I, Daniel Miller, hereby submit this original work as part of the requirements for the degree of Master of Architecture in Architecture (Master of).

It is entitled:
Reconnection: Establishing A Link Between Physical And Virtual Space

Student's name: Daniel Miller

This work and its defense approved by:

Committee chair: Michael McInturf, M.Arch.

Committee member: Anton Harfmann, M.Arch.
Reconnection: Establishing A Link Between Physical And Virtual Space

A thesis submitted to the
Graduate School
of the University of Cincinnati
in partial fulfillment of the
requirements for the degree of

Master of Architecture

in the School of Architecture and
Interior Design of the College of
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By

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Abstract

The Internet has established itself as an essential part of the modern world. Socializing, shopping, banking, entertainment, and more, can now occur in a virtual environment. Companies have spent billions of dollars and thousands of man-hours developing the interfaces, websites, and devices that allow users to be constantly connected. The space beyond the screen, however, has advanced in a very different manner than that of the user interface. This unseen infrastructure is the physical response to the virtual demand. Warehouse sized servers, internet exchange points, and thousands of miles of cabling combine to create a machine that actively challenges the epithet of “the cloud.”

This thesis attempts to create a design process for data centers that places importance on client identity, site response, and user interaction. Data centers are the foundation of the Internet, providing storage, processing, and hosting for nearly every web-based action. The design of a data center that exposes its function, while serving as a connection point to the intangible virtual environment, has the opportunity to change the way users view data. The cloud is not simply a virtual space to store information and interact with distant users; it is the tangible monument of our digital selves.
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Figure 1: Typical Data Hall Aisle
There is little doubt that the defining machine of our society is the computer. The rapid growth in the computer industry has led to changes in almost every realm of society. According to George Gilder, the invention of the microchip in 1972 is the spawn of modern information technology movement. This technology made it possible for computers to perform more tasks, in a smaller space, while using less electricity. While this made computers less expensive and more available to a wider audience, it was another technology that allowed computers to transform society. Starting with the first transmission across ARPANET on October 29, 1969, the Internet was born. The Internet is still a growing part of the modern world. As tasks move to digital format, there is an increased need for storage and networking. This need for storage has led to the creation of data centers.

A data center is a building or location containing a large group of networked computer servers used for the remote storage, processing, or distribution of large amounts of data. These centers can range from modular trucking containers, up to million square foot complexes. In 2012, Andrew Blum published Tubes, a book about journeying to various points of the Internet. He travels to intercontinental connection points, Internet exchange points, and data centers. When describing data centers he states, “A data center doesn’t merely contain the hard drives that contain our data. Our data has become the mirror of our identities, the physical embodiment of our most personal facts and

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feelings. A data center is the storehouse of the digital soul.”

As data centers become more prevalent in our built environment, should there be consideration given to the impact of this new typology in the architectural discourse?

It is important to define the role of the architect as a mediator between the formal and functional requirements of data centers. In an ArchDaily article, entitled “Data Centers: Anti-Monuments of the Digital Age”, Vanessa Quirk discusses how the idea of “the Cloud” is a misconception that hides the truth of the Internet’s footprint. Quirk discusses the current approach to the data center typology; “to make architecture so technically efficient, that the architecture becomes the machinery, and the machinery the architecture.”

This method of thinking is reminiscent of Le Corbusier’s “Machine for living in” or Mies van der Rohe’s “Machine Aesthetic.” The current state of data center typology has state of the art technology hidden behind a veil of blank, unbroken facades. Quirk and Blum see this as an attempt to create “anti-monuments that declare their own unimportance.” The question of what impact this has on architectural discourse is posed by Quirk, “if architecture is the expression of our society’s values and beliefs, then what does this architectural obliteration mean? That we are willfully ignoring the process that creates the data we daily consume.”

