Comparison of the environment at Virgo and LIGO Hanford and possible sources of important differences

R. Schofield, I. Fiori, F. Paoletti , N. Sing and M. Tringali

These spectra are just snapshots of the environment, but the LIGO ones are typical for science mode. The Virgo ones were taken recently in the middle of the night when the interferometer was locked on Aug. 30. I spot-checked a few other times to make sure that these spectra were representative.

Vacuum chamber wall motion. Figures 1a-c compare motions of test mass and beam splitter chambers at Virgo and LHO. Chamber motion can drive scattering noise. The Virgo chambers tend to move less between 10 and 30 Hz, where the LIGO chambers have a resonance, and the Virgo chambers move several times more than the LIGO chambers above 100 Hz.

Acoustic environment. Figure 2 shows that the greater vacuum enclosure motion above 100 Hz is consistent with the higher acoustic levels in the Virgo corner and end stations above 100 Hz. This noise is likely due to more electronics with fans in the chamber area at Virgo. The Virgo level is similar to the LIGO level in a LIGO electronics room (Figure 2b). Figure 2b also shows that Virgo is louder in the 10-30 Hz bands at the end stations, which has been shown to be driven by the HVAC (Figure 2c).

Magnetic environment. Figure 3 shows a comparison of magnetic fields. The field at Virgo around 50 Hz is several times greater than at LHO around 60 Hz. The broadening of the 50 Hz peak is likely due to modulation (e.g. things turning on and off) of the 50 Hz currents. The possibilities are that the dominant source of the magnetic field is current flows to Virgo equipment, or that the dominant source is non-Virgo currents. I think that Irene and Federico and their students have already shown that the source is not fields from external power lines. At LIGO LLO, the pedestal around 60 Hz is dominated by return ground currents from homes and businesses around Livingston that travel on our beam tube. A check of how fields vary with distance from the beam tubes was used to measure these beam tube currents. Beam tube currents are a possibility, but I think that the most likely source is just current flow to Virgo equipment. At LIGO we try to have no 60 Hz equipment, only DC power, in the experimental areas (LVEA and VEA). One large 41 Hz magnetic feature at NE is due to the fans (Figure 2c).

Seismic environment above 1 Hz. Figure 4 shows a comparison of seismic motion at the corner stations. Below 3 Hz, Virgo has more motion even during this night spectrum. In the day time, due to human activity, the signal below 3 Hz is significantly larger (Figure 4b). Above about 3 Hz, Virgo and LIGO LHO are comparable, in some bands Virgo levels are lower, in some bands, higher. There are several large peaks in the Virgo seismic spectra that go away when the fans are turned off, such as the 13.5 Hz peak at NE visible in Figure 2c zoom 1. These would likely be mitigated to background by putting the fan boxes on 3Hz equipment isolation springs. We have found that equipment that is rotating at such low frequencies often needs two stages of isolation, and there may also be some acoustic shorting within the fan box. The relatively high vertical motion at LHO, peaking at 10 Hz, may be due to to a shallow reflective basalt layer; LLO is more isotropic.

Possible sources of the acoustic differences between Virgo and LIGO and potential mitigation.
Above 100 Hz, the difference, as mentioned above, is likely due to fans in the experimental area. If it is important to reduce the 100+ Hz noise because of scattering, light clipping or microphonics, removing the fans from the chamber area would give the biggest change. I think there might be a factor of 2 or 3 that could be gained by damping electronics cabinet walls with constrained layer materials, and damping the platforms with similar material or rubber mats. Above a couple of hundred Hz, it would also be fairly easy to reduce the reverb time with acoustic panels. This mitigation may become important if coupling problems in this band become evident.

Below 100 Hz. Figure 5 has tabulations of LIGO HVAC parameters, such as approximate duct velocities and Reynolds numbers, photos comparing the LIGO and Virgo systems, as well as the HVAC as-built engineering drawings for LIGO. This information may be helpful in explaining why the Virgo end station is a few to ten times acoustically louder in the 10-50 Hz band than the LHO end station (Figure 2b), and in determining if the Virgo air flow can be reduced.

Following are a few differences between LIGO and Virgo that I think might play a role in the 10-100 Hz acoustic difference (this list may not be exhaustive).

1) *Less damping in the Virgo ducts*? Our LIGO specification is that all ducts be double walled with 1 inch rigid insulation and a perforated steel liner (see red box in engineering drawings of Figure 5c). We tried to determine if the Virgo ducts were well damped and I think that Federico has the most recent results. My impression is that the decay times suggest that they are not well damped, and so it would be worthwhile to inspect them directly to see if they are rigid, acoustically damped ducts or not. At LIGO LHO, some ducts were installed without damping and we ended up damping them from the outside.

2) *Fan box noise?* Another difference is that, at LIGO, the plenum that the HVAC fans empty into is made of cement block. This LIGO plenum is a rigid version of the fan boxes at Virgo. My impression was that the Virgo fan boxes were ”breathing” and may need more damping, from outside or from inside, or they may need redesign to make them stiffer. It might be worth placing an accelerometer on the fan box to see if it is vibrating in the 10 Hz band and to see if the fan box resonances are visible on the microphone in the experimental area.

3) *Higher air velocities in the Virgo ducts?* I think that the Virgo flow rates per square meter of floor space should be compared to the LIGO ones to see if it would be reasonable to reduce flow rates. Additionally, the duct air velocities and Reynolds numbers could be compared to those in Figure 5 to see if greater turbulence could contribute to the difference between sites.

There appears to be a consistent (over time) factor of 2 difference between Virgo end stations in the 10-20 Hz band (Figure 2b). It might be worth attempting to identify the source of this difference. Less air being pumped by the fan at WE is one possibility.

4) *Less likely, but possible*: *lack of HEPA filters on the duct outlets?* LIGO has HEPA filters in front of duct outlets (see photos and drawings in Figure 5). At LHO we have reduced 10 Hz HVAC noise using screens to break up 10 Hz eddies, and HEPA filters might have a similar effect.

5) *Less likely, but possible: lack of a suspended ceiling*? LIGO has suspended acoustic panel ceilings (Figure 5a). The panels themselves would not absorb well in the 10-100 Hz band, but the suspended ceiling may act as a lossy diaphragm, with a low frequency damping effect. There were improvements with a similar ceiling seen at 100 Hz (the lowest examined frequency) in this reference: C. Buratti, Indoor noise reduction index with open window, Applied Acoustics 63 (2002) 431–451.

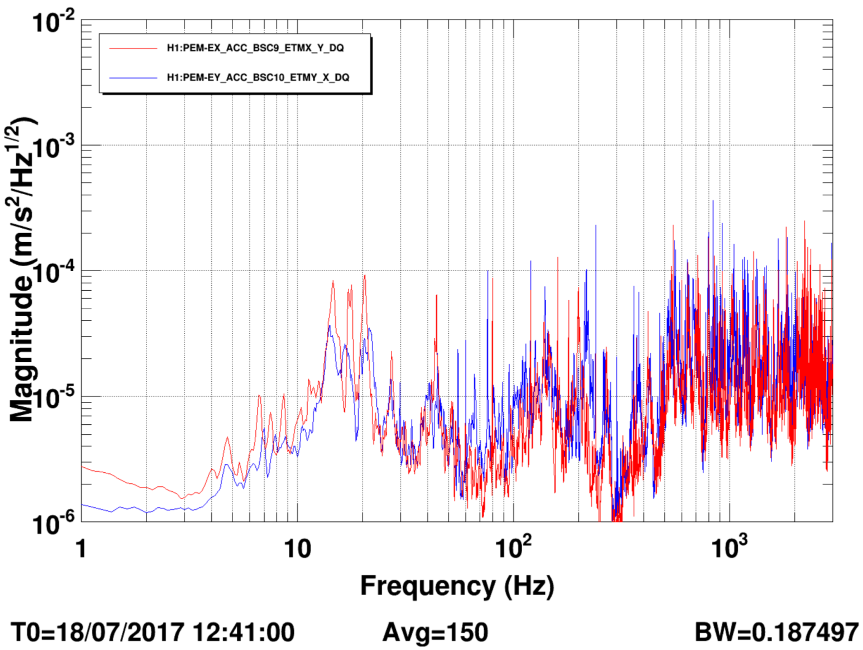
My impression is that the first two, fan box noise and duct noise are the most likely. This hypothesis can be tested, by, for example, placing microphones in the ducts and an accelerometer on the fan box. If the peaks visible in room microphone spectra are larger in amplitude in spectra for microphones located in the ducts or if the room microphone peaks are visible in signals from an accelerometer on the fan box, the duct noise/ fan box noise hypothesis would be supported.

In any case, the easiest solution to try, may be to reduce the fan pumping rate. This would reduce the amplitude of fan box and duct resonance features and reduce any excitation of room modes. One possibility would be to change the drive pulley to reduce the fan rotation rate. Another possibility would be to reduce the rotation rate with a variable frequency drive. A bypass is another option, but this might not reduce fan box noise.

Figure 1a

Comparison of vacuum enclosure motion channels

LIGO Hanford End Test Mass chambers



Virgo End Test Mass chambers

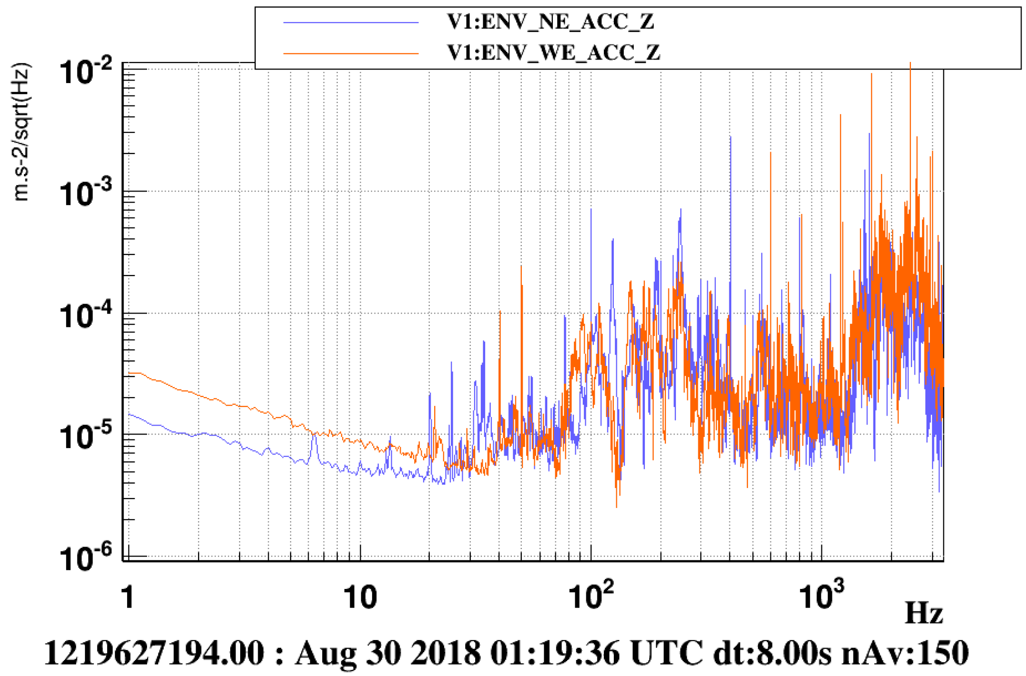
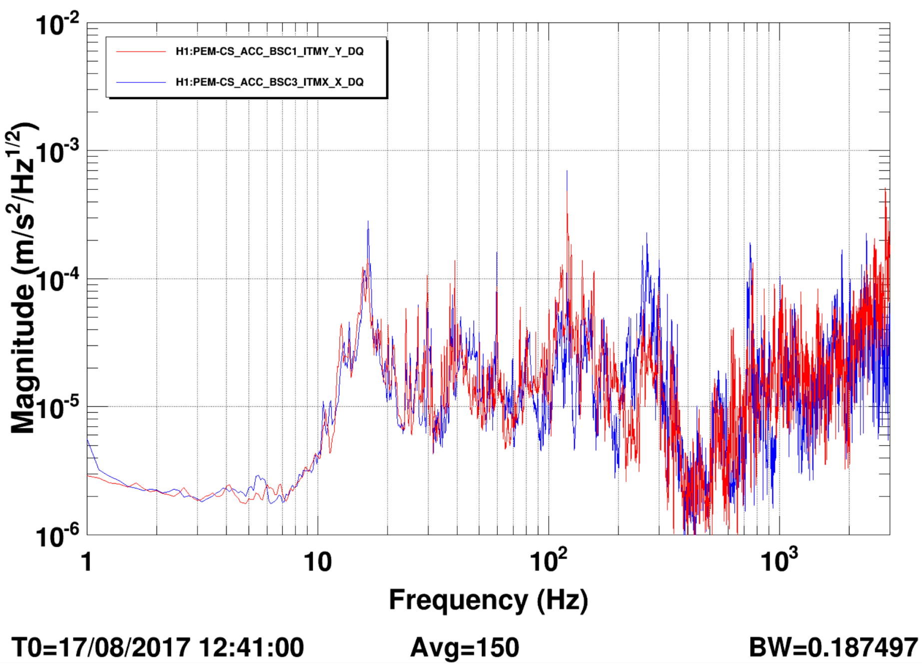


