NORTHEAST USA

INTEGRATED SCIENCES BUILDING

Technical Report II

Design Load Estimation

Energy Consumption and Emissions Estimation

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Contents

Executive Summary

The intention of this report is to explain and provide details of a block energy simulation for the Integrated Sciences Building and describe annual energy consumption and emissions estimates. As a result, an annual operating cost estimate can be generated. The result of the energy simulation and calculations are compared with those made available by the design engineer and the energy model that was performed for the proposed design and construction of the building. Since the building is intended to become LEED Gold certified, an energy analysis of the building is required to exhibit the efficiency characteristics of the building. The software packaged used to generate an energy model of this report is TRACE 700, which is a product of the Trane Incorporated.

The results of the block energy calculations are reasonable with some margin of error. The complexity of the air handling systems provides a tough task for an inexperienced energy model user. When compared to the annual operating costs of the design engineer, the margin of error for the model for this report is enough to merit further effort in order to more accurately model the building.

The estimated emissions of the building are also quantified to explain the impact of electrical consumption, natural gas combustion, and purchased district steam on the environment. The environmental impact of building is consistently becoming a more important focus during design and construction, and quantifying the impact of a new building on the atmosphere is a valuable metric in evaluating the success of a LEED building or any new structure.

Mechanical System Overview

The mechanical systems that serve the HVAC needs of the Integrated Sciences Building are very complex and are designed to be efficient in order to earn points toward LEED Certification. There are nine air handling units that serve the building. Three of the units are constant volume, terminal reheat systems that serve the electrical and data closets, auditorium, and atrium as well as providing adequate air for pressurization of the building. The other air handlers are all Variable Air Volume (VAV) Systems with hydronic terminal reheat that serve classrooms, offices, teaching laboratories, and research laboratories. The laboratory air handlers supply 100% outdoor air to the spaces they serve in order to provide adequate ventilation to the occupants and the purge the building of any contaminants that may result from the activities in those spaces. The laboratories are negatively pressurized relative to the remainder of the building to ensure that no contaminants enter the other occupied areas. Laboratory spaces are also equipped with VAV fume hood controls to limit the exhaust of the hoods and save energy when possible.

The thermal loads of the building are served by a chiller plant and purchased steam system. The chiller plant consists of two 620-ton two-stage centrifugal, water-cooled chillers with a coefficient of performance (COP) of 5.56 each. Heat is rejected via condenser water that is cooled by two 620-ton cooling towers. The purchased steam enters the building at 200 psi and maximum rate of 15,000 lbs/hr. The steam is used in four heat exchangers to make hot water to serve heating loads in the building's air handlers and hydronic reheat systems. Steam is also used to provide domestic hot water. Natural gas is used in the building, but not as a significant energy source. The natural gas consumption is limited to bench and fume hood use in the laboratories for scientific experiments.

System Design Load Estimation

The energy modeling software used for this report was Trane TRACE 700 Version 6.2.6.5. The purpose of the energy model was to determine the design load energy consumption and a full 8,760 hour, yearly model of energy consumption for the Integrated Sciences Building. The decision to use TRACE software was based upon experience using TRACE in the past and pre-existing knowledge of data input techniques for the particular software package.

Block Load Assumptions

A block loading technique was executed for the energy model performed for this report because it is simpler than a space-by-space model and provides a reasonably accurate estimation of loads and energy consumption when the amount of time spent is considered. Building characteristics that were used in the model were taken directly from design documents, including wall construction and thermal properties, room sizes, fenestration size and characteristics, and HVAC system methodology.

Several model assumptions were also included to further simplify the model with reasonable certainty that they would not adversely affect the results in any extreme fashion. One assumption made was that the exterior façade wall is of uniform construction and thermal resistance independent of curtain wall and fenestrations. Fenestrations were also assumed uniform and thermal characteristics were consistent for all windows and glass curtain walls. Internal loads for lighting and miscellaneous equipment loads were assumed to be uniform and consistent with the approximations used by the building's energy modeling engineer. This allowed for more appropriate comparison of the results from the building's design model and the model generated for this report.

Load Sources

Internal load sources for interior spaces include any heat generation that may be a result of occupants and their activity levels, lighting, receptacle usage, building envelope heat transfer, equipment heat generation, and infiltration. People within a building give off heat as a result of their normal metabolism and different levels of physical activity can increase the sensible or latent loads that they emit. For example, a person walking in an atrium or a research laboratory emits more heat than a person sitting in a classroom or in an office. Lighting thermal gains are a result of heat generated by the lighting fixtures. Lighting densities are listed below in Table 1. Most of the energy being sent to lighting fixtures eventually contributes to thermal gains to a space. Receptacle energy also become heat load as a result of task lighting, or the conversion of electrical energy to heat in computers, LCD screens, projectors, or laboratory equipment. The densities of power are also listed in Table 1. Building envelope thermal gains and infiltration loads are a result of the environment in which the building is located. Outdoor conditions are a huge factor in determining thermal loads and during hot and cold seasons, they play a huge role in the thermal loading of a building.

