NASA Langley Research Center – Administration Office Building One

Hampton, VA

TECHNICAL REPORT 2

Building and Plant Energy Analysis Report

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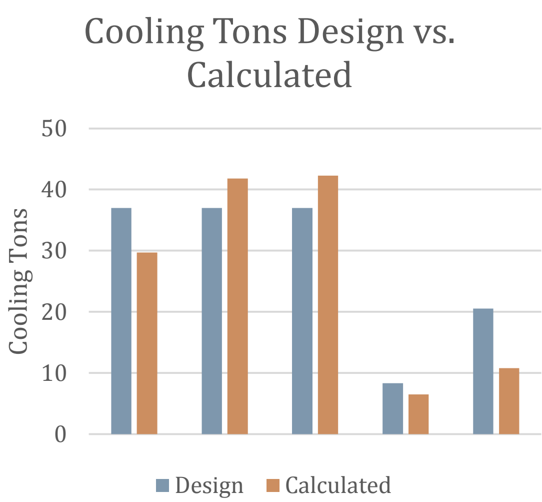
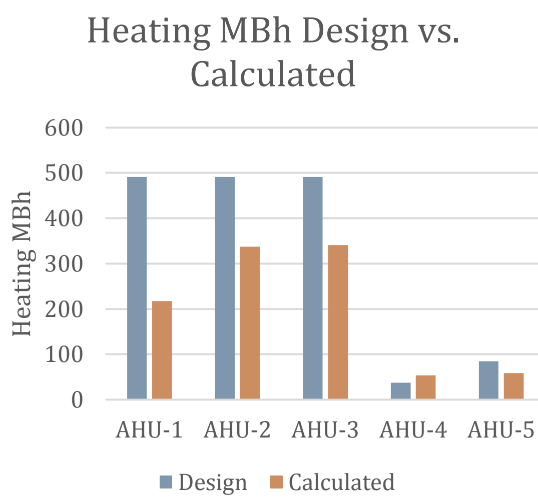
Executive Summary

The purpose of this report is to estimate the NASA Langley Research Center Administrative Office Building One, known as AOB1, design load and annual energy consumption and operating costs of various systems, in addition to determining the annual emissions footprint.

Trane's load and energy modeling program TRACE 700 was used for this analysis. The construction documents were used in addition to information obtained directly from the MEP engineer who created the TRACE 700 model used for the original design. For specific input information, see the Input Parameters section of this report. A utility rate also obtained from the MEP engineer was used with the load and energy outputs to calculate operating monthly and annual operating costs.

A comparison of the calculated results were made against the schedule values in the design drawings. This comparison showed sufficient airflow rates, but some air handling units had a higher calculated demand for the heating or cooling coils than designed. Overall, the total cooling and heating demand capacity calculated was found to be less than the design values.





The energy analysis provided the site and source electricity required. The utility cost per area calculated was compared to a national commercial average provided by the U.S. Department of Energy Buildings Energy Data Book. AOB1's annual energy expenditure was approximately 63% less than that average. The source electricity value was also used to determine the CO_2, NO_x, SO_x and PM10 emissions associated with building operation.

Building Overview

NASA LANGLEY

The NASA Langley Research Center was founded in 1917 as the first civil aeronautical research laboratory, and currently has approximately 110 buildings that were constructed over 50 years ago. NASA decided to implement a five-phase revitalization program, which would replace existing buildings with newer, more efficient ones. Their goals for these new buildings were sustainability/efficiency, functionality of the interior environment, pedestrian friendly, and curb appeal. The revitalization program is known as the New Town program, and the first phase consisted of the construction of AOB1.

NEW TOWN PHASE 1

AOB1 is the new headquarters building for NASA's Langley Research Center. The project broke ground in July of 2009 and occupancy began in May 2011. The three story building is approximately 79,000 square feet, with a mechanical penthouse. The building was designed to give viewers a perception of flight. The image below, a rendering from the bridging drawings created by AECOM, demonstrates this original concept, with the glass curtainwall and metal paneling façade and parallelogram footprint with the overhanging upper floors.

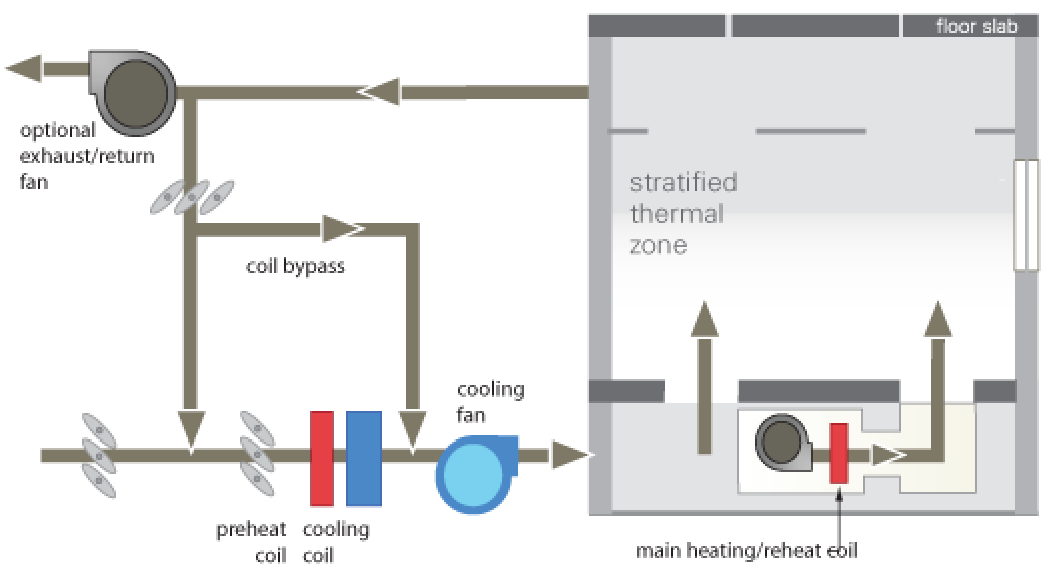
Figure 1 – South façade rendering from AECOM Bridging Drawings

