ENERGY ANALYSIS OF MECHANICAL SYSTEMS ALTERNATES FOR COUNTY OF MENDOCINO SB844 JAIL EXPANSION PROJECT

Mendocino County Jail
951 Low Gap Road
Ukiah, California

June 12, 2020

Prepared by:

nacht&lewis

with

Capital Engineering Consultants	Mechanical Engineering
AVS Engineers	Electrical Engineering
Vanir Construction Management	Cost Estimating

Energy Analysis

of

Mechanical Systems
Alternates

for

County of Mendocino

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June 18, 2020

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Project Description

The purpose of this report is to compare mechanical system options based on their life-cycle energy performance of the proposed, approximately 22,000 SF Mendocino County SB844 jail facility currently under design.

The study will determine annual energy costs associated with the mechanical systems alternates to the current design to allow for an all-electric system.

The options studied are compared to determine the lowest 30-year life-cycle cost incorporating the initial equipment cost, annual energy costs, and maintenance costs.

Description of Alternates

Base Case – Packaged Air-conditioning Units (Pkg AC):

1. Description: The alternates proposed will be compared to a base case which is the current design. Currently the project has variable-volume, packaged air-conditioning units with direct-expansion (DX) cooling, and gas furnaces for heating. Each housing pod is served from a separate unit, (6) total. The rest of the administration, program, treatment, etc. spaces are served from a large central unit. There is a central gas-fired boiler that provides heating hot water to reheat coils at the terminal variable-air-volume (VAV) boxes for zone control within the administration area.

2. Domestic Hot Water: There is a gas fired domestic water heater that is 76% efficient. The gas-fired domestic water heater does not present an electrical power load.

3. Efficiency: The gas heating system is 81% efficient. The boiler is 95% efficient. The efficiency of the smaller units is 12.9 EER (energy efficiency ratio) and the larger unit is 11.3 EER.

4. HVAC in Cooling Mode: The current design of the electrical power distribution system (normal and emergency) considers the electrical power load of seven rooftop mounted packaged air-conditioning units, AC-1 thru AC-6 that serve the housing pods and one larger AC-7 unit that serves the administration area.

5. HVAC in Heating Mode: There is no electrical power load presented by the seven packaged air-conditioning units and the reheating coil of the VAVs. The packaged units have gas furnace for heating and there is a central gas-fired boiler that provides heating hot water to reheat coil at the VAV boxes.

6. Electrical Power Distribution System: The current design for normal and emergency power system is depicted on single line diagram shown on attached **SKE-B**.

Alternate 1 - Air-Source Heat Pumps (Air HPs):

1. Description: The first alternate to the base case studied would be to keep the current zoning and unit locations but to change the rooftop units to an air-source, heat pump (HP) system. The rooftop units would no longer have gas furnaces but would now be heat pumps. The central gas-fired boiler would also be changed to an air to water heat pump to provide the necessary heating hot water to the VAV box reheat coils.

2. Domestic Hot Water: The domestic water heater would also be changed to a heat pump water heater. Additional electrical power load of 43.4 KW (kilowatts) (54.3 KVA (kilo-volt-ampere)) is presented by the heat pump water heater HP-WH.

3. Efficiency: The efficiency of the rooftop units is the same at 11.3 and 12.9 EER. The heat pump boiler has a coefficient of performance (COP) of 3.13. The domestic water heater heat pump has a Uniform Energy Factor (UEF) efficiency of 2.9 UEF.

4. Layout: An approximately 10-foot x 17-foot outdoor concrete pad will be required for the central air-to-water heat pump unit. An "Aermec" NRK-0300 unit with 232,000 Btuh heating capacity and 21.0 kW input power was used as the basis of the study. A sketch of a potential location for the concrete pad is provided below as **Figure 1.**

5. HVAC in Cooling Mode: Electrical power load for seven rooftop units HP-1 thru HP-7 is estimated to be the same as for units AC-1 thru AC-7 in the Base Option.

6. HVAC in Heating Mode: Electrical power load for seven rooftop units HP-1 thru HP-7 is same as in cooling mode. Additional electrical power load of 21 KW (26.2 KVA) is presented by the central air-to-water heat pump HP-RH to provide heating hot water to reheat coil at the VAV boxes.

7. Electrical Power Distribution System: An additional electrical power load of 64.4 KW (80.5 KVA) will be presented in comparison with the load for the base case option, imposed by the HVAC in heating mode and the domestic hot water loads. Changes in the ratings of the various components of the normal and emergency power system are depicted on single line diagram shown on attached **SKE-1**.

Alternate 2 - Water-source Heat Pumps (WSHPs):

1. Description: The second alternate studied changes the system entirely to a water-source heat pump system. The VAV boxes zones would be changed to above ceiling WSHPs serving larger areas. The housing area would be provided with rooftop WHSPs. This system would be piped to a central closed loop fluid cooler for heat rejection in cooling modes and to an air-to-water heat pump for heat addition in heating mode.

2. Domestic Hot Water: The domestic water heater is changed to a heat pump like Alternate 1. Additional electrical power load is also the same as for Alternate 1.

3. Efficiency: The cooling efficiencies range between 14.8 EER and 16.5 EER depending on the unit size. The heating efficiencies range between 5.3 COP and 5.8 COP depending on the unit size.

4. Layout: An approximately 10-foot x 20-foot outdoor concrete pad will be required for the central air-to-water heat pump unit. An "Aermec" NRK-0600 unit with 464,000 Btuh heating capacity and 43.4 kW input power was used as the basis of the study. Another 10-foot x 20-foot outdoor concrete pad will be required for the central fluid cooler. A "BAC" Model VFL-036-32K with 10 HP fan motor and 1 HP pump motor was used as the basis of the study.

