DOCKETED

Docket Number:	22-SPPE-03
Project Title:	Martin Backup Generating Facility (MBGF)
TN #:	250723
Document Title:	Martin Properties Supplemental Response to DR 37 - MBGF
Description:	N/A
Filer:	Scott Galati
Organization:	DayZenLLC
Submitter Role:	Applicant Representative
Submission Date:	6/23/2023 1:02:42 PM
Docketed Date:	6/23/2023

SUPPLEMENTAL RESPONSE TO STAFF DATA REQUEST 37

Martin Backup Generating Facility (22-SPPE-03)

SUBMITTED TO: CALIFORNIA ENERGY COMMISSION
SUBMITTED BY: **Martin Avenue Properties LLC**

June 23, 2023

INTRODUCTION

Attached is Martin Properties' Supplemental Response to California Energy Commission (CEC) Staff Data Request Set No. 1, Number 37 for the Martin Backup Generation Facility (MBGF) Application for Small Power Plant Exemption (SPPE) (22-SPPE-03).

BACKGROUND: Thermal Plume Analysis

On page 4-103, the applicant states an airport consultant has been commissioned to prepare an analysis of established airport procedures to assess the potential for flights at the Norman Y. Mineta San José International Airport encountering either a plume at or below the heights identified in a thermal plume analysis.

DATA REQUEST

37. Please provide the report of the analysis by the airport consultant.

RESPONSE TO DATA REQUEST 37

Appendix TRANS DR-37 includes a revised Thermal Plume Analysis, with modifications shown in redline, and a Technical Memorandum, Data Center Plume Airspace Analysis. The Thermal Plume Analysis was revised to reflect further refined information provided for the roof top chiller. Specifically, the top of the chiller was overestimated in the original analysis and the revised analysis corrects the height of exhaust discharge.

ATTACHMENT TRANS DR-37

Airport Flight Analysis and Revised Thermal Plume Analysis

TECHNICAL MEMORANDUM

To:	Ms. Brandee Mitchell 651 Martin Properties
From:	Mr. Andrew Scanlon Kimley-Horn and Associates, Inc.
Date:	June 23, 2023
Subject:	Data Center Plume Airspace Analysis

On behalf of 651 Martin Properties (Client) Kimley-Horn an airspace evaluation to analyze potential aeronautical impacts of a thermal plume generated from a proposed 468,175 square foot data center with an associate backup generator facility and chiller system located near Norman Y. Mineta San Jose International Airport (SJC). As discussed in this Technical Memorandum, an overall approximated building, generator, and chiller footprint was analyzed. The height of the thermal plumes to be analyzed were provided by the Client and adjusted by the Client to represent the maximum height above the ground. Therefore, Kimley-Horn did not adjust the thermal plume heights to account for any stacks or exhaust cowls.

Proposed Site

The site is located at 651 Martin Avenue, as shown in ***Figure 1***. The site is within 0.37 nautical miles (nm) southwest of the Runway 12R displaced landing threshold. ***Table 1*** provides points analyzed which approximates the overall potential footprint of the backup generator and chiller plume locations. The client provided an Architectural Drawing set, dated October 14, 2022, which was annotated with point numbers correlating to the tabular data represented in ***Table 1.*** The drawing set is included as ***Attachment A*** *to this Technical Memorandum*.

For the site, two plume heights were evaluated: the backup diesel generator plume which was calculated to be 121 feet Above Ground Level (AGL) and the chiller plume which was calculated to be 127 feet AGL. For the purposes of this evaluation, a site elevation of 50 feet was assumed and added to the plume heights to get an Above Mean Sea Level (AMSL) elevation of 171 and 177 feet for the backup generator and chiller plumes, respectively.

The plume heights were provided by the Client and were calculated assuming a max height associated with a velocity of 5.3 meters per second which represents the minimum velocity to cause light turbulence. The Vertical Plume Velocity Assessment Report is attached to this analysis for reference as ***Attachment B***.

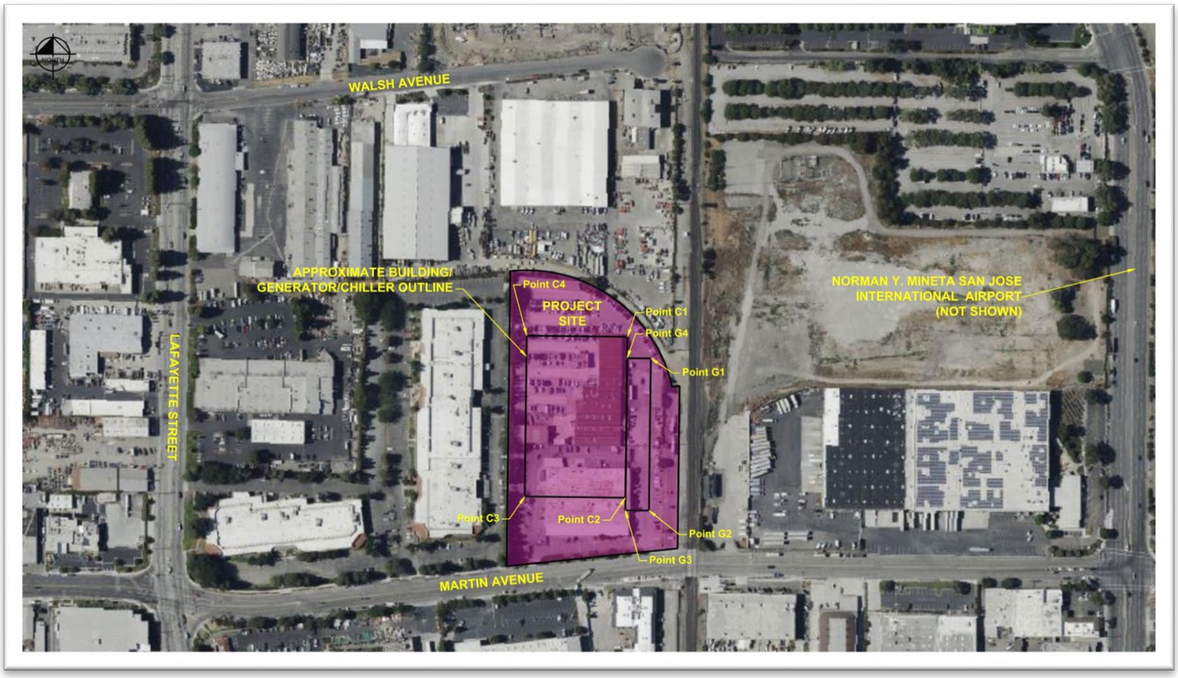

Figure 1 – Project Site

Table 1 – Points Analyzed

Point	Latitude	Longitude
Chiller Points		
Point C1	37° 22' 05.44" N	121° 56' 46.02" W
Point C2	37° 22' 01.19" N	121° 56' 46.01" W
Point C3	37° 22' 01.19" N	121° 56' 49.35" W
Point C4	37° 22' 05.43" N	121° 56' 49.36" W
Backup Generator Points		
Point G1	37° 22' 04.88" N	121° 56' 45.24" W
Point G2	37° 22' 00.87" N	121° 56' 45.23" W
Point G3	37° 22' 00.87" N	121° 56' 46.01" W
Point G4	37° 22' 04.88" N	121° 56' 46.02" W

Methodology

Kimley-Horn modeled the airport imaginary surfaces at SJC, as defined in 14 Code of Federal Regulations (CFR) Part 77 – Safe, Efficient Use, and Preservation of Navigable Airspace (Part 77) and evaluated applicable airport design standards set forth in Federal Aviation Administration (FAA) Advisory Circular (AC) 150/300-13B, Airport Design.

Kimley-Horn also modeled the obstacle clearance surfaces as defined in FAA Order 8260-3E, United States Standard for Terminal Instrument Procedures (TERPS), including Change 1. Specifically, Kimley-Horn modeled the following:

- TERPS 40:1 Departure Surface for Runways 30L and 30R
- ILS[1] or LOC[2] Runway (RWY) 12R
- RNAV[3] RNP[4] Approach to RWY 12R
- RNAV GPS[5] Approach to RWY 12R
- RNAV RNP Approach to RWY 12L
- RNAV GPS Approach to RWY 12L
- Missed approach segments for Runways 30L and 30R

Assumptions and Limitations

Ultimately, the FAA is responsible for making the final determination regarding the cumulative impacts resulting from the proposed development. The results of Kimley-Horn's modeling should be used for informational purposes only.

This analysis is limited to an airspace study and does not include the investigation of potential impacts of the proposed development to navigational facilities (i.e., interference).

It is also important to note that the FAA evaluates the elevations of proposed construction with respect to AMSL. Often, civil engineers and surveyors report elevation values using other vertical datums, which, when compared with MSL, can cause discrepancies between the proposed and evaluated elevations. It is recommended that the Client consult with their surveyor prior to setting final building elevations, as to ensure consistency with the elevation values. The FAA requires the coordinates in North American Datum of 1983 (NAD83) and elevations in North American Vertical Datum of 1988 (NAVD88).

Findings

The following includes findings for the project site.

CFR PART 77

The site is southwest of Runway 12R/30L is completely below the Horizontal Surface for SJC. The Horizontal Surface is defined as a flat plane, 150 feet above the established airport elevation. At SJC, the Horizontal Surface is 212.16 feet AMSL. Plume heights of 171 and 177 feet AMSL do not exceed the CFR Part 77 Horizontal Surface and would not be considered obstructions.

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[1] ILS – Instrument Landing System
[2] LOC – Localizer
[3] RNAV – Area Navigation
[4] RNP – Required Navigation Approach
[5] GPS – Global Positioning System

AIRPORT DESIGN SURFACES

The project site is outside of Airport Design Surfaces and therefore does not adversely impact the airport design surfaces at SJC.

DEPARTURE SURFACE FOR RUNWAYS 30L AND 30R (TERPS)

The project site is not within the TERPS 40:1 Departure Surfaces for Runways 30L and 30R. For Diverse Departures, the project site is within the Diverse A area. The Diverse A obstacle identification surface clears the plumes by a minimum of 211 feet.

ILS OR LOC RWY 12R

The ILS or LOC RWY 12R instrument approach procedure consists of Vertically Guided (ILS) and Non-Vertically Guided (Localizer) components. The project site is not within the obstacle identification surfaces for the ILS or LOC RWY 12R instrument approach procedure.

RNAV (GPS) RWY 12R

The RNAV (GPS) RWY 12R instrument approach procedure consists of Precision Vertically Guided (LPV), Non-Precision Vertically Guided (LNAV/VNAV) and Non-Precision (LNAV) lines of minima. Each are discussed below.

<u>**LPV:**</u> The LPV uses the same obstacle identification surfaces as the above-mentioned ILS procedure. Thus, the project site is outside of the obstacle identification surface and do not penetrate the LPV procedure.

<u>**LNAV/VNAV:**</u> The site is within the obstacle identification surface of the LNAV/VNAV procedure. The plumes – diesel and chiller – do not adversely impact the existing LNAV/VNAV procedure. The required Decision Altitude (DA) to clear the chiller plumes is 338 feet AMSL, which is less than the currently published DA. For reference, the backup generator plumes require a DA of 332 feet AMSL, less than the chiller plumes and the currently published DA.

<u>**LNAV:**</u> The site is also within the LNAV obstacle identification surface. The existing LNAV procedure is not adversely impacted by the diesel and chiller plumes. The plumes require a Minimum Descent Altitude (MDA) of 440 feet AMSL and the published MDA is 520 feet AMSL.

<u>**Missed Approach:**</u> For the RNAV (GPS) RWY 12R approach procedure, there is a missed approach segment. This protects for aircraft executing an aborted landing maneuver when the runway is not in sight at the specified DA or MDA. The entire site is within the Missed Approach surface and the chiller plume is clear by at least 33 feet.

RNAV (RNP) RWY 12R

The RNAV (RNP) RWY 12R instrument approach procedure consists of Vertically Guided (RNP) segments that have different obstacle evaluation areas to accommodate aircraft with advanced avionics. The project site is within the obstacle evaluation areas and does not represent an obstacle at the evaluated heights.

RNAV (GPS) RWY 12L

The RNAV (GPS) RWY 12L instrument approach procedure also consists of LPV, LNAV/VNAV, and LNAV lines of minima.

LPV: There are no penetrations to the LPV procedure.

LNAV/VNAV: The site is within the obstacle identification surface of the LNAV/VNAV procedure. The plumes – diesel and chiller – do not adversely impact the existing LNAV/VNAV procedure. The required Decision Altitude (DA) to clear the chiller plumes is 338 feet AMSL, which is less than the currently published DA. For reference, the backup generator plumes require a DA of 332 feet AMSL, less than the chiller plumes and the currently published DA.

LNAV: The LNAV procedure is not adversely impacted by the diesel and chiller plumes. The plumes require a Minimum Descent Altitude (MDA) of 440 feet AMSL and the published MDA is 520 feet AMSL.

Missed Approach: There is a missed approach segment for this procedure. The entire site is within the Missed Approach surface and the chiller plume is clear by at least 3 feet.

RNAV (RNP) RWY 12L

The project site is within the RNAV (RNP) RWY 12L missed approach obstacle identification surface area and does not represent an obstacle at the evaluated points and heights.

MISSED APPROACH SEGMENTS FOR RUNWAYS 30L AND 30R

A review was performed of the missed approach segments for instrument approach procedures associate with Runways 30L and 30R. The lowest missed approach surface is the Runway 30L CAT II ILS and is clear by at least 215 feet.

Analysis of Overflights

Additional analysis was performed to determine the frequency at which overflights occurred over the project site, and at what altitudes those overflights occurred. Kimley-Horn obtained Automatic Dependent Surveillance – Broadcast (ADS-B) data for the area identified in ***Figure 2***. Powered aircraft are required to have ADS-B transponders when operating at SJC.

The area examined was larger than the project site because data samples were taken every five seconds by the vendor who supplied the ADS-B flight track data. The northeast corner of the box was used as the controlling point and the box was stretched west and south to capture as many aircraft pings as possible. The northeast corner of the box was identified as the critical corner and sited to capture the northern limit of the project site and remain clear of the Runway 12R/30L centerline. Encroachment on the runway centerline could artificially skew the results. Due to limitations, the vendor could only define data collection boxes that are square and aligned with true north. In other words, a box parallel with the runway centerline could not be used.

Figure 2 – ADS-B Collection Area

Data was collected from March 1, 2022, through March 17, 2023. Data was only collected for small airplanes (aircraft weighing less than 15,500 pounds) and helicopter operations. Aircraft altitudes from the ground up to 2,600 feet AMSL were collected. This was intended to capture aircraft arriving, departing, and conducting pattern work at SJC, while avoiding general SJC overflight traffic. ***Figure 3*** shows the number of operations through the identified box per month.

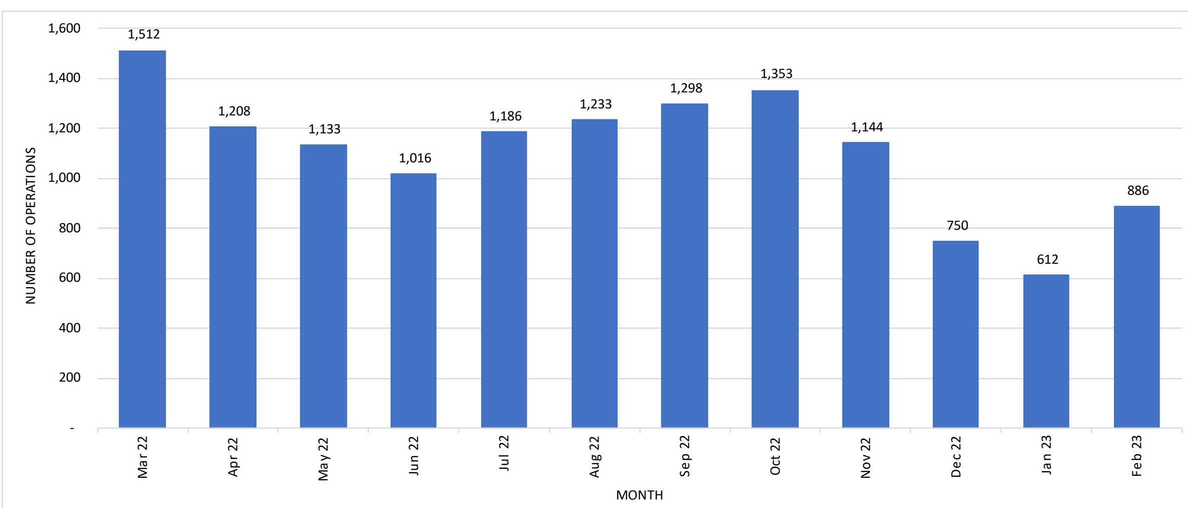


Figure 3 – Number of Aircraft Flying Over the Project Site

Figure 4 shows the range of altitudes aircraft were at when transiting this area.

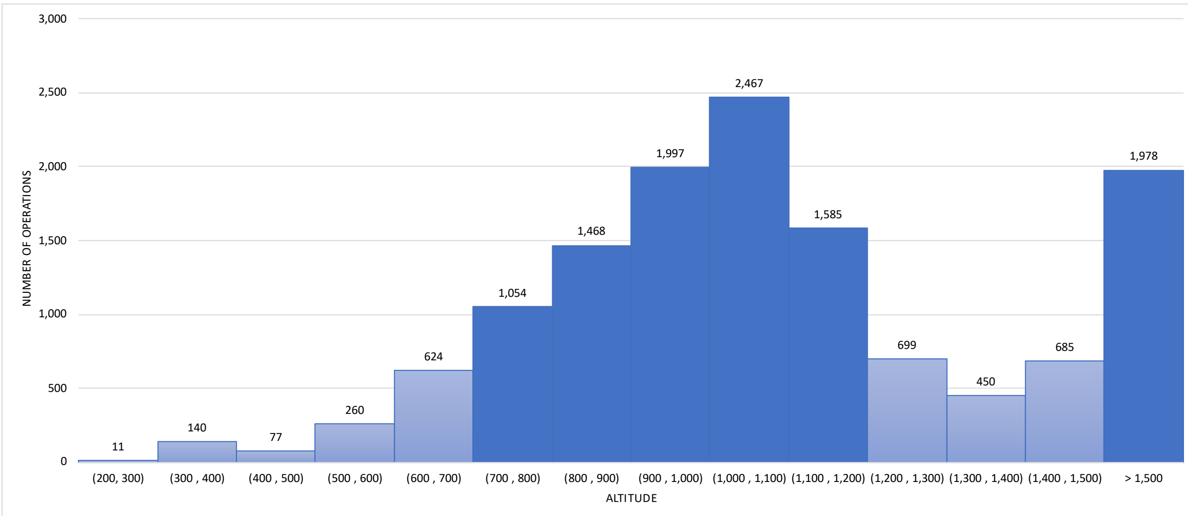


Figure 4 – Altitudes of Aircraft Flying Over the Project Site

On average, about 1,111 small airplanes overfly the project site monthly. These aircraft are generally at an altitude of 700 feet AMSL to 1,200 feet AMSL and greater than 1,500 feet AMSL. The lowest altitude observed was 207 feet AMSL. All small aircraft overflying this area over the last year were above the maximum plume height of 177 feet AMSL.

Conclusions

Table 2 summarizes the results presented in this analysis. The plume heights analyzed considered the maximum plume height with no wind. Any wind will dissipate the plume before it reaches this maximum height. The maximum plume heights are below the Part 77 surfaces associated with Norman Y. Mineta San Jose International Airport. The plumes would not represent a controlling obstacle to the existing instrument approach procedures. Also, based on the acquired ADS-B data, no small airplanes or helicopters overfly this site at an altitude that will be affected by the plumes.

As with any development near an airport, it is recommended that FAA Form 7460-1, Notice of Proposed Construction or Alternation, be completed and submitted to the FAA to receive a formal determination on the proposed development's potential hazards to air navigation.

Table 2 – Summary of Results

Component Analyzed	Thermal Plume Impacts		Additional Information
	Yes	No	
Part 77		✓	Below the Part 77 Horizontal Surface
Airport Design Surfaces		✓	
Departure Surface for Runways 30L and 30R		✓	Clear by at least 211 feet.
ILS/LOC RWY 12R		✓	Not within the obstacle identification surface.
RNAV (GPS) RWY 12R		✓	
RNAV (RNP) RWY 12R		✓	
RNAV (GPS) RWY 12L		✓	
RNAV (RNP) RWY 12L		✓	
Missed Approach Segments for Runways 30L and 30R		✓	Clear by at least 215 feet

Attachments:

A: Architectural Drawing
B: Thermal Plume Calculation & Analysis

* * * * * * *

Please do not hesitate to contact me at 909.991.4398 (mobile), or Andrew.scanlon@kimley-horn.com to discuss further or if you have any questions or comments.