The exterior form matches the interior function, with the vertical form towards the center of the building indicating the location of the elevators and lobby. This vertical section also helps to separate the first floor into two sections: employee offices, with a glass façade providing adequate daylighting matching the rest of the building, and large conference rooms for hosting events with its stone façade and windows that are more practical for visual presentations (5)(6).

Mechanical Systems Overview

The air distribution system in AOB1 consists of five air handling units and one dedicated outdoor air unit with a heat recovery wheel. The primary air distribution system in the building is an under floor air distribution system (UFAD). The system serves all office spaces and teaming areas on all three floors. Each floor has an air handling unit (AHU-1, 2, 3) located on that floor which ducts into an open floor plenum that distributes to diffusers for the interior spaces and fan powered boxes (FPB) at the perimeter. There is ceiling return, where air is either recirculated to the air handling unit or relieved to the roof, where it goes through the enthalpy wheel at the dedicated outdoor air handling unit (DOAS) that provides pre-conditioned outdoor air for the building. This unit contains heating, cooling and reheat coils, and is set-up for dehumidification. A diagram of the UFAD air handling units is shown in Figure 2.

Figure 2 - AHU-1, 2, 3 Diagram



There are four VAV's located in the penthouse that control the amount of OA distributed to each respective AHU. Figure 3 shows the mechanical system breakdown of the second floor.

- AHU-5 serves the large conference rooms (such as those in pink in Figure 3) of the upper floors separate of the UFAD system and is located in the penthouse.
- AHU-4 is located on the first floor and serves the large conference rooms on the first floor. It has its own OA louver and is not supplied by the DOAS unit.

- Blower coil units (BCU) serve the atrium and lobby spaces
- Fan coil units (FCU) are used for the IT room on each floor

All areas in white are not directly supplied, which include spaces such as stairwells, elevators, restrooms, kitchenettes, mechanical rooms and electrical rooms.

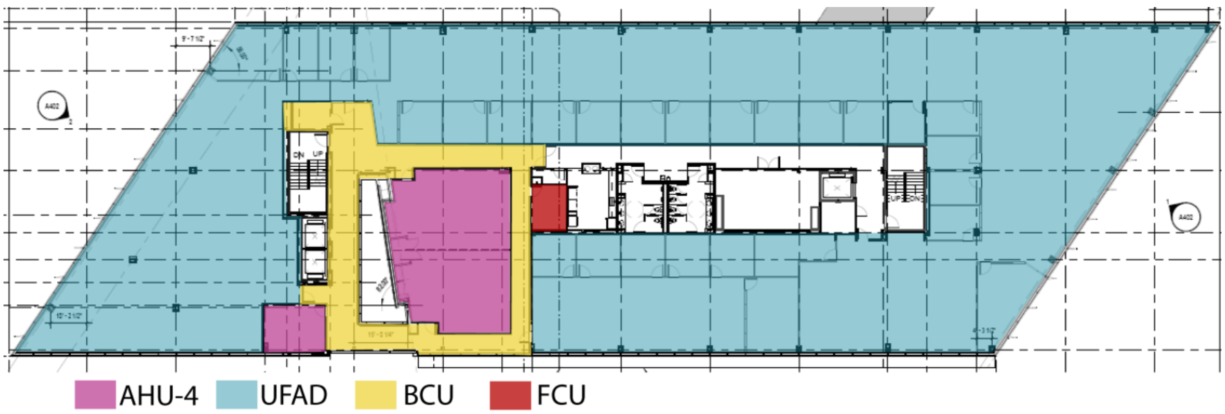


Figure 3 - Second Floor Mechanical System Overview

A geothermal transfer field handles the entire heating and cooling load of the building, with 90 boreholes that are six inches in diameter and 500 feet deep. The well field is connected to six water to water heat pumps (WWHP) with scroll compressors and two sets of three-way control valves that allow the heat pumps to switch between cooling and heating operating, located in the penthouse. The WWHP's have an EER of fourteen and a heating COP of 3.25. Two geothermal water loop circulation pumps with variable frequency drives control the geothermal water loop.

Design Load Estimation

A load analysis was performed on AOB1 using Trane TRACE 700. For this analysis, spaces were broken down by equipment zones and space types. The space type breakdown consisted mainly of offices, conference rooms, restrooms, corridors, and pantries. The open office spaces, private offices, and teaming spaces that are supplied from the same under floor air distribution air handling unit are modeled as one space. All other spaces that are supplied from adjacent air transfer or are supplied from other equipment were modeled individually.