5. HVAC in Cooling Mode: Electrical power load for six rooftop units WSHP-1 thru WSHP-6 to serve the housing pods is estimated to be the power load for the seven AC units in the base option less the 34 KW (42.5 KVA) power load of the larger packaged air-conditioned unit AC-7. Additional electrical power of 38.1 KW (47.6 KVA) is presented by twenty-one ceiling mounted WSHPs to serve the administration area, these units will be located at the VAVs location in the base case option. Additional electrical power load of 10 KW (12.5 KVA) is presented by the cooling tower CT for heat rejection.

6. HVAC in Heating Mode: Electrical power load for six rooftop units WSHP-1 thru WSHP-6 to serve the housing pods is same as in cooling mode. Additional electrical power for twenty-one ceiling mounted WSHPs to serve the administration area is same as in cooling mode. Additional electrical power load of 43.4 KW (54.3 KVA) is presented by the air-to-water heat pump HP-SH for heat addition.

7. Electrical Power Distribution System: An additional electrical power load of 90.9 KW (113.6 KVA) will be presented in comparison with the load for the base case option, imposed by the HVAC in heating mode and the domestic hot water loads. Changes in the ratings of the various components of the normal and emergency power system are depicted on single line diagram shown on attached **SKE-2**.

Alternate 3 - Ground Water-Source Heat Pumps (GSHPs):

1. Description: In this alternate, water-source heat pump are used throughout the building like Alternate 2. Instead of the units being connected to a central cooling tower and heat pump boiler, they are piped to a ground loop for heat rejection and heat addition.

2. Well Field: The system would require approximately 40 bore holes, anticipated to be 300 feet deep, and spaced at least 20 feet apart. The piping would be closed loop with a U-tube pipe placed in a 6-inch bore hole and then encased in a thermally enhanced grout. Water is pumped from the heat pumps through the U-tube in the ground where it picks up or rejects heat before being returned to the heat pump. There was no thermal conductivity test performed as part of this study or well logs provided. Ground conditions and ability to transfer heat is largely unknown and estimated. If this alternate is selected a test well of the proposed depth will be required to determine the thermal parameters to allow for the design of the system.

3. Domestic Hot Water: The domestic water heater is changed to a heat pump like Alternate 1. Additional electrical power load is same as for Alternate 1

4. Efficiency: The cooling efficiencies range between 17 EER and 19.3 EER depending on the unit size. The heating efficiencies range between 4.2 COP and 5.3 COP depending on the unit size.

5. Layout: Space in the current mechanical room would be utilized for the well field loop pumps.

6. HVAC in Cooling Mode: Electrical power load for six rooftop units GSHP-1 thru GSHP-6 to serve the housing pods is estimated to be the power load for the seven AC units in the base option less the 34 KW (42.5 KVA) power load of the larger packaged air-conditioned unit AC-7. Additional electrical power of 38.1 KW (47.6 KVA) is presented by twenty-one ceiling mounted GSHPs to serve the administration area, these units will be located at the VAVs location in the base case option. Additional electrical power load of 4.4 KW (5.5 KVA) is presented by the well field loop pump.

7. HVAC in Heating Mode: Electrical power loads are same as in cooling mode.

8. Electrical Power Distribution System: An additional electrical power load of 51.9 KW (64.9 KVA) will be presented in comparison with the load for the base case option, imposed by the HVAC in cooling or heating mode and the domestic hot water loads. Changes in the ratings of the various components of the normal and emergency power system are depicted on single line diagram shown on attached **SKE-3**

Economic Analysis

The initial costs of the various options were estimated and included in **Table 1**.

A detailed energy model of the building was created in using E-Pro energy modeling software. The various building, lighting and mechanical features were input along with the utility company rates and the program was run using typical Ukiah weather to determine the energy use and energy cost that is input into the output spreadsheet.

The results (see **Table 1**) show that the lowest 30-year, life-cycle cost of ownership is for the base case approach. This is largely because it is cheaper to provide heating with gas-based systems. It is also the lowest initial cost system. The heat pump alternates all have higher expected annual maintenance costs, as there will be more equipment to maintain. In the case of the water-based heat pump alternates 2 and 3, the administration and treatment area equipment will be located above the ceiling making maintenance more difficult. Detailed estimates HVAC Initial cost for each scenario are provided on page 16.

Of the three all-electric alternates studied, the ground-source heat pump system uses the least amount of energy at 25% less than the base case. It is also the alternate with the least annual maintenance costs since there is no fluid cooler or boiler to maintain. However, the system will require a large well field which adds significantly to the initial cost of the system. During the construction of the well field, the parking lot will not be usable. In addition, there may be procurement issues with engaging a geothermal well driller given the remote location. A sketch of a potential well field configuration is provided below as Figure 2. The cost of the 40 bore wells is a rough estimate requiring further verification.

Reviewing the projected 30-year life cycle cost, alternate 1 has the lowest additional cost. It is still higher than the current base case but would be the best choice for an all-electric alternate.

Envelope Analysis

In addition to analyzing all-electric mechanical system options, the effect of adding an exterior insulation finish system (EIFS) at the housing area walls was studied. A sketch showing the extent of the EIFS application to the housing area walls is provided below as **Figure 3.**

The energy model results show that with 8-inch Concrete Masonry Unit (CMU) block, the expected annual energy use of the building is 1,249 Million BTUs (British Thermal Units). With the addition of 2-inch EIFS the annual energy use is 1,147 MBTUs; for a reduction in energy of 8.1%, or an annual energy cost savings of $1,050.