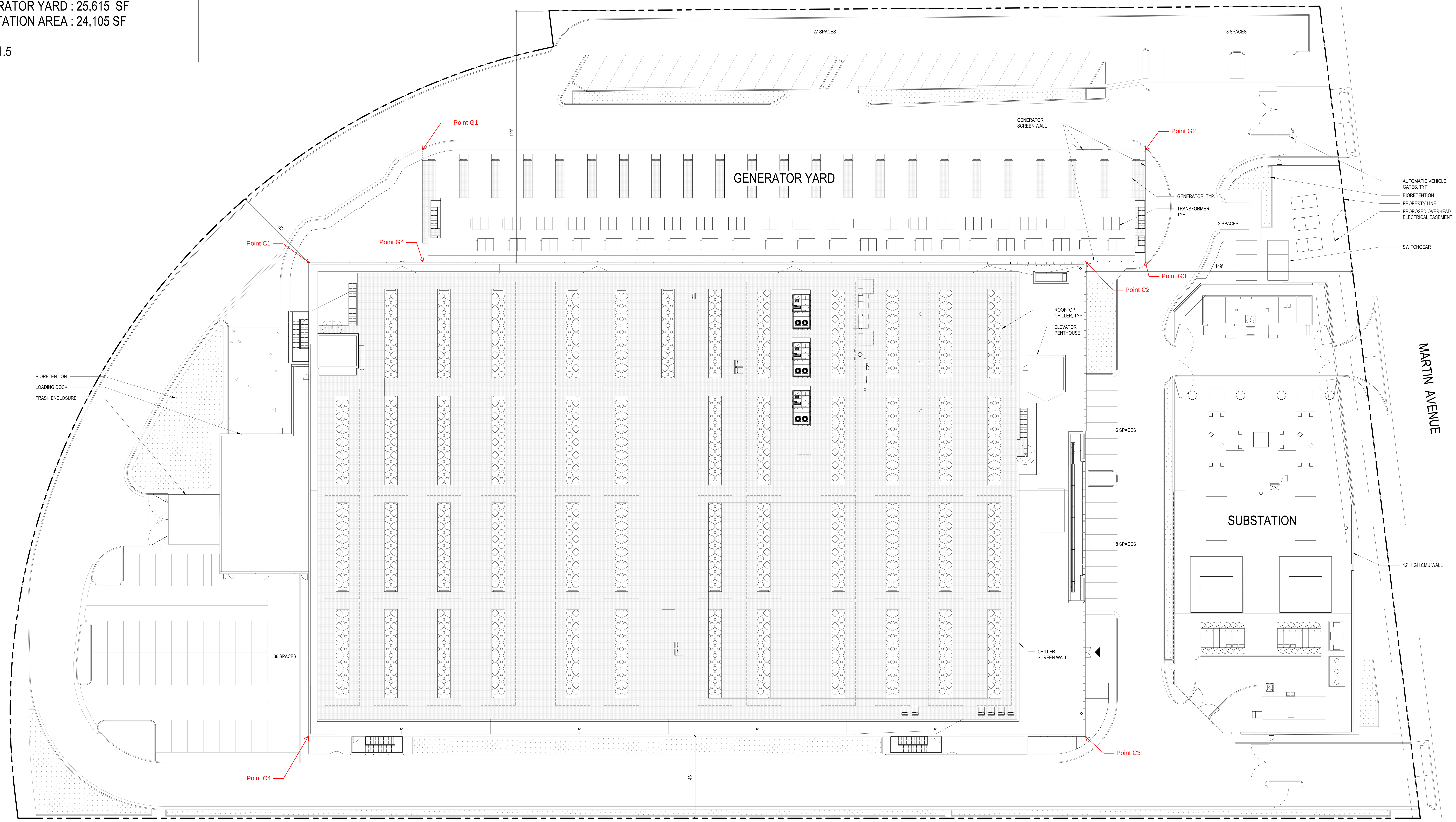
Attachment A

Architectural Drawing

651 MARTIN AVENUE

TOTAL SITE AREA : 312,237 SF
GROSS BUILDING AREA : 468,175 SF
GENERATOR YARD : 25,615 SF
SUBSTATION AREA : 24,105 SF

FAR : 1.5



1 ARCHITECTURAL SITE PLAN
3/64" = 1'-0"

GENERAL NOTES

OWNER
MARTIN AVENUE PROPERTIES

CONTRACTOR
DPR CONSTRUCTION
1450 Veterans Blvd.
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San Francisco, CA
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PROGRESS SET
NOT FOR CONSTRUCTION

No.	Description	Date

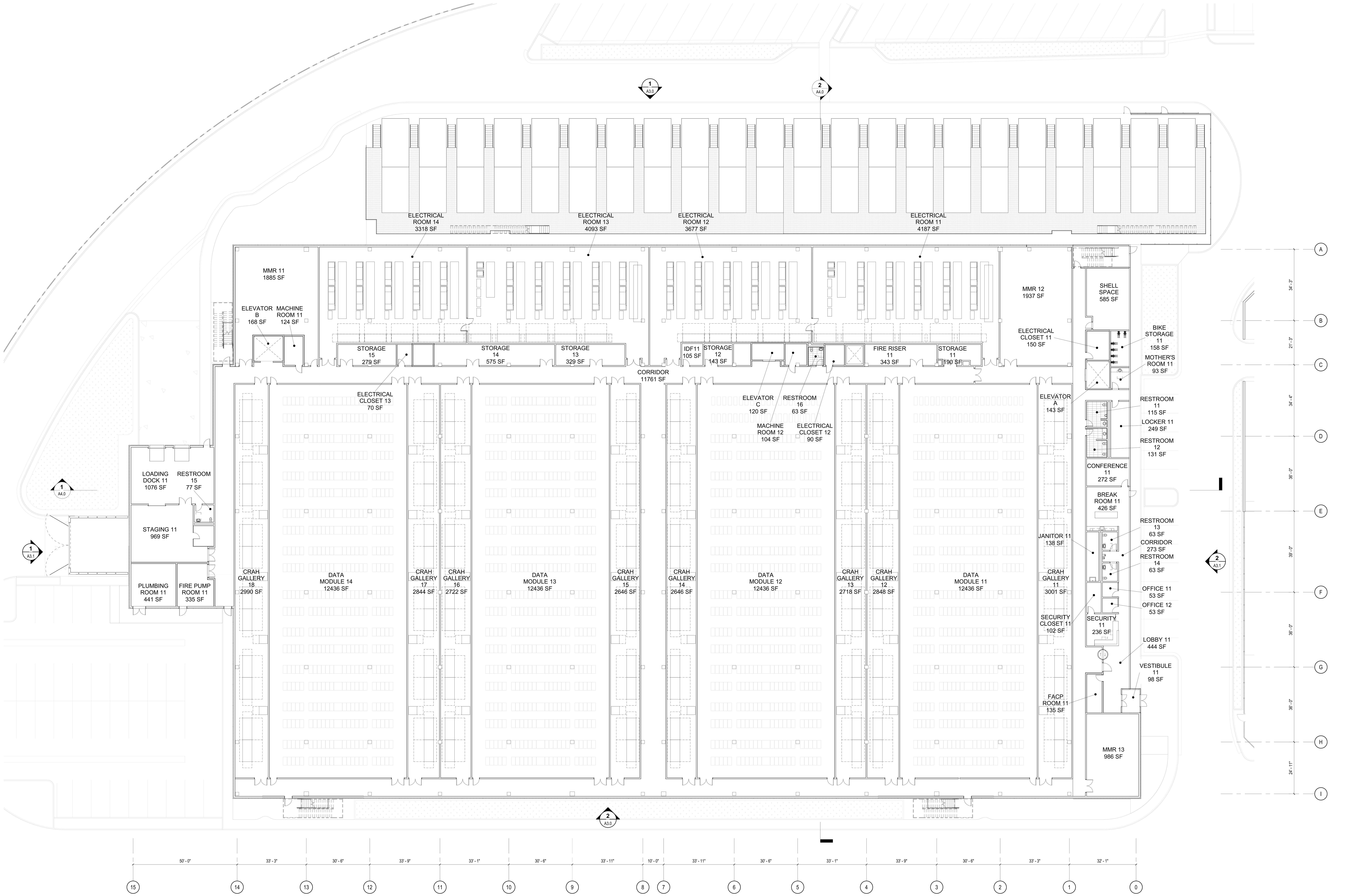
651 MARTIN AVENUE

651 MARTIN AVENUE
SANTA CLARA, CA
95050
APN: 224-04-071

ARCHITECTURAL SITE PLAN

A0.0

SCALE: Scale as Noted



1 FLOOR PLAN - LEVEL 1
1/16" = 1'-0"

GENERAL NOTES

OWNER

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No.	Description	Date

651 MARTIN AVENUE

651 MARTIN AVENUE
SANTA CLARA, CA
95050
APN: 224-04-071

LEVEL 01 FLOOR PLAN

A1.1

SCALE: Scale as Noted

OWNER

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651 MARTIN AVENUE

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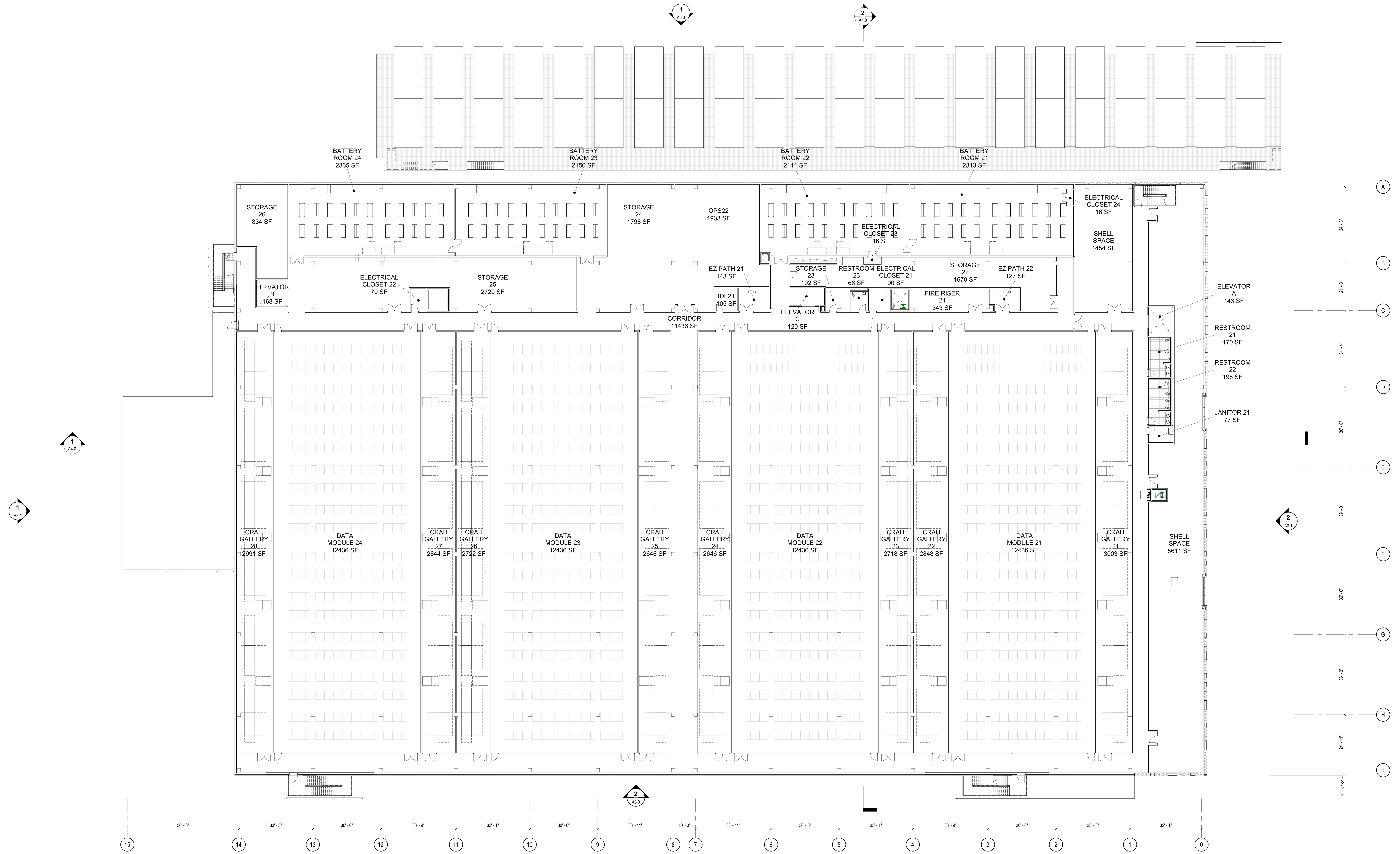
APN: 224-04-071

LEVEL 02 FLOOR PLAN

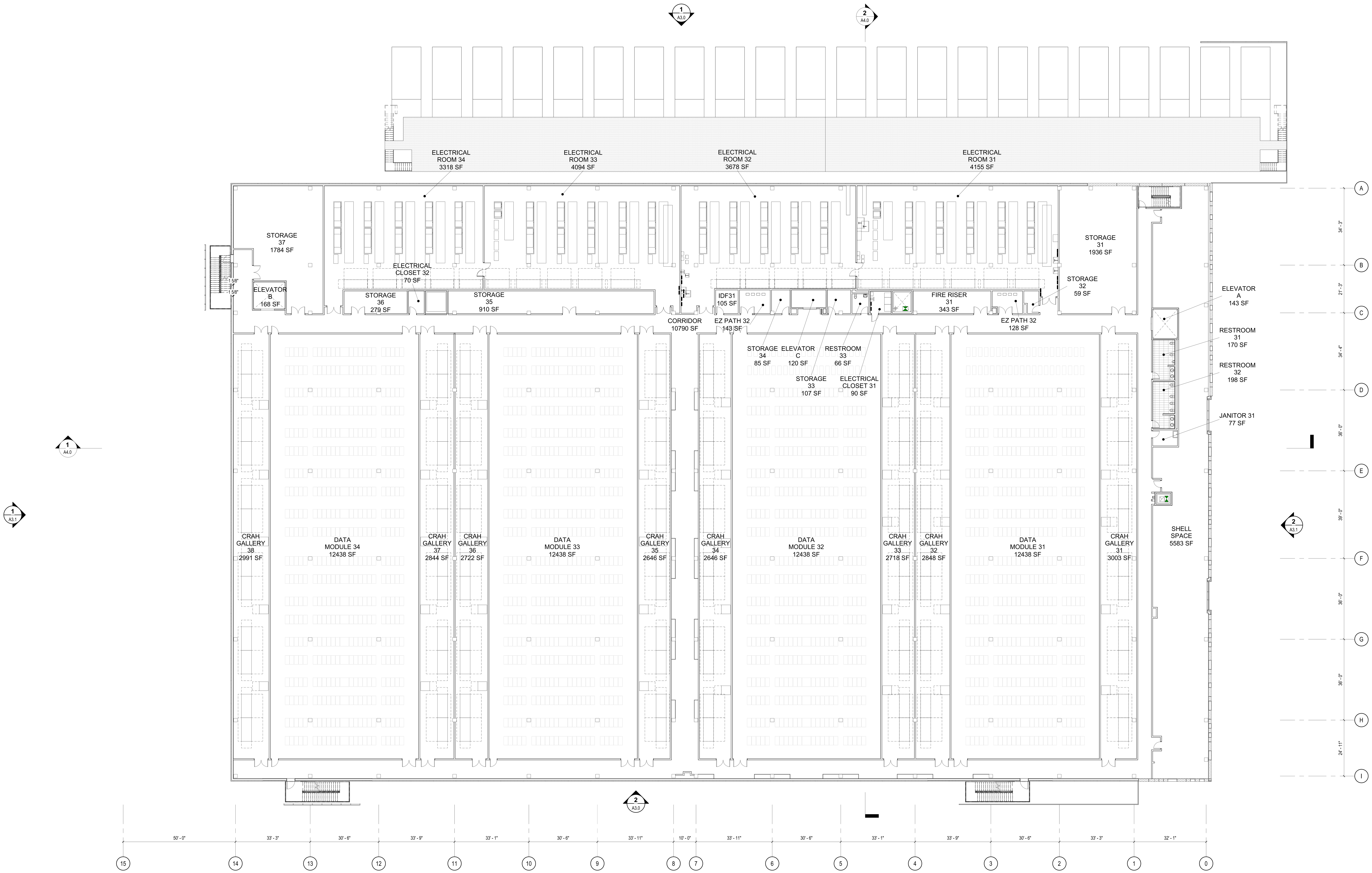
A1.2

SCALE: Scale as Noted



1 FLOOR PLAN - LEVEL 2
1/16" = 1'-0"

GENERAL NOTES



1 FLOOR PLAN - LEVEL 3
1/16" = 1'-0"

GENERAL NOTES

OWNER

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No.	Description	Date

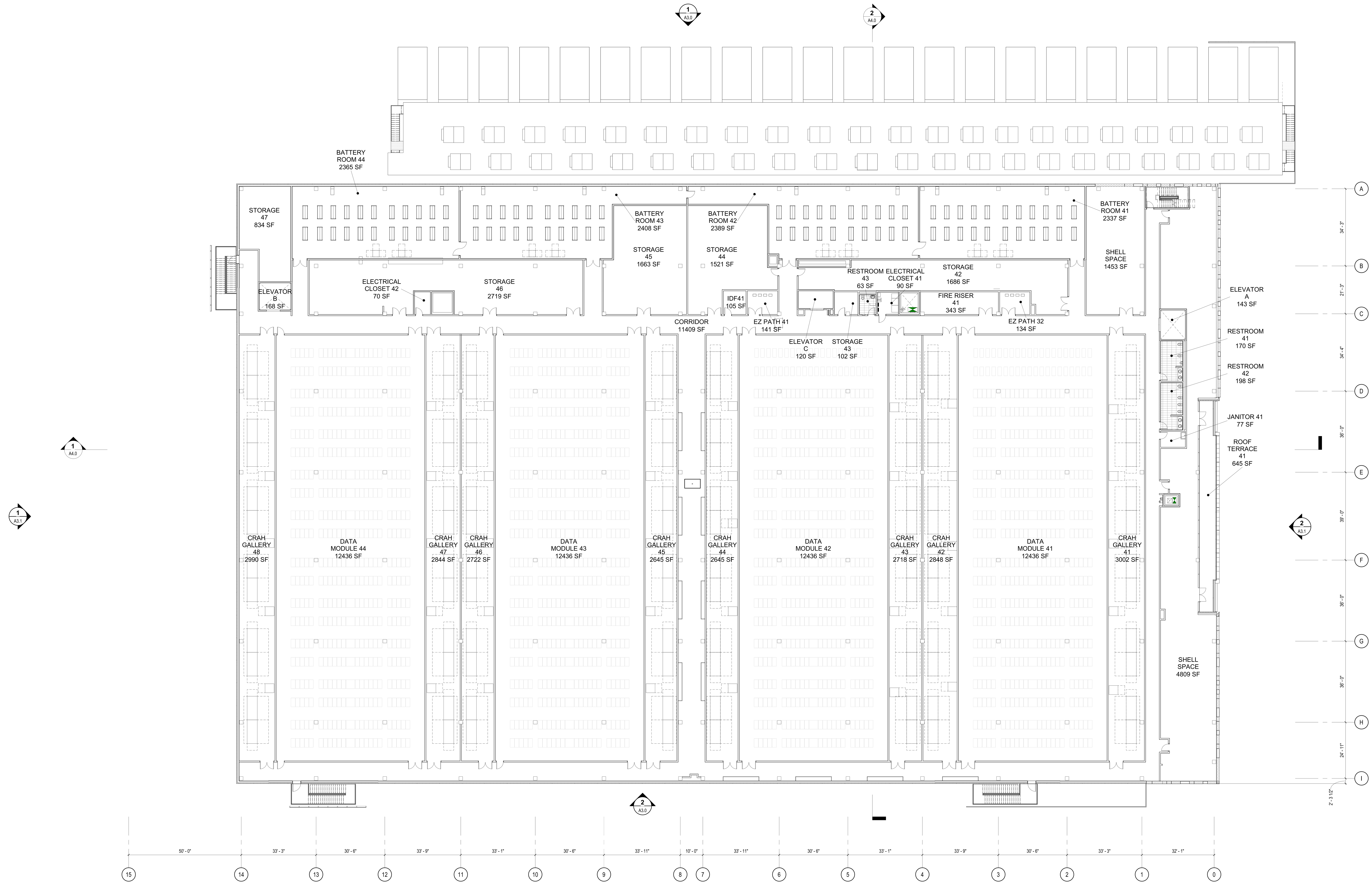
651 MARTIN AVENUE

651 MARTIN AVENUE
SANTA CLARA, CA
95050
APN: 224-04-071

LEVEL 03 FLOOR PLAN

A1.3

SCALE: Scale as Noted



1 FLOOR PLAN - LEVEL 4
1/16" = 1'-0"

GENERAL NOTES

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651 MARTIN AVENUE
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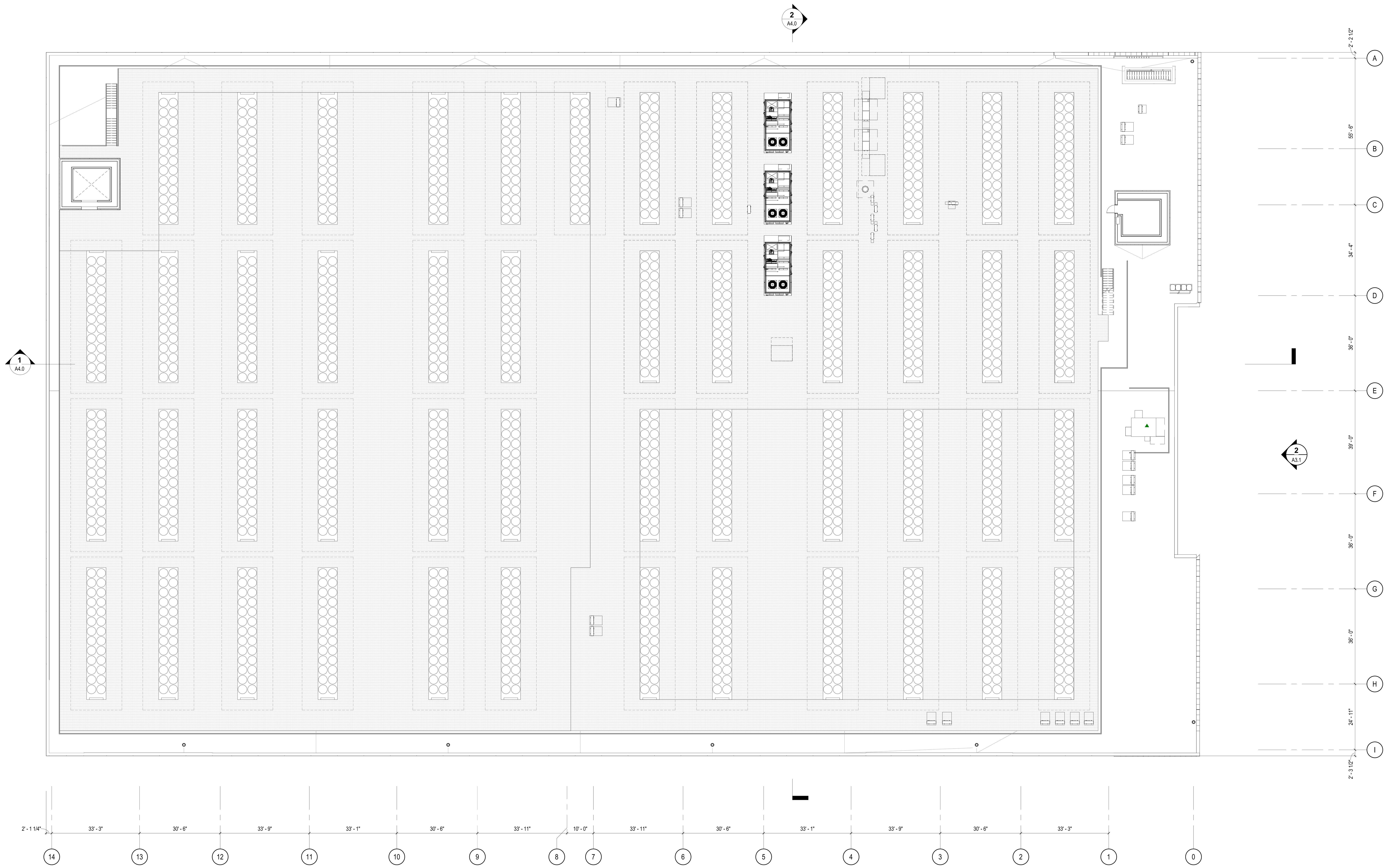
LEVEL 04 FLOOR PLAN