Miscellaneous and Lighting Loads

Lighting power densities and miscellaneous equipment loads which contribute to thermal internal loads on the building are shown in Table 1 below. The lighting power densities are higher than those given as the maximum allowed by ASHRAE Standard 90.1 as well as calculated lighting densities for the building. However, because some spaces have higher lighting power density levels than other spaces, a conservative estimate was used in the energy model. Again, these values were the same as those used by the energy modeling engineer and were also used in the model to provide an appropriate comparison between model results. The miscellaneous equipment internal loads are also conservative estimates and are likely higher than actual internal loads, but are the same as those used by the design engineer.

Space	Lighting Density [W/ft^2]	Power Density [W/ft^2]
Research Lab	1.5	8
Teaching Lab	1.5	3
Lab Support	2	8
Office	1.5	2.5
Corridors & Atrium	1.5	0.25
Classroom	1.5	50W per laptop (1 laptop per seat)
Auditorium	1.5	2.5

Table 1 – Lighting and Internal load densities for ISB energy model.

Ventilation Rates

Minimum outdoor air ventilation rates were determined based on code and specifications provided in the Integrated Sciences Building documents. Outside air rates for most spaces such as entrance lobbies and office spaces were calculated based on International Mechanical Code occupant density guidelines given in the ventilation section of the code. Occupancies for lecture halls, classrooms, and the auditorium were determined based on the number of fixed seats provided as shown on the architectural drawings. Many spaces had airflows that exceed code for the purpose of pressurizing the building to prevent laboratory contaminants from entering other areas of the building. In the laboratories, minimum air change rates per hour were provided in the mechanical specifications for laboratory spaces. They are shown below, in Table 2. Wherever possible, air flow rates were taken directly from design documents.

Operation Mode	Minimum Laboratory Ventilation Rates [ACH]	
	Occupied	Unoccupied
Research Labs	10	6
Teaching Labs	8	4

Table 2 – Laboratory minimum air changes per hour (ACH).

Schedules

The actual schedule of occupied and unoccupied hours for the Integrated Sciences Building which will control the operation of the Building Automation System will be decided upon at the time of installation of the mechanical and control systems. For the purposes of energy analysis, the model done for this assessment, as well as that done by the design engineer, used the schedule outlined below in Table 3. The table shows weekday occupancy rates as a percentage of a fully occupied building. Weekday occupancies were assumed to be zero.

Hours		Occupancy
Start	**End**	
12:00 AM	7:00 AM	0
7:00 AM	8:00 AM	30%
8:00 AM	12:00 PM	100
12:00 PM	1:00 PM	75%
1:00 PM	5:00 PM	100%
5:00 PM	6:00 PM	30%
6:00 PM	12:00 AM	0%

Table 3 – normal weekday occupancy schedule.

Other schedules were used for miscellaneous loads in the building such as exterior lighting and small unitized cooling equipment. TRACE 700 comes equipped with many default schedules to choose from for these cases which were utilized in the model.

Weather Data

Weather data used for the energy model of the Integrated Sciences Building was taken from the ASHRAE Handbook of Fundamentals for Philadelphia International Airport. This is the same weather data which was used by the design engineer and was chosen to ensure an appropriate comparison between that model and the one executed for this report. Below is Table 4, which compares the weather design temperatures given in the ASHRAE Handbook of Fundamentals and those provided as defaults in Trane's TRACE 700 Software. The ASHRAE values were more stringent than those from the software, and therefore will provide a more rigorous analysis of the building's performance. The full ASHRAE weather chart for the building location is shown in Appendix A.

	Summer Design Cooling Temperatures		Winter Design Heating Temperatures	
	ASHRAE - 0.4%	Trace 700 Default	ASHRAE - 99.6%	Trace 700 Default
OA Dry Bulb (°F)	93.2	92.7	12.6	14
OA Wet Bulb (°F)	75.4	74	-	-

Table 4 – ASHRAE design temperatures vs. TRACE 700 default values.

Interior Conditions

The interior set points of the Integrated Sciences Building are shown below in Table 5. These set points were assigned using the templates feature of the TRACE 700 software.

Space	Summer		Winter	
	Temp [°F]	RH	Temp [°F]	RH
General Teaching Lab	74	55%	72	30%
Office & Administration	75	55%	72	30%
Classrooms & Auditorium	75	55%	72	30%
Lobbies and Corridors	75	55%	72	30%
Research Laboratories	74	55%	72	30%

Table 5 – Interior temperature and humidity set points.

Exterior Wall Construction

Exterior wall thermal properties were evaluated for compliance with ASHRAE Standard 90.1-2007, with which they fully complied. Those values were used in the energy model of the Integrated Sciences Building. The exact values for different building envelope surfaces are shown in Table 6. Likewise, fenestration data which was used in the energy model is shown in Table 7.

Component	U-Value
Roof	0.04
Exterior Wall	0.089
Basement Wall	0.058
Slab on Grade	0.058
Opaque Doors	0.5

Table 6 – Opaque surface U-Values.

