New Science & Technology Center
The Chestnut Hill Academy

Philadelphia, PA

Technical Report 2:
Building and Plant Energy Analysis Report

October 24, 2008

Prepared for:
Dr. James D. Freihaut, PhD
Department of Architectural Engineering
The Pennsylvania State University

Prepared by:
David Klug
5th year Architectural Engineering Student
Mechanical Option

Table of Contents

Executive Summary

Technical report 2 consists of a design load estimation of the New Science and Technology Center as well as a summary of the annual energy consumption and operating costs. These values were calculated using the Trace 700 simulation program.

The design load estimate of the building is best summarized by three values: the cooling load, supply air, and ventilation supply. These values are 208 ft^2/ton, 0.93 cfm/ft^2 and 0.54 cfm/ft^2. When compared with the design loads the calculated loads are slightly higher. This can be attributed to a more cautious building design in Trace as to prevent an underestimation of the loads created by the building. The loads created by the building are attributed to sensible and latent loads created by user occupancy, lighting loads, miscellaneous equipment loads (computers, lab equipment), and HVAC loads. Greater detail on the design load is provided further in the report.

Once the design load calculations were completed the annual energy consumption and operating costs could be calculated. After the input of utilization schedules and utility rates Trace 700 calculated the consumption rates and yearly costs. The overall energy usage of the building was calculated at 132,347 Btu/(ft^2-year). The overall electric usage was 392,308 kWh/year and the 405,030 kBtu/year for natural gas. The peak demand load of the chiller was 89.73 kW. The total operating cost was calculated at $24,589 per year. This breaks down into $0.352/$ft^2$ for cooling and $0.439/$ft^2$ for heating. The corresponding schedules and utility rates are provided further in the report.

The owner furnished photovoltaic panels and wind turbine were not included in the Trace analysis. By leaving these out of the simulation the energy consumption for the building will be calculated at a higher value . It turn this will lead to an inflated annual operating cost. As the PV panels and turbine are integrated into the building and optimized for energy efficiency the buildings annual energy consumption and operating costs will begin to decrease.

Building Summary

The New Science and Technology Center at the Chestnut Hill Academy is a two level building with a footprint area of 9,200 square feet and an aggregate area of 18,400 square feet on the two levels. The cost of construction is $9.6 million. The first and second levels are both occupied by classrooms and laboratories with the second level also containing a faculty office suite. The labs will be equipped to teach physics, biology, and chemistry classes, with a separate lab for robotics that will include a workshop area. The building will include a photovoltaic roof array and a wind turbine to harvest solar and wind energy. Both will be owner installed and operated. The adjacent parking lot and sidewalks will be paved with porous asphalt covering an uncompacted subgrade, providing better absorption back into the earth. It is the intent of the owner to achieve a LEED certified level once the construction of the building is completed in November of 2008.

Mechanical System Summary

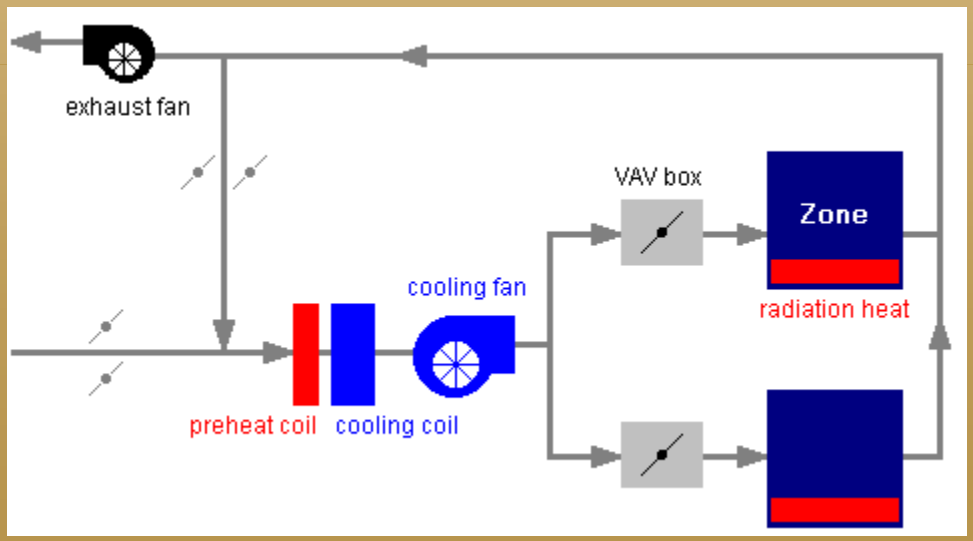
The New Science and Technology Center is planned to act as an addition to the already existing MEP infrastructure on campus. Power and water (domestic, heated, and fire suppression) will all be supplied from the central plant. A 480/277 V feeder will be run from the neighboring Inn building for the power supply. A 57.1 ton scroll chiller will be installed remotely for current use, with plans to upgrade to a 144.4 ton unit for use with future developments. The first and second levels will both be supplied by separate AHU's, AHU-1 and AHU-2, respectively. AHU-1 has a 6,300 CFM capacity and AHU-2 a 8,000 CFM capacity. Both are VAV units with an economizer and energy recovery in the form of a variable speed heat recovery wheel. The initial supply air setpoint from each AHU is 55^{o}F. Once the zones are satisfied, the setpoint will be gradually adjusted to reduce energy use from heating and cooling. The air is supplied to the different zones using a single duct VAV system. The system is run on a user defined schedule with both occupied and unoccupied modes. During the occupied mode, the cooling setpoint is 74^{o}F and the heating setpoint is 70^{o}F. During the unoccupied mode, the cooling setpoint is raised to 85^{o}F and the heating setpoint is dropped to 65^{o}F. The system is also equipped to monitor zone CO_2 levels and override the damper controls to maintain a level of 500 PPM. Several exhaust fans are located in the labs to provide extra ventilation, if needed.