A1.4

SCALE: Scale as Noted



1 OVERALL ROOF PLAN
1/16" = 1'-0"

GENERAL NOTES

OWNER

MARTIN AVENUE PROPERTIES

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PROGRESS SET
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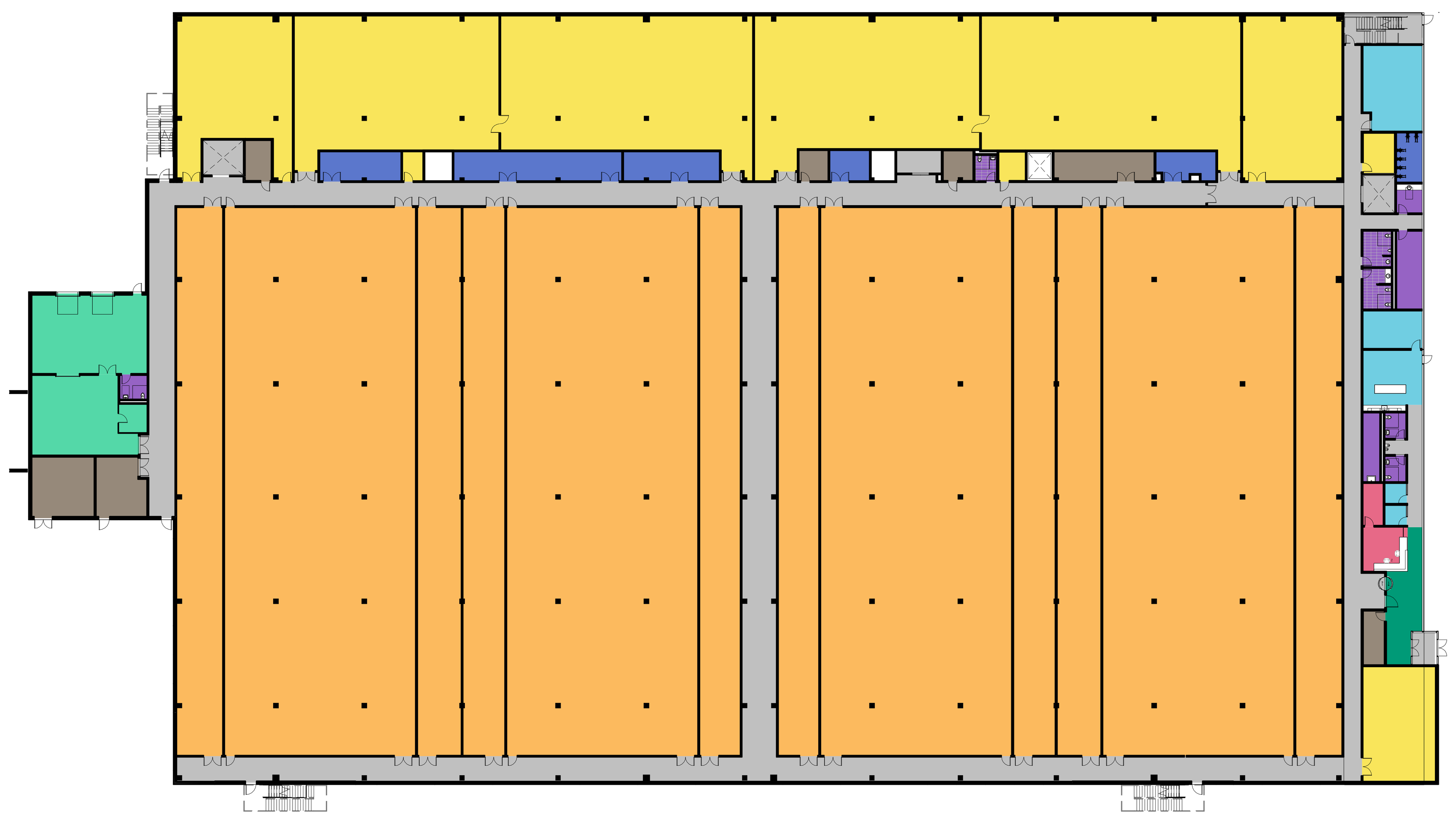
95050
APN: 224-04-071

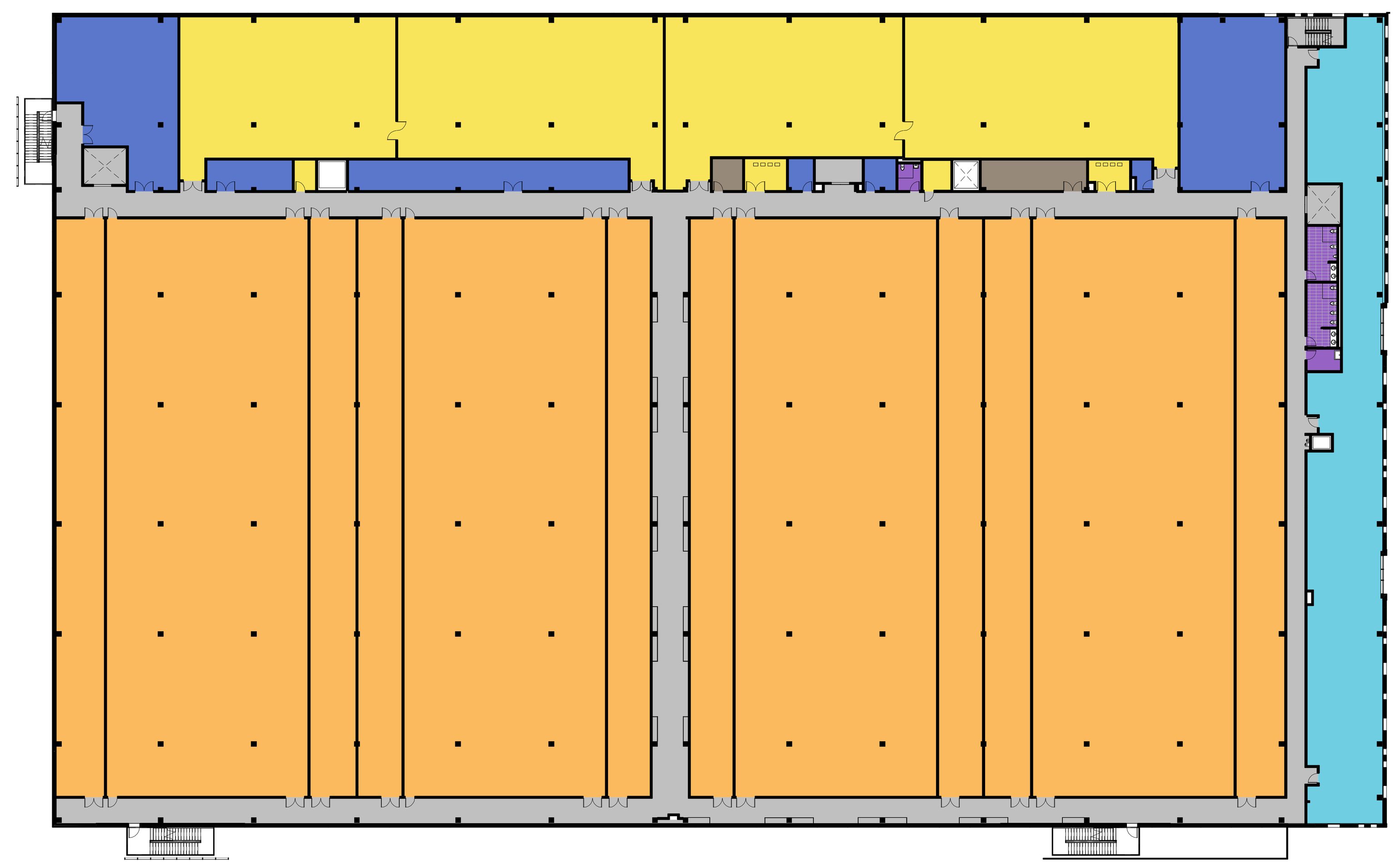
ROOF LEVEL FLOOR PLAN

A1.5

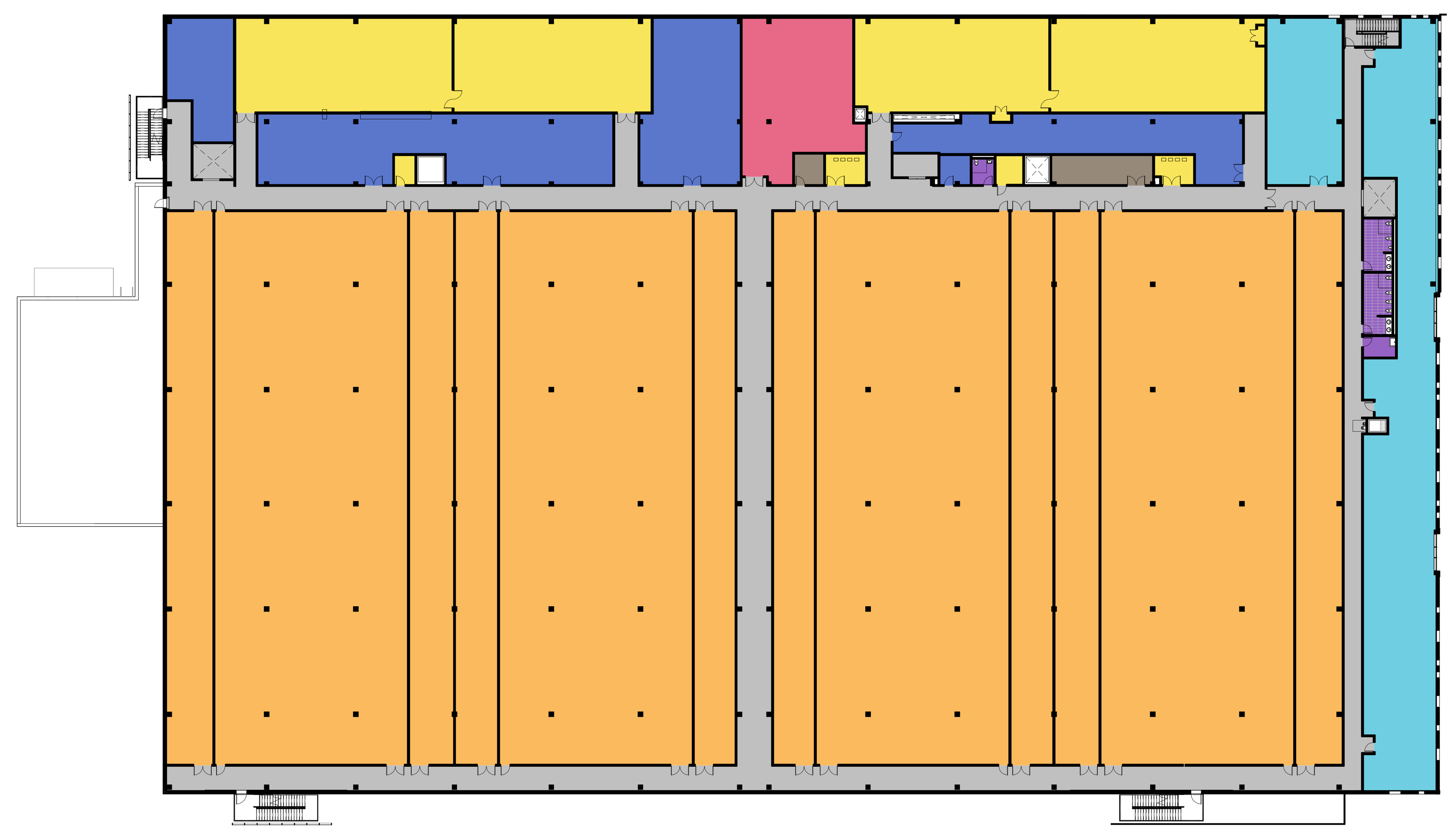
SCALE: Scale as Noted



1 LEVEL 01 - AREA CALCULATION
1/32" = 1'-0"



3 LEVEL 03 - AREA CALCULATION
1/32" = 1'-0"



2 LEVEL 02 - AREA CALCULATION
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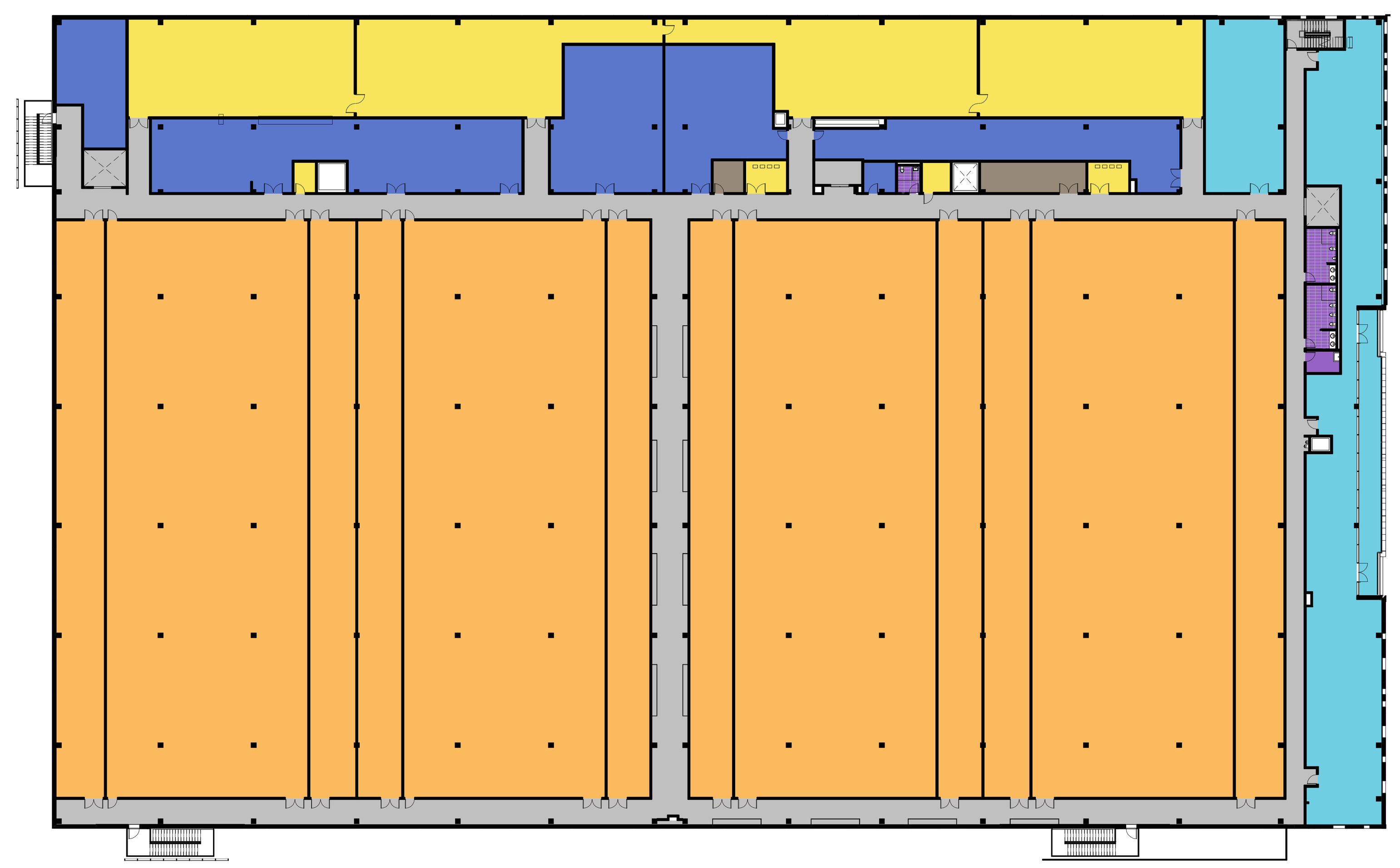

4 LEVEL 04 - AREA CALCULATION
1/32" = 1'-0"

TOTAL GROSS AREA: 468,175 SF

TOTAL ADMIN AREA REQUIRED
19,200 SF (300 SF / MW)

TOTAL ADMIN AREA PROVIDED
20,942 SF (327 SF / MW)

TOTAL STORAGE AREA REQ.
19,200 SF (300 SF / MW)

TOTAL STORAGE AREA PROV.
22,481 SF (351 SF / MW)

TOTAL COMBINED AREA REQ.
38,400 SF (600 SF/MW)

TOTAL COMBINED AREA PROV.
43,423 SF (678 SF / MW)

NOTE: NOT ALL SPACES ARE PROGRAMMED,
AREAS LIKELY TO REDUCE

AREA LEGEND

- ADMIN
- BACK OF HOUSE
- CIRCULATION
- COMMON AREA
- DATA HALL MODULE
- DATA MODULE SUPPORT
- LOADING DOCK
- LOBBY
- STORAGE
- VANTAGE FACILITY OPS

ADMIN

LEVEL 1	BREAK ROOM 11	426 SF
LEVEL 1	CONFERENCE 11	272 SF
LEVEL 1	OFFICE 11	53 SF
LEVEL 1	OFFICE 12	53 SF
LEVEL 1	SHELL SPACE	585 SF
LEVEL 2	SHELL SPACE	5611 SF
LEVEL 2	SHELL SPACE	1454 SF
LEVEL 3	SHELL SPACE	5583 SF
LEVEL 4	ROOF TERRACE 41	645 SF
LEVEL 4	SHELL SPACE	4809 SF
LEVEL 4	SHELL SPACE	1453 SF
		20942 SF

BACK OF HOUSE

LEVEL 1	FACP ROOM 11	135 SF
LEVEL 1	FIRE PUMP ROOM 11	335 SF
LEVEL 1	FIRE RISER 11	343 SF
LEVEL 1	IDF11	105 SF
LEVEL 1	MACHINE ROOM 11	124 SF
LEVEL 1	MACHINE ROOM 12	104 SF
LEVEL 1	PLUMBING ROOM 11	441 SF
LEVEL 2	FIRE RISER 21	343 SF
LEVEL 2	IDF21	105 SF
LEVEL 3	FIRE RISER 31	343 SF
LEVEL 3	IDF31	105 SF
LEVEL 4	FIRE RISER 41	343 SF
LEVEL 4	IDF41	105 SF
		2928 SF