	U-Value	SHGC
Fenestrations	0.3	0.33

Table 7 – Fenestration Assembly heat gain information.

Design Load Estimation Results

The results of the energy model simulation show that there is some discrepancy between the design engineer's model and the one made for this assessment. The Integrated Sciences Building has very complex air handling systems. There are many possible sources for error in the model done for this report.

One of the most evident sources is likely the inexperience of the modeler in this simulation. TRACE 700 is a powerful tool for block loading data, but inputs are very sensitive and sometimes require in-depth knowledge of the software and various mechanical systems. Ventilation requirements must be input in exactly the correct manner, or errors are certain. Numerous attempts were made to assure accuracy of this model via consultation with experienced student colleagues as well as the Trane Technical Support Team.

Another source for error is the complexity of the ventilation systems within the Integrated Sciences Building. The systems used in the building are very complex to ensure proper pressurization of the building. Some air handlers were explicitly described in the mechanical specifications to bring excess outside air into the building in order to assure proper pressurization in some locations. For example, the auditorium air handler (AHU-1) brings in 3400 cubic feet per minute (CFM) while the minimum outside air requirements for people and area are approximately half of that value. A portion of the air that is supplied to that auditorium is then transferred to the atrium to ensure positive pressure in relation of laboratories. This method is used with several air handlers in order to ensure positive pressure. Another unique feature of the air systems is that all outside air supplied to offices, classrooms, and lecture halls will be exhausted through laboratories to maintain the pressure in all lab spaces. Some portions of return air from classrooms will be transferred back to the atrium in order to maintain pressurization in all spaces except the laboratories. These features make design difficult in a software program such as TRACE, which does not explicitly allow transfer of air from one space to another or the specification of how air volumes are exhausted and transferred.

Further complicating the air handling model of the building is control of the laboratory air handlers. The supply air volume in lab air handlers is the highest of (I) total fume hood exhaust, (II) minimum air change rate, and (III) room temperature control. Based on the frequency of fume hood use, the energy consumption for lab air handlers could fluctuate very much. Below in Table 8, is an outline of the loads calculated for each air handling unit.

It should be pointed out that, as mentioned in the mechanical system overview, Air Handlers Units five through eight serve laboratory spaces and are 100% outdoor air units. This, combined with the large fume hood exhaust and large air change rates, is justification for the high cooling and heating loads and large ventilation supply rates. If the full impact of the fume hood exhaust had been modeled, the heating and cooling loads of the additional outside air intake would be even more extreme. The lack of this consideration is more evident in the annual energy cost comparison in the later parts of this report. The high total supply air rates of the auditorium and lecture halls is the impact of the excess outdoor air intake that is intended to maintain positive pressurization of the building in contrast of the laboratories.

Zone	Data Source	Cooling Load [ft^2/ton]	Heating Load [Btu-h/ft^2]	Total Supply Air [CFM/ft^2]	Ventilation Supply Air [CFM/ft^2]
AHU-1 (Auditorium)	Model	86.54	157.6	2.19	1.23
	Design	-	-	2.17	1.23
AHU-2 (Lecture Halls)	Model	184.7	83.02	2.07	1.21
	Design	-	-	2.44	1.22
AHU-3 (Atrium)	Model	464.9	45.24	1.22	0.52
	Design	-	-	1.62	0.81
AHU-4 (Offices)	Model	202.9	117.47	1.25	0.82
	Design	-	-	1.62	0.81
AHU-5 (Research Labs)	Model	64.2	228.97	2.50	2.50
	Design	-	-	2.56	2.56
AHU-6 (Research Labs)	Model	103.3	137.84	2.36	2.36
	Design	-	-	2.45	2.45
AHU-7 (Teaching Labs)	Model	110.9	93.66	2.21	2.21
	Design	-	-	3.57	3.57
AHU-8 (Teaching Labs)	Model	167	74.18	1.17	0.17
	Design	-	-	1.59	1.59
AHU-9 (Electrical & Data)	Model	372.5	20.49	1.53	0.21
	Design	-	-	1.37	0.25

Table 8 – Modeled and design temperature and ventilation indices. Note that cooling and heating load information was not provided by the design engineer.

Annual Energy Consumption & Operating Costs

Building Engineering Analysis

During design of the Integrated Sciences Building, a separate engineering company provided energy analysis services in order to demonstrate the building's superior performance and qualification for LEED certification. Since the building is still under construction during the writing of this report, limited information about the specific energy profile of the building was available. For future reports, more information will hopefully be obtained for further comparison between the TRACE 700 energy model performed by the design engineer.

The software used by the design engineer is called eQuest, which uses the DOE 2 simulation model. eQuest is similar to TRACE 700 in that it provides affordable energy modeling with minimal effort and in an appropriate amount of time. Due to inexperience in building energy modeling, it was not used for this report in favor or TRACE 700 which has numerous accessible help sources for the user. There is the possibility of creating an eQuest model for future assessment of the Integrated Sciences Building in order to evaluate enhancements to the redesign of the building. This could provide more accurately comparable results than the TRACE 700 model.

