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DESIGN OF MODERN ACADEMIC LABORATORIES BASED ON VDI INFRASTRUCTURE[1]

Abstract: The article describes the causes of the economic and organizational case for implementing VDI solutions in the learning centers of Academic Centers. The analysis laboratory infrastructure allows for better understanding the broad ability to adapt to VDI and range of benefits they receive, administrators and staff research and teaching. Described implementation is based on VMware Horizon View 5.The author was the originator of the concept of VDI implementation at the University of Economics in Wrocław and participant of the project team.

Keywords: Private cloud, virtualization, VDI infrastructure, desktop as a service, student lab.

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1. Introduction

The increasing popularization of centralized computing centers popularly referred to as the clouds [Rosenberg, Mateos 2012] caused the universities of Poland to begin building their own private clouds, not only to support their internal processes, but also to provide the students with the virtualized workstations [Madden, Knuth 2014].

The article omits the description of virtualization as it is generally known. Instead, after a brief description of the VDI we will focus on the analysis of the suitability and potential benefits for the virtualization of a student laboratory.

The author is an employee of one of the first universities in Poland (University of Economics in Wrocław) which implemented this solution on a massive scale in their teaching process. In this article, we describe some of the benefits and other experiences gained from the implementation of this project.

The subject of this study are student academic laboratories, although the content also refers to any type of training centers and educational solutions in schools or centers of learning. Below we describe some general benefits of implementation of VDI solutions.

[1] Selected parts of this article were published under nonexclusive copyright in Proceedings of the Fe-derated Conference on Computer Science and Information Systems FedCSIS 2014 (see [Chrobak 2014]).

With the ever increasing prices of upgrading desktop computers, virtualization of the desktop is becoming very appealing. Here are some of the benefits of virtual desktop infrastructure (VDI) (see also [Serafin 2011]).

- **Management** – in a typical corporate infrastructure, you manage desktops using remote software technology such as Altiris or some other push technology. It is really hard to manage hundreds of desktops, which you are well aware of if you administer desktops in your corporate infrastructure. Using technology such as virtual desktop infrastructure (VDI) allows you to have central management of all your desktops and to really control what is being installed and used on the desktops. Deployment of virtual desktops is lightning fast as opposed to using imaging technology such as Norton or other antiquated technologies. Would you like to manage 500 desktops all over the United States or Europe, or manage them from one data center?
- **Security** – security is a key factor in rolling out VDI. With VDI, you have greater control of how you secure your desktop. You can lock down the image from external devices or prevent copying data from the image to your local machine; I am a big fan of this feature of VDI. Remote users or road warriors also benefit, as sensitive data is stored on the server in the data center and not in the device. If the device is stolen, the information is protected.
- **VDI image** – We can create a library of VDI images to meet all of your company needs. If your company is seasonal, you can have extra images to handle the increased employee traffic. If you use third-party vendors/contractors/consultants, you can use secure/encrypted locked down images to allow them to work in your environment [*Wady i zalety wirtualizacji*…].
- **Snapshot technology** – with VDI, you have the ability to roll back desktops to different states. This is a great feature, and it allows you to give a lot of flexibility to your end users.
- **Go green** – a thin client VDI session will use less electricity than a desktop computer. Using VDI is a way to reduce your carbon footprint on our planet and save your company money in power costs.
- **Independence** – with VDI, who cares what device you use? A thin client, a PC, Apple, Linux, etc. As long as you can connect to your VDI with ICA or RDP, you are golden [Miller, Pegah 2007].

2. The specificity of academic laboratory

Computer workstations in the student laboratories have their own characteristics; the analysis and understanding of them allows us to understand the ability to adapt to VDI in such an environment. Let us try to describe these specifics.

1. Most classes use the same software configuration of work stations (package Office + software specific to the various classes such as Mathematica, Visual Studio package, graphics packages, etc.).

