A Survey of Desktop Virtualization in Higher Education: An Energy- and Cost-Savings Perspective

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ABSTRACT

Benefits of utilizing desktop virtualization technology in higher education environments include the ability to deploy numerous applications, which may conflict on a traditional desktop, into a single image. Additionally, the utilization of thin-clients could produce substantial energy savings and reduce physical desktop replacement costs. Finally, virtualized desktops can be delivered to numerous non-enterprise devices, particularly student's personal laptops or dorm-room computers. While there appear to be numerous benefits to desktop virtualization, there are many barriers to adoption. This paper outlines the substantial energy- and cost-savings provided through desktop virtualization in higher education. A literature review of relevant works and findings of a university implementation workgroup are presented using a case-study approach.

Keywords:

Virtualization, desktop, academic computer labs, thin-clients, higher education, cost savings, energy savings.

INTRODUCTION

Problem Definition

Higher education institutions must provide varying degrees of computing resources to meet the computing needs of different academic programs (e.g.: word processing for liberal arts or computer-aided design application in engineering). Yet, such institutions are faced with a dilemma of determining if large investments into desktop/application virtualization will bring a return on investment and provide quality of service improvements. This investment of time and resources is especially difficult when the availability of software as a service (SaaS) options are increasing and may render the necessity of providing "standard" virtualized desktops and applications obsolete in the near future. Thus, a deeper understanding of the benefits, drawbacks and applications of desktop/application virtualization in higher education is needed by decision makers. While various benefits of virtual desktop infrastructure (VDI) are often cited, there is a lack of research emphasizing the energy-savings of such investments, particularly in higher education. To provide such an understanding, this paper provides an in-depth analysis of key literature regarding the topic of desktop virtualization as well as a practitioner-level perspective of the key aspects of desktop virtualization technology in higher education.

Energy consumption in datacenters alone is a serious concern and is expected to have eclipsed 250-billion US dollars worldwide in 2012 (See, 2008). Das et al. (2010) suggest that a balance between the energy savings of virtualization and the usability and performance requirements demanded by users could be achieved through desktop virtualization, particularly by moving a client-side desktop to a datacenter when idle. From a campus initiative and educational perspective, Yang and Li (2010) highlight that the primary ways to form a green teaching atmosphere are to build a green campus culture and integrate green thinking into the teaching activities. Expanding upon this, we feel that it is necessary to explore new ideas for the construction of energy efficient academic computer labs.

The first goal of this paper is to empower higher education decision makers with an in-depth understanding of desktop virtualization in higher education based on information systems literature. This will allow universities to more easily determine if desktop virtualization is a technology they wish to invest in. From a research perspective, a second goal of this survey is to provide a foundation for future research regarding the benefits and drawbacks of desktop virtualization. Furthermore, the accessibility, transparency and willingness of higher education institutions to participate in research projects that improve student experiences can provide researchers with a unique study laboratory.

Higher Education Computing Requirements

Most higher education institutions in the United States provide their students diverse computing environments on a variety of platforms. Indeed curriculums are often designed around an industry-standard software application, such as Final Cut Pro X, available only for the Apple Mac OSX platform, or Microsoft Access, only available for the Windows platform. Providing an environment that allows access to such specialized applications, regardless of what host operating system the client was utilizing or where the client was accessing from, would be the ideal solution. Virtualization can provide platform independence and facilitate cross-platform work. However, a variety of resource, technical and licensing complexities have created an environment in which there is currently no perfect solution, therefore important decisions must be made prior to choosing an implementation. This paper lays out key decision points based on prior research and vendor capabilities. It follows the process that a U.S. university used to determine its desktop virtualization strategy.

RELATED WORKS

Information systems (IS) literature addressing various concerns and benefits of virtualization, particularly in higher education, are presented in this section. Unlike non-virtualized desktop environments, VDI, introduces numerous complexities related to application licensing, network performance and security. Yet, benefits such as simplified maintenance through centralized computing, consolidated resources allowing for resource sharing and efficiency, as well as potential reductions in energy consumption are also delivered. As Vouk (2008) reminds us, these concepts are not new but computing paradigms built "on decades of research in virtualization, distributed computing, utility computing, and, more recently, networking, web and software services".