Fuel Costs

The fuel costs used for this analysis were the same used by the design engineer who performed the LEED energy analysis for the building. Since the building is under construction at the time of this report, these energy rates will likely change by the time of completion. For example, upon speaking with the building owner's Facilities Management, it was learned that electricity rates will be increasing between 20-40% in the year after construction is scheduled for completion. Nonetheless, energy prices that were used for the building consisted of electricity, natural gas, and purchased district steam. These rates are listed in Tables 9, 10, and 11 below.

Electricity (PECO - HT)	
Customer Monthly Charge	$291.43
Charge per kWh [Up to 150 lkwh]	$0.0635
Charge per kWh [Up to 7,500,000 kwh]	$0.0442
Charge per additional kwh	$0.0253
Demand Charge per kW	$8.79

Table 9 – Electricity Demand and Consumption rates from PECO.

Natural Gas (Philadelphia Gas Works)	
Customer Monthly Charge	$18.00
Cost per Therm	$1.22

Table 10 – Natural gas rate from Philadelphia Gas Works.

District Steam (Trigen Rate S)	
Winter (October - May)	
Consumption: Charge per first 100 Mlbs	$29.08
Consumption: Charge per Additional Mlbs	$28.17
Demand: Charge per first 300 lb/hr	$1.84
Demand: Charge per next 39,700 lb/hr	$1.24
Demand: Chare per Additional lbs/hr	$1.09
Summer (June-September)	
Consumption: Charge per first 100 Mlbs	$27.78
Consumption: Charge per Additional Mlbs	$26.87
Demand: Charge per first 300 lb/hr	$0.00

Table 11 – Trigen District Steam rate structure.

Annual Operating Cost Simulation Results

The TRACE 700 software the was used to measure anticipated cooling, heating, and ventilation loads of the Integrated Sciences Building also has the ability to estimate annual operating costs based on yearly weather data, utility rates, and equipment characteristics. The results of this calculation are shown below in Table 12. The energy usage is shown in kwh of electricity, kbtu of purchased district steam, and therms of natural gas. To gauge the amount of energy usage as a percentage of total building consumption, all energy units were converted to kbtu for the year. Percentages of total building load are shown.

Energy Consuming Function		Consumption Units		Equivalent Units		% of Total Use
Primary Heating						
	Primary Heating Coils	3565486	kBtu	5389991	kBtu	29%
	Heating Accessories	78086	kwh	266429.4	kbtu	1%
Primary Cooling						
	Cooling compressor	352,908	kwh	1204122	kbtu	6%
	Tower/Cond Fans	99766	kwh	340401.6	kbtu	2%
	Condenser Pump	98206	kwh	335078.9	kbtu	2%
	Other Cooling Accessories	121,539	kwh	414691.1	kbtu	2%
Auxiliary						
	Supply fans	563656	kwh	1923194	kbtu	10%
	Pumps	154586	kwh	527447.4	kbtu	3%
	Stand-Alone Base Utilities	37,724	kwh	128714.3	kbtu	1%
Lighting						
		368,045	kwh	1255770	kbtu	7%
Receptacle Loads						
		1,375,322	kwh	4692599	kbtu	25%
Fume Hood Natural Gas						
		23,706	therms	2370600	kbtu	13%
			Total Usage	18849038	kbtu	100%

Table 12 – Annual energy consumption breakdown estimate.

To understand the implications of the energy usage shown above, total annual energy consumption by source is shown below in Table 13 along with the total energy cost by source along with a comparison of the energy usage and costs as presented by the design engineer's energy analysis. As mentioned above, error in the energy analysis could be a result of incorrect fume hood exhaust modeling as well as error in modeling the unusual building pressurization methods. This error will be investigated thoroughly before analyzing the cost effectiveness of any redesign to ensure accurate justification of modifications to the design of the building.

	TRACE 700 Model		Design Model		ASHRAE 90.1-2004 Baseline Model	
	Annual Consumption	Annual Cost	Annual Consumption	Annual Cost	Annual Consumption	Annual Cost
Electricity	3,249,838 kwh	$ 257,543.00	4,984,300 kwh	$ 367,933.00	5020250 kwh	$ 369,182.00
Purchased Steam	3,565,486 kBtu	$ 76,765.68	5,132,000 kBtu	$ 110,637.00	12939000 kBtu	$ 278,973.00
Natural Gas	23,706 Therms	$ 28,921.00	23,706 Therms	$ 28,921.00	23,706 Therms	$ 28,921.00
Total Annual Cost	-	$ 363,229.68	-	$ 507,491.00	-	$ 677,076.00
Annual Cost/ft^2	-	$ 2.63	-	$ 3.68	-	$ 4.91

Table 13 – Annual energy consumption comparison between model, design, and ASHRAE 90.1-20004 Baseline.

Annual Emissions Footprint

The site of the Integrated Sciences Building is in the Eastern Interconnection region of the United States Electrical Grid. The regions of the national electric grid are shown in Figure 1.

