ECE463 Introduction to Data Centers
Team 8 Data Center Proposal

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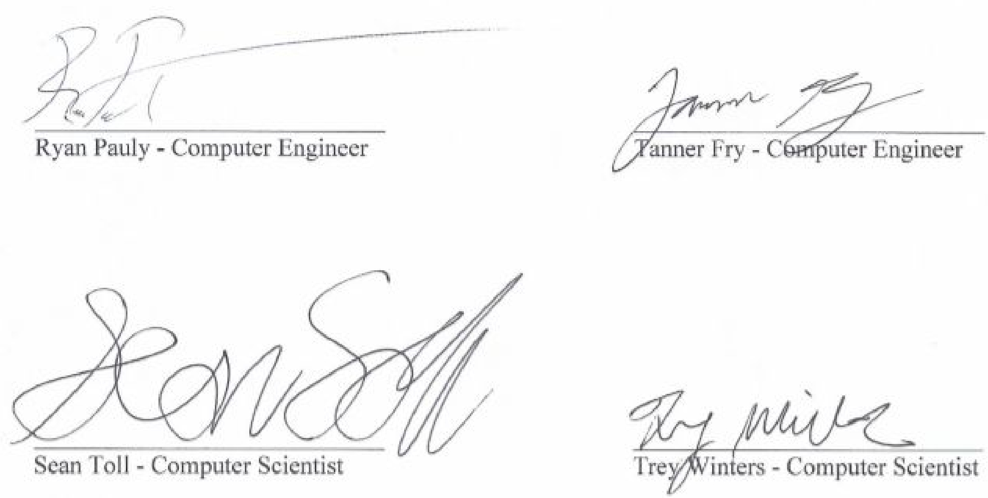

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Purpose, Objectives, and Scope of Proposal

Data Center Description

The data center being implemented includes 140 racks of IT equipment that will have a maximum load of 10 kW/cabinet. 40 of these cabinets require dual feeds, at least one of which need to be fed from an uninterruptible source (Tier III), and 20 of these 40 have access control requirements. The access control area must also support a 20 cabinet upgrade in the future. All cabinets are air cooled front-to-back. The goal is to obtain a PUE less than or equal to 1.4. The floor-to-load capacity is 250 PSF. There are existing cooling towers located above the chiller plant. Rack dimension include: 24"W x 41" D, 42U with a rack weight of 3,000 lbs.

Proposal Assumptions

- The data center floor space is assumed to be about 16,000 square feet (sqft).
- The data center floor load is 250 pounds per square foot (PSF).
- Rear door heat exchanger weight is assumed to be negligible to the minimum floor load capacity requirement of a server rack.
- The data center storage takes place outside of the data center. The data is transmitted back through the core layer switches to the greater ORNL network.
- The data center's new keycard scanners will be able to interface with the existing ORNL network.
- Mechanical Equipment power factor is assumed to be 0.85.
- A power factor of 0.95 is used for IT equipment power and estimate PDU calculations.
- The diesel fuel cost to run backup generator is assumed to be out of scope for this proposal.
- The main switchboard is assumed to be sufficient for the facility and its requirements.
- For cooling, it is assumed that the water piping is coming from the floor below at the top of the room layout, see floor plan for cooling implementation.

Project Plan and Requirements

Customer and System Requirements

For the power in the data center, the space will require various equipment for implementation with ranging requirements. The space has electrical power available for use from a 5000A 480V switchboard that is supplied from redundant 13.8V feeders. Power must be supplied to each cabinet through rack mounted PDU's with the PDU ratings as followed: 208V/60A/3-phase and connected with twist lock NEMA (National Electrical Manufacturers Association) plug. Spare circuits must be provided from the 5000A switchboard for future loads. A UPS with a generator back-up is required, and the generator must provide backup for cooling equipment that is also supplied from the generator. The UPS can be installed on the data center floor, and the generator can be located south of the building. Lighting of the space must come from LED's with central control that provides night-time cut back. An emergency power off system must be in place to de-energize all UPS, IT power, Heating, Ventilating, and HVAC systems supplying or moving air into the computer room. Also, an equipotential grounding system must be installed in the room.

For the cooling of the data center, the space will need multiple pieces of equipment with various requirements. The space already has an existing variable-primary chiller plant. The chiller plant has 2-1200 ton, constant speed chillers. The chiller plant has an assumed constant power draw of 0.8 kW/ton. It is required to have control over the environmental conditions at the inlet of the IT equipment. It is required to have a means to detect water leaks, to have environmental and equipmentent status alarms to be reported to an operator control room, to have all mechanical equipment to be located for safe and easy maintenance, and to have the cooling equipment and the head load concurrently maintain and provide N+1 redundancy.

For the network in the data center, the space will require various equipment for implementation with specific requirements from the customer needs. The implementation must provide a raceway for network cable between rack and from racks to remote data facility. The current connectivity in the space is 40 Gigabits per second (Gbps) from the ORNL network, and 100 Megabits per second (Mbps) from Comcast. The network gear must provide redundancy from outlying switches to core/central switches. 10 Gbps connectivity is required for the main data connected to each of the compute nodes, with redundancy. 1 Gbps connectivity is required for the management connection at each of the compute nodes.

Regarding local regulations and codes, this data center will be located in a building under the City of Oak Ridge's jurisdiction. As such, it will be compliant with all codes and regulations required and explicitly listed by the City of Oak Ridge. It will also adhere to the ramp standards laid out in the Americans with Disabilities Act.

Constraints and Limitations

The first constraint is the data center space itself. As this is a pre-existing space, the data center is constrained by the size and space of the dimensions allocated to the data center provided in the RFP. Because the data center space is one section of a pre-existing facility, it must be contained within the limitations of the allocated area dedicated to the size and area of the data center. The area of the data center is assumed to be 16,000 square feet, and thus the data center itself cannot expand beyond this area without extensive construction or the removal and relocation of office spaces and other rooms around the data center. The floor load capacity of the pre-existing data center is 250 PSF according to the RFP, but this can be upgraded with further support construction if need be. Without further construction, the maximum PSF is limited to 250 PSF, and thus the equipment floor load requirements are constrained in the data center floor space to satisfy the maximum 250 PSF floor load.

Further constraints include the already-in-place resources for electrical power, cooling, and connectivity. The space has electrical power available for use from a 5000A 480V switchboard that is supplied from redundant 13.8V feeders. There is an existing variable-primary chiller plant. The chiller plant has 2-1200 ton, constant speed chillers. The chiller plan has been assumed a constant power draw of 0.8 kW/ton. Also, the current connectivity in the space is 40 Gigabits per second (Gbps) from the ORNL network, and 100 Megabits per second (Mbps) from Comcast.

For implementation constraints, the data center must be able to achieve a PUE score of 1.4 or less, with 140 racks in place and a future 20 racks to be installed. There are 140 racks to be installed initially into the RFP data center, 40 of which are to be dual fed uninterruptible source (Tier III), and of those 40 racks, 20 require access control restraints as well as the future additional 20. Of the 140 racks, 20 require access control restraints, as well as the future 20 racks. Also, 40 of the total racks require a dual-fed uninterruptible source (Tier III).

Work Breakdown Structure

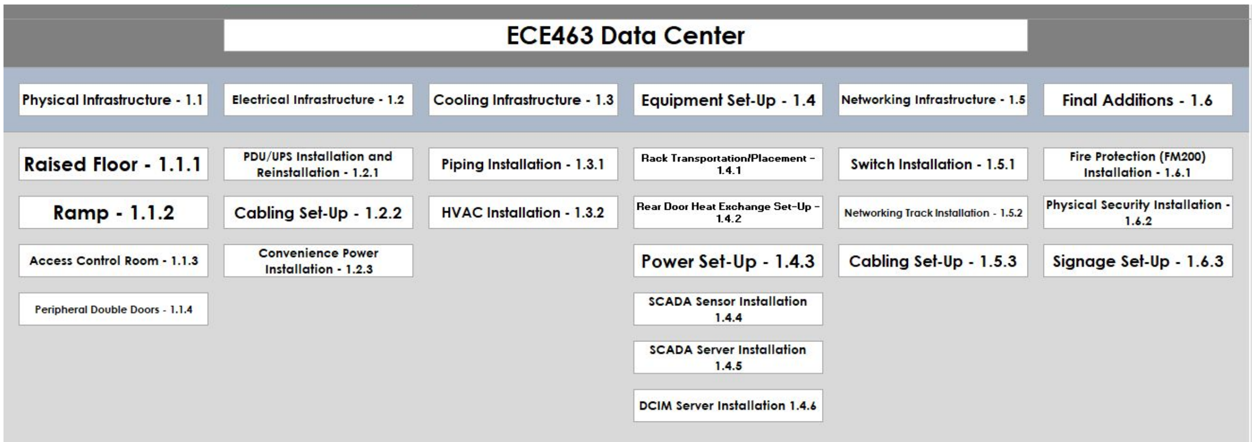

Figure 1. The work breakdown structure diagram for the proposed data center.

This project is broken down by system and organized temporally. There are six main sections: physical infrastructure, electrical infrastructure, cooling infrastructure, equipment set-up, networking infrastructure, and the final additions. Each of these sections will need to be accomplished in the order that has been described as the later sections rely on the sections. A more legible copy can be found in **Appendix AA**.

Proposed Schedule

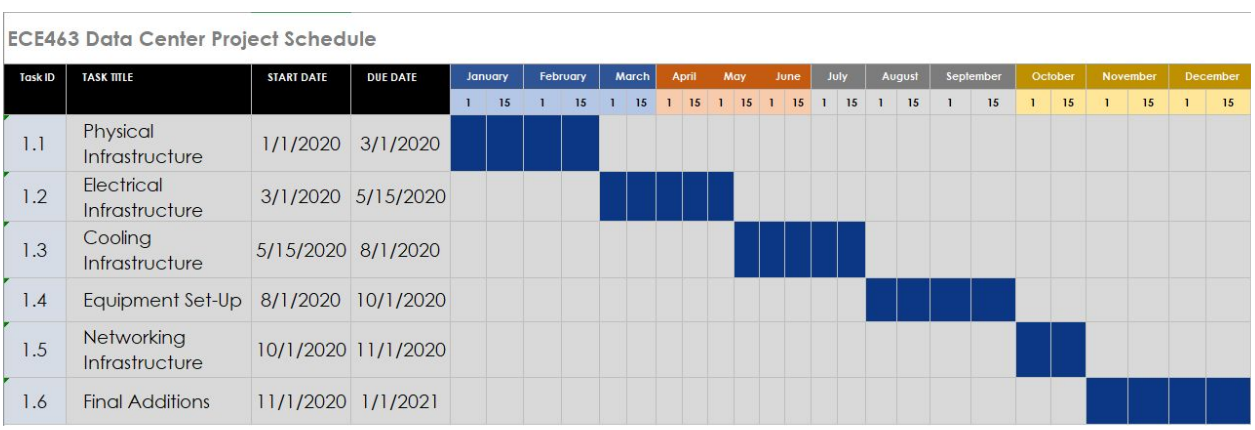

Figure 2. The estimated schedule to build and deploy the proposed data center.

This project is scheduled to take about one year to complete. In general, each major chunk (physical infrastructure, electrical, etc.) will take two or more months to complete. The only exception is the networking architecture, as it is only expected to take about one month to complete. The full estimated schedule can be found in **Appendix AB**.

Risk Assessment

Assessing the risks of the data center includes the following areas: electrical, cooling, fire, and access control. In electrical, equipment failures can lead to extensive downside and the destruction of equipment. To mitigate these risks, redundancy and monitoring are to be implemented into the proposed data center. SCADA monitoring is implemented for early detection of any electrical issues, and UPS generator back-ups are in-place to quickly takeover in the event of unexpected failures. Additionally, the SCADA system will allow for early failure detection to prevent hardware damage to surrounding equipment and for automatic shut downs of failing equipment and automatic switching to the redundant equipment in place. For cooling, equipment failure and piping breaks could lead to damaged equipment from and increase temperature or from water leaking from pipes. To mitigate these risks, the piping for the water will be under the floor to keep it clear of the cabinets, and the electrical wiring in place under the floor will be encased in metal piping to prevent damage to the wiring and its equipment it is connected to if water was to leak into the space. In the case of HVAC failure, there will be plenty of overhead in the cooling due to the rear door heat exchangers eliminating the hot air being placed in the space, thus providing sufficient cooling for equipment while and HVAC system is down. There will also be back-up generators in place in case of a power failure to the HVAC systems. In fire protection, certain implementation can increase the risk of equipment damage based on what solution is provided to suppress fires. For this data center implementation, only clean gaseous solutions will be used for suppression that are safe for the equipment, thus reducing the risk of equipment failure in the racks. There will also be manual suppression solutions in place, standard fire extinguishers also containing solutions safe for equipment, in case the automatic detection system was to fail. For access control, there are 40 cabinets, with 20 extra in the future, that will need secured access for only classified users. To handle this, the cabinets will be enclosed in a sub-room of the space, with the access doors providing scanners that will only allow cleared personnel that have permission to access the space. There will also be access control for all entrances to the data center, each having an ID scanner, only allowing personnel with the permission to enter the space.

Design Description and Details

Data Center Floor Plan

The proposed data center floor is a raised tile floor of 3 feet. A raised floor in the data center allows for additional air flow to be directed underneath the tile floors to exhaust cold air to racks for fresh intake air if required. Additionally, electrical routing from the main switchboard to PDUs is proposed to take place in the first floor ceiling space above the offices, and under the raised floor of the proposed data center. The assumed PSF for the raised floor is to be equivalent to the pre-existing 250 PSF floor load. The raised floor is composed of a standard 2 by 2 ft. tiling. The proposed material for the raised floor is an all-steel floor panel solution.

Two ramps are required in the data center floor space to make the data center floor accessible from both the offices to the eastern side of the building as well as the western side to the elevator lobby room. Requirements for the ramps are in compliance with the ADA (Americans with Disabilities Act) and thus require that the ramps have a 1:12, rise:run ratio, that the ramp be at least 3 feet wide, and that handrails be available on both sides of the ramp for ramps if the length meets or exceeds 72 inches or if the height of the ramp meets or exceeds 6 inches. The ramp for the proposed raised floor will be 36 feet in horizontal distance to conform with the ADA code requirements for a ramp that rises 3 feet. Additionally, the ramp will be 4 feet wide to accommodate the movement of equipment to and from the freight elevator, and to be in compliance with the ADA code. Handrails will be attached to the floor parallel to the ramp to follow the ADA requirements. A steel floor tile is estimated to be $15.00 per square foot. A total material cost for the full data center raised floor is estimated to be about $600,000, this includes materials for the ramp, guardrails, raised floor structure, raised floor tiles both solid and perforated, and accessories such as tile puller handles and underfloor cleaning equipment. Including labor, the total cost of the raised floor is estimated to be $1,000,000.

A primary concern of the data center raised floor is the server floor load requirement. The server rack is 2 ft. wide with a 3.4167 ft. depth.

