUP to the ISEB at 140 deg F, and return to the ECUP at 120 deg F. This water can be used in the ISEB heating/preheat loops to preheat return water upstream of the building heat exchangers. It may also be used to preheat domestic hot water.

6.5.7 Exhaust Hoods

6.5.7.1 Kitchen Hoods:

There are no kitchen spaces in this building, therefore this section is not applicable to ISEB.

6.5.7.2 Fume Hoods:

This project is comprised of many laboratory space, therefore lab fume hoods are a major consideration. The fume hoods in ISEB are compliant with this section because these systems utilize exhaust air terminal units that are capable or reducing exhaust air volume to 50% or less of design values.

6.5.8 Radiant Heating Systems:

6.5.8.1 Heating Unenclosed Spaces:

There are no unenclosed spaces in this building, therefore this section is not applicable to ISEB.

6.5.8.1 Heating Enclosed Spaces:

Enclosed spaces in ISEB are heating by hydronic coils only, weather the coils are in AHUs, FCUs or unit heaters. No radiant Heating is implemented in the design of this building, therefore this section is not applicable.

6.5.9 Hot Gas Bypass Limitations:

This section sets capacity limitations for the use of hot gas bypass in cooling systems. These capacity limits are shown below in table 5. Although ISEB meets its cooling requirements from the campus chilled water plant, it does contain an electric drive standby chiller with six 50 ton modules, two of which implement hot gas bypass. When the chillers capacity is evaluated with this section's standards it does not comply. An example of this calculation is show below in table 6.

Table 5: Cooling Capacity Limits for the Use of Hot Gas Bypass

TABLE 6.5.9 Hot Gas Bypass Limitation

Rated Capacity	Maximum Hot Gas Bypass Capacity (% of Total Capacity)
≤240,000 Btu/h	50%
>240,000 Btu/h	25%

Table 6: Hot Gas Bypass % of Total Chiller Capacity

Hot Gas Bypass Compliance				
Chiller Module	Capacity	HG Bypass	% of total capacity	Compliant
1	50	YES		
2	50	YES		
3	50	NO		
4	50	NO		
5	50	NO		
6	50	NO		
Total	300 tons	100 tons	33%	NO

Section 7: *Service Water Heating*

7.5.1 Space Heating and Water Heating:

ISEB does not contain any on site boilers, all of the heating needs are met via steam-to-hot water heat exchanger or steam-to-water semi-instantaneous water heater, which are fed from the campus steam plant. Therefore this section does not apply to ISEB.

7.5.2 Service Water Heating Equipment:

ISEB does not contain any hot water heating equipment listed on table 7.8 (appendix-B) and therefore this section does not apply.

Section 8: *Power*

8.4.1.1 Voltage Drop:

Section 8 of standard 90.1 specifies that feeder conductors shall be sized for a maximum voltage drop of 2% and branch circuits shall be sized for a maximum drop of 3% at design load. The electrical specification states: "All wires and cables will be copper with Type THHN/THWN insulation rated for 600 volt at 75°C. Sizes will be designed to have current carrying capacities and voltage drop limits to meet NEC requirements". The NEC requirements are in agreement with section 8, therefore ISEB is in compliance with this section as well.
NEC Requirements:

Feeders – Conductors for feeders as define in article 100, sized to prevent a voltage drop exceeding 3% at the farthest outlet of power, heating, and lighint loads or a combination of such loads, and where the maximum voltage drop on both differs and branch circuits to the farthest outlet does not exceed 5%, will provide reasonable efficiency of operation.

Section 9: *Lighting*

9.5 Building Area Method Compliance Path:

9.5.1 Building Area Method of Calculating Interior Lighting Power Allowance
This method of section 9 lays out steps to fallow in order to determine the interior lighting power allowance by building area. The calculations and results for ISEB are presented in tables 7 below.

Table 7: Lighting Power Densities Compliance Per Area Type

Lighting Power Density					
Area Type	**Floor Area (SF)**	**Watts**	**Watts/S.F.**	**Standard 90.1**	**Compliant?**
University	85,000	52,552	0.62	1.2	YES
Office	89,000	16,750	0.19	1	YES
Warehouse	20,000	4,350	0.22	0.8	YES

As table 7 above illustrates, ISEB is completely compliant with the lighting power density section of 90.1. Some speculation as to why the numbers calculated in this report are so much lower than the standard prescribes are that many of the fixtures on the lab lighting plans were not present when this calculation was conducted. Also, the designers of this building incorporated a healthy dose of day lighting into the design on this building, which could cut down on the number of lighting fixtures required.

Section 10: *Electric Motor Efficiency*

10.4Mandatory Provisions:

10.4.1 Electric Motors
Section 10 of standard 90.1 states that all motors must comply with the Energy Policy Act of 1992, which is shown in appendix B, table 10.8. The mechanical engineer has specified motors to have Premium efficiency, as defined in NEMA MG 1, which requires higher efficiencies than section 10 of standard 90.1, therefore all of the motors are compliant. The NEMA MG1 requirements can be found in appendix B.

ASHRAE Standard 90.1 Conclusions:

After evaluating ISEB against standard 90.1 it is apparent that the engineers and designers on this project wanted to design a building that would be a model for energy conscience design. There are few places that this building falls short of the stringent criteria set forth in standard 90.1. This idea of energy conservation was an important one because it is a driving force behind the research and education that will take place in this building for years to come. Not only have the designers of this building used standard 90.1 to design an energy sound building but they have used it to help define the identity of the building as well.