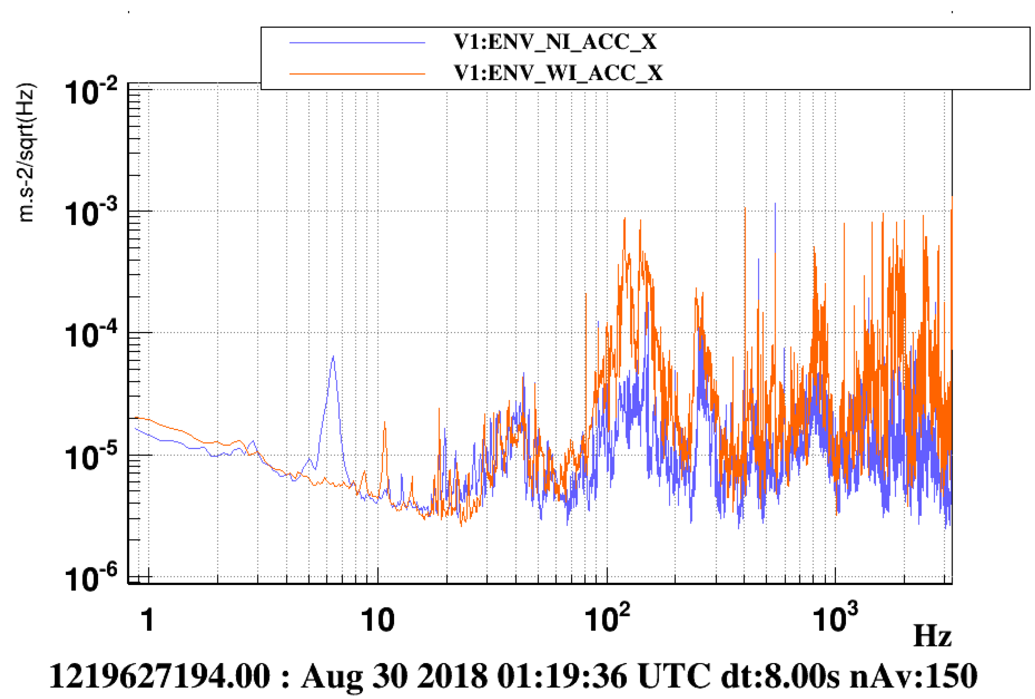
Figure 1b

Comparison of vacuum enclosure motion channels

LIGO Hanford Corner Test Mass chambers



Virgo Corner Test Mass chambers



lower values for NI chamber ?

Figure 1c

Comparison of vacuum enclosure motion channels

LIGO Hanford Beam Splitter Chamber

Virgo Beam Splitter Chamber

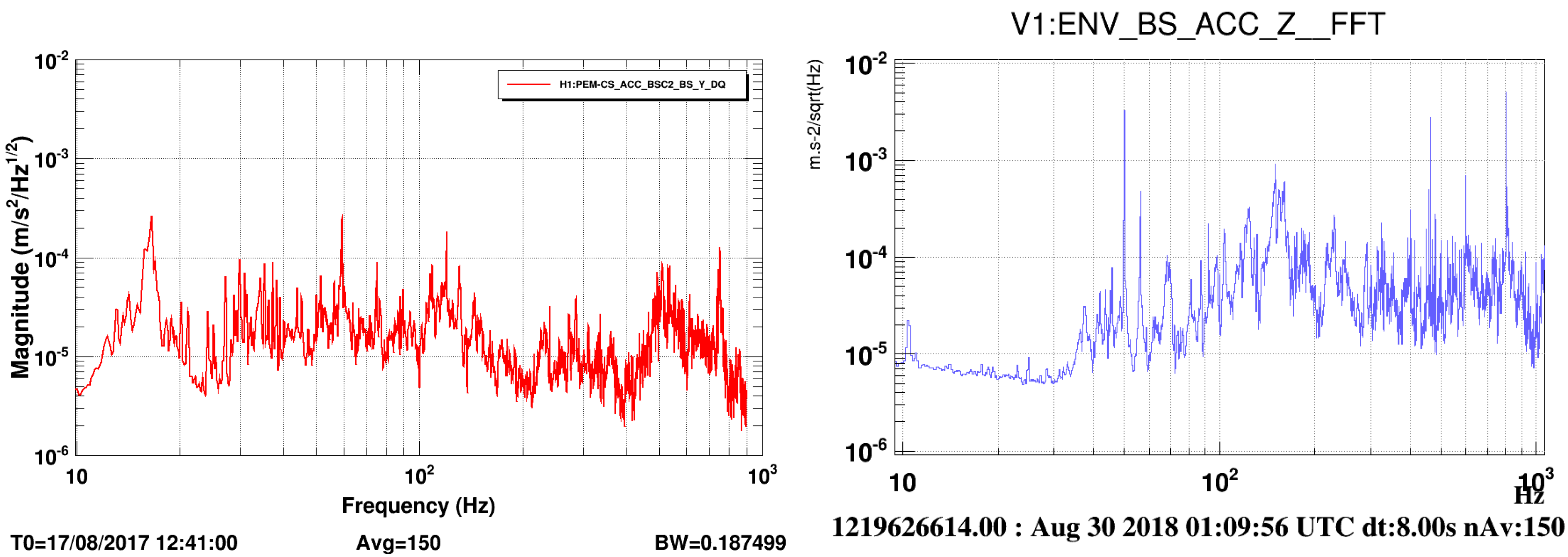
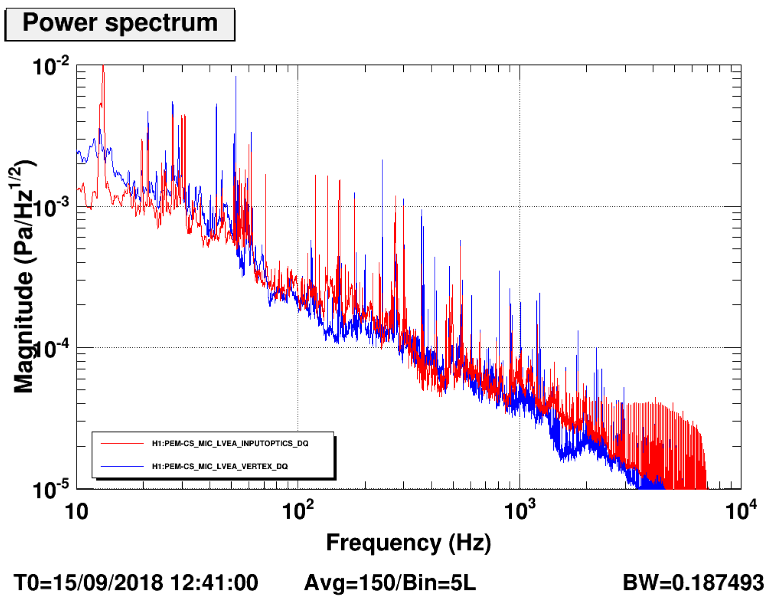


Figure 2a

Acoustic comparison

LIGO Hanford Corner Station



Virgo Corner station

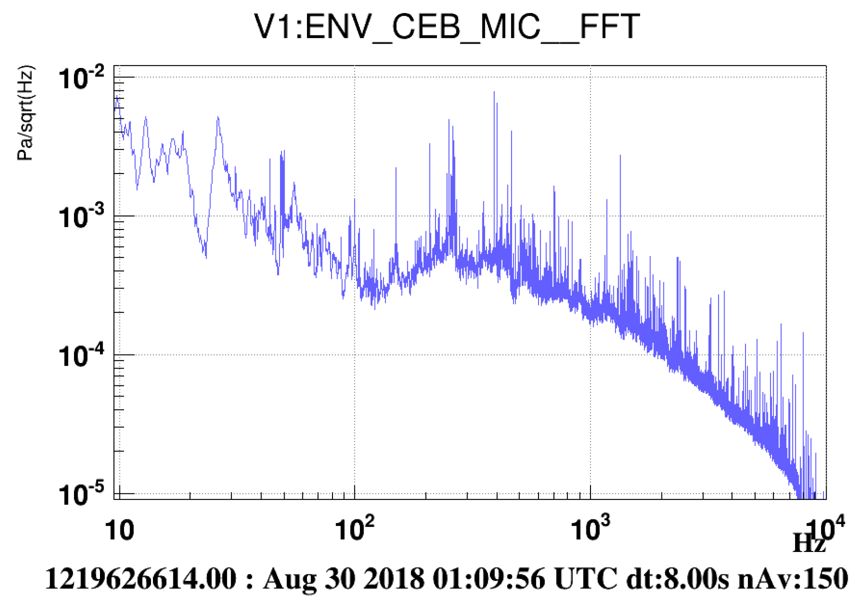
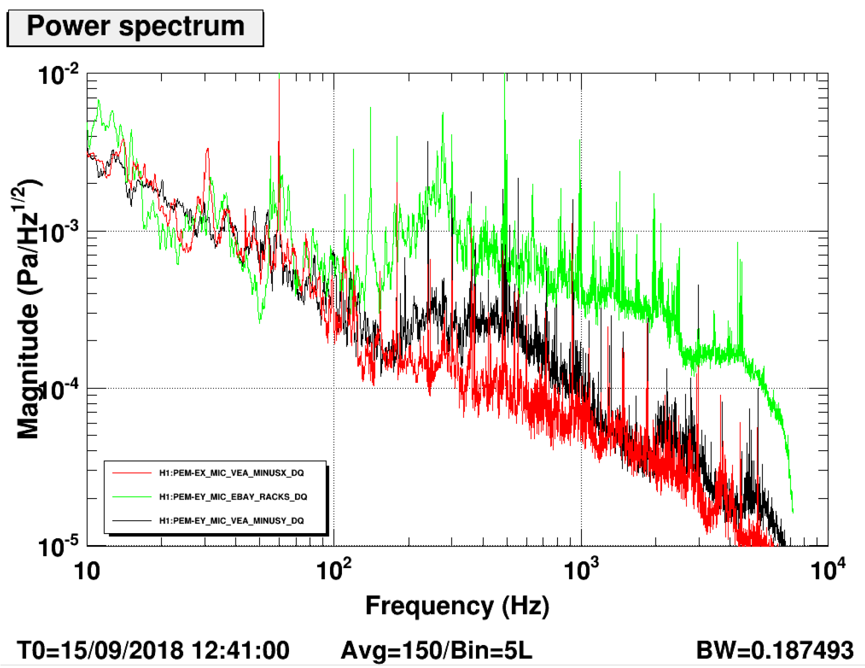