This thesis attempts to create a design process for data centers that places importance on client identity, site response, and user interaction. Data centers are the foundation of

3 Ibid, 229.


5 Ibid.
the Internet, providing storage, processing, and hosting for nearly every web-based action. The design of a data center that exposes its function, while serving as a connection point to the intangible virtual environment, has the opportunity to change the way users view data. The cloud is not simply a virtual space to store information and interact with distant users; it is the tangible monument of our digital selves.
The Internet has become an essential part of modern society. But, when we talk about the Internet, what is being discussed? The Internet can be viewed at two parts, the physical and the virtual. The physical is comprised of the infrastructure; data centers, internet exchange points, routers, hard drives, miles of cable, etc. The second part is referred to in this paper as the virtual; the 1’s and 0’s, the packets of information, the websites, the emails, the chat rooms, and dating sites. All of these have a very physical presence as information magnetically written onto hard drives, rays of light traveling through fiber optic cables, and pixels illuminated on a screen. What makes them the virtual is their perception by the user. The experience created by these numbers and pulses of light and electricity create a world that the mind occupies while the body remains in front of a screen.

What if the physical side of the Internet could contribute more to the user’s experience? What if a data center could create a place that compliments the virtual environment, instead of simply supporting it? For this to occur, data centers would need to offer more to users than just the virtual environment. Marc Augé describes the idea that a building needs to offer more than walls to create place through his definition of the non-place. He defines non-place by stating that, “If a place can be defined as relational, historical and concerned with identity, then a space which cannot be defined as relational, or historical, or concerned with identity will be a non-place.” Many data centers fail to meet Auge’s definition of a place due to a lack of relation and identity.

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Figure 5: Apple Data Center
Maiden, NC

Figure 6: Microsoft Data Center
San Antonio, TX

Figure 7: Microsoft Data Center
Dublin, Ireland
Relation

Data centers fail to meet Marc Auge’s definition of a place for several reasons. First, there is very little relationship between data centers and their sites or users. For reasons of security, data centers often establish their presence on a site by constructing fences (Figure 8) and earth mounds that separate them from the surrounding context. Closed facades eliminate any visual connection that occurs through the fences. In addition to efforts on site that limit external relations, the chosen location often moves the data center far from any users. While this is often done to take advantage of low land and electricity costs, the remoteness increases the disconnection between the physical user and their virtual self. The lack of relation between users and their data is further compounded by the lack of identity of most data centers.

Figure 8: Anti-climb, K-Rated Fencing
Figure 9: Chart of Infrastructure Design Strategies
Identity

Most data centers have very little concern with expressing their function. They live in ubiquitous boxes that act to conceal their purpose, rather than promote it. This process is employed, in part, with the hopes of added security through ambiguity. This data center design strategy is questioned by Corbin Keech who states, “a formal observation exposes [data center’s] inherent contradictions, they reveal nothing about the complex machinery within, while broadcasting the apparatus within requires protection and constant monitoring.”¹ This conflict of security through concealment versus security through protection has been handled in a contrasting approach by the typology of banks. Rather than hiding banks far from users, they place them in central, accessible locations. The banks broadcast their strength and security by exposing the massive vaults that protect their products. A data center’s ability to use the hidden and remote approach to security stems from the manner in which its users interact with the product. Rather than walking into the building and trading data with a teller, users connect through miles of cables.

The lack of exposure and limited proximity to users has left very little demand for data centers to develop a unique identity or typology. The opportunity for identity has two paths. First, the data center can develop an identity for the machine that is the Internet. Currently, it holds a false identity of “the cloud.” Expression of internal components, exposure of massive energy requirements, and celebration of societal importance can create an identity for data centers that reflects their role. The second identity that can be created or promoted by data centers is that of the institution, client, or business that commissions them. The construction

¹ Corbin Keech, Mies Reprised, CLOG: Data Space (Canada, Clog, 2012) 15.
Figure 10: Bahnhof’s Pionen White Mountain Data Center has developed an Identity through its design and site history.
of a data center is a massive expenditure that takes state-of-the-art equipment and pushes it to its threshold. There is an opportunity for the finished product to celebrate the institution and promote their goals and values of technological, environmental, and social advancement.