References:

ASHRAE Standard 62.1-2007

ASHRAE Standard 90.1-2007

ASHRAE Handbook of Fundementals–2008

National Electrical Code – 2007

http://www.NEMA.org

Mechanical & Electrical Equipment for Builders, tenth edition

Thomas Syvertsen

Appendix A

AHU-2 62.1 VENTILATION CALCULATIONS									
	Az	Ra	Pz	Rp	Vbz (= Voz)	SUPPLY AIR	Zp	Zone Design OA	
	(ft^2)	CFM / ft^2	# People	cfm / person	CFM OA	CFM	(cfm OA/ cfm supply)	CFM	Compliance?
102 Commons	604	0.06	38	5	226.24	2,290	**10**	227.00	**YES**
200A Corridor 1	295	0.06	0	0	17.7	45	**40**	18.00	**YES**
102 Commons	302	0.06	38	5	208.12	2,240	**10**	260.00	**YES**
102 Commons	302	0.06	38	5	208.12	2,240	**10**	209.00	**YES**
200A Corridor 1	590	0.06	0	0	35.4	95	**38**	36.00	**YES**
102 Commons	604	0.06	38	5	226.24	2,500	**10**	282.00	**YES**
102 Commons (west)	3,576	0.06	150	5	964.56	8,515	**12**	1204.00	**YES**
102A Food Services	482	0.18	4	7.5	116.76	820	**15**	146.00	**YES**
101 Lobby	1,000	0.06	0	0	60	910	**7**	60.00	**YES**
103 Entry Foyer	345	0.06	0	5	20.7	91	**23**	21.00	**YES**
200A Corridor 1	295	0.06	0	0	17.7	45	**40**	18.00	**YES**
200B Balcony	511	0.06	0	0	30.66	1,426	**3**	31.00	**YES**
300A Corridor 1	1,120	0.06	0	0	67.2	1,957	**4**	84.00	**YES**
400A Corridor 1	960	0.06	0	0	57.6	1,918	**4**	72.00	**YES**
	10,986				**2,257**	**25,092**		**2,668**	

AHU-3 62.1 VENTILATION CALCULATIONS									
	Az	Ra	Pz	Rp	Vbz (= Voz)	SUPPLY AIR	Zp	Zone Design OA	
	(ft^2)	CFM / ft^2	# People	cfm / person	CFM OA	CFM	(cfm OA/ cfm supply)	CFM	Compliance?
001 Building Storage	125	0.12	0	0	15	50	**30**	15.00	**YES**
001A Basement Corridor	1,405	0.06	0	0	84.3	500	**17**	85.00	**YES**
106 Prep	798	0.18	8	10	223.64	1,771	**13**	280.00	**YES**
107 Instructional Lab	755	0.18	13	10	265.81	1,995	**14**	332.00	**YES**
109 Food SVC Storage	399	0.12	0	0	47.88	414	**12**	60.00	**YES**
111 Informal Gathering	580	0.06	12	5	94.8	658	**15**	119.00	**YES**
104 Fire Security Room	100	0.06	0	0	6	410	**2**	12.00	**YES**
105 Storage	79	0.12	0	0	9.48	53	**18**	10.00	**YES**
100C Corridor	775	0.06	0	0	46.5	896	**6**	58.00	**YES**
113 Women	206	0.06	0	0	12.36	155	**8**	25.00	**YES**
114 Men	206	0.06	0	0	12.36	145	**9**	25.00	**YES**
211 Storeroom	798	0.12	0	0	95.76	659	**15**	120.00	**YES**
212 Instructional Lab	755	0.18	13	10	265.81	1,995	**14**	332.00	**YES**
216 Informal Gathering	594	0.06	12	5	95.64	693	**14**	120.00	**YES**
215 AV	322	0.12	0	0	38.64	193	**21**	39.00	**YES**
214 Vending	30	0.06	0	0	1.8	791	**1**	2.00	**YES**
210 Tech Offices	198	0.06	2	5	21.88	107	**21**	27.00	**YES**
218 Women	206	0.06	0	0	12.36	140	**9**	25.00	**YES**
219 Men	206	0.06	0	0	12.36	140	**9**	25.00	**YES**
200C Corridor	1,175	0.06	0	0	70.5	662	**11**	88.00	**YES**
311 Glasswash	798	0.06	2	0	47.88	1,228	**4**	91.00	**YES**
312 Instructional Lab	755	0.18	13	10	265.81	1,995	**14**	332.00	**YES**
315 PBL Classroom	1,407	0.12	47	10	638.84	1,369	**47**	800.00	**YES**
316 Informal Gathering	580	0.06	12	5	94.8	689	**14**	120.00	**YES**
314 Physics Storage	399	0.12	0	0	47.88	630	**8**	60.00	**YES**
310 Tech Offices	198	0.06	2	5	21.88	107	**21**	28.00	**YES**
318 Women	206	0.06	0	0	12.36	140	**9**	25.00	**YES**
319 Men	206	0.06	0	0	12.36	143	**9**	25.00	**YES**
300B Corridor	1,420	0.06	0	0	85.2	1,070	**8**	107.00	**YES**
406 Prep	798	0.18	8	0	143.64	1,728	**9**	208.00	**YES**
407 Instructional Lab	755	0.18	13	10	265.81	1,995	**14**	332.00	**YES**
410 PBL Classroom	1,407	0.12	49	10	658.84	1,864	**36**	824.00	**YES**
411 Informal Gathering	580	0.06	12	5	94.8	690	**14**	119.00	**YES**
409 Physics Storage	399	0.12	0	0	47.88	650	**8**	60.00	**YES**
413 Women	206	0.06	0	0	12.36	170	**8**	25.00	**YES**
414 Men	206	0.06	0	0	12.36	170	**8**	25.00	**YES**
400B Corridor	1,175	0.06	0	0	70.5	1,115	**7**	88.00	**YES**
405 Tech Office	175	0.06	2	5	20.5	131	**16**	26.00	**YES**
	19,824	3	218	100	3,883	26,895		4,955	