CIRCULATION

LEVEL 1	CORRIDOR	11761 SF
LEVEL 1	CORRIDOR	273 SF
LEVEL 1	ELEVATOR A	143 SF
LEVEL 1	ELEVATOR B	168 SF
LEVEL 1	ELEVATOR C	120 SF
LEVEL 1	STAIR A	283 SF
LEVEL 1	VESTIBULE 11	98 SF
LEVEL 2	CORRIDOR	11436 SF
LEVEL 2	ELEVATOR A	143 SF
LEVEL 2	ELEVATOR B	168 SF
LEVEL 2	ELEVATOR C	120 SF
LEVEL 2	STAIR A	180 SF
LEVEL 3	CORRIDOR	10790 SF
LEVEL 3	ELEVATOR A	143 SF
LEVEL 3	ELEVATOR B	168 SF
LEVEL 3	ELEVATOR C	120 SF
LEVEL 3	STAIR A	180 SF
LEVEL 4	CORRIDOR	11409 SF
LEVEL 4	ELEVATOR A	143 SF
LEVEL 4	ELEVATOR B	168 SF
LEVEL 4	ELEVATOR C	120 SF
LEVEL 4	STAIR A	180 SF
		48314 SF

COMMON AREA

LEVEL 1	JANITOR 11	138 SF
LEVEL 1	LOCKER 11	249 SF
LEVEL 1	MOTHER'S ROOM 11	93 SF
LEVEL 1	RESTROOM 11	115 SF
LEVEL 1	RESTROOM 12	131 SF
LEVEL 1	RESTROOM 13	63 SF
LEVEL 1	RESTROOM 14	63 SF
LEVEL 1	RESTROOM 15	77 SF
LEVEL 1	RESTROOM 16	63 SF
LEVEL 2	JANITOR 21	77 SF
LEVEL 2	RESTROOM 21	170 SF
LEVEL 2	RESTROOM 22	198 SF
LEVEL 2	RESTROOM 23	66 SF
LEVEL 3	JANITOR 31	77 SF
LEVEL 3	RESTROOM 31	170 SF
LEVEL 3	RESTROOM 32	198 SF
LEVEL 3	RESTROOM 33	66 SF
LEVEL 4	JANITOR 41	77 SF
LEVEL 4	RESTROOM 41	170 SF
LEVEL 4	RESTROOM 42	198 SF
LEVEL 4	RESTROOM 43	63 SF
		2525 SF

DATA HALL MODULE

LEVEL 1	CRAH GALLERY 11	3001 SF
LEVEL 1	CRAH GALLERY 12	2848 SF
LEVEL 1	CRAH GALLERY 13	2718 SF
LEVEL 1	CRAH GALLERY 14	2646 SF
LEVEL 1	CRAH GALLERY 15	2646 SF
LEVEL 1	CRAH GALLERY 16	2722 SF
LEVEL 1	CRAH GALLERY 17	2844 SF
LEVEL 1	CRAH GALLERY 18	2990 SF
LEVEL 1	DATA MODULE 11	12436 SF
LEVEL 1	DATA MODULE 12	12436 SF
LEVEL 1	DATA MODULE 13	12436 SF
LEVEL 1	DATA MODULE 14	12436 SF
LEVEL 2	CRAH GALLERY 21	3003 SF
LEVEL 2	CRAH GALLERY 22	2848 SF
LEVEL 2	CRAH GALLERY 23	2718 SF
LEVEL 2	CRAH GALLERY 24	2646 SF
LEVEL 2	CRAH GALLERY 25	2646 SF
LEVEL 2	CRAH GALLERY 26	2722 SF
LEVEL 2	CRAH GALLERY 27	2844 SF
LEVEL 2	CRAH GALLERY 28	2991 SF
LEVEL 2	DATA MODULE 21	12436 SF
LEVEL 2	DATA MODULE 22	12436 SF
LEVEL 2	DATA MODULE 23	12436 SF
LEVEL 2	DATA MODULE 24	12436 SF
LEVEL 3	CRAH GALLERY 31	3003 SF
LEVEL 3	CRAH GALLERY 32	2848 SF
LEVEL 3	CRAH GALLERY 33	2718 SF
LEVEL 3	CRAH GALLERY 34	2646 SF
LEVEL 3	CRAH GALLERY 35	2646 SF
LEVEL 3	CRAH GALLERY 36	2722 SF
LEVEL 3	CRAH GALLERY 37	2844 SF
LEVEL 3	CRAH GALLERY 38	2991 SF
LEVEL 3	DATA MODULE 31	12438 SF
LEVEL 3	DATA MODULE 32	12438 SF
LEVEL 3	DATA MODULE 33	12438 SF
LEVEL 3	DATA MODULE 34	12438 SF
LEVEL 4	CRAH GALLERY 41	3002 SF
LEVEL 4	CRAH GALLERY 42	2848 SF
LEVEL 4	CRAH GALLERY 43	2718 SF
LEVEL 4	CRAH GALLERY 44	2645 SF
LEVEL 4	CRAH GALLERY 45	2645 SF
LEVEL 4	CRAH GALLERY 46	2722 SF
LEVEL 4	CRAH GALLERY 47	2844 SF
LEVEL 4	CRAH GALLERY 48	2990 SF
LEVEL 4	DATA MODULE 41	12436 SF
LEVEL 4	DATA MODULE 42	12436 SF
LEVEL 4	DATA MODULE 43	12436 SF
LEVEL 4	DATA MODULE 44	12436 SF
		288648 SF

DATA MODULE SUPPORT

LEVEL 1	ELECTRICAL CLOSET 11	150 SF
LEVEL 1	ELECTRICAL CLOSET 12	90 SF
LEVEL 1	ELECTRICAL CLOSET 13	70 SF
LEVEL 1	ELECTRICAL ROOM 11	4187 SF
LEVEL 1	ELECTRICAL ROOM 12	3677 SF
LEVEL 1	ELECTRICAL ROOM 13	4093 SF
LEVEL 1	ELECTRICAL ROOM 14	3318 SF
LEVEL 1	MMR 11	1885 SF
LEVEL 1	MMR 12	1937 SF
LEVEL 1	MMR 13	986 SF
LEVEL 2	BATTERY ROOM 21	2313 SF
LEVEL 2	BATTERY ROOM 22	2111 SF
LEVEL 2	BATTERY ROOM 23	2150 SF
LEVEL 2	BATTERY ROOM 24	2365 SF
LEVEL 2	ELECTRICAL CLOSET 21	90 SF
LEVEL 2	ELECTRICAL CLOSET 22	70 SF
LEVEL 2	ELECTRICAL CLOSET 23	16 SF
LEVEL 2	ELECTRICAL CLOSET 24	16 SF
LEVEL 2	EZ PATH 21	143 SF
LEVEL 2	EZ PATH 22	127 SF
LEVEL 3	ELECTRICAL CLOSET 31	90 SF
LEVEL 3	ELECTRICAL CLOSET 32	70 SF
LEVEL 3	ELECTRICAL ROOM 31	4155 SF
LEVEL 3	ELECTRICAL ROOM 32	3678 SF
LEVEL 3	ELECTRICAL ROOM 33	4094 SF
LEVEL 3	ELECTRICAL ROOM 34	3318 SF
LEVEL 3	EZ PATH 32	128 SF
LEVEL 3	EZ PATH 32	143 SF
LEVEL 4	BATTERY ROOM 41	2337 SF
LEVEL 4	BATTERY ROOM 42	2389 SF
LEVEL 4	BATTERY ROOM 43	2408 SF
LEVEL 4	BATTERY ROOM 44	2365 SF
LEVEL 4	ELECTRICAL CLOSET 41	90 SF
LEVEL 4	ELECTRICAL CLOSET 42	70 SF
LEVEL 4	EZ PATH 32	134 SF
LEVEL 4	EZ PATH 41	141 SF
		55403 SF

LOADING DOCK

LEVEL 1	LOADING DOCK 11	1076 SF
LEVEL 1	STAGING 11	969 SF
		2045 SF

LOBBY

LEVEL 1	LOBBY 11	444 SF
		444 SF

STORAGE

LEVEL 1	BIKE STORAGE 11	158 SF
LEVEL 1	STORAGE 11	190 SF
LEVEL 1	STORAGE 12	143 SF
LEVEL 1	STORAGE 13	329 SF
LEVEL 1	STORAGE 14	575 SF
LEVEL 1	STORAGE 15	279 SF
LEVEL 2	STORAGE 22	1670 SF
LEVEL 2	STORAGE 23	102 SF
LEVEL 2	STORAGE 24	1798 SF
LEVEL 2	STORAGE 25	2720 SF
LEVEL 2	STORAGE 26	834 SF
LEVEL 3	STORAGE 31	1936 SF
LEVEL 3	STORAGE 32	59 SF
LEVEL 3	STORAGE 33	107 SF
LEVEL 3	STORAGE 34	85 SF
LEVEL 3	STORAGE 35	910 SF
LEVEL 3	STORAGE 36	279 SF
LEVEL 3	STORAGE 37	1784 SF
LEVEL 4	STORAGE 42	1686 SF
LEVEL 4	STORAGE 43	102 SF
LEVEL 4	STORAGE 44	1521 SF
LEVEL 4	STORAGE 45	1663 SF
LEVEL 4	STORAGE 46	2719 SF
LEVEL 4	STORAGE 47	834 SF
		22481 SF

VANTAGE FACILITY OPS

LEVEL 1	SECURITY 11	236 SF
LEVEL 1	SECURITY CLOSET 11	102 SF
LEVEL 2	OPS22	1933 SF
		2271 SF
		446001 SF

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PROGRESS SET
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No.	Description	Date

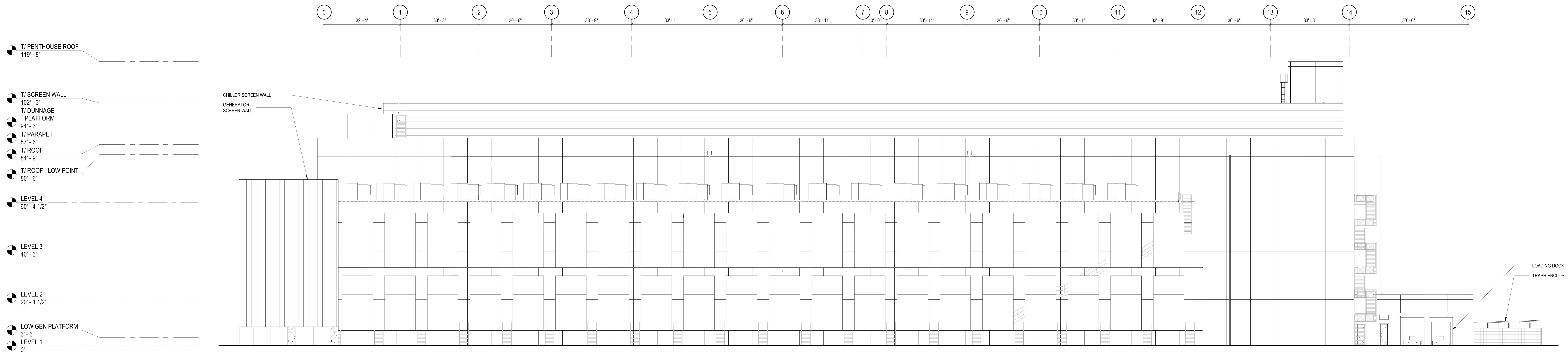
651 MARTIN AVENUE

651 MARTIN AVENUE
SANTA CLARA, CA
95050
APN: 224-04-071

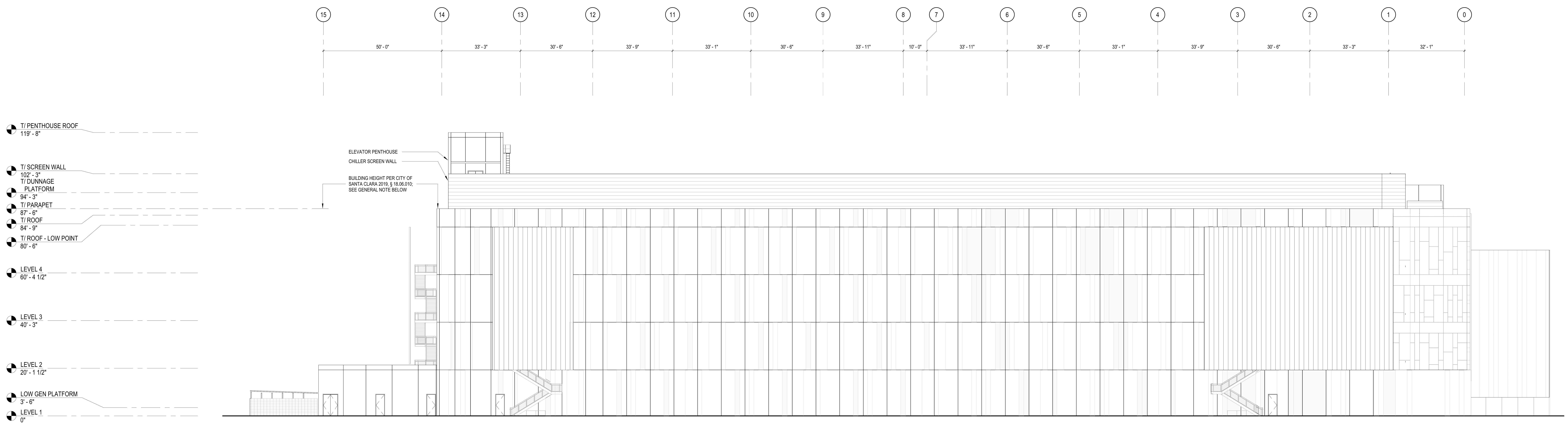
AREA CALCULATIONS

A2.0

SCALE: Scale as Noted



1 ELEVATION DIAGRAM - EAST
1/16" = 1'-0"



2 ELEVATION DIAGRAM - WEST
1/16" = 1'-0"

GENERAL NOTES

BUILDING HEIGHT EXCEEDANCE

MAXIMUM PERMITTED BUILDING HEIGHT IN THE ML ZONING DISTRICT IS 70 FEET (CITY OF SANTA CLARA 2019, § 18.48.070). AS STATED ABOVE, HEIGHT OF BUILDINGS IS DEFINED AS THE VERTICAL DISTANCE FROM THE ADJACENT GROUND ELEVATION "TO THE HIGHEST POINT OF THE COPING OF A FLAT ROOF…" (CITY OF SANTA CLARA 2019, § 18.06.010, SUBD. (H)(1)). THE DATA CENTER BUILDING WOULD HAVE A TYPICAL HEIGHT OF 87.5 FEET FROM ADJACENT GRADE TO THE TOP OF THE PARAPET.

THE PROPOSED BUILDING HEIGHT WOULD BE A 25 PERCENT EXCEEDANCE, WHICH IS WITHIN THE 25 PERCENT LIMIT THE ZONING ADMINISTRATOR CAN GRANT AS A MINOR MODIFICATION TO THE REGULATION. THUS, IF THE ZONING ADMINISTRATOR GRANTS THE MINOR MODIFICATION TO THE REGULATION TO ALLOW THE 25 PERCENT EXCEEDANCE, THE PROJECT WOULD CONFORM TO THE REGULATION LIMITING HEIGHT OF BUILDINGS IN THE ML ZONING DISTRICT, AND NO CONFLICT WOULD OCCUR.

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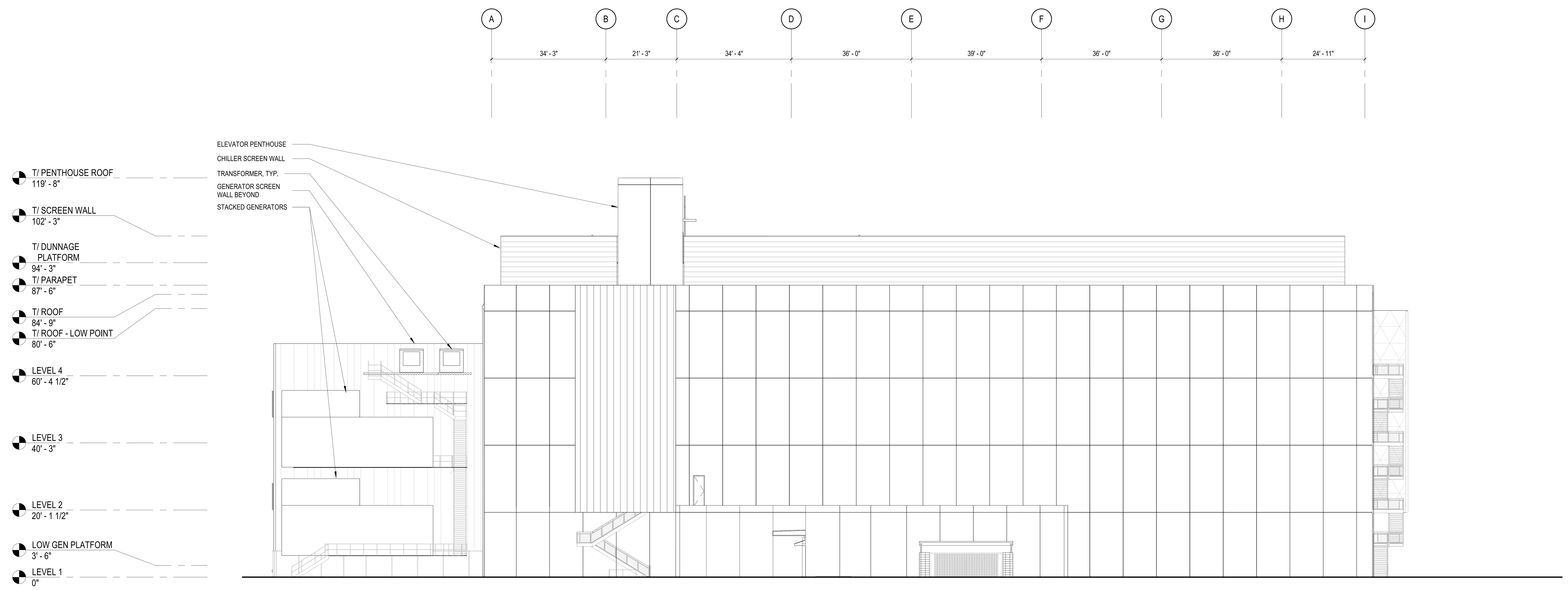
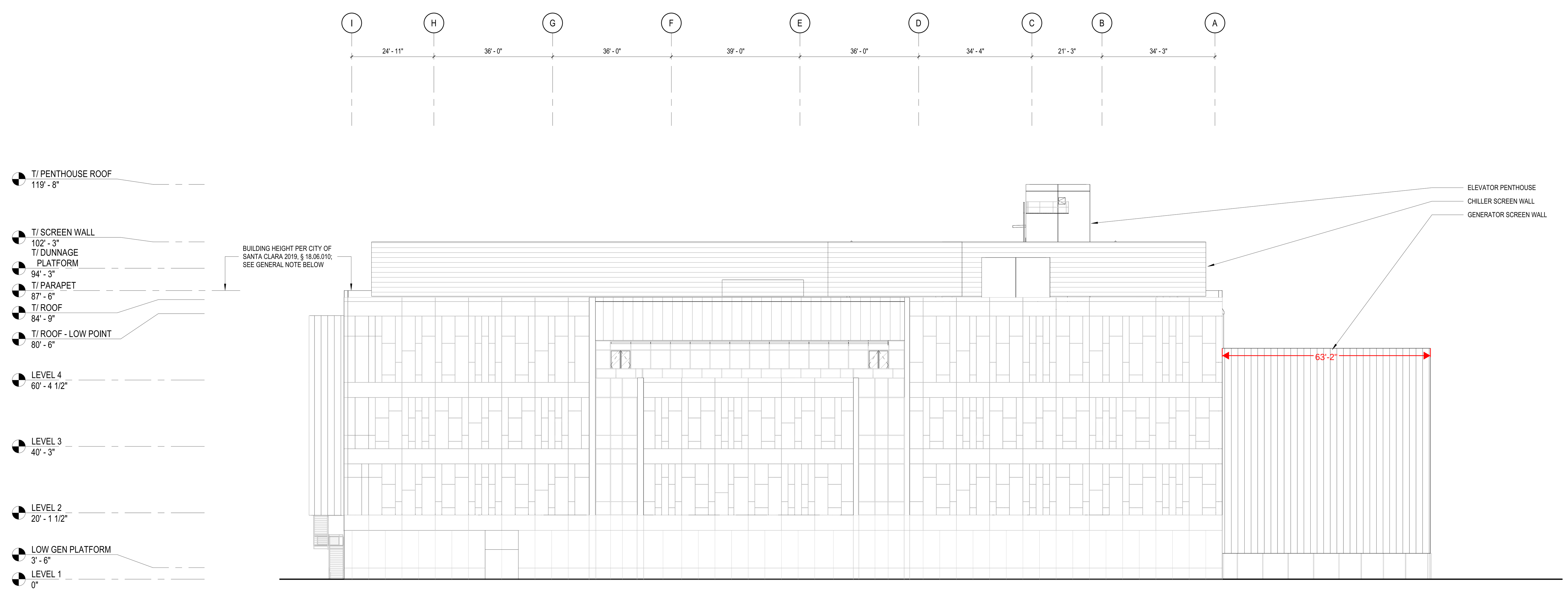
FULL BUILDING EXTERIOR ELEVATIONS