The identity of data centers and our relation to them create an experience that occurs in the physical environment, not the virtual environment. This new experience can change data centers from anti-monuments of infrastructure, to monuments of technology and the institutions and societies that created them.
Figure 11: Facebook Data Center, Prineville, Oregon.

Figure 12: Evaporative Coolers in the Facebook Data Center.

Figure 13: Syracuse Data Center, Syracuse University.

Figure 14: Microturbines for Primary Power, Syracuse Data Center.
Facebook uses its data center, in Prineville, Oregon, as a flagship for data center design. Douglas Alger, in The Art of the Data Center, explains the strategy:

”Believing in the efficiency and innovation of the building’s design—and the environmental benefits of extending that to other parts of the Internet’s infrastructure—Facebook has published all the plans, all the way from the custom-designed motherboards to the unusual swamp cooler-like system that keeps the building cool. Architecture always expresses the ideals of an organization. In Facebook’s case, this meshes with Mark Zuckerberg’s founding vision of making the world more open and connected.”

While Facebook utilized its data center as a showpiece for company policy, Syracuse University utilized its data center for research purposes. Alger states that the data center “serves dual functions as a hosting location for University IT services, as well as being a full scale testing ground for data center technologies. The building brings together multiple programs, including labs and meeting spaces, to minimize waste heat and increase efficiency. The site serves as a successful example of Universities allowing infrastructure to become a learning opportunity.”

The possibility exists for a data center to take on multiple roles, serving as both a learning space and a monument to a university’s position on technology.

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2 Ibid, 299.
Figure 15: High Tension Power Lines
In addition to the impact of data centers in the architectural discourse, there is also a need to address the environment impact of the infrastructure. According to the US Environmental Protection Agency’s Report to Congress on Server and Data Center Energy Efficiency, data centers use 1.5% total U.S. electrical consumption in 2006.\(^1\) With the growing amount of power use, it is important to incorporate power saving principles into the design process. The use of passive cooling, waste heat recovery, and alternative energy sources can reduce the overall energy impact of data centers.

The total electrical load required by a data center consists of three loads: server loads, cooling loads, and operational loads. The operational loads include lighting and hvac for support spaces, IT staff computers, and other basic building operations. The server and cooling loads are the two largest demands. Every watt of IT capacity contributes 3.41 BTUs per hour that must be removed. As data centers grow into the megawatt IT range, the heat load becomes a major issue. The cooling systems must remove millions of BTUs to protect the sensitive equipment. The efficiency of data centers is measured by a ratio of the IT energy use to the entire facility use. The Power Utilization Effectiveness, or PUE, shows how much energy is not being used to directly power the IT equipment. A PUE of 1.0 means that all power entering the facility is being used to run the servers. As air handlers, chillers, lights, and water pumps are added, the PUE increases.\(^2\)

While PUE is a good indicator of electrical use, there are

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Figure 16: Chilled Water Piping, Google Data Center
many other factors that contribute to the environmental impact of data centers. Water use and generator emissions also have a large ecological footprint. Cooling towers used to remove waste heat from servers consume millions of gallons of fresh water each month. Standby generators produce exhaust when in operation, which even without power interruption, occurs for testing several times per month. There is also material waste through the use of standby batteries and replaced hard drives that must be destroyed and disposed of.

3 Douglas Alger, Grow a Greener Data Center (Cisco Systems, 2010), 39.
Figure 18: NSA Data Center
Bluffdale, Utah

Figure 19: NSA Headquarters, *The Simpsons Movie*
It is 2007: Marge, Bart, Lisa, and Maggie sit on a train bound for Seattle. As fugitives of the law, they speak in whispers about their escape plan. Queue the shot of the National Security Agency building, in Fort Meade, Maryland. The camera pans along row after row of operators watching monitors and listening to calls. The conversation of the fleeing fugitives is intercepted and they are apprehended to face justice. This story is a scene from “The Simpsons Movie.” It is a lighthearted look into the big-brother government agency that culminates in a character exclaiming, “The government finally found someone we were looking for.” The scene had little resonance at the time, being largely overshadowed by the larger story. It was not until June 5th, 2013, that many Americans, along with citizens of many other countries, learned that the NSA was performing monitoring actions without the use of warrants or probable cause.