AHU-4 62.1 VENTILATION CALCULATIONS

	Az	Ra	Pz	Rp	Vbz (= Voz)	SUPPLY AIR	Zp	Zone Design OA	Compliance?
	(ft^2)	CFM / ft^2	# People	cfm / person	CFM OA	CFM	(cfm OA/ cfm supply)	CFM	
119 Prep Room	450	0.18	5	10	131	1,180	12	164.00	YES
112 Instructional Lab	755	0.18	13	10	265.9	1,995	14	332.00	YES
110 PBL Classroom	1,407	0.12	10	10	268.84	1,999	14	824.00	YES
115 Electrical Room	141	0.06	0	0	8.46	407	3	11.00	YES
118 Media Services Office	258	0.06	3	5	30.48	247	13	31.00	YES
120 Storage	192	0.12	0	0	23.04	246	10	23.00	YES
100C Corridor	775	0.06	0	0	46.5	300	16	58.00	YES
223 Prep Room	424	0.18	10	10	176.32	955	19	120.00	YES
217 Instructional Lab	755	0.18	13	10	265.9	1,995	14	332.00	YES
220 Electrical Room	141	0.06	0	0	8.46	412	3	11.00	YES
215 PBL Classroom	1,407	0.12	10	10	268.84	1,364	20	799.00	YES
222 PBL Corner Classroom	511	0.12	20	10	261.32	1,540	17	327.00	YES
200C Corridor	1,018	0.06	0	0	61.08	300	21	76.00	YES
323 Prep	422	0.18	10	10	175.96	952	19	157.00	YES
317 Instructional Lab	755	0.18	13	10	265.9	1,995	14	332.00	YES
322 PBL Corner Classroom	509	0.12	20	10	261.08	1,620	17	326.00	YES
320 Electrical Room	141	0.06	0	0	8.46	412	3	11.00	YES
300B Corridor	1,018	0.06	0	0	61.08	300	21	76.00	YES
418 Prep	424	0.18	10	10	176.32	1,050	17	145.00	YES
412 Instructional Lab	755	0.18	13	10	265.9	1,995	14	332.00	YES
415 Electrical Room	141	0.06	0	0	8.46	408	3	11.00	YES
417 Seminar	495	0.06	13	5	94.7	1,530	7	118.00	YES
400B Corridor	1,018	0.06	0	0	61.08	300	21	76.00	YES
	13,912				**3,195**	**23,502**		**4,692**	

AHU-5 62.1 VENTILATION CALCULATIONS

	Az	Ra	Pz	Rp	Vbz (= Voz)	SUPPLY AIR	Zp	Zone Design OA	
	(ft^2)	CFM / ft^2	# People	cfm / person	CFM OA	CFM	(cfm OA/ cfm supply)	CFM	Compliance?
174 Microscopy & Imaging Suite	385	0.18	1.0	10	79.3	645	13	99.00	YES
155 Microscopy & Imaging Suite	355	0.18	1.0	10	73.9	645	12	92.00	YES
173 Microscopy & Imaging Suite	385	0.18	1.0	10	79.3	645	13	99.00	YES
157 Microscopy & Imaging Suite	375	0.18	1.0	10	77.5	645	13	97.00	YES
172 Microscopy & Imaging Suite	365	0.18	1.0	10	75.7	645	12	95.00	YES
158 Microscopy & Imaging Suite	370	0.18	1.0	10	76.6	645	12	96.00	YES
171 Microscopy & Imaging Suite	370	0.18	1.0	10	76.6	645	12	96.00	YES
159 Microscopy & Imaging Suite	370	0.18	1.0	10	76.6	645	12	96.00	YES
154 Microscopy & Imaging Prep	1,150	0.18	5.0	10	257	645	40	259.00	YES
156 Pump Room	185	0.06	0.0	0	11.1	933	2	14.00	YES
169 Pump Room	189	0.06	0.0	0	11.34	955	2	15.00	YES
	4,499				895	7,693		1,058	

AHU-6 ASHRAE 62.1 VENTILATION COMPLIANCE

	Az	Ra	Pz	Rp	Vbz (= Voz)	SUPPLY AIR	Zp	Zone Design OA	Compliance?
	(ft^2)	CFM / ft^2	# People	cfm / person	CFM OA	CFM	(cfm OA/ cfm supply)	CFM	
151 Advanced Material Characterizatior	2,956	0.18	10	10	632.08	7,680	9	790.00	YES
251 Synthesis Suite	2,946	0.18	16	10	690.28	14,100	5	862.00	YES
200D Corridor	450	0.06	0	0	27	200	14	34.00	YES
100G Corridor	450	0.06	0	0	27	275	10	34.00	YES
	6,802				**1,376**	**22,255**		**1,720**	