Centralized Computing and Resource Sharing

Li (2010) presents four alternative virtualization architectures, of which one uses a decentralized virtual lab approach in which students in a course receive a virtual machine that can be deployed on their own computers. Advantages of such a configuration include that students do not need to have a persistent connection with the university datacenter, virtual desktops should be more responsive since they are running locally, and there are lower maintenance costs. Drawbacks of such an approach include concerns that licensing requirements may not allow such virtual machines to be distributed and that the end-user computer may not have enough hardware resources to instantiate a virtual machine. However, most research involving implementations, suggest that cost savings, agility and alternate sourcing options are reasons to consider virtualization (Dawson and Bittman, 2008). Averitt et al. (2007) describe a virtual computer laboratory implementation at North Carolina State University. Their solution, built as open-source software, allows students and faculty to access applications, desktops and research computing resources through the Internet.

Educational Impact

In addition to administrative benefits, several studies have suggested that virtualization also provides several student benefits (e.g. Denk and Fox, 2008; O'Reilly, 2010; Pandey, 2012). For instance, O'Reilly (2010) discovered that the use of virtual desktop infrastructure in education provides a common-level starting point for technology education, as all students would be allocated an identically capable environment. For instance, students who struggle with technology components of assignments due to end-user configurations or settings could instead focus on the actual learning goals, which could be essential to develop student self-efficacy, particularly when working off-campus. Additionally, Denk and Fox (2008) suggest that by providing a virtual computer lab the myriad of issues encountered when running software on various student workstations is removed. However, Chang et al. (2010) suggest that such virtual computer labs are often designed to meet the needs of just an individual student, and do "little to encourage the collaboration of students, offering little improvement over the traditional approach where students work at home independently."

Pandey (2012) discusses technological and economical evidence that validate the benefits of green computing in classrooms, academic departments, and research labs, and shows possible energy costs savings in India. Awodele, Malasowe and Onuiri (2012) report a case at which a Nigerian university adopted the greenhouse gas protocol, resulting in a design of a generic green IT model for higher education. Chowdhury (2012) suggests that more research needs be done on information systems and sustainable development in general, and especially on the environmental impact of such services. Their paper shows that information systems and services for higher education and research institutions currently generate massive greenhouse gas emissions. Their research emphasizes the immediate need for developing a green information service to minimize emissions and proposes a way for building and managing green information systems to support education and research/scholarly activities in the UK and Australia.

Kanth et al. (2012) show the importance of green information technology courses in the curriculum of graduate studies. To do so, a course was developed at a technical university in Finland, which aims to provide a unified view of sustainable embedded system technologies. It focuses on the efficient use of computers and telecommunication equipment, environmental assessment strategies and life cycle management of electronic components and end-products. The objective of this new course is to give knowledge and foresight toward assessment of environmental impacts. The curriculum is designed to disseminate knowledge of sustainable design approach in life cycle of the materials, manufacturing processes, use/reuse and recycling of the electronic equipment and components.

Martin and Samels (2012) have worked closely with college and university presidents, provosts, and trustees in adopting best practices that establish sustainable policies and programs. Their book identifies four major challenges facing higher education leaders: effectively institutionalizing sustainability thinking; developing an efficient, flexible system for benchmarking; implementing a supporting budget model; and engaging the entire campus in sustainability agenda. They also discovered that the meaning of sustainability is evolving, and it differs from campus to campus. But universities have a significant role in establishing and promoting sustainability at institutional level, and they need to look into their own policies and practices.

Finally, Conolly (2012) provides a summary of information regarding state-level initiatives that encourage the general population as a whole to consider green computing. Their approach is not to focus on a technical perspective, yet present information in language suitable for a layperson. The presented resources are available from the federal government, state governments, non-profit groups, trade associations, and colleges and universities. To best explain the underlying issues, the entire life-cycle of computing equipment is covered so that businesses and individuals are able to obtain and evaluate the information needed to make environmentally conscious technology decisions.