Design Loads

Trace 700 was used to model the New Science and Technology Center's annual energy consumption. A model was created using the drawings and specifications provided by Turner Construction with the approval of the school. All floors, walls, windows, and partitions were designed as accurately as possible. The building and spaces were modeled to face the proper direction, with ASHREA Standard 62.1-2004 providing the requirements for the outdoor air supply. The internal lighting loads were calculated from the drawings, while the miscellaneous loads were estimated from the design documents. Tables showing the space breakdown for airflows and load schedules are provided in the appendix.

The HVAC system used in the Trace simulation consisted of a VAV system with baseboard heating. A variable speed heat recovery wheel and an enthalpy enabled economizer were both included in the design. A simplified schematic of the HVAC system is provided below. For information on the specifications and operating procedures refer to the first Technical Report. The design supply air temperature was 55°F at maximum and 50°F at minimum. The entering and leaving hot water temperatures for the baseboard heating were 180°F and 160°F, respectively. The location of the New Science and Technology Center is Philadelphia, PA. The corresponding heating and cooling design temperatures were provided by ASHREA Handbook of Fundamentals. The heating temperature was 11°F, and the cooling dry-bulb and wet-bulb were 89°F and 74°F, respectively.

Simplified HVAC Schematic



Design Loads

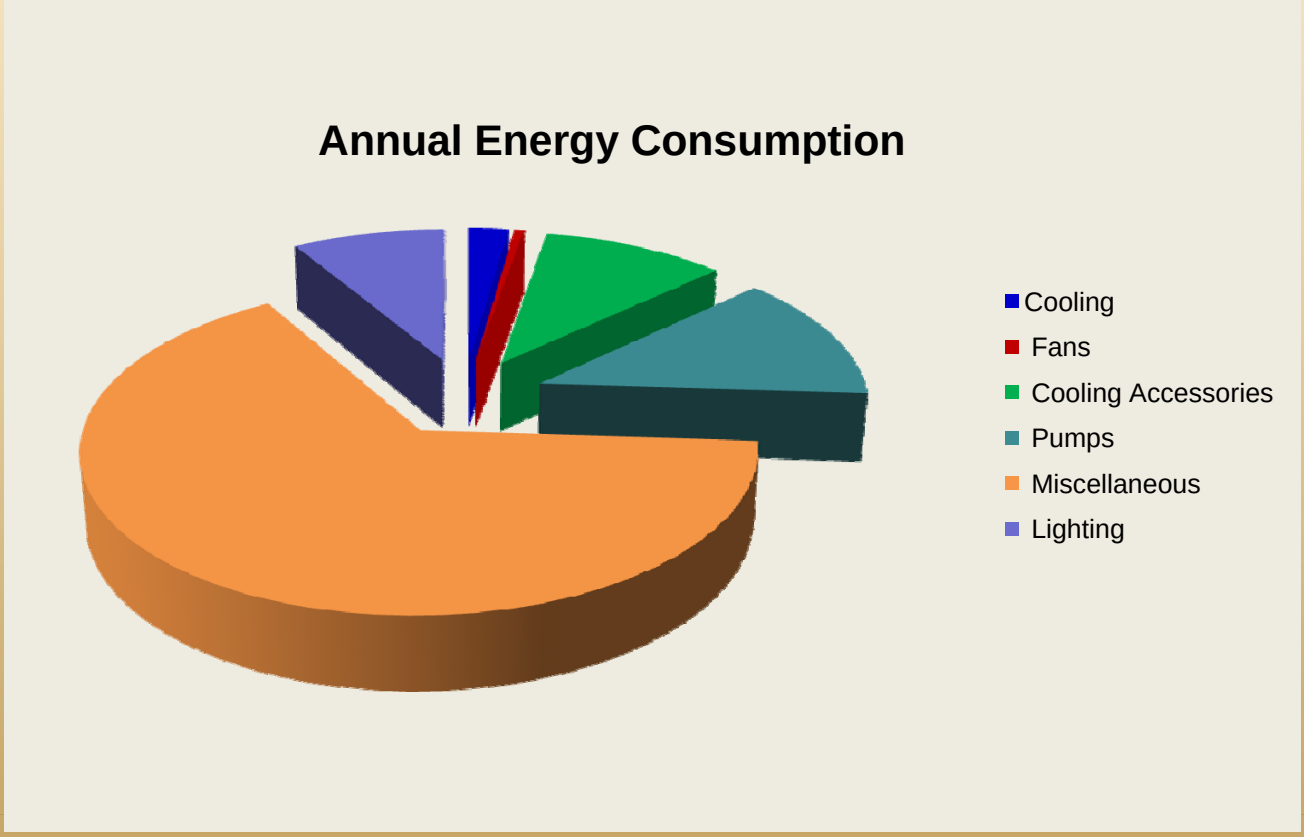
Computed VS Design Loads

	Cooling Load (ft^2/ton)	Supply Air (cfm/ton)	Ventilation Supply
Computed	208	0.93	0.54
Design	230	0.72	0.36