Figure 2b

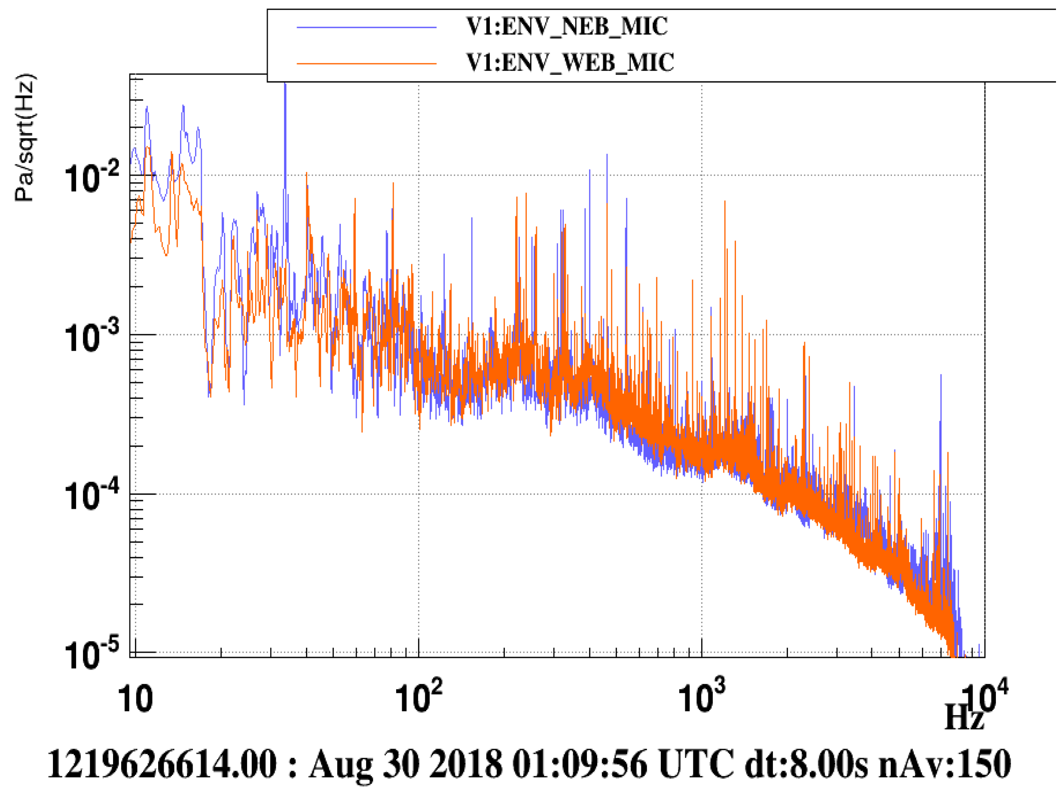
Acoustic comparison

LIGO Hanford End Station

Red and Black are spectra for the vacuum chamber area,
Green is for the electronics room.



Virgo End Stations



Note that NE is a factor of 2 worse than WE in the 10-30 Hz band, which suggests a difference that might be easily corrected. Less air being pumped at NE?

Figure 2c

Shutdown of HVAC at NEB

All HVAC off (RED) compared to fans only on (BLUE) in seismic, acoustic, chamber motion and magnetic

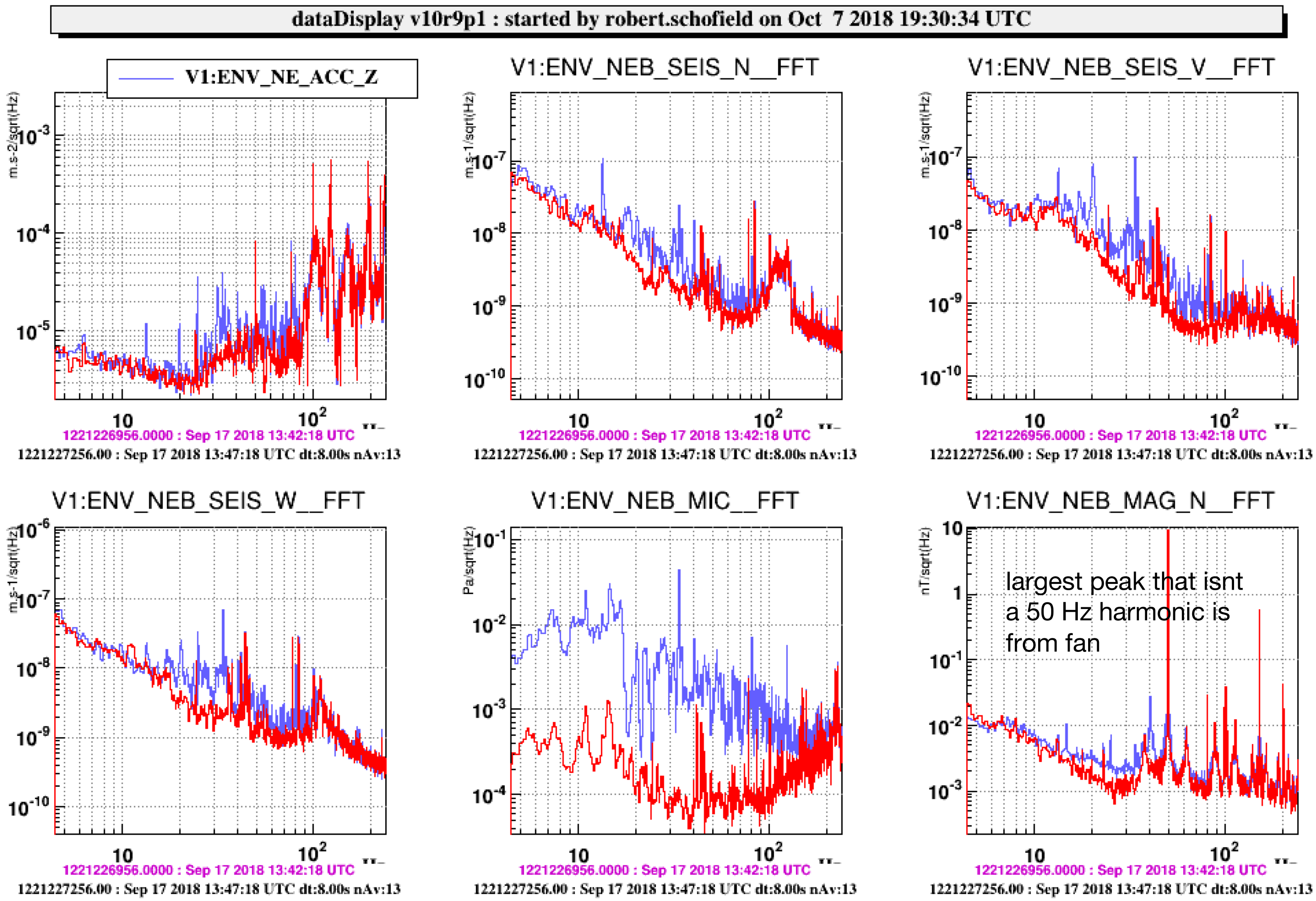


Figure 2c zoom 1

Shutdown of HVAC at NEB

All HVAC off (RED) compared to fans only on (BLUE) in seismic, acoustic, chamber motion and magnetic

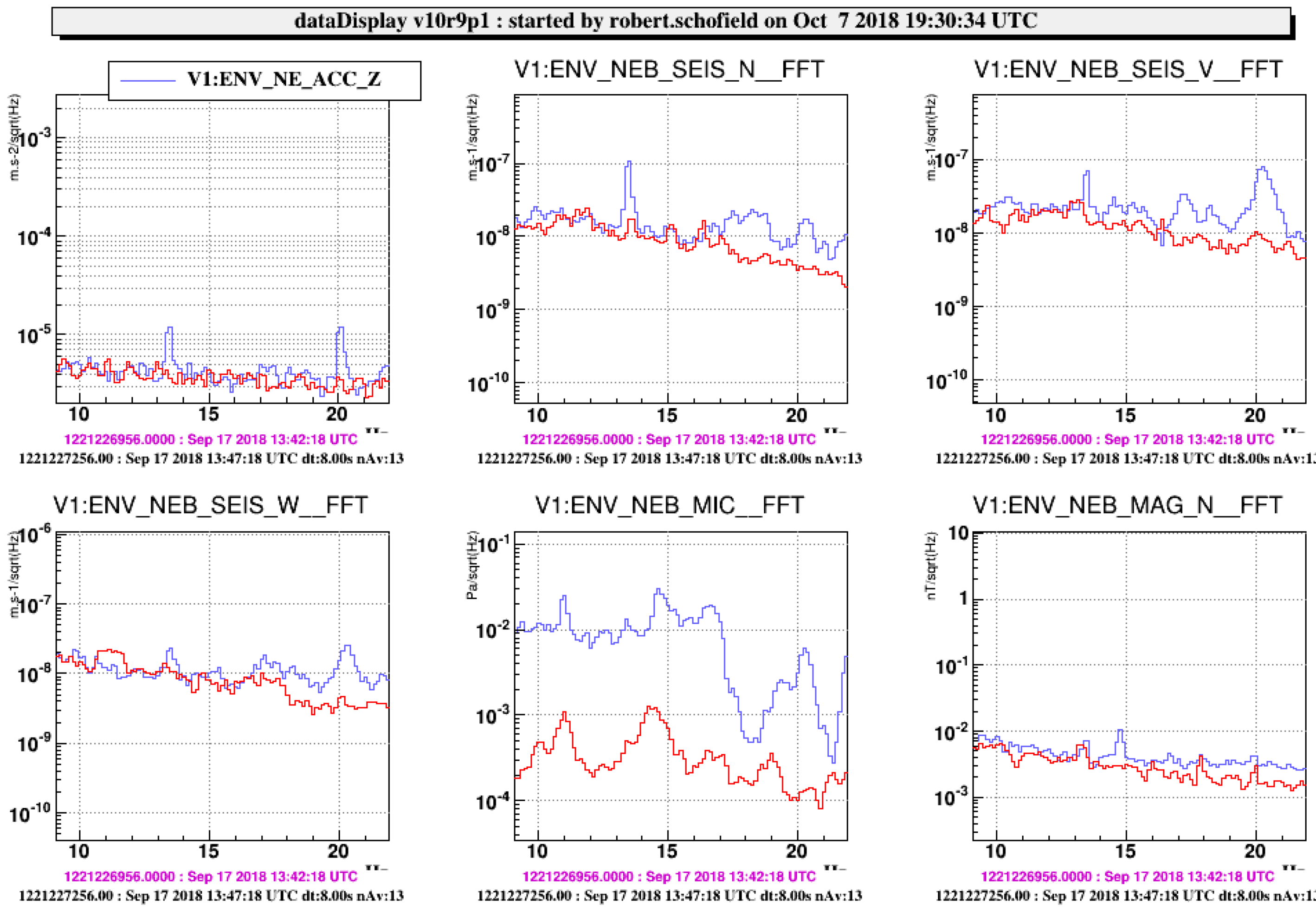


Figure 2c zoom 2

Shutdown of HVAC at NEB

All HVAC off (RED) compared to fans only on (BLUE) in seismic, acoustic, chamber motion and magnetic