Infrastructure Improvements

While this review focuses on the client-side benefits and drawbacks, the concept of virtualization generally will involve numerous infrastructure enhancements. Thus, Nakagawa et al. (2012) point out that not only the devices that are connected to a network need to be environmentally friendly but also that the networking/switching device planning has to follow those principles. Enokido, Aikebaier and Takizawa (2012) extended their investigation to the full scope of information systems, and argue, that to build an energy-aware information system, it is critical to reduce the total electrical power consumption of computers and networks. They classified applications on distributed systems into computation, communication, and general types of applications. Then, they defined power consumption models of a server to perform each type of application process. Based on the power consumption models, the authors developed and proposed algorithms to select one of the servers for each type of application area so that the total power consumption of servers can be reduced.

Barriers to VDI Implementations

While there are cited benefits of VDI, particularly energy- and cost-savings, there are also numerous barriers to implementation of such technologies. Such barriers often relate to software licensing, network performance, resource intensive applications, platform considerations, security and political resistance. For instance, software licensing is often based on a one-to-one relationship between the application and the hardware, which becomes a challenge in a VDI environment (Brown and Long, 2006). It is imperative that application developers provide licensing models that compliment a VDI environment. In addition to licensing, network performance and resource intensive applications, such as Adobe Photoshop, have a great impact on VDI environments due to the necessity of increased resources (Apparo et al., 2006; Miller and Pegah, 2007). However, for universities with enhanced bandwidth and processing capabilities this may not be an issue. Of additional concern is lack of a Macintosh OSX VDI environment, which is particularly challenging in higher education where courses may be built around Macintosh-only software applications, such as Final Cut Pro X (Miller and Pegah, 2007). Currently, only Windows and Linux/UNIX environments support VDI implementations. Another important consideration is system security, as a large VDI implementation may become extremely complex and host environments may not be properly isolated and secured. Particularly, a compromised host environment could lead to the unauthorized monitoring of the virtual machines (Reuben, 2007). Another challenge is a political barrier caused by managers of desktop computing, who may feel that their responsibilities will move outside their scope and into the datacenter in a VDI environment (Sturdevant, 2010). However, a recent survey has been shown that up to 85.9% of faculty would be willing to use virtualized applications if they were available (MSU Denver, 2010).

RESEARCH METHOD

An analysis of literature from scholarly journal databases (e.g. EBSCOhost and Google Scholar) using keywords such as ‘application virtualization’ and ‘desktop virtualization’ was used to ascertain distribution alternatives that would best meet the unique configurations and needs of academic computer labs. Next, a specific implementation analysis of a VDI academic computer lab at an U.S. university is examined using a case study approach. For this case, features, benefits and costs of available technical solutions were evaluated. Finally, based on the recommended solution of the case, a cost- and energy-savings analysis was performed comparing traditional and virtual academic computer labs.

DISTRIBUTION ALTERNATIVES

Several distribution models for delivering software applications to remote workstations exist. The specific alternatives reviewed include physical software distribution, application virtualization, software as a service, and remote desktop technologies. The benefits and drawbacks of each of these alternatives are described next.

Physical Software Distribution

Physical software distribution is the ability to package installable software onto media such as DVDs, CDs or USB Drives, or providing the installable applications via download. While this method would allow distribution of software to remote users, major drawbacks exist. These include the inability to manage licenses; for example, if a student returns the media a university cannot guarantee that the software was actually uninstalled from the student's personal computer. Additionally, software configurations, operating system (OS) configurations, and various hardware setups could create a remote troubleshooting challenge for support staff. Another consideration is that manufacturing, packing and shipping could significantly impact sustainability of this alternative. The greatest benefit of this alternative is that application does not require a persistent Internet connection.

