New Science & Technology Center

The Chestnut Hill Academy

Philadelphia, PA

Senior Thesis Final Report

April 7, 2007

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

New Science & Technology Center

Chestnut Hill Academy

Philadelphia, PA

David Klug - Mechanical

Project Information

Size: 26, 870 SF

Cost: $9.6 Million

Construction: Nov 07 to Nov 08

Delivery Method: CM at Risk

Project Team

Associate Architect : Krieger & Associates

Architect of Record: Lilley Dadagian Architects

Contractor: Turner Construction

Lab Designers: Jacob Consultancy

"Green" Design Consultant: M2 Architecture

Engineers

- **-Structural:** Room & Guarrancino
- **-Mechanical / Electrical /Plumbing:** Bruce E. Brooks & Associates
- **-Civil &Landscape:** Cairone & Kaupp

Architecture

Design

-Stone/stucco façade

-Glass enclosed lobby

-Asphalt shingle roof over building

-Galvalum roofing over lobby

Function

-Classrooms and physics / biology / chemistry labs for K-12 students

MEP

Chiller

-air cooled scroll

-57.1 ton

AHU

-6300 cfm for classrooms

-8000 cfm for labs

-VAV with heat recovery wheel

Specialties

-grey water system, porous pavement in parking lot and sidewalks

Lighting/Electrical

MDP

-480/277 V, 3ϕ, 4w

Feeder

-480v from nearby Inn Building

Emergency Switchboard

-480/277v

Lighting

-Labs & Classroom: Pendant direct/indirect

-Lobby: Fluorescent downlights

-Corridors: Recessed direct/indirect

Specialties

-photovoltaic cells, wind turbine, daylight harvesting

Structural

Floors

-metal deck/concrete

-slab on grade

Frame

-steel braced

Exterior Walls

-metal studs, ext. sheathing, air/vapor barrier, rigid insulation, stone and stucco veneer

Table of Contents

Executive Summary

The following report serves to provide an alternative design proposal for the New Science and Technology Center at the Chestnut Hill Academy. The alternative design includes three parts: an acoustical study, a daylight study, and the main HVAC design which consisted of switching the VAV system to a dedicated outdoor air system with active chilled beams. An ice thermal storage system was also included to help recover part of the electric costs.

The acoustical and daylight studies both served to evaluated the building outside of it's HVAC performance. The acoustic breadth focused on the reverberation time of the classrooms and corridors, but included sound transmission ratings as well. The results showed that each of the spaces met the target reverberation time range of 0.4 - 0.6 seconds at almost all frequencies. Each exterior and interior wall type, with one exception, met the recommended STC rating as well.

The daylight breadth served two purposes. The first was to justify the cost of including a daylight harvesting system in the original design. The second was to try and either improve the current design in order to maximize the daylight potential. The results showed that a daylight harvesting system was justified. Several attempts, such as new glazing layouts and building re-orientation, were compared to the original design to see if the interior daylight levels could be increased. Of all the trials, the original design proved to provide the best conditions for daylight harvesting.

The main HVAC alternative, as stated above, included both ACB and TES. Each space was supplied with dehumidified air which was conditioned and mixed locally. Simulations showed a significant increase in energy use, as expecting with a DOA system. In an attempt to decrease the resulting increase in annual operating costs an ice storage system was included. The ice storage system was intended to create ice using electricity during off-peak hours and then supplying cold water to the chiller during the on-peak hours. While the system did lower the operating costs, it was not significant enough to justify the alternative design. The alternative design saved roughly 4% in capital costs, while the annual operating costs were 27% higher than the original design. In comparison the original design for the Science & Technology Center's HVAC system is the better choice.

Two parts of the re-design were included as part of the MAE requirement; the daylight study and the thermal storage system.

Acknowledgements

Through the course of the last two semesters many people have helped to make this report possible. First, I would like to thank the Chestnut Hill Academy for allowing me to use their building for my work and Turner for providing all of the necessary drawings, specifications, and contact information. I would like to thank Doug Belling at Turner for helping me to get started. I would also like to thank Ryan Fitzpatrick and Matt Ronca at Bruce E. Brooks & Associates for their help with the mechanical and electrical systems.

I would like to thank all of the AE faculty and staff who have helped me over the last five years. Without their help I would not have been able to make it to where I am today. In particular I would like to thank my faculty advisor, Proffessor Freihaut, for helping me through senior thesis.

I would also like to thank all of my classmates who helped me not only on my thesis but through our classes as well. I want to thank my parents for providing me with the opportunity to explore the areas that interested me in school, and for helping me whenever I needed it. Lastly I would like to thank my friends outside of the AE department for providing the necessary release for the stress which we all know comes with the program.

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. Floor plans are attached in Appendix D with the mechanical plans.

Existing 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 140 ton scroll chiller will be installed remotely for current use. The system was sized for 57.1 tons but the chiller was upgraded in order to handle future expansion. 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 55ºF. 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 74ºF and the heating setpoint is 70ºF. During the unoccupied mode, the cooling setpoint is raised to 85ºF and the heating setpoint is dropped to 65ºF. 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.

Original Design Objectives

The design of the mechanical system for the New Science and Technology Center included several specific objectives. The first was the control sequence of the various exhaust fans. There are three types of exhausts installed in the building: teacher fumehoods, student fumehoods, and snorkel exhausts. The teacher fumehoods are in continuous operation, while the student fumehood only operates when called for by the teacher. The snorkel exhaust is a local exhaust located at every student workstation in the labs.

One problem with the exhausts was with the student fumehood and snorkel exhausts. If both were activated at the same time, the makeup air would be significantly larger, causing an increase in zone loads. That would require a larger size AHU unit, which would lead to an overall increase in the project cost. The solution lay in the sequencing. The system controls were developed to only allow either the student fumehood or the snorkel exhaust to run, but not both at the same time.

One specific design objective was the inclusion of energy recovery wheels in each AHU. These wheels allow for either pre-heating or pre-cooling of air, thus lower the energy required to condition each zone.

The most interesting objective was the use of a two-pipe dual temperature system as opposed to a more traditional four-pipe system. Though the transition period between seasons can be uncomfortable with this system, the school agreed in order to further lower their energy consumption.

The last design objective was the minimum goal of LEED certification. In order to help achieve a rating level, the school installed two sources of alternate energy; two groups of photovoltaic cells and a wind turbine. The PV panels are also used to create hot water. The adjacent parking lot and pathways were also paved with porous pavement in order to lower the percent of impervious covering on the site.

Original Design Conditions

The design conditions for the New Science and Technology Building were broken into four categories: indoor and outdoor design conditions, ventilation requirements, heating and cooling loads, and annual energy usage.

Indoor and Outdoor Design Conditions

The indoor design conditions were fairly simple; there was a cooling setpoint of 74ºF and a heating setpoint of 70ºF during the occupied hours of operation. When the space is un-occupied, the setpoints were adjusted to 85ºF and 65ºF, respectively, to lower the cooling and heating loads. The relative humidity was 47%. The design cooling load occurred on August 14 when the outdoor air was at 91.5ºF dry bulb and 74.9ºF wet bulb. The outdoor air for the design heating load was 47.4ºF dry bulb for AHU-1 and 21.9ºF for AHU-2.

Ventilation requirements

The ventilation requirements, heating and cooling loads, and annual energy use for the building have been previously calculated in the first and second technical reports. The calculated ventilation rates for AHU-1 and AHU-2 were 1,955 and 2,801 CFM, respectively. The design rates were 2,257 and 2,239 CFM, respectively. The supply and return fans for each AHU were sized for standard flows of 6,305 and 7,947 CFM. In comparison, the design rates for ventilation are slightly higher than the calculated rates. This resulted from the more conservative use of required OA CFM/person in the design.

Heating and Cooling Loads

HAP was used to calculate the design heating and cooling loads for the New Science and Technology Center. The table on the following page shows the cooling and heating load breakdown for each AHU.

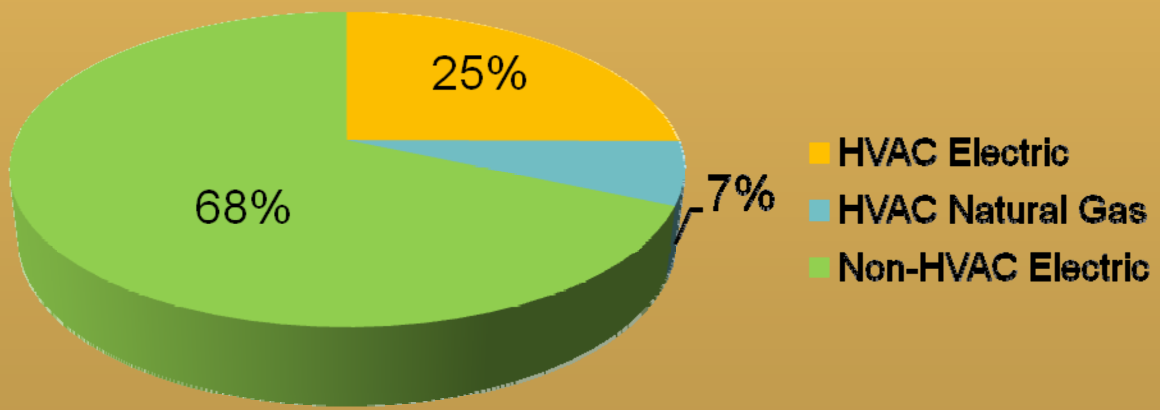
Original Design Conditions

	Cooling (BTU/hr)		Heating (BTU/hr)	
	Total Sensible	Latent	Total Sensible	Latent
AHU-1	168,763	119,447	147,731	-
AHU-2	170,926	123,514	179,380	59,559

These values represent all of the building loads, including the building envelope, people, lights, and HVAC equipment among others.

Annual Energy Use

HAP was also used to calculate the design annual energy usage and operating costs for the building. The following charts show the energy breakdown between systems and the annual operating costs.



Original Design Conditions

Component	Site Energy		Source Energy	
	(kBTU)	(kBTU/ft^2)	(kBTU)	(kBTU/ft^2)
Primary Heating	105,133	4.621	375,476	16.503
Primary Cooling	482,026	21.186	482,026	21.186
Auxiliary	1,816,744	79.253	6,025,389	287.766
Lighting	122,944	6.00	368,869	18.01
Receptacles	11,911	0.524	35,738	1.571
Total	2,538,758	111.584	7,287,498	344.036

The non-HVAC electric components include lights, equipment, and miscellaneous loads. The design cooling coil load was calculated at 1,543,900 kBTUs and the heating coil load was 504,004 kBTUs. The above chart shows the breakdown by system component. The costs for the building system are shown in the tables below. Costs were broken down into HVAC and plumbing related to fire protection. The right table shows the total cost and the cost per square foot. The total cost, including HVAC and fire protection, is roughly 13.4% of the overall cost for the building.

	Annual Cost ($/yr)	**($/ft^2)**
HVAC Components		
Electric	13,272	0.583
Natural Gas	3,440	0.151
Sub-Total	16,712	0.735
Non-HVAC Components		
Electric	36,156	1.589
Sub-Total	36,156	1.589
Total	52,868	2.324

	Total Cost ($)	**Cost ($)/ft^2**
Fire Protection	90,300	3.97
HVAC	1,196,700	52.57
Total	1,287,000	56.53

Existing Conditions

ASHRAE standards 90.1 and 62.1 provide recommended performance baselines for buildings. Standard 90.1's scope includes building envelope and lighting power density, among others. Standard 62.1 provides guidelines for calculating minimum outdoor air requirements.

Standard 90.1-2007 Evaluations

In order to evaluate the performance of the building, I compared the design to sections 5 through 9 of standard 90.1. All of the requirements were determined using data from climate zone 4A. Included are the results from section 5 and section 9.

Section 5 - Building Envelope Compliance

The objective of section 5 is to ensure that the building envelope is properly designed. Since the vertical fenestration area was calculated at 29% of the total gross wall area, the Prescriptive Building method was used for evaluation.

Wall Area (ft^2)	Glass Area (ft^2)	% Total Vertical Fenestration
6,242	1,812	29.0

Table 1 on the next page shows the minimum required insulation values and the design values for the building envelope. All of the values meet or exceed standard minimum requirements. All of the insulation is also required to meet ASTM C578 specifications for rigid cellular polystyrenne thermal insulation. The SOG, cavity walls, and roof insulation are specified as type IV, X, and VI, respectively. Table 2 Shows the requirements of ASTM C578 for each type.

Due to the number of interface joints between the various building envelope systems, air and moisture barriers were very important in the design. All flashing, joints, and seals on the walls, windows, and doors were designed to minimize the amount of air and moisture penetration. All connections include thermal breaks as well to limit a heat transfer short circuit. All spandrels are required to include a layer of R-19 insulation. The air barriers for all systems have a maximum air leakage rate of 0.004 cfm per square foot of wall area. All adjacent systems will be connected in a flexible matter to allow for thermal and moisture variations, as well as creep.