Edward Snowden broke into the public spotlight with his release of classified NSA documents to The Guardian newspaper. The documents exposed secret US government programs that permitted wire-tapping, data interception, and other forms of spying on almost any telecommunication user. This exposure cast a veil of distrust on the NSA at a time when they were beginning construction on a massive new data center. The center will store collected information so that data mining processes can attempt to extract information that might represent a future threat to national security.

Every data center serves a unique role for the government,

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1 The Simpsons Movie, dir. by David Silverman (2007; 20th Century Fox).

Figure 20: NSA Headquarters, Fort Meade.

Figure 21: NSA Data Leaker, Edward Snowden.
institution, or company that commissions them. The breach of trust caused by the NSA programs has spread to the entire industry. The growing skepticism of data centers can be counteracted by an architecture that emphasizes and celebrates transparency while maintaining security.
The architect has often shaped the built environment around the technology of the time. Building construction and techniques followed the ideals of society and reflected the social context in which they emerged. Universities have often been at the forefront of technological advancement, including the origins of the Internet through ARPANET. This makes university data centers a prime source to initiate change. Syracuse University used its recent data center project as an opportunity to create a functioning research environment inside an active data center. While many new technologies were implemented, including the use of on-site power generation, the center left the architectural portion of the data center largely untouched. The state-of-the-art facility is housed in a windowless metal-sided building that sits in a remote campus parking lot. In order to engage the architectural issues present in the current data center field, it is necessary to combine internal technological advances with architectural intervention.

The University of Cincinnati started in 1819 as a collection of smaller schools, including Cincinnati College and the Medical College of Ohio. The Cincinnati Board of Education chartered the University of Cincinnati in 1870. The University moved to the current main campus site, south of Burnet Woods, in 1889. The campus did not receive state funding until 1967. The campus remained primarily a commuter campus through the 1970s and into the early 1980s. In 1984 university president Joseph A. Steger commissioned landscape architect George Hargreaves to develop a master plan for the main campus and medical campus. Through the next two decades the campus underwent major renovations, including the addition of many signature buildings. The campus improvements have managed to boost enrollment: 2013 fall enrollment was 41,970 students, up from
Figure 23: McMicken Hall, University of Cincinnati
33,823 in fall 2003. This drastic increase in population has added new demands to the university. There is a growing set of critical infrastructure that is supporting the growing university. With only 3,900 on-campus residents, the majority of students only access the campus temporarily. This makes the campus a hub with thousands of occupants entering and exiting each day.

While universities used to rely on the physical boundaries, aesthetics, and buildings to define their campus, the move to the digital environment is blurring those lines. Students can take courses online, access university information and libraries remotely, and take virtual tours of the campus. The expression of the virtual environment requires the university to update its infrastructure. With current data center functions at UC reaching critical mass, there is an immediate need for additional capacity. The new data center will provide disaster recovery, redundant equipment and uninterruptable power supplies that will allow the center to stay online in the event of power failure. The design of a new data center should be taken as an opportunity for the university to expand storage functions, address research capabilities, educational opportunities, ecological responsibilities, and client identity.

There has been a push in the United State’s education system for a focus on Science, Technology, Engineering, and Math, or STEM, as a way for the US to be a world leader in technical innovation. As a research institution, it is important for UC to stay at the forefront of technology that aids and improves that process.

University of Cincinnati Mission Statement:

The University of Cincinnati serves the people of Ohio, the

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Figure 24: University of Cincinnati Seal
nation, and the world as a premier, public, urban research university dedicated to undergraduate, graduate, and professional education, experience-based learning, and research. We are committed to excellence and diversity in our students, faculty, staff, and all of our activities. We provide an inclusive environment where innovation and freedom of intellectual inquiry flourish. Through scholarship, service, partnerships, and leadership, we create opportunity, develop educated and engaged citizens, enhance the economy and enrich our university, city, state and global community.²

The UC mission statement makes it clear that research and technology are key to the success of their institution. Research is often used as the public face of a university. It shows taxpayers, future students, and industry professionals what the university has to offer. The image of UC as a public research institution would greatly benefit from a space that competing schools cannot compare to. In addition to UC’s status as a research institution, it is also highly respected for design. The integration of arts and sciences, through the architectural design of a Technology and Research Innovation Center, will provide UC with the tools it needs to remain a leading public research institution.