Application Virtualization

Application virtualization is the distribution of an encapsulated software package that can operate independently of the host operating system, because it has the necessary environment packaged along with the application. Advantages of this alternative extend far beyond providing remote software access. Such benefits include the ability to run applications in environments that are normally incompatible with the application's native environment; the ability to protect the operating system from the application; the ability to simplify software and operating system image deployment; fast application provisioning; license management; improved security; improved operating system implementations/upgrades; ability to run incompatible applications side-by-side. Disadvantages of application virtualization include the inability of some applications to be virtualized and that each application must be 'packaged' (installed and configured) independently which often requires heavy up-front configuration for implementation staff.

Software As A Service (SaaS)

SaaS provides software to remote users on demand, usually as a web application. Examples of such technologies include Google Docs, Office 365, and Office Web. An advantage of SaaS is that a third-party provider usually hosts applications, which reduces the need for additional on-site administrators. Additionally, SaaS applications are distributed in real-time, thus changes and upgrades can be made on a continuous basis without requiring the end-user to download updates. Drawbacks of such technologies are that the universities will be locked into a solution hosted outside of the institution's control, compatibility issues between existing and new electronic documents, as well as the need for standardization to one platform for interoperability. Often access to usage logs is difficult to achieve and account management may not be easily integrated with our existing or planned systems. Additionally, SaaS applications may not have the same features as non-SaaS applications (e.g. Microsoft Word vs. Google Docs.) Also, as there is no single provider of all SaaS applications, each suite of applications would need to be managed independently which could create confusion for students and make administration particularly challenging.

Remote Desktop

Advantages of remote desktop services are that students would be able to use a full desktop remotely and system administrators can easily deploy configurations to new users from predefined templates depending on user roles (student, faculty, and administrator). However, a major disadvantage is that host and client resources must be configured for each individual user session. Additionally, this alternative puts significant burden on administrators as well as network storage, and requires sufficient bandwidth for delivery.

Virtual Desktop Infrastructure (VDI)

An additional alternative evaluated was the use of VDI, which provides the capability to download or stream a full desktop environment to remote users. Advantages of this solution include the ability to deliver pre-configured environments to users, which mimics a physical workstation with applications, network connections, peripheral configurations and user customization, as well as taking advantage of centralized license management. For new users, additional VDIs can be provisioned on-demand from a standard image. Drawbacks include the need for high network bandwidth, improved storage performance and some client platform limitations (i.e. OSX licensing does not allow clients to be virtualized).

Recommended Distribution Alternative

In our research case the advantage of a true VDI solution became evident by weighing the benefits and drawbacks of each distribution alternative. Particularly, when VDI is implemented with remote connectivity capability and application virtualization, it is a prudent investment for higher education academic computer labs.

Once the technology was narrowed to VDI with application virtualization, a total of 23 technologies were reviewed to determine their feasibility of meeting the scope and requirements of an academic computer lab. Of these initial alternatives eight were removed due to their limited applications, extremely complex implementations, OS/hardware specific implementations, lack of product roadmaps or other technical constraints. These eight packages included AIX Application Mobility, Cameyo, BoxedApp, klik, Zero, Runz, Sandboxie, and InstallFree. Each of the 15 remaining solutions was analyzed in-depth and each company was given an opportunity to provide more information. A summary of this analysis and information provided follows.

DESKTOP VIRTUALIZATION TECHNOLOGIES

Table 1 presents several VDI (and application virtualization) solutions that would provide potential benefits to a higher education academic computer lab implementation. Specifically, whether or not a persistent connection is required, if concurrent licensing exist and the specific client-side platforms supported are presented.