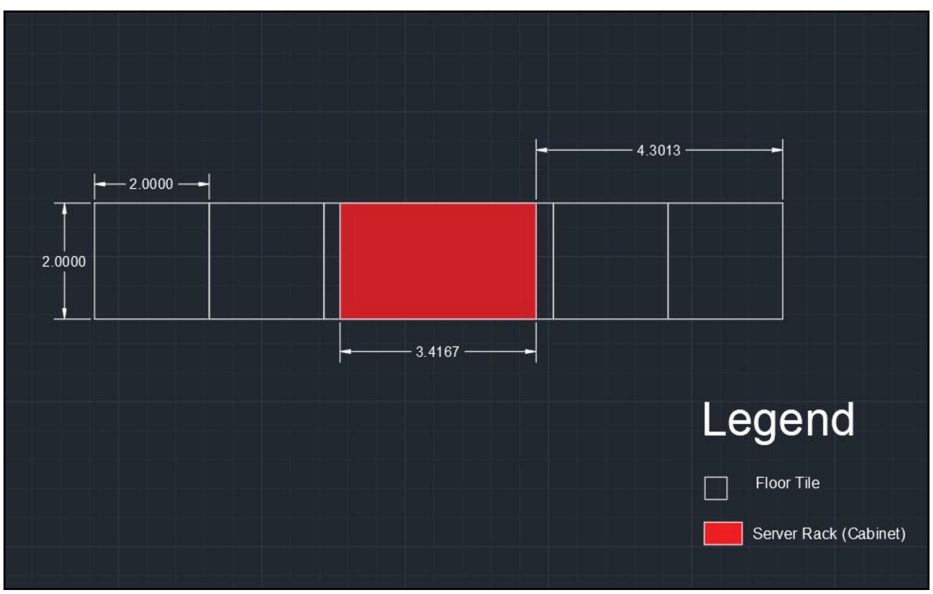

Figure 3. A CAD view of an example server rack sitting on two floor tiles with a front and rear aisle consisting of two tiles on the left and right of **Figure 3**, each dimension is labeled in feet.

To calculate the floor load capacity, the rack is first centered on two floor tiles, which leaves about a 3.5 inch gap of floor tile exposed in front and behind the server rack. This gives an aisle length of about 51.5 inches or about 4.29 feet, which the drawing in **Figure 3** labels as about 4.3 feet. In order to calculate the floor load requirement, 50% of the width of the floor aisles to the front and rear of the server rack are taken into consideration.

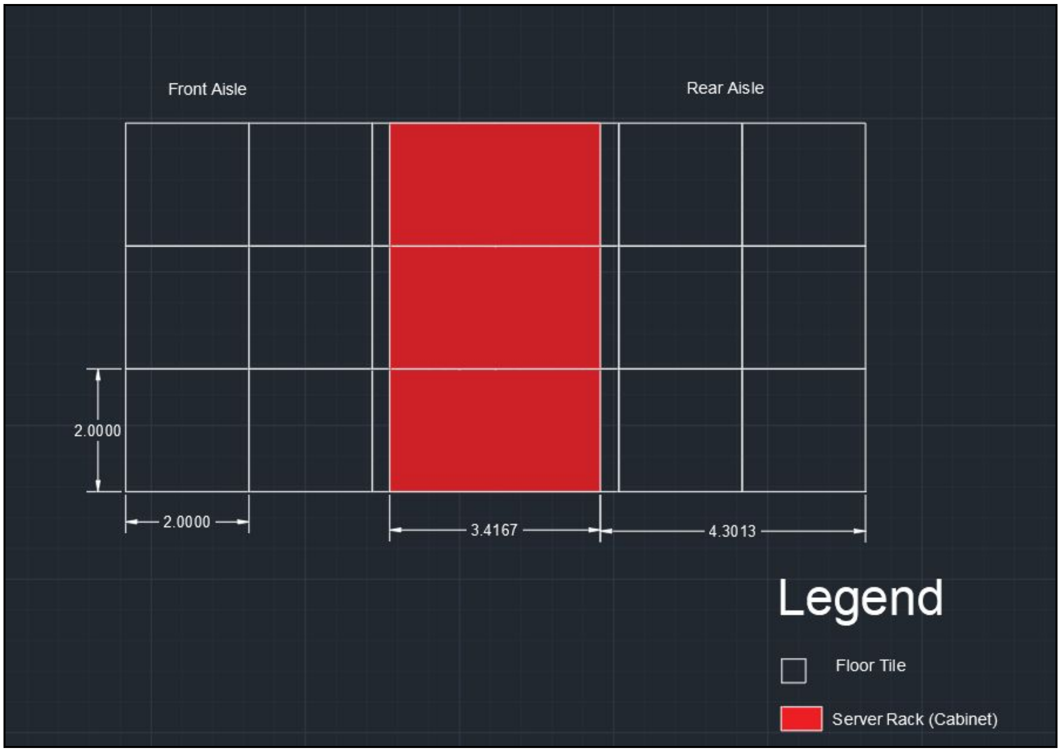

Figure 4. A more descriptive example with more server racks included for better illustration.

The floor load requirement for a server rack can be calculated and described with the following equation:

$$Minimum\ Floor\ Load\ Requirement\ =\ \frac{Weight}{Width \times [Depth + 50\%\ Front\ Aisle + 50\%\ Rear\ Aisle]}\ .$$ [1]

Plugging in the numbers with respect to the layout in **Figure 4** provides the following result:

$$Minimum\ Floor\ Load\ Requirement\ \approx 194.59\ PSF\ .$$ [2]

For design purposes the rack minimum floor load requirement is rounded to 200 PSF to account for error. This minimum floor load requirement for a cabinet is satisfied by the current floor load capacity which is given as 250 PSF.

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[1] The weight, width, and depth are all with respect to the server rack weight and dimensions respectively. The front aisle and rear aisle variables refer to the front and rear aisle depths.

[2] The minimum floor load requirement is with respect to a server rack.

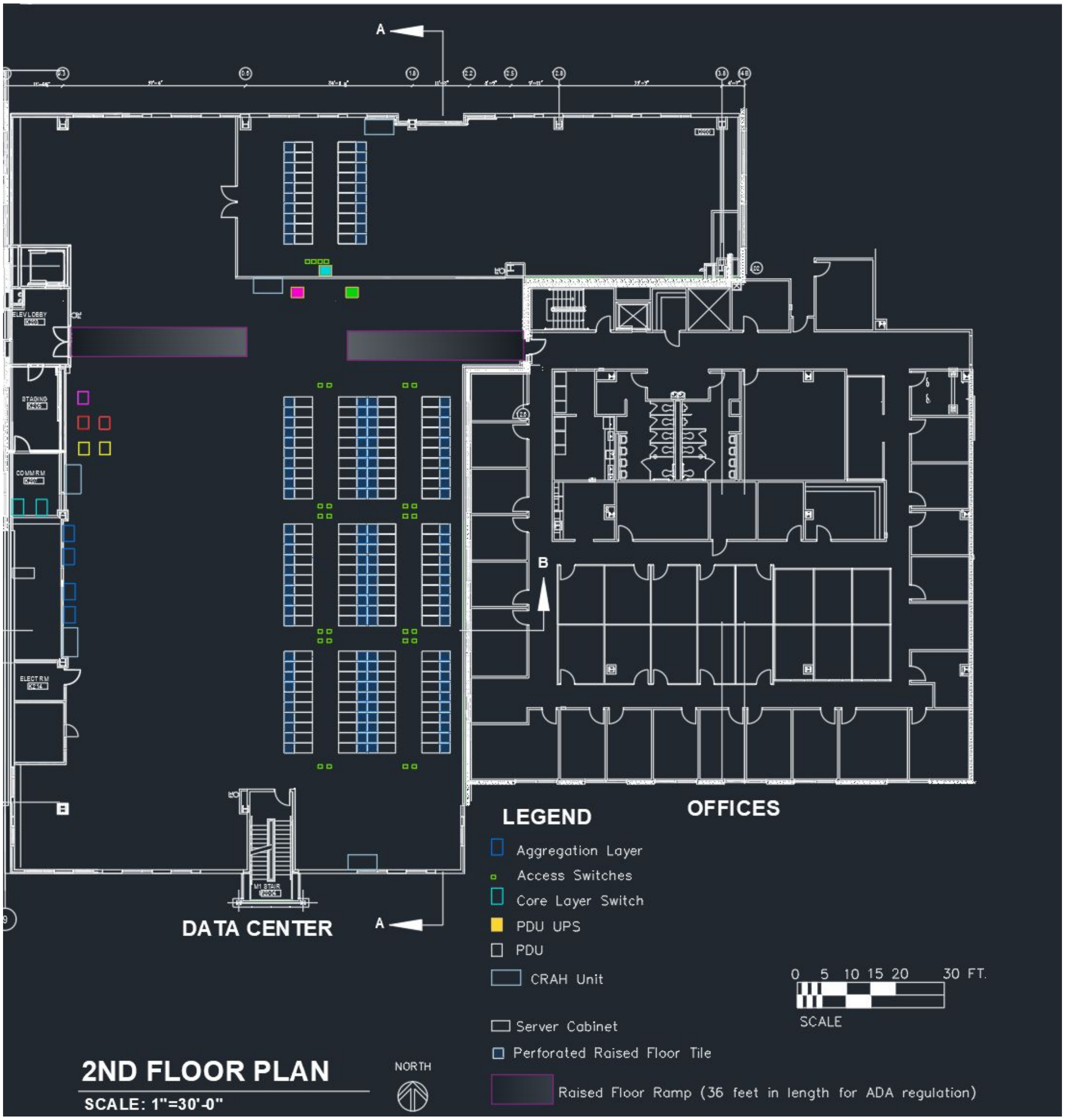


Figure 5. A simplified layout of the proposed data center floor space with key components crucial to the operation of a data center labeled.

The data center floor space shown in **Figure 5** is proposed to have a column structure setup in order to allow for rear door heat exchanger coolant water in and coolant water return to have a simple movement pattern down the length of the floor space from north to south of the building, to be discussed further in **Figure 8** below. Two ramps are shown in **Figure 5**, both are necessary in order to follow the ADA codes with respective to ramp dimensions and requirements. Cabinets are arranged in cold and hot aisle arrangements. A fence wall is implemented along the north end of the floor space for a secure access partition of the data center floor space. Any windows within the floor space are to be replaced with walling to enhance floor security as well as prevent additional heat from entering the floor space. A perforated floor tile element is represented in front of each rack, but this is solely for purposes of demonstrating the front of each rack and the space available in front of the rack. Perforated floor tile locations are to be adjusted on a case-by-case basis during operations of the proposed data center. **Appendice A through I** contains more in-depth images for each diagram.

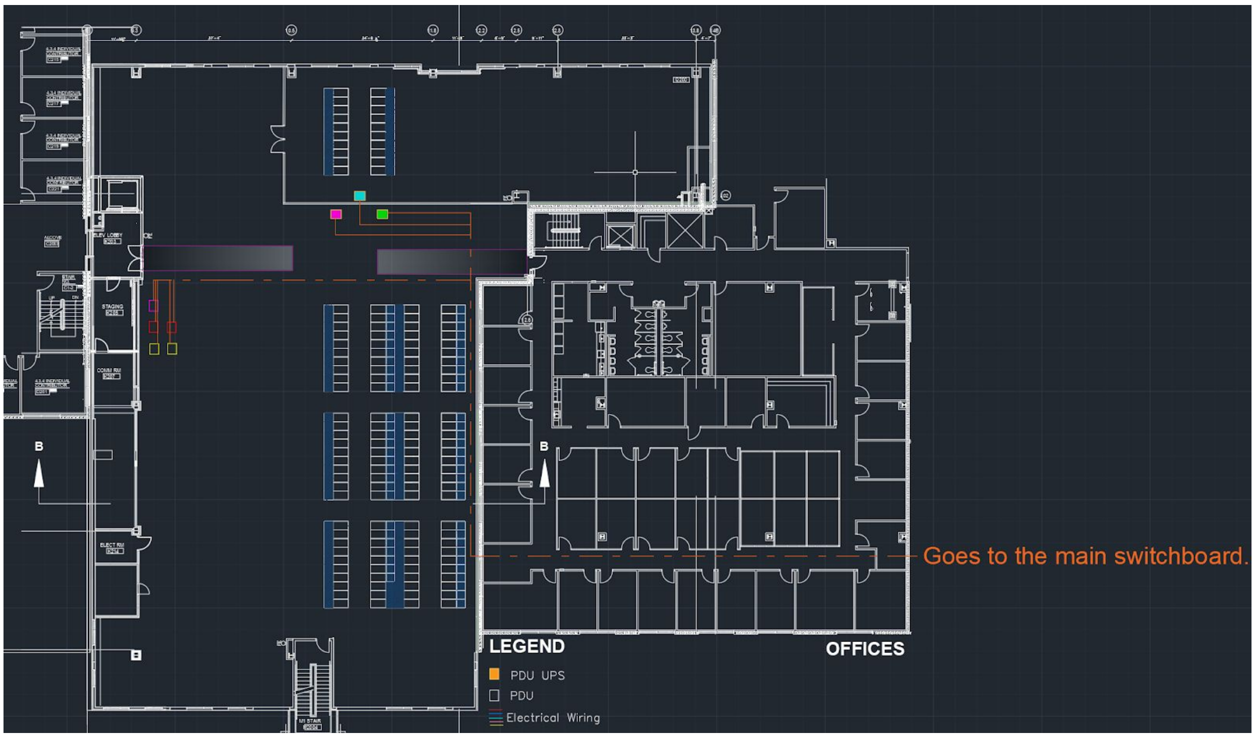


Figure 6. Electrical wiring from the main switchboard to the PDUs via the first floor ceiling space and under the raised floor of the data center floor space.

The electrical wiring from the main switchboard to the data center raised floor takes place in the ceiling space of the first floor office space. The routing is to be determined on site, but is planned to be high enough as to not impede on any future construction projects within this region of the building. Once the electrical wiring reaches the data center floor space it is to traverse up to be underneath the 3 ft. raised floor where it then connects to each PDU. **Appendices C and D** contain closer images for clearer observation of the elements in **Figure 6**.

Figure 7. Bus routing from 4 panelboard PDUs via electrical raceway to rack mounted PDUs.

The electrical routing from the 42 position panelboards with only 4 panelboards connects to rack mounted PDUs. PDU UPS systems integrate together for redundancy, where 20 of the racks in the non-access-controlled floorspace have this PDU connection and the 20 in the access control region also have this type of connection. Raceways keep the electrical routing in channels above aisles that allow for future racks to be installed into the data center. **Appendices E, F, and G** contain more images of the connections in **Figure 7**.