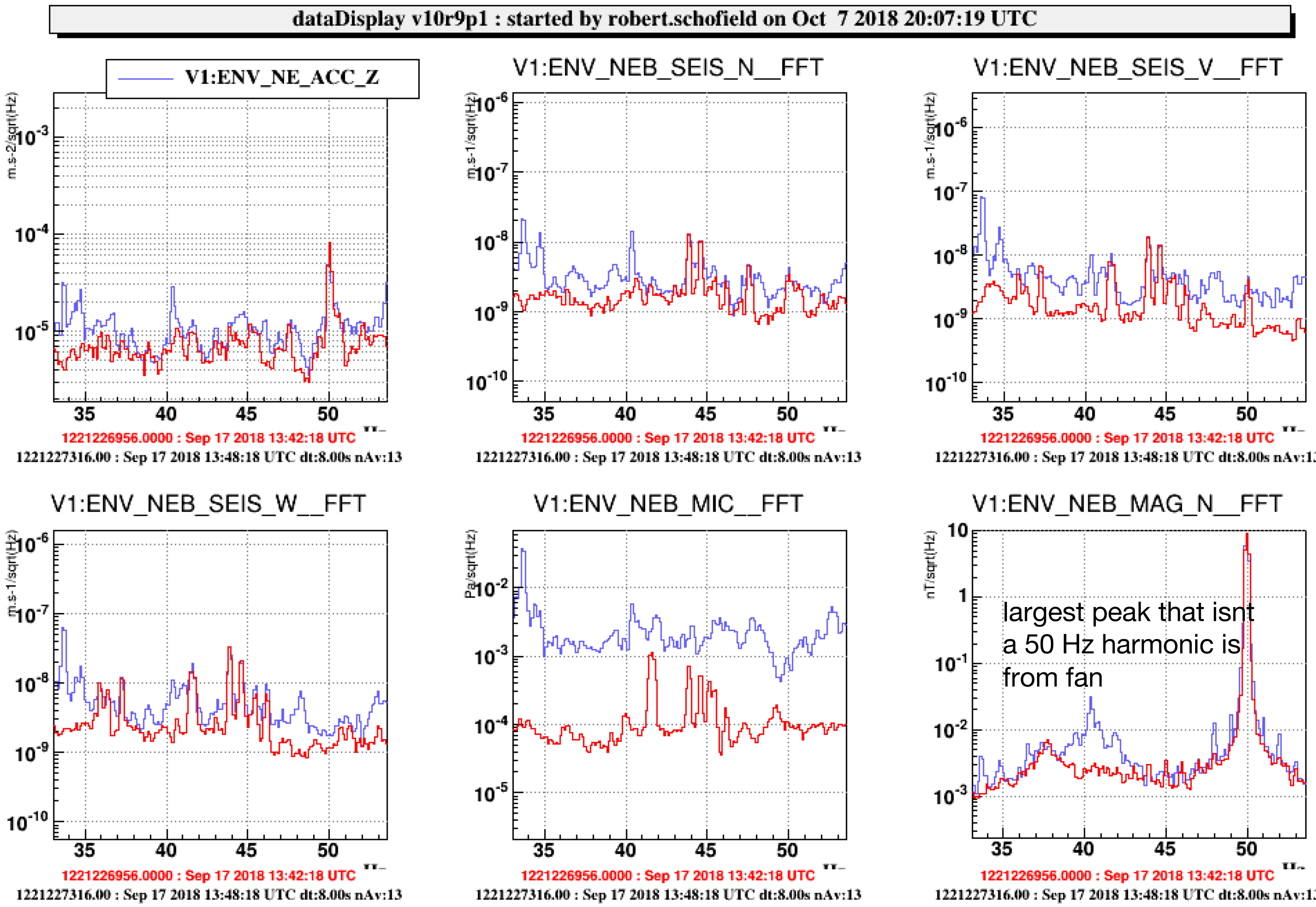


Figure 2d

Shutdown of HVAC at NEB

All HVAC off (RED) compared to chiller and water only on (BLUE)

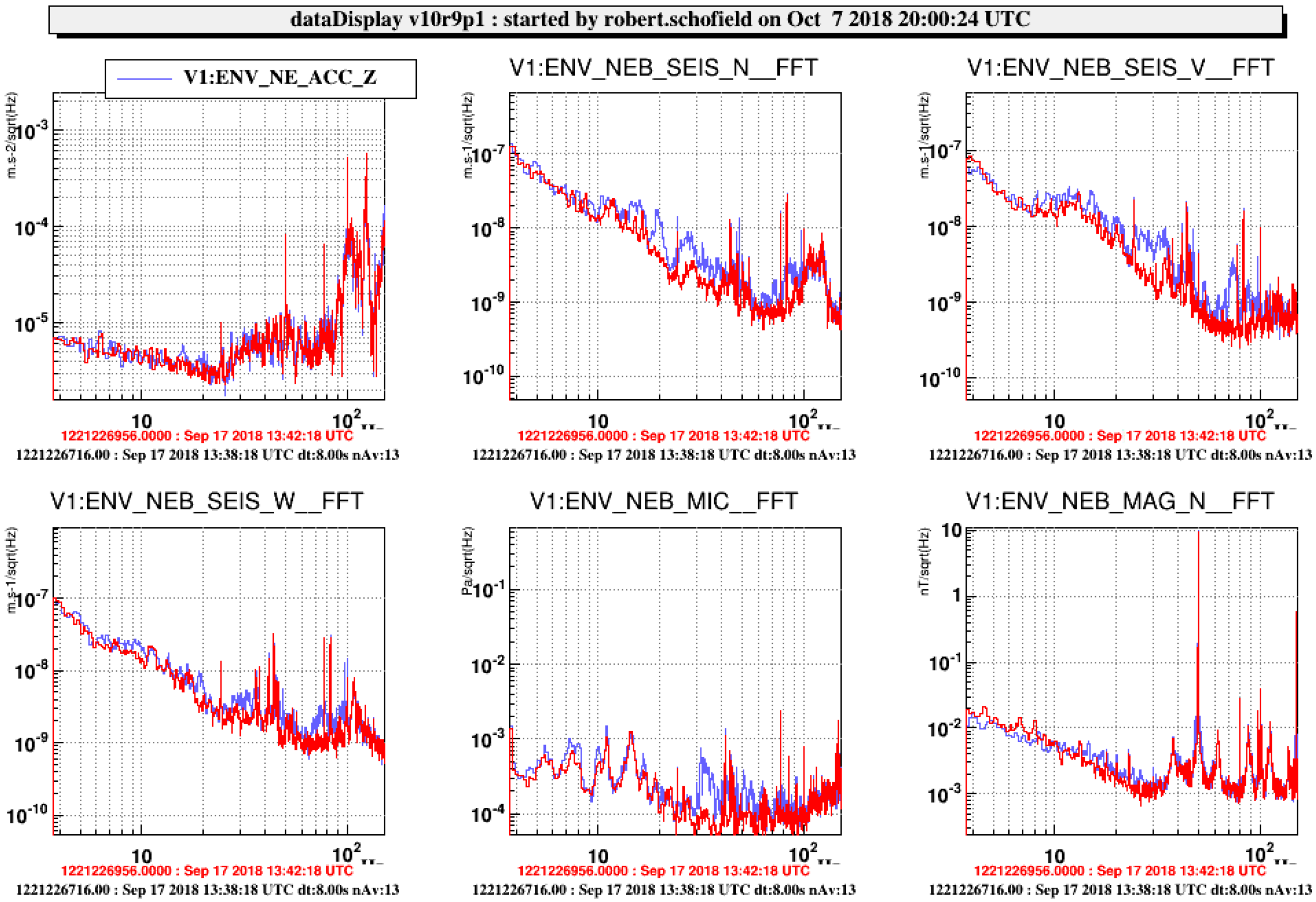


Figure 3

Magnetic field comparison

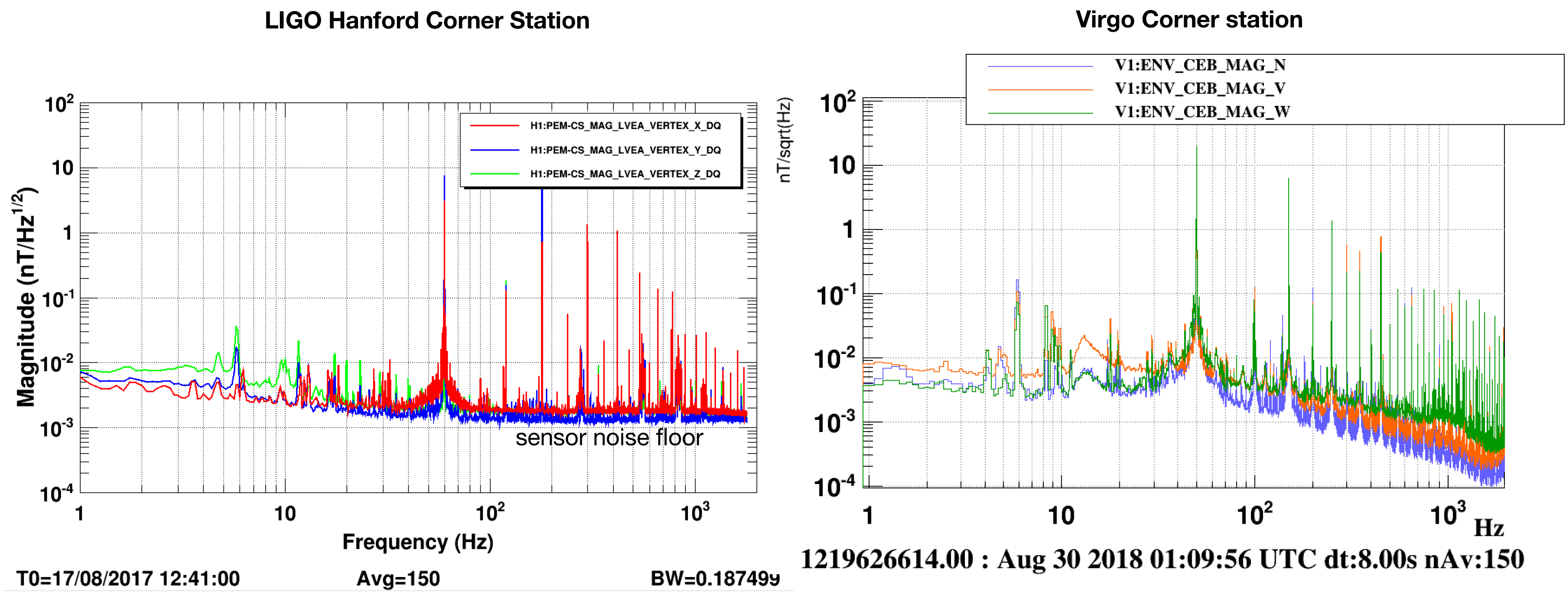


Figure 4a

Seismic comparison, 1-50 Hz

LIGO Hanford Corner Station

Virgo Corner station

Horizontal

Vertical

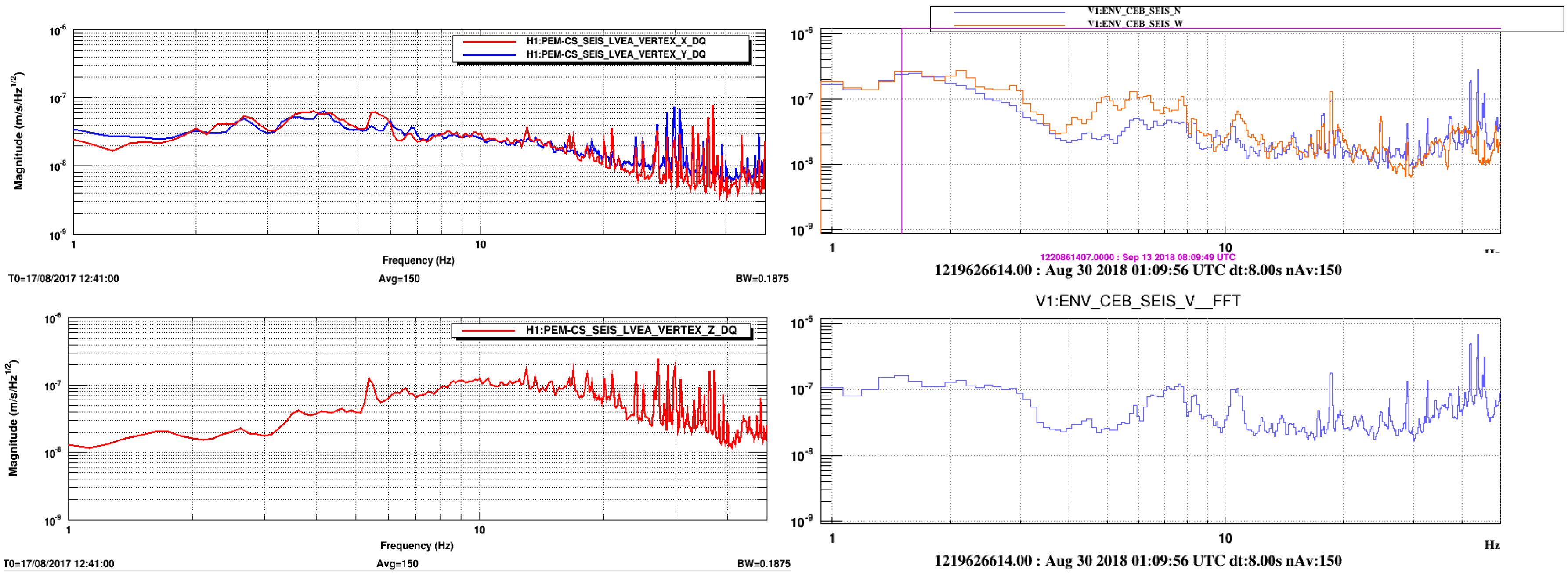
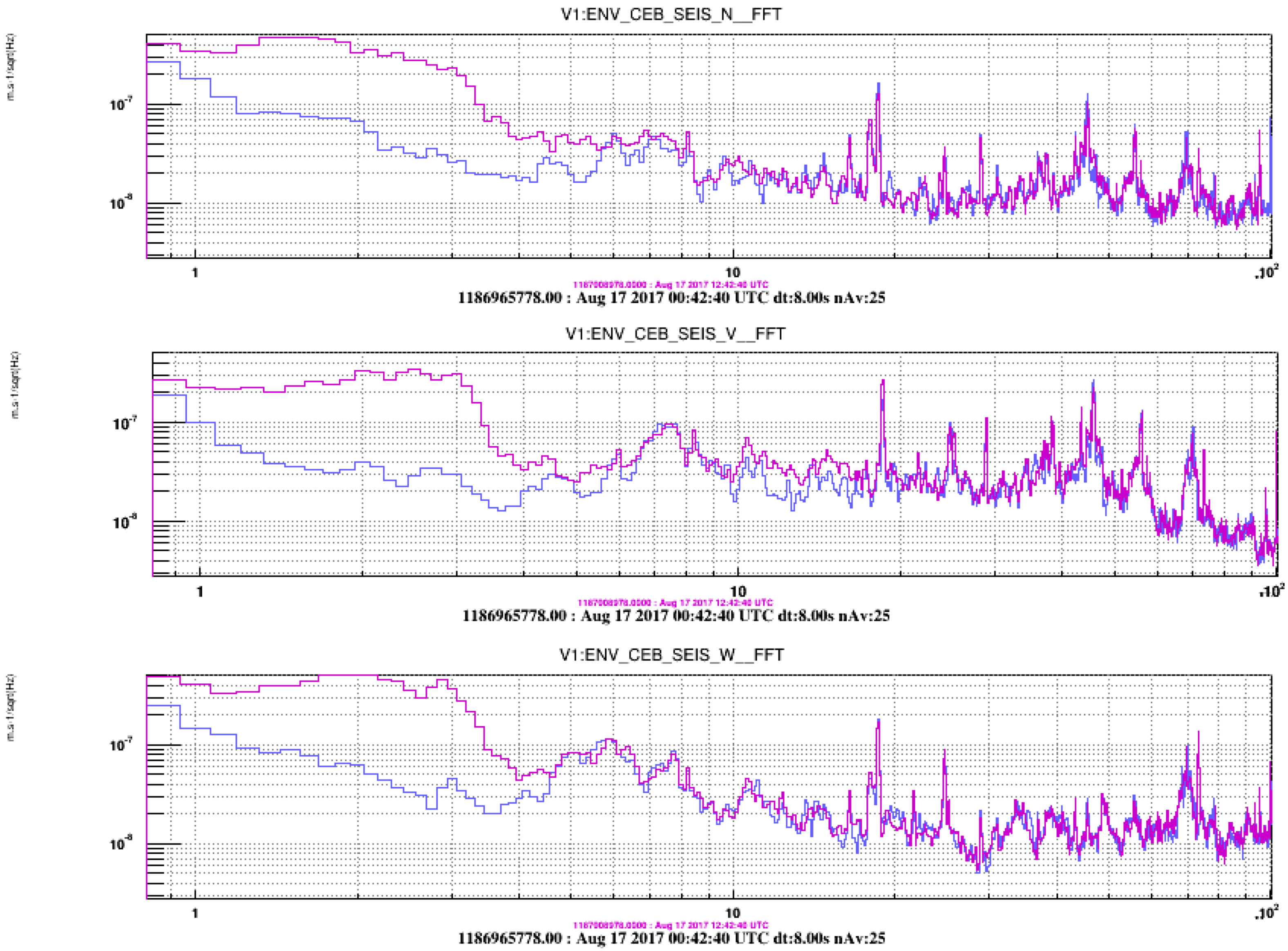