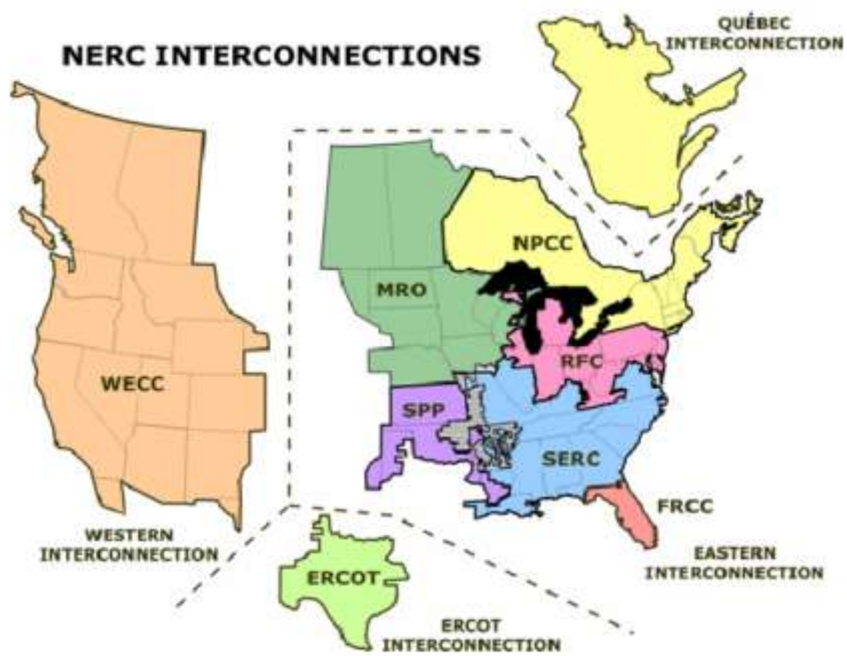

Figure 1 North American electrical grid interconnections, including the 10 NERC regional reliability councils (NERC 2007)

From the annual energy consumption simulation, it is possible to generate an estimate of annual emissions using information from the National Renewable Energy Laboratory. Figure 2, shown below shows the amount of different pollutants produced in pounds per kwh of electricity generated in the different regions of the national grid.

Table 3 Total Emission Factors for Delivered Electricity
(lb of pollutant per kWh of electricity)

Pollutant (lb)	National	Eastern	Western	ERCOT	Alaska	Hawaii
CO_{2e}	1.67E+00	1.74E+00	1.31E+00	1.84E+00	1.71E+00	1.91E+00
CO_2	1.57E+00	1.64E+00	1.22E+00	1.71E+00	1.55E+00	1.83E+00
CH_4	3.71E-03	3.59E-03	3.51E-03	5.30E-03	6.28E-03	2.96E-03
N_2O	3.73E-05	3.87E-05	2.97E-05	4.02E-05	3.05E-05	2.00E-05
NO_X	2.76E-03	3.00E-03	1.95E-03	2.20E-03	1.95E-03	4.32E-03
SO_X	8.36E-03	8.57E-03	6.82E-03	9.70E-03	1.12E-02	8.36E-03
CO	8.05E-04	8.54E-04	5.46E-04	9.07E-04	2.05E-03	7.43E-03
TNMOC	7.13E-05	7.26E-05	6.45E-05	7.44E-05	8.40E-05	1.15E-04
Lead	1.31E-07	1.39E-07	8.95E-08	1.42E-07	6.30E-08	1.32E-07
Mercury	3.05E-08	3.36E-08	1.86E-08	2.79E-08	3.80E-08	1.72E-07
PM10	9.16E-05	9.26E-05	6.99E-05	1.30E-04	1.09E-04	1.79E-04
Solid Waste	1.90E-01	2.05E-01	1.39E-01	1.66E-01	7.89E-02	7.44E-02

Figure 1 – Emission factors for Electricity consumption of different grid regions.

Table 14 shows the estimated emissions for the Integrated Sciences Building based on the values shown in Figure 1 for the Eastern Interconnection grid region.

Annual Emissions for Electrical Consumption				
Pollutant	Eastern Interconnection	Modeled Buidling Pollution per Year [lb]	Proposed Building Pollution per Year [lb]	Baseline Building Pollution per Year [lb]
Electric Use	1 kwh	3,249,838 kwh	4,984,300 kwh	5,020,250 kwh
CO_{2e}	1.74E+00	5.65E+06	8.67E+06	8.74E+06
CO_2	1.64E+00	5.33E+06	8.17E+06	8.23E+06
CH_4	3.59E-03	1.17E+04	1.79E+04	1.80E+04
N_2O	3.87E-05	1.26E+02	1.93E+02	1.94E+02
NO_x	3.00E-03	9.75E+03	1.50E+04	1.51E+04
SO_x	8.57E-03	2.79E+04	4.27E+04	4.30E+04
CO	8.54E-04	2.78E+03	4.26E+03	4.29E+03
TNMOC	7.26E-05	2.36E+02	3.62E+02	3.64E+02
Lead	1.39E-07	4.52E-01	6.93E-01	6.98E-01
Mercury	3.36E-08	1.09E-01	1.67E-01	1.69E-01
PM10	9.26E-05	3.01E+02	4.62E+02	4.65E+02
Solid Waste	2.05E-01	6.66E+05	1.02E+06	1.03E+06

Table 14 – Annual Integrated Sciences Building emissions based on estimated energy consumption from model, proposed building, and baseline building.