The University of Cincinnati Information Technologies, UCIT, operates the existing data center for the university. The description below is from the UCIT website:

As you can imagine, the university needs to store a lot of information. As we move away from paper files and archives and towards electronic storage and processing, our needs for data storage and capacity grow very quickly…³

The current, outgrown data center does not allow UCIT to operate to the efficiency and quality standards that befit this university.


Figure 25: University Avenue Garage, UC West Campus
Project

The proposed project is a data center and pedestrian bridge at a key location between the East and West campuses. The site provides close proximity to the University Power Center, as well as site frontage along two heavy vehicular corridors. The design of the data center focuses on creating a transparency between users and infrastructure. This is accomplished through the use of a broken façade, interwoven spaces, and program adjacencies that will immerse users in the machine of the Internet.

The façade of the data center is made up of three systems: a glazing system, an opaque wall system, and a metal screen system. The opaque wall system is used to define the main volume of the building; a series of intersecting masses that house the different programs. The glazing system is used to break the solid façade, allowing for views into and out of the building. The location of the glazing allows for natural day lighting, including some of the data halls.

The metal screen system is used for two purposes; to add a layer of information and to have continuity on all sides of the building. The information layer takes an important part of the client’s culture, the UC Alma Mater, and creates a sculptural form that celebrates the physical side of data. To create the pattern for the metal screen, the UC Alma Mater was converted to binary. The pattern is then used to place the cutouts in the metal. In order to respond to views at various distances there are three scales of cutout used. The smallest scale is used in close proximity to pedestrian paths, while the larger cutouts occur above paths and on the roof. Due to the location and the extension over the street, the building is visible from all sides. The tall dormitories to the West provide views down onto the rooftop, while the underside is exposed to vehicular and pedestrian traffic. The metal screen creates a unified form that extends out beyond the edges of the building and becomes part of the bridges and landscape.
Figure 26: Pattern Sample from UC Alma Mater

Figure 27: Facade Pattern on de Young Museum, Herzog & de Meuron.
The metal screen takes code that typically travels as pulses of light, and lives as magnetized fragments on a disk, and creates a permanent object that can be seen and touched. The static surface becomes dynamic through its interaction with sunlight, rain, and wind, without the use of electricity. The façade’s representation of data becomes a monument that expresses the unseen physical structure of the Internet.

The addition of the pedestrian bridge to the data center program allows for the direct interaction of users and data. The bridge also allows for the physical connection of the two campuses to be juxtaposed with the virtual connections created by the data center. The connection of new and old infrastructure will reaffirm the massive physical impact of the Internet. Even as people move to virtual connections, there is a built environment that supports it.
The placement of the new data center near existing infrastructure allows for the juxtaposition of technologies. The decaying structure of the university avenue garage is a product of vehicular technology. The roads surrounding the campus allow for connections for drivers, while severing the pedestrian link between West and East campus.

By reestablishing the pedestrian connection between campuses, attention is drawn to the scale of vehicular and virtual infrastructure. The data center establishes a physical, visual, and experiential connection between users and the university.
Figure 31: Climatic Zone Map
Climate

Cincinnati belongs to a climatic transition zone, at the northern limit of the humid subtropical climate and the southern limit of the humid continental climate zone. These are defined as zones three and nine by Norbert Lechner. The region has an average of 5248 heating degree days, with only 996 cooling degree days. This means there is an opportunity for passive cooling techniques utilizing cool outside air. The location inside humid climatic zones will make it hard to utilize evaporative cooling systems, as seen in Facebook’s Prineville, Oregon, data center. The humid air does not accept moisture as easily as dry air, reducing evaporative cooling efficiency.

