Technical Assignment 2

Building and Plant Energy Analysis

David H. Koch Institute for Integrative Cancer Research

Massachusetts Institute of Technology

Cambridge, Ma



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Executive Summary

Part 1 of this report utilizes energy simulation software, Trane TRACE, to estimate the loads of the David H. Koch Institute. The energy model constructed in this program was based off information found in the design documents to most accurately simulate the building conditions. In the event that information was not readily available in the design documents, rule of thumb values taken from AHSRAE Handbook of Fundamentals and approximations were assumed.

The resulting loads generated by the simulation software were found to be similar to the project design loads. Discrepancies and variance from the design values was for the most part due to assumptions during the modeling procedure. The estimated heating load varied the most from the design load which could have been a result of many things. By omitting the hydronic system that is designed to alleviate high intensity loads from the model, this placed excessive loads on the 100% Outdoor Air System. This coupled with assumptions made during fan selection led to a high amount of heat gain from the fans, rendering all other heating loads minute.

Part 2 of this report analyzes the energy consumption of the building and all of its components. The estimated loads from Part 1 were divided up among the various building systems and were turned into energy consumptions in kWh. Utilizing regional utility rates and emission factors, these fractional consumptions were then used to generate annual operational building cost and emissions footprint.

The cost per square foot of the building was found to be $1.27 which is reasonable. It is a bit low considering the equipment loads generated in a laboratory building, yet this may also be attributed to the abnormally low heating load. Also, the 7th floor that was omitted from the model contains many high load intensity spaces that would bring the cost per square foot closer to its expected value.

It is important to note that the following report is based on a simplified energy model. Though the majority of the data was retrieved from the design documents, the complexity of the spaces and systems could not be precisely modeled within the time constraints of this project.

Part 1
Design Load Estimation

Assumptions

Energy Simulation Program

The energy analysis that is evaluated throughout this report was performed in Trane Air Conditioning Economics (TRACE) 700H. To accurately simulate the n necessary. A large portion of the design criteria entered into TRACE was available in the design documents themselves. Information regarding the building envelope was provided to the engineers by the Architect Ellenzweig.

The TRACE model constructed for the purpose of this report is limited in detail due to the complexity of the design and time restraints of the project. Therefore, to model the building in an accurate manner a block load approximation method was utilized, dividing the building into perimeter and interior zones. To estimate accurate peak and yearly design loads, information from the design documents was thoroughly analyzed and entered into TRACE. The following sections of the report describe in depth the data entered into TRACE, as well as the methods utilized to attain this data accurately.

Outdoor and Indoor Design Conditions

The weather data entered into Trace was taken from ASHRAE Weather Data as well as d by the design engineers. The Koch Institute is located in Cambridge, Ma and the following data was entered into Trace.

Outdoor Design Conditions	
Weather Location	Boston, MA
Summer Dry Bulb (°F)	88
Summer Wet Bulb (°F)	74
Winter Dry Bulb (°F)	9
Summer Clearness	0.85
Winter Clearness	0.85
Summer Ground Reflectiveness	0.2
Winter Ground Reflectiveness	0.2
Carbon Dioxide Level	400

Figure 1 *– Outdoor Design Conditions*

Thermostat Settings	
Cooling Dry Bulb (°F)	74
Heating Dry Bulb (°F)	72
Relative Humidity %	50
Cooling Driftpoint (°F)	90
Heating Driftpoint (°F)	55

Sensor Locations	
Thermostat	Room

Humidity	
Moisture Capacitance	Medium
Humidistat Location	Room

Figure 2 *– Indoor Design Conditions*

Airflow

Two separate airflow templates were created for the TRACE Model, one for the Corridor/Lobby zones and the second for all other zones. They differ in the Ventilation, where Corridor/Lobby assumes 0.5 cfm/ft^2 (heating and cooling) and the remaining spaces receive 100% Clg. Airflow. Both templates assume:

- Neutral, Tight Construction
- VAV minimum rate of 30% Clg. Airflow

Building Construction

Construction		
Location	Type	U-Value (Btu/h*ft^2*°F)
Slab	4" LW Concrete	0.213
Roof	4" LW Concrete	0.214
Wall	8" LW Block, 2" Insulation	0.100
Partition	0.75" Gypsum Frame	0.388

Figure 3 *– Slab, Roof, Wall and Partition Construction*

Heights	
Wall	9.5 ft
Floor to Floor	15 ft
Plenum	5.5 ft

Figure 4 *– Heights*

Glass Type			
Location	Type	U-Value (Btu/h*ft^2*°F)	Shading Coefficient
Window	Double Coated 1/4"	0.35	0.4
Skylight	Double Coated 1/4"	0.35	0.4

Figure 5 *– Glass Types and Associated U-Value's*

Block Load Approximation - Method & Procedure

The Koch Institute is comprised of a variety of office spaces, biology labs, engineering labs, lab support, conference rooms, lobby spaces and a multitude of public spaces. Therefore, to properly model the 360,000 GSF building, a detailed analysis of the distribution of these spaces throughout the building levels was performed.

During this procedure it was noticed that Level 2-6 followed similar layouts and could be modeled as one typical floor in TRACE. Level 1 does not share this layout and therefore was modeled separately. Level 7 is a very complex vivarium space served by its own two air handling units AHU 4 & 5. Due to complexity and time constraints this floor was not modeled in TRACE. It was noted however that the 2 factory built-up air handling units that serve Level 7 are the same size as the 8 AHU's that serve Levels 1-6. Therefore, the missing load can be approximated based off the results of this simulation.

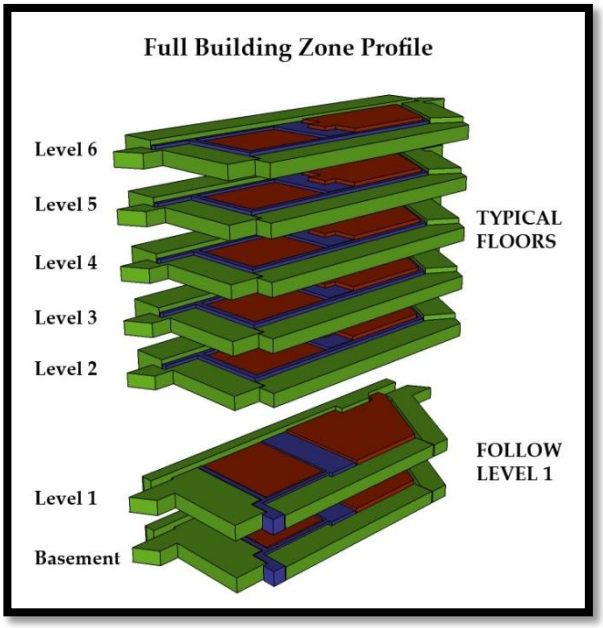


Figure 6 *– Full Building Zone Profile*

The Levels were broken up into perimeter, interior and corridor/lobby zones for evaluation. In the following figures, blue depicts the Corridor/Lobby zones, red depicts the Interior zones and green depicts the Perimeter zones. Interior zones were split into east and west following the east and west shaft design through which these areas are served by their respective air handling units.