A3.0

SCALE: Scale as Noted



1 ELEVATION DIAGRAM - NORTH
1/16" = 1'-0"



2 ELEVATION DIAGRAM - SOUTH
1/16" = 1'-0"

GENERAL NOTES

BUILDING HEIGHT EXCEEDANCE

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651 MARTIN AVENUE
SANTA CLARA, CA
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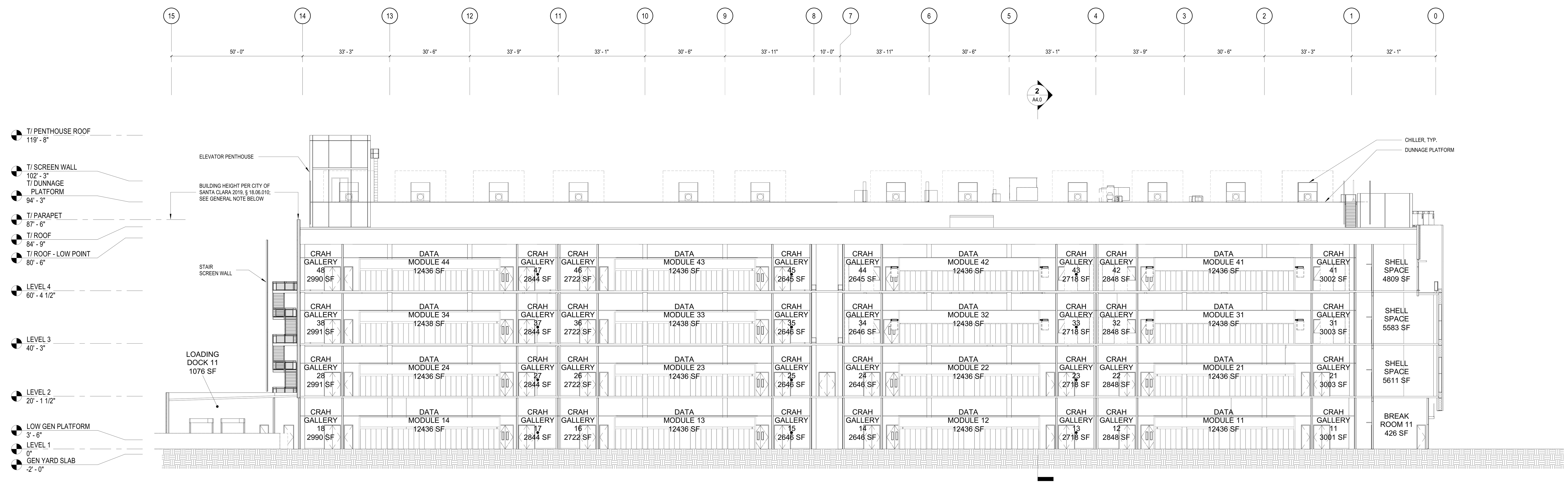
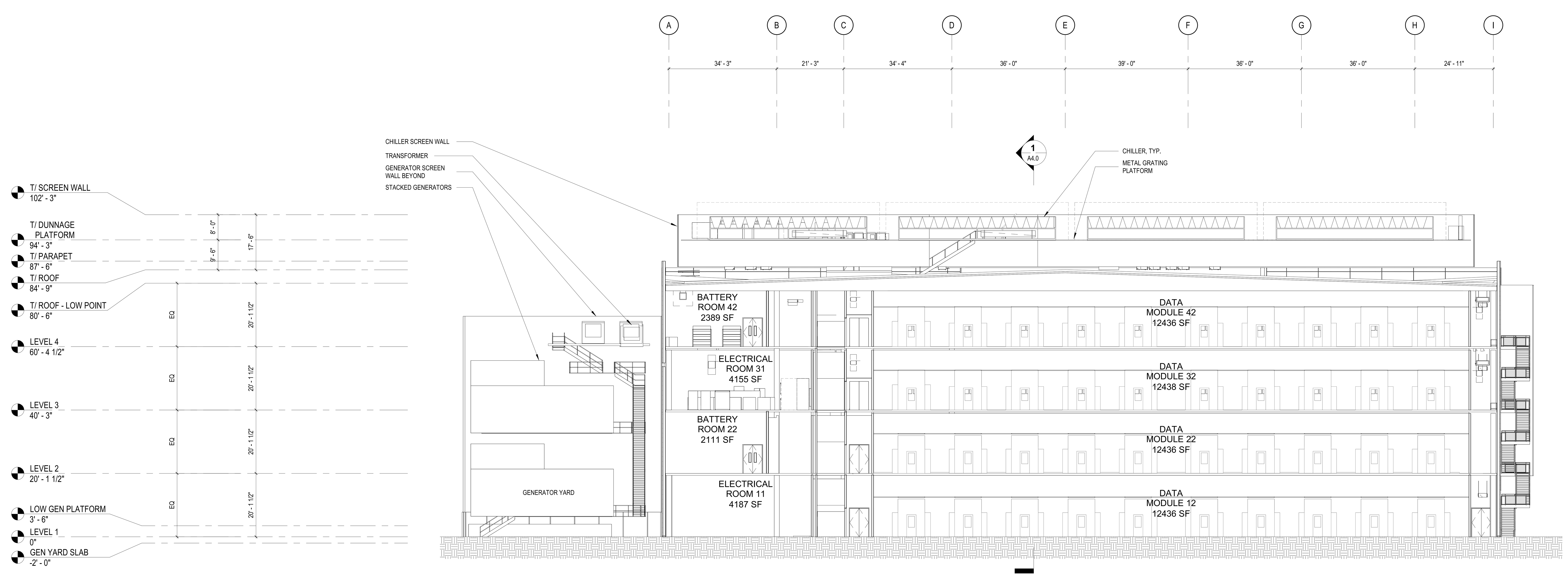
FULL BUILDING EXTERIOR ELEVATIONS

A3.1

SCALE: Scale as Noted



1 FULL BUILDING SECTION - N/S
1/16" = 1'-0"



2 FULL BUILDING SECTION E/W
1/16" = 1'-0"

GENERAL NOTES

BUILDING HEIGHT EXCEEDANCE

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PROGRESS SET NOT FOR CONSTRUCTION

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651 MARTIN AVENUE

651 MARTIN AVENUE
SANTA CLARA, CA
95050
APN: 224-04-071

FULL BUILDING SECTIONS

A4.0

SCALE: Scale as Noted

Attachment B

Thermal Plume Calculation & Analysis

Prepared for
California Energy Commission

Prepared by
Ramboll US Consulting, Inc.
San Francisco, California

Project Number
1690027327

Date
June 2023

Deleted: October 2022

PLUME RISE ASSESSMENT

MARTIN AVENUE PROPERTIES, LLC
SANTA CLARA, CALIFORNIA

CONTENTS

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LIST OF FIGURES

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LIST OF ACRONYMS

ACFM	Actual cubic feet per minute
AGL	above ground level
CASA	Civil Aviation Safety Authority
CEC	California Energy Commission
°F	degree Fahrenheit
ft	feet
ft/s	feet per second
K	Kelvin
m	meter
m/s	meters per second
PEP	Palmdale Energy Project
s	second

1. INTRODUCTION

1.1 Background

Martin Avenue Properties, LLC (Martin LLC) is proposing to develop a data center in Santa Clara, California, at 651 Martin Avenue. The data center will involve forty-four (44) backup emergency diesel generators and forty-eight (48) roof-mounted air chillers.

To supplement its Small Power Plant Exemption application to the California Energy Commission (CEC), Martin LLC has engaged Ramboll US Consulting, Inc. (Ramboll) to conduct a screening assessment to evaluate the potential implications of the thermal plumes from the proposed equipment stacks on aviation safety. The assessment of vertical plume velocity was conducted in accordance with CEC methodology, invoking the Spillane methodology to analytically solve for plume height. The effect of merged plumes is taken into account.

The acceptable plume vertical velocity threshold is specified in supplemental testimony of James Adams and Appendix TT-2 of a CEC project titled "Palmdale Energy Project" (PEP) docketed on December 29, 2016. This project defines the significance level of 5.3 meters per second (m/s) at all heights above 1,500 feet above ground level (AGL). The threshold of 5.3 m/s average velocity is used in this assessment.

The vertical velocity of the emissions from the emergency standby generators and the air-cooled chillers will be greater than 5.3 m/s at the point of discharge and therefore an assessment of the vertical velocity is required to be undertaken.

2. SCREENING ASSESSMENT

2.1 Vertical Plume Velocity Guidelines

The assessment will conservatively determine the potential for turbulence generated by the plume-averaged vertical velocity of the emergency standby generator and chiller exhaust plumes. The method uses worst-case assumptions of calm winds and neutral atmospheric conditions for the entire vertical extent of the plume to determine the worst-case impacts.

Since the development of a simple-cycle gas turbine power station at the end of a runway in Australia in the mid-1990s,[1] the Australian Civil Aviation Safety Authority (CASA) has taken an active role in the review of the siting of facilities with the potential to affect aviation activities.

Potential hazards that could affect the safety of aircraft include tall visible or invisible obstructions. Visible obstructions include structures such as tall stacks or communication towers. Invisible obstructions include industrial exhausts that generate significant turbulence due to high velocity and buoyancy. CASA has issued an Advisory Circular (CASA 2012) that specifies the requirements and methodologies to be used to assess whether a new industrial plume is likely to have adverse implications for aviation safety.

The general CASA requirement is to determine the height at which the plume (or plumes) could generate atmospheric turbulence and to determine the dimensions of the plume in these circumstances. The frequency of in-plume vertical velocities at the lowest height an aircraft may travel over the site, and at other heights are also required. For large plumes that are remote from airports, CASA requires an assessment that determines the size of a hazard zone to alert pilots to the potential hazard. Normally this analysis uses a sophisticated air dispersion model that determines plume vertical velocities and lateral/ vertical extents based on wind fields generated from actual meteorological data. Rather than use such a refined technique, a conservative screening analysis based on calm wind field assumptions was used for this project.

For this assessment, the plume-averaged vertical velocities were calculated as a function of height under calm conditions. The established CEC significance criteria is for an averaged plume velocity to equal or exceed 5.3 m/s at altitudes where aircraft can operate. This significance criteria were adopted in the CEC PEP.

[1] Note that this project consists of internal combustion engines (ICEs) and air-cooled chillers that have plume exhausts with much smaller volumetric flows and buoyancy fluxes than the turbine projects that elicited the initial interest of CASA.

3. MODEL INPUT DATA

3.1 Emissions Information

The proposed data center will have a number of atmospheric emission sources including:

1. Emergency standby diesel generators; and
2. Air-cooled "free cooling" chillers.

Ramboll analyzed these sources under three ambient temperature scenarios—30 degrees Fahrenheit (ºF), 59ºF, and 76ºF. The emission parameters used within the screening assessment for the three scenarios considered are presented in **Table 1**.

Table 1 - Stack Parameters

	Emergency generators		
	Scenario 1	**Scenario 2**	**Scenario 3**
Ambient Potential Temp (ºF)	30	59	76
Stack Height (feet)	55.2	55.2	55.2
Stack Diameter (feet)	2.8	2.8	2.8
Stack Velocity at exit (m/s)	35.5	35.5	35.5
Stack Potential Temp (F)	893	893	893
	Air-cooled chillers		
	Scenario 1	**Scenario 2**	**Scenario 3**
Ambient Potential Temp (ºF)	30	59	76
Stack Height (feet)	104.2	104.2	104.2
Stack Diameter (feet)	3	3	3
Stack Velocity at exit (m/s)	10.2	10.2	10.2
Stack Potential Temp (F)	120.0	120.0	120.0

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The 44 generator stacks and 48 chiller stacks are arranged in the configuration displayed in **Figure 1**. The generators will be in a double-stacked arrangement in a single row, with 22 generators on each level. The exhaust stacks for both levels would be routed away from the building horizontally, penetrate an adjacent screening wall, and discharge at a 45-degree angle. For purposes of this analysis, the exhaust from the lower-level generators was conservatively assumed to be released at the same height as the upper-level generators. To account for the additional exhaust volume, the stack diameter in the model was updated to reflect the cross-sectional area equivalent of two single stacks. Lastly, although the exhaust will be discharged at a 45-degree angle, the full flow velocity (rather than the y-component of the flow velocity) was conservatively evaluated in this analysis.

The chillers are located on the roof of the main data center building. The roof deck of the data center building is at approximately 85 feet, while the tops of the chillers are approximately 19 feet higher.

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Deleted: Buildings are approximately 104 feet in height. The chillers are placed on acoustical stacks which are 66 inches tall. The top of the chillers would be nearly 110 feet AGL (including the 5 ft 6 inches for the platforms).

3.2 Methodology

This assessment analyses vertical plume rise using the Spillane methodology, developed by Dr. Kevin Spillane, to analytically solve for plume heights above the jet phase in calm conditions. Three methods were evaluated: Method 1 assumes conservation of buoyancy and a Gaussian distribution of the vertical velocities, Method 2 is based on the Best et al., 2003 paper's analytical solution, and Method 3 considers the enhancement of vertical velocities that may occur if the plumes from multiple stacks merge and form a higher buoyancy combined/merged plume. Method 3, developed by the CEC, is based on the single stack plume velocity multiplied by the number of stacks raised to the 0.25 power.

4. MODEL RESULTS

4.1 Worst-Case Calm Wind Scenario

Plumes that may have a vertical velocity of greater than 5.3 m/s are of primary interest to the airport safety authorities. While the vertical velocity of the plumes at the point of discharge are in excess of 5.3 m/s, the vertical velocity is quickly dissipated following discharge as the plume mixes with ambient air.

Ramboll evaluated all three scenarios described in **Table 1** and found that the results for the emergency generators under all three ambient temperatures was nearly the same, whereas the results for the chillers were slightly worse under an ambient temperature of 76ºF (Scenario 3). Results of the plume vertical velocities at various heights are presented in Appendix A and summarized in **Table 2** based both the Spillane methodology and the CEC methodology (merged plumes).

For this conservative analysis, both single plume and merged plume velocities were evaluated. Using the Spillane methodology Method 1, the plume-averaged vertical velocity drops below the CEC screening threshold of 5.3 m/s at 121 feet AGL for one emergency generator and at 122 feet AGL for one chiller. Method 2 yielded a lower height than Method 1 of 108 feet for the emergency generators and the same height as Method 1 for the chillers. Using the CEC methodology of merged plumes, the vertical velocity drops below 5.3 m/s for the 44 generators at 108 feet AGL and for the 48 chillers at 127 feet AGL.

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Table 2 - Model Results

Assumptions							Maximum Height Above Ground with Vertical Velocity above Threshold (5.3 m/s)		
Source (Number of Units)	**Ambient Temperature**	**Stack Height (h_s)**	**Stack Diameter (D)**	**Stack Velocity (V_{exit})**	**Volumetric Flow**	**Stack Potential Temperature (θ_S)**	**Method 1**	**Method 2**	**Merged Plumes**
Emergency Diesel Generators (44)	272 K (30°F)[1]	16.84 m (55.2 ft)	0.86 m (2.8 ft)	35.48 m/s (116.4 ft/s)	44,497 ACFM	752 K (893.1°F)	36.88 m (121 ft)	32.92 m (108 ft)	32.92 m (108 ft)
Chillers[2] (48)	272 K (76°F)	31.75 m (104.2 ft)	0.91 m (3.0 ft)	10.15 m/s (33.3 ft/s)	14,130 ACFM	322 K (120.0°F)	37.19 m (122 ft)	37.19 m (122 ft)	38.71 m (127 ft)

Notes:

K - Kelvin

[1] The results were the same for all three ambient temperatures assessed (30ºF, 59ºF, 76ºF).

[2] These values apply for a single fan; for a turbine array, a volumetric flow was utilized for 26 adjacent fans, as is the case for the facility chillers.

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5. SUMMARY AND CONCLUSION

Modelling of the characteristics of the plumes from the diesel emergency generators and roof-mounted air chillers at the Vantage Walsh data center has been completed and indicates:

1. Under worst-case ambient conditions and calculation methodology, predicted vertical velocities are below 5.3 m/s for emergency generators at a height of 121 feet AGL; and
2. Under worst-case ambient conditions and calculation methodology, predicted vertical velocities are below 5.3 m/s for roof-mounted air chillers at a height of 127 feet AGL.

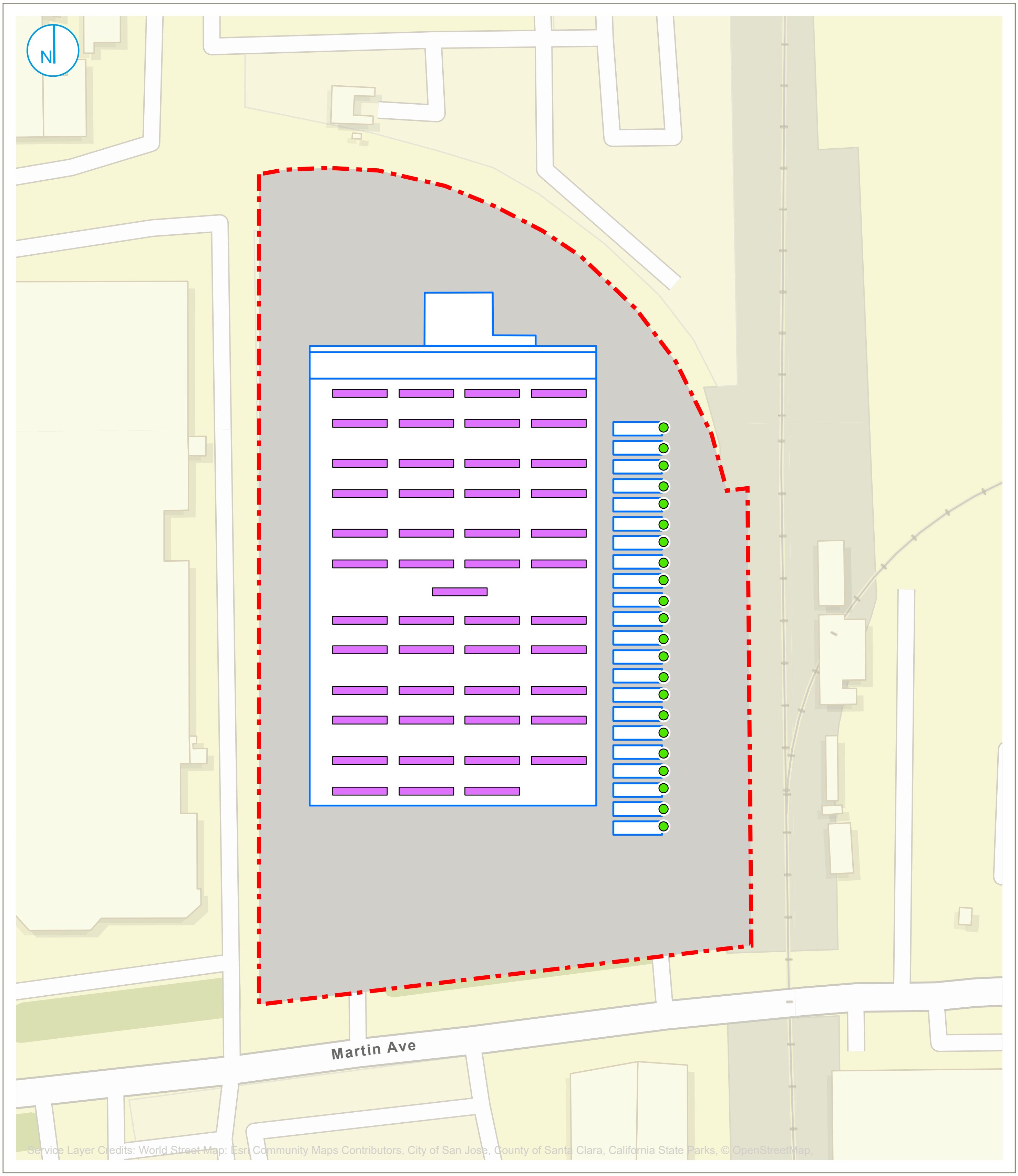
Deleted: 133

6. REFERENCES

Best, P., Jackson, L., Killip, C., Kanowski, M., Spillane, K. (2003) "Aviation Safety and Buoyant Plumes." Clean Air Conference, Newcastle, New South Wale, Australia.

Civil Aviation Safety Authority. 2012. Advisory Circular. AC 139-5(1). Australian Government. November.