Existing Conditions

Table 1 - Building Envelope Minimum Requirements

	Roof Insulation R-Value	Wall Insulation R-value	SOG Insulation R-Value	Fenestration U-Value	Fenestration SHGC
Minimum required value	20	13	NR	0.5	0.4
Design value	20	13	10.2	0.32	0.39

Reference from Table 5.5-4 from Standard 90.1

Table 2 - Insulation Properties

Insulation	Density (lb/ft^3)	R-Value per inch ($^oF\text{-}ft^2h/BTU$)	
		At 40^oF	At 75^oF
Type IV	1.6	5.4	5.0
Type X	1.6	5.4	5.0
Type VI	1.6	5.4	5.0

Referenced from Table 1 from ASTM C578

The SOG will have a two inch thick layer of type IV insulation below the concrete. All cavity walls will have 2-1/2" layer of type X. The roof will have two 2" layers of type VI for a total of 4" of insulation. All three types have maximum flame-spread and smoke-developed indices of 75 and 450, respectively.

Existing Conditions

Section 9 - Lighting Compliance

Lighting Compliance Table

LDP (W/ft^2)	Gross lighted floor area (ft^2)	Interior lighting power allowance (W)	Installed interior lighting allowance (W)
1.2	18,400	22,080	19,569

The above table shows the results of the installed interior lighting allowance compared with the interior lighting power allowance. As indicated, the installed lighting allowance is 11% below the maximum allowed. Lighting played an important part in the buildings design. An advanced daylighting system , which will be discussed in further detail, was installed in order to reduce energy use

Standard 62.1-2007 Evaluation

Section 6 of Standard 62.1 deals with proper ventilation rates of indoor spaces. There are two different methods of determining if a system is compliant: either the IAQ or Ventilation Rate Procedure. For evaluation, the Ventilation Rate Procedure was used to calculate the nominal outside air (V_{oz}) and the required outside air (V_{ot}). The table below compares the values for each with the maximum outdoor air capacity of each AHU. Both AHUs are capable of supplying the required amount of outdoor air to each space.

Outdoor Air Requirements

	$\sum V_{oz}$ (cfm)	**V_{ot} (cfm)**	**Max OA Supplied (cfm)**
AHU-1	1,709	2,801	6,300
AHU-2	1,564	1,955	8,000

Acoustical Breadth

First and foremost the Science & Technology Center is an academic building. It's main purpose is to educate students from kindergarten through high school. One important factor in a learning environment is the ability to clearly understand what is being taught. Acoustics can play a crucial role in this. If the reverberation time for a space is too high, a teacher's voice can echo around the room, not only making it difficult for students to understand but physically painful as well. On the other side, if the reverberation time is too low a teacher's voice may not carry far enough for every student to hear. Equally as important is the sound ratings of the exterior walls and interior partitions. The walls must have enough of a damping effect to ensure that as little sound as possible travels through as not to disrupt the learning environment. As one of my breadth topics I chose to evaluate the various interior spaces of the Science & Technology Center to see if the reverberation times fell into the recommended design guidelines. I also checked the Sound Transmission Class of the various wall construction types to make sure that enough sound was blocked from entering the learning environment.

Reverberation Times

The following table shows the reverberation times for each space at six different frequencies. With the few exceptions shown, all of the spaces fall within the recommended 0.4-0.6 second range for classrooms. Full breakdowns of each space are attached in Appendix A.

	T_{60} @ 125	T_{60} @ 250	T_{60} @ 500	T_{60} @ 1000	T_{60} @ 2000	T_{60} @ 4000
Lobby	0.460	0.464	0.556	0.509	0.423	0.436
Room 107	0.419	0.457	0.579	0.543	0.444	0.472
Room 109	0.415	0.459	0.584	0.536	0.439	0.469
Room 111	0.448	0.474	0.600	0.559	0.453	0.484
Room 115	0.415	0.455	0.575	0.530	0.433	0.463
Room 203	0.304	0.390	0.502	0.445	0.364	0.387
Room 204	0.374	0.417	0.471	0.410	0.367	0.386
Room 206	0.451	0.471	0.591	0.543	0.447	0.481
Room 208	0.453	0.470	0.588	0.541	0.446	0.480
Room 211	0.466	0.471	0.584	0.541	0.448	0.483
1st Floor Corridor	0.596	0.536	0.675	0.622	0.506	0.552
2nd Floor Corridor	0.628	0.553	0.694	0.630	0.513	0.563

Acoustic Breadth

STC Ratings

The Sound Transmission Class is a rating of how well a partition attenuates sound. For the second part of my breadth I calculated the STC ratings for each of the various wall types, both exterior and interior. The first table below shows the various STC ratings and a description of the sound transmission through each. The second table lists the different wall constructions for the building and their associated STC ratings at various frequencies and overall.

STC	What can be heard
25	Normal speech can be understood quite easily and distinctly through wall
30	Loud speech can be understood fairly well, normal speech hear but not understood
35	Loud speech audible but not intelligible
40	Onset of “privacy”
42	Loud speech audible as a murmur
45	Loud speech not audible; 90% of statistical population not annoyed
50	Very loud sounds such as musical instruments or a stereo can be faintly hear; 99% of population not annoyed
60+	Superior soundproofing; most sounds inaudible

Courtesy of Cyril M. Harris. “Noise Control in Buildings”

	f_{125}	f_{160}	f_{200}	f_{250}	f_{315}	f_{400}	f_{500}	f_{630}	f_{800}	f_{1000}	f_{1250}	f_{1600}	f_{2000}	f_{2500}	f_{3200}	F_{4000}	STC
Exterior Walls																	
Masonary	38	39	46	47	52	54	57	58	60	61	69	68	71	71	72	74	**58**
Stucco	35	41	50	49	53	55	58	58	58	59	59	60	58	57	60	64	**57**
Glass	27	25	26	28	30	30	33	33	33	33	34	35	36	36	38	41	**34**
Windows	27	25	26	28	30	30	33	33	33	33	34	35	36	36	38	41	**34**
Interior Partitions																	
Hallway	32	37	42	45	48	50	51	52	52	52	51	49	49	48	48	50	**50**
Classrooms	29	35	40	42	43	48	52	55	57	57	57	54	45	40	44	50	**44**
Robotics Workshop	29	35	40	42	43	48	52	55	57	57	57	54	45	40	44	50	**44**
Doors	21	24	27	27	27	27	30	30	28	26	25	25	25	27	28	29	**27**

Acoustic Breadth

STC Ratings

As we can see from the second chart, each of the exterior wall types exceeds the minimum STC of 50. The windows and glass curtain wall are significantly lower, but that is to be expected. Glazing is traditionally the weak link in wall construction in terms of sound transmission. Fortunately, for this building the glazing percentage is relatively minimal (with the exception of the entrance lobby).

As for the interior, the partitions between the corridors and classrooms meet the minimum rating. The partitions between classrooms are slightly below the recommended rating. However, due to the location of prep spaces between each room there is enough of a sound barrier between spaces. If a higher STC rating was still desirable, the simplest solution would be to add an extra layer of drywall to each side of the wall. This addition would boost the current classroom partitions to an STC rating of 50. The floor separating the first and second levels has an STC rating of 65, well above the minimum.

In addition to building materials and construction types, the exterior conditions of a building site are equally as important in sound transmission. The Science & Technology Center is located on the Chestnut Hill Academy's campus across the street from various sports fields. Adjacent are the Inn Building on one side and the football field on the other. The building is set back approximately 100 feet from Willow Grove Avenue. Sound from the Inn Building should not be a problem nor the football field as it will not be in significant use during the academic day. The road is the largest contributing factor to exterior sound generation. Willow Grove Avenue is a small two lane road that travels through a neighborhood and loops around behind the campus. The road is not heavily trafficked, although it is used during the day. The building is already oriented with the small side facing the road, thus minimizing the exposure to sound from passing traffic. According to data from "Architectural Acoustics" by Marshall Long, light traffic in a residential setting produces roughly 50 dBA at a hundred foot range. Since the building is located one hundred feet from the road, sound attenuation should not be a problem, as supported by the STC rating of the exterior walls. In addition, all mechanical equipment has been specified with NC ratings of 25-30, which is the recommendation for classrooms. All of the mechanical equipment is located on the roof or in the mechanical attic, which is separated from the second level by a slab construction with an STC rating of 65.

Daylight Breadth

As part of an energy saving measure, the Science & Technology Center will include a daylight harvesting system. The Dual Room miniZ^{tm} by Leviton was installed in the classrooms and office. This system allows two separate rooms to be controlled from a single panel. It is capable of combining several inputs, including daylight and occupancy sensors. It is also the first self-calibrating daylight harvesting system. Each of the classrooms are equipped with occupancy sensors with a 30 minute user adjustable time out. 4-button scene control override switches will be located in all of the classrooms and labs, as well as the conference room.

While the daylighting system was designed in accordance with the most modern techniques and utilizes some of the newest equipment, a study was never completed to predict the daylight levels inside of the spaces. The second breadth topic was an evaluation of the daylighting system. This included analyzing the space using AGI and simulating the daylight levels throughout the year. First, a 3-D model was built using Autocad 2009 and then imported it into AGI. Once the model was properly imported, each surface was assigned the proper reflectance and transmittance based on the design drawings and specifications. The daylight levels in each space were then simulated at four different points during the year: December 21st, March 21st, June 21st, and September 21st at 12:00 PM, using both clear and overcast sky conditions.

Original Design

The purpose of the study was to conclude whether a daylighting system was economically justifiable. Some concerns revolved around the adjacent buildings and trees blocking a significant amount of daylight from entering the space. These were intended to be used as a baseline reading to which various designs could be compared. Once the baseline was established, different glazing layouts and building orientations were to be compared. However, after analyzing the results it was evident that during the clear days the spaces already receive adequate amounts of daylight. In a few limited scenarios too much light (in the form of direct sunlight) was a concern. During the cloudy days several spaces had enough light near the windows, but electric lighting will still be needed to illuminate the spaces to proper levels.

Daylight Breadth

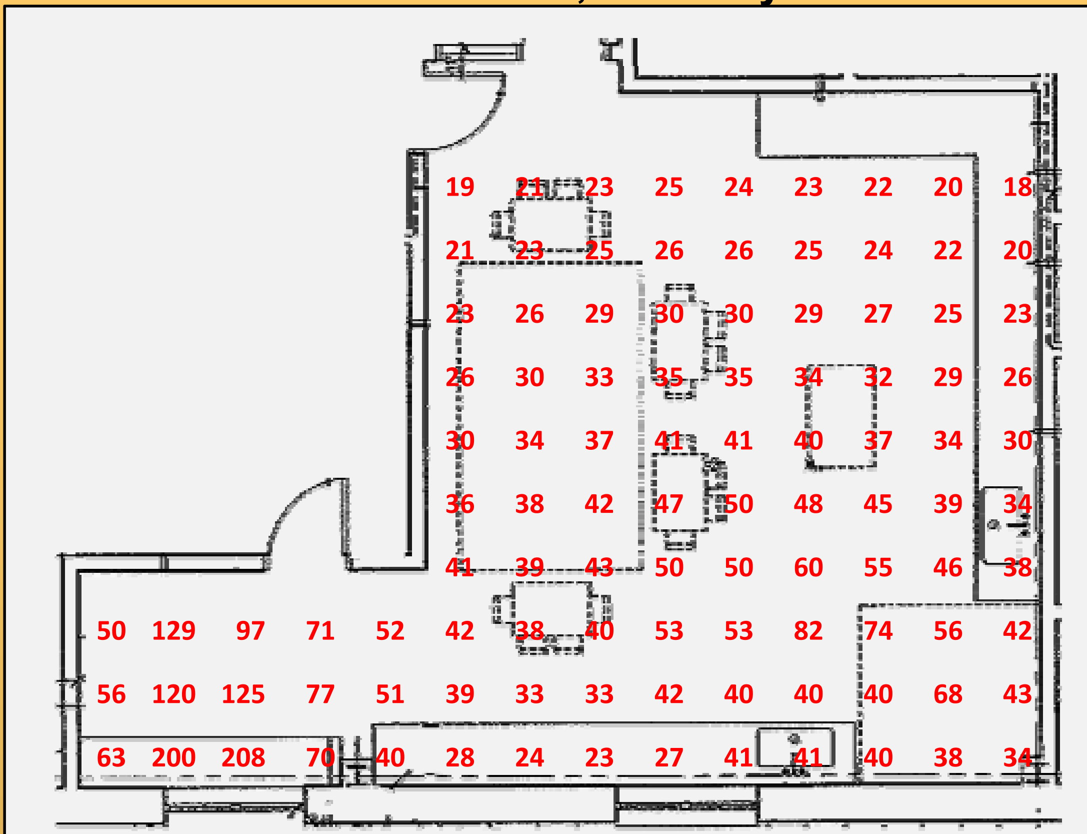
Re-design

The first study showed that the interior spaces received enough daylight to justify a daylight harvesting system. For comparison, I experimented with different building orientations and glazing layouts. These were intended to either improve the available daylight in the building or further justify the original layout.