2. For some of the more advanced subjects, a specific configuration is needed (usually requiring more powerful computers) mainly in the case of configurations where the database is locally installed. Mostly these are classes related to databases, ERP software (e.g. SAP with local database) or computer networks (another network configuration or other elements of the local virtualization.) This situation is often resolved by separating the specialized laboratories or the ability to run different systems during take-off of systems (separate systems with different configuration on different disk partitions).

3. It is desirable that every student joining the course has a “clean machine” with no files or configuration changes that previous student could leave.

4. The key principle is that all the computers in the lab have exactly the same software configuration.

5. One of the main problems of the administrators are configuration changes caused by students. The complexity of Windows has the result that despite imposing further restrictions on student accounts regarding permission to install, there are still a lot of gaps that clever students use to show their abilities (for example by: changing the desktop background, installing add-ons to the browser or some malware). On the other hand, revoking permission causes problems with the software update, or drivers (e.g. drivers for USB sticks), which handicap the life of students and teachers.

6. Most students perform simple tasks (e.g. working in Excel) by which the CPU utilization remains at 5–10% for 90% of the time.

So we summarize some of the implications arising from these observations. It is very time consuming and tedious for administrators to maintain a number of such labs (in the form of a PC) and the continuous outgoing students of ingenuity who more or less deliberately modify the standard configurations of the operating system or application. Of course, this time consumption increases the amount of administrators’ posts, who spend half of their time performing the same, often unnecessary tasks. There are, of course, administrative tools which allow you to automate part of the action (Active Directory, automation of software installation and other items), but here are new difficulties arising:

- administrators working in colleges and universities are not always proficient in implementing new solutions (which implicitly detracts from the earnings of such positions in the public schools),
- tools to automate software deployment often require administrators to take the time to be able to perform this process (not all programs can be automatically installed and may require a rewriting the installation version to “msi”.

In addition, there are a number of activities which cannot be automated and require intervention, such as system recovery, repair of damaged units, etc.

We also need to take a minute to analyze the second point of this described characteristic. Both of the described variants are inefficient and cumbersome in practice. Creating specialized laboratories causes difficulties in allocating and scheduling classes and must lead to not optimal time management of the use of these laboratories, or to problems with their availability, especially if there are several. The second option often used in colleges (multi-system configurations) is more efficient, but requires a restart of the computers before classes, which in practice can take up to five minutes and then require another restart (at the end or at the beginning of successive classes).

3. Economic benefits of a VDI implementation in students labs

From the analysis in the previous section an organizational model of the optimal solution is emerging: ideally, it would be that a student at the beginning of classes receives a computer with a freshly installed operating system and applications he needs during the classes, and he could do on the computer what he wants (and even in some cases have administrative privileges). Then after completing the course, such a system could be completely erased and an entirely new one be substituted in its place. Precisely this possibility can be achieved by replacing the traditional PC by VDI architecture and terminal devices in the class of the "zero client". However, all these considerations are only an introduction to the change of the organizational model for maintaining laboratories. We will focus further on the economic benefits and will show savings that will enable institutions to manage their budget in the IT area more effectively.

Expenses of maintaining administration – the implementation of the VDI architecture can significantly simplify the process of administration and maintaining laboratories and computer workstations. In the corporate environment in the 90s it was assumed that one administrative post covered support of about 50 workstations. With the passage of time and the expanding range of tools to automate administrative processes, it is today assumed that one administrator (one full time post) is sufficient to support about 500 or more workstations. However, in academic environments (especially in public schools), because of different ancillary factors that go beyond this discussion, a trend can be seen for employment in this sector to be increasing. The VDI specification itself means that whether you have 100 or 500 workstations, for the maintenance of laboratories and implementation of demand, one half position is enough. The method of its distribution and scheduling is already in the hands of the management of the institution.

Operating costs – a typical terminal integrated with a LED monitor made with "zero client" technology consumes on average 40–50 W of electricity, which is one fourth of the consumption of a typical workstation (which consumes about 200 W with the monitor). Of course, the VDI infrastructure includes also a set of servers and disk array, so averaging the results for a typical example of ten 30-bench laboratories, we can assume electricity savings of 50%.