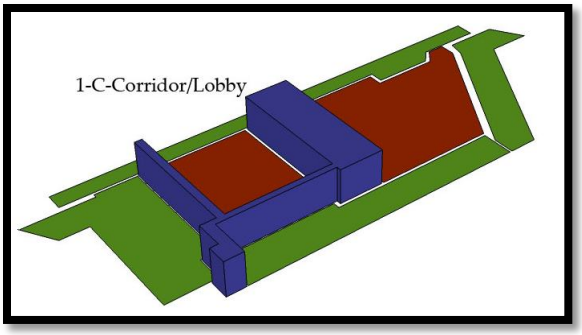


Figure 7 *– Interior Corridor/Lobby Zone – Levels B-l*

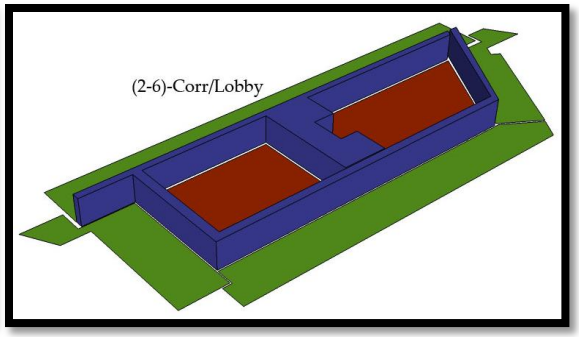


Figure 10 *– Interior Corridor/Lobby Zones – Levels 2-6*

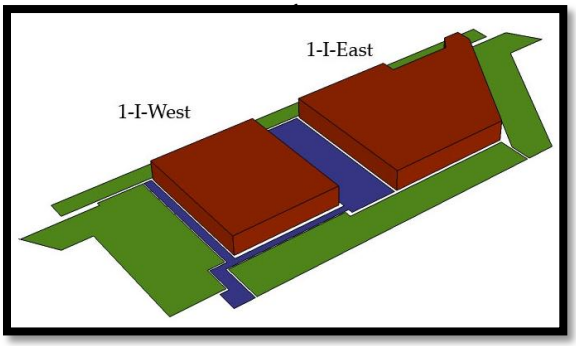


Figure 8 *– Interior East and West Zones – Levels B-1*

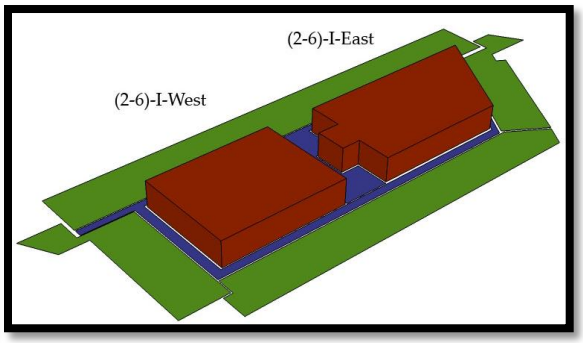


Figure 11 *– Interior East and West Zones – Levels 2-6*

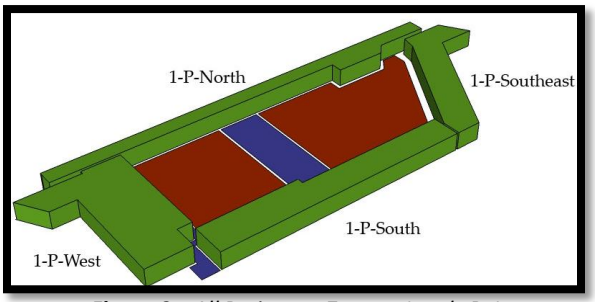


Figure 9 *– All Perimeter Zones – Levels B-1*

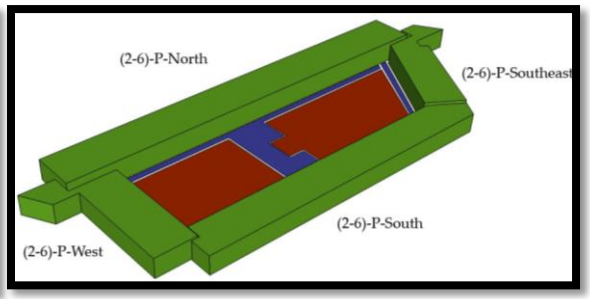


Figure 12 *– All Perimeter Zones – Levels 2-6*

Trace Template Name	Levels	Zone
(2-6)-Corr/Lobby	2 to 6	Corridor/Lobby
(2-6)-I-East	2 to 6	Interior East
(2-6)-I-West	2 to 6	Interior West
(2-6)-P-North	2 to 6	Perimeter North
(2-6)-P-South	2 to 6	Perimeter South
(2-6)-P-Southeast	2 to 6	Perimeter Southeast
(2-6)-P-West	2 to 6	Perimeter West
1-C-Corr/Lobby	1	Corridor/Lobby
1-I-East	1	Interior East
1-I-West	1	Interior West
1-P-North	1	Perimeter North
1-P-South	1	Perimeter South
1-P-Southeast	1	Perimeter Southeast
1-P-West	1	Perimeter West

Irregularly shaped zones were assigned a length and width based on an equivalent areas

Figure 13 *– Zone list with Trace Template Names*

The figures above are diagrammatic views of the zones created in the TRACE Model for this design load evaluation. Down the left column, ***Figures 7, 8 & 9*** portray the Level 1 zones as they are in the Model. Down the right column, ***Figures 10, 11 & 12*** depict the Level 2-6 typical zone distribution.

The Table to the left shows the breakdown of these zones. Here the TRACE Template can be matched with the full name of each zone.

When performing block load estimations, it is imperative to ensure that critical spaces within each zone are not overlooked. To most accurately decide on internal load characteristics for each zone, a breakdown of the spaces within each zone was created. ***Figure 14*** below is a sample of the 1st Floor West Perimeter zone. (All other zone breakdowns can be found in Appendix B)

Perimeter Zones - 1st Floor West Wall			
Room #	Space Name	Space Type	Floor Area (ft^2)
181	N. Proteo./Biopolymers	Science Laboratories	1168
181A	Prep/Equip	Science Laboratories	424
181B	BP Office	Office Space	113
185	S. Proteo./Biopolymers	Science Laboratories	884
185A	Data Analysis	Office Space	258
189	Office	Office Space	261
189A	BI Office	Office Space	125
189B	BI Office	Office Space	143
189C	BI Office	Office Space	156
189D	Proteometrics	Office Space	115
			3647

The areas of each "Space Type" were then added up producing a breakdown of the West Perimeter Zone's area. A sample of a zone breakdown is shown in the bottom left ***Figure 15***.