The building is modeled with 4-inch continuous roof insulation, and primarily CMU walls with administration area exterior walls constructed with metal studs and R-19 insulation. Windows are limited at the building and are modeled with better than standard U-value and shading values. The resulting building envelope is very efficient.

The heavy mass associated with the CMU walls results in a high heat capacity, lowering the peak cooling load transmitted through the walls to the space, as the wall stores the heat.

With the heavy mass walls and overall good envelope construction, the savings associated with additional heating or cooling load reduction measures, such as added insulation, is lessened.

The initial cost associated with adding additional 2-inches of insulation at the housing area walls is estimated at $190,000. This means the simple payback associated with this energy saving measure is 181 years, or beyond the life of the building.

Table 1 – Analysis Results

	Base case Pkg AC (current design)	Alt 1: Air HPs	Alt 2: WSHPs	Alt 3: GSHPs
HVAC INITIAL COST	**954,760**	**1,120,600**	**1,253,726**	**2,430,490***
ANNUAL ENERGY USE:				
Electrical (kWh)	188,100	256,500	241,700	225,900
Gas (Therms)	3,830	0	0	0
TOTAL (Million BTUs)	**1,025**	**875**	**825**	**771**
% Difference		-14.6%	-19.5%	-24.8%
ANNUAL ENERGY COSTS:				
Electricity	$33,106	$45,144	$42,539	$39,758
Gas	$4,443	$0	$0	$0
TOTAL	**$37,548**	**$45,144**	**$42,539**	**$39,758**
% Difference		20.2%	13.3%	5.9%
Annualized Maintenance and Replacement Costs	$14,071	$19,887	$22,013	$18,843
TOTAL MAINTENANCE OVER 30 YRS (PV):	**$275,796**	**$389,782**	**$431,456**	**$369,320**
% Difference		41.3%	56.4%	33.9%
ANNUAL OPERATING COST:	**$51,620**	**$65,031**	**$64,552**	**$58,601**
% Difference		26.0%	25.1%	13.5%
30 YR. LIFE CYCLE COST	**$1,966,505**	**$2,395,205**	**$2,518,950**	**$3,579,075**
% Difference		21.8%	28.1%	82.0%
SITE CO2 (Metric Tons/Yr.)	**38.5**	**24.3**	**22.9**	**21.4**
% Difference		-37.0%	-40.6%	-44.5%

Notes:

1. Electrical costs based on $0.176/kWh; Gas costs based on $1.16/therm.
2. 30 yr. Cost of ownership is a present value cost based on 3% discount rate, 3% energy escalation rate, 3% replacement and maintenance escalation rate.
3. Annual energy costs include interior lighting electrical use.
4. Note that energy usage is based on computer energy models of the building which a may differ significantly from actual measured data due to weather conditions, building occupancy and use, mechanical and lighting system operational schedules, system maintenance and operation, etc.
5. Maintenance costs are rough estimates only and are for the purpose of determining potential operational savings and payback.
6. Site CO2 assumes electricity provided to the site was generated with 3% coal, 46% natural gas (includes unspecified) and the remainder renewable/carbon-neutral based on Ukiah power content provided. Additional losses associated with energy generation or delivery is not included.