Costs of equipment replacement – the average amortization time of a workstation is assumed to be three years, and in university practice this time is estimated at five years. VDI equipment manufacturers point to one of the advantages of VDI being that the amortization period of a VDI client is twice as long compared to the typical workstation. The key is the fact that the VDI terminal has not in itself any components that determine aging hardware. So there is no processor or graphics card that will be too slow, no disc you can drive crash, ending RAM, etc. All of these components are found in servers; so long as the terminal does not break down naturally in the aging process of electronics or display, there is no need to replace it. VDI terminals have no mechanical parts, including the lack of fans, so the MTBF indicator (Mean Time between Failures) is for them around 70 000 hours, which is a value more than twice that of a typical workstation (MTBF – 30 000 hours).

It should be noted that the cost alone of a VDI terminal is by about ¼ smaller than the cost of an average computer set to the lab.

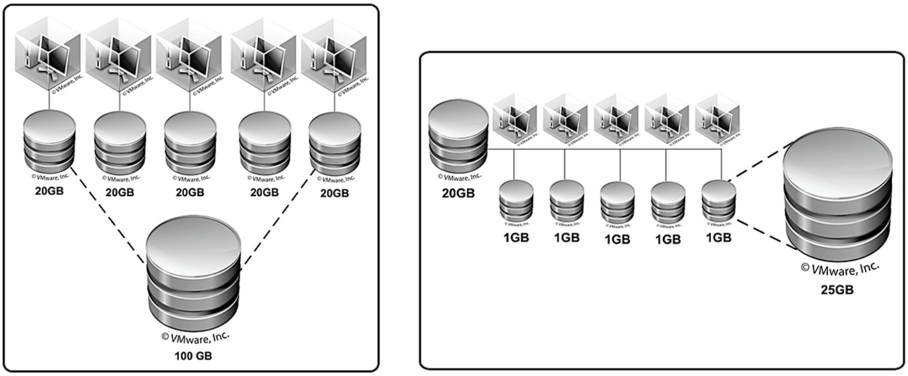
Costs of licensed – with VDI we need to buy extra license for virtualization software and special license for Windows desktop. Because prices are changing quite rapidly and licensing will be different, each scenario would require the separate analysis.

4. Technical benefits of a VDI implementation in students labs

Further description of the functionality is based on the author's experience with VMware Horizon View [*VMware Horizon…*]; however, Microsoft's [*Microsoft Virtual…*] solution offers similar functionality. Of course, solutions based on VMware are currently considered the most technologically advanced. However, it should be kept in mind that this solution is most expensive and, if in addition a university has the ability of implementation licensed under the MSDN Academic Alliance (or similar program), the Microsoft solution can significantly reduce the cost of licensing and thus of the entire implementation.

The philosophy and VDI infrastructure give administrators of the university an efficient and stable management environment for teaching laboratories, automating many processes and increasing the reliability of the entire solution. The main aspects that empower administrators are the following.

Central deployment and maintenance of virtual systems – the administrator prepares a single system image, the so called "Gold Image" (also known as "copy-on-write") which will be available in read-only option, then cloning of each image and creating a virtual system does not copy the entire image. The system reads the data from the golden image and all the changes that are implemented in the virtual system are stored in so called paintings, the "Linked Clone". This process is visualized in the figure below. We compared here the volume of disk space for five virtual desktops, providing that each prospective of the images saved 1 GB of data for its own needs, while the volume of the golden image is 20 GB (see Figure 1). Of course, space images "Linked Clone" will be automatically increased while writing new data until achieving the maximum value (defined by the administrator) [Lowe, Marshall 2013].



Classic allocation of virtual disks

Technique "Gold Image" and "Linked Clone"

Figure 1. Compare disk space allocation

Source: VMware inc. Training materials.

For the given example average 75% disk space is saving and in the process of increasing the number of working stations factor will still grow. Of course, this technique requires a sufficiently fast disk to store the golden image. It should be stored on SSD disks, or disk data should be cached, preferably also using the SSD. Using such technology also gives another key benefit for our case and laboratories, namely the fast refreshing of virtual systems.