Figure 4b



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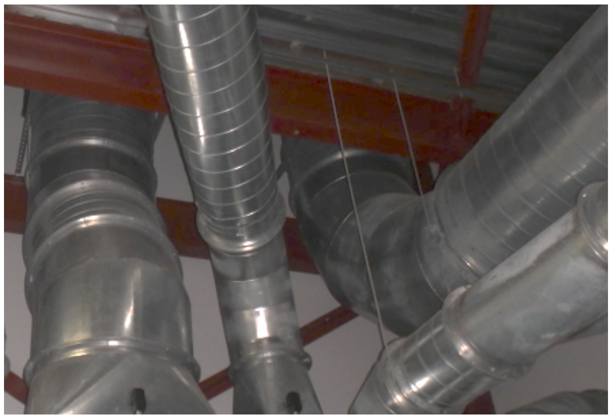
m.s-1/sqrt(Hz)
10^{-7}
10^{-8}
1
10
10^2
1186965778.00 : Aug 17 2017 00:42:40 UTC dt:8.00s nAv:25
V1:ENV_CEB_SEIS_V__FFT
m.s-1/sqrt(Hz)
10^{-7}
10^{-8}
1
10
10^2
1186965778.00 : Aug 17 2017 00:42:40 UTC dt:8.00s nAv:25
V1:ENV_CEB_SEIS_W__FFT
m.s-1/sqrt(Hz)
10^{-7}
10^{-8}
1
10
10^2
1186965778.00 : Aug 17 2017 00:42:40 UTC dt:8.00s nAv:25

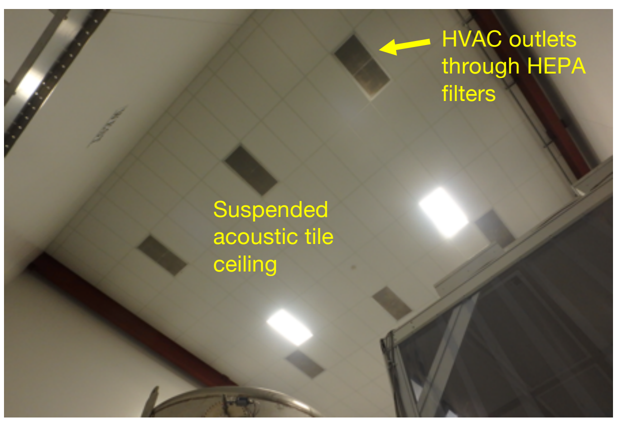
Figure 5a

Location	Experimental area, square meters	Meters to suspended ceiling	Experimental area, cubic meters	Fan total cmm (cubic meters per minute)	Minutes to pump experimental area volume	Cubic meters per minute pumped per square meter (cmm/sm)	Original specification for cmm/sm	Total trunk duct area in meters^2	Air velocity in ducts, m/s, assuming velocity is same in all trunk ducts connected to fans	Reynolds number in main trunk ducts
Corner station	2933.969643	9.7536	28616.73155	849.504	33.6864	0.289540828	0.609599259	5.650815021	2.505550075	152738.3
End station	282.42512	9.7536	2754.658304	184.0592	14.96615385	0.651709735	0.609599259	1.015444163	3.020996571	163697.7

LIGO LHO end station

Virgo NE end station





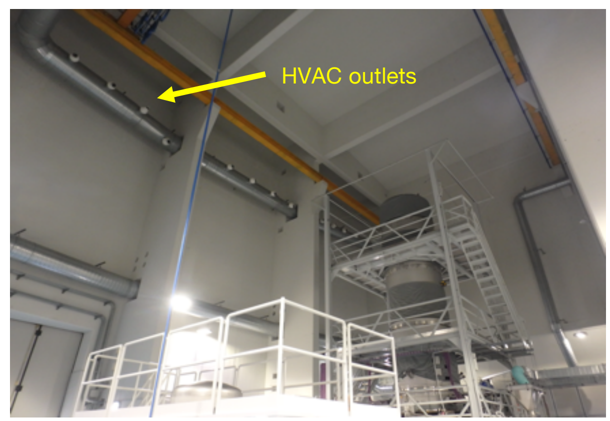


Figure 5b

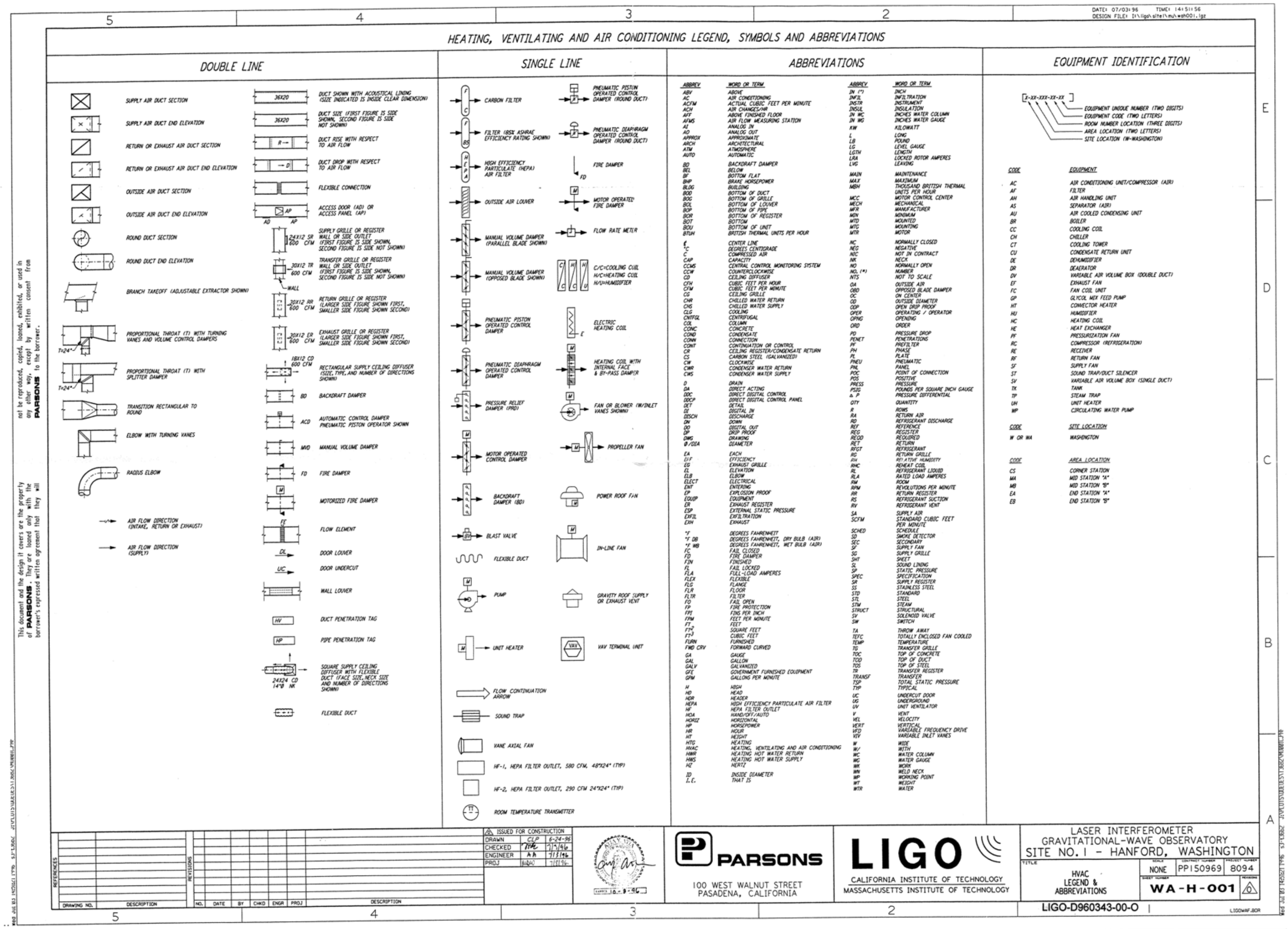

HEATING, VENTILATING AND AIR CONDITIONING LEGEND, SYMBOLS AND ABBREVIATIONS
DOUBLE LINE
SINGLE LINE
ABBREVIATIONS
EQUIPMENT IDENTIFICATION
PARSONS
100 WEST WALNUT STREET
PASADENA, CALIFORNIA
LIGO
CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LASER INTERFEROMETER
GRAVITATIONAL-WAVE OBSERVATORY
SITE NO. 1 - HANFORD, WASHINGTON
HVAC
LEGEND &
ABBREVIATIONS
NONE
PP150969
8094
WA-H-001
LIGO-D960343-00-O

Figure 5c

2. ALL SUPPLY AIR DUCTS SHALL BE DOUBLE WALL WITH 1" RIGID INSULATION AND PERFORATED SHEET METAL LINER.

3. RETURN AIR DUCTS FROM VEA ROOM (202) SHALL BE DOUBLE WALL WITH $\frac{1}{2}$" RIGID INSULATION AND PERFORATED SHEET METAL LINER.