In order to get a more accurate estimate of emissions for the electric provided to the Integrated Sciences Building, a look at local electric production facilities may be useful. The energy company serving the building is Pennsylvania Electric Company (PECO), now a unit of Exelon, a nationwide corporation which owns and operates electrical generation facilities. Upon researching Exelon facilities surrounding the greater Philadelphia region, it is clear that most of the electrical generation in the region is either nuclear or fossil fuel. Table 15, shown below, estimates the emissions generated by Exelon power facilities for different fuel sources. At a glance, it is clear that fossil fuel electricity produces more emissions that the combination of all sources due to the combination of nuclear sources into the "all sources" category. Naturally, the low pollution of nuclear helps the "all sources" category appear more environmentally friendly. Since the amount of nuclear facilities in the mid-Atlantic region of the United States, it is fair to assume that the emissions for the "all sources" category is a good estimate of emission rates for the Integrated Sciences Building.

Exelon Emission									
	All Sources			Fossil Fuels			Coal		
Pollutant	lbs/MWh	Modeled	Designed	lbs/MWh	Modeled	Designed	lbs/MWh	Modeled	Designed
SO_x	0.7	2.27E+03	3.49E+03	8.8	2.86E+04	4.39E+04	12	3.90E+04	5.98E+04
NO_x	0.2	6.50E+02	9.97E+02	2.5	8.12E+03	1.25E+04	3.2	1.04E+04	1.59E+04
CO_2	158.3	5.14E+05	7.89E+05	1977.7	6.43E+06	9.86E+06	2288.5	7.44E+06	1.14E+07
Hg	-	-	-	-	-	-	0.07	2.27E+02	3.49E+02

Table 15 – Exelon emission values for different power sources.

The use of natural gas at laboratory benches and fume hoods is not a predominant source of energy consumption for the Integrated Sciences Building, but it consumes energy nonetheless. In much the way electricity emissions can be approximated, so can emissions for on-site combustion. In Figure 3, emission factors for this type of combustion can be estimated based on thousand cubic feet (kcf) of natural gas. In one year, the building will consume an estimated 23,706 therms of natural gas, or 2303.8 kcf.

Since the laboratories do not burn natural gas in engines, or small turbines, we will use the residential furnace emission factors as an estimate for normal combustion. Table 16, below, gives an approximate yearly estimate of natural gas emissions for the Integrated Sciences Building.

Table 10 Emission Factors for On-Site Combustion in Other Equipment (lb of pollutant per unit of fuel)

Pollutant (lb)	Stationary Reciprocating Engine			Small Turbine		Residential Furnace *
	Natural Gas	Distillate Fuel Oil	Gasoline	Natural Gas	Distillate Fuel Oil	Natural Gas
	1000 ft^3 **	1000 gal	1000 gal	1000 ft^3 **	1000 gal	1000 ft^3 **
CO_{2e}	1.37E+02	2.27E+04	1.76E+04	1.25E+02	2.29E+04	1.21E+02
CO_2	1.16E+02	2.25E+04	1.72E+04	1.22E+02	2.28E+04	1.20E+02
CH_4	8.38E-01	1.20E+00	8.31E+00	5.26E-02	2.58E-01	2.30E-03
N_2O	3.41E-03	6.11E-01	5.51E-01	4.54E-03	6.11E-01	2.20E-03
NO_X	3.56E+00	4.76E+02	3.02E+02	3.51E-01	4.02E+01	9.40E-02
SO_X	6.32E-04	3.24E+01	4.18E+00	6.32E-04	3.24E+01	6.00E-04
CO	2.29E+00	1.26E+02	1.22E+03	1.75E-01	2.66E+00	4.00E-02
VOC	2.06E-03	1.22E+01	2.56E+01	2.06E-03	4.08E-01	5.50E-03
Lead	5.00E-07	ND †	ND †	5.00E-07	1.40E-08	5.00E-07
Mercury	2.60E-07	ND †	ND †	2.60E-07	1.20E-09	2.60E-07
PM10	1.66E-02	1.49E+01	2.40E+00	2.64E-02	5.19E+00	7.60E-03

* data from EPA's AP-42, volume 1, 5th edition, 1995 (EPA 2005b)
** Gas volume at 60°F and 14.70 psia.
† no data available

Figure 2 – Emission factors for on-site combustion

Annual Emissions for Natural Gas Consumption		
Pollutant	Eastern Interconnection	Modeled Building Pollution per Year [lb]
Natural Gas Use	Lb of pollutant/kcf	2,304 kcf
CO_{2e}	1.21E+02	2.79E+05
CO_2	1.20E+02	2.76E+05
CH_4	2.30E-03	5.30E+00
N_2O	2.20E-03	5.07E+00
NO_x	9.40E-03	2.17E+01
SO_x	6.00E-04	1.38E+00
CO	4.00E-02	9.22E+01
TNMOC	5.50E-03	1.27E+01
Lead	5.00E-07	1.15E-03
Mercury	2.60E-07	5.99E-04
PM10	7.60E-03	1.75E+01

Table 16 – ISB Natural gas emission estimate based on residential furnace rates.