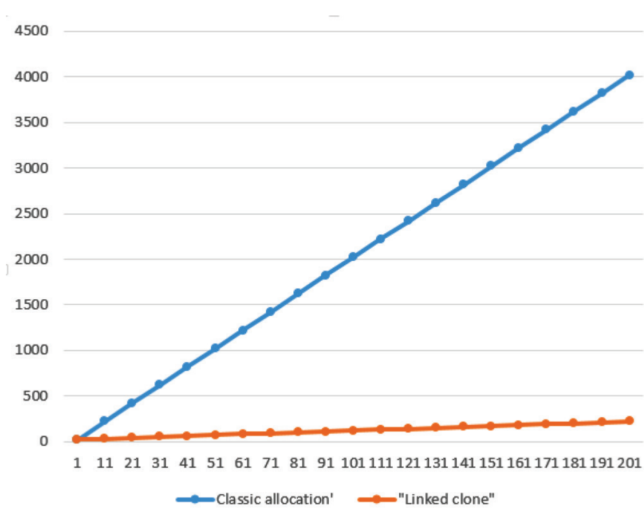


Figure 2. Estimated space required for virtual systems (in GB)

Source: own elaboration.

"Link cloned" technology is particularly useful in these environments. We have here a lot in the exact same virtual machines, allowing large savings relative to the disk space used. For example, with 100 of the same virtual machines where each would take 20 GB and "link clone" would be at the level of savings we achieve (1 GB), we can save almost 18 times more space on hard drives (20 GB × 100 machines = 2 TB and 100 × 1 GB + 20 GB = 120 GB). An estimate of the space required (for similar parameters 20 GB – used space, and 1 GB of "link cloned") is shown in Figure 2. The figure shows estimated disk storage capacity requirements (in GB) depending on the amount of the same virtual systems.

Instant refreshing virtual systems – one of the implications of the golden images is the fact that a virtual operating system only reads data from the golden image (without the possibility of writing anything on it). All the changes differential writes on "Linked Clone," is to delete the data in this place immediately and restore the clean image of the system (see Figure 3). The system automatically disconnects the user after 15 minutes of inactivity and instantly refreshes the image of the virtual system, which restores it to its original state (this process takes about five seconds for each system) [Asselin, O'Doherty 2014; Guthrie et al. 2013].

Business continuity of laboratory – a user cannot spoil anything, unless he physically damages the terminal. Since the virtual system which works will be cleared immediately after work, it does not matter how much the student reconfigures, causes disorder or allows viruses into the system.

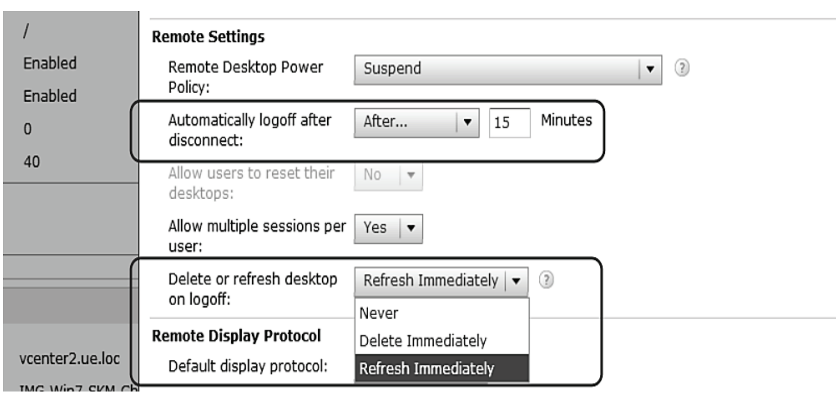


Figure 3. Refreshing virtual OS configuration

Source: screenshot from VMware application.

Security policy – depending on the philosophy adopted by the security administrators, one central antivirus program with agents for individual virtual systems can be installed. Or you can even resign from having antivirus software on the workstations, based on the assumption that even if a student hacked the computer, or even computers in the vicinity of this, they will anyway not exist after the classes.