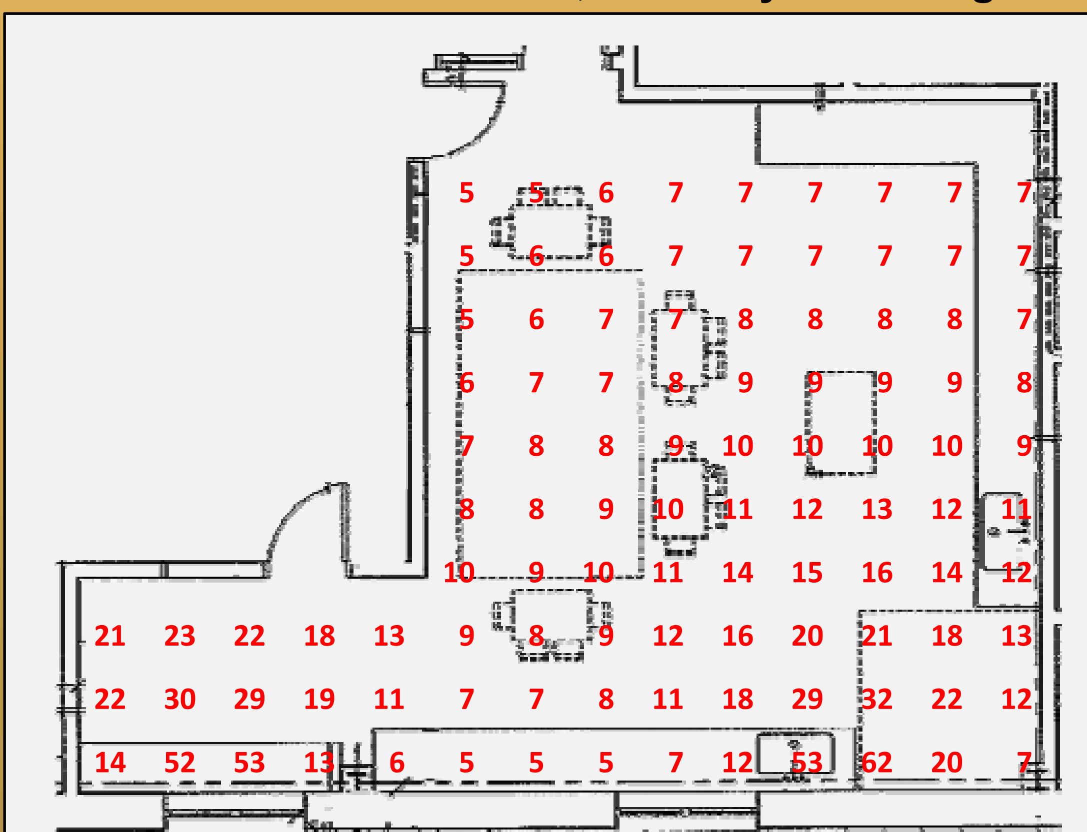
Building Orientation

Building orientation can play a large role in daylighting systems. Having the proper sides facing north, south, east, and west is a science in itself. Various site features - such as large trees and adjacent buildings - can also block or reflect sunlight penetration into a space. For this building, only two orientations are practical, either the current or a 90 degree rotation. Since the current one has already been tested, the building model was rotated to simulate data for the second orientation. Once the simulations were complete, the results were compared to the original data. The results showed that by rotating the building 90 degrees on the site, the daylight levels increased in some rooms and decreased in others. Daylight levels near the windows in certain rooms increased up to 25% while levels near the interior walls increased by up to 50%. However, in other rooms levels decreased by roughly the same amounts. On the following two pages are examples pulled from K-2 Classroom and the Physics Lab. The K-2 example shows that the original configuration provides more daylight that the rotated configuration, while the Physics Lab example shows the opposite. This variation was consistent with the remaining rooms in the building.

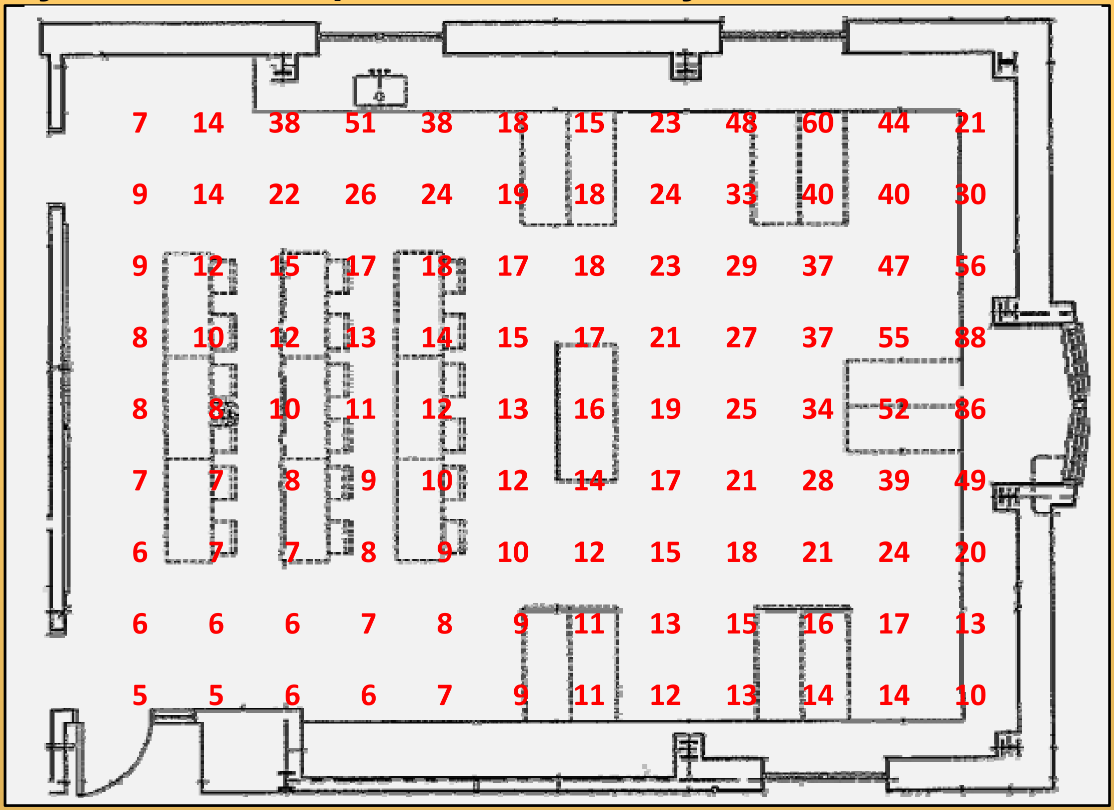
K-2 Classroom – December, clear sky



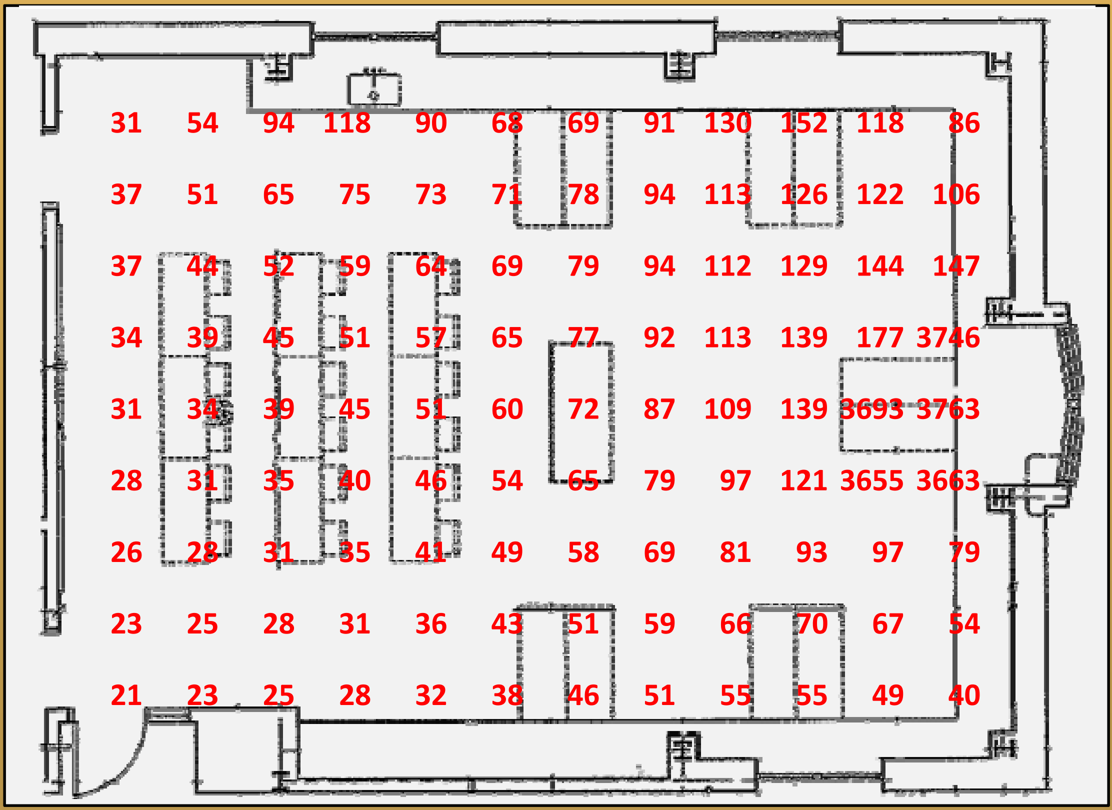
K-2 Classroom – December, clear sky – building rotated



Physics Lab – September, clear sky



Physics Lab – September, clear sky – building rotated



Daylight Breadth

Glazing

The second re-design kept the original glazing layout, but looked at including the use of light shelves. Light shelves are a very useful tool in extending the reach of daylight further into interior spaces. Exterior lights shelves were disregarded because of the impact they would have on the architecture of the building. That left interior light shelves to work with. The problem that was encountered with incorporating interior light shelves was the extensive use of fumehoods in the spaces. Since the classrooms are mainly labs, there are workbenches around the exterior of the rooms, each equipped with a fumehood exhaust. Unfortunately, these benches and exhausts are also located in front of the windows. Because of this, light shelves in the labs were ruled out. The remaining spaces, which are the office suite and two elementary classrooms, were more practical for light shelves. Once light shelves were added to the 3-D models and imported into AGI, simulations were run to compare the new daylight values to the baseline data. Results showed no significant increase in overall room daylight levels for the elementary classrooms, and in certain situations decreases levels by several footcandles. This is most likely attributed to the relatively low levels of glazing in the space. In the office space daylight levels at the work plan remained relatively constant due to the high partitions that surround each work station.

Conclusions

The original design of the Science & Technology Center is the best for a daylighting scheme. The current configuration already provides ample levels of daylight to the space. The only major concern with the original design is the limited situations in which there is too much daylight near the windows. However, this is not a major problem since blinds will be used to block the direct sunlight. As for the incorporation of light shelves, due to the nature of the spaces inside the building they were not practical in many of the spaces. In the spaces where light shelves were tested, little improvement was noted.

Re-orienting the building proved to have the most drastic change on daylight levels. Unfortunately, the results were mixed. In certain situations, the daylight levels increased, while in others, the levels decreased. Overall, the best daylight scheme for the building is the current configuration.

Mechanical Re-Design

Part One - Active Chilled Beams

The original HVAC system for the Science & Technology Center was a typical VAV system. Each space was provided with a mixed supply of outdoor and return air to meet cooling/heating as well as ventilation requirements. VAV systems, when used properly, can be very effective and efficient systems. In the building the majority of spaces are lab spaces. While these labs are not intended for advanced research that may require very stringent space conditioning, return air quality may be a concern. The spaces are each equipped with regular hood vents and emergency snorkel exhaust in case of an accident, such as a chemical spill. However, one area that may have been overlooked is the slow leakage of toxics and/or particulate matter into the return air. While filters are designed to handle situations such as this, they should not be relied on as the main failsafe. As a more secure measure, a dedicated outdoor air (DOA) system could provide each space with a constant supply of fresh air. One major concern with a DOA system is the usually larger energy use treating the air. An energy recover system, such as an enthalpy wheel, could still be used as in the original VAV design. However the mixing of return and supply air would be eliminated.

As part of the new DOA system, a more localized system was desired. Active chilled beams are a good solution for this goal. Active chilled beams are located in each individual space and are capable of handling both sensible and latent gains in single package. Active chilled beams can also result in lower electric use by using forced induction to draw air into the unit, where it is treated before being mixed with the outdoor air and returned to the space. By using active chilled beams to localize the heating and cooling, each space is separated from each other. This use of a ACB system with DOA helps to localize any accident, thus protecting the air quality of the other spaces. By eliminating the mixing of return air contaminants will not be introduced into the other spaces as well.