AHU-7 62.1 VENTILATION CALCULATIONS

	Az	Ra	Pz	Rp	Vbz (= Voz)	SUPPLY AIR	Zp	Zone Design OA	
	(ft^2)	CFM / ft^2	# People	cfm / person	CFM OA	CFM	(cfm OA/ cfm supply)	CFM	Compliance?
351A Instrument Room	316	0.18	0.0	10	56.88	969	6	71.00	YES
351 North Research Labs	2,351	0.18	7.0	10	493.18	10,875	5	528.00	YES
350 North Research Labs	723	0.18	4.0	10	170.14	6,699	3	212.00	YES
300D Corridor	345	0.06	0.0	0	20.7	310	7	26.00	YES
Environmental Room	90	0.18	0.0	10	16.2	25	65	-----	N/A
450 North Research Labs	1,892	0.18	10.0	10	440.56	7,100	7	550.00	YES
450A Instrument Room	309	0.18	0.0	10	55.62	813	7	70.00	YES
452 North Research Labs (small)	371	0.18	1.0	10	76.78	1,400	6	96.00	YES
400D Corridor	450	0.06	0.0	0	27	470	6	34.00	YES
	6,847				1,357	28,661		1,587	

AHU-8 62.1 VENTILATION CALCULATIONS

	Az	Ra	Pz	Rp	Vbz (= Voz)	SUPPLY AIR	Zp	Zone Design OA	
	(ft^2)	CFM / ft^2	# People	cfm / person	CFM OA	CFM	(cfm OA/ cfm supply)	CFM	Compliance?
355 South Research Labs	3,852	0.18	14	10	833.36	19,350	5	1040.00	YES
355B Equipment Room 2	231	0.12	0	0	27.72	870	4	52.00	YES
355A Equipment Room	200	0.12	0	0	24	609	4	45.00	YES
Research Commons Corridor 3	600	0.06	0	0	36	112	33	45.00	YES
359 LN2 Dewar Fill Room	98	0.06	0	0	5.88	181	4	15.00	YES
455B Equipment Room 2	326	0.12	0	0	39.12	1,398	3	74.00	YES
455A Equipment Room	243	0.12	0	0	29.16	1,001	3	55.00	YES
455 South Research Labs	2,872	0.18	14	10	656.96	12,900	6	984.00	YES
Research Commons Corridor 3	600	0.06	0	0	36	300	12	45.00	YES
	9,022				1,688	36,721		2,366	

AHU-9 62.1 VENTILATION CALCULATIONS

	Az	Ra	Pz	Rp	Vbz (= Voz)	SUPPLY AIR	Zp	Zone Design OA	
	(ft^2)	CFM / ft^2	# People	cfm / person	CFM OA	CFM	% (cfm OA/ cfm supply)	CFM	Compliance?
161 Tool Gas Dispensing Room	273	0.18	0	10	49.14	179	28	61.00	YES
160 Gown	273	0.18	0	10	49.14	96	52	61.00	YES
160G Vestibule (Service Chase)	3,498	0.06	0	0	209.88	876	24	262.00	YES
160F Cleanroom Class (342)	816	0.12	8	10	177.92	3,903	5	222.00	YES
160E Cleanroom Class (343)	1,199	0.12	10	10	243.88	5,706	5	305.00	YES
160C Cleanroom Class (344)	1,050	0.12	10	10	226	5,017	5	282.00	YES
160B Cleanroom Class (345)	1,042	0.12	10	10	225.04	4,980	5	281.00	YES
160H Cleanroom Storage	100	0.12	0	0	12	45	27	15.00	YES
160J Air lock (128)	90	0.06	0	0	5.4	45	12	7.00	YES
160A Air lock (132)	87	0.06	0	0	5.22	45	12	7.00	YES
254 Cleanroom Mechanical	464	0.18	0	10	83.52	2,238	4	105.00	YES
254 Cleanroom	8,308	0.18	0	10	1495.44	200	748	1869.00	YES
	17,200				2,783	23,330		3,477	