Estimating the emission footprint of a building is not as simple for purchased district steam is not as simple as for electricity or natural gas because of the wide range of fuels, efficiencies, and methods or delivering the steam. The distance from steam plant to end-user could dictate the amount of thermal losses just as the insulation method or age of piping. For a rough estimation of emissions for purchased steam, the Energy Information Administration has published Figure 4, which gives emissions for different district heating and cooling mediums.

Table 2 Indirect Greenhouse Gas Emission Factors (District Energy)[7]	
Fuel Type	**kg CO_2e /MBtu**
District Steam	78.95
District Hot Water	78.95
District Chilled Water – Electric Driven Chiller	0.238095*eGRID Subregion Rate
District Chilled Water – Absorption Chiller using Natural Gas	66.50
District Chilled Water - Engine-Driven Chiller using Natural Gas	44.33

Figure 3 – Energy Information Administration estimate CO_{2e} emissions for district utilities.

Based on this table, a conversion from kg to lb produces an estimate of 175.04 lb CO_{2e}/Mbtu, Table 17, shows an estimate of CO_{2e} emissions for the Integrated Sciences Building for the modeled and proposed purchased steam consumption.

Annual Purchased Steam CO_{2e} Emission		
	Modeled Building	Proposed Building
lb CO_{2e}/Mbtu	3565.00 Mbtu	5132 Mbtu
174.05	620488.25 lb CO_{2e}	893224.6 lb CO_{2e}

Table 17 – ISB purchased district steam annual CO_{2e} emissions estimate.

The Integrated Sciences Building is project to use 25% less total energy annually than the LEED Baseline, ASHRAE 90.1-2004 equivalent building, according to the energy modeling engineer of record. Regardless of emissions or exact load calculations, there will be substantial energy savings as a result of a glycol heat recovery system for the laboratory air handler units. This is a simple system that will produce substantial savings. This, among other environmentally friendly choices during the design and construction of the building make it a very energy-responsible building.

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Torcellini, M. D. (June 2007). Source Energy and Emission Factors for Energy Use in Buildigns. Golden, Colorado: National Renewable Energy Laboratory.

Appendix A: ASHRAE Weather Data – Philadelphia, PA

2009 ASHRAE Handbook - Fundamentals (IP)

PHILADELPHIA INTERNATIONAL AP, PA, USA

WMO# 724080

Lat: 39.87N Long: 75.23W Elev: 30 StdP: 14.68 Time Zone: -5.00 (NAE) Period: 82-06 WBAN: 13739

Annual Heating and Humidification Design Conditions

Coldest Month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB	
			99.6%			99%			0.4%		1%			
	99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD
1	12.6	16.9	-4.4	4.3	16.3	-0.4	5.4	19.9	28.3	37.1	26.0	34.0	11.5	290

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

Hottest Month	Hottest Month DB Range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB	
		0.4%		1%		2%		0.4%		1%		2%			
		DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD
7	16.9	93.2	75.4	90.6	74.5	88.0	73.0	78.3	88.5	77.0	86.3	75.7	83.8	11.2	240

Dehumidification DP/MCDB and HR									Enthalpy/MCDB						Hours 8 to 4 & 55/69
0.4%			1%			2%			0.4%		1%		2%		
DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB	
75.4	133.4	82.5	74.3	128.2	81.4	73.1	123.3	80.3	41.7	89.1	40.3	86.0	39.1	83.9	720

Extreme Annual Design Conditions

Extreme Annual WS			Extreme Max WB	Extreme Annual DB				n-Year Return Period Values of Extreme DB							
				Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years	
1%	2.5%	5%		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
24.4	20.6	18.5	86.4	6.6	97.0	7.1	3.0	1.5	99.2	-2.7	101.0	-6.7	102.6	-11.9	104.8