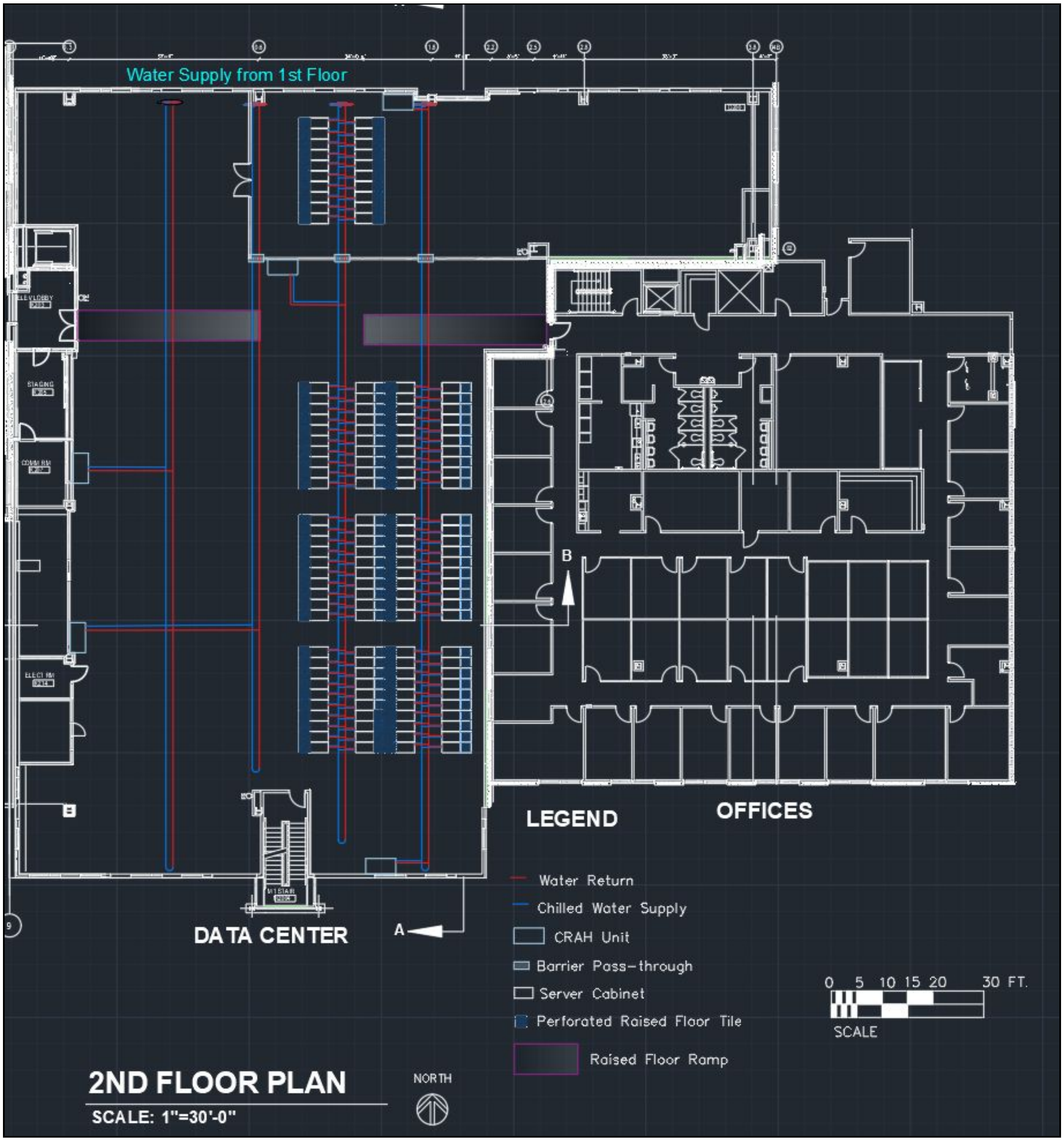


Figure 8. The floor layout for the proposed cooling solution utilizing rear door heat exchangers.

Rear door heat exchangers require a water cooling solution in order to lower the temperature of the radiator exhaust from individual server racks. This requires a water solution to flow into the data center and then return the then heated water back out to be cooled again and repeat the process. The proposed routing of the water in and water return is to be underneath the raised floor of the data center, where it connects up through the tile flooring to each individual rear door heat exchanger. Additionally, the water solutions connect to each CRAH unit present in the room, an additional cooling instrument for the data center.

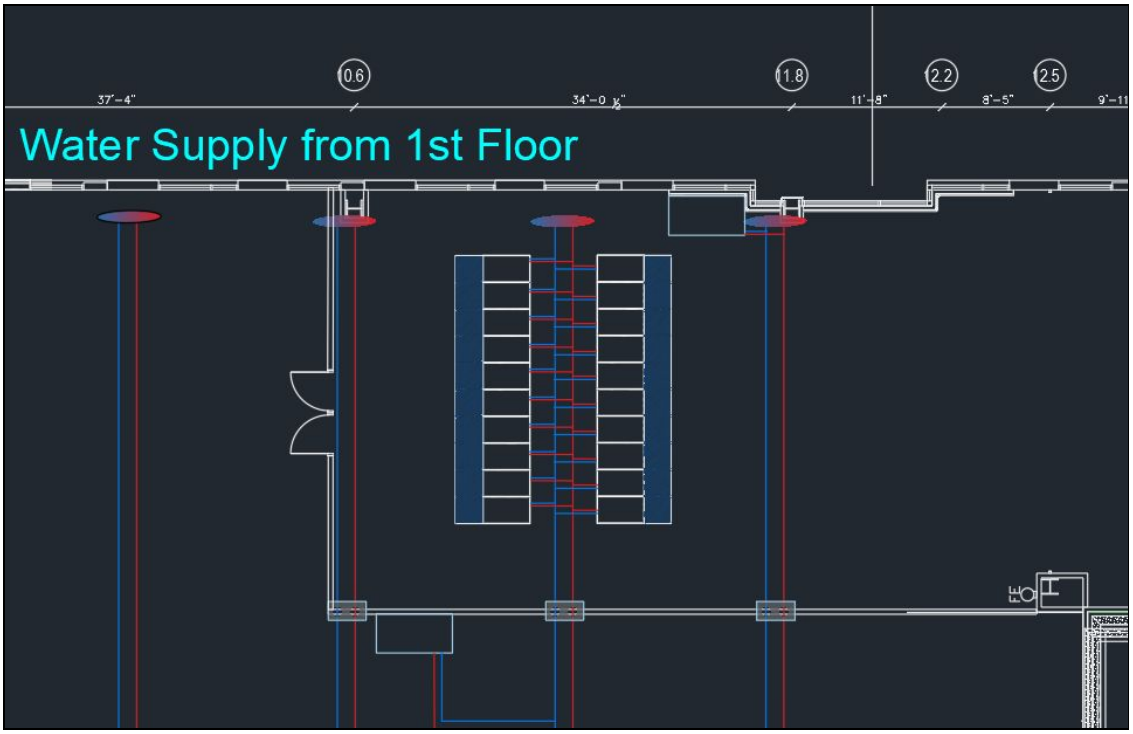


Figure 9. A closer inspection of the water solution source at the northern end of the data center.

The water source piping is received from the first floor where it is routed up into the data center floor space underneath the proposed 3 ft. raised floor space. Because some of the piping of the water traverses underneath the raised floor of the secure access-controlled room, the pipes must go through a concrete pass-through to reach the rest of the data center floor space, as seen in **Figure 9**.

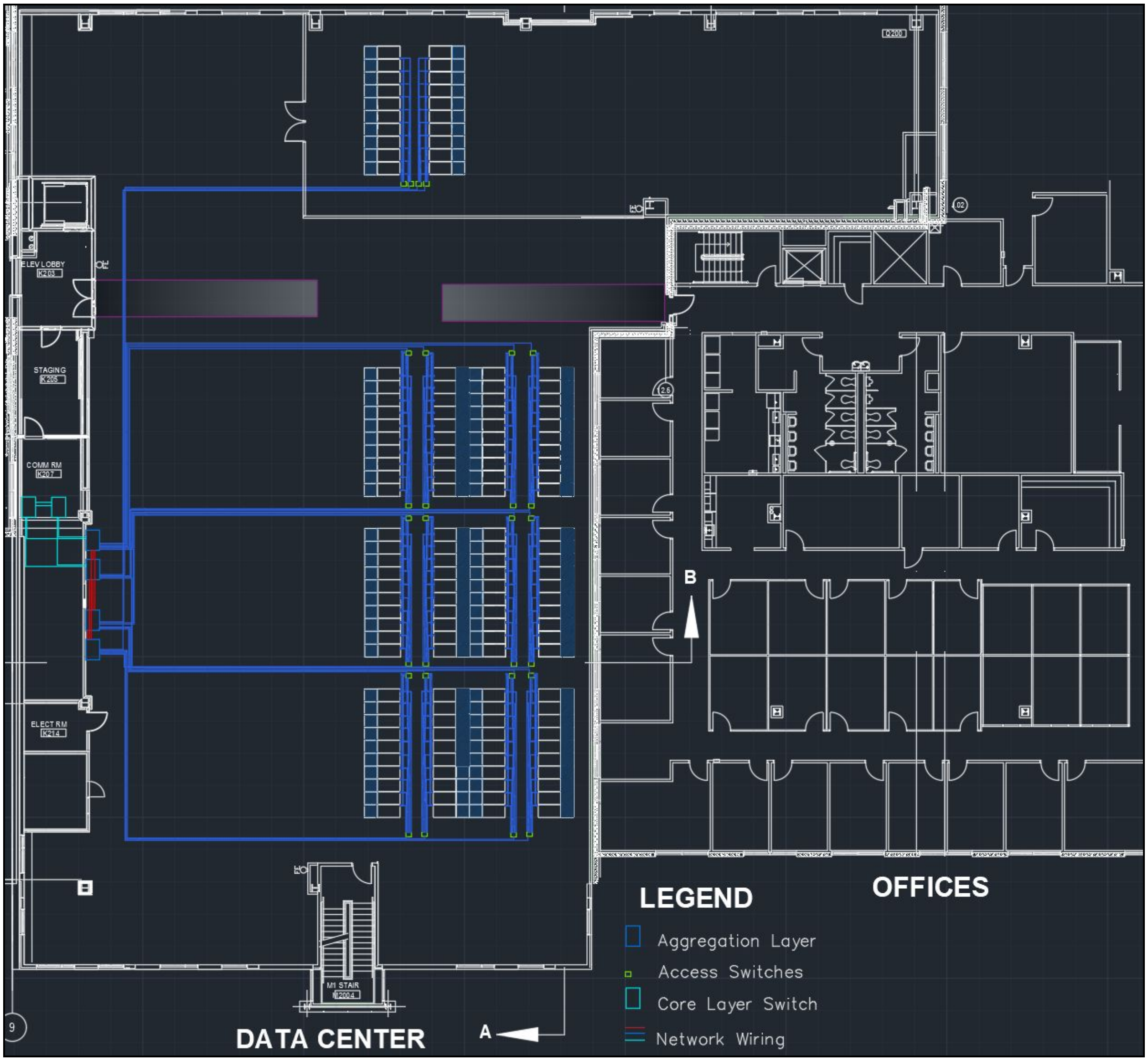


Figure 10. A network diagram illustrating the network wiring from individual racks to access switches, then aggregation, and finally core layer switches.

Network wiring runs along raceways in a tight form factor that allows for additional rows of racks to be installed with little interruption in the rest of the raceway, moving from access switches to the aggregation layer as seen in **Figure 10**. **Appendices H and I** show a closer view of the access-control room and the aggregation layer to core layer switch connections as seen in **Figure 10**.

Figure 11. A fire protection and data center floor safety diagram labeling all fire suppression system elements and additional safety elements within the proposed data center floor space.

Nozzles for the gaseous extinguishing agent are spread uniformly throughout the data center floor space from the ceiling. Emergency power off and emergency device area elements are located close together so that individuals inside can quickly take action in the event of a fire or any other hazardous event in the data center. All doors within the space have a path of common flow for exiting the data center, as to not clog up exits in a state of emergency. Floodlights and exit signs are also placed strategically in the data center. **Appendix J** shows a closer view of one of **Figure 11**'s exits and nearby EPO and EPA zones.

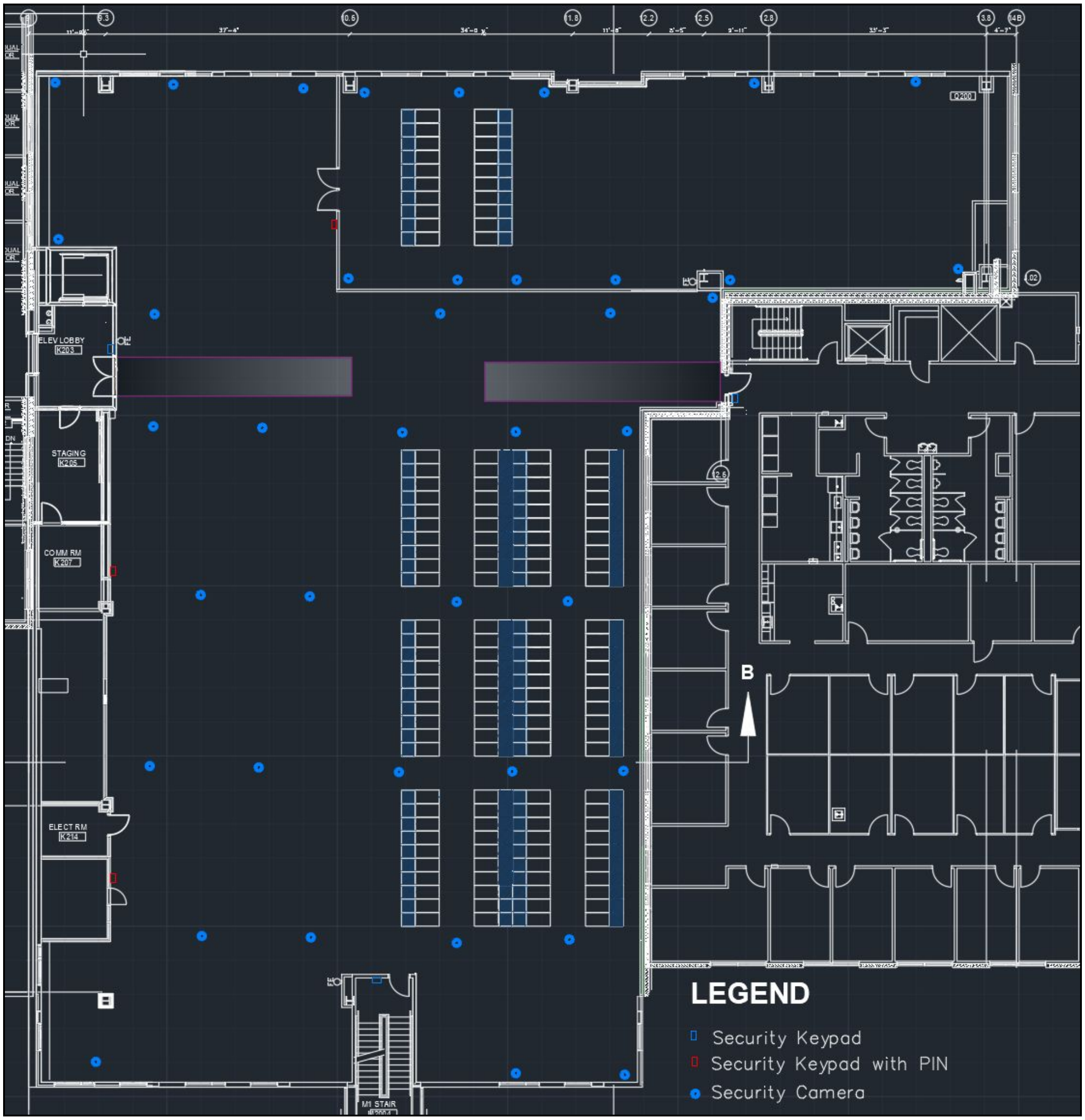


Figure 12. A proposed security solution for the data center floor space involving cameras and two levels of security keypads.