The above table summarizes the computed loads from Trace and the design loads from design documents. The computed loads from the simulation run by Trace are slightly larger than the design loads, as evident from the previous table. The program calculated a greater cooling load and supplied more cfm of supply air to the space. A possible reason for this is because of the schedules used in the model. Longer hours of space occupancy and equipment operation can account for higher cooling loads. The thermostat schedule that was used for heating and cooling (provided in the appendix) used a simple version of the design change in space temperature setpoints, as described in the mechanical systems overview (increased cooling setpoint and decreased heating setpoint during unoccupied times). A more thorough schedule could further reduce the computed cooling loads for the building. The insulation of the exterior walls, including the glass curtain wall and windows, could have been underestimated as well, which would have resulted in higher loads. Some of the materials specified in the design documents were not available as choices in the Trace simulation. In these situations the walls and floors were constructed using the closest approximations available.

Annual Energy Consumption and Operating Costs

The simulation run by Trace was also used to calculate the annual energy consumption and operating costs of the New Science and Technology Center. The total electric consumption was calculated at 392,308 kWh per year. The charts below shows the breakdown of various systems. The heating consumption was calculated at 405,030 kBtu per year as well.

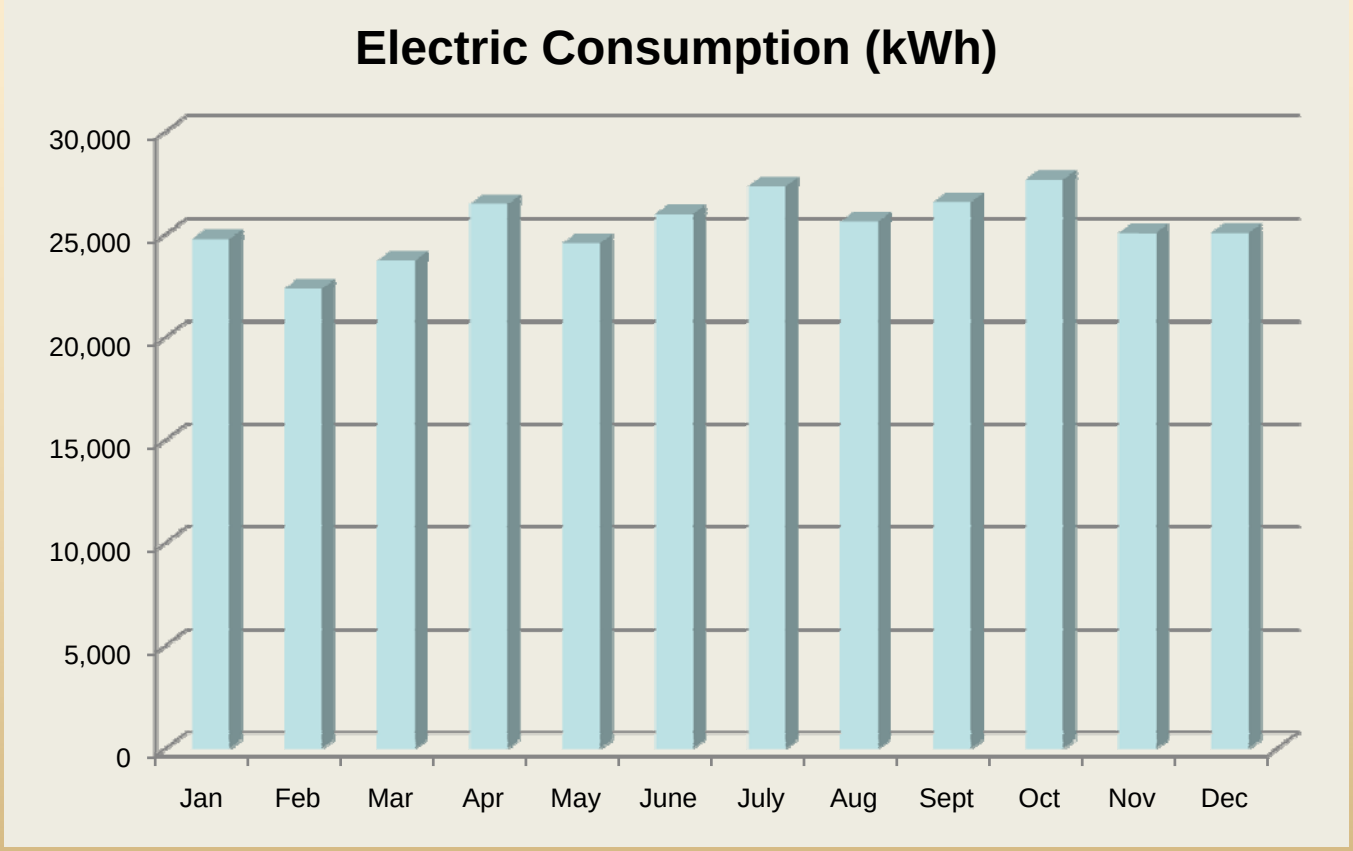


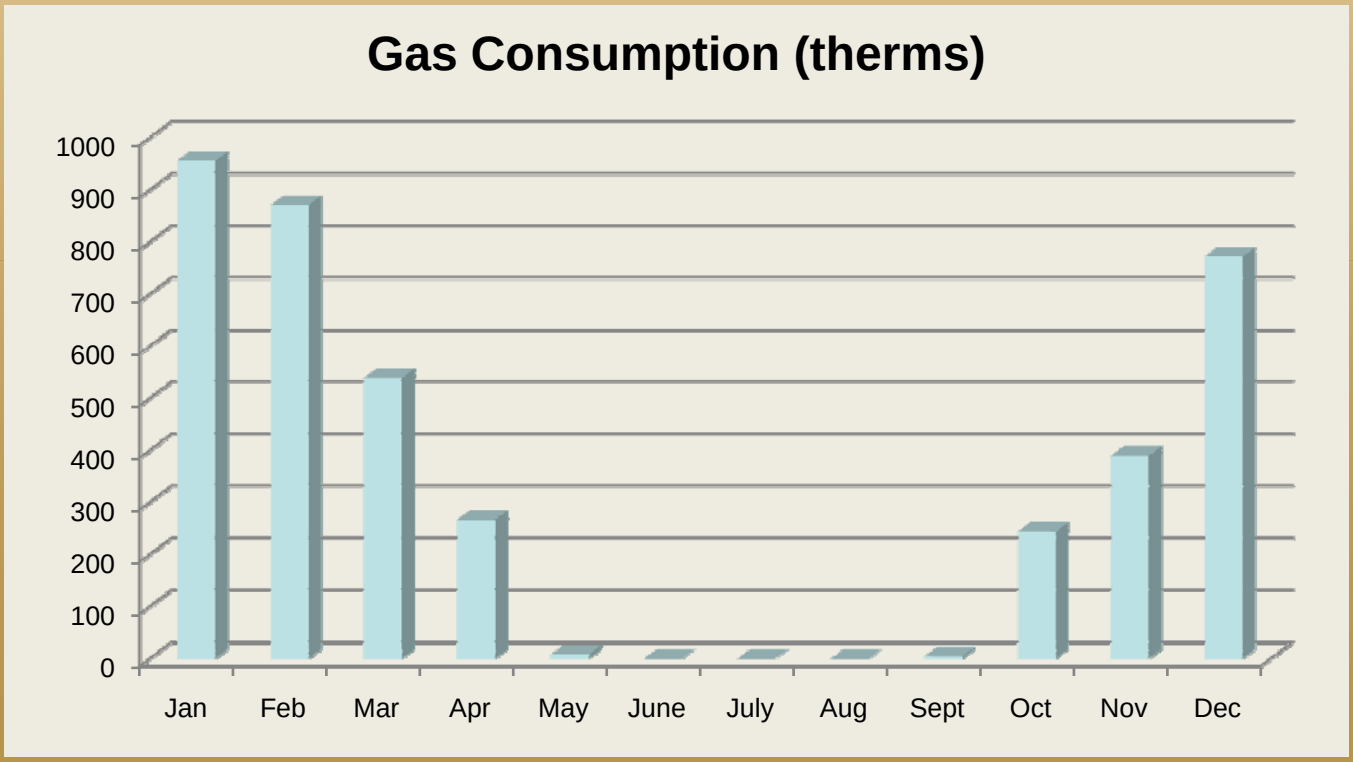
System Breakdown

Cooling	8,777 kWh	**Pumps**	50,786 kWh
Fans	2,035 kWh	**Miscellaneous**	256,666 kWh
Accessories	40,433 kWh	**Lighting**	33,610 kWh

The miscellaneous loads include various lab equipment, including fridges, dishwashers, and the numerous extractor arms. The cooling and heating loads combine to make up the majority of the annual energy consumption. The total energy consumption given by the simulation was 132,347 Btu/(ft^2-year). The charts on the following page shows the monthly breakdown of energy consumption for electricity and gas.