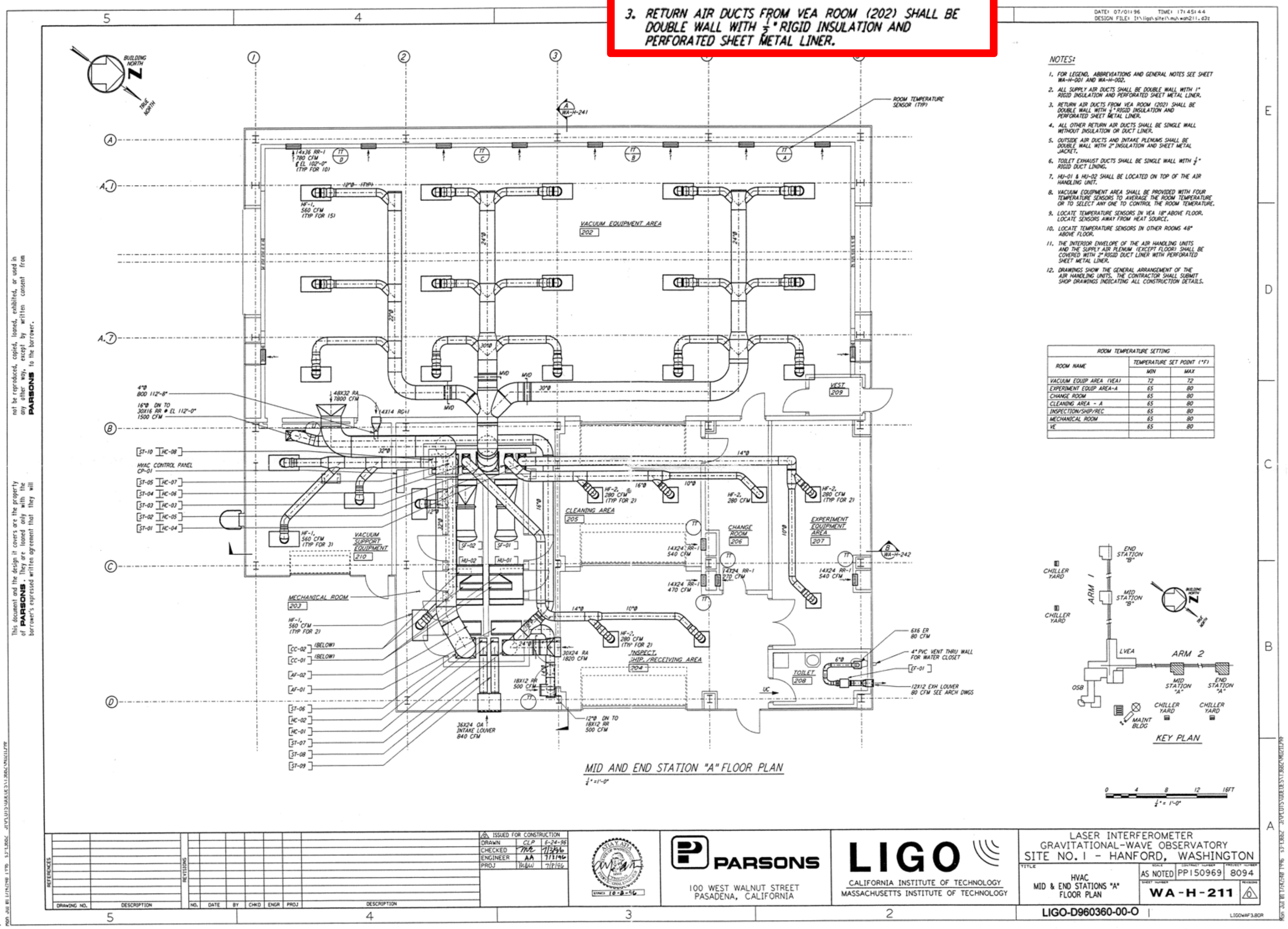
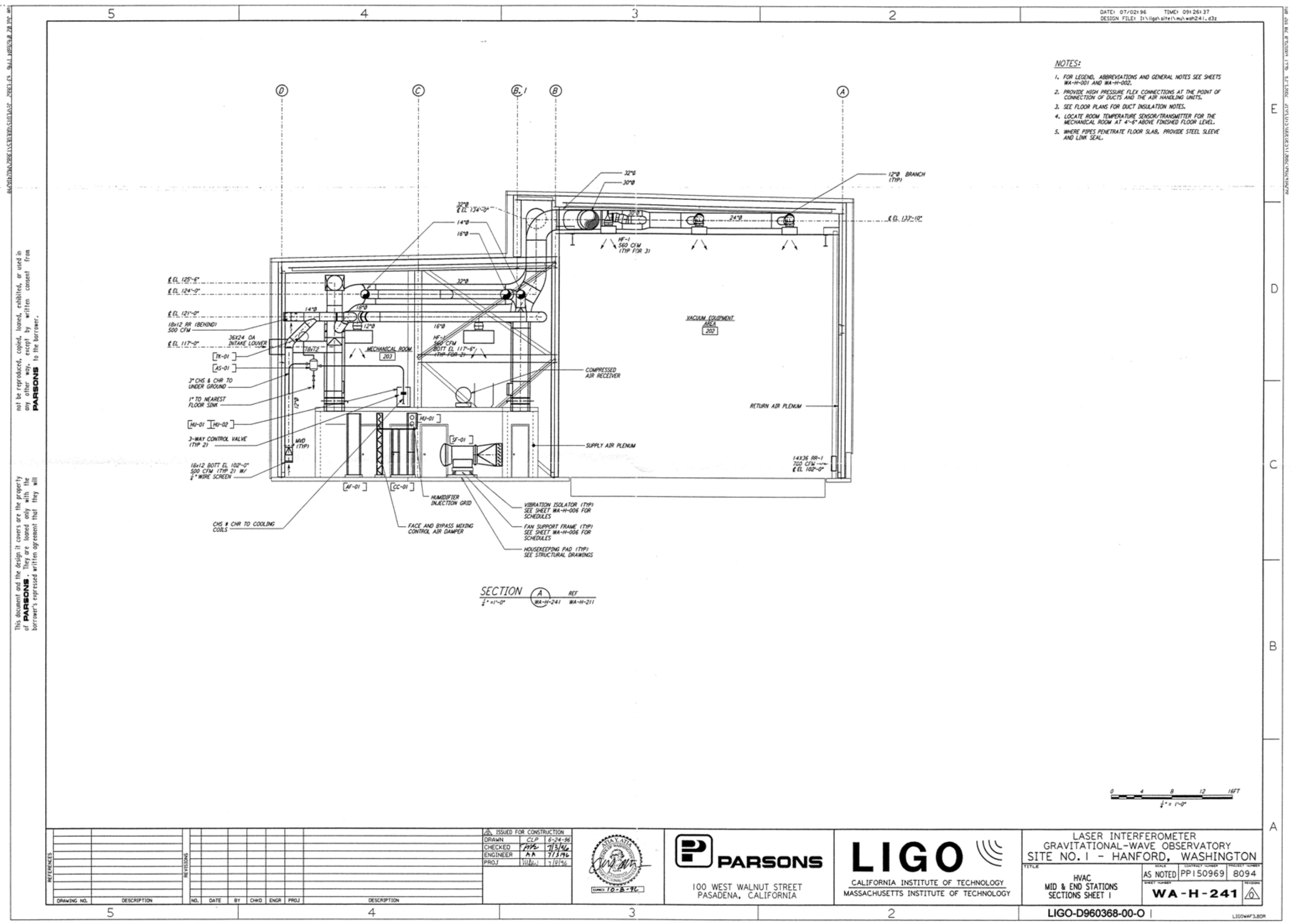


Figure 5d



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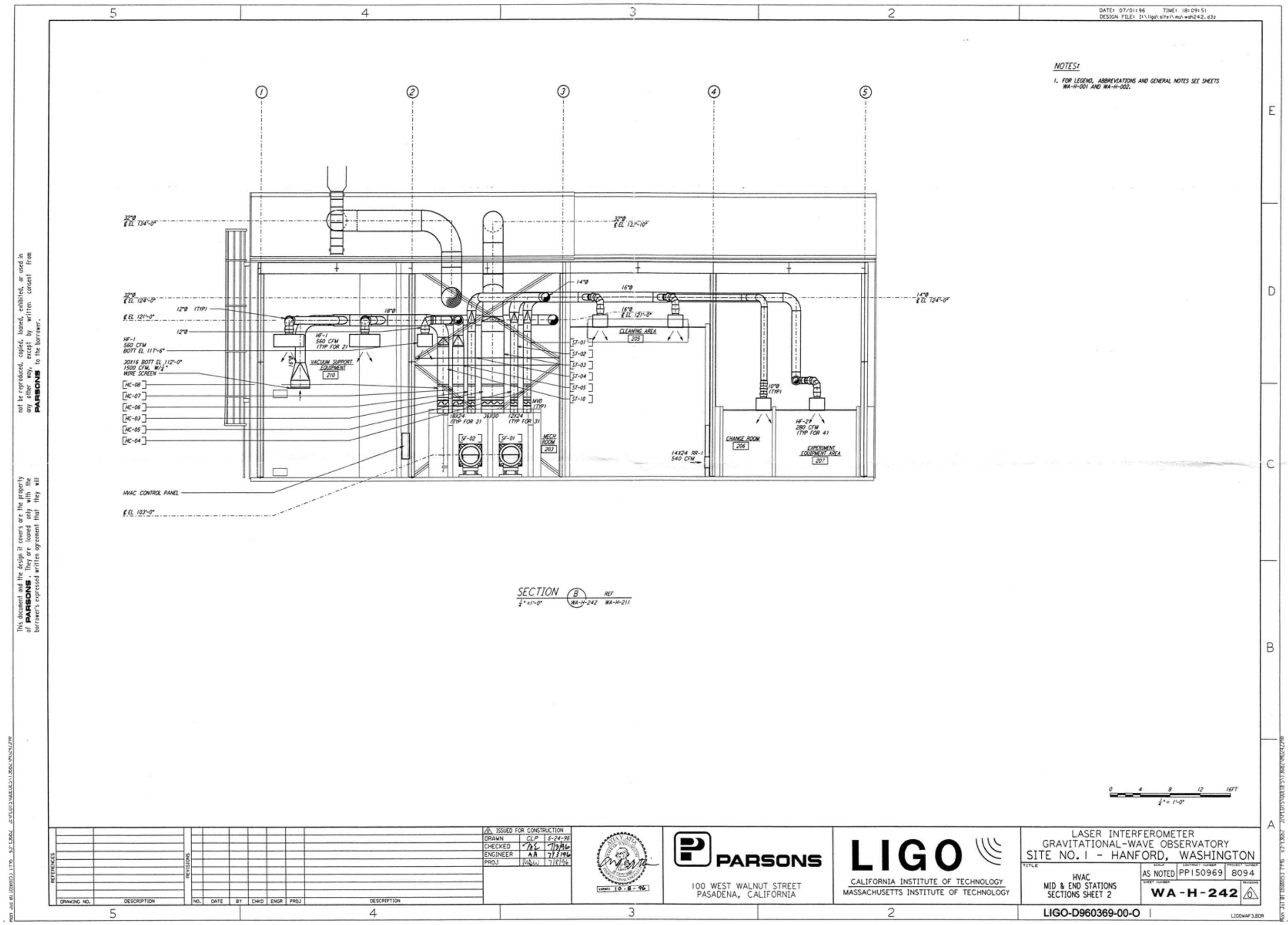
NOTES:
1. FOR LEGEND, ABBREVIATIONS AND GENERAL NOTES SEE SHEETS WA-H-001 AND WA-H-002.
2. PROVIDE HIGH PRESSURE FLEX CONNECTIONS AT THE POINT OF CONNECTION OF DUCTS AND THE AIR HANDLING UNITS.
3. SEE FLOOR PLANS FOR DUCT INSULATION NOTES.
4. LOCATE ROOM TEMPERATURE SENSOR/TRANSMITTER FOR THE MECHANICAL ROOM AT 4'-6" ABOVE FINISHED FLOOR LEVEL.
5. WHERE PIPES PENETRATE FLOOR SLAB, PROVIDE STEEL SLEEVE AND LINK SEAL.
MECHANICAL ROOM
203
VACUUM EQUIPMENT AREA
202
COMPRESSED AIR RECEIVER
RETURN AIR PLENUM
SUPPLY AIR PLENUM
HUMIDIFIER INJECTION GRID
FACE AND BYPASS MIXING CONTROL AIR DAMPER
CHS & CHR TO COOLING COILS
VIBRATION ISOLATOR (TYP) SEE SHEET WA-H-006 FOR SCHEDULES
FAN SUPPORT FRAME (TYP) SEE SHEET WA-H-006 FOR SCHEDULES
HOUSEKEEPING PAD (TYP) SEE STRUCTURAL DRAWINGS
SECTION A WA-H-241 REF WA-H-211
0 4 8 12 16FT
PARSONS
100 WEST WALNUT STREET
PASADENA, CALIFORNIA
LIGO
CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LASER INTERFEROMETER
GRAVITATIONAL-WAVE OBSERVATORY
SITE NO. 1 - HANFORD, WASHINGTON
HVAC
MID & END STATIONS
SECTIONS SHEET 1
AS NOTED
PP150969
8094
WA-H-241
LIGO-D960368-00-O