The security solution involves a number of 360° cameras with additional cameras already in-place for the addition of future cabinets. A blue level security keypad is set at all main entrances to the data center space, involving a keycard scan. Further security is added for secure-access control rooms that involve both an authorized keycard scan and a PIN input from the user, labeled with red in **Figure 12**. **Appendix K** shows a closer view **Figure 12**'s communications room and entrance from the freight elevator with security elements.

Electrical Distribution System

The Electrical systems are proposed to be routed from the main switchboard in through the second floor of the data center underneath the proposed 3 foot high raised floor to distribute itself to the power distribution units (PDUs), as shown in **Figure 6**. Further, from the PDU the electrical wiring then traverses up onto an electrical raceway in the ceiling space of the proposed data center area to distribute itself to each rack PDU respectively, shown in **Figure 7**. Two backup generators are supplied and placed to the south of the building, one of which to back up the UPS system, and the second generator to backup the cooling system. The proposed UPS energy storage is battery operated in order to have as much time as possible in the event of failure versus the shorter allotted time provided by a flywheel operated energy storage.

Energy in the data center is primarily required to power the heavy IT equipment load, cooling equipment required for the IT equipment load, and the infrastructure of the data center itself. Additional concerns for power in the data center includes redundancy, thus the proposed solution is to have a dual corded distribution for PDU UPS powered racks in order to maximize reliability on these more crucial systems. This configuration is more costly but it guarantees a higher reliability on mission critical racks. This system works by running a PDU UPS to the other PDU UPS devices in order to quickly take a failed system's place and continue operations incase of such events. Assuming a maximum load of 10 kW for each cabinet, and with a total of 140 cabinets plus an additional 20 cabinets to be implemented at a later date, the total normal power for the IT equipment can be determined to be roughly 1638 kVA, the IT equipment's maximum load.[3]

Given this max theoretical load, the determined number of PDUs required by the data center is 7, but the proposed solution is to add an additional PDU, increasing the total number of PDUs to 8 for higher reliability and maintainability. This is the determined number of PDUs to power 160 racks in the data center. Of the provided 140 cabinets, 40 are to be on dual feed with a PDU UPS configuration. To prepare for an additional 20 cabinets in the future, the total power required by the backup generators is to be enough to power the original 40 and the additional 20 racks to come at a later date. The estimate is then that of the 8 PDUs, 3 of these need UPS power. The generator to backup the UPS system is thus determined to be 1200 kW.

The total heat that 160 racks put off assuming maximum load is about 1600 kW. The heat that needs to be removed is assumed to be a 1:1 ratio with the amount of power the rack uses. Assuming a more realistic 80% power usage, the amount of power required to run 1 ton of cooling is estimated to be 364 kW. The total power the backup cooling and mechanical system requires is then estimated to need a 750 kW generator.

[3] Where kVA is simply kW / power factor.

Starting with the rack mounted PDUs, the proposed option is APC part AP6007A, a rack mounted PDU. The estimate for a single rack mounted PDU is $600.00, then to power 160 total cabinets, 140 at the beginning and the additional 20, the total cost for the required number of rack mounted PDUs is about $96,000. The main PDU cabinets are proposed to be Leibert's FPC 150-300kVA model which estimates at about $28,000 per unit, making the total PDU cabinet cost approximately $224,000. Further, a 750 kW generator is estimated to cost $125,000, and the 1200 kW generator is estimated to cost $230,000. Both of the two generators are diesel fueled. The 1200 kW generator is proposed to be Triton's MTU diesel generator engine model# 18V2000G85. Next, the 750kW generator is proposed to be from Perkins, model# 4006-23TAG3A.To include labor costs for generator installation, the total cost of both generator and installation is estimated to be $700,000. Lighting is estimated at a rate of $2 per square ft. and thus an LED light system is estimated to cost $32,000.The total estimated cost for the electrical distribution system including labor is $2,000,000.

Data Center Cooling Specification and Design

For the overall cooling design, the data center will have a hot aisle/cold aisle layout with rear door heat exchangers, see **Appendix N**, transferring the hot air from the equipment into ambient room temperatures. There will be CRAH units, see **Appendix M**, in place to provide cooling throughout the raised floor to the front of each cabinet in case of rear door heat exchanger failure. The CRAH units use fans and chilled water coils to remove heat from the ambient air and funnel it to the raised floor. The chiller's on site will provide cold water to the rear door heat exchangers and CRAH units, and the loops will return the heated water back to the chillers. For the 20 cabinets sectioned off from the rest, that space will have its own CRAH unit for backup, with a barrier in place under the floor to keep the pressure within that space on its own scale rather than combining into the rest of the floor space where the other 120 cabinets are. The piping for the water loops to the rear door heat exchangers and CRAH units will be in place under the floor and attached to the necessary pumps, but the CRAH loops will not be running unless needed. It is assumed that the necessary pumps for the water to reach the rear door heat exchangers and CRAH units are outside of the data center space, coming in from the floor at the top of the floor plan. For airflow and water supply design structure, see **Appendix L**.

For this data center, each cabinet has a max load of 10kW of heat dissipated. Each cabinet will have a Liebert XDR rear door heat exchanger that can handle up to 20.5 kW of heat. With the max load of each cabinet being 10kW, the heat exchangers will have 51.22% reserve capacity, allowing for more dissipated heat if future rack equipment produces such. There will be 11 Liebert XDP pumps in place, outside the space, that will be used to handle transferring the water supply to the rear door heat exchangers. With each pump handling a max heat load of 160kW, and each running at 80% capacity (handling ~128kW of heat), 1 pump will be able to handle 12.8 rear door heat exchangers, thus needing 11 total for 140 rear door heat exchangers. There will be 5 Qcooling CLC-CWR CRAH units in place, each of which can handle cooling 170kW. These will be in place for redundancy / backup if any rear door heat exchangers fail.

Networking Design

At a high level, the proposed data center's network follows a traditional three-tier design, where the outermost core layer interfaces with the greater ORNL network, the innermost access layer interfaces with the individual racks, and the aggregate layer in-between connects the two together. This layout was chosen because it is simple and easily adaptable to a variety of systems, while also having a decent amount of redundancy automatically built into each layer. Further, the access layer follows a top-of-rack design, allowing for easier expandability alongside future growth.

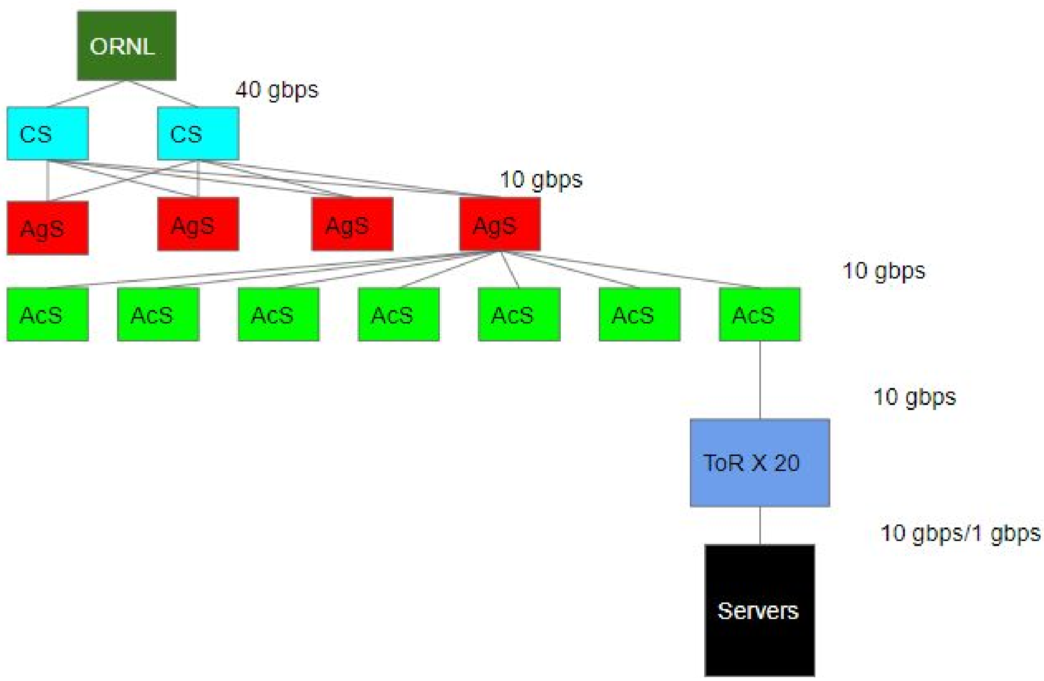


Figure 13. Block diagram of network connectivity in the proposed data center.

Going into specifics, there are two core layer switches in the telecommunications room, each connected to four aggregate switches. Only two aggregate switches are active at a time, with the other two serving as backup. This, coupled with the fact that there are two active core layer switches at all times, ensures that there is redundancy in the outer layer of the network. Regarding the inner layer, each row follows a top-of-rack network design. Specifically, each rack will have two top-of-rack switches, one for the main data connection and the other for the management connection. Each top-of-rack switch will be connected to all of the compute nodes in the rack. There will be 2 connections coming out of each top-of-rack switch, even though only one is functionally necessary. This will ensure redundancy in the inner layer of the network later on. Ten of these connections per switch (20 total) will connect to an access switch on one end and the other ten connections per switch (another 20 total) will connect to another access switch on the other end. From here, this access switch connection will lead onto the main networking track and head for the appropriate aggregate switch. There will be two intermediate access switches per row, meaning that there will be 28 in total. Therefore, each aggregate switch will be responsible for 7 individual access switches. Since two aggregate switches are initially inactive, the two active aggregate switches will be connected to the full range of rows in their 14 combined access switches. Likewise for the inactive aggregate switches. In preparation for an additional 20 racks in the future, the four aggregate switches will be able to take on one additional connection each from the four new access switches that will be need to be installed (two for each row).

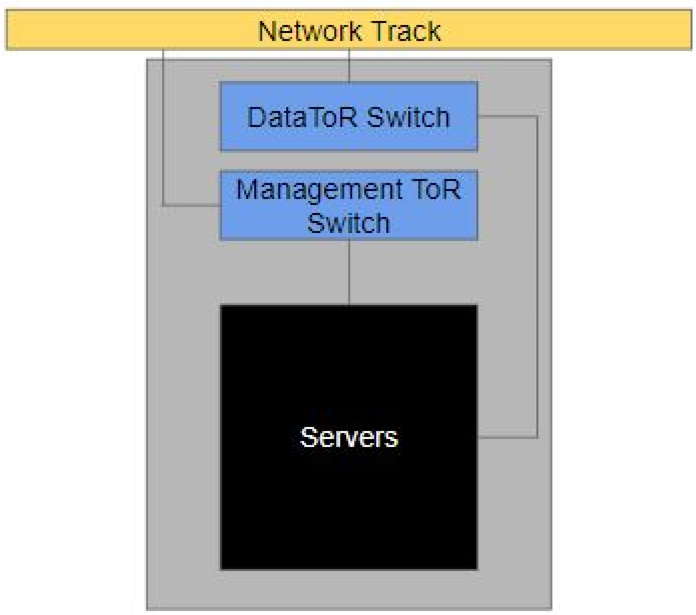


Figure 14. Individual rack connectivity block diagram.

Before discussing the specific products that will be purchased, one must first consider the bandwidth requirements of the data center. From the greater ORNL network, 40 gbps will be piped into both core layer switches. This 40 gbps bandwidth will then be split four ways per core layer switch and piped into each aggregate switch. Thus, each aggregate switch will have access to two 10 gbps connections, even though it will only use one. Each aggregate switch will then transmit its 10 gbps to each intermediary access switch that it is connected to it (7 in total). Similarly, each access switch will transmit its 10 gbps to each top-of-rack switch that is connected to it (20 in total). Finally, each top-of-rack switch will transmit its 10 gbps or 1 gbps (data or management) connection to each compute node that is connected to it.

With bandwidth requirements appropriately described, the full list of required equipment follows. Both the core and aggregate switches will be composed of Cisco Nexus 5624Q switches (~$25,000 each), while the access and top-of-rack switches will be Cisco 5672UP switches (~$8,000 each). These switches will be connected using ORNL-provided cables. These cables will run over the top of the racks in a networking track. The specific route of this network track can be seen in the networking floor plan (**Figure 10**). There will be about 8,000 feet of cabling needed in total.

Infrastructure Management

To handle infrastructure management, our datacenter will use an open-source DCIM system developed specifically for our desired needs. The DCIM system will collect and manage information about the data center's assets, used resources, and operational status. This information will be used to make sure the customers requirements are met, and help with future expandability by knowing the data center's capabilities based on the resources already in use. The system will also allow customers to view the current data centers available space and resources, and allow requests to be made for new equipment installations.

The DCIM system at the highest level will show the overview of the floor's equipment layout, providing basic information on the current spacing, cabinet capacity levels, and overall infrastructure. It will also allow for users to create / view dashboards of overall data center performance and effectiveness. From the high-level layout, the DCIM software will allow to go to a mid-level overview by clicking on the equipment in the high-level layout (ie. clicking on a cabinet will take the software to the cabinet layout). For an example dashboard for the high-level of a DCIM system, see **Appendix P**. For an example layout for the high-level of a DCIM system, see **Appendix O**.

At the mid-level of the DCIM system, the software will show information specific to the equipment chosen at the high level. Choosing a cabinet for example, will move to a level showing the cabinet's layout with the equipment being used in it, showing occupied space in the rack. It will also provide statistics for that cabinet specifically: power usage, device ownership, temperatures, etc. For and example layout of the mid-level of a DCIM system, see **Appendix Q**.

At the lowest level of the DCIM software, the software will display statistics for specific equipment selected at the mid-level. The system will show statistics related to power, loads, costs, temperature, PUE, energy, and connectivity relative to the selected device. For and example layout of the low-level of a DCIM system, see **Appendix R**.

Overall, the DCIM system will provide information on the current state of the data center and its resources, showing performance, effectiveness, and any weaknesses in the system. It will also track the data centers available space and potential expandability for future customers. The DCIM will require sensors to be in place for the various measurements needed to report the statistics expected. Sensors include temperature sensors, power measurement sensors, weight sensors, and some software in place to measure statistics in the networking infrastructure. New equipment that gets brought in will need to have their appropriate sensors installed, and must manually be added into the DCIM software to begin tracking of the equipment,

Some future features the DCIM system could benefit from would be a form of automated equipment tracking that gets brought in and brought out of the data center. New equipment could have a simple bar code, for example, that could be used to scan equipment into the DCIM system, and the equipment specifications could be automatically loaded into the software. Weight sensors could also be used to automatically use the loaded in specifications to know the equipment weight and detect where it is put in the floor design when brought in by using weight detection from floor sensors. This idea could also be applied to removing equipment, when a weight is tracked as moving across the floor and out the datacenter, that weight would be associated to equipment and would be removed from the DCIM system.