DESIGN CONDITIONS

AOB1 is located in climate zone 4A. Table 1 below shows the weather information used in the Trace 700 analysis. This data was received from H.F. Lenz, the MEP engineers for the project.

Table 1 - TMY Weather Data

COOLING MAX 0.4%			DEHUMIDIFICATION MAX 0.4%			WINTER DESIGN 99.6%
DB	**MCWB**	**DP**	**DB**	**MCWB**	**DP**	**DB**
93.2	77.5	71.7	83.9	79.02	77.3	20.5

INPUT PARAMETERS

The construction parameters used in this model were obtained from H.F. Lenz Company, the MEP Engineers. These values were obtained from the basis of design documents and from H.F. Lenz Company and construction submittals for elements whose final design thermal properties differed from the basis of design. A summary of these construction parameters used for the TRACE 700 model are shown in Table 2.

Table 2 - Construction Design

	U-FACTOR (BTU/H*FT^2*^{o}F)	SHADING COEFFICIENT	HEIGHTS (FT.)	
Slab	0.21		**Wall**	14.75
Roof	0.063		**Floor to floor**	14.75
Wall	0.113			
Window	0.37	0.29	**Plenum**	2.8
Skylight	0.46	0.39		

The U-values and Solar Heat Gain Coefficients from the window submittals were adjusted to account for decreased performance due to the curtainwall system. For this adjustment, data from a Kawneer product that had similar attributes to the glass installed was used and can be found in APPENDIX A.

The original energy model completed by H.F. Lenz used the ASHRAE Standard 62.1-2004/2007 Ventilation calculation procedure, with a 30% increase over the baseline requirements, as shown in Table 3. For the analysis performed for this report, the ASHRAE Standard 62.1 was used with the 30% increase for IEQ credit.

Table 3 – Original Mechanical Narrative Supply Air Quantity

SPACE:	APPROXIMATE CFM/SF	APPROXIMATE CFM/PERSON
Offices	0.078	6.5
Conference Rooms	0.078	6.5
Corridors	0.060	0
Toilet Rooms:	40 per fixture	0

Table 4 - Ventilation Air Supplied

FLOOR	APPROXIMATE CFM/SF
1st floor	0.19
2nd floor	0.15
3rd floor	0.16

Table 5 - AHU Static Pressure

UNIT	SUPPLY SP (IN. WG)	RETURN SP (IN. WG)
AHU-1	1.5	1.5
AHU-2	1.5	1.5
AHU-3	1.5	1.5
AHU-4	2.0	1.5
AHU-5	2.0	1.5

The static pressures to be used for each air handling unit were obtained from the MEP engineers and coincide with the values given in the design schedule. These static pressures range from 1.5 to 2.0 in. wg for each unit. The exact values are given in Table 5. No diversity was taken for the equipment.

The lighting and power densities used for the model, shown in Table 6, were based on the values provided in the basis of design. These represent the maximum anticipated load contribution. Daylight sensors for the perimeter offices allow for lower lighting densities.

Table 6 - Lighting, Power and People Load Densities for Cooling

LIGHTING AND POWER LOAD DENSITIES

	Lighting	Power
Office areas	1.0 W/SF	1.0 W/SF
Lobbies	1.0 W/SF	0.3 W/SF
Conference	1.0 W/SF	0.3 W/SF
Training rooms	1.0 W/SF	0.3 W/SF

The occupancies used for the model were based on the final design furniture layout. An exact person count was used for each room, as opposed to a per square foot basis that was used for the original design model by the mechanical engineers. For floor plans with occupancies, see APPENDIX B.

Table 7 - Thermostat Settings

Cooling dB:	75^{o}F
Heating DB:	72^{o}F
Relative Humidity:	60%
Cooling Driftpoint:	75^{o}F
Heating Driftpoint:	62^{o}F

The thermostat settings used in the TRACE 700 were taken from the basis of design and assumed to be that used in the current building. The dry bulb settings, relative humidity, and driftpoint temperatures are displayed in Table 7.

A schedule was applied to the model, which has a base work occupancy of weekdays from 8 a.m. to 5 p.m. The system will be set to maintain temperature between 55^{o}F and 90^{o}F for all hours of the day, and between 65^{o}F and 80^{o}F an hour before occupancy and as low as 60^{o}F after occupancy. A summary of this information for heating and cooling is shown in Table 8.

Table 8 - Thermostat Schedule

COOLING STAT			HEATING STAT		
		WEEKDAYS			
Start Time	**End Time**	**Setpoint (^{o}F)**	**Start Time**	**End Time**	**Setpoint (^{o}F)**
Midnight	7 a.m.	90	Midnight	7 a.m.	55
7 a.m.	8 a.m.	80	7 a.m.	8 a.m.	65
8 a.m.	5 p.m.	75	8 a.m.	5 p.m.	72
5 p.m.	6 p.m.	80	5 p.m.	6 p.m.	60
6 p.m.	Midnight	90	6 p.m.	Midnight	55
		WEEKENDS			
Midnight	Midnight	90	Midnight	Midnight	60

The geothermal system was modeled in TRACE 700, and all AHU's were modeled separately and rooms assigned accordingly.

LOAD ANALYSIS RESULTS

The calculated airflow rates and load requirements from the TRACE 700 model were compared to the values from the design drawings provided. These results, provided in Table 9, show that the design airflow rates exceeded those required. However, some of the cooling and heating requirements did exceed those designed. These included AHU-4's heating coil and AHU-2 and AHU-3's cooling coils.