As you can see in ***Figure 16*** the "**Density (People)"** column was calculated for each "**Space Type**" and summed. The "**Heat Gain**" and "**Energy**" columns are weighted by the "**% Zone Area**" column, producing values representative of the spaces within the West Perimeter Zone. These values were then summed to specify accurate internal load characteristics for the zone. The values entered into TRACE are shown to the right in Figure #. This method was performed for every individual zone to ensure accuracy throughout the model. All other tables can be found in Appendix B.

Level 1 - Perimeter West Zone								
Space Type	Area	% Zone Area	Density (ft^2/person)	Density (people)	Heat Gain (W/ft^2)	Avg. Heat Gain (W/ft^2)	Energy (W/ft^2)	Avg. Energy (W/ft^2)
Office	1171	0.32	100.00	11.71	1.50	0.48	2.00	0.64
Laboratory	2052	0.56	33.00	62.18	1.80	1.01	5.00	2.81
Equipment	424	0.12	400.00	1.06	1.30	0.15	40.00	4.65
	3647			**74.95**		**1.65**		**8.11**

WEST ZONE AVERAGE VALUES	
Density (people)	**74.00**
Heat Gain (W/ft2)	**1.65**
Energy (W/ft2)	**8.00**

Figure 15 – *Sample Zone Space Breakdown and Internal Load Determination Method*

Figure 16 – *Internal Load Values Entered into Trace*

System

The roof was not entered into the TRACE model based on the following condition:

- The large penthouse located on the building generates large amounts of heat leaves very little roof area above conditioned spaces, therefore rendering conduction through the roof negligible.

The air handlers shown in red are the 2 air handling units that serve the 7th Level vivarium space, which were omitted from the TRACE Model. Therefore the goal of this model was to best simulate the energy consumption of remaining 8 units that serve the Basement through 6th Level. Together these units provide 200,000 cfm of conditioned air to the seven levels. The individual floor distribution of this air all stems from the two main ducts running down the East and West shafts.

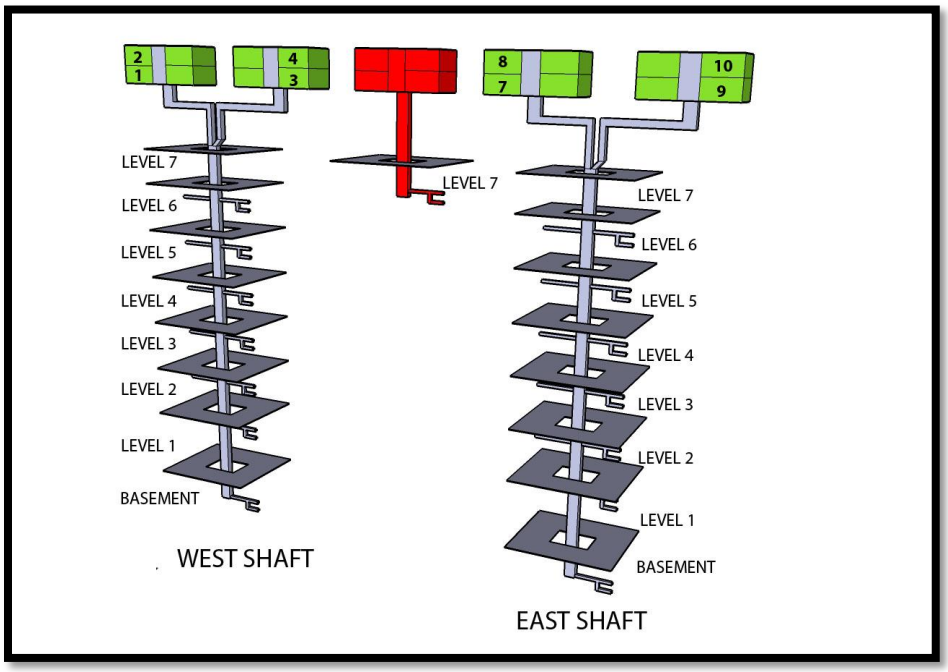


Figure 17 *– Air Riser Diagram Representation*

The air handlers modeled follow the same nomenclature as the designed units depicted above in ***Figure 17***. For organizational purposes the zones were assigned to AHU's based on their location relative to each shaft. For example, the West Perimeter Zone on all levels has been assigned to AHU-3 because those zones are designed to be served via the West Shaft.

Design vs. Estimate Comparison

Ventilation and Cooling Capacity

Air Handling Units Serving West Shaft (Estimate)				Total Capacity CC	
Loaction Served	Floors	cfm	ton	MBh	
AHU-1	Corr/Lobby	B - 3rd	12,862	75	904
AHU-2	Per-South	B - 6th	65,534	322	3,867
AHU-3	Per-West	B - 6th	38,497	170	2,042
AHU-4	Int-West	B - 6th	34,974	169	2,024
		Totals	151,867	736	8,837

Designed Air Handling Units Serving West Shaft				Total Capacity CC	
Loaction Served	Floors	cfm	ton	MBh	
AHU-1	West Shaft	B - 6th	50,000	308	3,700
AHU-2	West Shaft	B - 6th	50,000	308	3,700
AHU-3	West Shaft	B - 6th	50,000	308	3,700
AHU-4	West Shaft	B - 6th	50,000	308	3,700
	Totals	200,000	1,232	14,800	

Air Handling Units Serving East Shaft (Estimate)				Total Capacity CC	
Loaction Served	Floors	cfm	ton	MBh	
AHU-7	Corr/Lobby	4th - 6th	12,295	67	799
AHU-8	Per-North	B - 6th	67,358	381	4,565
AHU-9	Per-Southeast	B - 6th	32,145	164	1,969
AHU-10	Int-East	B - 6th	88,633	464	5,572
		Totals	200,431	1,076	12,906

Designed Air Handling Units Serving East Shaft				Total Capacity CC	
Loaction Served	Floors	cfm	ton	MBh	
AHU-7	East Shaft	B - 6th	50,000	308	3,700
AHU-8	East Shaft	B - 6th	50,000	308	3,700
AHU-9	East Shaft	B - 6th	50,000	308	3,700
AHU-10	East Shaft	B - 6th	50,000	308	3,700
	Totals	200,000	1,232	14,800	

Figure 18 *– Modeled Air Handling Units vs. Designed Air Handling Units*

The The individual air handling units estimated and designed do not match due to the assumed zone assignments during the construction of the TRACE model. The design system serves all floors through common ducts, combining the capacities of the 8 units to meet the load. Therefore, a better comparison can be seen below in ***Figure 19***. This shows that the cfm, tons and MBh of the estimate is fairly close to that of the design, especially with the number of assumptions made in the construction of the TRACE model. Time permitting, more detailed area calculations as well as the addition of the basement and roof conduction loads would help to bring the estimated values closer to the designed.