Fire Protection

For fire protection in the data center, the space will have both a passive and active solution to prevent and suppress fires. The space’s passive features include fireproofing the structure of the space with flame resistant ceramic panels, in order to keep heat and exposure from fires more contained to protect surrounding rooms. More passive features come from the compartmentation for the 20 cabinets that have access control requirements, and the spacing of the cabinets away from other electrical equipment in the space such as PDUs, and CRAH units. For active control, the space will use the FM200 system. The FM200 system will contain the control panel for the system, alarms, agent solutions, discharge nozzles, detectors, and distribution piping. The basic system consists of extinguishing agent stored in high strength steel cylinders. The agent is distributed and discharged into the hazard area through fixed piping and nozzles. Each nozzle is designed to deliver a uniform discharge of agent into the protected area. Automatic actuation is accomplished through an approved detection system. When a fire condition cause the detector(s) located in the hazard area to go into alarm, a signal is sent to the detection control panel. This causes actuation of the release circuit which electrically operates the actuator located on the cylinder valve. The actuator opens the valve and allows the agent to enter the piping network and discharge out the nozzles. The space will also have fire extinguishers in place for manual suppression in case of an emergency with a clean solution inside, as well as EPO (Emergency Power Off) switches. Manual switches for the FM200 system will be at each exit along with flood lights. See **Appendix S** for an implementation sample of the FM200 system.

Industrial Controls

For Industrial controls, the data center will use the Experimental Physics and Industrial Control System (EPICS). EPICS utilizes the TCP/IP based Channel Access (CA) Network Protocol. Channel Access protocol is an application layer built on top of TCP/IP that allows many devices to communicate at high speeds on the same network. EPICS also implements a client/server architecture. Channel Access Servers (CA Servers) will act as real world I/O points through the use of Input/Output Controllers (IOCs). CA Servers publish data to and read data from the network as an EPICS Process Variable (PV). In contrast, Channel Access Clients (CA Clients) monitor the network for updates to process variables, see **Appendix T**.

The Supervisory Control And Data Acquisition (SCADA) system will provide monitoring of electrical usage, gas usage, water usage, steam metering, temperature, humidity, and pressure. The electrical monitoring hardware will have on-board alarming for faster response time. Each section of monitoring hardware will have redundant monitoring tools to increase overall reliability. The client for the SCADA software will be a web-based client for remote access. The SCADA software will be distributed across multiple servers to keep the server loads light, and prevent throttling for the servers. There will also be hot standby servers, ready to take over if the primary servers fail. See **Appendix U** and **Appendix V** for sample web-based client dashboards of the SCADA software.

Physical Security

To protect the data center from intruders, each entrance will be outfitted with keycard scanners that are connected to the greater ORNL network. Using this network, only those with the appropriate permissions will be allowed to get into the data center's main area. From there, there will be additional keycard scanners at the entrances to the telecommunications room, the operating room, and the access control room. Each of these additional keycard scanners will also have a keypad input installed on it that will take a special six-digit pin. This pin will be required in addition to the keycard for a person to gain access to these rooms. These pins will be unique to each person who has access to those areas. These keypad scanners will be the same brand as what the rest of ORNL uses. As such, about $250 will be allotted for each keypad scanner.

Moving on, there will be 40 closed-circuit cameras watching each doorway in the data center from both the inside and the outside. These cameras will be CTSI D-Link DCS-5615 Full HD Mini P/T Dome Network Cams ($505 each). The placement of these cameras is shown in the physical security floor plan (**Figure 12**). The fire exits will not be openable from the outside, so people will not be able gain access that way. These fire exits will also trigger an alarm when they are used so that people will know to evacuate. Finally, all windows will be removed from the data center at the very beginning of the project.

Adherence to Building/Environmental Codes

This data center will be compliant with all relevant codes and regulations laid out by the City of Oak Ridge [1], as well as the Americans with Disabilities Act. The full listing of these codes and regulations and how this data center will adhere to them can be found below in **Table 1**.

Code/Regulation	**Description of Adherence**
2018 International Building Code	Fire protection system in place, appropriate signage over emergency exits, unobstructed paths to exits, quality cabling, appropriate safeguards around electrical equipment.
2018 International Residential Code	N/A.
2018 International Plumbing Code	Quality piping in place for cooling.
2018 International Mechanical Code	Quality cabling and appropriate safeguards around electrical equipment.
2018 International Fire Code	Fire protection system in place (to both put out fires and alert those inside), appropriate signage over emergency exits, unobstructed paths to exits.
Americans with Disabilities Act (ADA)	Ramp present at the entrance with the following specifications: 1:12 rise:run ratio (3 feet wide, 36 feet long) with handrails on each side.

Table 1. A table of relevant codes and compliance descriptions for the proposed data center.

Signage

The layout of the space will be on a number and letter grid, where each cabinet will have a number and letter associated to each cabinet in place (i.e. 1A, 1B, 2A, etc.). The labels for the grid will be high up on the walls, and each cabinet will also have a small sticker showcasing its number / letter. Other equipment that will be labeled include structured cabling, power receptacles and circuit panels, raised floor tiles, individual servers and networking devices, and major infrastructure components. The structured cabling will include labeling that contains what type of media is in use (i.e. 50 mm multimode or Category 6 copper) and the cabinet locations that a cable run connects from and to (i.e. from cabinet 1A to cabinet 1D). Cable labeling will be present at the main networking row, in network substations, and at server cabinet locations. For the electrical equipment, there will be labeling in place for electrical receptacles, circuit breaker panels, and power distribution units. The labels will Include circuit information, voltage and amperage, the type of electrical receptacle, and where in the data center the conduit terminates. The raised floor tiles, and underfloor piping will be labeled based on the grid system. This labeling will be provided to know which areas to use caution around due to piping being underneath, and be used to know exactly where a failure could be occurring. For the fire protection equipment, there will be explanatory signage that informs users of their function and what to do in the event that they activate. The fire suppressant cylinders will also be labeled accordingly. There will be signs labeling each exit location in the space, as well as signs to point to the nearest exit at various locations. There will be signage in place for the emergency power off (EPO) system, explaining how to activate, and what the equipment does. Lastly, there will be signage for emergency contact at each exit in case of an emergency where an expert needs to be contacted. For sample signage, see **Appendix W, X, Y, and Z**.

Overview

Measures to Achieve Required PUE

For calculating the PUE of the data center, the following equation is used:

$$\frac{IT + Power + Cooling + Lighting}{IT} = PUE$$

Starting with the electrical equipment, each PDU is rated for 208V / 225A, producing 46.8kW. With 8 PDUs, the total power drawn is 374.4 kW. With 140 current racks, IT equipment draws 1400kW. The cooling equipment containing 11 pumps produces 10.956 kW all together. Assuming 2 W per square foot of usage from the lighting, and a 16,000 square foot space, the lighting produces 32 kW. If everything is running at full capacity, the PUE comes out to be:

$$\frac{1400kW + 374.4kW + 10.956kW + 32kW}{1400kW} \simeq 1.29$$

This is just an estimation based on max loads of all equipment. True PUE measurements will be recorded and adjusted accordingly annually through the SCADA system measurements of power draw for the various equipment.

Integration Strategy into Existing Facility

To effectively integrate with ORNL's existing facility, a variety of considerations have been made in the design of this proposed data center. For power, the data center will branch off of the incoming power source of 480V/5000A to provide power to all IT, power, cooling, and infrastructure equipment. For cooling, the data center will be accessing the chiller plants already on site for the rear door heat exchangers and CRAW units to provide cooling to the space. For networking, the core layer switches will be connected to the greater ORNL network, so that the data center can be utilized from the outside. Additionally, the data center will use ORNL-provided cables to set up the networking infrastructure. This should allow for easier integration with the existing ORNL network. For security, the keycard scanners will be the same brand as what ORNL already uses, so it will be easier to integrate with the existing security infrastructure.

Future Growth Strategy

For future growth, the data center space has plenty of open area for more cabinets based on the current layout. There are already water cooling pipes in place for future rack cooling, but more pumps and rear door heat exchangers will need to be installed accordingly. There is enough power from the PDUs and UPSs to power the 20 cabinets already planned for the future, but any further expansion will require more PDUs / UPSs based on the needs of the equipment. For networking, the core and aggregate switches are much larger than functionally necessary in preparation for future racks. Additionally, the top-of-rack architecture of each row allows new racks to be easily incorporated into the existing network infrastructure in the future. However, this will require many more switches and cables to link them. More DCIM and infrastructure monitoring tools will need to be installed with future equipment for measurements based on power usage, temperature, etc. Fire protection is already sufficient for more expansion due to its coverage spanning the entire space. If future equipment has access control restraints, more physical security will need to be installed. With future equipment expansion, building / environmental codes will need to be reviewed to confirm codes are still met as well.

Final Considerations, Concerns, and Issues

In terms of cooling, one concern found later in planning was that the hot/cold aisle layout might not be the most efficient layout for the rear door heat exchangers. The reasoning for this concern would be due to the pressure levels possibly being unbalanced with the cold isles having cabinets on each side pulling in air, and the hot aisles having cabinets on each side pushing air out. Too much negative/positive pressure could cause throttling in the cooling design. One solution could be to face the cabinets front to back so the back to one cabinet outputs air from the rear door heat exchanger to the front of the cabinets on the next row. Another solution could be activating the HVAC systems to provide additional airflow up the perforated tiles at the front of each cabinet.

Budget

The projected costs have been divided into their respective categories: cooling, power, networking, DCIM and infrastructure, fire protection, signage, floor plan and infrastructure, and physical security, along with the total projected cost for the proposed data center. The bulk of the budget was allocated towards the networking equipment at about $5,000,000.. A dual corded distribution for PDU UPS powered racks is also implemented in the data center design, an expensive but required component. This configuration is more costly, but it allows for higher reliability on the more important systems. Rounding out the more expensive portions of the budget is the floor plan infrastructure at about $1,000,000. This would cover the cost of the steel-tile raised floor, modifications to make the data center ADA compliant, and other physical features for the interior of the facility. This also includes labor costs for actually building the data center. Outside of that, other smaller costs include $15,000 for fire protection equipment, $30,000 for physical security systems for the facility, $10,000 for signage, and $20,000 for DCIM and Infrastructure management. **Table 2** represents these values and the total projected cost of the proposed data center, which comes out to approximately $10,075,000.

Data Center Proposal Budget	
Section	Estimate Cost ($)
Power	$ 2,000,000.00
Cooling	$ 2,000,000.00
Networking	$ 5,000,000.00
DCIM and Infrastructure	$ 20,000.00
Fire Protection	$ 15,000.00
Signage	$ 10,000.00
Floor Plan / Infrastructure	$ 1,000,000.00
Physical Security	$ 30,000.00
Total	**$ 10,075,000.00**

Table 2. The full proposed data center budget spreadsheet.

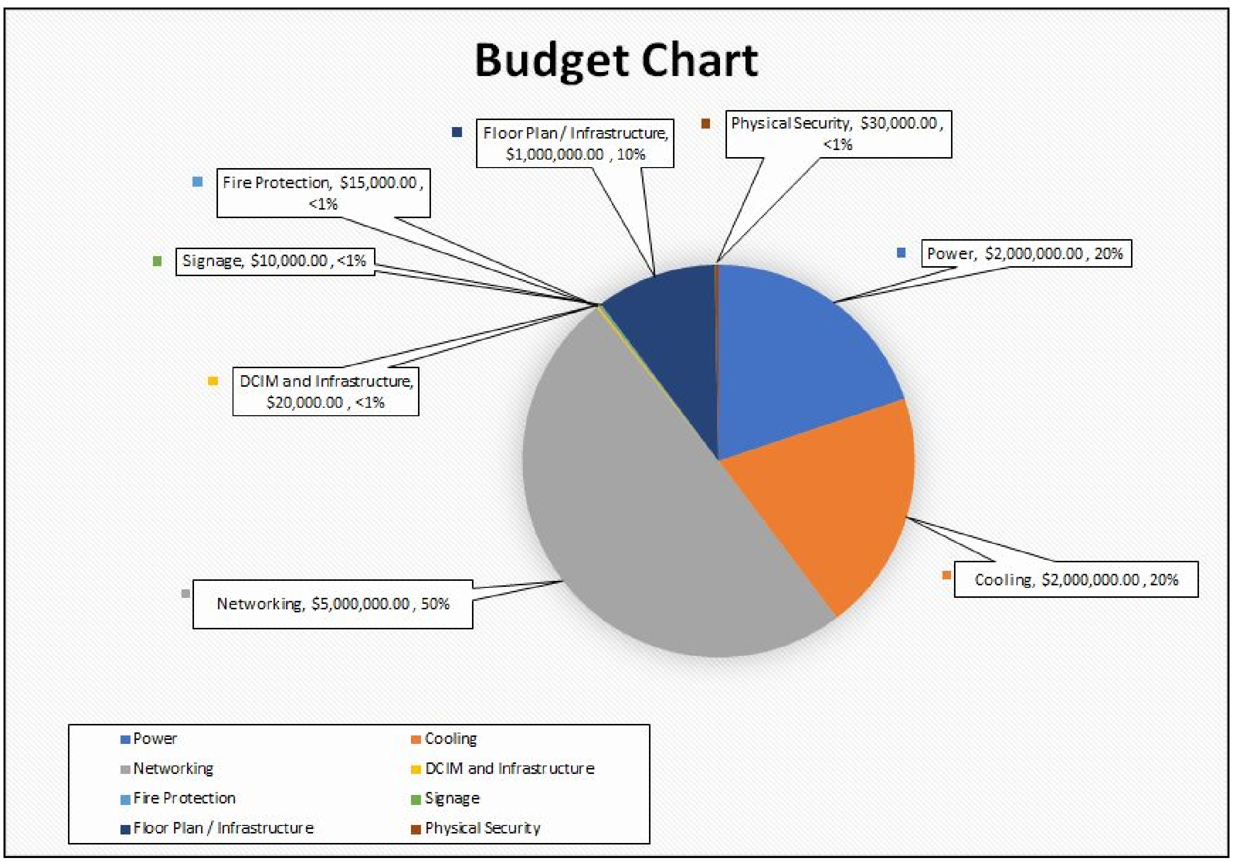


Figure 15. Budget Chart.

References

[1] *Welcome to the City of Oak Ridge, Tennessee*. [Online]. Available: http://www.oakridgetn.gov/content.aspx?article=1908. [Accessed: 25-Nov-2019].

[2] "The Growing Importance of Physical Security in the Data Center," *Data Center Solutions Provider*. [Online]. Available: https://www.rahisystems.com/flexit/the-growing-importance-of-physical-security-in-the-data-center/. [Accessed: 18-Nov-2019].

[3] B. Felter, "What Are the Most Important Data Center Security Standards," *Data centers and Colocation Services*. [Online]. Available: https://www.vxchnge.com/blog/data-center-physical-security-standards. [Accessed: 17-Nov-2019].

[4] S. D. Scalet, "19 ways to build physical security into your data center," *CSO Online*, 31-Mar-2015. [Online]. Available: https://www.csoonline.com/article/2112402/physical-security-19-ways-to-build-physical-security-into-a-data-center.html. [Accessed: 17-Nov-2019].

[5] "Data Center Physical Security," *Infosec Resources*. [Online]. Available: https://resources.infosecinstitute.com/category/certifications-training/cissp/domains/security-engineering/data-center-physical-security/#gref. [Accessed: 20-Nov-2019].

[6] B. Dobran, "Data Center Security, the Often-Overlooked Data Security Risk," *PhoenixNAP Global IT Services*, 28-Sep-2019. [Online]. Available: https://phoenixnap.com/blog/data-center-security. [Accessed: 20-Nov-2019].

[7] "CLC-CWR CRAC Unit," *QCooling*. [Online]. Available: http://www.qcooling.com/crac-units/clc-cwr-crac-unit/. [Accessed: 15-Nov-2019].