Table 9 - Design and Calculated Airflow Rates

EQUIPMENT	RESULT TYPE	COOLING CFM	OA CFM	COOLING TON	HEATING MBH
AHU-1	Design	17000	5100	37	491
	Calculated	8520	2023	29.7	217
AHU-2	Design	17000	5100	37	491
	Calculated	12212	2689	41.8	337
AHU-3	Design	17000	5100	37	491
	Calculated	12367	2595	42.3	341
AHU-4	Design	2600	780	8.3	37.7
	Calculated	1958	530	6.5	53.3
AHU-5	Design	6500	1950	20.5	85
	Calculated	2562	986	10.8	58.4

Because the dedicated outdoor air system (DOAS) preconditions the air before the air handling units condition it further, the conditioning provided by both systems had to be included in the design data above. Since the air is assumed to be conditioned uniformly at the DOAS unit, the cooling and heating loads were proportionally split and the total capacity at both the DOAS unit and AHU combined are the values displayed in Table 9.

A total design cooling capacity for a building maximum block load was found to be 113.7 tons through this simulation, and a total heating capacity of 1091 MBh. This can be compared to the design capacities of the water-to-water heat pumps used for the geothermal well field. These heat pumps have a total capacity of 172.5 tons cooling and 1773 MBh heating, well beyond the calculated values.

Energy Consumption Analysis

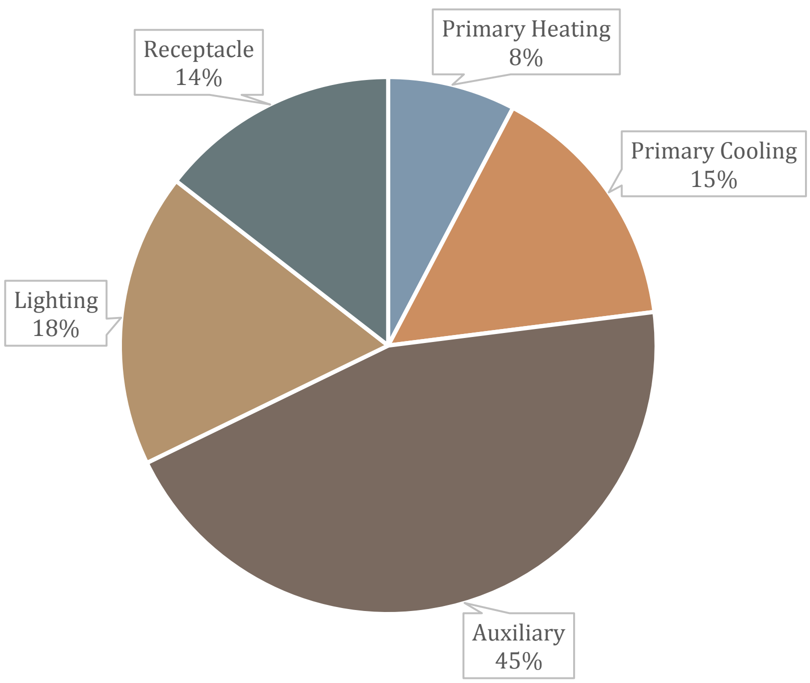
ANNUAL ENERGY AND OPERATING CONSUMPTION

An economical simulation was also run using the same TRACE 700 model used for the load analysis above. The fuel rate used for AOB1 was $0.077/kWh. This value was provided by the MEP engineers and represents the rate provided to them by the appropriate local utility. All consumption is electric. Through this analysis the following energy consumption data was found:

- Building energy consumption: 45,760 Btu/ft^2*year
- Source energy consumption: 137,293 Btu/ft^2*year

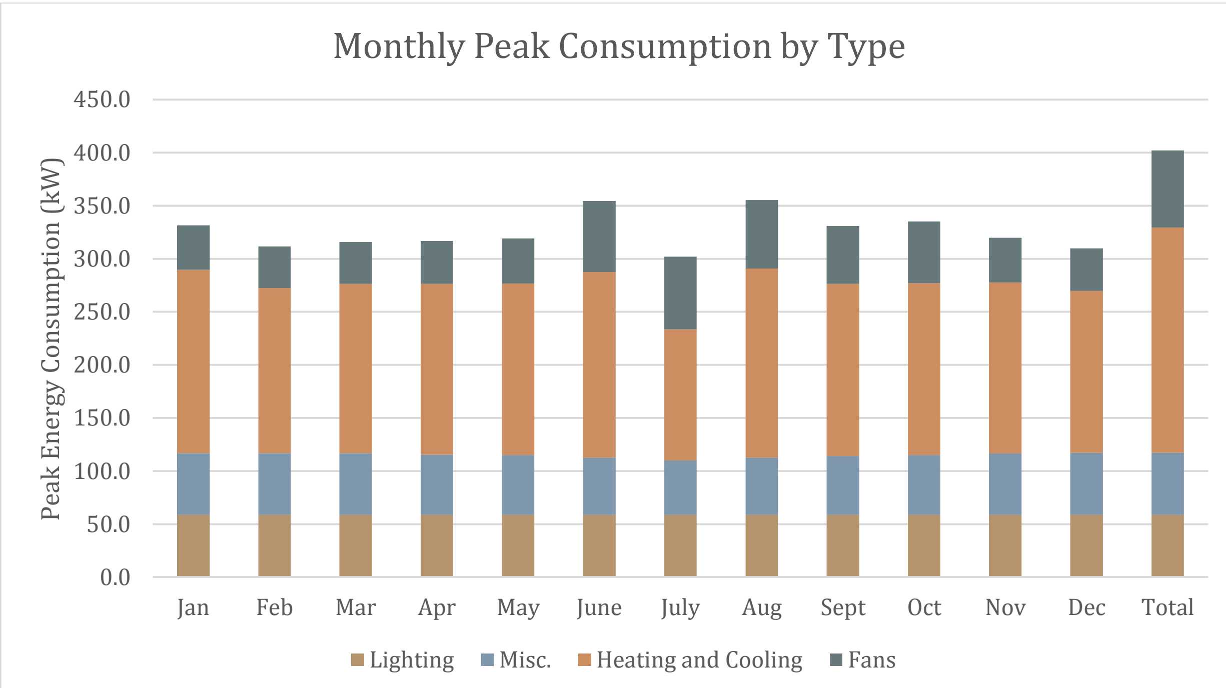
A breakdown of the energy consumption can be found in Figure 4. This shows that the auxiliary equipment, such as fans, are the largest consumers, which is logical considering that the geothermal well field takes care of the load for the entire building and no supplemental boilers or chillers were needed.