Solution	*Persistent Connection*	*Windows*		*OSX*	*Linux/Unix*	*Concurrent Licensing*	*Costs*
		XP	*7*				
Citrix XenApp	Yes	X	X	X	X	X	Requires formal request for proposal (RFP)
Citrix XenDesktop	Yes	X	X	X	X	X	Requires RFP
VMWare ThinApp	Yes	X	X				Requires RFP
Parallels VDI	Yes	X	X	X	X	X	Requires RFP
Endeavors Application Jukebox: Enterprise	Yes	X	X			X	Requires RFP
Microsoft App-V	Yes	X	X			X	Requires RFP
AppZero	Yes	X	X		X	X	Requires RFP
Symantec Workspace Streaming	Hybrid	X	X			X	Requires RFP
Spoon Studio	Yes	X	X			X	Requires RFP
Installfree Bridge	Yes	X	X			X	Requires RFP
Ceedo Personal	None; USB or Portable HDD transfer	X	X			X	$39.96 per license, plus device (USB or portable HDD drive)
Altiris SVS	Yes	X	X		X	X	Requires RFP
LANDesk Application Virtualization	Yes	X	X			X	Requires RFP
RingCube MojoPac	None; USB or Portable HDD transfer	X	X			N/A	Free
Trustware BufferZone	None; USB or Portable HDD transfer	X	X			N/A	Free

Table 1: List of Technology Alternatives Evaluated

FINDINGS

Based on the analysis of desktop virtualization in higher education and the numerous complexities, it has become clear that this area needs further exploration and could substantially benefit from the additional perspectives of computer science and IS researchers. Next, the cost- and energy-savings discovered through the implementation of a 30-seat academic computer lab are discussed.

Case Solution

Based on an in-depth evaluation by a U.S. university committee, in which both authors participated, both a VDI and application virtualization solution provided by Citrix was implemented as a pilot project for further evaluation. Specifically, these products were selected to meet the multi-platform (Windows, Mac, Linux) environment of the existing academic computer labs as well as simplified integration with existing authentication and authorization solutions. Early tests have revealed that this hybrid VDI and application virtualization solution can successfully deliver applications to a variety of operating systems including Windows, Apple and Linux desktops, laptops and mobile devices (e.g. Windows Mobile, Android, iPad, and iPhone), Linux and UNIX workstations, ChromeBooks, and most of the thin-clients available on the market today (e.g. Devon IT, HP, Wyse, NComputing).

Potential Cost Savings

Cost savings of desktop hardware were developed for a 30-seat academic computer lab, with hardware replacement based on a three-year hardware replacement cycle, both of which are commonly found in higher education. Other evaluations of VDI have also demonstrated significant cost savings over time (Murphy, 2010).

For example, large cost savings could be achieved by reducing the hardware required in just a single 30-seat academic computer lab. Table 2 demonstrates the six-year hardware cost of a traditional lab compared with the hardware cost of a VDI lab which replacing existing workstation with thin-clients and implements some server upgrades. While only the first six years of thin-client use are considered, many of such devices have potential life spans of 10+ years due to low heat emissions and no moving parts.

6-Year DC in a Traditional Computer Lab		
Year 1	30 Lab Machines ($1,800)	$54,000
Year 2		
Year 3		
Year 4	30 Lab Machines ($1,800)	$54,000
Year 5		
Year 6		
Six Year DC		$108,000

6-Year DC in a VDI Computer Lab		
Year 1	Server Updates ($20,000) + NComputer N-series ($200)	$26,000
Year 2		
Year 3		
Year 4		
Year 5		
Year 6		
Six Year DC		$26,000

Table 2: Deployment Costs (DC)

Unlike the traditional academic computer lab, the VDI-based computer lab would require some datacenter resource improvements. However, in most cases a single mid-range server (approx. $20,000) update would be capable of providing enough computing resources for an entire 30-seat VDI lab using common software. While the benefits from an energy-savings perspective suggested that an immediate replacement of all traditional desktop computers would provide a higher benefit, most universities cannot afford such expenditures. Additionally, political resistance and attitudes may hinder the short-term green solution implementation. Thus, universities could chose to phase in VDI using their existing hardware, as this would allow the realization of some benefits while providing time to raise sufficient capital for full-scale thin-client implementation.