AHU-10 STANDARD 62.1 VENTILATION CALCS

	Az	Ra	Pz	Rp	Vbz (= Voz)	SUPPLY AIR	Zp
	(ft^2)	CFM / ft^2	# People	cfm / person	CFM OA	CFM	(cfm OA/ cfm supply)
170 Core Workspace	324	0.06	1	5	24.44	518	**5**
163 Core Office	107	0.06	1	5	11.42	93	**13**
164 Core Office	114	0.06	1	5	11.84	71	**17**
100L Corridor	235	0.06	0	0	14.1	100	**15**
165 B Holding	112	0.06	0	0	6.72	67	**11**
165 General Receiving	613	0.06	0	0	36.78	190	**20**
165D Chemical Waste Storage	184	0.12	0	0	22.08	138	**16**
100J Corridor	1,000	0.06	0	0	60	309	**20**
100K/O Corridor	930	0.06	0	0	55.8	643	**9**
162 Core Storage	137	0.12	0	0	16.44	87	**19**
166 Women	208	0.18	0	5	37.44	65	**58**
168 Men	213	0.18	0	5	38.34	65	**59**
100H Corridor 3	1,695	0.06	0	0	101.7	1,479	**7**
100G Corridor 1	934	0.06	0	0	56.04	368	**16**
150 Lobby	589	0.06	0	5	35.34	1,000	**4**
250A Director	250	0.06	1	5	20	403	**5**
250D Associate Director	130	0.06	1	5	12.8	242	**6**
250E Assistant	150	0.06	1	5	14	242	**6**
250F Associate Director	130	0.06	1	5	12.8	242	**6**
250B Office	133	0.06	1	5	12.98	65	**20**
250C Office	133	0.06	1	5	12.98	65	**20**
200F Corridor 3	405	0.06	0	0	24.3	110	**23**
250G Director	250	0.06	1	5	20	403	**5**
250M Director	250	0.06	1	5	20	403	**5**
250P Associate Director	146	0.06	1	5	13.76	242	**6**
250X Conference	222	0.06	6	5	43.32	344	**13**
250P Copy Room	116	0.12	0	5	13.92	124	**12**
255T Building Manager Office	126	0.06	1	5	12.56	84	**15**
250Q Office	126	0.06	1	5	12.56	84	**15**
256V Core Office	118	0.06	1	5	12.08	73	**17**
200F Corridor 3	405	0.06	0	0	24.3	110	**23**
250 Staff (Open Office)	1,405	0.06	7	5	119.3	448	**27**
250H Reception	93	0.06	1	5	10.58	55	**20**
250 Staff (Open Office Circulation)	1,230	0.06	0	5	73.8	118	**63**
259 Women	224	0.18	0	5	40.32	73	**56**

261 Men	216	0.18	0	5	38.88	74	**53**
258 Core Office	225	0.06	2	5	23.5	120	**20**
200F Corridor	805	0.06	0	0	48.3	220	**22**
200G Closet	90	0.06	0	0	5.4	86	**7**
254A Clean Room Mechanical Storage	245	0.12	0	0	29.4	99	**30**
250R Assistant	150	0.06	1	5	14	242	**6**
250S Associate Director	130	0.06	1	5	12.8	242	**6**
250U Director	255	0.06	2	5	25.3	400	**7**
255 Custodial	231	0.12	2	0	27.72	227	**13**
257 Unisex Toilet	108	0.18	0	5	19.44	89	**22**
256 Storage	648	0.12	0	0	77.76	447	**18**
200BR Corridor	480	0.06	0	0	28.8	2,500	**2**
250Y Conference Small	327	0.06	10	5	69.62	763	**10**
250DD Assistant	97	0.06	1	5	10.82	56	**20**
250CC Assistant	98	0.06	1	5	10.88	56	**20**
250BB Assistant	97	0.06	1	5	10.82	56	**20**
250AA Assistant	97	0.06	1	5	10.82	56	**20**
200F Corridor 3	405	0.06	0	0	24.3	110	**23**
253 Electrical Room	170	0.06	0	0	10.2	1,135	**1**
200DE Corridor 2	926	0.06	0	0	55.56	448	**13**
150 Lobby	144	0.06	0	5	8.64	960	**1**
257W Kitchen/Breakroom	245	0.06	0	5	14.7	377	**4**
250J Office	274	0.06	2	5	26.44	136	**20**
381 Conference	355	0.06	10	5	71.3	816	**9**
356 Copy	107	0.06	0	5	6.42	143	**5**
357 Post Doc Cluster	158	0.06	2	5	19.48	133	**15**
358 Workroom	106	0.06	1	5	11.36	93	**13**
377 PI Office	149	0.06	1	5	13.94	210	**7**
376 PI Office	149	0.06	1	5	13.94	210	**7**
375 PI Office	149	0.06	1	5	13.94	210	**7**
374 PI Office	149	0.06	1	5	13.94	210	**7**
373 PI Office	149	0.06	1	5	13.94	210	**7**
372 PI Office	149	0.06	1	5	13.94	210	**7**
371 PI Office	149	0.06	1	5	13.94	210	**7**
370 PI Office	149	0.06	1	5	13.94	210	**7**
369 PI Office	149	0.06	1	5	13.94	210	**7**
368 PI Office	149	0.06	1	5	13.94	210	**7**
362 Mens Toilet	160	0.18	0	5	28.8	68	**43**
364 Post Doc	160	0.06	2	5	19.6	101	**20**
365 Post Doc	160	0.06	2	5	19.6	101	**20**
366 Post Doc	160	0.06	2	5	19.6	101	**20**
(Grad Clusters, Research Circ)	2,980	0.06	24	5	298.8	1,160	**26**
(Grad Clusters, Research Circ)	3,820	0.06	21	5	334.2	1,220	**28**
300 Corridor BR	480	0.06	0	0	28.8	2,500	**2**