Totals		
	Estiamated	Designed
cfm	352,298	400,000
ton	1,812	2,464
MBh	21,744	29,600

Figure 19 *– Sum of 8 AHU Characteristics (Modeled vs. Design)*

Estimated		Designed	
248,984	Floor Area	280,000	
352,298	cfm	400,000	
1,812	ton	2,464	
Cooling			% Difference
1.41	cfm/ft^2	1.43	0.95
194.42	cfm/ton	162.34	-19.77
137.41	ft^2/ton	113.64	-20.92

Figure 20 *– Engineering Check Comparisons*

The estimated supply air cfm/ft^2 is within 1% of the design because it was driven by the ventilation in this case, which was modeled precisely to meet the design documents. The values for cooling cfm/ton and ft^2/ton are roughly 20% higher than the design. The discrepancy in the floor area could be driving these values apart due to some initial area tabulation error.

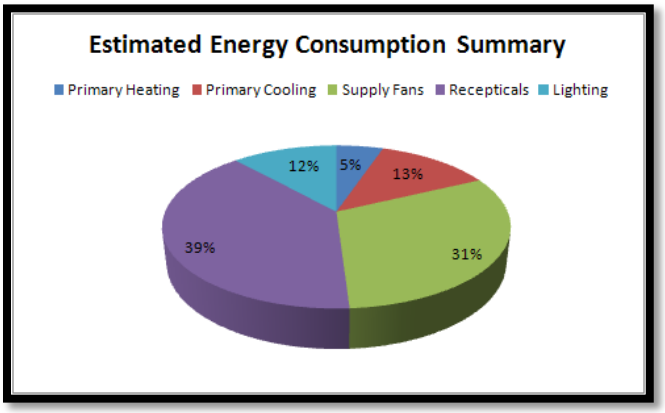


Figure 21 *– Estimated Energy Consumption Summary*

Figure 21 shows the breakdown of estimated energy consumption throughout the Koch Institute. The estimation appears to be reasonable in all areas except the Primary Heating Load. The low heating load could be a result of the assumption to not model a roof or basement walls which would drive the conduction losses up, increasing the heating load. There is also a large amount of heat produced by the fans that is included in the model that in reality exits through the penthouse and does not aid in heating the modeled zones. Heating load is expected to be a smaller load than cooling in a 100% Outdoor Air System as a result of high latent loads during the summer months, which remains consistent in this estimation.

A research facility of its magnitude is expected to have a high equipment load, which is modeled above as a 39% receptacle load. The 100% outdoor air cooling system is also anticipated to produce large cooling loads. The Supply Fans and Primary Cooling load fractions make up the total cooling load for this 100% outdoor air cooling system. This represents 44% of the total building energy consumption which is high, yet the heat pipe system was not modeled. This preconditioning of the outdoor airstream would reduce this load significantly.

Part 2
Design Load Estimation

Monthly Consumption

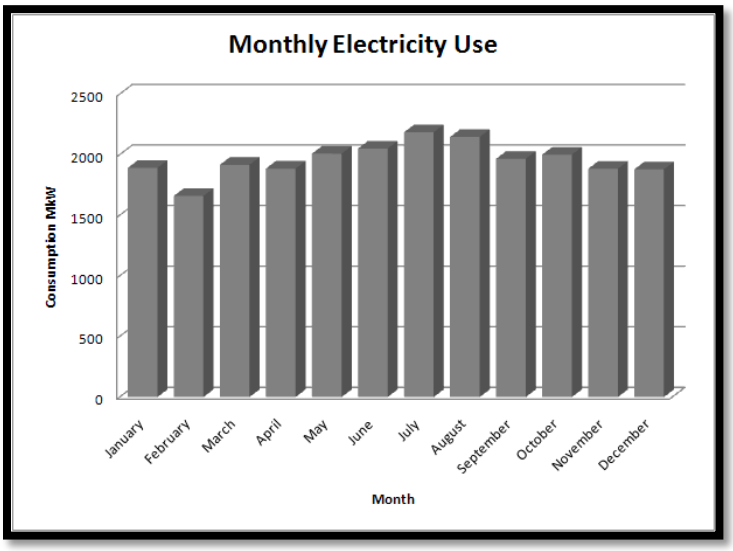


Figure 22 *– Monthly Electricity Use*

Figure 22 shows the monthly electric consumption in Mega Watts estimated by the TRACE energy model. The consumption peaks during the summer months as anticipated. The high dehumidification loads on the 100% Outdoor Air System during these months coupled with the solar gain and internal loads. ***Figure 23*** illustrates the water used by the mechanical systems per month for one calendar year. The volumes are shown in thousand gallons, peaking in July at 5,153,000 gallons.

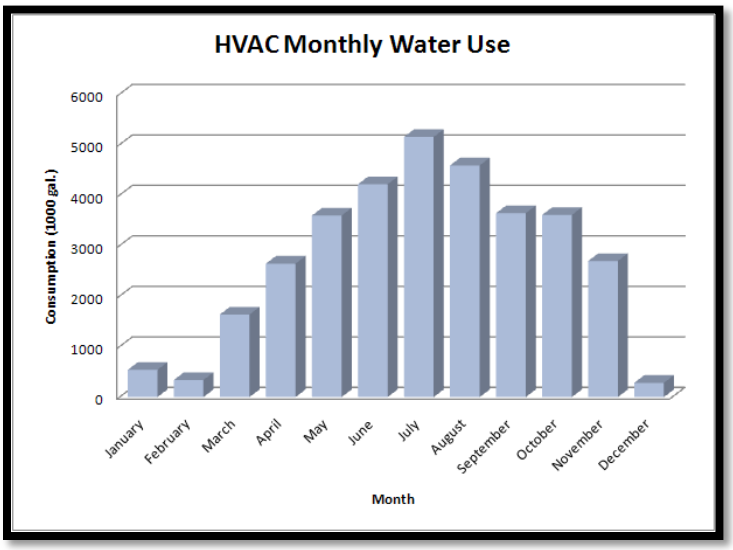


Figure 23 *– Monthly HVAC Water Consumption*

MIT's cogeneration plant utilizes a 25MW Combustion Turbine Generator. This generator provides 80% of the electricity consumed by the campus. The turbine runs on Natural Gas purchased from NSTAR based on a large commercial service rate (G-43).