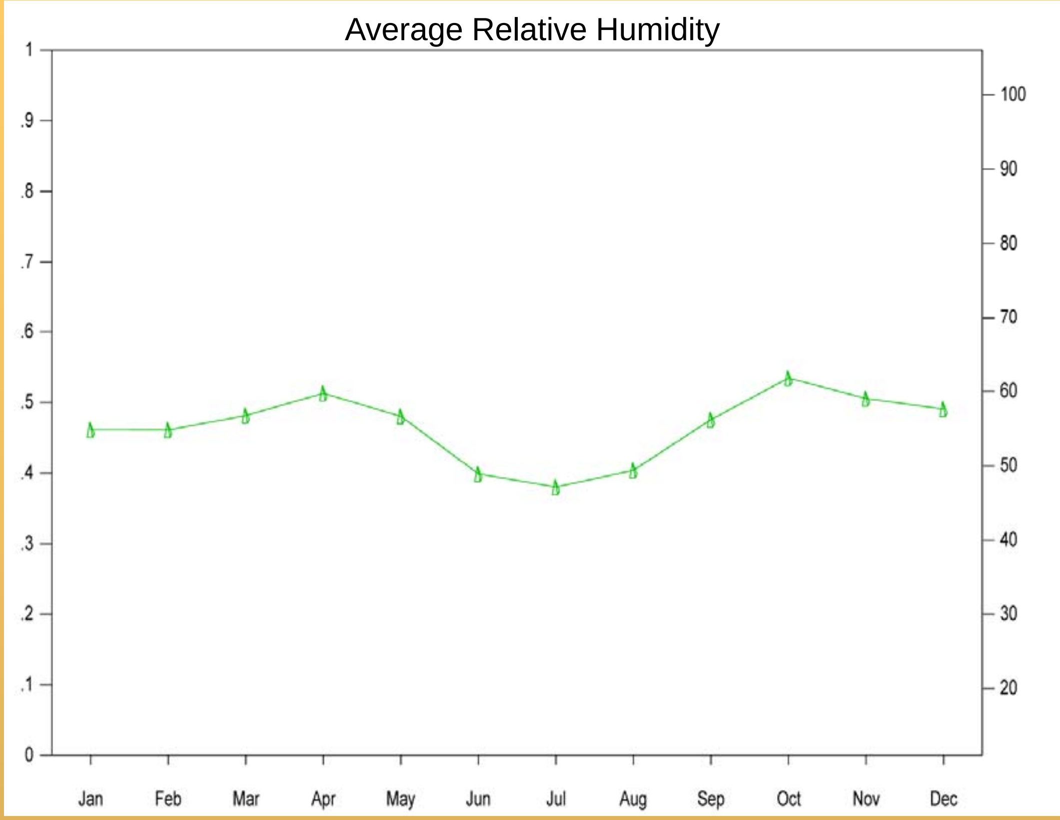
Mechanical Re-Design

Humidity Control

One concern with a dedicated outdoor air system is humidity control. The supply air must be dehumidified enough to meet the entire building load before it is supplied to each space. In order to properly model the system, each space's humidity loads were calculated individually and entered into Trane Trace for evaluation. The humidity loads were calculated according to ASHREA standards. The table below shows the overall loads for each space, while a more detailed breakdown is presented in Appendix D. The graph on the next page shows the average relative humidity for the building throughout the year as calculated by Trane Trace. The relative humidity decreases during the summer months due to the significant decrease in occupancy.

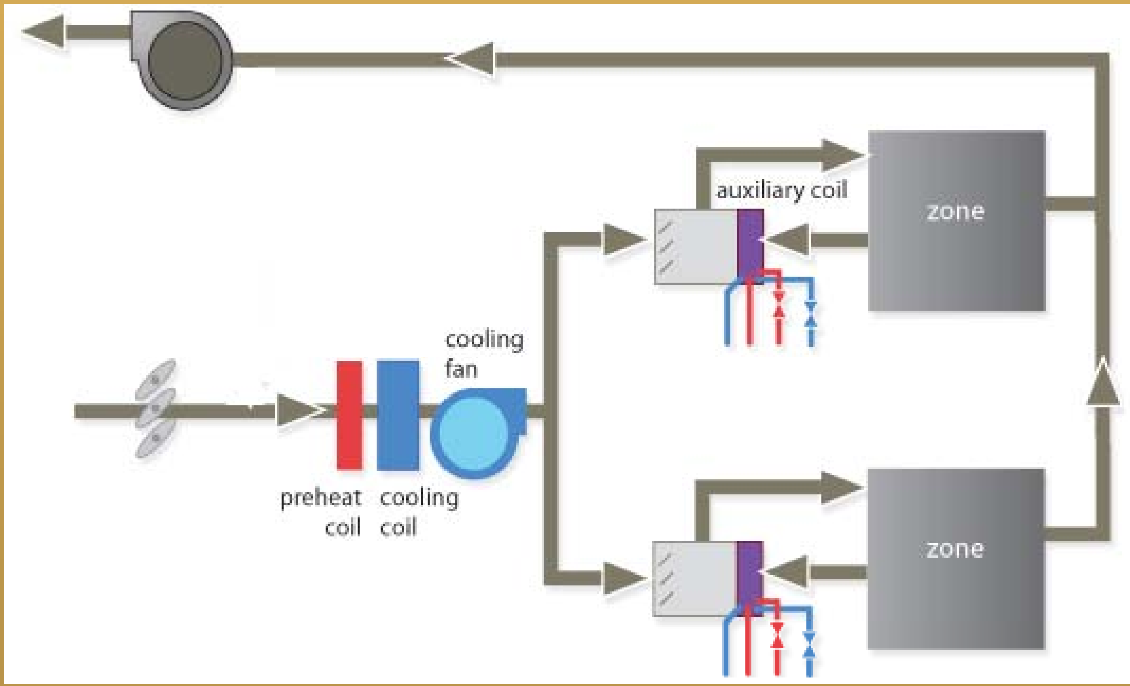
	W [lbs/h]	hours	People	Total [BTUs/h]	Total [BTUs/(h-person)]
Second Level					
Chem./Biology Lab	15.09	8	21	16,225	773
Chem./Bio./Phy. Prep.	10.54	1.5	3	11,329	3,776
Ind. Lab	2.61	2	3	2,801	934
Chem./Physics Lab	16.95	8	21	18,218	868
Office Suite	4.87	8	5	5,236	1,047
Conference Room	4.75	3	13	5,101	392
Bio. Prep	5.54	1.5	3	5,960	1,987
Biology	15.23	8	22	16,369	744
Corridor	2.85	2	3	3,064	1,021
First Level					
Physics Lab	11.05	8	21	11,879	566
Phy. Prep.	1.21	1.5	2	1,298	649
Ind. Phy. Lab	1.06	2	2	1,138	569
Robotics and Workshop	13.82	8	27	14,855	550
Porch	22.28	8	20	23,948	1,197
Commons	3.63	8	12	3,906	325
K-2 Lab	6.48	8	12	6,970	581
Prep	1.14	1.5	1	1,226	1,226
3-5 Lab	6.89	8	12	7,407	617
Womens WC	0.79	2	3	846	282
Mens WC	0.79	2	3	846	282
Corridor	2.95	2	3	3,173	1,058

Mechanical Re-Design



Energy Use

The energy use of the building was calculated with Trance Trace 700 version 6.2. The ACB was modeled using a 4-pipe induction system whose schematic is shown below.



Mechanical Re-Design

Energy Use

The table below shows a breakdown of the energy use of both the building and the site. As stated in the original design conditions, the original design consumed 2,538,758 kBTUs of site energy and 7,287,498 kBTUs in source energy. As we can see, this is a 17% increase in site energy and a 11% decrease in source energy. If we compare the original design to the re-design, we see a dramatic increase in heating energy and a substantial decrease in cooling energy. The increase in heating energy is solely responsible for the increase in overall site energy. This is due to the DOA system and the increased need for heating the colder supply air constantly during the longer heating season. Additional data from the Trane Trace simulation is available in Appendix E.

Component	Site Energy		Source Energy	
	(kBTU)	(kBTU/ft^2)	(kBTU)	(kBTU/ft^2)
Primary Heating	1,354,340	66.14	1,425,621	69.62
Primary Cooling	328,651	16.05	986,052	48.15
Auxiliary	1,225,909	59.87	3,678,096	179.62
Lighting	122,944	6.00	368,869	18.01
Receptacles	11,911	0.58	35,738	1.75
Total	3,043,756	148.64	6,494,375	317.15

	Annual Cost ($/yr)	**($/ft^2)**	**difference**
HVAC Components			
Electric	24,939	1.21	+13,272
Natural Gas	11,503	0.56	+3,440
Sub-Total	36,442	1.77	+19,730
Non-HVAC Components	36,156	1.77	0
Total	72,598	3.55	+19,730

If we compare the original annual costs to the new operating costs, there is an increase of approximately $20,000 for the new design. If we look closely we can see that the majority of the increase is in electric consumption, while the natural gas component has increased slightly as well. This increase in electric consumption is due to the increase in pumping required for the ACBs. The Non-HVAC components remained constant throughout the re-design and thus have not affected the price.

Mechanical Re-Design

Part Two - Thermal Storage

Electric consumption is the largest contributor to energy use in buildings. Contributors include electric lighting, HVAC equipment, various work stations, etc. One way of offsetting this consumption is through a thermal storage system. Thermal storage can be used to offset the cost of cooling and heating during peak hours. By taking advantage of lower electric costs at off-peak hours, chilled water or ice can be created and stored for later use by the HVAC equipment. As part of the re-design, an ice thermal storage system was sized according to the energy data provided by a Trane Trace simulation of the new active chilled beam outdoor air system. By graphing the load profile of the chiller, it was easy to determine how much of the building load exceeded the chiller's capacity. In this situation, the thermal storage system is drawn upon to help with loads. When the chiller is below capacity, such as during off-peak hours, the thermal storage system is charged to recover for later use. The building peak cooling load was 79 tons and occurred on July 18th. This information was used with the CALMAC First Past ™ software to determine sizing, equipment costs, and annual operating savings for the inclusion of an ice storage system. The total cost of installation for an ice storage system was $99,069. With current on and off-peak energy rates, this system would provide $4,533 of savings in annual operating costs for the ACB system. The table below shows the results.

Cooling Load & System Input				
Building Peak Cooling Load (tons)	79	40	(tons) Minimum Conventional System Capacity with one chiller failure	
Installed Conventional Capacity (with redundancy) (tons)	80	2	<-- No. of Conventional System Chillers (tons ea) -->	40
System Type (Air cooled "0" / Water Cooled "1")	0	2	<-- No. of Ice System Chillers (tons ea) -->	22
Cooling Period (hours)	10			
Ice Making Period (hours of off-hours typically)	8			
Ice Chiller(s) Ice Making Capacity (% of Nominal)	65%		Load Diversity during cooling period (average load)	84%
Ice Chiller(s) Daytime Limit (% of daytime full load)	100.0%		Building Cooling Requirement (ton-hours)	663
Ice Storage System Size			**Conventional Chiller System Size**	
Min. Nominal Chiller Capacity Required (tons)	44		Min. Nominal Chiller Capacity Required (tons)	80
*** 1190 Canisters required	2			
ECONOMIC Input (Assume airside does not change, see FirstPass CALCs sheet for details)				
Electric Utility Rates				
On Peak Energy Charge ($ / kWh)	$ 0.0685		On Peak Demand Charge ($ / kW)	$ 12.00
Off Peak Energy Charge ($ / kWh)	$ 0.0030		Off Peak Demand Charge ($ / kW)	
Number of Cooling Months to Analyze per Year	6		Energy Inflation Rate (%)	3.0%
Financing Interest Rate (%)	6.0%		Life of System (years)	25
Ice System Installation Costs			**Conventional System Installation Costs**	
Ice Chiller(s) Installation Costs ($/ton)	$ 1,450		Conventional Chiller(s) Installation Costs ($/ton)	$ 1,450
Special costs (TES install costs shown on CALC pg) ($)	$ -	$ 116	Construction Contingency Costs ($)	$ -
Utility Rebate (if available) ($)	$ -			
Plate Frame HX (Yes "1" / No "0")	0			
Total Ice System Cost	**$ 99,069**	($16,931)	**Total Standard System Cost**	**$ 116,000**
Annual Operating Cost Savings	**$ 5,533**		**Simple Payback (years)**	**Immediate**
Net Present Value	**$105,091**		**Internal Rate of Return (per year)**	**#DIV/0!**

Mechanical Re-Design

Costs

The original total cost of the HVAC system for the Science & Technology Center was $1,287,000. The first table below shows the breakdown for the new cost of the ACB system with an ice storage system. The second table shows the original operating cost and the new operating cost.

System Costs	Cost ($)
Original Cost	1,287,000
Subtracted Equipment	760,500
New Equipment	706,224
Total	1,232,724

Operating Cost	Cost ($/year)
Original Operating Cost	52,868
ACB Operating Cost	+19,730
TES Operating Cost	-5,533
Total	67,065

As we can see from the first chart the new system cost is lower than the original system cost by roughly 4%. The subtracted equipment included the VAV units, ductwork, insulation, and piping, and one AHU. The new equipment included smaller ductwork, the ACBs and associated piping, and the ice storage system. As we can see in the second chart the ACB system does have an increase in operating costs by about $20,000 per year. The ice storage does help to ease this slightly, resulting in the new operating cost of $67,065 per year, a 27% increase.