363 Coffee/Breakroom	300	0.06	1	5	23	793	3
300D Corridor 2	1,286	0.06	0	0	77.16	340	23
354 Storage	109	0.12	0	0	13.08	14	94
353 Electric Room	170	0.06	0	0	10.2	562	2
360 Womens Toilet	207	0.18	0	5	37.26	130	29
378 Post Doc	136	0.06	2	5	18.16	90	21
379 Post Doc	136	0.06	2	5	18.16	90	21
380 Post Doc	136	0.06	2	5	18.16	90	21
472 PI Office	149	0.06	1	5	13.94	210	7
473 PI Office	149	0.06	1	5	13.94	210	7
474 PI Office	149	0.06	1	5	13.94	210	7
470 PI Office	149	0.06	1	5	13.94	210	7
471 PI Office	149	0.06	1	5	13.94	210	7
468 PI Office	149	0.06	1	5	13.94	210	7
469 PI Office	149	0.06	1	5	13.94	210	7
467 Conference	365	0.06	10	5	71.9	640	12
456 Copy	105	0.06	0	5	6.3	185	4
457 Post Grad Cluster	182	0.06	2	5	20.92	209	11
458 Workarea	105	0.18	1	5	23.9	125	20
459 Men	213	0.18	0	5	38.34	70	55
462 Post Doc	170	0.06	2	5	20.2	101	20
463 Post Doc	170	0.06	2	5	20.2	101	20
464 Post Doct	170	0.06	2	5	20.2	101	20
400J Corridor 3	150	0.06	0	0	9	100	9
(Grad Clusters, Research Circ)	4,380	0.06	10	5	312.8	2,170	15
(Grad Clusters, Research Circ)	1,600	0.06	22	5	206	880	24
400 Corridor BR	480	0.06	0	0	28.8	2,500	2
400K Coffee/Breakroom	300	0.06	1	5	23	803	3
400D Corridor 2	695	0.06	0	0	41.7	300	14
453 Electric Room	170	0.06	0	0	10.2	580	2
363 Commons		0.12		7.5			
461 Women	207	0.18	0	5	37.26	131	29
475 Post Doc	133	0.06	2	5	17.98	92	20
476 Post Doc	133	0.06	2	5	17.98	90	20
477 Post Doct	133	0.06	2	5	17.98	89	21
454 Storage	95	0.12	0	0	11.4	61	19
Grad Clusters	1,010	0.06	6	5	90.6	240	38
	44,525		**199**		**4,016**	**39,705**	

Appendix B

TABLE 5.5-4 Building Envelope Requirements For Climate Zone 4 (A, B, C)*

Opaque Elements	Nonresidential		Residential		Semiheated	
	Assembly Maximum	Insulation Min. R-Value	Assembly Maximum	Insulation Min. R-Value	Assembly Maximum	Insulation Min. R-Value
Roofs						
Insulation Entirely above Deck	U-0.048	R-20.0 c.i.	U-0.048	R-20.0 c.i.	U-0.173	R-5.0 c.i.
Metal Building	U-0.065	R-19.0	U-0.065	R-19.0	U-0.097	R-10.0
Attic and Other	U-0.027	R-38.0	U-0.027	R-38.0	U-0.053	R-19.0
Walls, Above-Grade						
Mass	U-0.104	R-9.5 c.i.	U-0.090	R-11.4 c.i.	U-0.580	NR
Metal Building	U-0.113	R-13.0	U-0.113	R-13.0	U-0.134	R-10.0
Steel-Framed	U-0.064	R-13.0 + R-7.5 c.i.	U-0.064	R-13.0 + R-7.5 c.i.	U-0.124	R-13.0
Wood-Framed and Other	U-0.089	R-13.0	U-0.064	R-13.0 + R-3.8 c.i.	U-0.089	R-13.0
Walls, Below-Grade						
Below-Grade Wall	C-1.140	NR	C-0.119	R-7.5 c.i.	C-1.140	NR
Floors						
Mass	U-0.087	R-8.3 c.i.	U-0.074	R-10.4 c.i.	U-0.137	R-4.2 c.i.
Steel-Joist	U-0.038	R-30.0	U-0.038	R-30.0	U-0.069	R-13.0
Wood-Framed and Other	U-0.033	R-30.0	U-0.033	R-30.0	U-0.066	R-13.0
Slab-On-Grade Floors						
Unheated	F-0.730	NR	F-0.540	R-10 for 24 in.	F-0.730	NR
Heated	F-0.860	R-15 for 24 in.	F-0.860	R-15 for 24in.	F-1.020	R-7.5 for 12 in.
Opaque Doors						
Swinging	U-0.700		U-0.700		U-0.700	
Nonswinging	U-1.500		U-0.500		U-1.450	
Fenestration	**Assembly Max. U**	**Assembly Max. SHGC**	**Assembly Max. U**	**Assembly Max. SHGC**	**Assembly Max. U**	**Assembly Max. SHGC**
Vertical Glazing, 0%–40% of Wall						
Nonmetal framing (all)[b]	U-0.40	SHGC-0.40 all	U-0.40	SHGC-0.40 all	U-1.20	SHGC-NR all
Metal framing (curtainwall/storefront)[c]	U-0.50		U-0.50		U-1.20	
Metal framing (entrance door)[c]	U-0.85		U-0.85		U-1.20	
Metal framing (all other)[c]	U-0.55		U-0.55		U-1.20	
Skylight with Curb, Glass, % of Roof						
0%–2.0%	U_{all}-1.17	$SHGC_{all}$-0.49	U_{all}-0.98	$SHGC_{all}$-0.36	U_{all}-1.98	$SHGC_{all}$-NR
2.1%–5.0%	U_{all}-1.17	$SHGC_{all}$-0.39	U_{all}-0.98	$SHGC_{all}$-0.19	U_{all}-1.98	$SHGC_{all}$-NR
Skylight with Curb, Plastic, % of Roof						
0%–2.0%	U_{all}-1.30	$SHGC_{all}$-0.65	U_{all}-1.30	$SHGC_{all}$-0.62	U_{all}-1.90	$SHGC_{all}$-NR
2.1%–5.0%	U_{all}-1.30	$SHGC_{all}$-0.34	U_{all}-1.30	$SHGC_{all}$-0.27	U_{all}-1.90	$SHGC_{all}$-NR
Skylight without Curb, All, % of Roof						
0%–2.0%	U_{all}-0.69	$SHGC_{all}$-0.49	U_{all}-0.58	$SHGC_{all}$-0.36	U_{all}-1.36	$SHGC_{all}$-NR
2.1%–5.0%	U_{all}-0.69	$SHGC_{all}$-0.39	U_{all}-0.58	$SHGC_{all}$-0.19	U_{all}-1.36	$SHGC_{all}$-NR