Monthly Climatic Design Conditions

			Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperatures, Degree-Days and Degree-Hours	Tavg		55.9	33.2	36.0	43.5	53.8	63.8	73.0	78.0	76.5	69.0	57.6	47.9	37.9
	Sd			9.98	8.47	8.95	7.98	7.21	6.30	5.07	5.23	6.71	7.47	8.28	9.05
	HDD50		1750	526	396	242	46	0	0	0	0	0	16	137	387
	HDD65		4579	985	811	668	348	112	11	0	1	37	252	514	840
	CDD50		3921	5	5	41	160	428	689	867	821	569	251	73	12
	CDD65		1273	0	0	1	11	74	250	402	357	155	22	1	0
	CDH74		11035	0	0	22	130	707	2174	3829	3050	993	125	5	0
	CDH80		4040	0	0	3	40	230	791	1587	1118	256	15	0	0
Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures	0.4%	DB		63.9	64.9	77.0	85.7	91.0	94.4	97.5	96.0	90.5	82.1	73.0	65.6
		MCWB		58.7	54.1	62.2	66.7	71.7	74.8	77.8	76.4	73.7	69.0	63.4	60.1
	2%	DB		57.4	58.2	68.6	77.0	86.2	91.0	93.8	92.0	85.9	77.6	68.3	59.8
		MCWB		53.4	51.4	56.9	62.1	69.4	74.0	76.0	75.8	71.5	67.3	61.5	55.3
	5%	DB		51.1	53.4	63.0	72.1	81.8	87.8	91.0	88.8	82.8	73.6	64.7	55.1
		MCWB		46.2	46.8	53.9	59.4	67.5	72.2	75.2	73.9	70.3	64.6	58.8	50.4
	10%	DB		46.2	48.8	57.7	67.5	77.3	84.7	88.2	86.1	79.8	70.0	61.2	51.1
		MCWB		42.0	43.3	50.2	56.1	65.0	70.9	73.9	72.3	68.9	62.3	55.9	46.7
Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures	0.4%	WB		60.4	58.8	64.3	68.8	74.7	78.0	80.4	79.9	77.1	72.8	66.5	61.9
		MCDB		62.9	62.1	74.2	82.1	86.2	89.4	92.0	90.1	84.9	77.2	69.9	64.7
	2%	WB		54.0	52.6	59.5	65.0	71.8	76.2	78.6	78.1	75.1	69.8	63.6	56.6
		MCDB		56.6	56.5	65.5	73.9	82.4	86.3	89.3	87.6	81.3	74.7	67.0	59.5
	5%	WB		47.2	47.9	55.2	61.9	69.3	74.9	77.4	76.5	73.4	66.7	60.2	51.8
		MCDB		50.1	52.0	60.7	69.2	78.8	84.0	87.4	84.5	78.9	71.8	63.9	54.3
	10%	WB		42.9	44.1	51.0	58.4	66.8	73.3	76.1	75.2	71.7	63.9	56.8	47.1
		MCDB		45.8	48.2	57.2	65.5	75.4	81.3	84.7	82.1	77.0	68.6	60.4	50.2
Mean Daily Temperature Range		MDBR		13.8	15.1	17.1	18.7	18.7	18.0	16.9	16.3	16.6	17.1	15.9	13.7
	5% DB	MCDBR		20.3	21.6	25.7	25.2	24.7	21.6	19.7	18.7	18.6	20.9	20.0	19.2
		MCWBR		16.3	16.4	16.3	13.7	11.3	9.0	7.4	7.4	8.4	12.0	14.6	16.1
	5% WB	MCDBR		18.8	19.7	23.9	22.9	22.1	18.8	18.2	16.6	16.1	17.8	18.5	17.9
		MCWBR		17.1	16.7	17.3	14.6	11.8	9.0	7.6	7.6	9.3	11.8	15.8	17.2
Clear Sky Solar Irradiance	taub			0.322	0.357	0.419	0.421	0.482	0.552	0.550	0.552	0.417	0.374	0.352	0.319
	taud			2.357	2.166	1.965	2.021	1.865	1.734	1.776	1.750	2.178	2.266	2.292	2.443
	Ebn,noon			266	269	262	271	256	238	237	231	261	261	251	259
	Edh,noon			31	40	53	53	63	72	69	69	43	36	32	27

CDDn Cooling degree-days base n°F, °F-day
CDHn Cooling degree-hours base n°F, °F-hour
DB Dry bulb temperature, °F
DP Dew point temperature, °F
Ebn,noon } Clear sky beam normal and diffuse hori-
Edh,noon } zontal irradiances at solar noon, Btu/h/ft2
Elev Elevation, ft
Enth Enthalpy, Btu/lb
HDDn Heating degree-days base n°F, °F-day
Hours 8/4 & 55/69 Number of hours between 8 a.m. and 4 p.m with DB between 55 and 69 °F
HR Humidity ratio, grains of moisture per lb of dry air

Lat Latitude, °
Long Longitude, °
MCDB Mean coincident dry bulb temperature, °F
MCDBR Mean coincident dry bulb temp. range, °F
MCDP Mean coincident dew point temperature, °F
MCWB Mean coincident wet bulb temperature, °F
MCWBR Mean coincident wet bulb temp. range, °F
MCWS Mean coincident wind speed, mph
MDBR Mean dry bulb temp. range, °F
PCWD Prevailing coincident wind direction, °, 0 = North, 90 = East

Period Years used to calculate the design conditions
Sd Standard deviation of daily average temperature, °F
StdP Standard pressure at station elevation, psi
taub Clear sky optical depth for beam irradiance
taud Clear sky optical depth for diffuse irradiance
Tavg Average temperature, °F
Time Zone Hours ahead or behind UTC, and time zone code
WB Wet bulb temperature, °F
WBAN Weather Bureau Army Navy number
WMO# World Meteorological Organization number
WS Wind speed, mph