The VDI environment also offers many useful additional features that allow load balancing (moving virtual systems to the other servers in the cluster), shutdown of servers with lighter loads, snapshots, and much more.

Prior to the implementation, it is essential, of course, to ensure the layout of server resources necessary to ensure adequate performance: the next section describes an example configuration and load of up to 300 images, in these pages you can find the relevant calculators to calculate the parameters of the environment.

5. The limitations of VDI technology

Although the systems used for laboratories are not especially graphically demanding (not taking into consideration specific graphics applications), you should be aware that the real-time transmission of multiple video streams can cause performance problems for the entire ecosystem of VDI. These problems grow not only with an increase in the amount of terminals, but also with an increase in resolution of displayed images (which begins to be particularly important in Full HD resolutions and larger sizes [*VMware Infrastructure*…].

The specificity of VDI and streaming overshadows many virtual desktops through a common internet network, and the servers, even when you start YouTube, are very heavily loaded, for two reasons.

First reason – the PCoIP stream is encoded in the default workstation and sent to the LAN. While decoding the entire image (especially for the Full HD resolution and larger), it turns out that the process of decoding the stream can take as many as 50–60% of the two-core virtual processor. To remedy this, the server can be equipped with a special card decoding hardware PCoIP streams (Card Teradici Apex 2800 [*What Are the Benefits*…]). The application card offloads the streaming process several times. One card is able to decode 40 HD streams or 25 streams of 2560 × 1600 at the same time [*Accelerate the Virtual*…].

Second reason – a problem with such high resolutions: default graphics 2/3D is emulated by VMware as the desktop becomes a bottleneck (especially using newer Windows systems, even with off AERO). The solution to this problem is the use of specialized graphics cards designed for VDI environment- (e.g. Nvidia Grid K1 or K2 Grid) [Eaves, Stockman 2012], which can be used with SVGA (shared VGA) graphics card that is shared for multiple virtual systems. Although the power of the card (and the price as well) seems to be huge, in the case of dividing its power between 20–30 virtual machines, it can barely support the basic graphical operations.

Both of the above measures cannot be applied in Blade servers, though with the HP Blade Gen8 solutions it is possible to use a miniaturized version of the card. Projecting such solutions for large format displays, you should mount them on traditional servers (e.g. Dell R720) [*GPU Accelerators*...].

6. Examples of implementation of VDI at the Wrocław University of Economics

The concept of rebuilding IT infrastructure at the University of Economics and building its own private cloud began to emerge in mid-2010 and after passaging of all the procedures, fixing concept and finding financing of the project, in September 2011 began the process of public procurement and the project was run in early 2012. The University of Economics was the first university in Poland, which has implemented such solutions on such a large scale.

At the university are working more than 240 terminals (mainly Samsung NC240), more than 400 virtual systems and students can connect to one of five available images, depending on the classes and necessary configuration. For the purposes of VDI six 2-processor servers are dedicated, giving a total of 1.2 TB of RAM. Disk array and some servers are equipped with cache memory for SSD-based. One of the servers is equipped with an Nvidia card GRID K1 and streaming card supporting hardware PCoIP (Apex 2800).

As a storage the EMC disk array is used with a total of 20 TB working gross capacity.

7. VDI architecture performance analysis

Instead of carrying out theoretical calculations of VDI performance, we will show a practical instance of the above-described example, at the Wrocław University of Economics.

As has already been mentioned, we use a few images of virtual system and the main virtual computers are:

1. **Windows XP** – with 1.5 GB RAM and one core processor, 60 GB provisioned disk and emulated graphics card by VMware system. Mostly used to run office and economics applications.

2. **Windows XP with Oracle local database** – with 2 GB RAM, two cores, 40 GB provisioned disk, shared graphics card like Nvidia Grid K1 and PcoIP acceleration card (Apex 2800). This system is used for classes of databases.

3. **Windows 7** – with 3 GB RAM, two cores, 50 GB provisioned disk and shared graphics card like Nvidia Grid K1 and PcoIP acceleration card (Apex 2800). This system has software for computer networks and some graphics and business applications.