Energy Cost Analysis - Utilizes MIT's 25MW Steam Turbine Generated Electricity
Natural Gas Rates Based on Low Load Factor General Service - Large (G-43)

	On-Peak Natural Gas $0.4571 per therm					Off-Peak Natural Gas $0.3241 per therm			
	Electric		Purchased Steam			Electric		Purchased Steam	
	kWh	Therms	Therms			kWh	Therms	Therms	
January	804,336	34,305	7.00	$ 15,683.98	January	1,087,260	46,372	339.00	$ 21,351.43
February	725,369	30,937	148.00	$ 14,208.95	February	934,579	39,860	785.00	$ 18,578.74
March	894,152	38,136	0.00	$ 17,431.77	March	1,022,659	43,616	0.00	$ 19,937.06
April	793,222	33,831	0.00	$ 15,464.11	April	1,092,452	46,593	0.00	$ 21,297.70
May	903,845	38,549	0.00	$ 17,620.74	May	1,104,994	47,128	0.00	$ 21,542.21
June	962,544	41,053	0.00	$ 18,765.10	June	1,088,359	46,419	0.00	$ 21,217.90
July	894,085	38,133	0.00	$ 17,430.47	July	1,291,034	55,063	0.00	$ 25,169.11
August	1,018,389	43,434	0.00	$ 19,853.81	August	1,128,107	48,114	0.00	$ 21,992.80
September	831,319	35,456	0.00	$ 16,206.83	September	1,135,509	48,429	0.00	$ 22,137.11
October	898,652	38,328	0.00	$ 17,519.50	October	1,101,999	47,000	0.00	$ 21,483.82
November	830,615	35,426	0.00	$ 16,193.10	November	1,053,594	44,936	0.00	$ 20,540.15
December	760,308	32,427	25.00	$ 14,833.87	December	1,118,783	47,716	609.00	$ 22,089.40

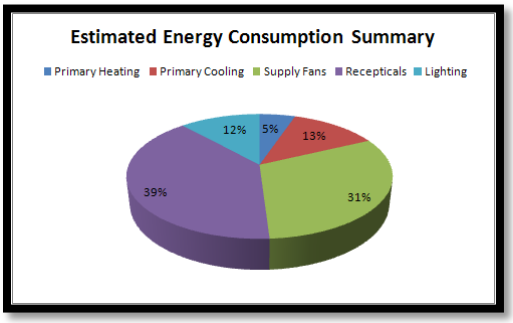
On-Peak Total $201,212.25 **Off-Peak Total** $257,337.42

Note: Therm=kWh*0.03412 conversion was utilized as well as an efficiency of 80% was assumed for the steam turbine

Figure 24 *– Energy Cost Analysis Table*

To estimate the energy cost incurred on the University the monthly energy consumption was exported from TRACE. Electric energy consumption was converted from kWh to Therms and added to the Purchased Steam. The estimated total yearly energy consumption is roughly $460,000. No utility bills are available yet because the building is not yet operable so a baseline consumption cost is not known.

The cost of natural gas is very low based on this rate which lowers the energy consumption cost considerably. The energy plant specifics were not available so rough approximations were made in the TRACE model which would vary the consumption. A hydronic system is responsible for many high intensity load areas such as equipment rooms and cold rooms throughout the building which was not modeled in TRACE. ***Figure 25*** below provides a breakdown of the annual cost to provide energy to all major end users.

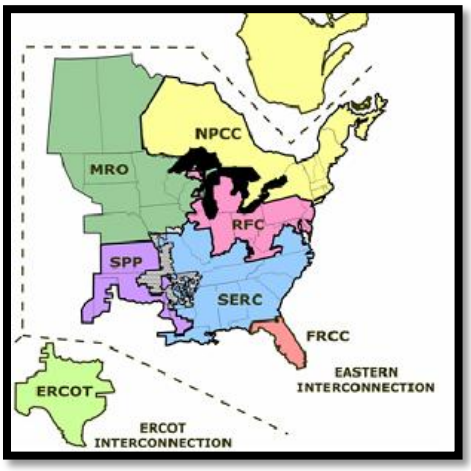


Energy Cost Breakdown

End User	Yearly Cost of Operation	$/ft²
Primary Heating	$ 23,844.58	0.066
Primary Cooling	$ 58,235.81	0.162
Supply Fans	$ 142,608.95	0.396
Recepticals	$ 180,210.02	0.501
Lighting	$ 53,650.31	0.149
Building Total	$ 458,549.66	1.274

Figure 25 *– Fractional Energy Consumption*

Emissions



Pollutant (lb) Generated During On-Site Combustion		
Pollutant	(lb pollutant/1000m3 Natural Gas)	lb pollutant
CO_{2e}	1.25E+02	4.51E+04
CO_2	1.22E+02	4.41E+04
CH_4	5.26E-02	1.90E+01
N_2O	4.54E-03	1.64E+00
NO_X	3.51E-01	1.27E+02
SO_X	6.32E-04	2.28E-01
CO	1.75E-01	6.32E+01
TNMOC	2.06E-03	7.44E-01
Lead	5.00E-07	1.81E-04
Mercury	2.60E-07	9.39E-05
PM10	2.64E-02	9.53E+00

Figure 26 *– Building Emissions Footprint Analysis*

Figure 26 demonstrates the estimated building emissions profile based on data taken from the ***Source Energy and Emission Factors for Energy Use in Buildings*** provided. To calculate the amount of Natural Gas consumed annually, the therms were converted to m^3 Natural Gas (therm*0.36) and then divided by 1000, leaving the desired units for the pollutant calculation.

Summary

The above analysis is a simplified estimation of the Koch Institute's energy consumption. Many assumptions were made in the construction of the TRACE energy model due to time constraints and availability of the building and campus system specifics. All assumptions are limited to the data contained within the design documents and discussions with the design engineer. Small changes in the criteria entered into TRACE can affect the levels of consumption considerably due to the scale of the project.

The design engineers conducted a similar energy analysis in TRACE yet a detailed model was conducted by an outside party. Results from this analysis were not readily available at the time of this report, and therefore the two have not been compared. The building is not yet operable and therefore utility bills do not yet exist for comparison. Overall, the estimated costs are within reason based on the efficiency of the Campus Cogeneration Plant and the low cost Natural Gas.

References

1. ASHRAE Handbook of Fundamentals 2005
2. Trane TRACE 700H
3. Bard, Rao and Athanas Consulting Engineers, LLC, Mechanical and Electrical Drawings
4. Ellenzweig Architecture, Drawings and Specifications
5. Past Thesis Technical Reports, e-Studio Archives, 2008-2009

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Figure 8 *– Interior East and West Zones – Levels B- 1*