[8] VertivHeadquarters, 1050 Dearborn Drive, Columbus, OH, 43085, USA. "Liebert Xtreme Density System Design Manual." (2017). Accessed: Nov. 14, 2019. [Online]. Available: https://www.vertiv.com/globalassets/shared/liebert-xd-system-design-manual_00.pdf.

[9] "Liebert FPC 150-300kVA". [Online]. Available: https://www.vertiv.com/en-us/products-catalog/critical-power/power-distribution/liebert-fpc-150-300kva/. [Accessed: 27-Nov.-2019].

[10] "Quick quote for raised floor kits", *Accessfloorsystems.com*, 2019. [Online]. Available: https://www.accessfloorsystems.com/index.php/quickquote/index/raisedfloorquoteform/. [Accessed: 20- Nov- 2019].

[11] “Rack-PDU-Basic-Vertical-208V-60A-21-C13-6-C19/P-AP6007A”. [Online]. Available: https://www.apc.com/shop/us/en/products/Rack-PDU-Basic-Vertical-208V-60A-21-C13-6-C19/P-AP6007A. [Accessed: 27-Nov.-2019].

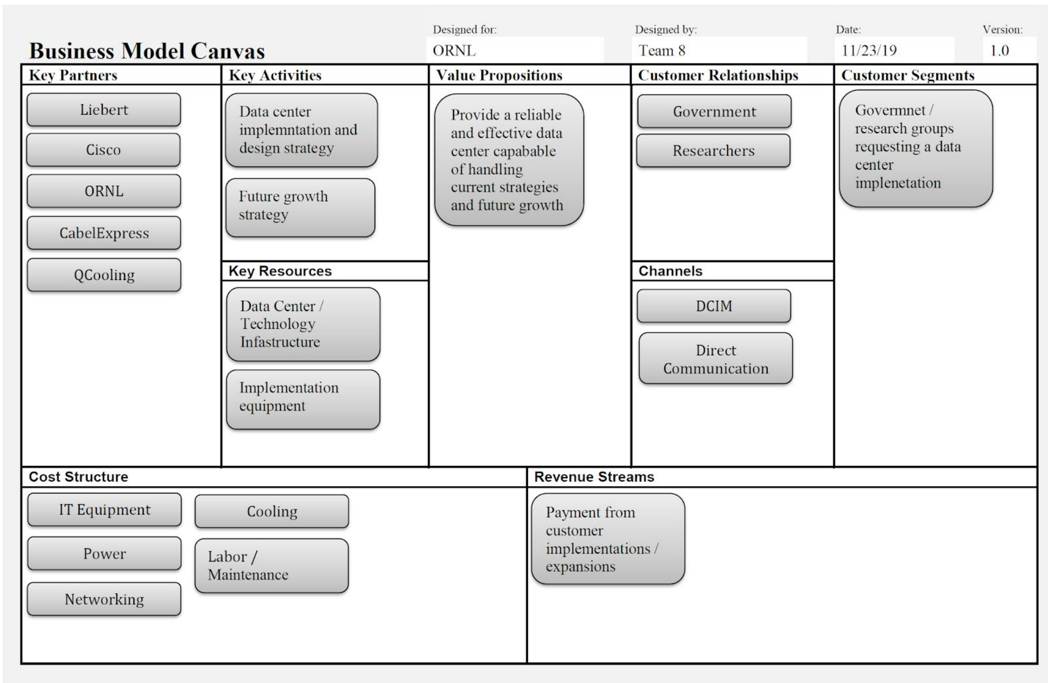
[12] “Vertiv-Liebert MSRP Price List”. [Online]. Available: http://accs.syndcs.com/liebert.pdf. [Accessed: 27-Nov.-2019].

[13] “750 kW Perkins Diesel Generator Set - Non EPA”, Americasgenerators.com. [Online]. Available: https://www.americasgenerators.com/750-kW-Perkins-Diesel-Generator-Set-Non-EPA.aspx. [Accessed: 27 Nov. 2019].

[14] “1200 kW MTU Diesel Generator Set - *UL2200”*, Americasgenerators.com. [Online]. Available: https://www.americasgenerators.com/1200-kW-MTU-Diesel-Generator-Set-UL2200.aspx [Accessed 27 Nov. 2019].

Appendices

Appendix A: Business Canvas Model



Appendix B: Quad Chart

Team 8
Quad Chart

Objective

- Provide a reliable and effective data center capable of handling current strategies and future growth.

Key Customers

- ORNL
- QCooling
- Cisco
- CableExpress
- Liebert

Key Partners

- Government
- Researchers

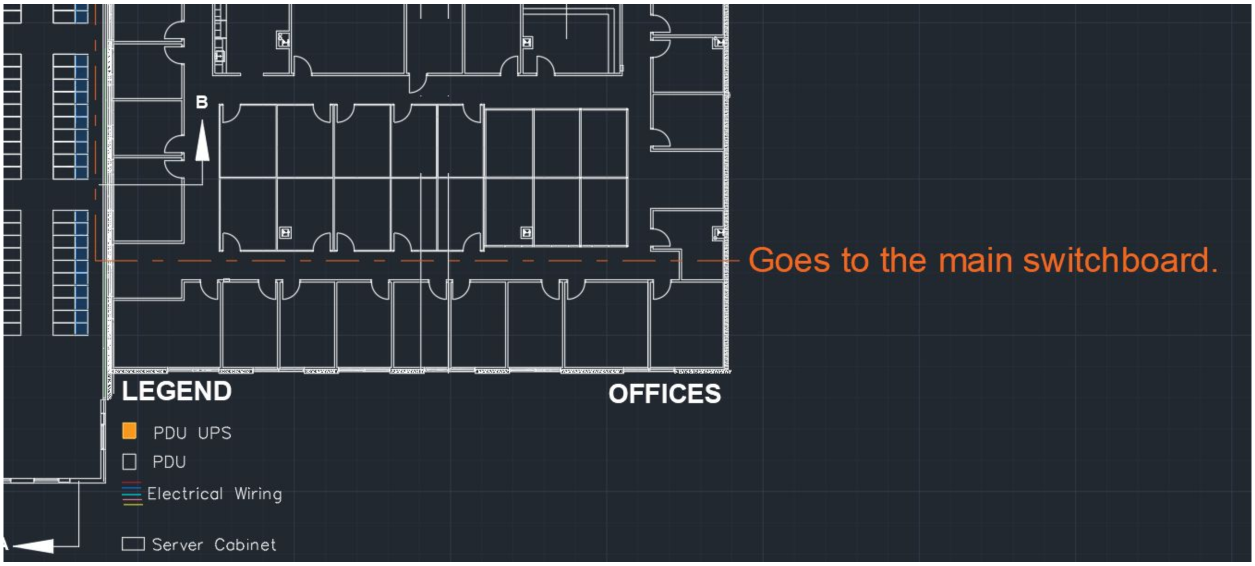
Cost Structure

- IT equipment
- Power
- Cooling
- Networking
- Labor / Maintenance

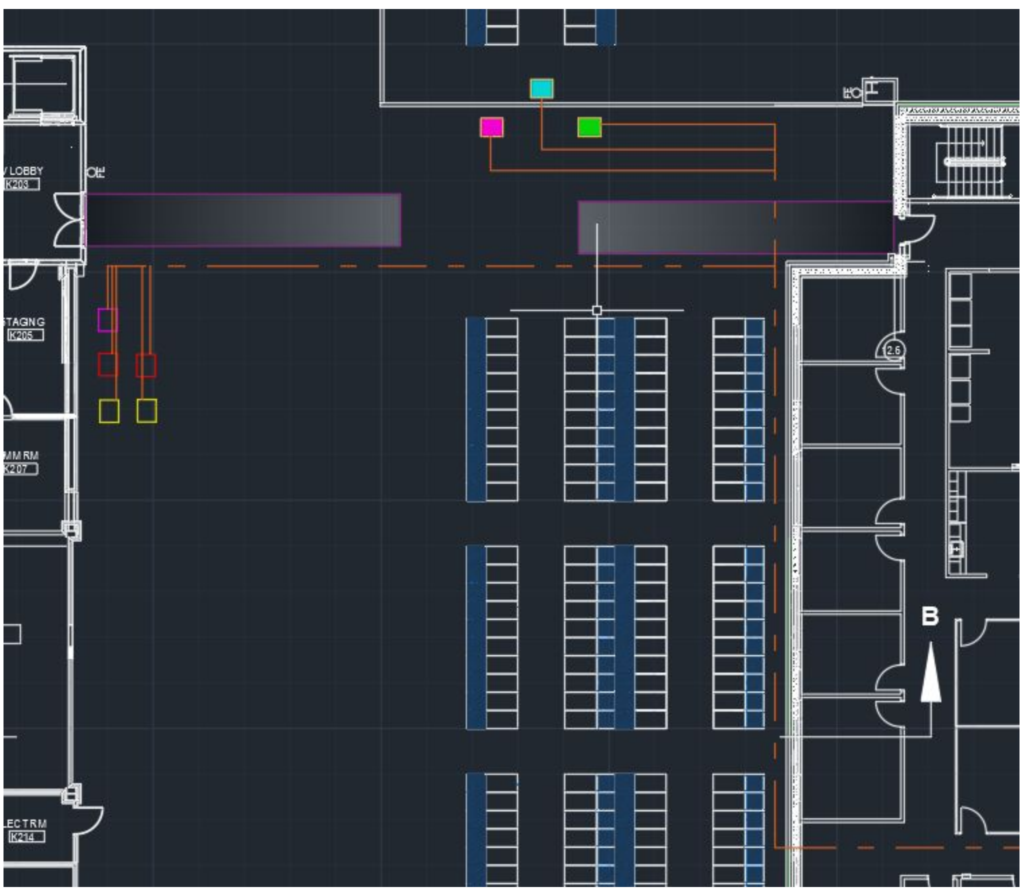
Key Resources

- Data Center / Technology Infrastructure
- Implementation Equipment

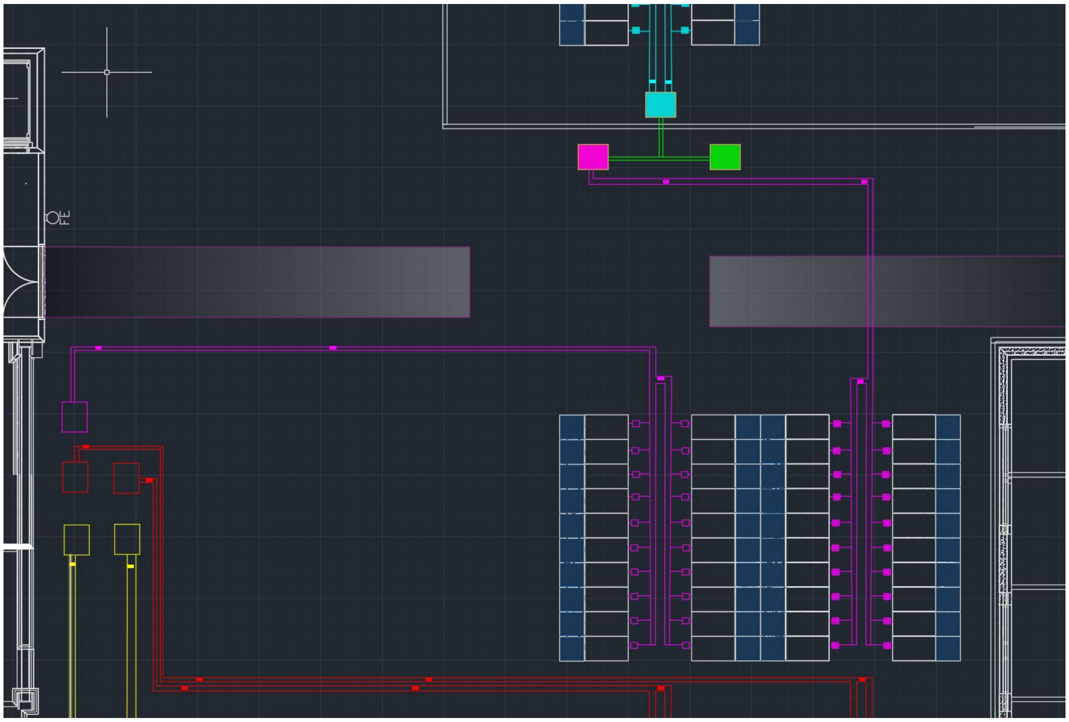
Appendix C: Closer view of the main electrical path from the main switchboard into the data center raised floor space. This path through the offices is in the first floor ceiling space.



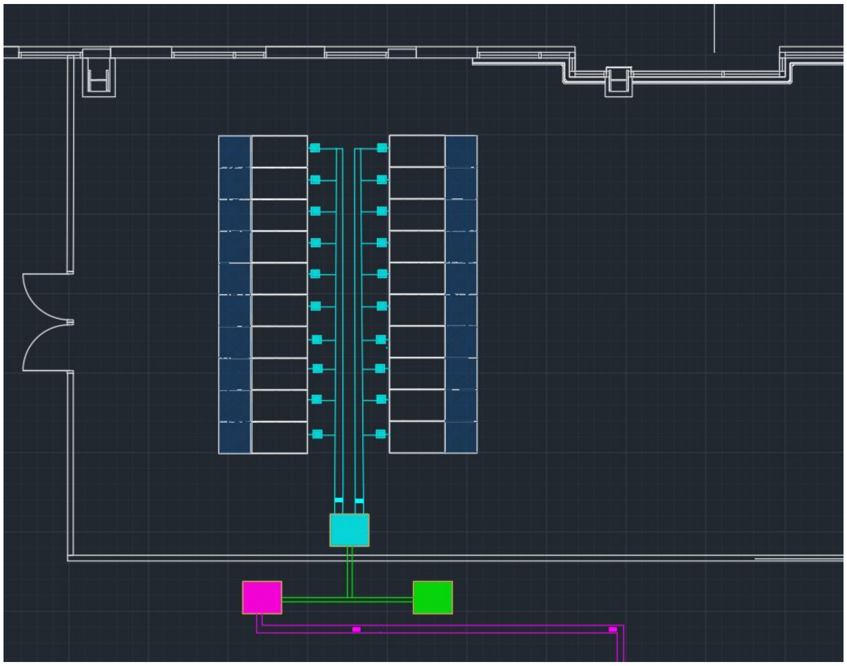
Appendix D: The electrical path then traverses in the data center raised floor space to the PDUs.