Below we present some examples of server load in these virtual systems in a typical working day. Figure 4 shows typical load in the entire cluster. The cluster consists of:

- five 2-processors Xeon E5645 – 2.4 GHz (16 logical cores) servers (Dell M710HD) with 196 GB RAM each –described as ESX2 – ESX6 on the figures;
- one 2-processors Xeon E5-2630 – 2.3 GHz (24 logical cores) server (Dell R720) with 262 GB RAM each, with Nvidia Grid K1 Video Card and Hardware Acceleration PcoIP Card (Apex 2800) –described as ESX17 on the figures.

Name	State	Status	% CPU	% Memory	Memory Size	CPU Count
esx5.ue.loc	Connected	Normal	44	50	196587,10 MB	2
esx6.ue.loc	Connected	Normal	34	52	196587,10 MB	2
esx2.ue.loc	Connected	Normal	47	53	196587,10 MB	2
esx3.ue.loc	Connected	Normal	40	55	196587,10 MB	2
esx4.ue.loc	Connected	Normal	31	60	196587,10 MB	2
esx17.ue.loc	Connected	Normal	64	68	262098,50 MB	2

Figure 4. Typically loaded VDI cluster

On the ESX17 there are 84 virtual systems:

- 32 virtual systems of **Windows XP with Oracle local database**,
- 52 virtual systems of **Windows 7.**

On Figures 5 and 6 we can see typically loaded virtual systems when the student class is working.

Name	State	Status	Host	Provisioned ...	Used Space	Host CPU - MHz	Host Mem - MB	Guest Mem - %
Win7-VS2013-9	Powered On	Normal	esx3.ue.loc	80,78 GB	30,78 GB	0	2781	2
Win7-VS2013-8	Powered On	Normal	esx5.ue.loc	80,78 GB	30,78 GB	0	2761	2
Win7-VS2013-7	Powered On	Normal	esx5.ue.loc	80,78 GB	30,78 GB	0	2759	3
Win7-VS2013-6	Powered On	Normal	esx3.ue.loc	80,78 GB	30,78 GB	23	2938	1
Win7-VS2013-5	Powered On	Normal	esx6.ue.loc	80,78 GB	30,82 GB	0	1166	3
Win7-VS2013-4	Powered On	Normal	esx2.ue.loc	80,78 GB	30,78 GB	23	2756	1
Win7-VS2013-35	Powered On	Normal	esx3.ue.loc	80,78 GB	30,82 GB	0	1230	4
Win7-VS2013-34	Powered On	Normal	esx2.ue.loc	80,78 GB	30,78 GB	47	2782	1
Win7-VS2013-33	Powered On	Normal	esx6.ue.loc	80,78 GB	30,78 GB	23	2788	0
Win7-VS2013-32	Powered On	Normal	esx2.ue.loc	80,78 GB	30,78 GB	95	2768	2
Win7-VS2013-31	Powered On	Normal	esx4.ue.loc	80,78 GB	30,78 GB	95	2776	3
Win7-VS2013-30	Powered On	Normal	esx3.ue.loc	80,78 GB	30,78 GB	71	2925	2
Win7-VS2013-3	Powered On	Normal	esx4.ue.loc	80,78 GB	30,78 GB	95	2796	4
Win7-VS2013-29	Powered On	Normal	esx3.ue.loc	80,78 GB	30,78 GB	71	2788	3
Win7-VS2013-28	Powered On	Normal	esx5.ue.loc	80,78 GB	30,78 GB	71	2768	1