Figure 1 – Concrete Pad Location

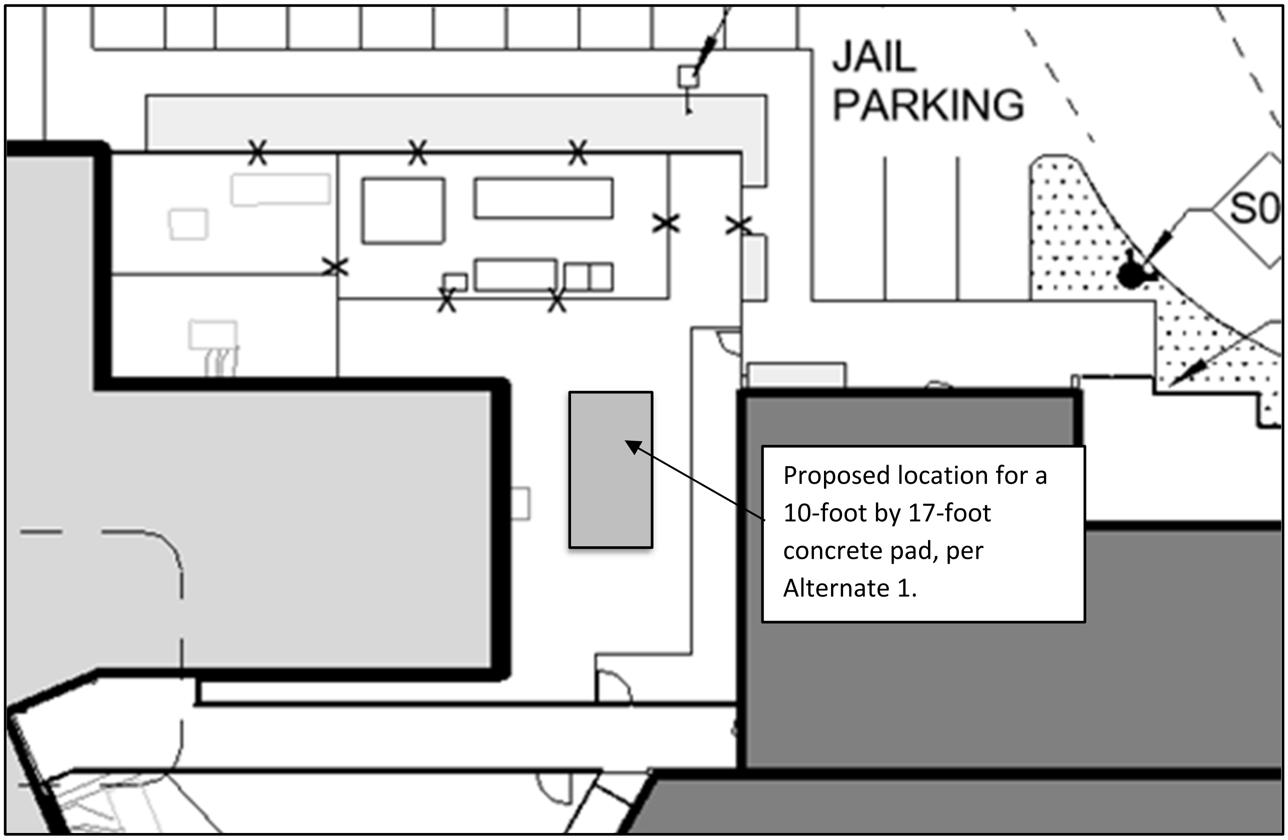
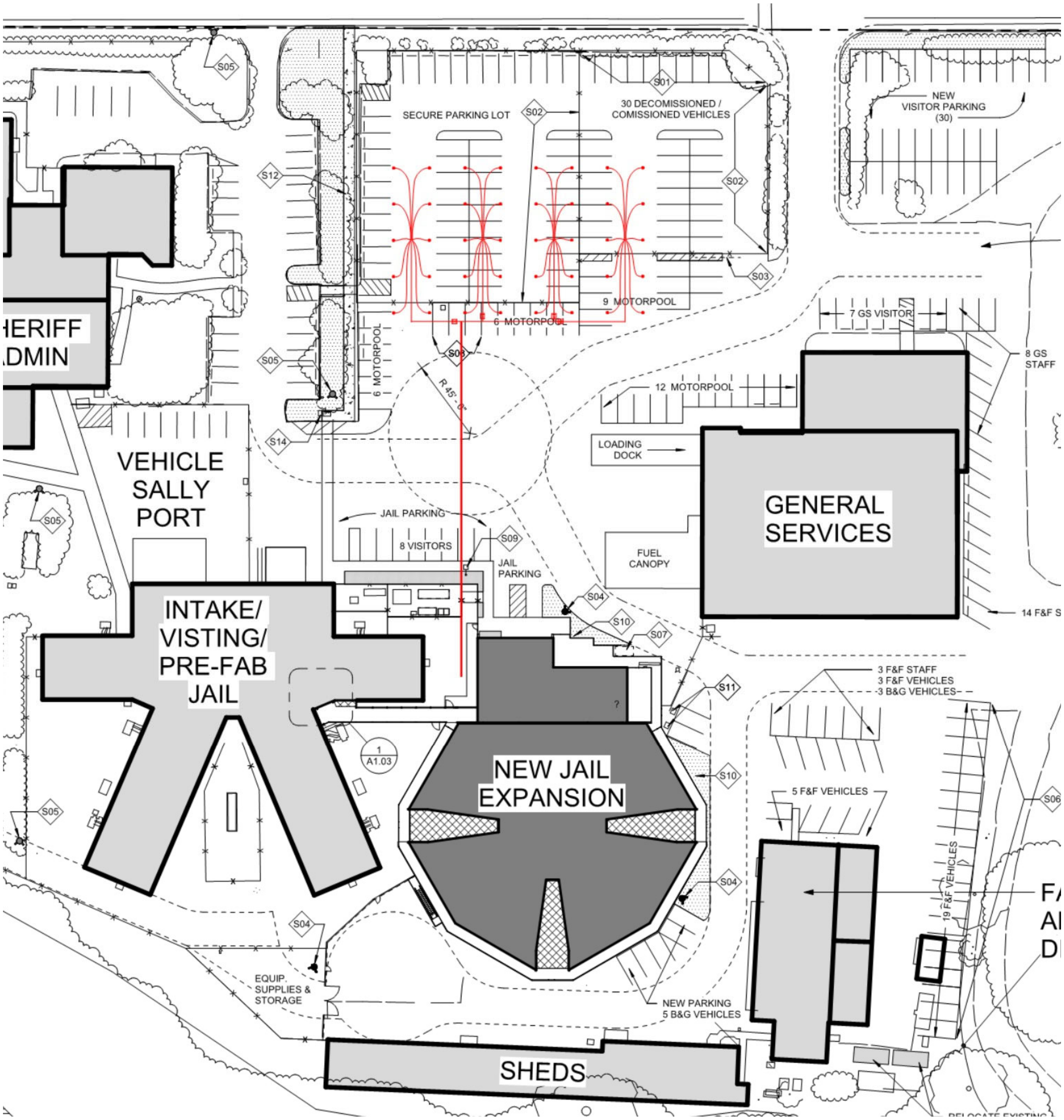