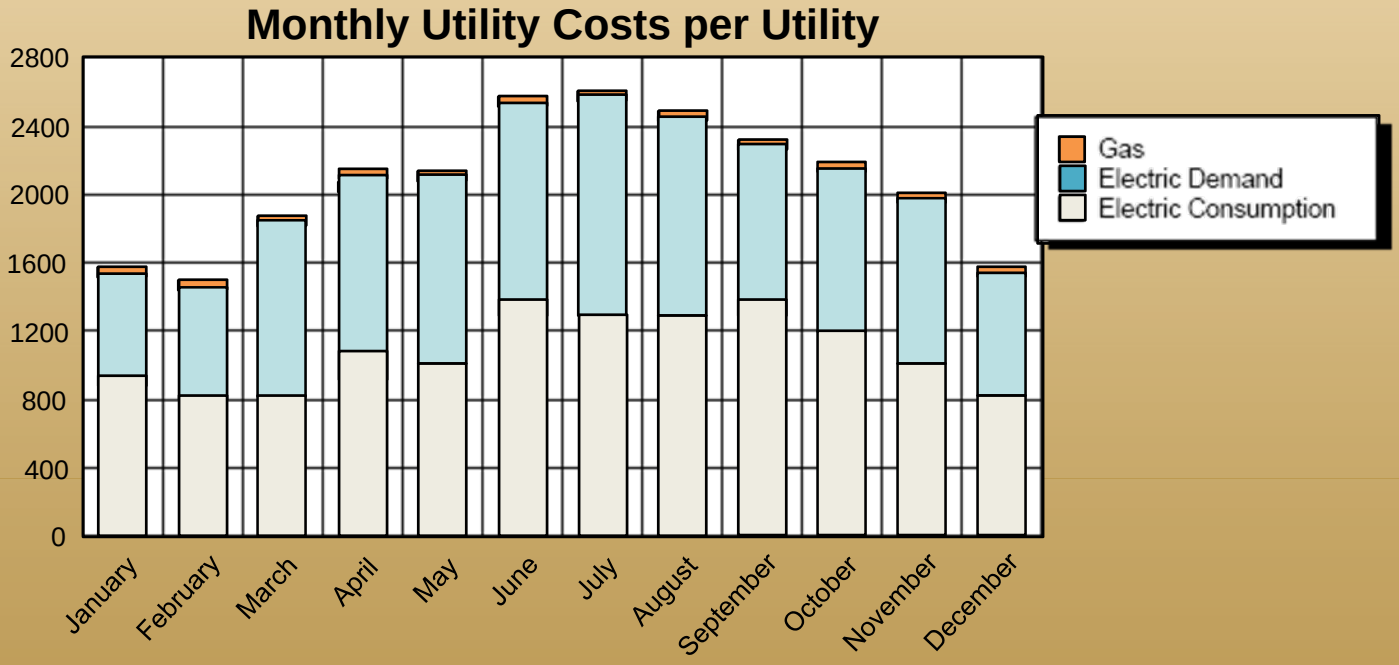
Annual Energy Consumption and Operating Costs





Annual Energy Consumption and Operating Costs

The electric consumption is fairly constant throughout the year. For a school, the electric consumption would normally be expected to decrease during the summer because of the summer holiday. The reason why this is not the case is because of the schedule used for the Trace simulation. During the colder months when less cooling is needed (the majority of the school year), the miscellaneous and lighting loads are at their peaks. During the warmest months (during the summer holiday), the miscellaneous and lighting loads are at a minimum as the space is used less. However, the cooling loads are still at their peaks to keep the space properly conditioned to protect the space from damage due to moisture or overheating. After a full year cycle of building occupancy, a more accurate schedule of occupancy and equipment use could be used to minimize energy usage on a monthly basis.



The chart above shows the monthly breakdown of utility costs for the building. As expected, the gas costs are very minimal compared to the electric consumption and demand. If we compare the electric consumption with the chart on the previous page we can see it varies accordingly. The chart on the following page shows the local utility rates that were used in calculating the utility costs.

Annual Energy Consumption and Operating Costs

Utility Rates

Electricity	
On-Peak Consumption	0.0753 $/kWh
Off-Peak Consumption	0.0202 $/kWh
On-Peak Demand	11.88 $/kW
Off-Peak Demand	6.534 $/kW
Gas	
Rate and Distribution	0.3213 $/therm

For the simulation a time of day schedule was used to determine peak times. The Philadelphia Electric Company, PECO, is the supplier for electricity and the Philadelphia Gas Works is the gas supplier. Water costs were not included in the simulation as the entire campus is supplied as a whole. The New Science and Technology Center was connected to the already existing campus infrastructure and was not set up to separately monitor the water consumption, thus an individual cost for water could not be calculated. The total annual operating cost was $24,589. This can also be broken down into $0.382/ft^2 for cooling and $0.439/ft^2 for heating.

Environmental Impact Analysis

CO_2	1,606,763 lbm/year
SO_2	12,388 gm/year
NO_x	3,529 gm/year

The above table shows the emission produced by the new Science and Technology Center on a per year basis. This table includes emission directly created by the building and what was created by utility suppliers. These rates are based on the loads calculated by the Trace simulation

References

•ANSI/ASHRAE Standard 62.1-2007. Ventilation for Acceptable Indoor Air Quality. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA.

•ANSI/ASHRAE/IESNA Standard 90.1-2007. Energy Standard for Buildings Except Low-Rise Residential Buildings. American Society of Heating, Refrigerating and Air-Conditioning Engineers. Atlanta, GA.