Figure 4 - Energy Consumption Summary



A monthly breakdown of the energy consumption for heating and cooling equipment, fans, lighting and miscellaneous loads is given in Figure 5. This breakdown categorizes all pumps and equipment, other than fans and accessory equipment, into cooling and heating.

Figure 5 - Load Type Monthly Peak Consumption

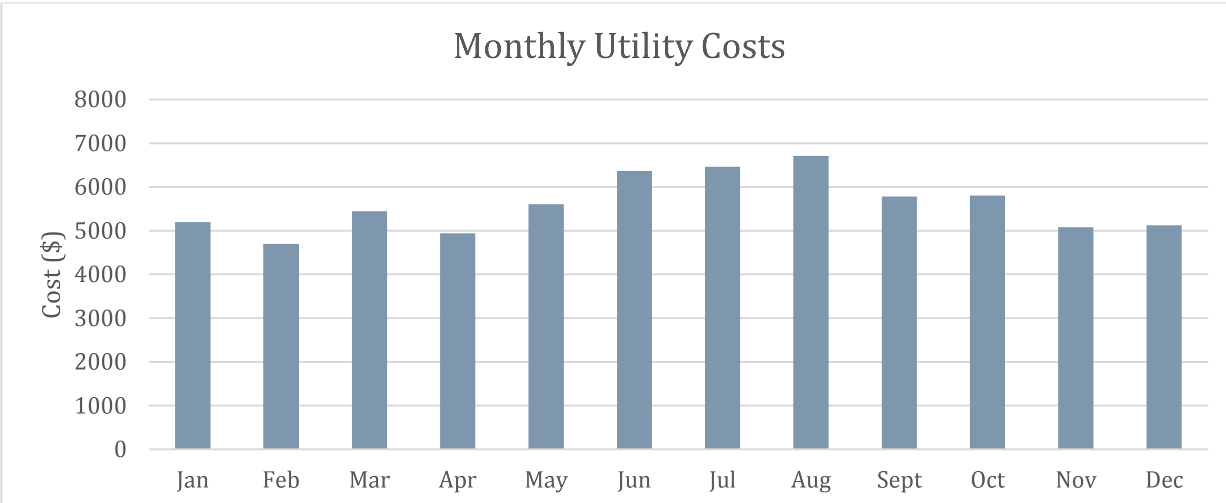


Using the fuel rate provided above, the approximate utility cost per area came out to $0.91/ft². The total operating cost is estimated to be $67,200 a year, based on an annual energy consumption of 2979*10⁶ Btu/year. A monthly breakdown for the energy consumption and cost can be found in Table 10.

Table 10- Monthly Energy Consumption and Utility Costs

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
kW	242	242	242	235	234	257	277	256	240	244	241	242
Total on-peak demand:				277 kW								
$	5195	4699	5444	4937	5607	6370	6462	6715	5783	5803	5080	5127
Total cost:				67,219								
Utility cost per area:				0.91$/ft²								

Figure 6 - Monthly Utility Costs



The U.S. Department of Energy Buildings Energy Data Book provides an average annual energy expenditure per square foot of commercial floorspace on their website. This data shows an average cost of \$2.44/ft^2 for commercial buildings, over 250% more than what is anticipated for AOB1. This Data Book is provided in APPENDIX C.