Figure 9 *– All Perimeter Zones – Levels B- 1*

Figure 10 *– Interior Corridor/Lobby Zones – Levels 2-6*

Figure 11 *– Interior East and West Zones – Levels 2-6*

Figure 12 *– All Perimeter Zones – Levels 2-6*

Figure 13 *– Zone list with Trace Template Names*

Figure 14 *– Sample Zone Area Breakdown*

Figure 15 *– Sample Zone Space Breakdown and Internal Load Determination Method*

Figure 16 *– Internal Load Values Entered into Trace*

Figure 17 *– Air Riser Diagram Representation*

Figure 18 *– Modeled Air Handling Units vs. Designed Air Handling Units*

Figure 19 *– Sum of 8 AHU Characteristics (Modeled vs. Design)*

Figure 20 *– Engineering Check Comparisons*

Figure 21 *– Estimated Energy Consumption Summary*

Figure 22 *– Monthly Electricity Use*

Figure 23 *– Monthly HVAC Water Consumption*

Figure 24 *– Energy Cost Analysis Table*

Figure 25 *– Fractional Energy Consumption*

Figure 26 *– Building Emissions Footprint Analysis*

APPENDIX B

Supplemental Tables

Trace Template Name	Levels	Zone	L	W	Area
(2-6)-Corr/Lobby	2 to 6	Corridor/Lobby	77.00	77.00	5929.00
(2-6)-I-East	2 to 6	Interior East	98.00	65.00	6370.00
(2-6)-I-West	2 to 6	Interior West	90.00	49.00	4410.00
(2-6)-P-North	2 to 6	Perimeter North	297	28.00	8316.00
(2-6)-P-South	2 to 6	Perimeter South	210.00	26.00	5460.00
(2-6)-P-Southeast	2 to 6	Perimeter Southeast	110.00	26.00	2860.00
(2-6)-P-West	2 to 6	Perimeter West	86	32	2752.00
1-C-Corr/Lobby	1	Corridor/Lobby	77.00	77.00	5929.00
1-I-East	1	Interior East	124.00	64.00	7936.00
1-I-West	1	Interior West	86.00	64.00	5504.00
1-P-North	1	Perimeter North	280.00	14.50	4060.00
1-P-South	1	Perimeter South	188.00	21.00	3948.00
1-P-Southeast	1	Perimeter Southeast	110.00	26.00	2860.00
1-P-West	1	Perimeter West	107.00	44.00	4708.00

Trace Template Name	Levels	Zone	L	W	Area	Perimeter
B-Corr/Lobby	B	Corridor/Lobby	77.00	77.00	5929.00	308.00
B-I-East	B	Interior East	124.00	64.00	7936.00	376.00
B-I-West	B	Interior West	86.00	64.00	5504.00	300.00
B-P-North	B	Perimeter North	280.00	14.50	4060.00	589.00
B-P-South	B	Perimeter South	188.00	21.00	3948.00	418.00
B-P-Southeast	B	Perimeter Southeast	110.00	26.00	2860.00	272.00
B-P-West	B	Perimeter West	107.00	44.00	4708.00	302.00

North Wall - Level 1		
Wall Length	367.5	4777.5
Wall Height	13	
Glass Length	138	828
Glass Height	6	

North Wall - Levels 2-6		
Wall Length	301	2859.5
Wall Height	9.5	
Glass Length	243	1458
Glass Height	6	

South Wall - Level 1		
Wall Length	290	3480
Wall Height	12	
Glass Length	135.1	945.7
Glass Height	7	

South Wall - Levels 2-6		
Wall Length	226.5	2151.75
Wall Height	9.5	
Glass Length	162	972
Glass Height	6	

Southeast Wall - Level 1		
Wall Length	169	1859
Wall Height	11	
Glass Length	45.5	341.25
Glass Height	7.5	

Southeast Wall - Levels 2-6		
Wall Length	110	1045
Wall Height	9.5	
Glass Length	72	432
Glass Height	6	

West Wall - Level 1		
Wall Length	99	1039.5
Wall Height	10.5	
Glass Length	38	285
Glass Height	7.5	

West Wall - Levels 2-6		
Wall Length	86.5	821.75
Wall Height	9.5	
Glass Length	63	378
Glass Height	6	

Internal Load Assumptions

People Loads - Level 1			
Space Type	Density (ft^2/person)	Sensible (Btu/h)	Latent (Btu/h)
Breakout	24	250	250
Equipment	400	250	250
Laboratory	33	250	250
Lobby	20	250	250
Meeting Room	20	250	250
Office	100	250	200
Restrooms	0	250	250
Stair/Corridor	0	250	250
Vestibule	0	250	250

Lighting Loads - Level 1		
Space Type	Fixture Type	Heat Gain (W/ft^2)
Breakout	Flourescent, hung below ceiling, 100% load to space	1.5
Equipment	Flourescent, hung below ceiling, 100% load to space	1.3
Laboratory	Flourescent, hung below ceiling, 100% load to space	1.8
Lobby	Flourescent, hung below ceiling, 100% load to space	1.8
Meeting Room	Flourescent, hung below ceiling, 100% load to space	1.5
Office	Flourescent, hung below ceiling, 100% load to space	1.5
Restrooms	Flourescent, hung below ceiling, 100% load to space	1
Stair/Corridor	Flourescent, hung below ceiling, 100% load to space	0.9
Vestibule	Flourescent, hung below ceiling, 100% load to space	0

Miscellaneous Loads - Level 1	
Space Type	Energy (W/ft^2)
Breakout	1
Equipment	40
Laboratory	5
Lobby	1.5
Meeting Room	2
Office	2
Restrooms	0
Stair/Corridor	0
Vestibule	0

People Loads - Levels 2-6			
Space Type	Density (ft^2/person)	Sensible (Btu/h)	Latent (Btu/h)
Bio. Lab	33	250	250
Breakout	24	250	250
Eng. Lab	33	250	250
Equipment	40	250	250
Lab Support	40	250	250
Lobby	20	250	250
Meeting Room	20	250	200
Office	100	250	200
Restrooms	0	250	250
Stair/Corridor	0	250	250
Tissue Culture	40	250	250
Vestibule	0	250	250

Lighting Loads - Levels 2-6		
Space Type	Fixture Type	Heat Gain (W/ft^2)
Bio. Lab	Recessed Flourescent, not vented, 80% load to space	1.25
Breakout	Flourescent, hung below ceiling, 100% load to space	1.5
Eng. Lab	Recessed Flourescent, not vented, 80% load to space	1.25
Equipment	Recessed Flourescent, not vented, 80% load to space	1.25
Lab Support	Recessed Flourescent, not vented, 80% load to space	1.25
Lobby	Recessed Flourescent, not vented, 80% load to space	1.25
Meeting Room	Recessed Flourescent, not vented, 80% load to space	1.25
Office	Recessed Flourescent, not vented, 80% load to space	1.25
Restrooms	Recessed Flourescent, not vented, 80% load to space	1
Stair/Corridor	Recessed Flourescent, not vented, 80% load to space	1.25
Tissue Culture	Recessed Flourescent, not vented, 80% load to space	1.25
Vestibule	Recessed Flourescent, not vented, 80% load to space	0

Miscellaneous Loads - Levels 2-6	
Space Type	Energy (W/ft^2)
Bio. Lab	5
Breakout	1
Eng. Lab	8
Equipment	20
Lab Support	8
Lobby	1.5
Meeting Room	2
Office	2
Restrooms	0
Stair/Corridor	0
Tissue Culture	15
Vestibule	0