FIGURES



Facility Boundary
Buildings and Structures
Roof-Top Chillers
Emergency Generator Stacks (each dot represents two stacks)

0 62.5 125 Feet

STACK AND CHILLER LOCATIONS

MARTIN AVENUE PROPERTIES DATA CENTER

651 Martin Avenue
Santa Clara, California

FIGURE 01

RAMBOLL US CONSULTING, INC.
A RAMBOLL COMPANY

RAMBOLL

APPENDIX A
PLUME RISE CALCULATIONS

EDGs - 30F, 100% Load

PETER BEST PAPER ILLUSTRATIVE EXAMPLE - SINGLE TURBINE - Assumes Heights in Table 2 are meters above ground

Plume Averaged Vertical Velocities: **"*Aviation Safety and Buoyant Plumes*," Peter Best, et. al.**

Constants:

Assume neutral conditions ($d\theta/dz=0$)

Gravity g	9.81	m/s^2
λ	1.11	
	0.3048	meters/feet

Ambient Conditions:

Ambient Potential Temp θ_a	**272**	Kelvins	**30.0**	°F		

Plume Exit Conditions:

Stack Height h_s	**16.84**	meters	**55.2**	feet		
Stack Diameter D	**0.86**	meters	**2.8**	feet		
Stack Velocity V_{exit}	**35.5**	m/s	**116.4**	ft/sec		
Volumetric Flow	**21**	cu.m/sec	**44,497**	ACFM	$\pi V_{exit}D^2/4$	Sect.2/¶1
Stack Potential Temp θ_s	**752**	Kelvins	**893**	°F	Back-Calc'd from Buoyancy Flux	
Initial Stack Buoyancy Flux F_o	**41**	m^4/s^3			$gV_{exit}D^2(1-\theta_a/\theta_s)/4$ = Vol.Flow$(g/\pi)(1-\theta_a/\theta_s)$	Sect.2/¶1
Plume Buoyancy Flux F	N/A	m^4/s^3			$\lambda^2 gVa^2(1-\theta_a/\theta_p)$ for a,V,θ_p at plume height (not used here)	

Conditions at End (Top) of Jet Phase:

Height above Stack z	**5.388**	meters*	**17.7**	feet*	6.25D, meters*=meters above stack top		Sect.3/¶1
Height above Ground z+h_s	**22.228**	meters	**72.9**	feet	h_s + 6.25D		"
Vertical Velocity V_{plume}	**17.740**	m/s	**58.20**	ft/sec	$0.5V_{exit}$	$V_{exit}/2$	"
Plume Top-Hat Diameter 2a	**1.724**	meters	**5.7**	feet	2D	Conservation of momentum	"

Spillane Methodology - Analytical Solutions for Calm Conditions for Plume Heights above Jet Phase

Plume Top-Hat Radius a	**Solutions in Table Below**				$0.16(z-z_v)$, or linear increase with height	Sect.2/Eq.6
Virtual Source Height z_v	**2.146**	meters*	**7.0**	feet*	$6.25D[1-(\theta_e/\theta_s)^{1/2}]$, meters*=meters above stack top	Sect.2/Eq.6
Height above Ground z_v+h_s	**18.987**	meters	**62.3**	feet	where $(\theta_a/\theta_s)^{1/2} = (\theta_e/\theta_s)^{1/2}=$	0.6016438

Method(1): Simplified Plume-averaged Vertical Velocity V' - Assumes Product Va constant above jet phase such that $V_{plume}(2a) = V_{exit}D$

Vertical Velocity V'	**Solutions in Table Below**	$V_{exit}D/2a'$ (conservation of buoyancy)	Sect.3&4

Method(2): Plume-averaged Vertical Velocity V given by Analytical Solution in Paper where Product Va given by equations below:

Vertical Velocity V	**Solutions in Table Below**		$\{(Va)_o^3 + 0.12F_o [(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)} / a$	Sect.2.1(6)
Product $(Va)_o$	**9.201**	m^2/s	$V_{exit}D/2(\theta_e/\theta_s)^{1/2}$	

Table of plume Top-Hat Diameters (2a) and Plume-averaged Vertical Velocities for both Method(1) (assuming conservation of buoyancy & gaussian distribution of vertical velocities) and Method (2) (based on Peter Best's paper's Analytical Solution) starting at end of jet phase:

from 100 meters above ground in increments of 50.0 meters

				Vert.Vel (m/s)	
				Method(1)	**Method(2)**
	Ht above Ground =	$h_{plume}+h_s$	$D_{plume}=2a=$	$V_{plume}=$	$\{(Va)_o^3+0.12F_o[(z-z_v)^2$
Height above stack top, meters*	meters	feet	$2*0.16(z-z_v)$	$V_{exit}*D/2a$	$-(6.25D-z_v)^2]\}^{1/3}$ / a
End of jet phase at 6.25D = 5.38822 meters*	***22.228***	***72.9***	***1.724***		***17.74***
83.160 meters*	**100.000**	328.1	25.924	1.18	**2.48**
133.160 meters*	150.000	492.1	41.924	0.73	2.10
183.160 meters*	**200.000**	656.2	57.924	0.53	**1.89**
233.160 meters*	250.000	820.2	73.924	0.41	1.74
283.160 meters*	**300.000**	984.3	89.924	0.34	**1.63**
333.160 meters*	350.000	1148.3	105.924	0.29	1.54
383.160 meters*	400.000	1312.3	121.924	0.25	1.47
433.160 meters*	450.000	1476.4	137.924	0.22	1.41
483.160 meters*	**500.000**	1640.4	153.924	0.20	**1.36**
533.160 meters*	550.000	1804.5	169.924	0.18	1.32
583.160 meters*	600.000	1968.5	185.924	0.16	1.28
633.160 meters*	650.000	2132.5	201.924	0.15	1.24
683.160 meters*	**700.000**	2296.6	217.924	0.14	**1.21**
733.160 meters*	750.000	2460.6	233.924	0.13	1.18
783.160 meters*	800.000	2624.7	249.924	0.12	1.16
833.160 meters*	850.000	2788.7	265.924	0.12	1.13
883.160 meters*	900.000	2952.8	281.924	0.11	1.11
933.160 meters*	950.000	3116.8	297.924	0.10	1.09
983.160 meters*	**1000.000**	3280.8	313.924	0.10	**1.07**
1033.160 meters*	1050.000	3444.9	329.924	0.09	1.05
1083.160 meters*	1100.000	3608.9	345.924	0.09	1.04
1133.160 meters*	1150.000	3773.0	361.924	0.08	1.02
1183.160 meters*	1200.000	3937.0	377.924	0.08	1.01
1233.160 meters*	1250.000	4101.0	393.924	0.08	0.99

EDGs - 30F, 100% Load

	m	ft		Method(1) m/s	Method(2) m/s
1.448 meters*	18.288	60.0	-0.223	-136.86	-80.55
4.191 meters*	21.031	69.0	0.654	46.75	27.74
4.496 meters*	21.336	70.0	0.752	40.68	24.21
4.801 meters*	21.641	71.0	0.849	36.01	21.50
5.106 meters*	21.946	72.0	0.947	32.30	19.36
5.410 meters*	22.251	73.0	1.044	29.28	17.62
5.715 meters*	22.555	74.0	1.142	26.78	16.19
6.020 meters*	22.860	75.0	1.240	24.68	14.99
6.325 meters*	23.165	76.0	1.337	22.88	13.96
6.630 meters*	23.470	77.0	1.435	21.32	13.08
6.934 meters*	23.775	78.0	1.532	19.96	12.32
7.239 meters*	24.079	79.0	1.630	18.77	11.65
7.544 meters*	24.384	80.0	1.727	17.71	11.06
7.849 meters*	24.689	81.0	1.825	16.76	10.53
8.154 meters*	24.994	82.0	1.922	15.91	10.07
8.459 meters*	25.299	83.0	2.020	15.14	9.64
8.763 meters*	25.604	84.0	2.117	14.45	9.26
9.068 meters*	25.908	85.0	2.215	13.81	8.92
9.373 meters*	26.213	86.0	2.312	13.23	8.61
9.678 meters*	26.518	87.0	2.410	12.69	8.32
9.983 meters*	26.823	88.0	2.508	12.20	8.06
10.287 meters*	27.128	89.0	2.605	11.74	7.82
10.592 meters*	27.432	90.0	2.703	11.32	7.59
10.897 meters*	27.737	91.0	2.800	10.92	7.39
11.202 meters*	28.042	92.0	2.898	10.56	7.20
11.507 meters*	28.347	93.0	2.995	10.21	7.02
11.811 meters*	28.652	94.0	3.093	9.89	6.85
12.116 meters*	28.956	95.0	3.190	9.59	6.70
12.421 meters*	29.261	96.0	3.288	9.30	6.55
12.726 meters*	29.566	97.0	3.385	9.04	6.42
13.031 meters*	29.871	98.0	3.483	8.78	6.29
13.335 meters*	30.176	99.0	3.580	8.54	6.17
13.640 meters*	30.480	100.0	3.678	8.32	6.06
13.945 meters*	30.785	101.0	3.776	8.10	5.95
14.250 meters*	31.090	102.0	3.873	7.90	5.85
14.555 meters*	31.395	103.0	3.971	7.70	5.75
14.859 meters*	31.700	104.0	4.068	7.52	5.66
15.164 meters*	32.004	105.0	4.166	7.34	5.58
15.469 meters*	32.309	106.0	4.263	7.17	5.49
15.774 meters*	32.614	107.0	4.361	7.01	5.42
16.079 meters*	32.919	108.0	4.458	6.86	5.34
16.383 meters*	33.224	109.0	4.556	6.71	5.27
16.688 meters*	33.528	110.0	4.653	6.57	5.20
19.736 meters*	36.576	120.0	5.629	5.43	4.66
20.041 meters*	36.881	121.0	5.726	5.34	4.62
20.346 meters*	37.186	122.0	5.824	5.25	4.58
20.651 meters*	37.491	123.0	5.921	5.17	4.54
20.955 meters*	37.796	124.0	6.019	5.08	4.50
21.260 meters*	38.100	125.0	6.116	5.00	4.46
21.565 meters*	38.405	126.0	6.214	4.92	4.42
21.870 meters*	38.710	127.0	6.311	4.85	4.39

Combined Plume Method

Stack Distances (ft)	Number of Stacks
17.98	22

ft	m/s	merged cells	Plume Diamter Feet
60	-80.55	1.00	-0.73
69	27.74	1.00	2.15
70	24.21	1.00	2.47
71	21.50	1.00	2.79
72	19.36	1.00	3.11
73	17.62	1.00	3.43
74	16.19	1.00	3.75
75	14.99	1.00	4.07
76	13.96	1.00	4.39
77	13.08	1.00	4.71
78	12.32	1.00	5.03
79	11.65	1.00	5.35
80	11.06	1.00	5.67
81	10.53	1.00	5.99
82	10.07	1.00	6.31
83	9.64	1.00	6.63
84	9.26	1.00	6.95
85	8.92	1.00	7.27
86	8.61	1.00	7.59
87	8.32	1.00	7.91
88	8.06	1.00	8.23
89	7.82	1.00	8.55
90	7.59	1.00	8.87
91	7.39	1.00	9.19
92	7.20	1.00	9.51
93	7.02	1.00	9.83
94	6.85	1.00	10.15
95	6.70	1.00	10.47
96	6.55	1.00	10.79
97	6.42	1.00	11.11
98	6.29	1.00	11.43
99	6.17	1.00	11.75
100	6.06	1.00	12.07
101	5.95	1.00	12.39
102	5.85	1.00	12.71
103	5.75	1.00	13.03
104	5.66	1.00	13.35
105	5.58	1.00	13.67
106	5.49	1.00	13.99
107	5.42	1.00	14.31
108	5.34	1.00	14.63
109	5.27	1.00	14.95
110	5.21	1.01	15.27
120	4.86	1.18	18.47
121	4.84	1.20	18.79
122	4.81	1.22	19.11
123	4.78	1.24	19.43
124	4.76	1.26	19.75
125	4.74	1.27	20.07
126	4.71	1.29	20.39
127	4.69	1.31	20.71

22.175 meters*	39.015	128.0	6.409	4.77	4.35
22.479 meters*	39.320	129.0	6.507	4.70	4.32
22.784 meters*	39.624	130.0	6.604	4.63	4.29
25.832 meters*	42.673	140.0	7.579	4.04	4.01
28.880 meters*	45.721	150.0	8.555	3.58	3.79
31.928 meters*	48.769	160.0	9.530	3.21	3.62
34.976 meters*	51.817	170.0	10.506	2.91	3.47
38.024 meters*	54.865	180.0	11.481	2.66	3.35
41.072 meters*	57.913	190.0	12.456	2.46	3.24
44.121 meters*	60.961	200.0	13.432	2.28	3.15
74.601 meters*	91.441	300.0	23.185	1.32	2.58
105.081 meters*	121.921	400.0	32.939	0.93	2.28
135.562 meters*	152.402	500.0	42.693	0.72	2.09
166.042 meters*	182.882	600.0	52.447	0.58	1.95
196.522 meters*	213.363	700.0	62.200	0.49	1.84
227.003 meters*	243.843	800.0	71.954	0.43	1.75
257.483 meters*	274.323	900.0	81.708	0.37	1.68
287.964 meters*	304.804	1000.0	91.461	0.33	1.62

128	4.67	1.33	21.03
129	4.65	1.34	21.35
130	4.63	1.36	21.67
140	4.47	1.54	24.87
150	4.34	1.72	28.07
160	4.24	1.90	31.27
170	4.17	2.07	34.47
180	4.10	2.25	37.67
190	4.05	2.43	40.87
200	4.00	2.61	44.07
300	3.73	4.39	76.07
400	3.60	6.17	108.07
500	3.51	7.95	140.07
600	3.44	9.73	172.07
700	3.39	11.51	204.07
800	3.35	13.29	236.07
900	3.31	15.07	268.07
1,000	3.28	16.85	300.07

PETER BEST PAPER ILLUSTRATIVE EXAMPLE - SINGLE TURBINE - Assumes Heights in Table 2 are meters above ground

Plume Averaged Vertical Velocities: **"*Aviation Safety and Buoyant Plumes*," Peter Best, et. al.**

Ambient Conditions:

Constants:

Ambient Potential Temp θ_a	**288**	Kelvins	**59.0**	°F	Assume neutral conditions ($d\theta/dz=0$)		
Plume Exit Conditions:					Gravity g: 9.81 m/s^2		
Stack Height h_s	**16.84**	meters	**55.2**	feet	λ: 1.11		
Stack Diameter D	**0.86**	meters	**2.8**	feet	0.3048 meters/feet		
Stack Velocity V_{exit}	**35.5**	m/s	**116.4**	ft/sec			
Volumetric Flow	**21**	cu.m/sec	**44,497**	ACFM	$\pi V_{exit} D^2/4$		Sect.2/¶1
Stack Potential Temp θ_s	**752**	Kelvins	**893**	°F	Back-Calc'd from Buoyancy Flux		
Initial Stack Buoyancy Flux F_o	**40**	m^4/s^3			$gV_{exit}D^2(1-\theta_a/\theta_s)/4$ = Vol.Flow$(g/\pi)(1-\theta_a/\theta_s)$		Sect.2/¶1
Plume Buoyancy Flux F	N/A	m^4/s^3			$\lambda^2 gVa^2(1-\theta_a/\theta_p)$ for a,V,θ_p at plume height (not used here)		

Conditions at End (Top) of Jet Phase:

Height above Stack z	**5.388**	meters*	**17.7**	feet*	6.25D, meters*=meters above stack top		Sect.3/¶1
Height above Ground z+h_s	**22.228**	meters	**72.9**	feet	h_s + 6.25D		"
Vertical Velocity V_{plume}	**17.740**	m/s	**58.20**	ft/sec	$0.5V_{exit}$	$V_{exit}/2$	"
Plume Top-Hat Diameter 2a	**1.724**	meters	**5.7**	feet	2D	Conservation of momentum	"

Spillane Methodology - Analytical Solutions for Calm Conditions for Plume Heights above Jet Phase

Plume Top-Hat Radius a	**Solutions in Table Below**				$0.16(z-z_v)$, or linear increase with height	Sect.2/Eq.6
Virtual Source Height z_v	**2.052**	meters*	**6.7**	feet*	$6.25D[1-(\theta_e/\theta_s)^{1/2}]$, meters*=meters above stack top	Sect.2/Eq.6
Height above Ground z_v+h_s	**18.892**	meters	**62.0**	feet	where $(\theta_a/\theta_s)^{1/2} = (\theta_e/\theta_s)^{1/2}$=	0.619203299

Method(1): Simplified Plume-averaged Vertical Velocity V' - Assumes Product Va constant above jet phase such that $V_{plume}(2a) = V_{exit}D$

Vertical Velocity V'	**Solutions in Table Below**	$V_{exit}D/2a'$ (conservation of buoyancy)	Sect.3&4

Method(2): Plume-averaged Vertical Velocity V given by Analytical Solution in Paper where Product Va given by equations below:

Vertical Velocity V	**Solutions in Table Below**	$\{(Va)_o^3 + 0.12F_o\,[\,(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)} / a$	Sect.2.1(6)
Product $(Va)_o$	**9.470** m^2/s	$V_{exit}D/2(\theta_e/\theta_s)^{1/2}$	

EDGs - 59F, 100% Load

Table of plume Top-Hat Diameters (2a) and Plume-averaged Vertical Velocities for both Method(1) (assuming conservation of buoyancy & gaussian distribution of vertical velocities) and Method (2) (based on Peter Best's paper's Analytical Solution) starting at end of jet phase:

from 100 meters above ground in increments of 50.0 meters

				Vert.Vel (m/s)	
				Method(1)	**Method(2)**
	Ht above Ground =	$h_{plume}+h_s$	D_{plume}=2a=	V_{plume}=	$\{(Va)_o^3+0.12F_o[(z-z_v)^2$
Height above stack top, meters*	meters	feet	2*0.16($z-z_v$)	V_{exit}*D/2a	$-(6.25D-z_v)^2]\}^{1/3}$ / a
End of jet phase at 6.25D = 5.388 meters*	***22.228***	***72.9***	***1.724***		***17.74***
83.160 meters*	**100.000**	328.1	25.955	1.18	**2.45**
133.160 meters*	150.000	492.1	41.955	0.73	2.08
183.160 meters*	**200.000**	656.2	57.955	0.53	**1.86**
233.160 meters*	250.000	820.2	73.955	0.41	1.72
283.160 meters*	**300.000**	984.3	89.955	0.34	**1.61**
333.160 meters*	350.000	1148.3	105.955	0.29	1.52
383.160 meters*	400.000	1312.3	121.955	0.25	1.45
433.160 meters*	450.000	1476.4	137.955	0.22	1.39
483.160 meters*	**500.000**	1640.4	153.955	0.20	**1.34**
533.160 meters*	550.000	1804.5	169.955	0.18	1.30
583.160 meters*	600.000	1968.5	185.955	0.16	1.26
633.160 meters*	650.000	2132.5	201.955	0.15	1.23
683.160 meters*	**700.000**	2296.6	217.955	0.14	**1.20**
733.160 meters*	750.000	2460.6	233.955	0.13	1.17
783.160 meters*	800.000	2624.7	249.955	0.12	1.14
833.160 meters*	850.000	2788.7	265.955	0.12	1.12
883.160 meters*	900.000	2952.8	281.955	0.11	1.10
933.160 meters*	950.000	3116.8	297.955	0.10	1.08
983.160 meters*	**1000.000**	3280.8	313.955	0.10	**1.06**
1033.160 meters*	1050.000	3444.9	329.955	0.09	1.04
1083.160 meters*	1100.000	3608.9	345.955	0.09	1.03
1133.160 meters*	1150.000	3773.0	361.955	0.08	1.01
1183.160 meters*	1200.000	3937.0	377.955	0.08	1.00
1233.160 meters*	1250.000	4101.0	393.955	0.08	0.98

EDGs - 59F, 100% Load

	m	ft		Method(1) m/s	Method(2) m/s
1.448 meters*	18.288	60.0	-0.193	-158.31	-96.00
4.496 meters*	21.336	70.0	0.782	39.11	23.98
7.544 meters*	24.384	80.0	1.758	17.40	11.15
10.592 meters*	27.432	90.0	2.733	11.19	7.66
10.897 meters*	27.737	91.0	2.830	10.81	7.45
11.202 meters*	28.042	92.0	2.928	10.45	7.25
11.507 meters*	28.347	93.0	3.026	10.11	7.07
11.811 meters*	28.652	94.0	3.123	9.79	6.90
12.116 meters*	28.956	95.0	3.221	9.50	6.74
12.421 meters*	29.261	96.0	3.318	9.22	6.60
12.726 meters*	29.566	97.0	3.416	8.96	6.46
13.031 meters*	29.871	98.0	3.513	8.71	6.33
13.335 meters*	30.176	99.0	3.611	8.47	6.20
13.640 meters*	30.480	100.0	3.708	8.25	6.09
13.945 meters*	30.785	101.0	3.806	8.04	5.98
14.250 meters*	31.090	102.0	3.903	7.84	5.88
14.555 meters*	31.395	103.0	4.001	7.65	5.78
14.859 meters*	31.700	104.0	4.098	7.46	5.68
15.164 meters*	32.004	105.0	4.196	7.29	5.60
15.469 meters*	32.309	106.0	4.293	7.12	5.51
15.774 meters*	32.614	107.0	4.391	6.97	5.43
16.079 meters*	32.919	108.0	4.489	6.81	5.36
16.383 meters*	33.224	109.0	4.586	6.67	5.28
16.688 meters*	33.528	110.0	4.684	6.53	5.21
19.736 meters*	36.576	120.0	5.659	5.41	4.66
20.041 meters*	36.881	121.0	5.757	5.31	4.62
20.346 meters*	37.186	122.0	5.854	5.23	4.57
20.651 meters*	37.491	123.0	5.952	5.14	4.53
20.955 meters*	37.796	124.0	6.049	5.06	4.49
21.260 meters*	38.100	125.0	6.147	4.98	4.45
22.784 meters*	39.624	130.0	6.634	4.61	4.28
25.832 meters*	42.673	140.0	7.610	4.02	3.99
28.880 meters*	45.721	150.0	8.585	3.56	3.77
44.121 meters*	60.961	200.0	13.462	2.27	3.12
74.601 meters*	91.441	300.0	23.216	1.32	2.55
105.081 meters*	121.921	400.0	32.969	0.93	2.26
135.562 meters*	152.402	500.0	42.723	0.72	2.07
166.042 meters*	182.882	600.0	52.477	0.58	1.93
196.522 meters*	213.363	700.0	62.231	0.49	1.82
227.003 meters*	243.843	800.0	71.984	0.42	1.73
257.483 meters*	274.323	900.0	81.738	0.37	1.66
287.964 meters*	304.804	1000.0	91.492	0.33	1.60