It is seen in Figure 35 that, annually, wind is prevalent out of the southwest. While this is useful, it is also important to know the prevalent direction for different parts of the year. Figure 36 shows the change in wind patterns over four quarters of the year. It can be seen that winter winds originate mainly from the southwest, while summer winds are more dispersed. This means that in the warm summer months, wind direction will be less defined for passive cooling. This will require apertures on multiple faces to gather wind.

The psychrometric chart, shown in Figure 37, shows what passive design approaches can be utilized to attain the desired indoor conditions. In addition, the information is necessary to determine the effectiveness of evaporative chillers and outside air economization required to maintain the data hall environment.

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Figure 32: Cooling Towers
Functionality of critical data center processes is key. The space must create a controlled environment that allows servers to operate at peak performance. ASHRAE TC 9.9: 2011 Guidelines for Data Processing Environments provides a set of standard operating guidelines for optimal IT equipment performance.\(^1\) IT manufacturers with the support of the ASHRAE committee created the document to establish acceptable conditions in server environments. The recommended internal environmental conditions will be the main driver for defining temperature, humidity, and dew points of the data hall. Beyond environmental conditions, arrangement of data halls and support space are crucial to performance, maintenance, and security.

**Programmatic Elements**

Data centers have a basic set of spaces required to operate. It is important for these spaces to be scalable in order for the building to respond to an increase in demand. The following spaces are found in most data center environments.

**Office:** Space is required for data center operators to work. This is provided on-site or remotely within a larger office. With the high demand of a university IT department, it is necessary to include office space in close proximity to the data hall.

**Server Room/White Space:** This is the most demanding environment in a data center. There are tight restrictions on temperature range

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Figure 33: Typical Data Hall White Space.
and fluctuation rates, relative humidity, and dew point. These rigid controls provide optimal performance conditions for the IT equipment inside. The internal gains from IT equipment require a mechanical system capable of removing large amounts of heat during operation.

**Mechanical Rooms:** The requirements of the mechanical space fluctuate depending on the systems being employed. In the case of a university, there is the opportunity to use a centralized utility plant to provide heating/cooling to individual buildings. This reduces the mechanical footprint within the data center. In addition to a source of chilled water/air, data centers must be able to redirect heat away from the data hall. The heat can be expelled into the environment through cooling towers and heat sinks, or recovered and transferred to adjacent buildings during winter heating months. The University of Cincinnati’s Campus Utility Plant will provide chilled water to the data hall through the existing distribution tunnels.

**Electrical Rooms:** An uninterrupted power supply is required for the IT equipment and the supporting mechanical equipment. Utility power and/or onsite generation can be used to provide main power. Depending on the reliability desired back-up power is provided to allow IT and HVAC equipment to function during a power loss, or simply enough power to allow for a controlled shutdown. The main power to the data hall will be fed from the Campus Utility Center substation. This power is generated by the local utility and supplemented by the university’s turbine generators.

**Fire Protection:** Due to the high amount of electrical components dense environment, there is a high risk of fires. This risk is minimized by regular maintenance that reduces the risk of equipment failure. When preventative maintenance does not work, the fire suppression system must function with as little impact on functioning equipment as possible. This can be achieved through the use of water-mist systems, gas systems, and early detection devices.

In addition to the internal program, adjacent spaces will be used to increase the efficiency of the data center. Neighboring residence halls, including Morgens Hall and Scioto
Figure 34: Bahnhof Data Center Conference Room
Hall, allow for waste heat from the data center to be captured and reused. The close proximity to the data center will provide a strong visual connection to the on campus residents. This connection will be improved by devoting a portion of the site to future residential or academic development.

**Size Requirements**

The following spaces are sized to meet the University of Cincinnati’s IT needs for the near future. The design must allow for expansion in order to avoid becoming obsolete when demand increases. Careful consideration must be placed on the scalability of the data hall, support spaces, cooling capacity, and electrical supply.

In addition to an increase in future IT demands, space must be set aside to allow for the growth of other university program. The master planning of future academic or residential space will create a long-term approach for the section of campus.