Internal Load Estimation – Perimeter Zones – Level 1

Level 1 - Perimeter West Zone								
Space Type	Area	% Zone Area	Density (ft^2/person)	Density (people)	Heat Gain (W/ft^2)	Avg. Heat Gain (W/ft^2)	Energy (W/ft^2)	Avg. Energy (W/ft^2)
Office	1171	0.32	100.00	11.71	1.50	0.48	2.00	0.64
Laboratory	2052	0.56	33.00	62.18	1.80	1.01	5.00	2.81
Equipment	424	0.12	400.00	1.06	1.30	0.15	40.00	4.65
	3647			**74.95**		**1.65**		**8.11**

WEST ZONE AVERAGE VALUES	
Density (people)	**74.00**
Heat Gain (W/ft2)	**1.65**
Energy (W/ft2)	**8.00**

Level 1 - Perimeter South Zone								
Space Type	Area	% Zone Area	Density (ft^2/person)	Density (people)	Heat Gain (W/ft^2)	Avg. Heat Gain (W/ft^2)	Energy (W/ft^2)	Avg. Energy (W/ft^2)
Equipment	210	0.05	400.00	0.53	1.30	0.07	40.00	2.11
Laboratory	558	0.14	33.00	16.91	1.80	0.25	5.00	0.70
Meeting Room	855	0.21	20.00	42.75	1.50	0.32	2.00	0.43
Office	1814	0.46	100.00	18.14	1.50	0.68	2.00	0.91
Stair/Corridor	435	0.11	0.00	0.00	0.90	0.10	0.00	0.00
Vestibule	106	0.03	0.00	0.00	0.00	0.00	0.00	0.00
	3978			**78.32**		**1.43**		**4.15**

SOUTH ZONE AVERAGE VALUES	
Density (people)	**78.00**
Heat Gain (W/ft2)	**1.43**
Energy (W/ft2)	**4.15**

Level 1 - Perimeter Southeast Zone								
Space Type	Area	% Zone Area	Density (ft^2/person)	Density (people)	Heat Gain (W/ft^2)	Avg. Heat Gain (W/ft^2)	Energy (W/ft^2)	Avg. Energy (W/ft^2)
Office	1846	0.68	100.00	18.46	1.50	1.02	2.00	1.36
Stair/Corridor	867	0.32	0.00	0.00	0.90	0.29	0.00	0.00
	2713			**18.46**		**1.31**		**1.36**

SOUTHEAST ZONE AVERAGE VALUES	
Density (people)	**18.00**
Heat Gain (W/ft2)	**1.31**
Energy (W/ft2)	**1.36**

Level 1 - Perimeter North Zone								
Space Type	Area	% Zone Area	Density (ft^2/person)	Density (people)	Heat Gain (W/ft^2)	Avg. Heat Gain (W/ft^2)	Energy (W/ft^2)	Avg. Energy (W/ft^2)
Breakout	3493	0.88	24.00	145.54	1.50	1.32	1.00	0.88
Vestibule	400	0.10	0.00	0.00	0.00	0.00	0.00	0.00
Stair/Corridor	80	0.02	0.00	0.00	0.90	0.02	0.00	0.00
	3973			**145.54**		**1.34**		**0.88**

NORTH ZONE AVERAGE VALUES	
Density (people)	**145.00**
Heat Gain (W/ft2)	**1.34**
Energy (W/ft2)	**0.88**

Internal Load Estimation – Interior Zones – Level 1

Level 1 - Interior West Zones								
Space Type	Area	% Zone Area	Density (ft^2/person)	Density (people)	Heat Gain (W/ft^2)	Avg. Heat Gain (W/ft^2)	Energy (W/ft^2)	Avg. Energy (W/ft^2)
Equipment	368	0.07	400.00	0.92	1.30	0.09	40.00	2.75
Laboratory	1826	0.34	33.00	55.33	1.80	0.61	5.00	1.70
Office	529	0.10	100.00	5.29	1.50	0.15	2.00	0.20
Restrooms	718	0.13	0.00	0.00	1.00	0.13	0.00	0.00
Stair/Corridor	1040	0.19	0.00	0.00	0.90	0.17	0.00	0.00
Vestibule	881	0.16	0.00	0.00	0.00	0.00	0.00	0.00
	5362			**61.54**		**1.16**		**4.65**

WEST ZONE AVERAGE VALUES	
Density (people)	**60.00**
Heat Gain (W/ft2)	**1.16**
Energy (W/ft2)	**4.65**

Level 1 - Interior East Zones								
Space Type	Area	% Zone Area	Density (ft^2/person)	Density (people)	Heat Gain (W/ft^2)	Avg. Heat Gain (W/ft^2)	Energy (W/ft^2)	Avg. Energy (W/ft^2)
Breakout	1681	0.21	24.00	70.04	1.50	0.32	1.00	0.21
Equipment	550	0.07	400.00	1.38	1.30	0.09	40.00	2.77
Meeting Room	2716	0.34	20.00	135.80	1.50	0.51	2.00	0.68
Office	1399	0.18	100.00	13.99	1.50	0.26	2.00	0.35
Restrooms	60	0.01	0.00	0.00	1.00	0.01	0.00	0.00
Stair/Corridor	890	0.11	0.00	0.00	0.90	0.10	0.00	0.00
Vestibule	634	0.08	0.00	0.00	0.00	0.00	0.00	0.00
	7930			**221.21**		**1.30**		**4.02**

EAST ZONE AVERAGE VALUES	
Density (people)	**220.00**
Heat Gain (W/ft2)	**1.30**
Energy (W/ft2)	**4.02**

Internal Load Estimation – Corridor/Lobby Zones – Level 1

Level 1 - Interior Corridor & Lobby Zone								
Space Type	Area	% Zone Area	Density (ft^2/person)	Density (people)	Heat Gain (W/ft^2)	Avg. Heat Gain (W/ft^2)	Energy (W/ft^2)	Avg. Energy (W/ft^2)
Lobby	3606	0.60	20.00	12.06	1.80	1.09	1.50	0.90
Stair/Corridor	2086	0.35	0.00	0.00	0.90	0.31	0.00	0.00
Vestibule	289	0.05	0.00	0.00	0.00	0.00	0.00	0.00
	5981			**12.06**		**1.40**		**0.90**

CORRIDOR & LOBBY AVERAGE VALUES	
Density (people)	**12.00**
Heat Gain (W/ft2)	**1.34**
Energy (W/ft2)	**0.88**