•Chestnut Hill Academy New Science & Technology Center Construction Documents. Lilley Dadagian Architects. Lexington, MA

•Electric Service Tariff. Electric Service Tariff. PECO Energy Company. Philadelphia, PA.

•Gas Service Tariff. Gas Service Tariff. Philadelphia Gas Works. Philadelphia, PA.

•Trace 700 Analysis Program. Trane. http://www.trane.com/Commercial/Dna/View.aspx?i=1136

Appendix

Thermostat Schedule

Cooling	**Weekday**	12am-7am	85°F
		7am-6pm	74°F
		6pm-12am	85°F
	Weekend	12am-12am	85°F
Heating	**Weekend**	12am-7am	65°F
		7am-6pm	70°F
		6pm-12am	65°F
	Weekend	12am-12am	65°F

Utilization Schedules

Lights		% Occupancy
Weekday Sept-May	12am-6am	0
	6am-7am	10
	7am-8am	50
	8am-11am	100
	11am-12pm	80
	12pm-1pm	20
	1pm-3pm	100
	3pm-5pm	30
	5pm-12am	0
Weekday June-Aug	12am-7am	0
	7am-8am	10
	8am-3pm	30
	3pm-5pm	10
	5pm-12am	0
Weekend	12am-12pm	10

People		% Occupancy
Weekday Sept-May	12am-6am	0
	6am-7am	50
	7am-8am	100
	8am-11am	80
	11am-12pm	20
	12pm-1pm	100
	1pm-3pm	30
	3pm-5pm	0
	5pm-12am	0
Weekday June-Aug	12am-7am	0
	7am-8am	10
	8am-3pm	30
	3pm-5pm	10
	5pm-12am	0
Weekend	12am-12pm	0

Appendix

Trace Load and Airflow Summary

		Loads			Airflows				
Space	Floor Area (ft^2)	# People	Lighting (W/ft^2)	Misc (W/ft2)	People (cfm/person)	Area (cfm/ft^2)	VAV min (cfm)	Max SA (cfm)	ASHRAE std 62.1 OA fraction
3-5 Classroom	618	20	1.59	0	10	0.12	420	904	0.6528
Bio Prep	127	3	2.21	0	10	0.18	350	206	0.5034
Biology Lab	1,092	22	1.54	0.78	10	0.18	620	1,118	0.6719
Chem/Bio Lab	1,070	21	1.57	0.8	10	0.18	525	925	0.7669
Chem/Physics Lab	1,058	21	1.62	0.65	10	0.18	500	902	0.8009
Chem/Physics/Bio Prep	305	3	1.61	7.98	5	0.06	250	641	0.1334
Commons	184	12	1.53	0	5	0.06	70	180	1.0000
Conference Room	170	13	1.65	0	5	0.06	150	383	0.5014
Corridor 1st Floor	1,055	0	0.94	0	0	0.06	450	407	0.4688
Corridor 2nd Floor	1,055	0	0.74	0	0	0.06	200	882	1.0000
Faculty WC	91	1	0.66	0	0	0	0	58	0.0000
Unisex WC	64	0	0.66	0	0	0	0	48	0.0000
Ind Lab (2nd Floor)	170	3	1.65	1	10	0.18	100	176	0.6060
Ind Physics Lab (1st Floor)	113	2	1.24	0	5	0.06	70	74	0.2397
K-2 Classroom	588	12	1.55	0	10	0.12	250	671	0.7622
Lobby	1,290	20	0.73	0	5	0.06	440	2,396	1.0000
Men's WC	132	2	1.21	0	0	0	0	67	0.0000
Women's WC	166	2	0.97	0	0	0	0	72	0.0000
Office Suite	545	5	1.77	0.54	5	0.06	480	582	0.1202
Physics Lab	1,034	21	1.62	0.45	10	0.18	600	779	0.6602
Physics Prep	210	2	1.34	0	5	0.06	130	159	0.1738
Prep Room (108b)	107	1	2.62	9.35	5	0.06	80	245	0.1428
Robotics/Workshop	1,355	27	1.17	1.3	10	0.18	700	902	0.7341
Stairwell A	345	5	1.85	0	0	0	0	502	0.0000
Stairwell B	231	5	1.17	0	0	0	0	720	0.0000

Monthly Energy Consumption and Environmental Impact Analysis

------- Monthly Energy Consumption -------

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternative: 1	Technical Report 2												
Electric													
On-Pk Cons. (kWh)	6,460	5,845	7,075	9,569	10,972	14,224	12,668	13,540	13,794	11,302	8,614	6,153	120,216
Off-Pk Cons. (kWh)	18,336	16,542	16,664	16,922	13,612	11,784	14,674	12,100	12,789	16,391	16,463	18,931	185,209
Mid-Pk Cons. (kWh)	7,382	6,679	8,085	7,118	9,744	6,557	6,114	6,580	6,291	7,833	7,472	7,030	86,883
On-Pk Demand (kW)	58	58	92	93	96	125	137	121	96	93	92	58	137
Off-Pk Demand (kW)	42	42	42	42	35	38	40	36	35	42	42	42	42
Mid-Pk Demand (kW)	58	58	58	92	93	89	98	85	93	92	92	58	98
Gas													
On-Pk Cons. (therms)	269	238	174	71	5	0	0	0	3	78	125	202	1,164
Off-Pk Cons. (therms)	697	633	365	196	3	0	0	0	1	166	265	570	2,896
On-Pk Demand (therms/hr)	3	3	2	2	0	0	0	0	0	2	2	3	3
Off-Pk Demand (therms/hr)	4	4	4	3	1	0	0	0	0	3	4	4	4