**Spatial Relationships**

The placement of the data center within the existing campus will place students and faculty in close proximity to the infrastructure they depend upon. Neighboring buildings will benefit from the data center’s processes, capturing waste heat and recycling chilled water. The program must be arranged in a way that provides user visual access, without physical connections. Physical connections, including water pipes and network cables will occur in existing underground infrastructure.
Bibliography


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Appendix

Climate

Temperature Data

Wind Charts

Psychrometric Chart

Program

Diagrams
## Appendix - Climate

|                | Precipitation (in) | Temperature (F) | Heating Degree Days | Cooling Degree Days | Relative Humidity (AM|PM) |
|----------------|--------------------|-----------------|--------------------|--------------------|----------------------|
| Jan            | 3.00               | 30.4            | 10062              | 0                  | 79 68                |
| Feb            | 2.81               | 34.2            | 859                | 0                  | 78 64                |
| March          | 3.96               | 43.3            | 662                | 3                  | 78 59                |
| April          | 3.89               | 53.9            | 343                | 18                 | 76 54                |
| May            | 4.93               | 63.2            | 123                | 76                 | 80 55                |
| June           | 4.03               | 71.8            | 14                 | 227                | 82 56                |
| July           | 3.76               | 75.6            | 0                  | 338                | 85 57                |
| Aug            | 3.41               | 74.6            | 2                  | 308                | 88 58                |
| Sept           | 2.62               | 67.4            | 59                 | 137                | 88 58                |
| Oct            | 3.30               | 55.6            | 305                | 22                 | 84 55                |
| Nov            | 3.42               | 44.8            | 599                | 1                  | 80 63                |
| Dec            | 3.37               | 33.9            | 956                | 0                  | 80 69                |

**Figure 35: Wind Rose**
Figure 36: Wind Roses
Figure 37: Psychrometric Chart
Appendix - Program

Figure 38: Data Hall Layout/Expansion Diagrams
### DATA CENTER PROGRAM:

<table>
<thead>
<tr>
<th>PROGRAM</th>
<th>SIZE</th>
<th>ENVIRONMENTAL CONDITIONS</th>
<th>PROGRAM REQUIREMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical Rooms</td>
<td>5000 sf</td>
<td>Tightly controlled, 68-78°F with 40-55% Relative Humidity. Temperature and humidity changes must occur slowly.</td>
<td>Adjacent to Server Room. Controlled entry points. Not regularly occupied. High level of fire protection. High hazard storage if using batteries.</td>
</tr>
<tr>
<td>Mechanical Rooms</td>
<td>3000 sf</td>
<td></td>
<td>Air delivery plenums to Electric and Server Rooms. High sound levels.</td>
</tr>
<tr>
<td>Fire Protection</td>
<td>500 sf</td>
<td></td>
<td>Separate room or in Server Room depending on system used.</td>
</tr>
<tr>
<td>Offices</td>
<td>2000 sf</td>
<td>HVAC is independent of the data hall.</td>
<td>Close proximity to Server Room.</td>
</tr>
</tbody>
</table>

Figure 39: Proposed Program
Figure 40: Diagram of HVAC and Power Distribution

1. Standard operation power is provided by the campus power grid. In the event of failure, the load is transferred to generators.

2. Power conditioning and ride-through power are provided by the UPS. Power is provided to the servers and HVAC system until backup power is restored.

3. Power distribution units are in the aisles with the server cabinets, reducing powered cabling runs.

4. Chilled water from the campus utility plant and chilled water tank. Water is directed to in-row cooling units and CRAC units.

5. Warm air is blown across chilled loops. Humidity may be added to the incoming air. Chilled air enters the data hall below raised floor or in a ceiling plenum.

6. Rear door heat exchangers use chilled water to remove heat directly from server cabinets.

7. Heat is recovered from the warmed air and water. Heat is either rejected through cooling towers or is transferred to scotio hall.

8. Recovered heat is used to offset heating demands of residence halls. Outside air is warmed before entering the system.

9. In warm weather, cool water leaving the dorm HVAC system is used to cool the data center.