Conclusions

The alternative design for the Science & Technology Center is inadequate in comparison with the original design. As stated on the previous page, while the capital costs were slightly less the annual operating costs were significantly higher. The increase in energy in the alternative design was expected due to higher pumping requirements for ACBs. This is why an ice storage system was included in the design. However, the predicted savings in operating costs provided by the ice storage were not significant enough to offset the increase in operating costs. In a larger building the storage benefits may have provided for larger savings in operating costs. In the Science & Technology Center the high pumping demand is most likely the reason why the thermal storage could not offset the operating costs. In conclusion, the proposed alternative design for the Science & Technology Center consumes more energy and has a higher operating cost than the original design, and therefore cannot be justified as an alternative design.

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

•DiversiFoam Products. ASTM C 578-95 specifications for rigid cellular polystyrene thermal insulation. Rockford, MN http://www.diversifoam.com/cfproperties.htm

•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

•USGBC. LEED for New Construction & Major Renovations. Version 2.2. October 2005. Washington, DC.

•Ryan Fitzpatrick, E.I.T. Mechanical Project Engineer. Bruce E. Brooks & Associates. 2209 Chestnut St. Philadelphia, PA.

•Humidity Control Design Guide for Commercial and Institutional Buildings. Harriman, Brundrett, Kittler. 2001, ASHRAE

•Heating, Ventilation, and Air Conditioning Analysis and Design, 6th Edition. McQuiston, Parker, Spitler. 2006, John Wiley & Sons, Inc.

•Architectural Acoustics. Marshal Long. 2006, Elsevier.

•Catalog of STC and IIC Ratings for Wall and Floor/Ceiling Assemblies. Russell B. DuPree. Office of Noise Control, California Department of Health Services.

•CALMAC First Pass. Version 0501018NAEZ

Appendix A

Standard 62.1 Tables and Sample Calculations

Table A-1

Level/Room	Area (Net SF)	Calculated Population Basis (SF/P)	Occupancy Type	Calculated Population (CP)
Second Level				
Chem./Biology Lab	1,070	50	Science Lab	21
Chem./Bio./Phy. Prep	306	100	Office	3
Ind. Lab	170	50	Science Lab	3
Chem./Physics Lab	1,058	50	Science Lab	21
Office Suite	545	100	Office	5
Conference Room	196	15	Conference	13
Bio. Prep	127	50	Science Lab	3
Biology	1,092	50	Science Lab	22
Corridor	1,055	-	-	-
Second Level Totals	**4,564**			**92**
First Level				
Physics Lab	1,034	50	Science Lab	21
Phy. Prep.	210	100	Office	2
Ind. Phy. Lab	113	50	Science Lab	2
Robotics & Workshop	1,355	50	Science Lab	27
Porch	300	15	Lobbies	20
Commons	184	15	Lobbies	12
K-2 Lab	588	50	Science Lab	12
Prep	107	100	Office	1
3-5 Lab	618	50	Science Lab	12
Corridor	1,055	-	-	-
First Level Totals	**4,509**			**110**

Table A-1 lists each space in the building and it's respective area, estimated population, and occupancy type.

Appendix A

Standard 62.1 Tables and Sample Calculations

Table A-2

	R_p	R_a	V_{bz}	E_z	V_{oz}	V_{pz}	Z_p	E_v	D	V_{ou}	V_{ot}
	(cfm/person)	(cfm/ft^2)	(cfm)		(cfm)	(cfm)				(cfm)	(cfm)
Second Level											
Chem./Biology Lab	10	0.18	403	1	403	1460	0.28	-	1		
Chem./Bio./Phy. Prep.	5	0.06	33	1	33	1400	0.02	-	1		
Ind. Lab	10	0.18	61	1	61	300	0.20	-	1		
Chem./Physics Lab	10	0.18	400	1	400	1680	0.24	-	1		
Office Suite	5	0.06	58	1	58	500	0.12	-	1		
Conference Room	5	0.06	77	1	77	275	0.28	-	1		
Bio. Prep	10	0.18	53	1	53	700	0.08	-	1		
Biology	10	0.18	417	1	417	1450	**0.29**	0.8	1		
Corridor	-	0.06	63	1	63	420	0.15	-	1		
							Total	0.8	1	1564	1955
									AHU 2 MAX OA (CFM)		8000
First Level											
Physics Lab	10	0.18	396	1	396	820	0.48	-	1		
Phy. Prep.	5	0.06	23	1	23	80	0.28	-	1		
Ind. Phy. Lab	10	0.18	40	1	40	100	0.40	-	1		
Robotics and Workshop	10	0.18	514	1	514	874	0.59	-	1		
Porch	5	0.06	118	1	118	2220	0.05	-	1		
Commons	5	0.06	71	1	71	110	**0.65**	0.61	1		
K-2 Lab	10	0.18	226	1	226	480	0.47	-	1		
Prep	5	0.06	11	1	11	140	0.08	-	1		
3-5 Lab	10	0.18	231	1	231	480	0.48	-	1		
Corridor	-	0.06	63	1	63	435	0.15	-	1		
							Total	0.61	1	1709	2801
									AHU 1 MAX OA (CFM)		6300

Table A-2 shows all of the calculated values required for each zone to find V_{ot}. E_z was determined using table 6-2 and is 1 for every space. E_v was calculated using table 6-3 for AHU-2. For AHU-1 the alternate calculation method listed in Appendix A of 62.1 (equations A-1 through A-3). Like stated before, the diversity, D, was assumed to have a value of 1 in order to increase the minimum requirements. The actual diversity is not known as the building is still under construction.

Appendix B - Reverberation Time Calculations

Lobby	Gross Area	Net Area	α_{125}	α_{250}	α_{500}	α_{1000}	α_{2000}	α_{4000}
Floor	553	553	0.02	0.03	0.03	0.03	0.03	0.02
Interior Partitions	1,080	816	0.29	0.10	0.05	0.04	0.07	0.09
Interior Windows	21	21	0.18	0.06	0.04	0.03	0.02	0.02
Int. Wind. Frame	1	1	0.04	0.04	0.03	0.03	0.02	0.02
Doors	210	210	0.10	0.07	0.05	0.04	0.04	0.04
Ceiling	553	553	0.68	0.76	0.60	0.65	0.82	0.76
Tackboard	32	32	0.00	0.06	0.03	0.19	0.06	0.00
People	5	5	0.20	0.27	0.33	0.37	0.40	0.40

Reverberation Times	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}
Calculated	0.596	0.536	0.675	0.622	0.506	0.552
Target	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6
	√	√	X	X	√	√

K-2 Classroom	Gross Area	Net Area	α_{125}	α_{250}	α_{500}	α_{1000}	α_{2000}	A_{4000}
Floor	845	715	0.02	0.03	0.03	0.03	0.03	0.02
Walls	1,204	644	0.29	0.10	0.05	0.04	0.07	0.09
Window Glazing	88	88	0.18	0.06	0.04	0.03	0.02	0.02
Window Framing	2	2	0.04	0.04	0.03	0.03	0.02	0.02
Doors	42	42	0.10	0.07	0.05	0.04	0.04	0.04
Ceiling	845	845	0.68	0.76	0.60	0.65	0.82	0.76
Tackboard	32	32	0.00	0.06	0.03	0.19	0.06	0.00
Whiteboard	24	24	0.00	0.00	0.00	0.00	0.00	0.00
Visual Display	23	23	0.18	0.06	0.04	0.03	0.02	0.02
Wall Cabinet Tops	129	129	0.15	0.11	0.10	0.07	0.06	0.07
Wall Cabinets	349	349	0.15	0.11	0.10	0.07	0.06	0.07
Desks/Chairs	100	100	0.15	0.19	0.22	0.39	0.38	0.30
People	17	17	0.20	0.27	0.33	0.37	0.40	0.40

Reverberation Times	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}
Calculated	0.419	0.457	0.579	0.543	0.444	0.472
Target	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6
	√	√	√	√	√	√

Appendix B - Reverberation Time Calculations

3-5 Classroom	Gross Area	Net Area	α_{125}	α_{250}	α_{500}	α_{1000}	α_{2000}	α_{4000}
Floor	810	670	0.02	0.03	0.03	0.03	0.03	0.02
Walls	1,071	722	0.29	0.10	0.05	0.04	0.07	0.09
Window Glazing	99	99	0.18	0.06	0.04	0.03	0.02	0.02
Window Framing	2	2	0.04	0.04	0.03	0.03	0.02	0.02
Doors	21	21	0.10	0.07	0.05	0.04	0.04	0.04
Ceiling	810	810	0.68	0.76	0.60	0.65	0.82	0.76
Tackboard	56	56	0.00	0.06	0.03	0.19	0.06	0.00
Whiteboard	24	24	0.00	0.00	0.00	0.00	0.00	0.00
Visual Display	23	23	0.18	0.06	0.04	0.03	0.02	0.02
Wall Cabinet Tops	140	140	0.15	0.11	0.10	0.07	0.06	0.07
Wall Cabinets	124	124	0.15	0.11	0.10	0.07	0.06	0.07
Desks/Chairs	130	130	0.15	0.19	0.22	0.39	0.38	0.30
People	19	19	0.20	0.27	0.33	0.37	0.40	0.40

Reverberation Times	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}
Calculated	0.415	0.459	0.584	0.536	0.439	0.469
Target	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6
	√	√	√	√	√	√

Robotics	Gross Area	Net Area	α_{125}	α_{250}	α_{500}	α_{1000}	α_{2000}	α_{4000}
Floor	1,134	974	0.02	0.03	0.03	0.03	0.03	0.02
Walls	1,220	736	0.29	0.10	0.05	0.04	0.07	0.09
Window Glazing	83	83	0.18	0.06	0.04	0.03	0.02	0.02
Window Framing	2	2	0.04	0.04	0.03	0.03	0.02	0.02
Doors	108	108	0.10	0.07	0.05	0.04	0.04	0.04
Ceiling	1,134	1,134	0.68	0.76	0.60	0.65	0.82	0.76
Whiteboard	48	48	0.00	0.00	0.00	0.00	0.00	0.00
Visual Display	23	23	0.18	0.06	0.04	0.03	0.02	0.02
Wall Cabinet Tops	160	160	0.15	0.11	0.10	0.07	0.06	0.07
Wall Cabinets	220	220	0.15	0.11	0.10	0.07	0.06	0.07
Desks/Chairs	150	150	0.15	0.19	0.22	0.39	0.38	0.30
People	19	19	0.20	0.27	0.33	0.37	0.40	0.40

Reverberation Times	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}
Calculated	0.448	0.474	0.600	0.559	0.453	0.484
Target	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6
	√	√	X	√	√	√

Appendix B - Reverberation Time Calculations

Physics Lab	Gross Area	Net Area	α_{125}	α_{250}	α_{500}	α_{1000}	α_{2000}	α_{4000}
Floor	1,232	982	0.02	0.03	0.03	0.03	0.03	0.02
Walls	1,593	1,031	0.29	0.10	0.05	0.04	0.07	0.09
Window Glazing	130	130	0.18	0.06	0.04	0.03	0.02	0.02
Window Framing	3	3	0.04	0.04	0.03	0.03	0.02	0.02
Doors	42	42	0.10	0.07	0.05	0.04	0.04	0.04
Ceiling	1,232	1,232	0.68	0.76	0.60	0.65	0.82	0.76
Tackboard	32	32	0.00	0.06	0.03	0.19	0.06	0.00
Whiteboard	46	46	0.00	0.00	0.00	0.00	0.00	0.00
Visual Display	23	23	0.18	0.06	0.04	0.03	0.02	0.02
Wall Cabinet Tops	250	250	0.15	0.11	0.10	0.07	0.06	0.07
Wall Cabinets	286	286	0.15	0.11	0.10	0.07	0.06	0.07
Desks/Chairs	250	250	0.15	0.19	0.22	0.39	0.38	0.30
People	19	19	0.20	0.27	0.33	0.37	0.40	0.40

Reverberation Times	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}
Calculated	0.415	0.455	0.575	0.530	0.433	0.463
Target	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6
	√	√	√	√	√	√

Conference Room	Gross Area	Net Area	α_{125}	α_{250}	α_{500}	α_{1000}	α_{2000}	α_{4000}
Floor	179	179	0.02	0.03	0.03	0.03	0.03	0.02
Walls	491	352	0.29	0.10	0.05	0.04	0.07	0.09
Window Glazing	57	57	0.18	0.06	0.04	0.03	0.02	0.02
Window Framing	1	1	0.04	0.04	0.03	0.03	0.02	0.02
Doors	26	26	0.10	0.07	0.05	0.04	0.04	0.04
Ceiling	179	179	0.68	0.76	0.60	0.65	0.82	0.76
Whiteboard	32	32	0.00	0.00	0.00	0.00	0.00	0.00
Visual Display	23	23	0.18	0.06	0.04	0.03	0.02	0.02
Desks/Chairs	90	90	0.15	0.19	0.22	0.39	0.38	0.30
People	8	8	0.20	0.27	0.33	0.37	0.40	0.40