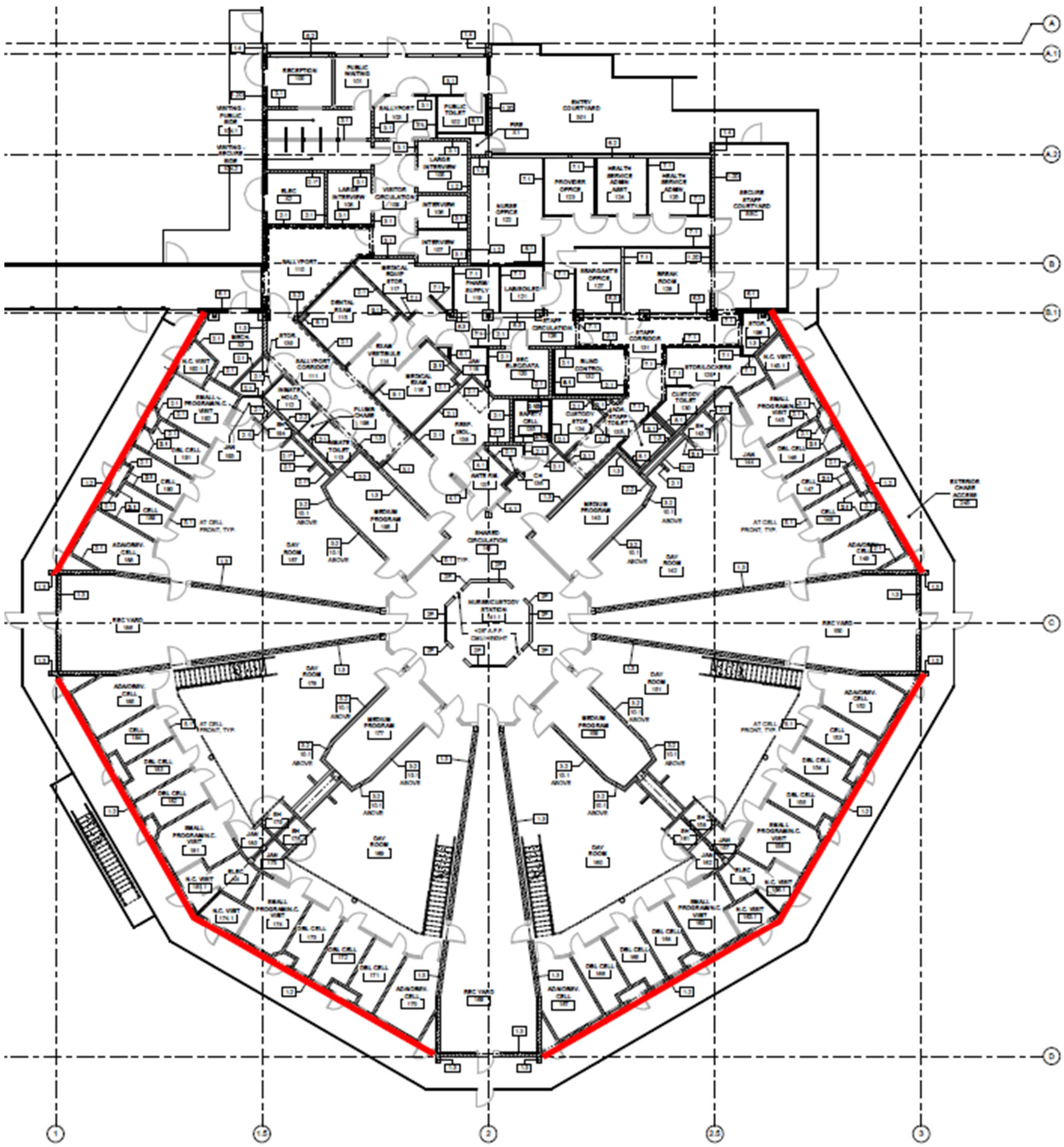
Figure 2 – Well Field Layout



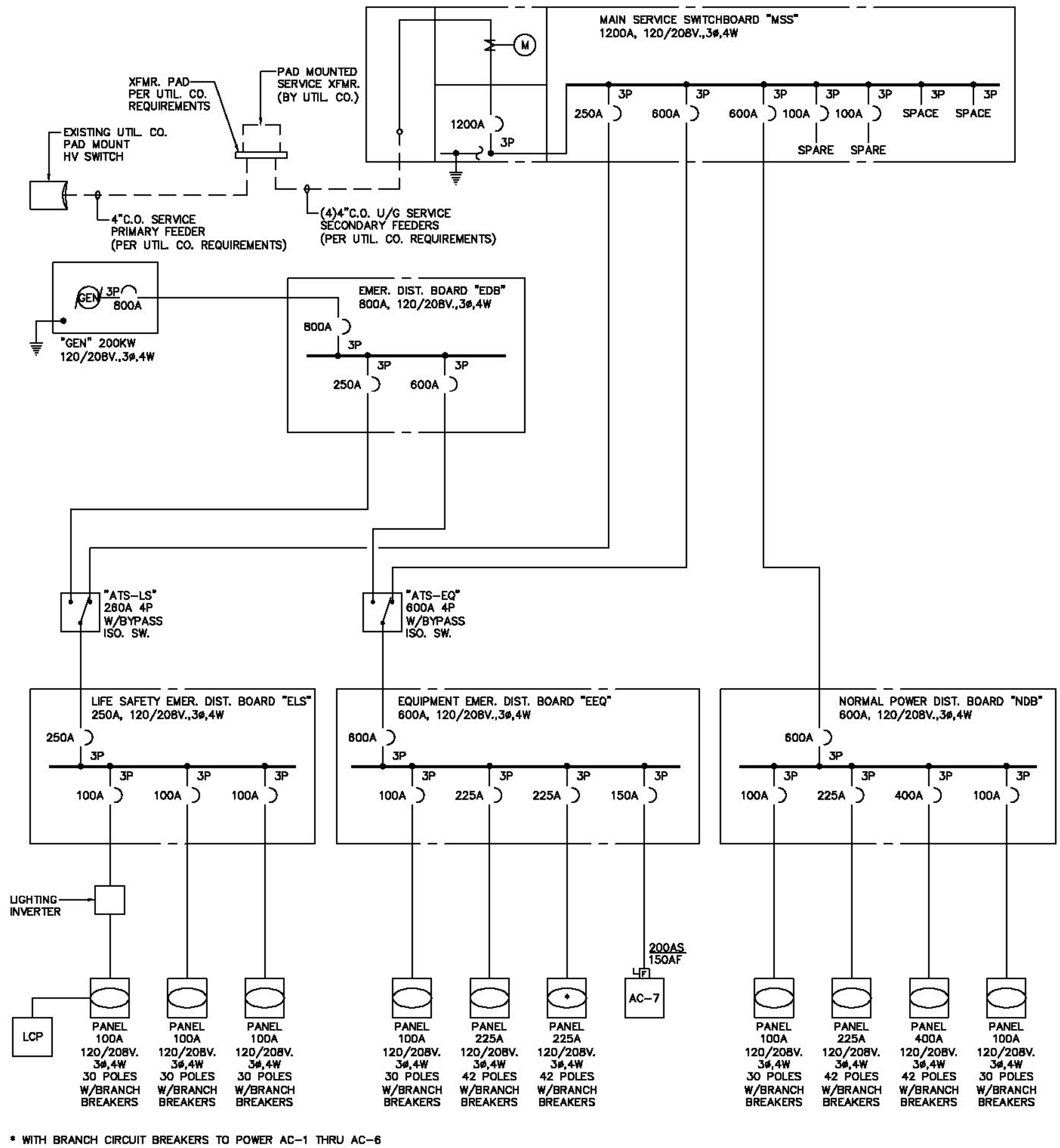
The well field layout is based on 40 bore holes spaced a minimum of 20 feet apart. Each will be approximately 300 feet deep. The field will be organized into (4) zones with (10) wells each.