Combined Plume Method

ft	m/s	merged cells
60	-96.00	1.00
70	23.98	1.00
80	11.15	1.00
90	7.66	1.00
91	7.45	1.00
92	7.25	1.00
93	7.07	1.00
94	6.90	1.00
95	6.74	1.00
96	6.60	1.00
97	6.46	1.00
98	6.33	1.00
99	6.20	1.00
100	6.09	1.00
101	5.98	1.00
102	5.88	1.00
103	5.78	1.00
104	5.68	1.00
105	5.60	1.00
106	5.51	1.00
107	5.43	1.00
108	5.36	1.00
109	5.28	1.00
110	5.23	1.01
120	4.87	1.19
121	4.84	1.21
122	4.81	1.23
123	4.78	1.24
124	4.76	1.26
125	4.73	1.28
130	4.62	1.37
140	4.45	1.55
150	4.32	1.72
200	3.97	2.61
300	3.69	4.39
400	3.56	6.17
500	3.47	7.95
600	3.41	9.73
700	3.35	11.51
800	3.31	13.29
900	3.27	15.07
1,000	3.24	16.85

Stack Distances (ft)	Number of Stacks
17.98	22

PETER BEST PAPER ILLUSTRATIVE EXAMPLE - SINGLE TURBINE - Assumes Heights in Table 2 are meters above ground

Plume Averaged Vertical Velocities: **"*Aviation Safety and Buoyant Plumes*," Peter Best, et. al.**

Ambient Conditions:

Constants:

Assume neutral conditions ($d\theta/dz=0$)

Gravity g	9.81	m/s^2				
λ	1.11					
	0.3048	meters/feet				

Ambient Potential Temp θ_a	**298**	Kelvins	**76.0**	°F		
Plume Exit Conditions:						
Stack Height h_s	**16.84**	meters	**55.2**	feet		
Stack Diameter D	**0.86**	meters	**2.8**	feet		
Stack Velocity V_{exit}	**35.5**	m/s	**116.4**	ft/sec		
Volumetric Flow	**21**	cu.m/sec	**44,497**	ACFM	$\pi V_{exit} D^2/4$	Sect.2/¶1
Stack Potential Temp θ_s	**752**	Kelvins	**893**	°F	Back-Calc'd from Buoyancy Flux	
Initial Stack Buoyancy Flux F_o	**39**	m^4/s^3			$gV_{exit}D^2(1-\theta_a/\theta_s)/4$ = Vol.Flow$(g/\pi)(1-\theta_a/\theta_s)$	Sect.2/¶1
Plume Buoyancy Flux F	N/A	m^4/s^3			$\lambda^2 gVa^2(1-\theta_a/\theta_p)$ for a,V,θ_p at plume height (not used here)	

Conditions at End (Top) of Jet Phase:

Height above Stack z	**5.388**	meters*	**17.7**	feet*	6.25D, meters*=meters above stack top		Sect.3/¶1
Height above Ground $z+h_s$	**22.228**	meters	**72.9**	feet	h_s + 6.25D		"
Vertical Velocity V_{plume}	**17.740**	m/s	**58.20**	ft/sec	$0.5V_{exit}$	$V_{exit}/2$	"
Plume Top-Hat Diameter 2a	**1.724**	meters	**5.7**	feet	2D	Conservation of momentum	"

Spillane Methodology - Analytical Solutions for Calm Conditions for Plume Heights above Jet Phase

Plume Top-Hat Radius a	**Solutions in Table Below**				$0.16(z-z_v)$, or linear increase with height	Sect.2/Eq.6
Virtual Source Height z_v	**1.998**	meters*	**6.6**	feet*	$6.25D[1-(\theta_e/\theta_s)^{1/2}]$, meters*=meters above stack top	Sect.2/Eq.6
Height above Ground z_v+h_s	**18.838**	meters	**61.8**	feet	where $(\theta_a/\theta_s)^{1/2} = (\theta_e/\theta_s)^{1/2}$=	0.629269032

Method(1): Simplified Plume-averaged Vertical Velocity V' - Assumes Product Va constant above jet phase such that $V_{plume}(2a) = V_{exit}D$

Vertical Velocity V'	**Solutions in Table Below**	$V_{exit}D/2a'$ (conservation of buoyancy)	Sect.3&4

Method(2): Plume-averaged Vertical Velocity V given by Analytical Solution in Paper where Product Va given by equations below:

Vertical Velocity V	**Solutions in Table Below**		$\{(Va)_o^3 + 0.12F_o [(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)} / a$	Sect.2.1(6)
Product $(Va)_o$	**9.624**	m^2/s	$V_{exit}D/2(\theta_e/\theta_s)^{1/2}$	

Table of plume Top-Hat Diameters (2a) and Plume-averaged Vertical Velocities for both Method(1) (assuming conservation of buoyancy & gaussian distribution of vertical velocities) and Method (2) (based on Peter Best's paper's Analytical Solution) starting at end of jet phase:

from 100 meters above ground in increments of 50.0 meters

Height above stack top, meters*	**Ht above Ground =** meters	$h_{plume}+h_s$ feet	D_{plume}=2a= 2*0.16($z-z_v$)	**Vert.Vel (m/s)** **Method(1)** V_{plume}= V_{exit}*D/2a	**Method(2)** $\{(Va)_o^3+0.12F_o[(z-z_v)^2 -(6.25D-z_v)^2]\}^{1/3}$ / a
End of jet phase at 6.25D = 5.388 meters*	***22.228***	***72.9***	***1.724***		***17.74***
83.160 meters*	**100.000**	328.1	25.972	1.18	**2.44**
133.160 meters*	150.000	492.1	41.972	0.73	2.07
183.160 meters*	**200.000**	656.2	57.972	0.53	**1.85**
233.160 meters*	250.000	820.2	73.972	0.41	1.71
283.160 meters*	**300.000**	984.3	89.972	0.34	**1.60**
333.160 meters*	350.000	1148.3	105.972	0.29	1.51
383.160 meters*	400.000	1312.3	121.972	0.25	1.44
433.160 meters*	450.000	1476.4	137.972	0.22	1.39
483.160 meters*	**500.000**	1640.4	153.972	0.20	**1.34**
533.160 meters*	550.000	1804.5	169.972	0.18	1.29
583.160 meters*	600.000	1968.5	185.972	0.16	1.25
633.160 meters*	650.000	2132.5	201.972	0.15	1.22
683.160 meters*	**700.000**	2296.6	217.972	0.14	**1.19**
733.160 meters*	750.000	2460.6	233.972	0.13	1.16
783.160 meters*	800.000	2624.7	249.972	0.12	1.14
833.160 meters*	850.000	2788.7	265.972	0.12	1.11
883.160 meters*	900.000	2952.8	281.972	0.11	1.09
933.160 meters*	950.000	3116.8	297.972	0.10	1.07
983.160 meters*	**1000.000**	3280.8	313.972	0.10	**1.05**
1033.160 meters*	1050.000	3444.9	329.972	0.09	1.04
1083.160 meters*	1100.000	3608.9	345.972	0.09	1.02
1133.160 meters*	1150.000	3773.0	361.972	0.08	1.00
1183.160 meters*	1200.000	3937.0	377.972	0.08	0.99
1233.160 meters*	1250.000	4101.0	393.972	0.08	0.98

EDGs - 76F, 100% Load

	m	ft		Method(1) m/s	Method(2) m/s
1.448 meters*	18.288	60.0	-0.176	-173.93	-107.26
4.496 meters*	21.336	70.0	0.800	38.26	23.85
7.544 meters*	24.384	80.0	1.775	17.23	11.20
10.592 meters*	27.432	90.0	2.750	11.12	7.69
10.897 meters*	27.737	91.0	2.848	10.74	7.48
11.202 meters*	28.042	92.0	2.945	10.39	7.28
11.507 meters*	28.347	93.0	3.043	10.05	7.10
11.811 meters*	28.652	94.0	3.140	9.74	6.93
12.116 meters*	28.956	95.0	3.238	9.45	6.77
12.421 meters*	29.261	96.0	3.335	9.17	6.62
12.726 meters*	29.566	97.0	3.433	8.91	6.48
13.031 meters*	29.871	98.0	3.531	8.66	6.35
13.335 meters*	30.176	99.0	3.628	8.43	6.23
13.640 meters*	30.480	100.0	3.726	8.21	6.11
13.945 meters*	30.785	101.0	3.823	8.00	6.00
14.250 meters*	31.090	102.0	3.921	7.80	5.89
14.555 meters*	31.395	103.0	4.018	7.61	5.79
14.859 meters*	31.700	104.0	4.116	7.43	5.70
15.164 meters*	32.004	105.0	4.213	7.26	5.61
15.469 meters*	32.309	106.0	4.311	7.10	5.52
15.774 meters*	32.614	107.0	4.408	6.94	5.44
16.079 meters*	32.919	108.0	4.506	6.79	5.37
16.383 meters*	33.224	109.0	4.603	6.64	5.29
16.688 meters*	33.528	110.0	4.701	6.51	5.22
19.736 meters*	36.576	120.0	5.676	5.39	4.66
20.041 meters*	36.881	121.0	5.774	5.30	4.61
20.346 meters*	37.186	122.0	5.871	5.21	4.57
20.651 meters*	37.491	123.0	5.969	5.12	4.53
20.955 meters*	37.796	124.0	6.067	5.04	4.49
21.260 meters*	38.100	125.0	6.164	4.96	4.45
44.121 meters*	60.961	200.0	13.479	2.27	3.10
74.601 meters*	91.441	300.0	23.233	1.32	2.54
105.081 meters*	121.921	400.0	32.987	0.93	2.24
135.562 meters*	152.402	500.0	42.741	0.72	2.05
166.042 meters*	182.882	600.0	52.494	0.58	1.92
196.522 meters*	213.363	700.0	62.248	0.49	1.81
227.003 meters*	243.843	800.0	72.002	0.42	1.72
257.483 meters*	274.323	900.0	81.755	0.37	1.65
287.964 meters*	304.804	1000.0	91.509	0.33	1.59

Combined Plume Method

ft	m/s	merged cells
60	-107.26	1.00
70	23.85	1.00
80	11.20	1.00
90	7.69	1.00
91	7.48	1.00
92	7.28	1.00
93	7.10	1.00
94	6.93	1.00
95	6.77	1.00
96	6.62	1.00
97	6.48	1.00
98	6.35	1.00
99	6.23	1.00
100	6.11	1.00
101	6.00	1.00
102	5.89	1.00
103	5.79	1.00
104	5.70	1.00
105	5.61	1.00
106	5.52	1.00
107	5.44	1.00
108	5.37	1.00
109	5.29	1.00
110	5.24	1.02
120	4.87	1.19
121	4.84	1.21
122	4.81	1.23
123	4.78	1.25
124	4.76	1.26
125	4.73	1.28
200	3.95	2.62
300	3.67	4.40
400	3.54	6.18
500	3.45	7.96
600	3.38	9.74
700	3.33	11.52
800	3.29	13.30
900	3.25	15.08
1,000	3.22	16.86

Stack Distances (ft)	Number of Stacks
17.98	22

CHILLERS - 30F, 100% Load

PETER BEST PAPER ILLUSTRATIVE EXAMPLE - SINGLE TURBINE - Assumes Heights in Table 2 are meters above ground

Plume Averaged Vertical Velocities: **"*Aviation Safety and Buoyant Plumes*," Peter Best, et. al.**

Ambient Conditions:					Constants:	
Ambient Potential Temp θ_a	**272**	Kelvins	**30.0**	°F	Assume neutral conditions ($d\theta/dz=0$)	
Plume Exit Conditions:					Gravity g **9.81** m/s^2	
Stack Height h_s	**31.75**	meters	**104.2**	feet	λ **1.11**	
Stack Diameter D	**0.91**	meters	**3.0**	feet	**0.3048** meters/feet	
Stack Velocity V_{exit}	**10.2**	m/s	**33.3**	ft/sec		
Volumetric Flow	**7**	cu.m/sec	**14,130**	ACFM	$\pi V_{exit} D^2/4$	Sect.2/¶1
Stack Potential Temp θ_s	**322**	Kelvins	**120**	°F	Back-Calc'd from Buoyancy Flux	
Initial Stack Buoyancy Flux F_o	**3**	m^4/s^3			$gV_{exit}D^2(1-\theta_a/\theta_s)/4$ = Vol.Flow$(g/\pi)(1-\theta_a/\theta_s)$	Sect.2/¶1
Plume Buoyancy Flux F	N/A	m^4/s^3			$\lambda^2 gVa^2(1-\theta_a/\theta_p)$ for a,V,θ_p at plume height (not used here)	

Conditions at End (Top) of Jet Phase:							
Height above Stack z	**5.715**	meters*	**18.8**	feet*	6.25D, meters*=meters above stack top		Sect.3/¶1
Height above Ground z+h_s	**37.465**	meters	**122.9**	feet	h_s + 6.25D		"
Vertical Velocity V_{plume}	**5.077**	m/s	**16.66**	ft/sec	$0.5V_{exit}$	$V_{exit}/2$	"
Plume Top-Hat Diameter 2a	**1.829**	meters	**6.0**	feet	2D	Conservation of mc	"

Spillane Methodology - Analytical Solutions for Calm Conditions for Plume Heights above Jet Phase

Plume Top-Hat Radius a	**Solutions in Table Below**				$0.16(z-z_v)$, or linear increase with height	Sect.2/Eq.6
Virtual Source Height z_v	**0.462**	meters*	**1.5**	feet*	$6.25D[1-(\theta_e/\theta_s)^{1/2}]$, meters*=meters above s	Sect.2/Eq.6
Height above Ground z_v+h_s	**32.213**	meters	**105.7**	feet	where $(\theta_a/\theta_s)^{1/2} = (\theta_e/\theta_s)^{1/2}=$	0.919096974

Method(1): Simplified Plume-averaged Vertical Velocity V' - Assumes Product Va constant above jet phase such that $V_{plume}(2a) = V_{exit}D$

Vertical Velocity V'	**Solutions in Table Below**	$V_{exit}D/2a'$ (conservation of buoyancy)	Sect.3&4

Method(2): Plume-averaged Vertical Velocity V given by Analytical Solution in Paper where Product Va given by equations below:

Vertical Velocity V	**Solutions in Table Below**	$\{(Va)_o^3 + 0.12F_o [(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)}$ / :	Sect.2.1(6)
Product $(Va)_o$	**4.267** m^2/s	$V_{exit}D/2(\theta_e/\theta_s)^{1/2}$	

Table of plume Top-Hat Diameters (2a) and Plume-averaged Vertical Velocities for both Method(1) (assuming conservation of buoyancy & gaussian distribution of vertical velocities) and Method (2) (based on Peter Best's paper's Analytical Solution) starting at end of jet phase:

from 100 meters above ground in increments of 50.0 meters

				Vert.Vel (m/s)	
				Method(1)	Method(2)
	Ht above Ground =	$h_{plume}+h_s$	D_{plume}=2a=	V_{plume}=	$\{(Va)_o^3+0.12F_o[(z-z_v)^2$
Height above stack top, meters*	meters	feet	$2*0.16(z-z_v)$	V_{exit}*D/2a	$-(6.25D-z_v)^2]\}^{1/3}$ / a
End of jet phase at 6.25D = 5.715 meters*	***37.465***	***122.9***	***1.829***		***5.08***
68.250 meters*	**100.000**	328.1	21.692	0.43	**1.13**
118.250 meters*	150.000	492.1	37.692	0.25	0.93
168.250 meters*	**200.000**	656.2	53.692	0.17	**0.83**
218.250 meters*	250.000	820.2	69.692	0.13	0.76
268.250 meters*	**300.000**	984.3	85.692	0.11	**0.71**
318.250 meters*	350.000	1148.3	101.692	0.09	0.67
368.250 meters*	400.000	1312.3	117.692	0.08	0.64
418.250 meters*	450.000	1476.4	133.692	0.07	0.61
468.250 meters*	**500.000**	1640.4	149.692	0.06	**0.59**
518.250 meters*	550.000	1804.5	165.692	0.06	0.57
568.250 meters*	600.000	1968.5	181.692	0.05	0.55
618.250 meters*	650.000	2132.5	197.692	0.05	0.54
668.250 meters*	**700.000**	2296.6	213.692	0.04	**0.52**
718.250 meters*	750.000	2460.6	229.692	0.04	0.51
768.250 meters*	800.000	2624.7	245.692	0.04	0.50
818.250 meters*	850.000	2788.7	261.692	0.04	0.49
868.250 meters*	900.000	2952.8	277.692	0.03	0.48
918.250 meters*	950.000	3116.8	293.692	0.03	0.47
968.250 meters*	**1000.000**	3280.8	309.692	0.03	**0.46**
1018.250 meters*	1050.000	3444.9	325.692	0.03	0.45
1068.250 meters*	1100.000	3608.9	341.692	0.03	0.45
1118.250 meters*	1150.000	3773.0	357.692	0.03	0.44
1168.250 meters*	1200.000	3937.0	373.692	0.02	0.43
1218.250 meters*	1250.000	4101.0	389.692	0.02	0.43

CHILLERS - 30F, 100% Load

	m	ft		Method(1) m/s	Method(2) m/s
4.826 meters*	36.576	120.0	1.396	6.65	6.02
5.131 meters*	36.881	121.0	1.494	6.22	5.66
5.436 meters*	37.186	122.0	1.591	5.83	5.34
5.740 meters*	37.491	123.0	1.689	5.50	5.05
6.045 meters*	37.796	124.0	1.787	5.20	4.81
6.350 meters*	38.100	125.0	1.884	4.93	4.58
6.655 meters*	38.405	126.0	1.982	4.69	4.38
6.960 meters*	38.710	127.0	2.079	4.47	4.20
7.264 meters*	39.015	128.0	2.177	4.27	4.04
7.569 meters*	39.320	129.0	2.274	4.08	3.89
7.874 meters*	39.624	130.0	2.372	3.92	3.76
8.179 meters*	39.929	131.0	2.469	3.76	3.63
8.484 meters*	40.234	132.0	2.567	3.62	3.52
8.789 meters*	40.539	133.0	2.664	3.49	3.41
9.093 meters*	40.844	134.0	2.762	3.36	3.31
9.398 meters*	41.149	135.0	2.859	3.25	3.22
9.703 meters*	41.453	136.0	2.957	3.14	3.14
10.008 meters*	41.758	137.0	3.055	3.04	3.06
10.313 meters*	42.063	138.0	3.152	2.95	2.99
10.617 meters*	42.368	139.0	3.250	2.86	2.92
10.922 meters*	42.673	140.0	3.347	2.77	2.86
11.227 meters*	42.977	141.0	3.445	2.70	2.80
11.532 meters*	43.282	142.0	3.542	2.62	2.74
11.837 meters*	43.587	143.0	3.640	2.55	2.69
12.141 meters*	43.892	144.0	3.737	2.48	2.64
12.446 meters*	44.197	145.0	3.835	2.42	2.59
12.751 meters*	44.501	146.0	3.932	2.36	2.55
13.056 meters*	44.806	147.0	4.030	2.30	2.50
13.361 meters*	45.111	148.0	4.127	2.25	2.46
13.665 meters*	45.416	149.0	4.225	2.20	2.43
13.970 meters*	45.721	150.0	4.322	2.15	2.39
29.210 meters*	60.961	200.0	9.199	1.01	1.59
59.691 meters*	91.441	300.0	18.953	0.49	1.19
90.171 meters*	121.921	400.0	28.707	0.32	1.03
120.651 meters*	152.402	500.0	38.461	0.24	0.93
151.132 meters*	182.882	600.0	48.214	0.19	0.86
181.612 meters*	213.363	700.0	57.968	0.16	0.81
212.093 meters*	243.843	800.0	67.722	0.14	0.77
242.573 meters*	274.323	900.0	77.475	0.12	0.73
273.053 meters*	304.804	1000.0	87.229	0.11	0.70

Combined Plume Method

ft	m/s	merged cells	Plume Diamter Feet
120	7.22	2.07	4.58
121	6.85	2.15	4.90
122	6.53	2.24	5.22
123	6.24	2.33	5.54
124	5.99	2.42	5.86
125	5.76	2.50	6.18
126	5.56	2.59	6.50
127	5.38	2.68	6.82
128	5.21	2.77	7.14
129	5.06	2.85	7.46
130	4.92	2.94	7.78
131	4.79	3.03	8.10
132	4.67	3.11	8.42
133	4.56	3.20	8.74
134	4.46	3.29	9.06
135	4.37	3.38	9.38
136	4.28	3.46	9.70
137	4.20	3.55	10.02
138	4.13	3.64	10.34
139	4.06	3.73	10.66
140	3.99	3.81	10.98
141	3.93	3.90	11.30
142	3.87	3.99	11.62
143	3.82	4.07	11.94
144	3.77	4.16	12.26
145	3.72	4.25	12.58
146	3.68	4.34	12.90
147	3.63	4.42	13.22
148	3.59	4.51	13.54
149	3.55	4.60	13.86
150	3.52	4.69	14.18
200	2.75	9.05	30.18
300	2.44	17.78	62.18
400	2.33	26.50	94.18
500	2.26	35.23	126.18
600	2.21	43.96	158.18
700	2.17	52.69	190.18
800	2.14	61.41	222.18
900	2.12	70.14	254.18
1,000	2.10	78.87	286.18