Reverberation Times	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}
Calculated	0.304	0.390	0.502	0.445	0.364	0.387
Target	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6
	X	X	√	√	X	X

Appendix B - Reverberation Time Calculations

Office Suite	Gross Area	Net Area	α_{125}	α_{250}	α_{500}	α_{1000}	α_{2000}	α_{4000}
Floor	704	704	0.02	0.03	0.03	0.03	0.03	0.02
Walls	1,091	924	0.29	0.10	0.05	0.04	0.07	0.09
Window Glazing	114	114	0.18	0.06	0.04	0.03	0.02	0.02
Window Framing	2	2	0.04	0.04	0.03	0.03	0.02	0.02
Doors	42	42	0.10	0.07	0.05	0.04	0.04	0.04
Ceiling	704	704	0.68	0.76	0.60	0.65	0.82	0.76
Tackboard	8	8	0.00	0.06	0.03	0.19	0.06	0.00
Desks/Chairs	150	150	0.15	0.19	0.22	0.39	0.38	0.30
Office Partitions	200	200	0.10	0.28	0.64	0.87	0.59	0.60
People	6	6	0.20	0.27	0.33	0.37	0.40	0.40

Reverberation Times	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}
Calculated	0.374	0.417	0.471	0.410	0.367	0.386
Target	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6
	X	√	√	√	X	X

Biology Lab	Gross Area	Net Area	α_{125}	α_{250}	α_{500}	α_{1000}	α_{2000}	α_{4000}
Floor	1,329	989	0.02	0.03	0.03	0.03	0.03	0.02
Walls	1,324	721	0.29	0.10	0.05	0.04	0.07	0.09
Window Glazing	183	183	0.18	0.06	0.04	0.03	0.02	0.02
Window Framing	4	4	0.04	0.04	0.03	0.03	0.02	0.02
Doors	63	63	0.10	0.07	0.05	0.04	0.04	0.04
Ceiling	1,329	1,329	0.68	0.76	0.60	0.65	0.82	0.76
Tackboard	56	56	0.00	0.06	0.03	0.19	0.06	0.00
Whiteboard	46	46	0.00	0.00	0.00	0.00	0.00	0.00
Visual Display	23	23	0.18	0.06	0.04	0.03	0.02	0.02
Wall Cabinet Tops	340	340	0.15	0.11	0.10	0.07	0.06	0.07
Wall Cabinets	229	229	0.15	0.11	0.10	0.07	0.06	0.07
Desks/Chairs	235	235	0.15	0.19	0.22	0.39	0.38	0.30
People	19	19	0.20	0.27	0.33	0.37	0.40	0.40

Reverberation Times	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}
Calculated	0.451	0.471	0.591	0.543	0.447	0.481
Target	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6
	√	√	√	√	√	√

Appendix B - Reverberation Time Calculations

Chem/Bio Lab	Gross Area	Net Area	α_{125}	α_{250}	α_{500}	α_{1000}	α_{2000}	α_{4000}
Floor	1,331	991	0.02	0.03	0.03	0.03	0.03	0.02
Walls	1,339	679	0.29	0.10	0.05	0.04	0.07	0.09
Window Glazing	133	133	0.18	0.06	0.04	0.03	0.02	0.02
Window Framing	3	3	0.04	0.04	0.03	0.03	0.02	0.02
Doors	70	70	0.10	0.07	0.05	0.04	0.04	0.04
Ceiling	1,331	1,331	0.68	0.76	0.60	0.65	0.82	0.76
Tackboard	56	56	0.00	0.06	0.03	0.19	0.06	0.00
White Board	46	46	0.00	0.00	0.00	0.00	0.00	0.00
Visual Display	23	23	0.18	0.06	0.04	0.03	0.02	0.02
Wall Cabinet Tops	340	340	0.15	0.11	0.10	0.07	0.06	0.07
Wall Cabinets	329	329	0.15	0.11	0.10	0.07	0.06	0.07
Desks/Chairs	235	235	0.15	0.19	0.22	0.39	0.38	0.30
People	19	19	0.20	0.27	0.33	0.37	0.40	0.40

Reverberation Times	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}
Calculated	0.453	0.470	0.588	0.541	0.446	0.480
Target	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6
	√	√	√	√	√	√

Chem/Physics	Gross Area	Net Area	α_{125}	α_{250}	α_{500}	α_{1000}	α_{2000}	α_{4000}
Floor	1,314	1,064	0.02	0.03	0.03	0.03	0.03	0.02
Walls	1,325	438	0.29	0.10	0.05	0.04	0.07	0.09
Window Glazing	177	177	0.18	0.06	0.04	0.03	0.02	0.02
Window Framing	4	4	0.04	0.04	0.03	0.03	0.02	0.02
Doors	70	70	0.10	0.07	0.05	0.04	0.04	0.04
Ceiling	1,314	1,314	0.68	0.76	0.60	0.65	0.82	0.76
Tackboard	24	24	0.00	0.06	0.03	0.19	0.06	0.00
Whiteboard	46	46	0.00	0.00	0.00	0.00	0.00	0.00
Visual Display	23	23	0.18	0.06	0.04	0.03	0.02	0.02
Wall Cabinet Tops	250	250	0.15	0.11	0.10	0.07	0.06	0.07
Wall Cabinets	544	544	0.15	0.11	0.10	0.07	0.06	0.07
Desks/Chairs	235	235	0.15	0.19	0.22	0.39	0.38	0.30
People	19	19	0.20	0.27	0.33	0.37	0.40	0.40

Reverberation Times	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}
Calculated	0.466	0.471	0.584	0.541	0.448	0.483
Target	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6
	√	√	√	√	√	√

Appendix B - Reverberation Time Calculations

1st Floor Corridor	Gross Area	Net Area	α_{125}	α_{250}	α_{500}	α_{1000}	α_{2000}	α_{4000}
Floor	553	553	0.02	0.03	0.03	0.03	0.03	0.02
Interior Partitions	1,080	816	0.29	0.10	0.05	0.04	0.07	0.09
Interior Windows	21	21	0.18	0.06	0.04	0.03	0.02	0.02
Int. Wind. Frame	1	1	0.04	0.04	0.03	0.03	0.02	0.02
Doors	210	210	0.10	0.07	0.05	0.04	0.04	0.04
Ceiling	553	553	0.68	0.76	0.60	0.65	0.82	0.76
Tackboard	32	32	0.00	0.06	0.03	0.19	0.06	0.00
People	5	5	0.20	0.27	0.33	0.37	0.40	0.40

Reverberation Times	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}
Calculated	0.596	0.536	0.675	0.622	0.506	0.552
Target	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6
	√	√	X	X	√	√

2nd Floor Corridor	Gross Area	Net Area	α_{125}	α_{250}	α_{500}	α_{1000}	α_{2000}	α_{4000}
Floor	553	553	0.02	0.03	0.03	0.03	0.03	0.02
Interior Partitions	736	499	0.29	0.10	0.05	0.04	0.07	0.09
Doors	189	189	0.10	0.07	0.05	0.04	0.04	0.04
Ceiling	553	553	0.68	0.76	0.60	0.65	0.82	0.76
Tackboard	48	48	0.00	0.06	0.03	0.19	0.06	0.00
People	5	5	0.20	0.27	0.33	0.37	0.40	0.40

Reverberation Times	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}	T_{60}
Calculated	0.628	0.553	0.694	0.630	0.513	0.563
Target	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6	0.4 - 0.6
	X	√	X	X	√	√

Appendix C – Humidity Loads

Respiration & Perspiration Load Per Hour

$W_{rp} = (n_1 \times rp_1) + (n_2 * rp_2) + ...$

n = # of people

rp = moisture release per person

Activity	lb/h
Seated, moderately active	0.19
Standing, light work, walking	0.19
Walking, standing	0.24
Seated, Light work	0.45

Second Level	n	Activity	n	Activity	n	Activity	W_{rp} [lb/h]
Chem./Biology Lab	20	0.19	1	0.24	-	-	4.04
Chem./Bio./Phy. Prep.	3	0.19	-	-	-	-	0.57
Ind. Lab	3	0.19	-	-	-	-	0.57
Chem./Physics Lab	20	0.19	1	0.24	-	-	4.04
Office Suite	5	0.19	-	-	-	-	0.95
Conference Room	13	0.19	-	-	-	-	2.47
Bio. Prep	3	0.19	-	-	-	-	0.57
Biology	21	0.19	1	0.24	-	-	4.23
Corridor			-	-	-	-	0
First Level							
Physics Lab	20	0.19	1	0.24	-	-	4.04
Phy. Prep.	2	0.19	-	-	-	-	0.38
Ind. Phy. Lab	2	0.19	-	-	-	-	0.38
Robotics and Workshop	18	0.19	8	0.45	1	0.19	7.21
Porch	5	0.19	15	0.24	-	-	4.55
Commons	12	0.19	-	-	-	-	2.28
K-2 Lab	11	0.19	1	0.24	-	-	2.33
Prep	1	0.19	-	-	-	-	0.19
3-5 Lab	11	0.19	1	0.24	-	-	2.33
Womens WC	2	0.19	-	-	-	-	0.38
Mens WC	2	0.19	-	-	-	-	0.38
Corridor			-	-	-	-	0

Appendix C – Humidity Loads

Clothing Load Per Hour

$W_c = n * (t/60) * ((R_{r1} - R_{r2})/2)$

n = # of visitors

t = minutes

R_{r1} = initial moisture release rate

R_{r2} = end-of-visit moisture release rate

	R_{r1}	R_{r2}
normal	0.0530	0.0165
with rain	0.0965	0.0300

Second Level	**n**	**t [min]**	**R_{r1} [lbs/h]**	**R_{r2} [lbs/h]**	**W_c [lb/h]**
Chem./Biology Lab	21	45	0.055	0.023	0.250
Chem./Bio./Phy. Prep.	3	-	-	-	0.000
Ind. Lab	3	-	-	-	0.000
Chem./Physics Lab	21	-	-	-	0.000
Office Suite	5	45	0.055	0.023	0.060
Conference Room	13	45	0.055	0.023	0.155
Bio. Prep	3	-	-	-	0.000
Biology	22	45	0.055	0.023	0.262
Corridor		15	0.097	0.055	0.000
First Level					
Physics Lab	21	45	0.055	0.023	0.000
Phy. Prep.	2	-	-	-	0.000
Ind. Phy. Lab	2	-	-	-	0.000
Robotics and Workshop	27	45	0.055	0.023	0.321
Porch	20	45	0.097	0.055	0.311
Commons	12	45	0.097	0.055	0.187
K-2 Lab	12	45	0.055	0.023	0.143
Prep	1	-	-	-	0.000
3-5 Lab	12	45	0.055	0.023	0.143
Womens WC		-	-	-	0
Mens WC		-	-	-	0
Corridor		15	0.097	0.055	0.000

Appendix C – Humidity Loads

Ventilation Air Load Per Hour

$Wv = Q * (60 * d) * (M_1 - M_2)$

Q = ventilation air flow

d = air density

M_1 = outdoor humidity ratio

M_2 = indoor humidity ratio

Second Level	**Q [cfm]**	**d [lb/ft³]**	**M_1 [lb/lb]**	**M_2 [lb/lb]**	**W_v [lb/h]**
Chem./Biology Lab	1460	0.0754	0.0065	0.005	9.91
Chem./Bio./Phy. Prep.	1400	0.0754	0.0065	0.005	9.50
Ind. Lab	300	0.0754	0.0065	0.005	2.04
Chem./Physics Lab	1680	0.0754	0.0065	0.005	11.40
Office Suite	500	0.0754	0.0065	0.005	3.39
Conference Room	275	0.0754	0.0065	0.005	1.87
Bio. Prep	700	0.0754	0.0065	0.005	4.75
Biology	1450	0.0754	0.0065	0.005	9.84
Corridor	420	0.0754	0.0065	0.005	2.85
First Level					
Physics Lab	820	0.0754	0.0065	0.005	5.56
Phy. Prep.	80	0.0754	0.0065	0.005	0.54
Ind. Phy. Lab	100	0.0754	0.0065	0.005	0.68
Robotics and Workshop	874	0.0754	0.0065	0.005	5.93
Porch	2220	0.0754	0.0065	0.005	15.06
Commons	110	0.0754	0.0065	0.005	0.75
K-2 Lab	480	0.0754	0.0065	0.005	3.26
Prep	140	0.0754	0.0065	0.005	0.95
3-5 Lab	480	0.0754	0.0065	0.005	3.26
Womens WC	60	0.0754	0.0065	0.005	0.41
Mens WC	60	0.0754	0.0065	0.005	0.41
Corridor	432	0.0754	0.0065	0.005	2.93

Appendix C – Humidity Loads

Infiltration Load Per hour-

$W_i = A * I_r * (60 * d) * (M_1 - M_2)$

A = wall surface exposed to wind
I_r = infiltration Rate
d = air density

M_1 = outdoor humidity ratio
M_2 = indoor humidity ratio

Probable Leak Rate	
Wall Construction	**cfm * ft²**
Tight	0.1
Average	0.3
Loose	0.6