*The following definitions apply: c.i. = continuous insulation (see Section 3.2), NR = no (insulation) requirement.
[b]Nonmetal framing includes framing materials other than metal with or without metal reinforcing or cladding.
[c]Metal framing includes metal framing with or without thermal break. The "all other" subcategory includes operable windows, fixed windows, and non-entrance doors.

7.8 Product Information

TABLE 7.8 Performance Requirements for Water Heating Equipment

Equipment Type	Size Category (Input)	Subcategory or Rating Condition	Performance Required [a]	Test Procedure[b]
Electric water heaters	≤12 kW	Resistance ≥20 gal	0.93–0.00132V EF	DOE 10 CFR Part 430
	>12 kW	Resistance ≥20 gal	$20 + 35\sqrt{V}$ SL, Btu/h	ANSI Z21.10.3
	≤24 Amps and ≤250 Volts	Heat Pump	0.93–0.00132V EF	DOE 10 CFR Part 430
Gas storage water heaters	≤75,000 Btu/h	≥20 gal	0.62–0.0019V EF	DOE 10 CFR Part 430
	>75,000 Btu/h	<4000 (Btu/h)/gal	80% E_t $(Q/800 + 110\sqrt{V})$ SL, Btu/h	ANSI Z21.10.3
Gas instantaneous water heaters	>50,000 Btu/h and <200,000 Btu/h	≥4000 (Btu/h)/gal and <2 gal	0.62–0.0019V EF	DOE 10 CFR Part 430
	≥200,000 Btu/h[c]	≥4000 (Btu/h)/gal and <10 gal	80% E_t	ANSI Z21.10.3
	≥200,000 Btu/h	≥4000 (Btu/h)/gal and ≥10 gal	80% E_t $(Q/800 + 110\sqrt{V})$ SL, Btu/h	
Oil storage water heaters	≤105,000 Btu/h	≥20 gal	0.59–0.0019V EF	DOE 10 CFR Part 430
	>105,000 Btu/h	<4000 (Btu/h)/gal	78% E_t $(Q/800 + 110\sqrt{V})$ SL, Btu/h	ANSI Z21.10.3
Oil instantaneous water heaters	≤210,000 Btu/h	≥4000 (Btu/h)/gal and <2 gal	0.59–0.0019V EF	DOE 10 CFR Part 430
	>210,000 Btu/h	≥4000 (Btu/h)/gal and <10 gal	80% E_t	ANSI Z21.10.3
	>210,000 Btu/h	≥4000 (Btu/h)/gal and ≥10 gal	78% E_t $(Q/800 + 110\sqrt{V})$ SL, Btu/h	
Hot-water supply boilers, gas and oil	≥300,000 Btu/h and <12,500,000 Btu/h	≥4000 (Btu/h)/gal and <10 gal	80% E_t	ANSI Z21.10.3
Hot-water supply boilers, gas		≥4000 (Btu/h)/gal and ≥10 gal	80% E_t $(Q/800 + 110\sqrt{V})$ SL, Btu/h	
Hot-water supply boilers, oil		≥4000 (Btu/h)/gal and ≥10 gal	78% E_t $(Q/800 + 110\sqrt{V})$ SL, Btu/h	
Pool heaters, oil and gas	All		78% E_t	ASHRAE 146
Heat pump pool heaters	All		4.0 COP	ASHRAE 146
Unfired storage tanks	All		R-12.5	(none)

[a] Energy factor (EF) and thermal efficiency (E_t) are minimum requirements, while standby loss (SL) is maximum Btu/h based on a 70°F temperature difference between stored water and ambient requirements. In the EF equation, V is the rated volume in gallons. In the SL equation, V is the rated volume in gallons and

TABLE 10.8 Minimum Nominal Efficiency for General Purpose Design A and Design B Motors[a]