Figure 5e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HVAC CONTROL PANEL
CLEANING AREA
205
VACUUM SUPPORT EQUIPMENT
210
MECH ROOM
203
CHANGE ROOM
206
EXPERIMENT EQUIPMENT AREA
207
SF-01
SF-02
SECTION B
WA-H-242
REF WA-H-211
LASER INTERFEROMETER
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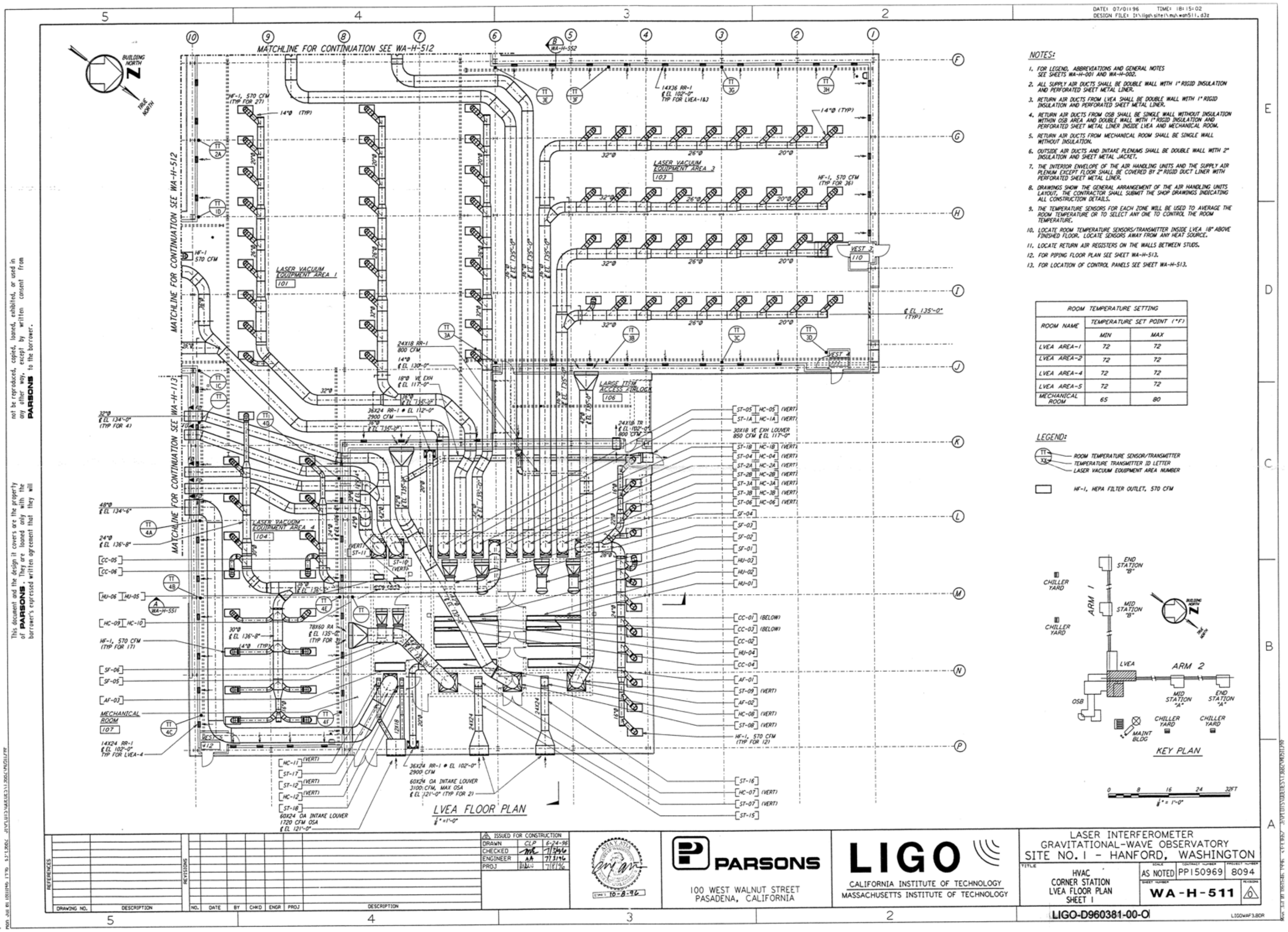
PASADENA, CALIFORNIA
LIGO
CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
HVAC
MID & END STATIONS
SECTIONS SHEET 2
AS NOTED
PP150969
8094
WA-H-242
LIGO-D960369-00-O

Figure 5f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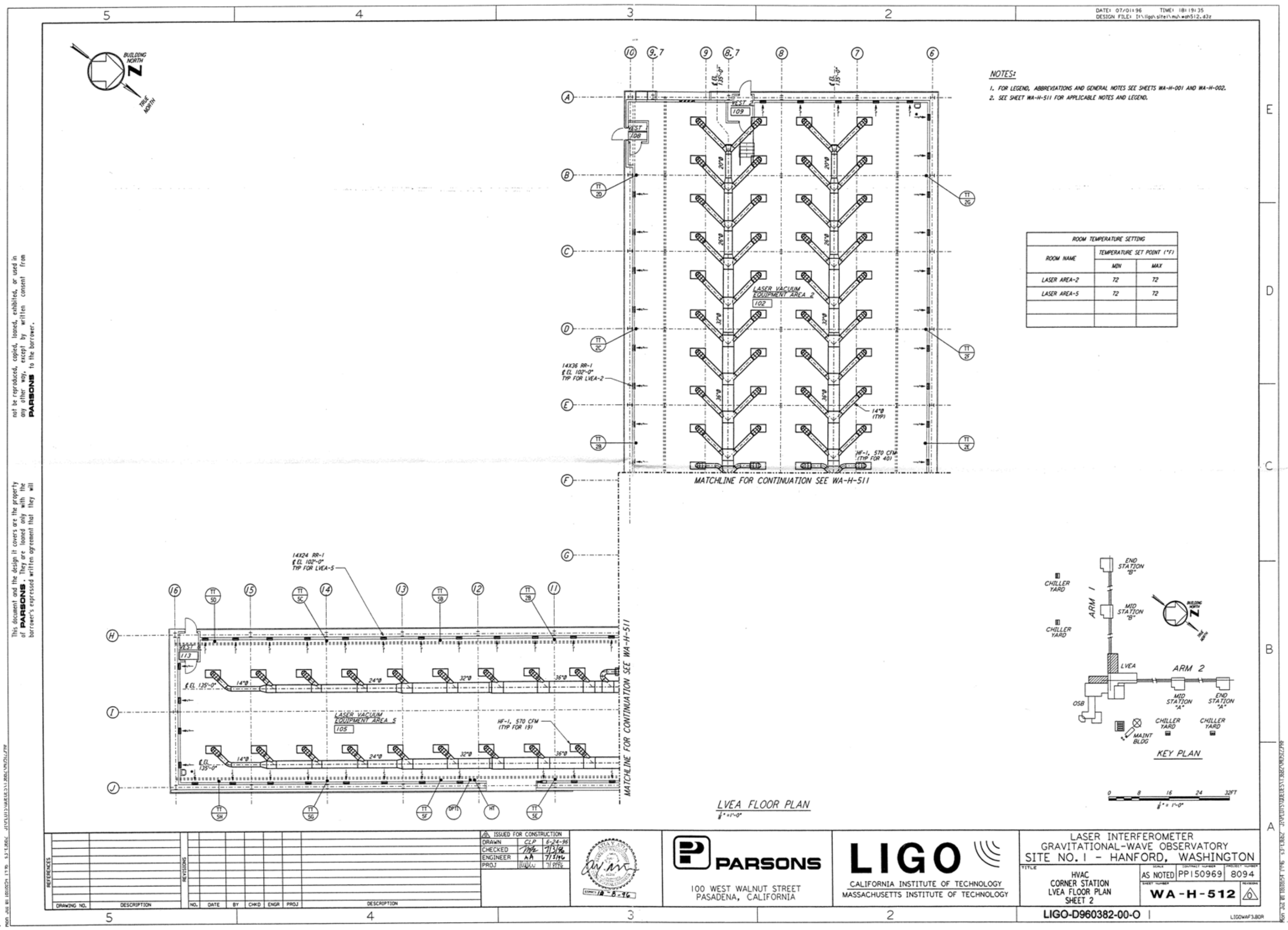
1. FOR LEGEND, ABBREVIATIONS AND GENERAL NOTES SEE SHEETS WA-H-001 AND WA-H-002.
2. ALL SUPPLY AIR DUCTS SHALL BE DOUBLE WALL WITH 1" RIGID INSULATION AND PERFORATED SHEET METAL LINER.
3. RETURN AIR DUCTS FROM LVEA SHALL BE DOUBLE WALL WITH 1" RIGID INSULATION AND PERFORATED SHEET METAL LINER.
4. RETURN AIR DUCTS FROM OSB SHALL BE SINGLE WALL WITHOUT INSULATION WITHIN OSB AREA AND DOUBLE WALL WITH 1" RIGID INSULATION AND PERFORATED SHEET METAL LINER INSIDE LVEA AND MECHANICAL ROOM.
5. RETURN AIR DUCTS FROM MECHANICAL ROOM SHALL BE SINGLE WALL WITHOUT INSULATION.
6. OUTSIDE AIR DUCTS AND INTAKE PLENUMS SHALL BE DOUBLE WALL WITH 2" INSULATION AND SHEET METAL JACKET.
7. THE INTERIOR ENVELOPE OF THE AIR HANDLING UNITS AND THE SUPPLY AIR PLENUM EXCEPT FLOOR SHALL BE COVERED BY 2" RIGID DUCT LINER WITH PERFORATED SHEET METAL LINER.
8. DRAWINGS SHOW THE GENERAL ARRANGEMENT OF THE AIR HANDLING UNITS LAYOUT, THE CONTRACTOR SHALL SUBMIT THE SHOP DRAWINGS INDICATING ALL CONSTRUCTION DETAILS.
9. THE TEMPERATURE SENSORS FOR EACH ZONE WILL BE USED TO AVERAGE THE ROOM TEMPERATURE OR TO SELECT ANY ONE TO CONTROL THE ROOM TEMPERATURE.
10. LOCATE ROOM TEMPERATURE SENSORS/TRANSMITTER INSIDE LVEA 18" ABOVE FINISHED FLOOR. LOCATE SENSORS AWAY FROM ANY HEAT SOURCE.
11. LOCATE RETURN AIR REGISTERS ON THE WALLS BETWEEN STUDS.
12. FOR PIPING FLOOR PLAN SEE SHEET WA-H-513.
13. FOR LOCATION OF CONTROL PANELS SEE SHEET WA-H-513.
ROOM TEMPERATURE SETTING
ROOM NAME | TEMPERATURE SET POINT (°F) MIN | MAX
LVEA AREA-1 | 72 | 72
LVEA AREA-2 | 72 | 72
LVEA AREA-4 | 72 | 72
LVEA AREA-5 | 72 | 72
MECHANICAL ROOM | 65 | 80
LEGEND:
HF-1, HEPA FILTER OUTLET, 570 CFM
KEY PLAN
LVEA FLOOR PLAN
MATCHLINE FOR CONTINUATION SEE WA-H-512
LASER VACUUM EQUIPMENT AREA 1
LASER VACUUM EQUIPMENT AREA 3
MECHANICAL ROOM
LARGE ITEM ACCESS
PARSONS
100 WEST WALNUT STREET
PASADENA, CALIFORNIA
LIGO
CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LASER INTERFEROMETER
GRAVITATIONAL-WAVE OBSERVATORY
SITE NO. 1 - HANFORD, WASHINGTON
HVAC
CORNER STATION
LVEA FLOOR PLAN
SHEET 1
AS NOTED
PP150969
8094
WA-H-511
LIGO-D960381-00-O