Internal Load Estimation – Perimeter Zones – Levels 2-6 Typical

Levels 2-6 - Perimeter West Zone								
Space Type	Area	% Zone Area	Density (ft^2/person)	Density (people)	Heat Gain (W/ft^2)	Avg. Heat Gain (W/ft^2)	Energy (W/ft^2)	Avg. Energy (W/ft^2)
Bio. Lab	137	0.06	33.00	4.15	1.25	0.08	5.00	0.32
Eng. Lab	512	0.24	33.00	15.52	1.25	0.30	8.00	1.90
Office	1199	0.56	100.00	11.99	1.25	0.69	2.00	1.11
Stair/Corridor	63	0.03	0.00	0.00	1.25	0.04	0.00	0.00
Tissue Culture	247	0.11	40.00	6.18	1.25	0.14	15.00	1.72
	2158			**37.83**		**1.25**		**5.04**

WEST ZONE AVERAGE VALUES	
Density (people)	**18.00**
Heat Gain (W/ft2)	**1.25**
Energy (W/ft2)	**5.04**

Levels 2-6 - Perimeter South Zone								
Space Type	Area	% Zone Area	Density (ft^2/person)	Density (people)	Heat Gain (W/ft^2)	Avg. Heat Gain (W/ft^2)	Energy (W/ft^2)	Avg. Energy (W/ft^2)
Bio. Lab	2196	0.39	33.00	66.55	1.25	0.49	5.00	1.96
Eng. Lab	1365	0.24	33.00	41.36	1.25	0.31	8.00	1.95
Office	974	0.17	100.00	9.74	1.25	0.22	2.00	0.35
Stair/Corridor	1056	0.19	0.00	0.00	1.25	0.24	0.00	0.00
	5591			**117.65**		**1.25**		**4.27**

SOUTH ZONE AVERAGE VALUES	
Density (people)	**117.00**
Heat Gain (W/ft2)	**1.25**
Energy (W/ft2)	**4.27**

Levels 2-6 - Perimeter Southeast Zone								
Space Type	Area	% Zone Area	Density (ft^2/person)	Density (people)	Heat Gain (W/ft^2)	Avg. Heat Gain (W/ft^2)	Energy (W/ft^2)	Avg. Energy (W/ft^2)
Eng. Lab	1714	0.62	33.00	51.94	1.25	0.77	8.00	4.93
Office	567	0.20	100.00	5.67	1.25	0.25	2.00	0.41
Stair/Corridor	500	0.18	0.00	0.00	1.25	0.22	0.00	0.00
	2781			**57.61**		**1.25**		**5.34**

SOUTHEAST ZONE AVERAGE VALUES	
Density (people)	**57.00**
Heat Gain (W/ft2)	**1.25**
Energy (W/ft2)	**5.34**

Levels 2-6 - Interior North Zone								
Space Type	Area	% Zone Area	Density (ft^2/person)	Density (people)	Heat Gain (W/ft^2)	Avg. Heat Gain (W/ft^2)	Energy (W/ft^2)	Avg. Energy (W/ft^2)
Bio. Lab	1934	0.24	33.00	58.61	1.25	0.30	5.00	1.19
Breakout	634	0.08	24.00	26.42	1.50	0.12	1.00	0.08
Eng. Lab	3232	0.40	33.00	97.94	1.25	0.50	8.00	3.17
Meeting	771	0.09	20.00	38.55	1.25	0.12	2.00	0.19
Office	978	0.12	100.00	9.78	1.25	0.15	2.00	0.24
Stair/Corridor	608	0.07	0.00	0.00	1.25	0.09	0.00	0.00
	8157			**231.29**		**1.27**		**4.86**

NORTH ZONE AVERAGE VALUES	
Density (people)	**230.00**
Heat Gain (W/ft2)	**1.27**
Energy (W/ft2)	**4.86**

Internal Load Estimation – Interior Zones – Levels 2-6 Typical

Levels 2-6 - Interior West Zone								
Space Type	Area	% Zone Area	Density (ft^2/person)	Density (people)	Heat Gain (W/ft^2)	Avg. Heat Gain (W/ft^2)	Energy (W/ft^2)	Avg. Energy (W/ft^2)
Bio. Lab	609	0.14	33.00	18.45	1.25	0.17	5.00	0.69
Eng. Lab	53	0.01	33.00	1.61	1.25	0.01	8.00	0.10
Equipment	557	0.13	40.00	13.93	1.25	0.16	20.00	2.52
Lab Support	484	0.11	40.00	12.10	1.25	0.14	8.00	0.88
Meeting Room	359	0.08	20.00	17.95	1.25	0.10	2.00	0.16
Restrooms	446	0.10	0.00	0.00	1.00	0.10	0.00	0.00
Office	385	0.09	100.00	3.85	1.25	0.11	2.00	0.17
Stair/Corridor	1164	0.26	0.00	0.00	1.25	0.33	0.00	0.00
Vestibule	368	0.08	0.00	0.00	0.00	0.00	0.00	0.00
	4425			**67.89**		**1.12**		**4.51**

WEST ZONE AVERAGE VALUES	
Density (people	**68.00**
Heat Gain (W/ft2)	**1.12**
Energy (W/ft2)	**4.51**

Levels 2-6 - Interior East Zone								
Space Type	Area	% Zone Area	Density (ft^2/person)	Density (people)	Heat Gain (W/ft^2)	Avg. Heat Gain (W/ft^2)	Energy (W/ft^2)	Avg. Energy (W/ft^2)
Bio. Lab	625	0.10	33.00	18.94	1.25	0.12	5.00	0.49
Equipment	1997	0.31	40.00	49.93	1.25	0.39	20.00	6.26
Lab Support	983	0.15	40.00	24.58	1.25	0.19	8.00	1.23
Meeting Room	242	0.04	20.00	12.10	1.25	0.05	2.00	0.08
Office	352	0.06	100.00	3.52	1.25	0.07	2.00	0.11
Stair/Corridor	836	0.13	0.00	0.00	1.25	0.16	0.00	0.00
Tissue Culture	1346	0.21	40.00	33.65	1.25	0.26	15.00	3.16
	6381			**142.71**		**1.25**		**11.33**

EAST ZONE AVERAGE VALUES	
Density (people	**142.00**
Heat Gain (W/ft2)	**1.25**
Energy (W/ft2)	**11.33**

Internal Load Estimation – Corridor/Lobby – Levels 2-6 Typical

Level 1 - Interior Corridor & Lobby Zone								
Space Type	Area	% Zone Area	Density (ft^2/person)	Density (people)	Heat Gain (W/ft^2)	Avg. Heat Gain (W/ft^2)	Energy (W/ft^2)	Avg. Energy (W/ft^2)
Lobby	3606	0.60	20.00	180.30	1.25	0.75	1.50	0.90
Stair/Corridor	2086	0.35	0.00	0.00	1.25	0.44	0.00	0.00
	5692			**180.30**		**1.19**		**0.90**

CORRIDOR & LOBBY AVERAGE VALUES	
Density (people)	**180.00**
Heat Gain (W/ft2)	**1.19**
Energy (W/ft2)	**0.90**

Airflow Templates