Energy Consumption		Environmental Impact Analysis	
Building	132,347 Btu/(ft2-year)	CO2	1,606,753 lbm/year
Source	337,215 Btu/(ft2-year)	SO2	12,388 gm/year
		NOX	3,529 gm/year
Floor Area	13,177 ft2		

Appendix

Peak Cooling Loads by Space and Coil

				SPACE								COIL						
					OA Condition		Room	Supply	Space	Space	Space		OA Condition				Coil	Coil
			Floor	Peak			Dry	Dry	Air	Sensible	Latent	Peak			Supply	Coil	Sensible	Latent
			Area	Time	DB	WB	Bulb	Bulb	Flow	Load	Load	Time	DB	WB	Dry Bulb	Airflow	Load	Load
System	Zone	Room	ft²	Mo/Hr	°F	°F	°F	°F	cfm	Btu/h	Btu/h	Mo/Hr	°F	°F	°F	cfm	Btu/h	Btu/h
Alternative 1																		
	3-5 Classroom	Peak	618	9/14	81	65	74.0	55.0	904	19,158	4,000	7 /15	89	74	55.0	787	24,670	24,023
	Bio Prep	Peak	127	7/17	87	72	74.0	55.0	206	4,369	225	7 /15	89	74	55.0	206	6,303	5,317
	Biology Lab	Peak	1,092	9/15	81	65	74.0	55.0	1,118	23,687	5,500	7 /15	89	74	55.0	1,069	32,813	30,257
	Chem/Bio Lab	Peak	1,070	7/15	89	74	74.0	55.0	925	19,590	5,250	7 /15	89	74	55.0	925	27,848	25,724
	Chem/Physics Lab	Peak	1,058	7/11	82	71	74.0	55.0	902	19,114	5,250	7 /14	89	74	55.0	845	25,850	25,145
	Chem/Physics/Bio Prep	Peak	306	7/15	89	74	74.0	55.0	641	13,576	600	7 /15	89	74	55.0	641	19,363	14,789
	Commons	Peak	184	7/15	89	74	74.0	55.0	180	3,820	2,400	7 /15	89	74	55.0	180	5,409	6,392
	Conference Room	Peak	170	9/15	81	65	74.0	55.0	383	8,117	2,015	7 /15	89	74	55.0	339	10,537	10,498
	Corridor 1st floor	Peak	1,055	7/17	87	72	74.0	55.0	407	8,615	1,029	7 /15	89	74	55.0	407	13,519	10,707
	Corridor 2nd floor	Peak	1,055	7/17	87	72	74.0	55.0	882	18,678	1,029	7 /15	89	74	55.0	781	25,373	21,740
	Faculty WC	Peak	91	7/17	87	72	74.0	55.0	58	1,231	159	7 /15	89	74	55.0	49	1,768	1,641
	Ind Lab (2nd Floor)	Peak	170	7/15	89	74	74.0	55.0	176	3,719	600	7 /15	89	74	55.0	176	5,269	4,487
	Independant Physics Lab (1st Floor)	Peak	113	7/14	89	74	74.0	55.0	74	1,578	400	7 /14	89	74	55.0	74	2,207	2,042
	K-2 Classroom	Peak	588	11/11	55	46	74.0	55.0	671	14,215	2,400	7 /14	89	74	55.0	518	16,540	17,195
	Lobby	Peak	1,290	7/18	85	71	74.0	55.0	2,396	50,758	2,400	7 /15	89	74	55.0	1,538	58,376	55,450
	Mens WC 1st floor	Peak	132	7/15	89	74	74.0	55.0	67	1,421	453	7 /14	89	74	55.0	67	2,709	1,930
	Office Suite	Peak	545	9/15	81	65	74.0	55.0	582	12,323	1,000	7 /15	89	74	55.0	546	16,742	13,879
	Physics Lab	Peak	1,034	7/14	89	74	74.0	55.0	779	16,513	5,250	7 /14	89	74	55.0	779	23,449	22,437
	Physics Prep	Peak	210	7/15	89	74	74.0	55.0	159	3,378	500	7 /15	89	74	55.0	159	4,816	4,030
	Prep room (108b)	Peak	107	7/14	89	74	74.0	55.0	245	5,187	200	7 /14	89	74	55.0	245	7,315	5,599
	Robotics/workshop	Peak	1,355	7/14	89	74	74.0	55.0	902	19,115	6,750	7 /14	89	74	55.0	902	26,914	26,645
	Stairwell A	Peak	345	8/15	86	70	74.0	55.0	502	10,646	1,885	7 /14	89	74	55.0	493	15,217	14,064
	Stairwell B	Peak	231	7/19	83	70	74.0	55.0	720	15,257	559	7 /15	89	74	55.0	496	16,884	18,526
	Unisex WC	Peak	64	7/17	87	72	74.0	55.0	48	1,018	309	7 /15	89	74	55.0	42	1,517	1,387
	Womens WC 1st floor	Peak	166	7/15	89	74	74.0	55.0	72	1,525	590	7 /14	89	74	55.0	72	2,885	2,176
HVAC System		Peak	13,177		89	74	74.0	66.0	13,999	296,607	50,753		89	74	55.0	12,336	398,842	388,081
HVAC System		Block	13,177	7/15	89	74	74.0	66.0	12,234	259,193	53,749	7 /16	89	74	55.0	12,291	396,386	388,474