	Minimum Nominal Full-Load Efficiency (%)					
	Open Motors			Enclosed Motors		
Number of Poles ⇒	2	4	6	2	4	6
Synchronous Speed (RPM) ⇒	3600	1800	1200	3600	1800	1200
Motor Horsepower						
1	—	82.5	80.0	75.5	82.5	80.0
1.5	82.5	84.0	84.0	82.5	84.0	85.5
2	84.0	84.0	85.5	84.0	84.0	86.5
3	84.0	86.5	86.5	85.5	87.5	87.5
5	85.5	87.5	87.5	87.5	87.5	87.5
7.5	87.5	88.5	88.5	88.5	89.5	89.5
10	88.5	89.5	90.2	89.5	89.5	89.5
15	89.5	91.0	90.2	90.2	91.0	90.2
20	90.2	91.0	91.0	90.2	91.0	90.2
25	91.0	91.7	91.7	91.0	92.4	91.7
30	91.0	92.4	92.4	91.0	92.4	91.7
40	91.7	93.0	93.0	91.7	93.0	93.0
50	92.4	93.0	93.0	92.4	93.0	93.0
60	93.0	93.6	93.6	93.0	93.6	93.6
75	93.0	94.1	93.6	93.0	94.1	93.6
100	93.0	94.1	94.1	93.6	94.5	94.1
125	93.6	94.5	94.1	94.5	94.5	94.1
150	93.6	95.0	94.5	94.5	95.0	95.0
200	94.5	95.0	94.5	95.0	95.0	95.0

[a]Nominal efficiencies shall be established in accordance with NEMA Standard MG1. Design A and Design B are National Electric Manufacturers Association (NEMA) design class designations for fixed-frequency small and medium AC squirrel-cage induction motors.

Table 12-12

FULL-LOAD EFFICIENCIES FOR 60 HZ NEMA PREMIUM® EFFICIENCY ELECTRIC MOTORS RATED 600 VOLTS OR LESS (RANDOM WOUND)

	OPEN MOTORS					
	2 POLE		4 POLE		6 POLE	
HP	Nominal Efficiency	Minimum Efficiency	Nominal Efficiency	Minimum Efficiency	Nominal Efficiency	Minimum Efficiency
1	77.0	74.0	85.5	82.5	82.5	80.0
1.5	84.0	81.5	86.5	84.0	86.5	84.0
2	85.5	82.5	86.5	84.0	87.5	85.5
3	85.5	82.5	89.5	87.5	88.5	86.5
5	86.5	84.0	89.5	87.5	89.5	87.5
7.5	88.5	86.5	91.0	89.5	90.2	88.5
10	89.5	87.5	91.7	90.2	91.7	90.2
15	90.2	88.5	93.0	91.7	91.7	90.2
20	91.0	89.5	93.0	91.7	92.4	91.0
25	91.7	90.2	93.6	92.4	93.0	91.7
30	91.7	90.2	94.1	93.0	93.6	92.4
40	92.4	91.0	94.1	93.0	94.1	93.0
50	93.0	91.7	94.5	93.6	94.1	93.0
60	93.6	92.4	95.0	94.1	94.5	93.6
75	93.6	92.4	95.0	94.1	94.5	93.6
100	93.6	92.4	95.4	94.5	95.0	94.1
125	94.1	93.0	95.4	94.5	95.0	94.1
150	94.1	93.0	95.8	95.0	95.4	94.5
200	95.0	94.1	95.8	95.0	95.4	94.5
250	95.0	94.1	95.8	95.0	95.4	94.5
300	95.4	94.5	95.8	95.0	95.4	94.5
350	95.4	94.5	95.8	95.0	95.4	94.5
400	95.8	95.0	95.8	95.0	95.8	95.0
450	95.8	95.0	96.2	95.4	96.2	95.4
500	95.8	95.0	96.2	95.4	96.2	95.4

Table 12-12 *(Continued)*
FULL-LOAD EFFICIENCIES FOR 60 HZ NEMA PREMIUM® EFFICIENCY ELECTRIC MOTORS RATED 600 VOLTS OR LESS (RANDOM WOUND)

	ENCLOSED MOTORS					
	2 POLE		4 POLE		6 POLE	
HP	Nominal Efficiency	Minimum Efficiency	Nominal Efficiency	Minimum Efficiency	Nominal Efficiency	Minimum Efficiency
1	77.0	74.0	85.5	82.5	82.5	80.0
1.5	84.0	81.5	86.5	84.0	87.5	85.5
2	85.5	82.5	86.5	84.0	88.5	86.5
3	86.5	84.0	89.5	87.5	89.5	87.5
5	88.5	86.5	89.5	87.5	89.5	87.5
7.5	89.5	87.5	91.7	90.2	91.0	89.5
10	90.2	88.5	91.7	90.2	91.0	89.5
15	91.0	89.5	92.4	91.0	91.7	90.2
20	91.0	89.5	93.0	91.7	91.7	90.2
25	91.7	90.2	93.6	92.4	93.0	91.7
30	91.7	90.2	93.6	92.4	93.0	91.7
40	92.4	91.0	94.1	93.0	94.1	93.0
50	93.0	91.7	94.5	93.6	94.1	93.0
60	93.6	92.4	95.0	94.1	94.5	93.6
75	93.6	92.4	95.4	94.5	94.5	93.6
100	94.1	93.0	95.4	94.5	95.0	94.1
125	95.0	94.1	95.4	94.5	95.0	94.1
150	95.0	94.1	95.8	95.0	95.8	95.0
200	95.4	94.5	96.2	95.4	95.8	95.0
250	95.8	95.0	96.2	95.4	95.8	95.0
300	95.8	95.0	96.2	95.4	95.8	95.0
350	95.8	95.0	96.2	95.4	95.8	95.0
400	95.8	95.0	96.2	95.4	95.8	95.0
450	95.8	95.0	96.2	95.4	95.8	95.0
500	95.8	95.0	96.2	95.4	95.8	95.0