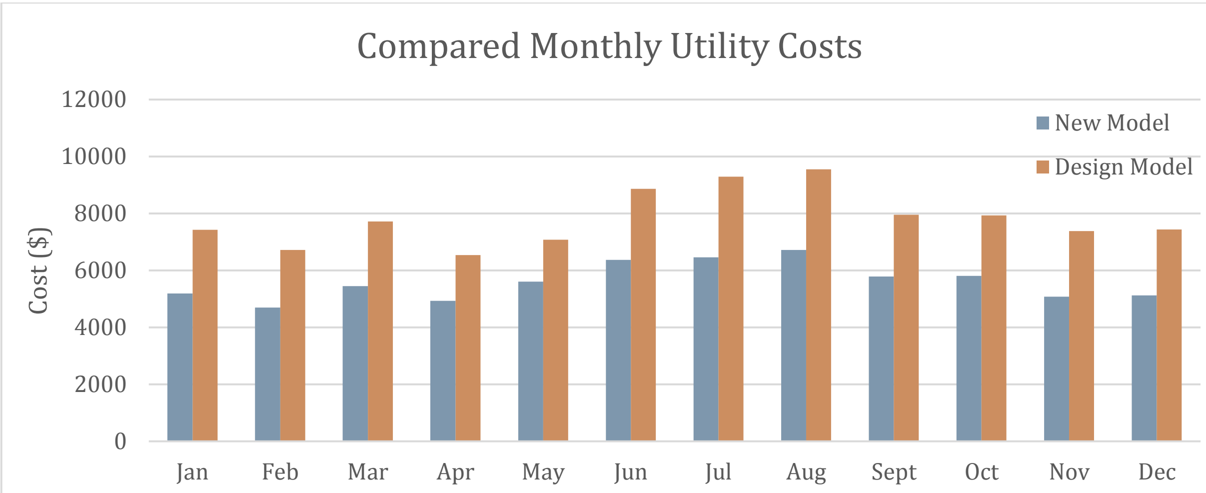
DESIGN ENGINEERS ENERGY ANALYSIS

A TRACE 700 model was created by the MEP engineer for the original design. The exports from this analysis were not obtained, but the original TRACE 700 model was and a simulation was run for comparison, and the energy consumption from this simulation exceed that of the new TRACE 700 files simulation. Below are the results of this analysis:

- Building energy consumption: 56,316 Btu/ft^2*year
- Source energy consumption: 168,969 Btu/ft^2*year

Additionally, the monthly utility costs from the simulation used for this analysis and the original design model from the mechanical engineer are compared in Figure 7. This figure shows the design model has a consistent higher monthly utility across throughout the year.

Figure 7 - Compared Monthly Utility Costs



Through inspection, it was discovered that the results from running the TRACE 700 archive file obtained from the MEP engineer are not consistent with the design capacities of the equipment. For this reason, it is assumed that this simulation resulted in a different outcome than what was originally calculated by the design engineer. This may be due to different software versions and changes in library files. Although the specific data obtained from this simulation is not a good representation of the original design information, it does follow the same trends as the new results.

BUILDING EMISSIONS

All energy consumed on the site was created off site and delivered. The building emissions data is based on the source energy consumption obtained through the TRACE 700 analysis. The building is located in the SERC NERC interconnection, an eastern region. The pounds of pollutant per kWh of electricity for each pollutant type are provided in Figure 8, which comes from the National Renewable Energy Laboratory's Source Energy and Emission Factors for Energy Use in Buildings technical report from 2007.

Figure 8 - Emission Factors from NREL Source Energy and Emission Factors for Energy Use in Buildings 2007

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

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

The energy results from TRACE 700 are in kBtu/year and were converted to the following kWh/year through the conversion of 1 Btu = 0.0002931 kWh:

- Total Building Energy: 3,066,312 kBtu/year = 898,736 kWh/year
- Total Source Energy: 9,199,856 kBtu/year = 2,696,478 kWh/year

Using these values, it was found that approximately 4.42 million pounds of CO_2 are emitted, 8,090 pounds of NO_x, 23,100 pounds of SO_x, and 250 pounds of PM10 (particulate matter less than 10 microns in size). This information will be compared to emissions anticipated from proposed alterations to the design, an analysis outside the scope of this report. This information is particularly important because larger environmental impacts are important for "green" building design and progress.

Resources

1. ANSI/ASHRAE. (2013). Standard 62.1-2013, *Ventilation for Acceptable Indoor Air Quality*. Atlanta, GA: American Society of Heating Refrigeration and Air Conditioning Engineers, Inc.
2. ANSI/ASHRAE. (2013). Standard 90.1-2013, *Energy Standard for Buildings Except Low Rise Residential Buildings*. Atlanta, GA: American Society of Heating Refrigeration and Air Conditioning Engineers, Inc.
3. ASHRAE. (2009). 2009 ASHRAE Handbook, *Fundamentals.*. Atlanta, GA: American Society of Heating Refrigeration and Air Conditioning Engineers, Inc.
4. Deru, M. P., Torcellini, P., & National Renewable Energy Laboratory (U.S.). (2007). *Source energy and emission factors for energy use in buildings* (Rev.). Golden, Colo.: National Renewable Energy Laboratory.
5. Flynn, J. (2008, January 1). Visualizing the Future of NASA Langley Research Center. Retrieved September 12, 2014, from http://proceedings.esri.com/library/userconf/feduc08/papers/feduc.pdf
6. Quinville, T. (2009, September 16). New Town NASA Langley Research Center's Revitalization Initiative Report to Hampton Roads SAME Chapter. Retrieved September 12, 2014, from http://posts.same.org/hamptonroads/NASANewTownSep2009.pdf
7. U.S. Department of Energy (2008) Buildings Energy Data Book, *Buildings Energy Data Book.* Retrieved September 30, 2014, from http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=3.3.8.