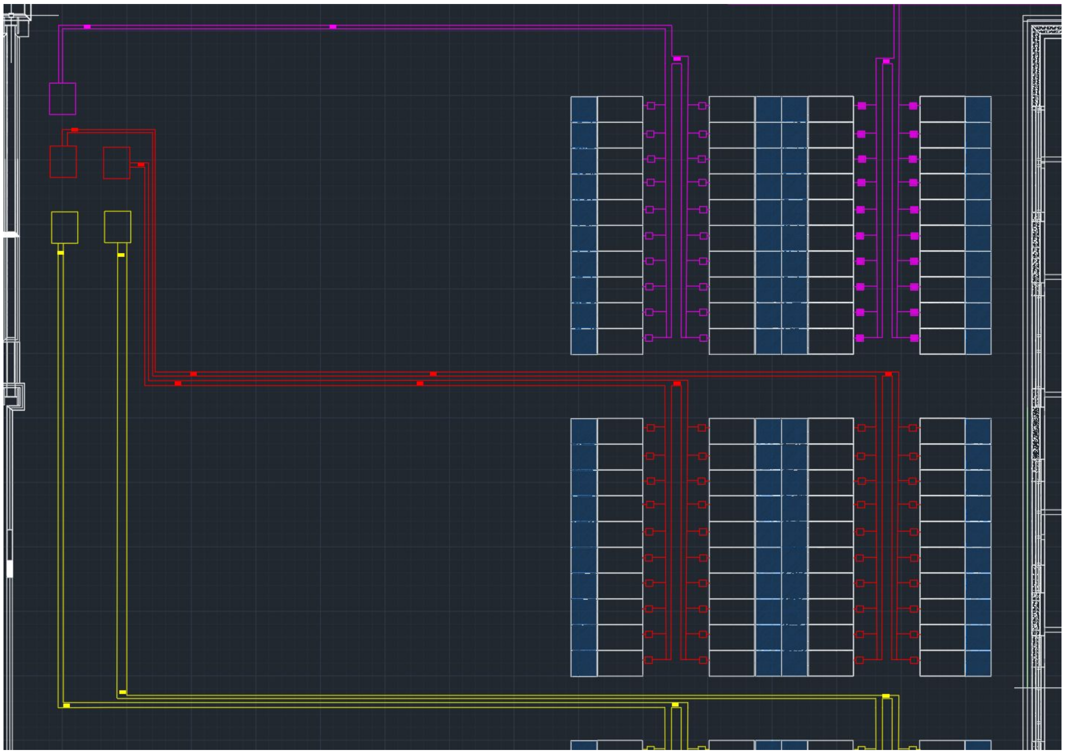
Appendix E: A close-up on the twenty racks with dual feeds with UPS source outside the secure access control area.



Appendix F: A close-up on the twenty racks within the secure access-control area with a dual feed UPS source.

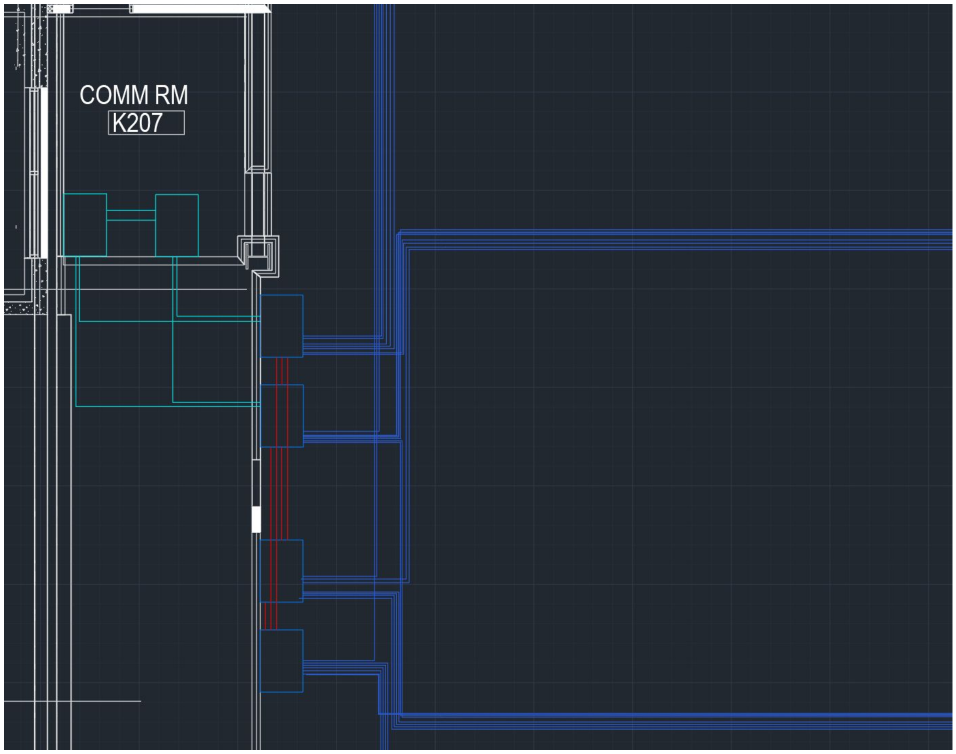


Appendix G: A close-up on the PDU bus connections to rack mounted PDUs.

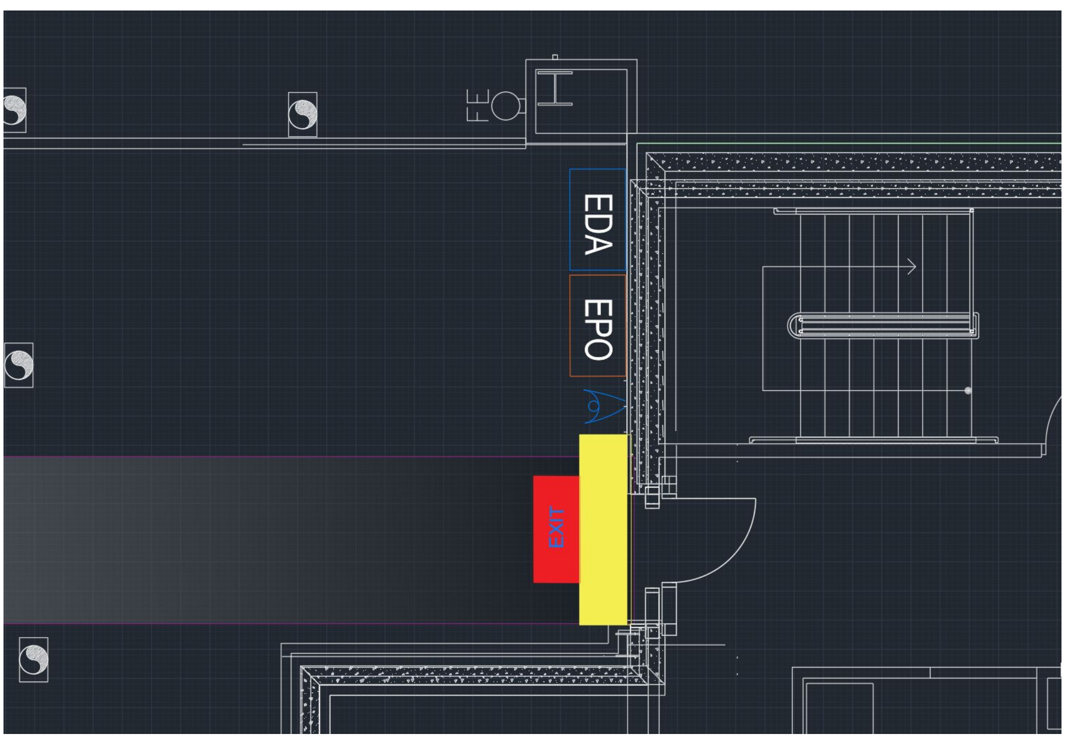


Appendix H: Secure access-control room rack network connection to access switches.

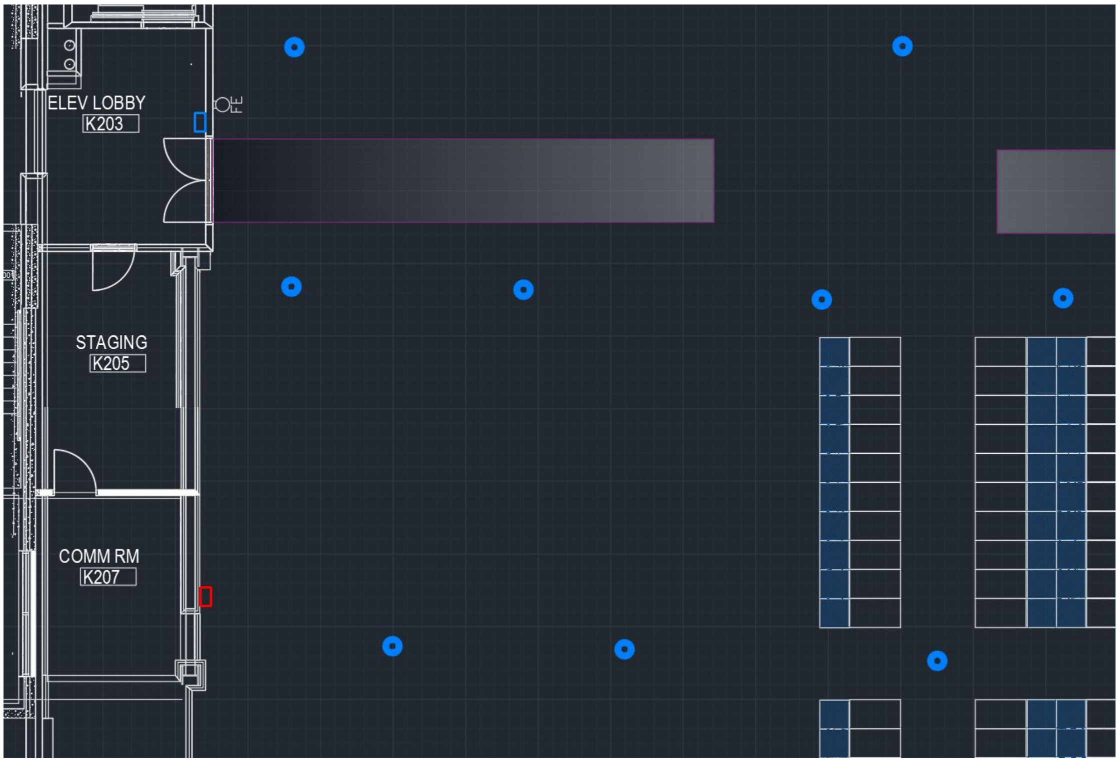
Appendix I: A close-up on the core layer switch and aggregation layer connections.



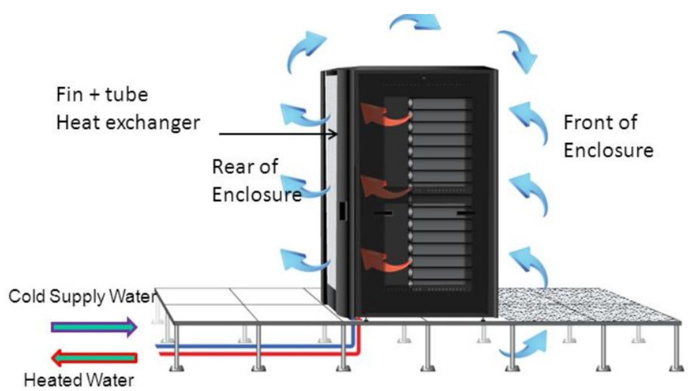
Appendix J: A close-up on the east data center exit ramp to the eastern offices.



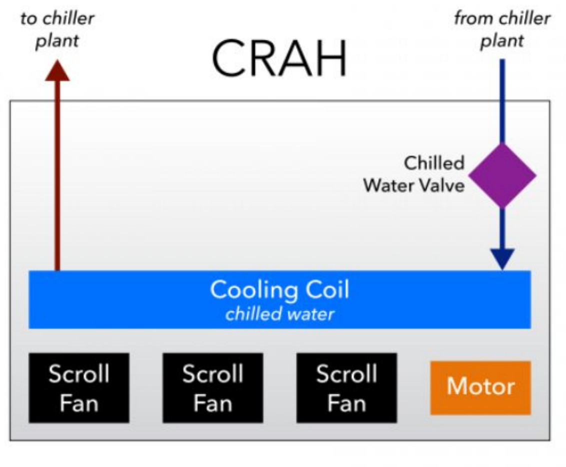
Appendix K: A close-up on the west freight elevator and communications room in the data center security diagram.



Appendix L: Air / Water Flow design.



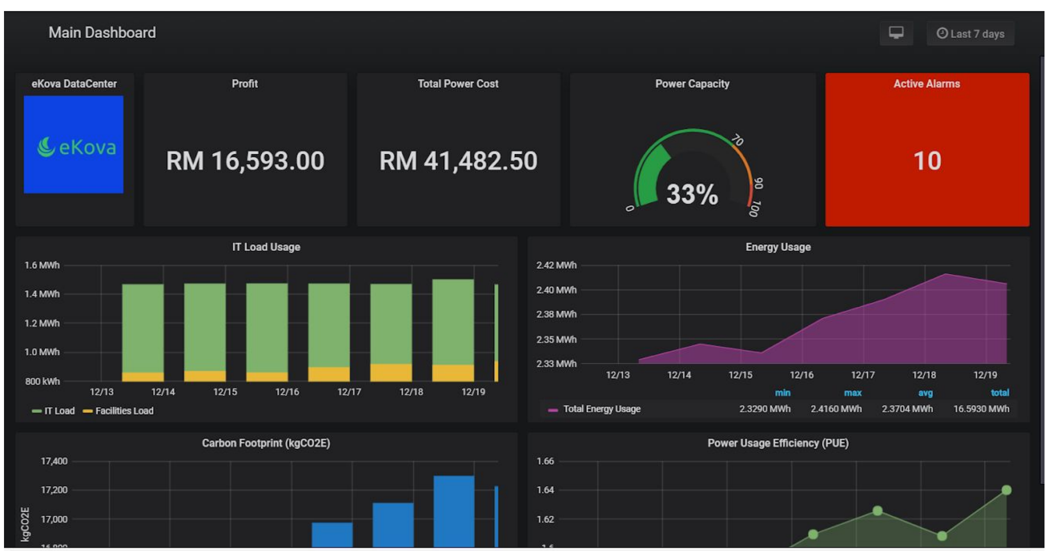
Appendix M: CRAH Unit.



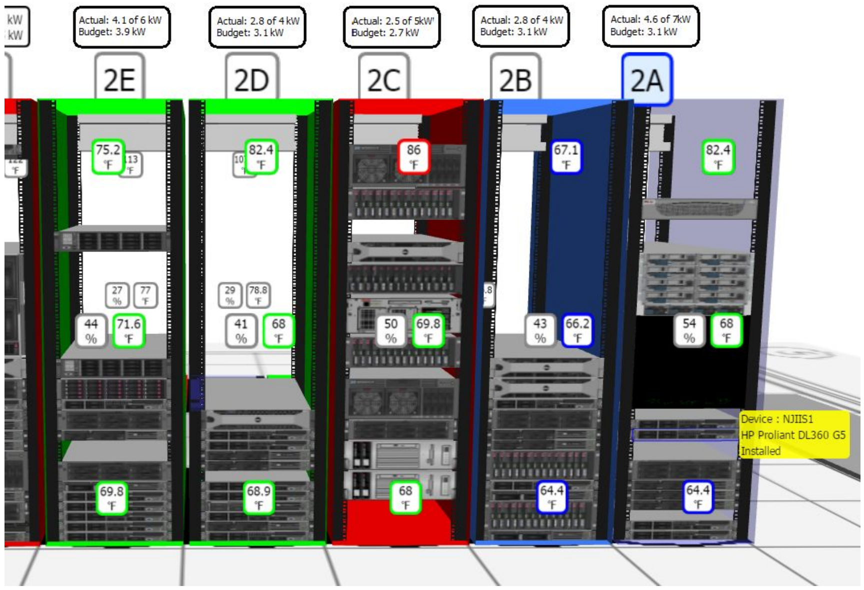
Appendix N: Rear Door Heat Exchanger.