Second Level	**A [ft²]**	**I_r [cfm / ft²]**	**d [lb / ft³]**	**M_1 [lb / lb]**	**M_2 [lb / lb]**	**W_i [lb / h]**
Chem./Biology Lab	440	0.3	0.0754	0.0065	0.005	0.90
Chem./Bio./Phy. Prep.	230	0.3	0.0754	0.0065	0.005	0.47
Ind. Lab		0.3	0.0754	0.0065	0.005	0.00
Chem./Physics Lab	740	0.3	0.0754	0.0065	0.005	1.51
Office Suite	230	0.3	0.0754	0.0065	0.005	0.47
Conference Room	125	0.3	0.0754	0.0065	0.005	0.25
Bio. Prep	110	0.3	0.0754	0.0065	0.005	0.22
Biology	440	0.3	0.0754	0.0065	0.005	0.90
Corridor		0.3	0.0754	0.0065	0.005	0.00
First Level						
Physics Lab	710	0.3	0.0754	0.0065	0.005	1.45
Phy. Prep.	140	0.3	0.0754	0.0065	0.005	0.29
Ind. Phy. Lab		0.3	0.0754	0.0065	0.005	0.00
Robotics and Workshop	175	0.3	0.0754	0.0065	0.005	0.36
Porch	1155	0.3	0.0754	0.0065	0.005	2.35
Commons		0.3	0.0754	0.0065	0.005	0.00
K-2 Lab	370	0.3	0.0754	0.0065	0.005	0.75
Prep		0.3	0.0754	0.0065	0.005	0.00
3-5 Lab	570	0.3	0.0754	0.0065	0.005	1.16
Womens WC	-	-	-	-	-	0
Mens WC	-	-	-	-	-	0
Corridor	-	-	-	0.0065	0.005	0.00

Appendix C – Humidity Loads

Door Load Per Hour

$W_d = n * A * V * d * (t/120)*(M_1 - M_2)$

n = # door openings

A = open door area

V = wind velocity

d = air density

t = open time

M_1 = outdoor humidity ratio

M_2 = indoor humidity ratio

Second Level	n [#]	A [ft2]	V [fpm]	d [lb/ft³]	t [s]	M_1 [lb/lb]	M_2 [lb/lb]	W_d [lb/h]
Chem./Biology Lab	-	-	792	0.0754	-	0.0065	0.005	0.00
Chem./Bio./Phy. Prep.	-	-	792	0.0754	-	0.0065	0.005	0.00
Ind. Lab	-	-	792	0.0754	-	0.0065	0.005	0.00
Chem./Physics Lab	-	-	792	0.0754	-	0.0065	0.005	0.00
Office Suite	-	-	792	0.0754	-	0.0065	0.005	0.00
Conference Room	-	-	792	0.0754	-	0.0065	0.005	0.00
Bio. Prep	-	-	792	0.0754	-	0.0065	0.005	0.00
Biology	-	-	792	0.0754	-	0.0065	0.005	0.00
Corridor	-	-	792	0.0754	-	0.0065	0.005	0.00
First Level								
Physics Lab	-	-	792	0.0754	-	0.0065	0.005	0.00
Phy. Prep.	-	-	792	0.0754	-	0.0065	0.005	0.00
Ind. Phy. Lab	-	-	792	0.0754	-	0.0065	0.005	0.00
Robotics and Workshop	-	-	792	0.0754	-	0.0065	0.005	0.00
Porch	-	-	792	0.0754	-	0.0065	0.005	0.00
Commons	5	22.5	792	0.0754	5	0.0065	0.005	0.42
K-2 Lab	-	-	792	0.0754	-	0.0065	0.005	0.00
Prep	-	-	792	0.0754	-	0.0065	0.005	0.00
3-5 Lab	-	-	792	0.0754	-	0.0065	0.005	0.00
Womens WC	-	-	-	-	-	-	-	0
Mens WC	-	-	-	-	-	-	-	0
Corridor	-	-	792	0.0754		0.0065	0.005	0.00

Wind Speed Conversion	
mph	fpm
1	88
2	176
3	264
4	352
5	440
6	528
7	616
8	704
9	792
10	880
11	968
12	10556
13	1144
14	1232
15	1320
16	1408
17	1496
18	1584
19	1672
20	1760

Appendix C – Humidity Loads

Vestibule Load Per Hour

$W_{vb} = n * V * f * d * (M_1 - M_2) / 2$

n = openings

V = vestibule volume

f = % vestibule volume that enters building

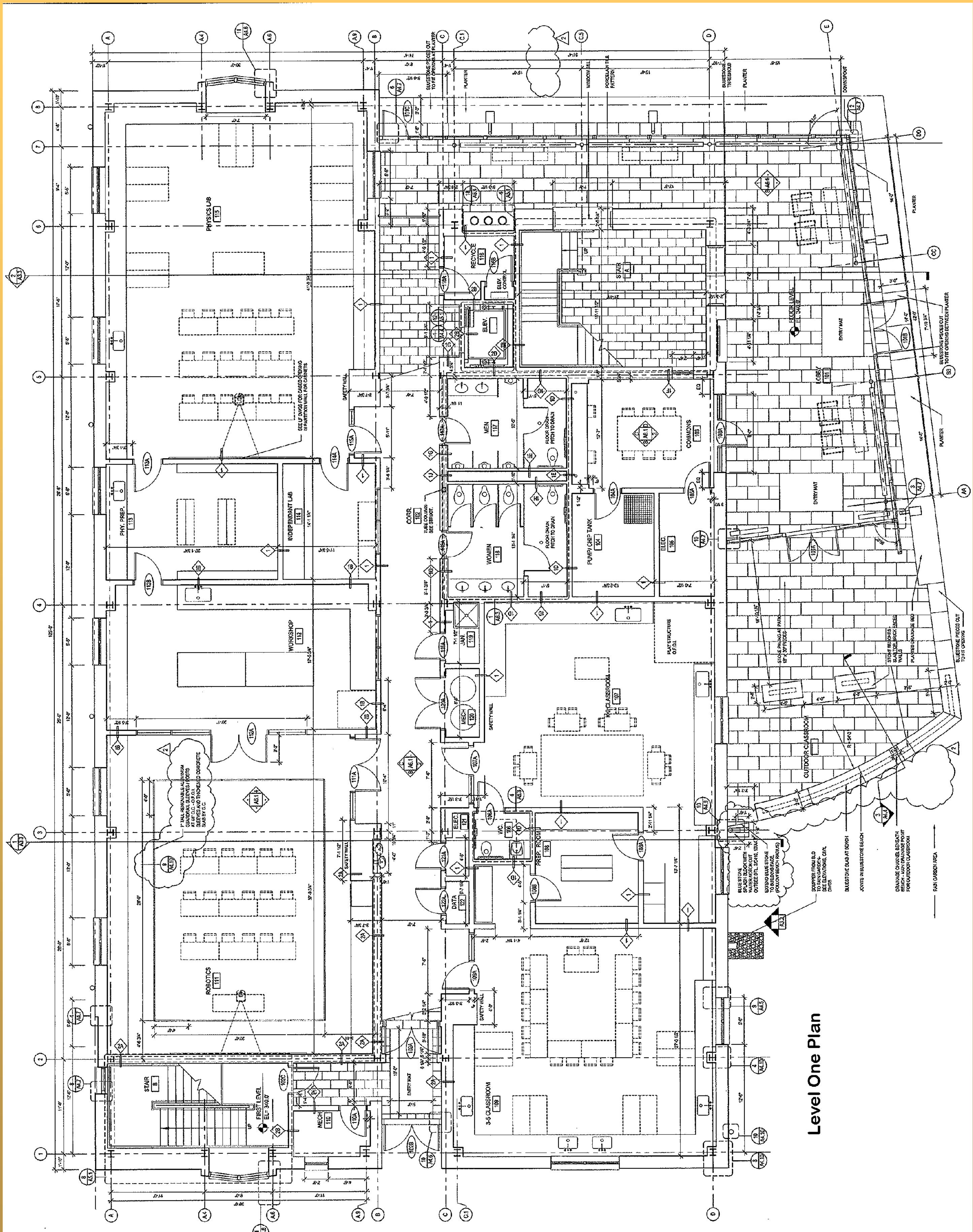
d = air density

M_1 = outdoor humidity ratio

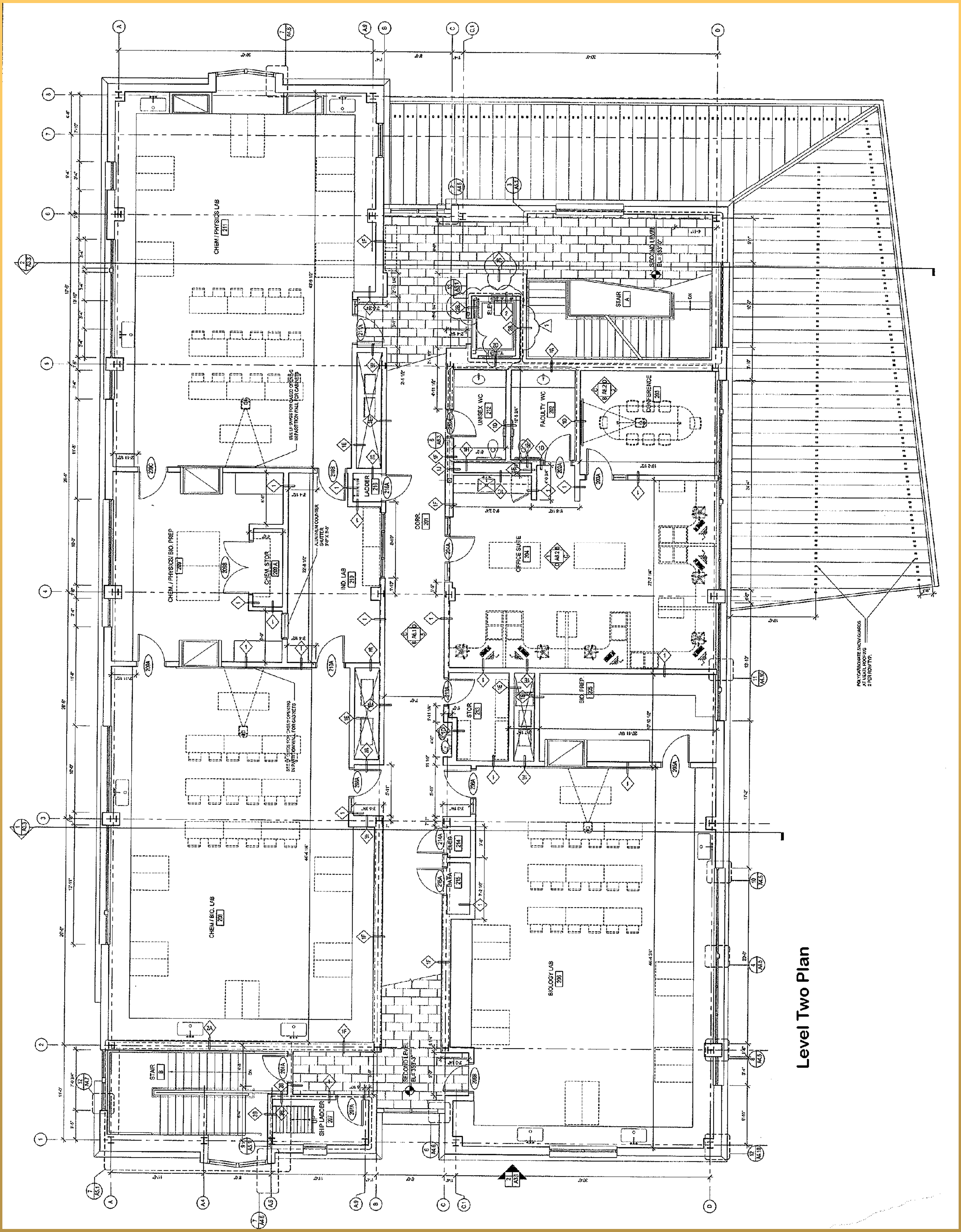
M_2 = indoor humidity ratio

Second Level	n [#/h]	V [ft³]	f [%]	d [lb/ft³]	M_1 [lb/lb]	M_2 [lb/lb]	W_d [lb/h]
Chem./Biology Lab	-	-	-	0.0754	0.0065	0.005	0.000
Chem./Bio./Phy. Prep.	-	-	-	0.0754	0.0065	0.005	0.000
Ind. Lab	-	-	-	0.0754	0.0065	0.005	0.000
Chem./Physics Lab	-	-	-	0.0754	0.0065	0.005	0.000
Office Suite	-	-	-	0.0754	0.0065	0.005	0.000
Conference Room	-	-	-	0.0754	0.0065	0.005	0.000
Bio. Prep	-	-	-	0.0754	0.0065	0.005	0.000
Biology	-	-	-	0.0754	0.0065	0.005	0.000
Corridor	-	-	-	0.0754	0.0065	0.005	0.000
First Level							0.000
Physics Lab	-	-	-	0.0754	0.0065	0.005	0.000
Phy. Prep.	-	-	-	0.0754	0.0065	0.005	0.000
Ind. Phy. Lab	-	-	-	0.0754	0.0065	0.005	0.000
Robotics and Workshop	-	-	-	0.0754	0.0065	0.005	0.000
Porch	-	-	-	0.0754	0.0065	0.005	0.000
Commons	-	-	-	0.0754	0.0065	0.005	0.000
K-2 Lab	-	-	-	0.0754	0.0065	0.005	0.000
Prep	-	-	-	0.0754	0.0065	0.005	0.000
3-5 Lab	-	-	-	0.0754	0.0065	0.005	0.000
Womens WC	-	-	-	-	-	-	0
Mens WC	-	-	-	-	-	-	0
Corridor	1	700	0.5	0.0754	0.0065	0.005	0.020