Renderings from AECOM bridging documents: www.aecom.com

APPENDIX A

Kawneer Glass Spec Sheet

Thermal Transmittance [1] (BTU/hr • ft [2] • °F)

Glass U-Factor [3]	Overall U-Factor [4]
0.47	0.54
0.46	0.53
0.44	0.52
0.42	0.50
0.40	0.48
0.38	0.47
0.36	0.45
0.34	0.43
0.32	0.42
0.30	0.40
0.28	0.38
0.26	0.37
0.24	0.35
0.22	0.33
0.20	0.32
0.18	0.30
0.16	0.28
0.14	0.26
0.12	0.25
0.10	0.23

1" GLAZING WITH ALUMINUM PRESSURE PLATE

NOTE: For glass values that are not listed, linear interpolation is permitted.

1. U-Factors are determined in accordance with NFRC 100.
2. SHGC and VT values are determined in accordance with NFRC 200.
3. Glass properties are based on center of glass values and are obtained from your glass supplier.
4. Overall U-Factor, SHGC, and VT Matricies are based on the standard NFRC specimen size of 2000mm wide by 2000mm high (78-3/4" by 78-3/4").

SHGC Matrix [2]

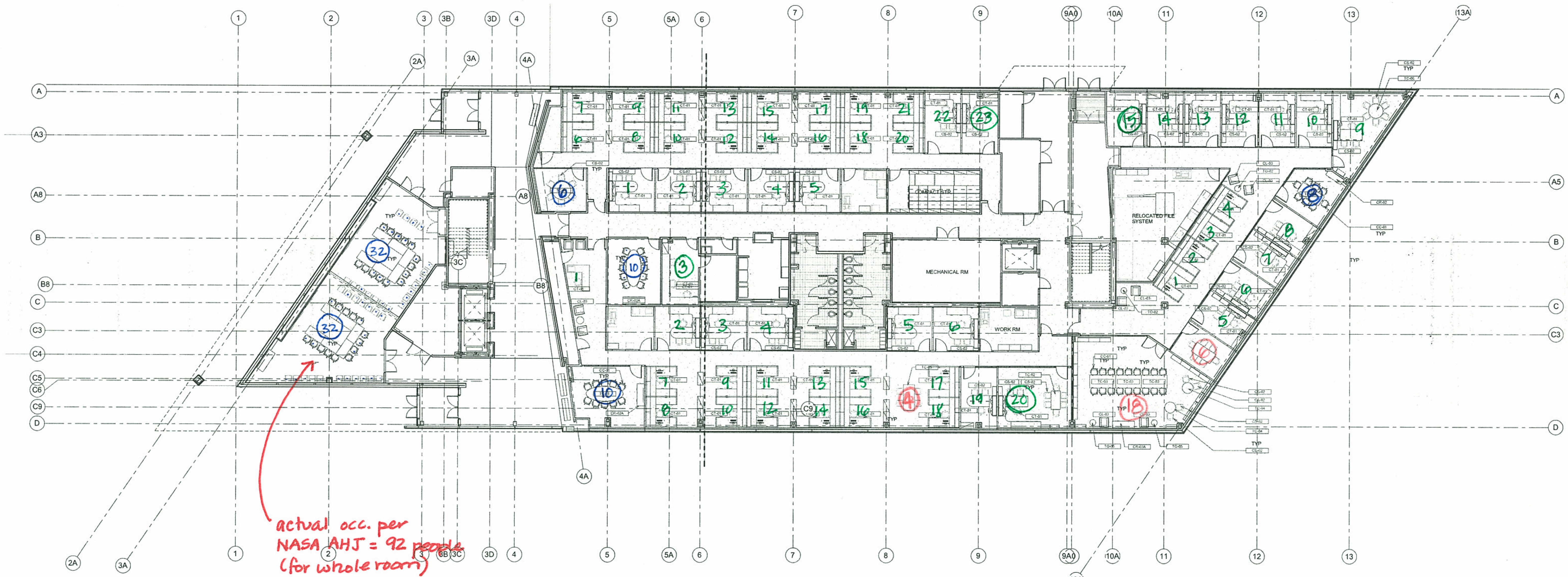
Glass SHGC [3]	Overall SHGC [4]
0.75	0.68
0.70	0.64
0.65	0.59
0.60	0.55
0.55	0.50
0.50	0.46
0.45	0.41
0.40	0.37
0.35	0.32
0.30	0.28
0.25	0.24
0.20	0.19
0.15	0.15
0.10	0.10
0.05	0.06

Visible Transmittance [2]

Glass VT [3]	Overall VT [4]
0.75	0.67
0.70	0.63
0.65	0.58
0.60	0.54
0.55	0.49
0.50	0.45
0.45	0.40
0.40	0.36
0.35	0.31
0.30	0.27
0.25	0.22
0.20	0.18
0.15	0.13
0.10	0.09
0.05	0.04

APPENDIX B

Occupancy floor plans obtained from H.F. Lenz Company



actual occ. per NASA AHJ = 92 people (for whole room)

(+28 over seat count)

Chair Counts

Level 1

• = 98 (Assembly areas per NASA)

• = 61 (workstations)

• = 28 (teaming areas outside of offices)

187

all 3 levels

[284]

[257]

[95] ?