Figure 5g



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2. SEE SHEET WA-H-511 FOR APPLICABLE NOTES AND LEGEND.
ROOM TEMPERATURE SETTING
ROOM NAME
TEMPERATURE SET POINT (°F)
MIN
MAX
LASER AREA-2 72 72
LASER AREA-5 72 72
LASER VACUUM EQUIPMENT AREA 2
102
LASER VACUUM EQUIPMENT AREA 5
105
14X36 RR-1
℄ EL 102'-0"
TYP FOR LVEA-2
14X24 RR-1
℄ EL 102'-0"
TYP FOR LVEA-5
HF-1, 570 CFM
(TYP FOR 40)
HF-1, 570 CFM
(TYP FOR 19)
MATCHLINE FOR CONTINUATION SEE WA-H-511
LVEA FLOOR PLAN
KEY PLAN
ARM 1
ARM 2
END STATION "B"
MID STATION "B"
END STATION "A"
MID STATION "A"
CHILLER YARD
LVEA
OSB
MAINT BLDG
BUILDING NORTH
TRUE NORTH
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CHECKED
ENGINEER
PROJ
PARSONS
100 WEST WALNUT STREET
PASADENA, CALIFORNIA
LIGO
CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LASER INTERFEROMETER
GRAVITATIONAL-WAVE OBSERVATORY
SITE NO. 1 - HANFORD, WASHINGTON
TITLE
HVAC
CORNER STATION
LVEA FLOOR PLAN
SHEET 2
AS NOTED
PP150969
8094
WA-H-512
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LIGO-D960382-00-O

Figure 5h

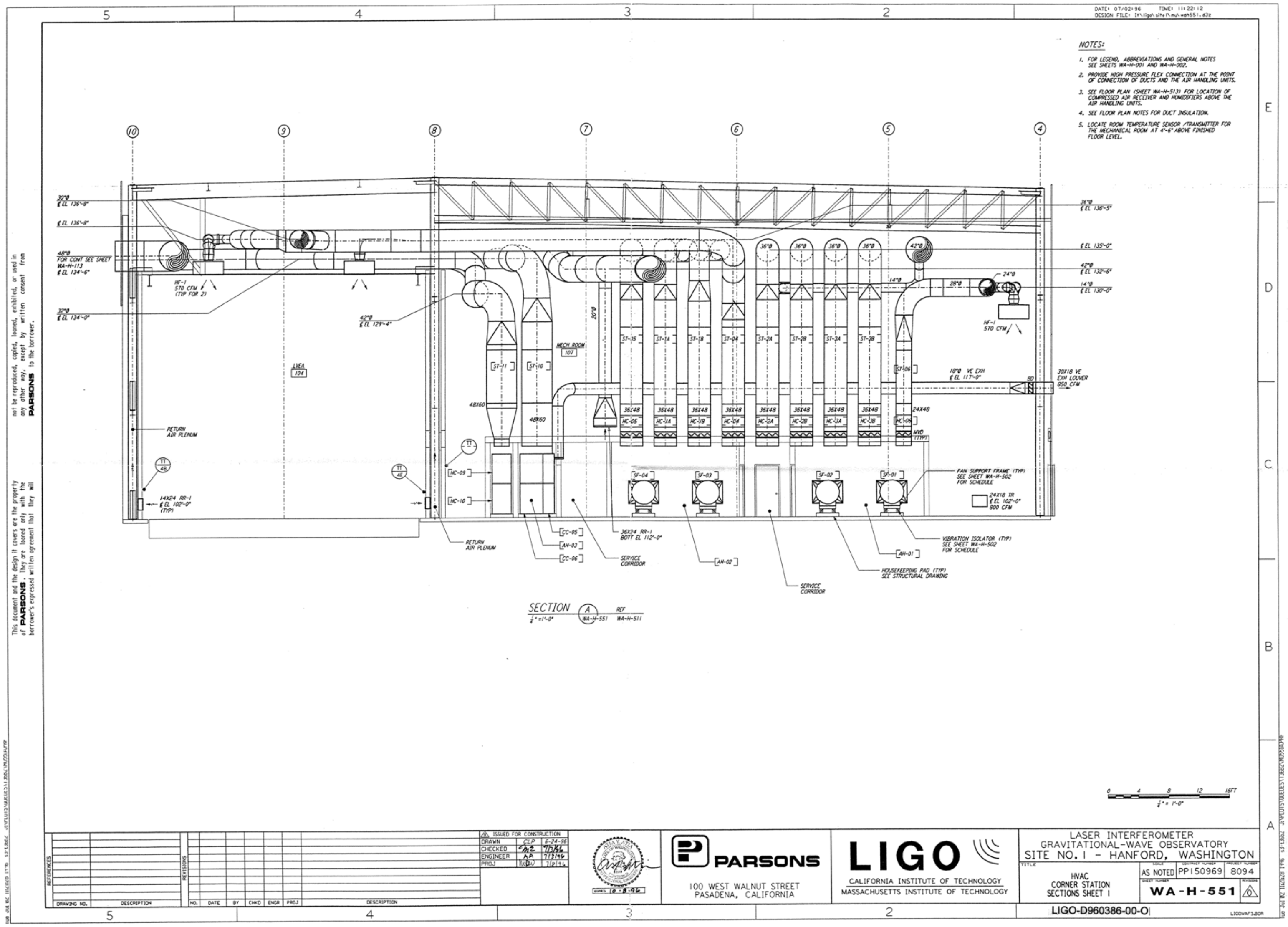
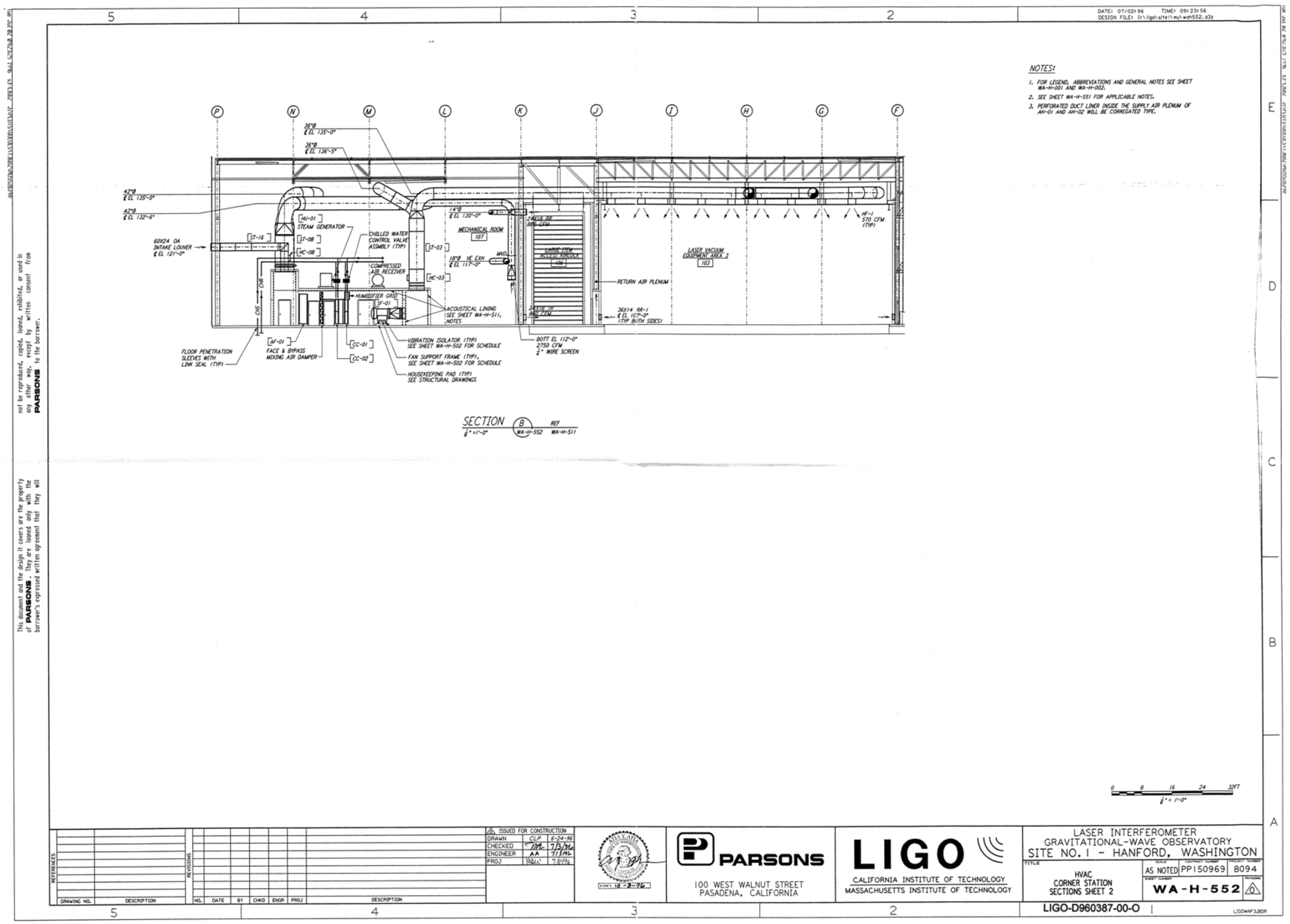

NOTES:
1. FOR LEGEND, ABBREVIATIONS AND GENERAL NOTES SEE SHEETS WA-H-001 AND WA-H-002.
2. PROVIDE HIGH PRESSURE FLEX CONNECTION AT THE POINT OF CONNECTION OF DUCTS AND THE AIR HANDLING UNITS.
3. SEE FLOOR PLAN (SHEET WA-H-513) FOR LOCATION OF COMPRESSED AIR RECEIVER AND HUMIDIFIERS ABOVE THE AIR HANDLING UNITS.
4. SEE FLOOR PLAN NOTES FOR DUCT INSULATION.
5. LOCATE ROOM TEMPERATURE SENSOR /TRANSMITTER FOR THE MECHANICAL ROOM AT 4'-6" ABOVE FINISHED FLOOR LEVEL.
LVEA 104
MECH ROOM 107
RETURN AIR PLENUM
SERVICE CORRIDOR
HOUSEKEEPING PAD (TYP) SEE STRUCTURAL DRAWING
VIBRATION ISOLATOR (TYP) SEE SHEET WA-H-502 FOR SCHEDULE
FAN SUPPORT FRAME (TYP) SEE SHEET WA-H-502 FOR SCHEDULE
SECTION A WA-H-551 REF WA-H-511
1/4" = 1'-0"
ISSUED FOR CONSTRUCTION
PARSONS
100 WEST WALNUT STREET PASADENA, CALIFORNIA
LIGO
CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY SITE NO. 1 - HANFORD, WASHINGTON
HVAC CORNER STATION SECTIONS SHEET 1
AS NOTED
PP150969
8094
WA-H-551
LIGO-D960386-00-O

Figure 5i


NOTES:
1. FOR LEGEND, ABBREVIATIONS AND GENERAL NOTES SEE SHEET WA-H-001 AND WA-H-002.
2. SEE SHEET WA-H-551 FOR APPLICABLE NOTES.
3. PERFORATED DUCT LINER INSIDE THE SUPPLY AIR PLENUM OF AH-01 AND AH-02 WILL BE CORREGATED TYPE.
MECHANICAL ROOM
107
LASER VACUUM EQUIPMENT AREA 3
103
STEAM GENERATOR
CHILLED WATER CONTROL VALVE ASSMBLY (TYP)
COMPRESSED AIR RECEIVER
RETURN AIR PLENUM
SECTION B
LASER INTERFEROMETER
GRAVITATIONAL-WAVE OBSERVATORY
SITE NO. 1 - HANFORD, WASHINGTON
HVAC
CORNER STATION
SECTIONS SHEET 2
AS NOTED
PP150969
8094
WA-H-552
PARSONS
100 WEST WALNUT STREET
PASADENA, CALIFORNIA
LIGO
CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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