Appendix O: DCIM High-level Floor Layout.

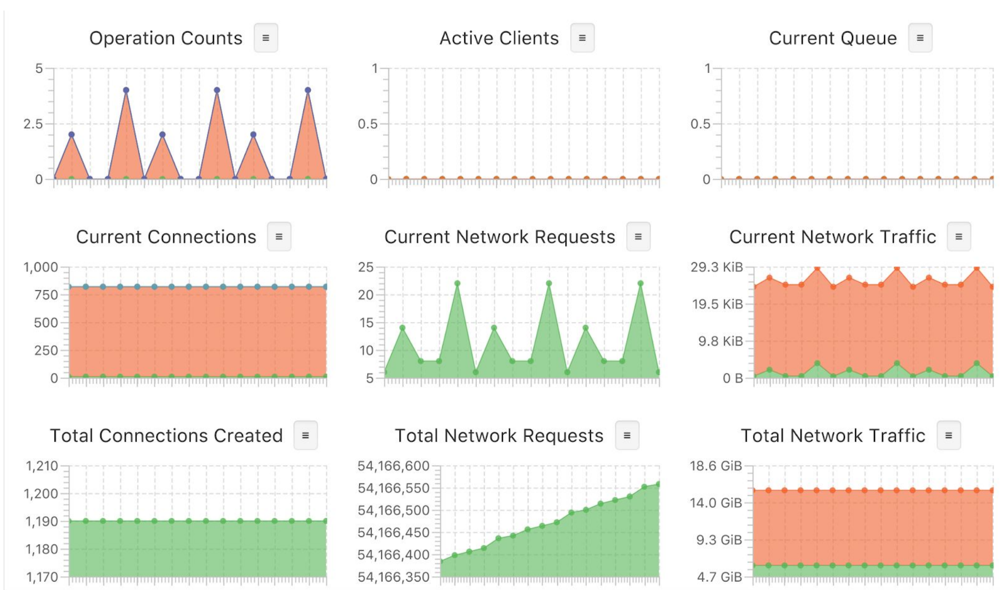
Appendix P: DCIM High-level Dashboard.



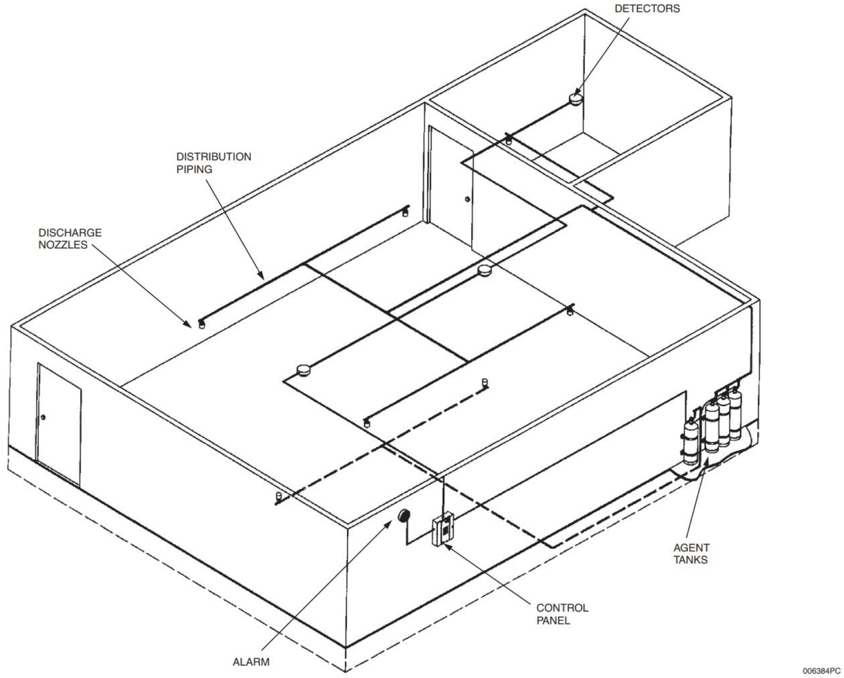
Appendix Q: DCIM Mid-level Layout.



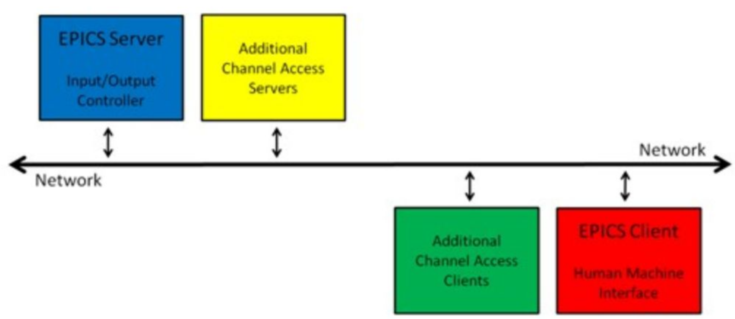
Appendix R: DCIM Low-level Dashboard.



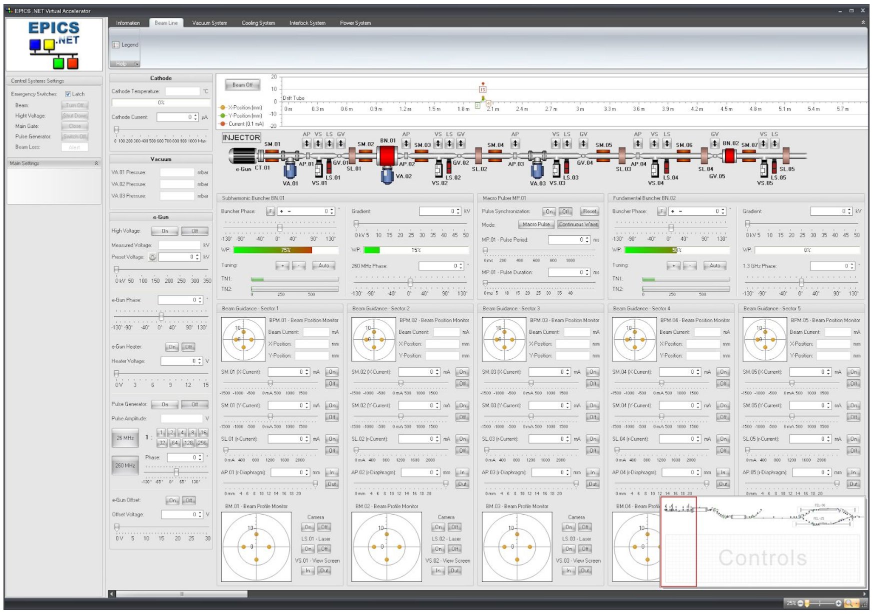
Appendix S: Sample FM200 Implementation.



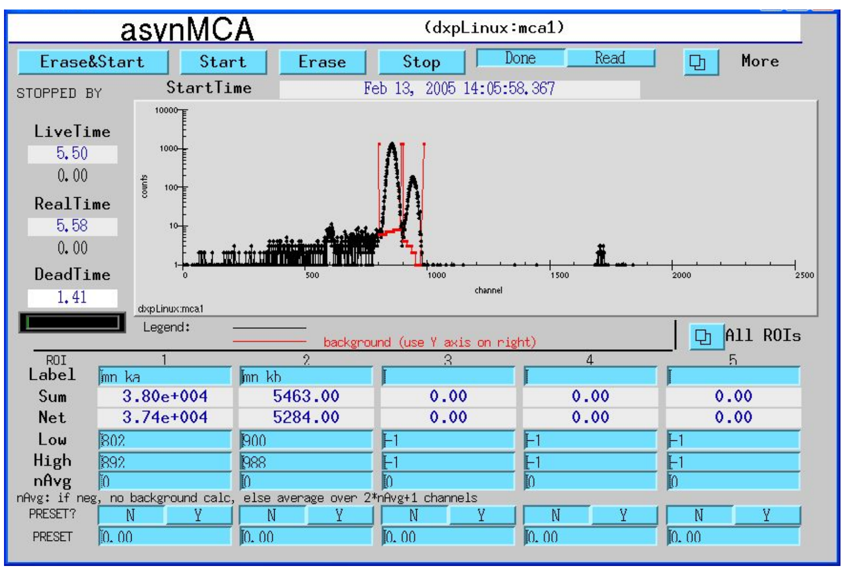
Appendix T: EPICS server / client layout.



Appendix U: sample EPICS dashboard.



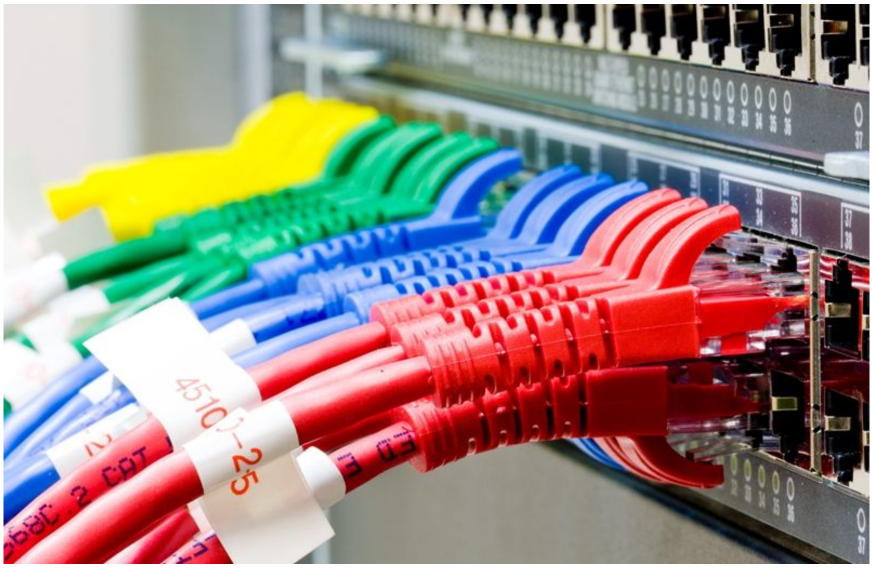
Appendix V: sample EPICS dashboard.



Appendix W: EPO signage.

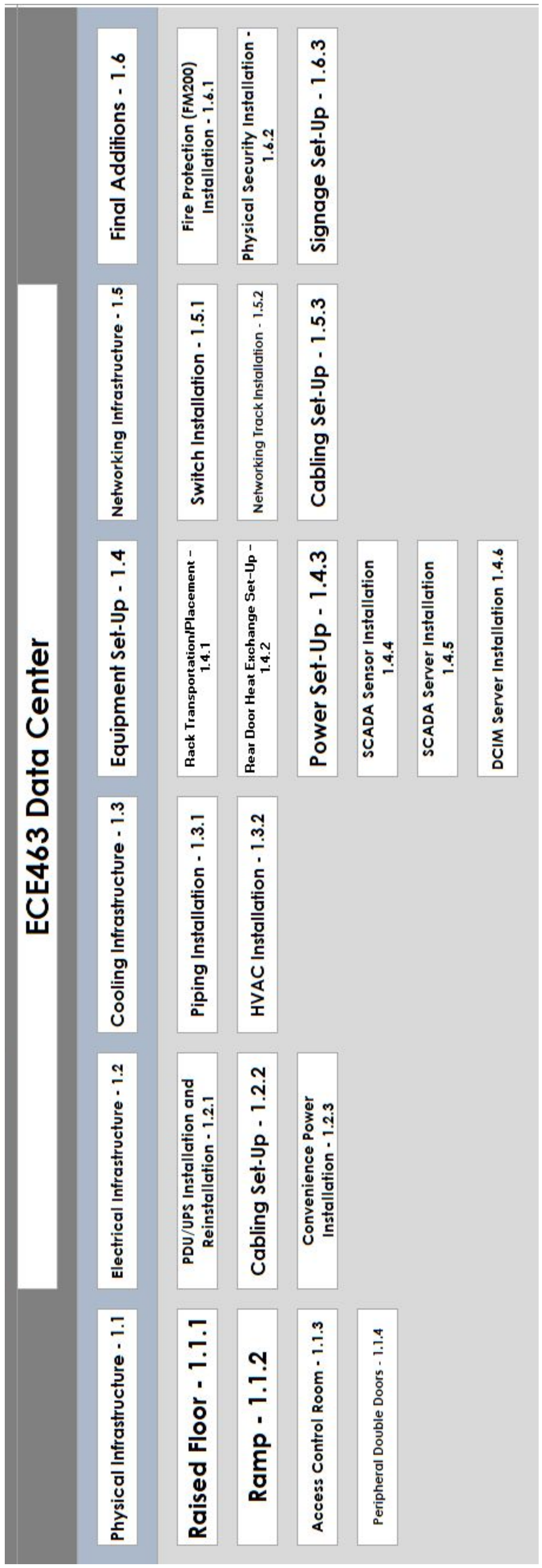
Appendix X: Circuit Breaker Signage.

Appendix Y: Cable Labeling.



Appendix Z: UPS labeling.

Appendix AA: Legible Work Breakdown Structure.



Appendix AB: Full Estimated Schedule.

ECE463 Data Center Project Schedule

Task ID	TASK TITLE	START DATE	DUE DATE
1.1	Physical Infrastructure	1/1/2020	3/1/2020
1.1.1	Raised Floor	1/1/2020	2/1/2020
1.1.2	Ramp	2/1/2020	3/1/2020
1.1.3	Access Control Room	2/1/2020	3/1/2020
1.1.4	Peripheral Double Doors	2/1/2020	3/1/2020
1.2	Electrical Infrastructure	3/1/2020	5/15/2020
1.2.1	PDU/UPS Installation and Reinstallation	3/1/2020	5/1/2020
1.2.2	Cabling Set-Up	5/1/2020	5/15/2020
1.2.3	Convenience Power Installation	5/1/2020	5/15/2020
1.3	Cooling Infrastructure	5/15/2020	8/1/2020
1.3.1	Piping Installation	5/15/2020	7/1/2020
1.3.2	HVAC Installation	6/15/2020	8/1/2020
1.4	Equipment Set-Up	8/1/2020	10/1/2020
1.4.1	Rack Transportation/Placement	8/1/2020	9/1/2020
1.4.2	Rear Door Heat Exchange Set-up	8/15/2020	9/15/2020
1.4.3	Power Set-Up	8/15/2020	9/15/2020
1.4.4	SCADA Sensor Installation	9/1/2020	10/1/2020
1.4.5	DCIM Sensor Installation	9/1/2020	10/1/2020
1.5	Networking Infrastructure	10/1/2020	11/1/2020
1.5.1	Switch Installation	10/1/2020	10/15/2020
1.5.2	Networking Track Installation	10/1/2020	10/15/2020
1.5.3	Cabling Set-Up	10/15/2020	11/1/2020
1.6	Final Additions	11/1/2020	1/1/2021
1.6.1	Fire Protection (FM200) Installation	11/1/2020	12/1/2020
1.6.2	Physical Security Installation	12/1/2020	1/1/2021
1.6.3	Signage Set-Up	12/1/2020	1/1/2021

January 1 15 · February 1 15 · March 1 15 · April 1 15 · May 1 15 · June 1 15 · July 1 15 · August 1 15 · September 1 15 · October 1 15 · November 1 15 · December 1 15