[636]

-95

= 541

rooms w/ moveable tables +126 over seat count

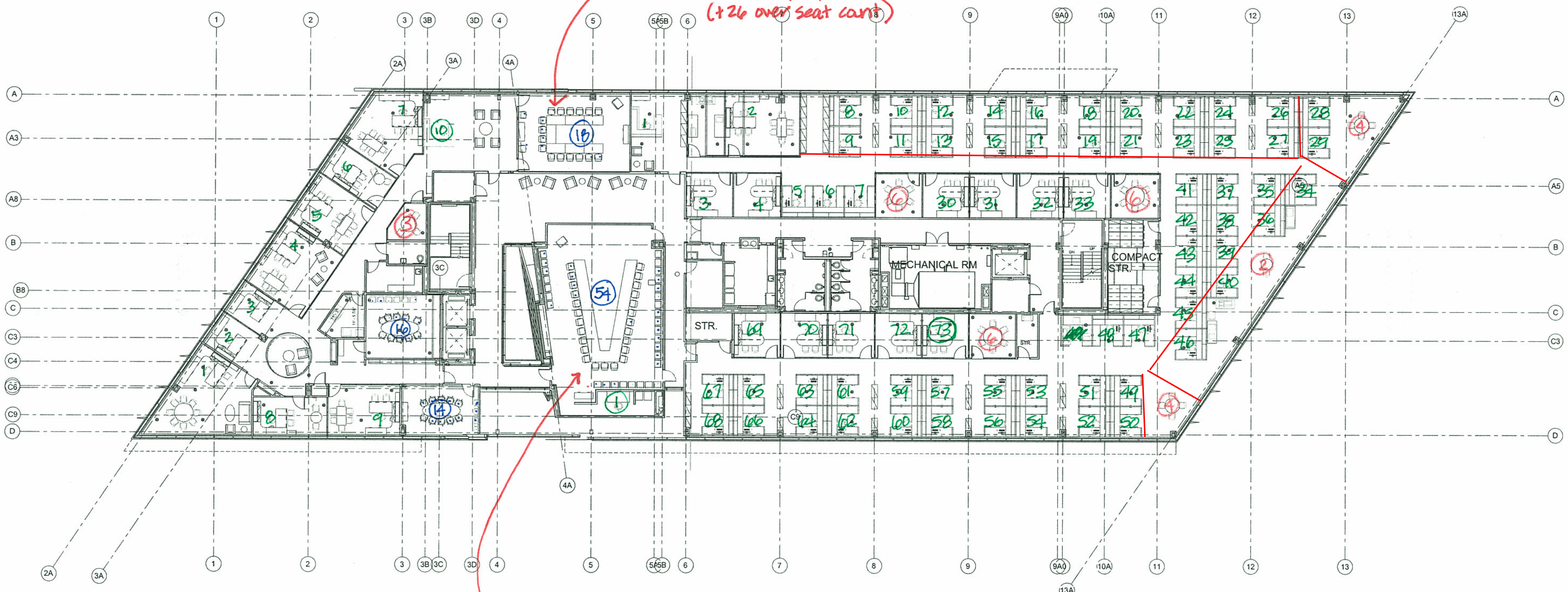
541 + 126 = 667

actual occ. per
NASA AHJ = 93 people
(for whole room)
(+31 over seat count)

Level 2
• = 84
• = 112
• = 36

232

actual occ. per
NASA AHJ = 44 people
(+26 over seat count)



actual occ. per
NASA AHJ = 95 people
(+41 over seat count)

Level 3

= 102

= 84

= 31

217

APPENDIX C

U.S. Department of Energy Buildings Energy Data Book: 3.3 Commercial Sector Expenditures

3.3.8 Average Annual Energy Expenditures per Square Foot of Commercial Floorspace, by Year ($2010)

Year	$/SF
1980 (1)	2.12
1981	2.22 (2)
1982	2.24
1983	2.21
1984	2.25
1985	2.20
1986	2.06
1987	2.00
1988	1.99
1989	2.01
1990	1.98
1991	1.92
1992	1.86
1993	1.96
1994	2.05
1995	2.12
1996	2.10
1997	2.08
1998	1.97
1999	1.88
2000	2.06
2001	2.20
2002	2.04
2003	2.13
2004	2.16
2005	2.30
2006	2.36
2007	2.35
2008	1.71
2009	2.43
2010	**2.44**
2011	2.44
2012	2.35
2013	2.28
2014	2.27
2015	2.29
2016	2.29
2017	2.28
2018	2.29
2019	2.29
2020	2.29
2021	2.31
2022	2.32
2023	2.32
2024	2.32
2025	2.32
2026	2.32
2027	2.33
2028	2.32
2029	2.31

2030	2.31
2031	2.32
2032	2.35
2033	2.37
2034	2.39
2035	2.42

Note(s): 1) End of year 1979. 2) Square footage estimated for years 1981, 1982, 1984, 1985, 1987, 1988, 1990, 1991, 1993, 1994, 1996, 1997, 1998, 2000, 2001, 2002, 2004, and 2005.

Source(s): EIA, State Energy Data Prices and Expenditures Database, June 2011 for 1980-2009; EIA, Annual Energy Outlook 2012 Early Release, Jan. 2012, Summary Reference Case Tables, Table A2, p. 3-5 and Table A5, p. 11-12 for consumption, Table A3, p. 6-8 for prices for 2008-2035; EIA, Annual Energy Review 2010, Oct. 2011, Appendix D, p. 353 for price deflators. for price deflators; EIA, AEO 1994, Jan. 1994, Table A5, p. 62 for 1990 floorspace; and PNNL for 1980 floorspace.