Each zone will be provided with a valve box for isolation. The pipe from each well in the zone will be connected to a common manifold header to reduce the number of field joints below ground.

Figure 3 – Extent of EIFS Application

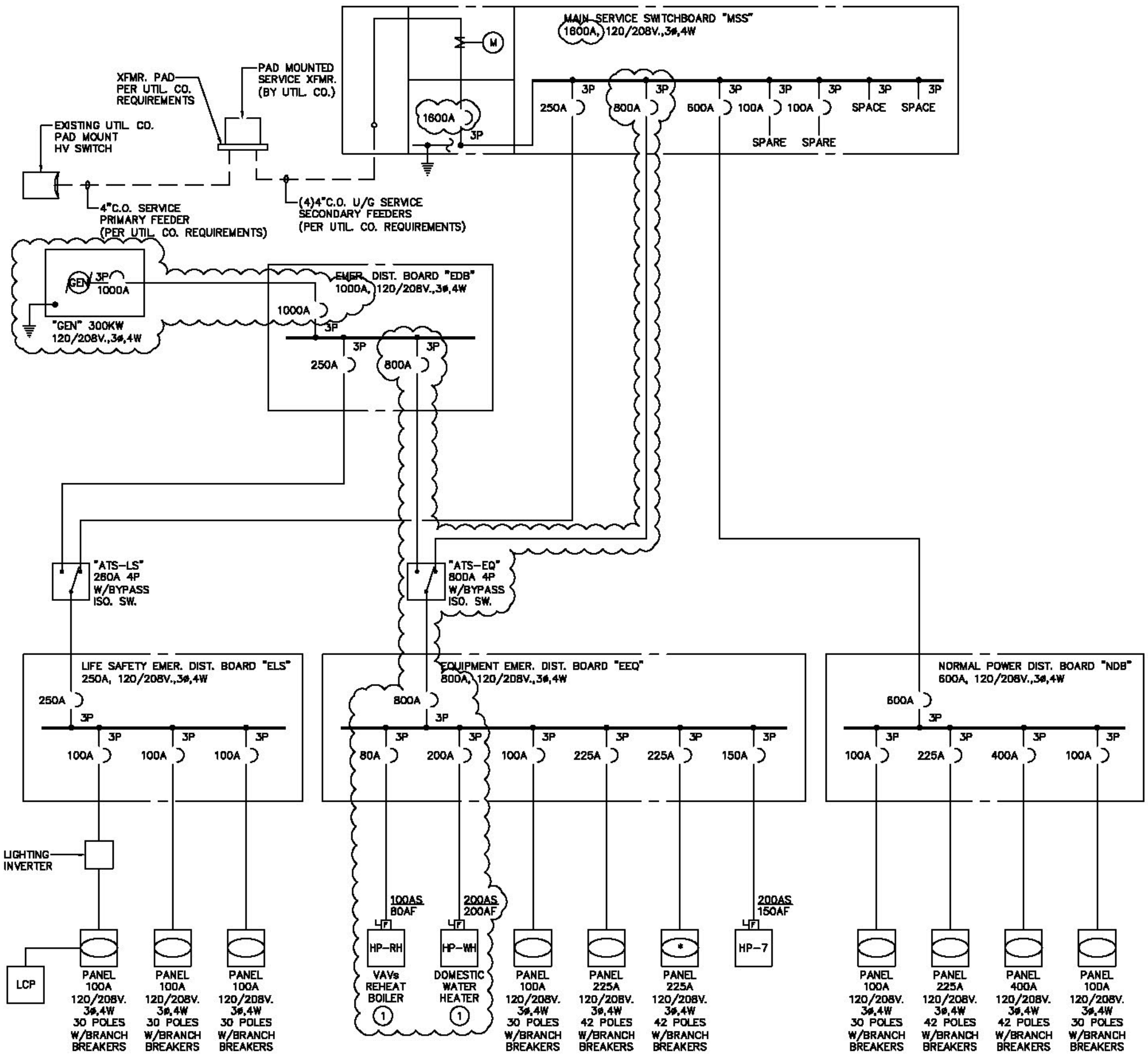


2" Exterior Insulation Finish System applied to the exterior wall of the housing unit (EIFS is not applied to the exterior walls of inmate accessible areas such as the recreation yards. Inmates can damage the finish and insulation requiring frequent repair)