System Temperature Profiles

	Unmet					--- Number of Hours at each Temp Range (°F) ---																Unmet
	Clg Load	---- Maximum----															---- Minimum----				Htg Load
Room Description	Hours	Temp	Mo	Hr	Day	>100°	100-96	96-90	90-85	86-80	80-76	75-70	70-65	65-60	60-55	55-50	< 50°	Temp	Mo	Hr	Day	Hours
3-5 Classroom	0	85	4	15	7	0	0	0	0	1,295	2,499	2,172	1,272	1,522	0	0	0	63	2	8	10	0
K-2 Classroom	0	85	4	14	7	0	0	0	0	1,288	3,423	2,262	1,452	335	0	0	0	64	1	6	10	0
Robotics/workshop	0	91	9	11	10	0	0	17	224	917	2,633	1,869	1,637	1,463	0	0	0	65	1	3	1	0
Physics Lab	0	78	7	23	8	0	0	0	0	0	1,884	5,957	919	0	0	0	0	65	1	7	2	0
Physics Prep	0	78	7	7	2	0	0	0	0	0	1,309	5,860	1,591	0	0	0	0	65	1	7	2	0
Independant Physics Lab (1st Floor)	0	78	7	5	2	0	0	0	0	0	1,246	7,148	366	0	0	0	0	68	1	6	2	0
Prep room (108b)	0	85	1	12	7	0	0	0	0	5,663	3,097	0	0	0	0	0	0	70	1	1	1	0
Womens WC 1st floor	0	78	7	6	2	0	0	0	0	0	1,631	6,864	265	0	0	0	0	68	2	7	2	0
Mens WC 1st floor	0	77	7	7	2	0	0	0	0	0	850	7,735	175	0	0	0	0	69	1	7	2	0
Commons	0	76	9	15	2	0	0	0	0	0	2,017	6,743	0	0	0	0	0	69	1	2	1	0
Lobby	0	85	6	19	8	0	0	0	0	622	2,385	2,178	2,693	882	0	0	0	64	1	24	7	0
Corridor 1st floor	0	79	7	21	8	0	0	0	0	0	1,749	5,629	1,382	0	0	0	0	65	2	7	2	0
Conference Room	0	79	7	21	8	0	0	0	0	0	2,382	3,244	1,520	1,614	0	0	0	65	1	5	1	0
Faculty WC	0	77	7	24	1	0	0	0	0	0	455	2,308	3,318	2,679	0	0	0	65	1	4	1	0
Unisex WC	0	77	7	24	1	0	0	0	0	0	455	2,446	3,121	2,738	0	0	0	65	1	3	1	0
Chem/Physics Lab	0	79	7	23	8	0	0	0	0	0	1,134	3,848	2,244	1,534	0	0	0	65	1	5	10	0
Chem/Physics/Bio Prep	0	85	5	9	7	0	0	0	0	2,797	3,254	2,210	499	0	0	0	0	67	2	13	8	0
Ind Lab (2nd Floor)	0	79	7	24	8	0	0	0	0	0	1,179	2,132	2,906	2,543	0	0	0	65	1	4	1	0
Chem/Bio Lab	0	78	7	22	8	0	0	0	0	0	583	3,678	2,351	2,148	0	0	0	64	12	6	1	0
Biology Lab	0	80	7	22	8	0	0	0	0	34	1,248	4,066	1,890	1,522	0	0	0	64	12	7	7	0
Bio Prep	0	78	7	1	10	0	0	0	0	0	1,043	2,332	3,207	2,178	0	0	0	65	1	5	1	0
Corridor 2nd floor	0	78	7	21	8	0	0	0	0	0	697	2,260	3,092	2,711	0	0	0	65	1	3	1	0
Office Suite	0	78	7	22	8	0	0	0	0	0	1,508	2,597	2,623	2,032	0	0	0	65	1	5	1	0
Stairwell B	0	85	6	20	8	0	0	0	0	843	2,893	2,072	2,155	797	0	0	0	65	1	9	7	0
Stairwell A	0	83	7	22	8	0	0	0	0	323	2,540	4,288	1,311	298	0	0	0	65	1	3	8	0

The above chart shows the space temperature profiles throughout the year. It is clear from the chart that all of the space were maintained within the desired temperature range throughout the simulation. This solidifies that the system is properly conditioning the space.