Stack Distances (ft)	Number of Stacks
3.67	1248

CHILLERS - 59F, 100% Load

PETER BEST PAPER ILLUSTRATIVE EXAMPLE - SINGLE TURBINE - Assumes Heights in Table 2 are meters above ground

Plume Averaged Vertical Velocities: **"*Aviation Safety and Buoyant Plumes*," Peter Best, et. al.**

Ambient Conditions:					Constants:	
Ambient Potential Temp θ_a	**288**	Kelvins	**59.0**	°F	Assume neutral conditions (dθ/dz=0)	
Plume Exit Conditions:					Gravity g 9.81 m/s^2	
Stack Height h_s	**31.75**	meters	**104.2**	feet	λ 1.11	
Stack Diameter D	**0.91**	meters	**3.0**	feet	0.3048 meters/feet	
Stack Velocity V_{exit}	**10.2**	m/s	**33.3**	ft/sec		
Volumetric Flow	**7**	cu.m/sec	**14,130**	ACFM	$\pi V_{exit} D^2/4$	Sect.2/¶1
Stack Potential Temp θ_s	**322**	Kelvins	**120**	°F	Back-Calc'd from Buoyancy Flux	
Initial Stack Buoyancy Flux F_o	**2**	m^4/s^3			$gV_{exit}D^2(1-\theta_a/\theta_s)/4$ = Vol.Flow$(g/\pi)(1-\theta_a/\theta_s)$	Sect.2/¶1
Plume Buoyancy Flux F	N/A	m^4/s^3			$\lambda^2 gVa^2(1-\theta_a/\theta_p)$ for a,V,θ_p at plume height (not used here)	
Conditions at End (Top) of Jet Phase:						
Height above Stack z	**5.715**	meters*	**18.8**	feet*	6.25D, meters*=meters above stack top	Sect.3/¶1
Height above Ground $z+h_s$	**37.465**	meters	**122.9**	feet	h_s + 6.25D	"
Vertical Velocity V_{plume}	**5.077**	m/s	**16.66**	ft/sec	$0.5V_{exit}$ $V_{exit}/2$	"
Plume Top-Hat Diameter 2a	**1.829**	meters	**6.0**	feet	2D Conservation of mc	"
Spillane Methodology - Analytical Solutions for Calm Conditions for Plume Heights above Jet Phase						
Plume Top-Hat Radius a	**Solutions in Table Below**				$0.16(z-z_v)$, or linear increase with height	Sect.2/Eq.6
Virtual Source Height z_v	**0.309**	meters*	**1.0**	feet*	$6.25D[1-(\theta_e/\theta_s)^{1/2}]$, meters*=meters above s	Sect.2/Eq.6
Height above Ground z_v+h_s	**32.059**	meters	**105.2**	feet	where $(\theta_a/\theta_s)^{1/2} = (\theta_e/\theta_s)^{1/2}$=	0.945921621
Method(1): Simplified Plume-averaged Vertical Velocity V' - Assumes Product Va constant above jet phase such that $V_{plume}(2a) = V_{exit}D$						
Vertical Velocity V'	**Solutions in Table Below**				$V_{exit}D/2a'$ (conservation of buoyancy)	Sect.3&4
Method(2): Plume-averaged Vertical Velocity V given by Analytical Solution in Paper where Product Va given by equations below:						
Vertical Velocity V	**Solutions in Table Below**				$\{(Va)_o^3 + 0.12F_o [(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)}$ / :	Sect.2.1(6)
Product $(Va)_o$	**4.392**	m^2/s			$V_{exit}D/2(\theta_e/\theta_s)^{1/2}$	

CHILLERS - 59F, 100% Load

Table of plume Top-Hat Diameters (2a) and Plume-averaged Vertical Velocities for both Method(1) (assuming conservation of buoyancy & gaussian distribution of vertical velocities) and Method (2) (based on Peter Best's paper's Analytical Solution) starting at end of jet phase:

from 100 meters above ground in increments of 50.0 meters

				Vert.Vel (m/s)	
				Method(1)	**Method(2)**
	Ht above Ground =	$h_{plume}+h_s$	$D_{plume}=2a=$	$V_{plume}=$	$\{(Va)_o^3+0.12F_o[(z-z_v)^2$
Height above stack top, meters*	meters	feet	$2*0.16(z-z_v)$	$V_{exit}*D/2a$	$-(6.25D-z_v)^2]\}^{1/3}$ / a
End of jet phase at 6.25D = 5.715 meters*	***37.465***	***122.9***	***1.829***		***5.08***
68.250 meters*	**100.000**	328.1	21.741	0.43	**1.00**
118.250 meters*	150.000	492.1	37.741	0.25	0.82
168.250 meters*	**200.000**	656.2	53.741	0.17	**0.73**
218.250 meters*	250.000	820.2	69.741	0.13	0.67
268.250 meters*	**300.000**	984.3	85.741	0.11	**0.62**
318.250 meters*	350.000	1148.3	101.741	0.09	0.59
368.250 meters*	400.000	1312.3	117.741	0.08	0.56
418.250 meters*	450.000	1476.4	133.741	0.07	0.54
468.250 meters*	**500.000**	1640.4	149.741	0.06	**0.52**
518.250 meters*	550.000	1804.5	165.741	0.06	0.50
568.250 meters*	600.000	1968.5	181.741	0.05	0.48
618.250 meters*	650.000	2132.5	197.741	0.05	0.47
668.250 meters*	**700.000**	2296.6	213.741	0.04	**0.46**
718.250 meters*	750.000	2460.6	229.741	0.04	0.45
768.250 meters*	800.000	2624.7	245.741	0.04	0.44
818.250 meters*	850.000	2788.7	261.741	0.04	0.43
868.250 meters*	900.000	2952.8	277.741	0.03	0.42
918.250 meters*	950.000	3116.8	293.741	0.03	0.41
968.250 meters*	**1000.000**	3280.8	309.741	0.03	**0.40**
1018.250 meters*	1050.000	3444.9	325.741	0.03	0.40
1068.250 meters*	1100.000	3608.9	341.741	0.03	0.39
1118.250 meters*	1150.000	3773.0	357.741	0.03	0.39
1168.250 meters*	1200.000	3937.0	373.741	0.02	0.38
1218.250 meters*	1250.000	4101.0	389.741	0.02	0.37

CHILLERS - 59F, 100% Load

	m	ft		Method(1) m/s	Method(2) m/s
4.826 meters*	36.576	120.0	1.445	6.42	6.02
5.131 meters*	36.881	121.0	1.543	6.02	5.66
5.436 meters*	37.186	122.0	1.641	5.66	5.34
5.740 meters*	37.491	123.0	1.738	5.34	5.06
6.045 meters*	37.796	124.0	1.836	5.06	4.80
6.350 meters*	38.100	125.0	1.933	4.80	4.58
6.655 meters*	38.405	126.0	2.031	4.57	4.37
6.960 meters*	38.710	127.0	2.128	4.36	4.19
7.264 meters*	39.015	128.0	2.226	4.17	4.02
7.569 meters*	39.320	129.0	2.323	4.00	3.87
7.874 meters*	39.624	130.0	2.421	3.84	3.73
8.179 meters*	39.929	131.0	2.518	3.69	3.60
8.484 meters*	40.234	132.0	2.616	3.55	3.48
8.789 meters*	40.539	133.0	2.713	3.42	3.37
9.093 meters*	40.844	134.0	2.811	3.30	3.27
9.398 meters*	41.149	135.0	2.908	3.19	3.18
9.703 meters*	41.453	136.0	3.006	3.09	3.09
10.008 meters*	41.758	137.0	3.104	2.99	3.01
10.313 meters*	42.063	138.0	3.201	2.90	2.93
10.617 meters*	42.368	139.0	3.299	2.82	2.86
10.922 meters*	42.673	140.0	3.396	2.73	2.79
11.227 meters*	42.977	141.0	3.494	2.66	2.73
11.532 meters*	43.282	142.0	3.591	2.59	2.67
11.837 meters*	43.587	143.0	3.689	2.52	2.61
12.141 meters*	43.892	144.0	3.786	2.45	2.56
12.446 meters*	44.197	145.0	3.884	2.39	2.51
12.751 meters*	44.501	146.0	3.981	2.33	2.46
13.056 meters*	44.806	147.0	4.079	2.28	2.42
13.361 meters*	45.111	148.0	4.176	2.22	2.37
13.665 meters*	45.416	149.0	4.274	2.17	2.33
13.970 meters*	45.721	150.0	4.372	2.12	2.29
29.210 meters*	60.961	200.0	9.248	1.00	1.44
59.691 meters*	91.441	300.0	19.002	0.49	1.05
90.171 meters*	121.921	400.0	28.756	0.32	0.90
120.651 meters*	152.402	500.0	38.510	0.24	0.82
151.132 meters*	182.882	600.0	48.263	0.19	0.76
181.612 meters*	213.363	700.0	58.017	0.16	0.71
212.093 meters*	243.843	800.0	67.771	0.14	0.67
242.573 meters*	274.323	900.0	77.524	0.12	0.64
273.053 meters*	304.804	1000.0	87.278	0.11	0.62

Combined Plume Method

Stack Distances (ft)	Number of Stacks
3.67	1248

ft	m/s	merged cells	Plume Diamter Feet
120	7.26	2.11	4.74
121	6.89	2.20	5.06
122	6.56	2.29	5.38
123	6.27	2.37	5.70
124	6.02	2.46	6.02
125	5.78	2.55	6.34
126	5.57	2.64	6.66
127	5.38	2.72	6.98
128	5.21	2.81	7.30
129	5.05	2.90	7.62
130	4.90	2.98	7.94
131	4.77	3.07	8.26
132	4.64	3.16	8.58
133	4.53	3.25	8.90
134	4.42	3.33	9.22
135	4.32	3.42	9.54
136	4.23	3.51	9.86
137	4.14	3.60	10.18
138	4.06	3.68	10.50
139	3.99	3.77	10.82
140	3.91	3.86	11.14
141	3.85	3.94	11.46
142	3.78	4.03	11.78
143	3.72	4.12	12.10
144	3.67	4.21	12.42
145	3.61	4.29	12.74
146	3.56	4.38	13.06
147	3.51	4.47	13.38
148	3.47	4.56	13.70
149	3.42	4.64	14.02
150	3.38	4.73	14.34
200	2.50	9.09	30.34
300	2.17	17.82	62.34
400	2.05	26.55	94.34
500	1.99	35.28	126.34
600	1.95	44.00	158.34
700	1.91	52.73	190.34
800	1.88	61.46	222.34
900	1.86	70.18	254.35
1,000	1.84	78.91	286.35

PETER BEST PAPER ILLUSTRATIVE EXAMPLE - SINGLE TURBINE - Assumes Heights in Table 2 are meters above ground

Plume Averaged Vertical Velocities: **"*Aviation Safety and Buoyant Plumes*," Peter Best, et. al.**

Ambient Conditions:

Constants:

Assume neutral conditions ($d\theta/dz=0$)

Gravity g	9.81	m/s^2
λ	1.11	
	0.3048	meters/feet

Ambient Potential Temp θ_a	**298**	Kelvins	**76.0**	°F		
Plume Exit Conditions:						
Stack Height h_s	**31.75**	meters	**104.2**	feet		
Stack Diameter D	**0.91**	meters	**3.0**	feet		
Stack Velocity V_{exit}	**10.2**	m/s	**33.3**	ft/sec		
Volumetric Flow	**7**	cu.m/sec	**14,130**	ACFM	$\pi V_{exit}D^2/4$	Sect.2/¶1
Stack Potential Temp θ_s	**322**	Kelvins	**120**	°F	Back-Calc'd from Buoyancy Flux	
Initial Stack Buoyancy Flux F_o	**2**	m^4/s^3			$gV_{exit}D^2(1-\theta_a/\theta_s)/4$ = Vol.Flow$(g/\pi)(1-\theta_a/\theta_s)$	Sect.2/¶1
Plume Buoyancy Flux F	N/A	m^4/s^3			$\lambda^2 gVa^2(1-\theta_a/\theta_p)$ for a, V, θ_p at plume height (not used here)	

Conditions at End (Top) of Jet Phase:

Height above Stack z	**5.715**	meters*	**18.8**	feet*	6.25D, meters*=meters above stack top		Sect.3/¶1
Height above Ground $z+h_s$	**37.465**	meters	**122.9**	feet	h_s + 6.25D		"
Vertical Velocity V_{plume}	**5.077**	m/s	**16.66**	ft/sec	$0.5V_{exit}$	$V_{exit}/2$	"
Plume Top-Hat Diameter 2a	**1.829**	meters	**6.0**	feet	2D	Conservation of mc	"

Spillane Methodology - Analytical Solutions for Calm Conditions for Plume Heights above Jet Phase

Plume Top-Hat Radius a	**Solutions in Table Below**				$0.16(z-z_v)$, or linear increase with height	Sect.2/Eq.6
Virtual Source Height z_v	**0.221**	meters*	**0.7**	feet*	$6.25D[1-(\theta_e/\theta_s)^{1/2}]$, meters*=meters above s	Sect.2/Eq.6
Height above Ground z_v+h_s	**31.972**	meters	**104.9**	feet	where $(\theta_a/\theta_s)^{1/2} = (\theta_e/\theta_s)^{1/2}$=	0.961298467

Method(1): Simplified Plume-averaged Vertical Velocity V' - Assumes Product Va constant above jet phase such that $V_{plume}(2a) = V_{exit}D$

Vertical Velocity V'	**Solutions in Table Below**	$V_{exit}D/2a'$ (conservation of buoyancy)	Sect.3&4

Method(2): Plume-averaged Vertical Velocity V given by Analytical Solution in Paper where Product Va given by equations below:

Vertical Velocity V	**Solutions in Table Below**		$\{(Va)_o^3 + 0.12F_o [(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)}$ / a	Sect.2.1(6)
Product $(Va)_o$	**4.463**	m^2/s	$V_{exit}D/2(\theta_e/\theta_s)^{1/2}$	

CHILLERS - 76F, 100% Load

Table of plume Top-Hat Diameters (2a) and Plume-averaged Vertical Velocities for both Method(1) (assuming conservation of buoyancy & gaussian distribution of vertical velocities) and Method (2) (based on Peter Best's paper's Analytical Solution) starting at end of jet phase:

from 100 meters above ground in increments of 50.0 meters

				Vert.Vel (m/s)	
				Method(1)	**Method(2)**
	Ht above Ground =	$h_{plume}+h_s$	$D_{plume}=2a=$	$V_{plume}=$	$\{(Va)_o^3+0.12F_o[(z-z_v)^2$
Height above stack top, meters*	meters	feet	$2*0.16(z-z_v)$	$V_{exit}*D/2a$	$-(6.25D-z_v)^2]\}^{1/3}$ / a
End of jet phase at 6.25D = 5.715 meters*	***37.465***	***122.9***	***1.829***		***5.08***
68.250 meters*	**100.000**	328.1	21.769	0.43	**0.91**
118.250 meters*	150.000	492.1	37.769	0.25	0.74
168.250 meters*	**200.000**	656.2	53.769	0.17	**0.65**
218.250 meters*	250.000	820.2	69.769	0.13	0.60
268.250 meters*	**300.000**	984.3	85.769	0.11	**0.56**
318.250 meters*	350.000	1148.3	101.769	0.09	0.53
368.250 meters*	400.000	1312.3	117.769	0.08	0.50
418.250 meters*	450.000	1476.4	133.769	0.07	0.48
468.250 meters*	**500.000**	1640.4	149.769	0.06	**0.46**
518.250 meters*	550.000	1804.5	165.769	0.06	0.45
568.250 meters*	600.000	1968.5	181.769	0.05	0.43
618.250 meters*	650.000	2132.5	197.769	0.05	0.42
668.250 meters*	**700.000**	2296.6	213.769	0.04	**0.41**
718.250 meters*	750.000	2460.6	229.769	0.04	0.40
768.250 meters*	800.000	2624.7	245.769	0.04	0.39
818.250 meters*	850.000	2788.7	261.769	0.04	0.38
868.250 meters*	900.000	2952.8	277.769	0.03	0.38
918.250 meters*	950.000	3116.8	293.769	0.03	0.37
968.250 meters*	**1000.000**	3280.8	309.769	0.03	**0.36**
1018.250 meters*	1050.000	3444.9	325.769	0.03	0.36
1068.250 meters*	1100.000	3608.9	341.769	0.03	0.35
1118.250 meters*	1150.000	3773.0	357.769	0.03	0.35
1168.250 meters*	1200.000	3937.0	373.769	0.02	0.34
1218.250 meters*	1250.000	4101.0	389.769	0.02	0.34

CHILLERS - 76F, 100% Load

	m	ft		Method(1) m/s	Method(2) m/s
4.826 meters*	36.576	120.0	1.474	6.30	6.02
5.131 meters*	36.881	121.0	1.571	5.91	5.66
5.436 meters*	37.186	122.0	1.669	5.56	5.34
5.740 meters*	37.491	123.0	1.766	5.26	5.05
6.045 meters*	37.796	124.0	1.864	4.98	4.80
6.350 meters*	38.100	125.0	1.961	4.73	4.57
6.655 meters*	38.405	126.0	2.059	4.51	4.37
6.960 meters*	38.710	127.0	2.156	4.31	4.18
7.264 meters*	39.015	128.0	2.254	4.12	4.01
7.569 meters*	39.320	129.0	2.351	3.95	3.86
7.874 meters*	39.624	130.0	2.449	3.79	3.72
8.179 meters*	39.929	131.0	2.546	3.65	3.59
8.484 meters*	40.234	132.0	2.644	3.51	3.47
8.789 meters*	40.539	133.0	2.742	3.39	3.35
9.093 meters*	40.844	134.0	2.839	3.27	3.25
9.398 meters*	41.149	135.0	2.937	3.16	3.15
9.703 meters*	41.453	136.0	3.034	3.06	3.06
10.008 meters*	41.758	137.0	3.132	2.97	2.98
10.313 meters*	42.063	138.0	3.229	2.88	2.90
10.617 meters*	42.368	139.0	3.327	2.79	2.82
10.922 meters*	42.673	140.0	3.424	2.71	2.75
11.227 meters*	42.977	141.0	3.522	2.64	2.69
11.532 meters*	43.282	142.0	3.619	2.57	2.63
11.837 meters*	43.587	143.0	3.717	2.50	2.57
12.141 meters*	43.892	144.0	3.814	2.43	2.51
12.446 meters*	44.197	145.0	3.912	2.37	2.46
12.751 meters*	44.501	146.0	4.010	2.32	2.41
13.056 meters*	44.806	147.0	4.107	2.26	2.36
13.361 meters*	45.111	148.0	4.205	2.21	2.32
13.665 meters*	45.416	149.0	4.302	2.16	2.28
13.970 meters*	45.721	150.0	4.400	2.11	2.24
29.210 meters*	60.961	200.0	9.277	1.00	1.34
59.691 meters*	91.441	300.0	19.030	0.49	0.96
90.171 meters*	121.921	400.0	28.784	0.32	0.82
120.651 meters*	152.402	500.0	38.538	0.24	0.73
151.132 meters*	182.882	600.0	48.291	0.19	0.68
181.612 meters*	213.363	700.0	58.045	0.16	0.64
212.093 meters*	243.843	800.0	67.799	0.14	0.60
242.573 meters*	274.323	900.0	77.553	0.12	0.58
273.053 meters*	304.804	1000.0	87.306	0.11	0.55

Combined Plume Method

Stack Distances (ft)	Number of Stacks
3.67	1248

ft	m/s	merged cells	Plume Diamter Feet
120	7.28	2.14	4.83
121	6.91	2.22	5.15
122	6.58	2.31	5.47
123	6.29	2.40	5.79
124	6.03	2.49	6.11
125	5.79	2.57	6.43
126	5.58	2.66	6.75
127	5.39	2.75	7.07
128	5.21	2.83	7.39
129	5.05	2.92	7.71
130	4.90	3.01	8.03
131	4.76	3.10	8.35
132	4.63	3.18	8.67
133	4.51	3.27	8.99
134	4.40	3.36	9.31
135	4.29	3.45	9.63
136	4.20	3.53	9.95
137	4.11	3.62	10.27
138	4.02	3.71	10.59
139	3.94	3.79	10.91
140	3.87	3.88	11.23
141	3.80	3.97	11.55
142	3.73	4.06	11.87
143	3.66	4.14	12.19
144	3.60	4.23	12.51
145	3.55	4.32	12.83
146	3.49	4.41	13.15
147	3.44	4.49	13.47
148	3.39	4.58	13.79
149	3.35	4.67	14.11
150	3.30	4.75	14.43
200	2.34	9.12	30.43
300	1.97	17.85	62.44
400	1.85	26.57	94.44
500	1.79	35.30	126.44
600	1.75	44.03	158.44
700	1.72	52.75	190.44
800	1.69	61.48	222.44
900	1.67	70.21	254.44
1,000	1.65	78.94	286.44