SINGLE LINE DIAGRAM - BASE OPTION

SKE-B



* WITH BRANCH CIRCUIT BREAKERS TO POWER HP-1 THRU HP-6

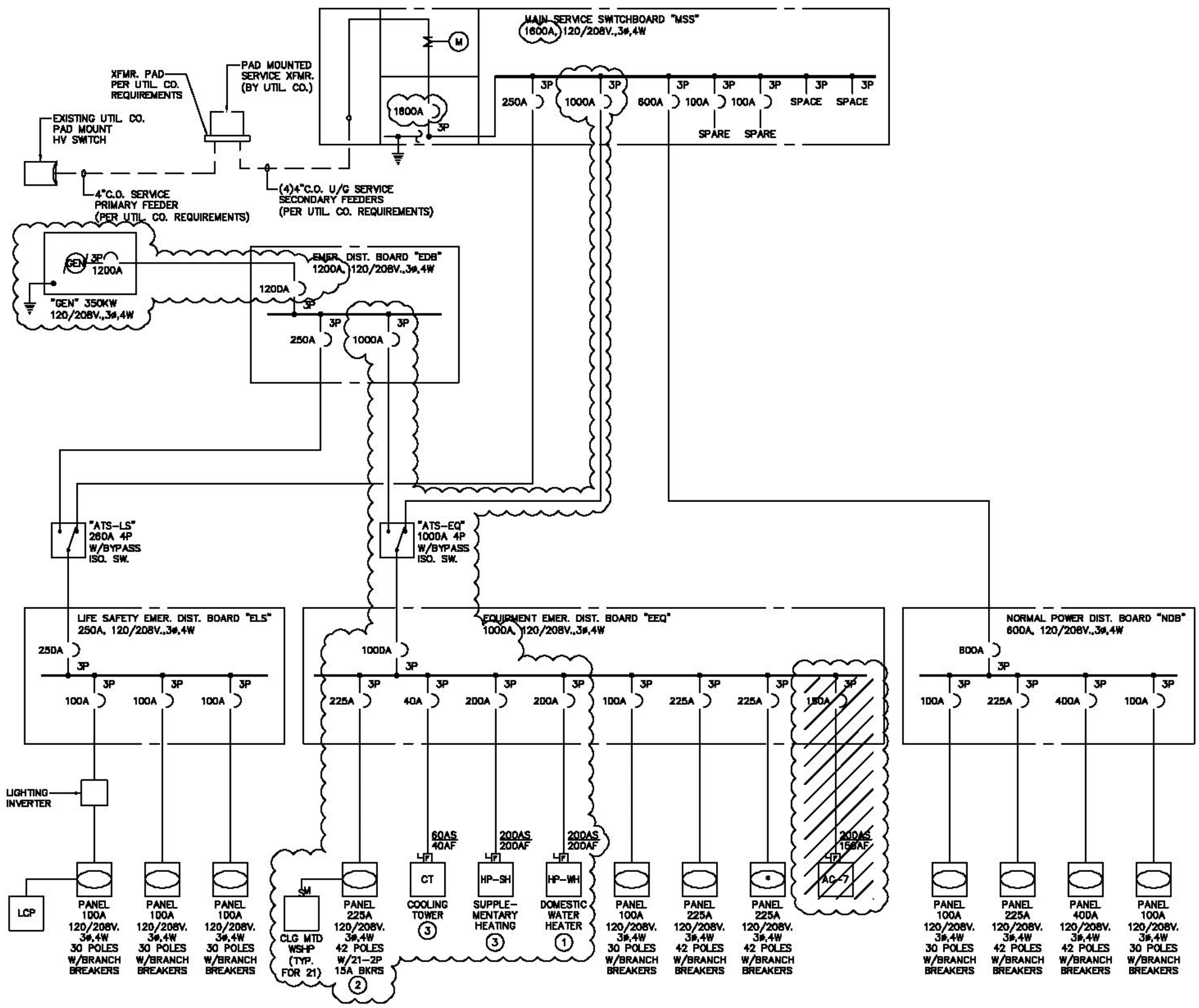
INDICATES CHANGES TO BASE OPTION SHOWN ON SKE-B

NOTES:

(1) LOCATED IN MECHANICAL ROOM

SINGLE LINE DIAGRAM - ALTERNATE 1

SKE-1



* WITH BRANCH CIRCUIT BREAKERS TO POWER WSHP-1 THRU WSHP-6

//// INDICATES REMOVED

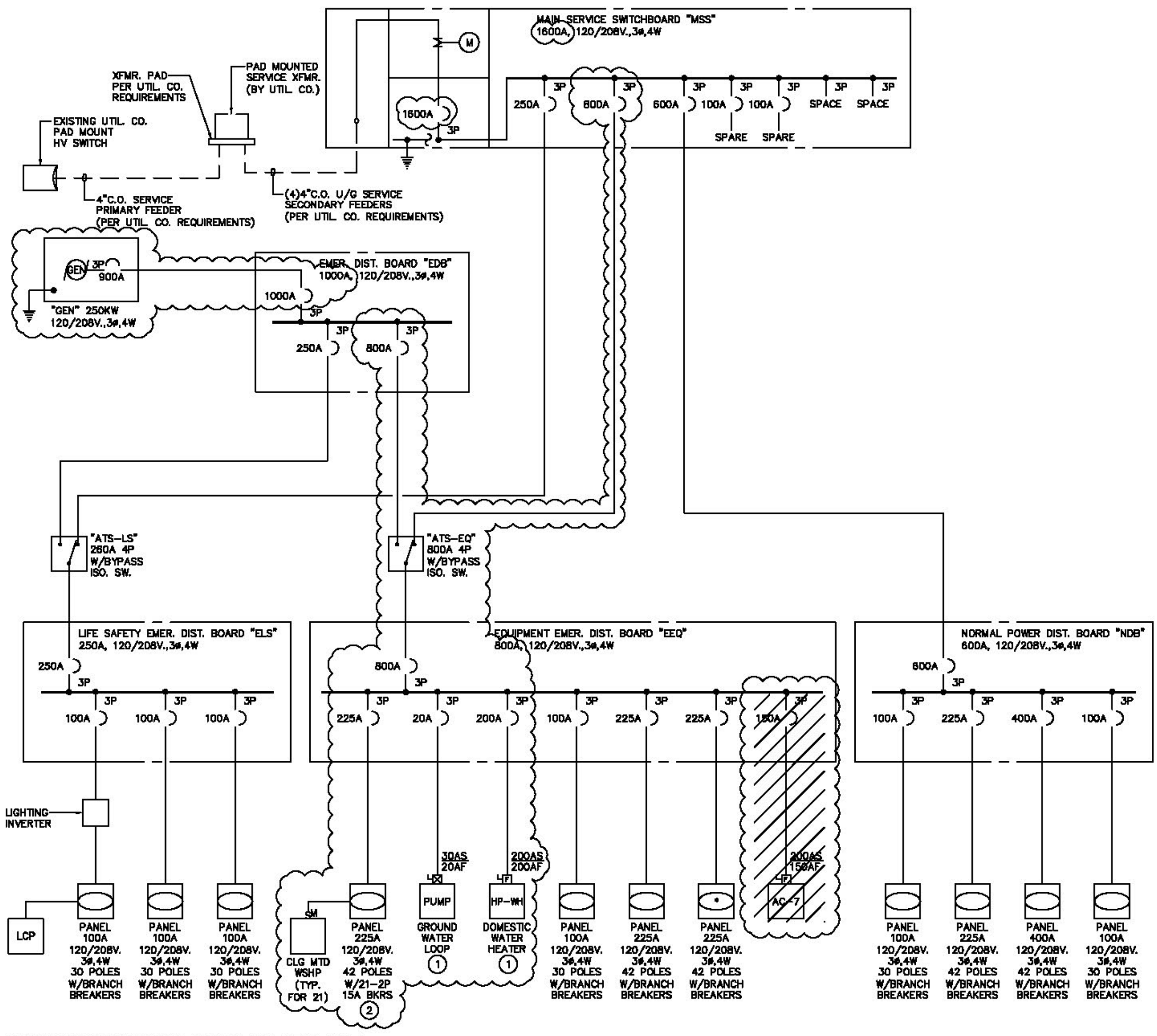
(cloud) INDICATES CHANGES TO BASE OPTION SHOWN ON SKE-B

NOTES:

1. LOCATED IN MECHANICAL ROOM
2. LOCATED IN MAIN ELECTRICAL ROOM
3. LOCATED OUTDOORS ON DEDICATED CONCRETE PAD

SINGLE LINE DIAGRAM - ALTERNATE 2

SKE-2



* WITH BRANCH CIRCUIT BREAKERS TO POWER GSHP-1 THRU GSHP-6

//// INDICATES REMOVED

INDICATES CHANGES TO BASE OPTION SHOWN ON SKE-B

NOTES:

1. LOCATED IN MECHANICAL ROOM
2. LOCATED IN MAIN ELECTRICAL ROOM

SINGLE LINE DIAGRAM - ALTERNATE 3

SKE-3

County of Mendocino - Jail Expansion (SB 844)

Energy Analysis of Mechanical Systems

Nacht & Lewis Architects

Systems	Base Case Package AC	Alt 1: Air Source HP	Alt 2: Water Source HP	Alt 3: Ground Source HP	Notes:
Initial HVAC Cost	$ 954,760.00	$ 1,005,000	$ 1,130,966	$ 1,063,990	Delete Gas, change to Domestic Water Heat Pump
Plumbing Cost	n/a	Incl	Incl	Incl	
Electrical Cost	n/a	$ 115,600.00	$ 122,760.00	$ 100,500.00	
(40) 300 ft bore and pipe	n/a	n/a	n/a	ADD	
TOTAL	**$ 954,760.00**	**$ 1,120,600.00**	**$ 1,253,725.75**	**$ 1,164,490.00**	
Initial HVAC Cost	$ 954,760.00	$ 1,005,000	$ 1,130,966	$ 1,063,990	Delete Gas, change to Domestic Water Heat Pump
Plumbing Cost	n/a	Incl	Incl	Incl	
Electrical Cost	n/a	$ 115,600.00	$ 122,760.00	$ 100,500.00	
(40) 300 ft bore and pipe	n/a	n/a	n/a	$ 1,266,000.00	Draft - to be verified
TOTAL	**$ 954,760.00**	**$ 1,120,600.00**	**$ 1,253,725.75**	**$ 2,430,490.00**	
Notes:	Base with HW reheat	Heat Pumps w/air to water heat pump	Watersource Heat Pumps , add cooling tower, air to water heat pump and piping, delete HW pining	Watersource Heat Pumps , delete cooling tower, delete air to water heat pump for heating, add ground source bores/piping, add condenser water piping	