Figure 5. Typically loaded Windows 7

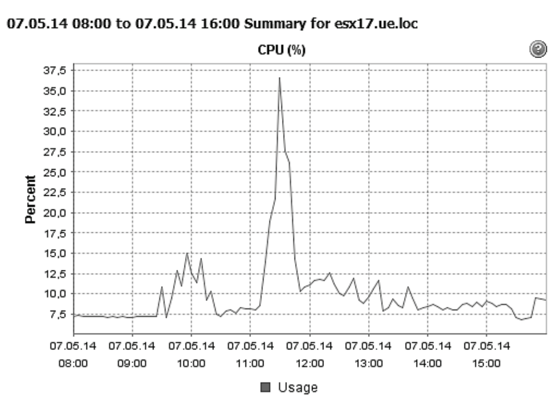
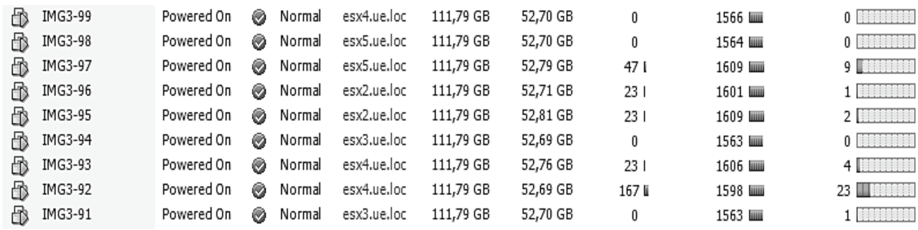


Figure 6. Typically loaded CPUs at ESX7 in the working day

On the ESX2-ESX6 we have 84 virtual systems:

- 32 virtual systems of **Windows XP with Oracle local database**,
- 52 virtual systems of **Windows 7.**

On the Figure 7 we can see typically loaded virtual systems with windows XP.



IMG3-99	Powered On	Normal	esx4.ue.loc	111,79 GB	52,70 GB	0	1566	0
IMG3-98	Powered On	Normal	esx5.ue.loc	111,79 GB	52,70 GB	0	1564	0
IMG3-97	Powered On	Normal	esx5.ue.loc	111,79 GB	52,79 GB	47	1609	9
IMG3-96	Powered On	Normal	esx2.ue.loc	111,79 GB	52,71 GB	23	1601	1
IMG3-95	Powered On	Normal	esx2.ue.loc	111,79 GB	52,81 GB	23	1609	2
IMG3-94	Powered On	Normal	esx3.ue.loc	111,79 GB	52,69 GB	0	1563	0
IMG3-93	Powered On	Normal	esx4.ue.loc	111,79 GB	52,76 GB	23	1606	4
IMG3-92	Powered On	Normal	esx4.ue.loc	111,79 GB	52,69 GB	167	1598	23
IMG3-91	Powered On	Normal	esx3.ue.loc	111,79 GB	52,70 GB	0	1563	1

Figure 7. Typically loaded Windows XP with emulated graphics cards

Of course, the Windows XP is the best system for virtualization because of low demand for computing power and RAM size, as we can see on Figure 7.

8. Conclusions

After two years since implementing VDI at our University (Wrocław University of Economics), we know that VDI promises more efficient use of the university's resources and we can offer students the convenience of accessing specialty software from any device, at any time, from any laboratory. We do not at present provide access from anywhere for students (only for teachers and some students involved in the student organization), but it is the next planned step. Certainly by improving the efficiency of administrators, their work time has been reduced by about 75%. During this time, they are able to more quickly deliver a more flexible work environment than ever before.

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WDROŻENIE INFRASTRUKTURY VDI W LABORATORIACH AKADEMICKICH

Streszczenie: Artykuł opisuje ekonomiczno-organizacyjne aspekty przemawiające za wdrażaniem rozwiązań VDI (*Virtual Desktop Infrastructure*) w ośrodkach dydaktycznych wyższych uczelni. Przeprowadzono analizę infrastruktury laboratoryjnej, która pozwala zrozumieć rozległe możliwości adaptacji VDI oraz korzyści, jakie zyskują administratorzy i pracownicy naukowo-dydaktyczni. Oprócz analizy korzyści przedstawiono studium przypadku wdrożenia modelowego rozwiązania na Uniwersytecie Ekonomicznym we Wrocławiu oraz przedstawiono wybrane doświadczenia z realizacji projektu.

Słowa kluczowe: chmura prywatna, wirtualizacja, infrastruktura VDI, laboratorium dydaktyczne.