Potential Energy Savings

Also of considerable note is the substantial energy savings that can be achieved utilizing VDI and thin-clients. For example, based on a per kilowatt-hour cost of $0.12, the six year cost in energy would be approximately $65,000 for traditional desktops (Table 3). A power consumption value of 350W was selected using an online calculator provided by a major hardware manufacturer assuming standard PC configuration at a U.S. university (Asus, 2013). Individual energy will be based on numerous factors such as application and peripheral use. As computer lab resources operate continuously, a 24/7 uptime was considered in the following calculations.

Year 1	30 Lab Machines (350W each)	10,500 W
Annual Expenditure (kWh)	(W/1000x24hx360d)	90,720 kWh
Annual Energy Cost ($)	(kWh*$0.12)	$10,886
Year 2		10,500 W
Annual Expenditure (kWh)		90,720 kWh
Annual Energy Cost ($)		$10,886
Year 3		10,500 W
Annual Expenditure (kWh)		90,720 kWh
Annual Energy Cost ($)		$10,886
Year 4		10,500 w
Annual Expenditure (kWh)		90,720 kWh
Annual Energy Cost ($)		$10,886
Year 5		10,500 W
Annual Expenditure (kWh)		90,720 kWh
Annual Energy Cost ($)		$10,886
Year 6		10,500 W
Annual Expenditure (kWh)		90,720 kWh
Annual Energy Cost ($)		$10,886
Six Year TCO		*$65,316*
Six Year Carbon Footprint	*(kWh x 0.0005883)**	*320.22 t*

Table 3: Energy Costs of a 30-Seat Traditional Academic Computer Lab

The same lab would only cost about $400 to power for six-years utilizing thin-terminals (Table 4.) Additionally, migrating to a thin-client environment would result in a carbon footprint reduction from 320.22 tons to 1.83 tons.

Year 1	30 NComputing N-Series (5W)	60 W
Annual Expenditure (kWh)	(W/1000x24hx360d)	518.4 kWh
Annual Energy Cost ($)	(kWh*$0.12)	$63
Year 2		60 W
Annual Expenditure (kWh)		518.4 kWh
Annual Energy Cost ($)		$63
Year 3		60 W
Annual Expenditure (kWh)		518.4 kWh
Annual Energy Cost ($)		$63
Year 4		60 W
Annual Expenditure (kWh)		518.4 kWh
Annual Energy Cost ($)		$63
Year 5		60 W
Annual Expenditure (kWh)		518.4 kWh
Annual Energy Cost ($)		$63
Year 6		60 W
Annual Expenditure (kWh)		518.4 kWh
Annual Energy Cost ($)		$63
Six Year TCO		*$378*
Six Year Carbon Footprint	*(kWh x 0.0005883)**	*1.83 t*

Table 4: Energy Costs of 30-Seat VDI Academic Computer Lab

(Source: Carbonfund.org: 1.297 lb CO2 per kWh; 0.000588 metric tons CO2 per kWh)*

CONCLUSION

This paper demonstrates the benefits and drawbacks concerning the use of VDI in higher education academic computer labs. For instance, benefits include the ability to deploy numerous applications, which may conflict on a traditional desktop, into a single image, the ability to deliver university desktop images to student's personal laptops or dorm-room computers, and the potential for substantial energy and cost savings. Specifically, the energy- and cost-savings demonstrate that the initial expense of moving to a VDI academic computing environment would be justified in most cases. This paper suggests that the physical hardware cost savings for a 30-seat VDI lab compared to a traditional 30-seat university computer lab would be over $80,000 in six years, while the energy-savings represent a carbon footprint reduction of over 300 tons.

However, there are also numerous barriers to the implementation of VDI environments that must still be addressed. These barriers provide an opportunity for further exploration by IS scholars. Thus, future research should examine true costs of migrating to virtualized desktops, bandwidth requirements, security concerns, application licensing concerns, and required datacenter enhancements. Industry can also benefit from this study by gaining an understanding of the unique needs of higher education desktop virtualization. Specifically, this paper provides industry with key issues that must be first addressed to allow higher education to adopt VDI in greater numbers for use in academic computer labs.

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