Floor Plans


Level One Plan
PHYSICS LAB
WORKSHOP
ROBOTICS
COMMONS
OUTDOOR CLASSROOM

Floor Plans



Appendix D – Trane Trace Results

ENERGY CONSUMPTION SUMMARY

By PENN STATE UNIVERSITY

	Elect Cons. (kWh)	Gas Cons. (kBtu)	% of Total Building Energy	Total Building Energy (kBtu/yr)	Total Source Energy* (kBtu/yr)
Alternative 1					
Primary heating					
Primary heating		1,354,340	44.5 %	1,354,340	1,425,621
Other Htg Accessories			0.0 %	0	0
Heating Subtotal		**1,354,340**	**44.5 %**	**1,354,340**	**1,425,621**
Primary cooling					
Cooling Compressor	14,764		1.7 %	50,388	151,180
Tower/Cond Fans	3,855		0.4 %	13,156	39,472
Condenser Pump			0.0 %	0	0
Other Clg Accessories	77,676		8.7 %	265,106	795,399
Cooling Subtotal....	**96,294**		**10.8 %**	**328,651**	**986,052**
Auxiliary					
Supply Fans			0.0 %	0	0
Pumps	102,522		11.5 %	349,909	1,049,832
Stand-alone Base Utilities	256,666		28.8 %	876,000	2,628,264
Aux Subtotal....	359,188		40.3 %	1,225,909	3,678,096
Lighting					
Lighting	36,022		4.0 %	122,944	368,869
Receptacle					
Receptacles	3,490		0.4 %	11,911	35,738
Cogeneration					
Cogeneration			0.0 %	0	0
Totals					
Totals**	**494,994**	**1,354,340**	**100.0 %**	**3,043,756**	**6,494,375**

* Note: Resource Utilization factors are included in the Total Source Energy value.
** Note: This report can display a maximum of 7 utilities. If additional utilities are used, they will be included in the total.

Project Name: New Science and Technology Center
Dataset Name: \\aep.coeaccess.psu.edu\profiles$\djk5003\Desktop\ACB MODEL-new.TRC

TRACE® 700 v6.2 calculated at 06:11 PM on 03/23/2009
Alternative - 1 Energy Consumption Summary report page 1

Appendix D – Trane Trace Results

MONTHLY ENERGY CONSUMPTION

By PENN STATE UNIVERSITY

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

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternative: 1	**ACB**												
Electric													
On-Pk Cons. (kWh)	11,132	10,037	12,327	10,879	12,332	16,662	14,247	16,166	15,986	11,907	11,433	10,648	153,755
Off-Pk Cons. (kWh)	18,619	16,798	17,410	18,472	20,164	17,449	20,835	17,848	18,726	18,690	17,884	19,224	222,117
Mid-Pk Cons. (kWh)	10,349	9,361	11,481	10,650	12,110	8,559	7,621	8,447	8,186	11,583	10,859	9,917	119,122
On-Pk Demand (kW)	101	103	98	100	109	112	104	108	112	103	101	101	112
Off-Pk Demand (kW)	42	42	42	46	48	51	51	50	49	47	47	42	51
Mid-Pk Demand (kW)	97	97	99	100	104	110	123	107	104	100	101	98	123
Gas													
On-Pk Cons. (therms)	751	710	515	270	150	134	97	160	115	271	454	556	4,185
Off-Pk Cons. (therms)	1,639	1,500	1,036	678	399	258	225	297	372	704	855	1,394	9,359
On-Pk Demand (therms/hr)	7	7	6	3	2	1	1	1	1	2	4	6	7
Off-Pk Demand (therms/hr)	13	14	10	9	3	1	1	1	1	9	9	11	14

Energy Consumption

Building	148,644 Btu/(ft2-year)
Source	317,156 Btu/(ft2-year)
Floor Area	20,477 ft2

Environmental Impact Analysis

CO_2	1,084,641 lbm/year
SO_2	8,386 gm/year
NOX	1,686 gm/year

Project Name: New Science and Technology Center
Dataset Name: \\aep.coeaccess.psu.edu\profiles$\djk5003\Desktop\ACB MODEL-new.TRC

TRACE® 700 v6.2 calculated at 06:11 PM on 03/23/2009
Alternative - 1 Monthly Energy Consumption report Page 1 of 1

Appendix D – Trane Trace Results

SYSTEM HUMIDITY PROFILES

By PENN STATE UNIVERSITY

Room Description	---- Maximum ---- %Rh	Mo	Hr	Day	Number of Hours at each Percentage Range >70%	70-66	66-62	62-58	58-54	54-50	50-46	46-42	42-38	38-34	34-30	<30 %	---- Minimum ---- %Rh	Mo	Hr	Day
3-5 Classroom	100	12	21	2	5,414	686	502	330	423	442	270	201	162	126	158	46	29	8	16	8
Attic	48	1	1	1	0	0	0	0	0	0	458	2,523	2,010	868	2,874	27	30	2	19	7
Bio Prep	100	12	24	2	4,886	488	450	721	457	305	972	319	162	0	0	0	39	7	1	2
Biology Lab	100	12	2	8	5,350	712	324	453	652	537	440	206	86	0	0	0	40	7	23	8
Chem/Bio Lab	100	12	24	2	6,241	626	639	702	295	195	55	7	0	0	0	0	41	1	1	1
Chem/Physics Lab	100	12	7	8	6,340	259	609	650	439	239	179	45	0	0	0	0	40	1	1	1
Chem/Physics/Bio Prep	100	2	11	2	2,417	234	300	480	485	610	582	700	590	606	475	1,281	20	7	15	7
Commons	100	12	17	7	4,182	546	615	445	522	733	984	488	239	6	0	0	36	2	11	2
Conference Room	100	12	24	2	6,599	964	735	334	102	9	3	11	3	0	0	0	40	2	8	2
Corridor 1st floor	50	9	15	2	0	0	0	0	0	3	879	2,107	2,052	1,871	1,848	0	30	11	6	10
Corridor 2nd floor	49	9	15	2	0	0	0	0	0	0	362	2,273	2,299	1,842	1,984	0	30	3	10	7
Electrical Room	44	6	18	8	0	0	0	0	0	0	0	419	2,759	1,415	4,117	50	30	1	15	10
Faculty WC	67	10	8	8	0	94	250	233	531	677	869	1,428	2,565	1,171	942	0	30	12	17	2
Ind Lab (2nd Floor)	100	12	8	7	3,902	392	564	527	389	664	801	802	490	229	0	0	34	7	1	2
Independant Physics Lab (1st Floor)	100	12	15	7	3,503	564	407	592	701	863	1,367	332	384	44	3	0	33	2	13	2
K-2 Classroom	100	12	21	2	4,850	1,092	821	560	571	354	151	147	123	87	4	0	34	8	15	8
Mens WC 1st floor	100	12	19	7	3,377	1,047	1,178	694	1,181	626	313	195	117	32	0	0	36	2	16	10
Office Suite	100	12	21	7	3,576	843	1,138	1,551	1,118	403	86	19	16	7	3	0	33	2	10	2
Physics Lab	100	12	6	2	6,390	143	746	544	455	276	206	0	0	0	0	0	40	1	1	1
Physics Prep	100	12	21	7	2,461	868	746	846	521	615	887	1,257	455	94	10	0	30	2	13	2
Porch	86	3	17	2	873	801	838	1,054	1,369	1,224	1,014	832	463	260	32	0	33	2	7	10
Prep room (108b)	99	2	11	10	1,290	412	361	274	259	281	284	504	873	855	1,019	2,348	16	8	3	8
Pump/Chip Tank Room	43	6	19	8	0	0	0	0	0	0	0	338	2,986	1,199	4,204	33	29	3	17	1
Robotics/workshop	100	12	23	2	6,411	667	521	474	314	163	126	84	0	0	0	0	43	7	19	8
Stairwell A	51	1	6	2	0	0	0	0	0	14	102	262	2,093	3,128	2,219	942	24	7	21	8
Stairwell B	56	2	8	8	0	0	0	0	281	167	209	417	1,095	1,900	3,233	1,458	19	7	23	8
Unisex WC	69	10	8	8	0	235	144	212	587	744	909	1,981	2,125	930	893	0	30	12	17	2
WC (k-2 Classroom)	72	4	3	8	100	273	141	197	491	948	1,228	2,186	1,791	714	691	0	30	1	10	1
Womens WC 1st floor	100	11	14	8	2,856	587	1,401	858	1,212	965	366	265	180	70	0	0	35	2	16	10

Daytypes:

1. Design 2. Monday 3. Tuesday 4. Wednesday 5. Thursday 6. Friday 7. Saturday 8. Sunday 9. Holiday 10. Weekday 11. Weekend

Project Name: New Science and Technology Center
Dataset Name: \\aep.coeaccess.psu.edu\profiles$\djk5003\Desktop\ACB MODEL-new.TRC

TRACE® 700 v6.2 calculated at 06:11 PM on 03/23/2009
Alternative - 1 System Humidity Profiles Report Page 1 of 1

Appendix D – Trane Trace Results

Design Cooling Load Summary

By PENN STATE UNIVERSITY
New Science and Technology Center
Philadelphia, PA

System - ACB

Type - 4-pipe Induction

Coil Location - System

Coil Peak Calculation Time: July, hour 18
Ambient DB/WB/HR: 85 / 71 / 94

COOLING COIL LOAD INFORMATION

Load Component	Sensible Btu/h	Latent Btu/h	Total Btu/h	Percent of Total
Solar Gain	60,586		60,586	17.2%
Glass Transmission	12,247		12,247	3.5%
Wall Transmission	11,058		11,058	3.1%
Roof Transmission	0		0	0.0%
Floor Transmission	-370		-370	-0.1%
Adj Floor Transmission	0		0.00	0.0%
Partition Transmission	49,521		49,521	14.1%
Net Ceiling Load	0		0	0.0%
Lighting	10,153		10,153	2.9%
People	19,416	36,156	55,571	15.8%
Misc. Equipment Loads	13,590	0	13,590	3.9%
Cooling Infiltration	-1,511	4,107	2,596	0.7%
Sub-Total ==>	174,690	40,262	214,952	61.1%
Ventilation Load	1,696	-87	1,609	0.5%
Exhaust Heat	-1,777	0	-1,777	-0.5%
Supply Fan Load	6,445		6,445	1.8%
Return Fan Load	3,659		3,659	1.0%
Net Duct Heat Pickup	0		0	0.0%
Wall Load to Plenum	2,383		2,383	0.7%
Roof Load to Plenum	105,167		105,167	29.9%
Adj Floor to Plenum	0		0	0.0%
Lighting Load to Plenum	9,432		9,432	2.7%
Misc. Equip. Load to Plenum	0	0	0	0.0%
Glass Transmission to Plenum	0		0	0.0%
Glass Solar to Plenum	0		0	0.0%
Over/Under Sizing	9,841		9,841	2.8%
Reheat at Design	0	0	0	0.0%
Underfloor Sup Heat Pickup	0		0	0.0%
Supply Air Leakage	0	0	0	0.0%
Total Cooling Loads	311,537	40,175	351,712	100.0 %

COOLING COIL SELECTION

Coil Selection Parameters

Coil Entering Air (DB / WB)	87.1 / 64.1	°F
Coil Entering Humidity Ratio	52.46	gr/lb
Coil Leaving Air (DB / WB)	53.6 / 51.2	°F
Coil Leaving Humidity Ratio	52.27	gr/lb
Coil Sensible Load	155.16	MBh
Coil Total Load	159.18	MBh
Cooling Supply Air Temperature	55.00	°F
Total Cooling Airflow	4,264.94	cfm
Resulting Room Relative Humidity	31.95	%

General Engineering Checks

Total Cooling Load	78.6	ton
Area / Load	543.42	ft²/ton
Total Floor Area	20,477	ft²
Cooling Airflow	0.21	cfm/ft²
Airflow / Load	113.18	cfm/ton
Percent Outdoor Air	3.7	%
Cooling Load Methodology	TETD-TA1	

Project Name: New Science and Technology Center
Dataset Name: \\aep.coeaccess.psu.edu\profiles$\djk5003\Desktop\ACB MODEL-new.TRC

TRACE® 700 v6.2 calculated at 06:11 PM on 03/23/2009
Alternative - 1 Design Cooling Load Report Page 1 of 1