Benefits, Limitations and Costs of IT Infrastructure Virtualization in the Academic Environment. Case Study using VDI Technology

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Abstract: The article describes the economic, organisational and technological reasons for implementing VDI solutions (Virtual Desktop Infrastructure) in the learning centers of academic institutions. It presents also major disadvantages, limitations and challenges of this technology. The comparison of total costs of previous solution (PC) and VDI technology has been also discussed. In addition to the benefits, limitations and costs analysis, a case study of the implementation of a model solution at the Wroclaw University of Economics was presented, which includes almost 400 zero client terminals and over 500 virtualised systems available to students in 12 laboratories. The authors were the originators of the concept of VDI implementation at this University and leaders of the project team. The article also presents selected experiences from project implementation and comments, the discussion of which may be crucial for the successful implementation of presented solutions.

1 INTRODUCTION

Increasing popularisation of centralised computing centres, commonly known as cloud computing, means that universities in Poland, among others, also began to build their own private clouds not only to support their internal processes, but also to provide students with virtualised workstations in the DaaS (Desktop as a Service) model (Madden, Knuth, 2014). One of the first universities that implemented this solution in Poland was the Wroclaw University of Economics. The concept of DaaS is to use a VDI (Virtual Desktop Infrastructure) environment to offer customers a persistent, highly available desktop that can be accessed from all of their mobile devices. This is significant because right now there are no services available that offer those services. The idea is to take the burden off of the customer by removing the tedious upkeep that the facilities must regularly go through. Desktop as a Service is used in enterprises for a similar reason. The employees no longer have to worry about maintaining a PC, since the operating system would be centrally managed. The idea is to reduce complexity by centralizing management, which leads to a more productive and efficient IT organization (Chrobak, 2014). The aim of the article is to present the potential of virtualisation technologies, in particular to identify and analyse the benefits of VDI technology for student laboratories on the example of the Wroclaw University of Economics. The article presents main benefits but also barriers and limitations of such solution. This is an extended and revised version of a preliminary conference article of the authors prepared in Polish language (Rot, Chrobak, 2017). The considerations presented in the article result from both literature research and the experience of authors, which is the result of managing the project of implementing a virtual environment at the Wroclaw University of Economics. The authors are employees of one of the first universities in Poland which implemented this solution on a massive scale in their teaching process.

The subject of this study are student academic laboratories, although the content contained herein also refers to any type of training centers and educational solutions in schools or centers of learning. In the development strategy for 2010-2020 prepared by the University's authorities, one of the postulates indicating the directions of development is to improve the functional efficiency of the university and all its organisational units through full integration based on advanced IT systems and development of the IT network, as well as to increase its security in order to more efficiently meet

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the didactic, research and management needs. The answer to these challenges was to create a virtual environment that not only supports currently existing services and systems at the University, but also allows to apply the latest IT solutions in the didactic process. The described implementation is based on the VMware Horizon View environment.

2 THE FUNDAMENTAL CONCEPT AND GENERAL BENEFITS OF IT RESOURCES VIRTUALISATION

Virtualization is basically making a virtual image or "version" of something such as server, operating system, storage devices or network resources so that they can be used on multiple machines at the same time. The main aim of virtualization is to manage the workload by transforming traditional computing to make it more scalable, efficient and economical. Virtualization can be applied to a wide range such as operating system virtualization, hardware-level virtualization and server virtualization (Malhotra, Agarwal, Jaiswal, 2014). The basis for the virtualisation of the IT environment is the identification of specific features and tasks of the information technology (IT) infrastructure elements and launching them in an abstract way, using foreign software, network and hardware solutions, while maintaining full functionality (Rule, Dittner, 2007). It is a very broad concept and it may concern: computer networks, data storage, servers, operating systems, applications, workstations.

Virtualisation has been quickly adapted by organisations and the academic community, as it offers numerous benefits, where among the most important ones is the reduction of investment outlays and operating costs. These effects are achieved thanks to consolidation of servers, and thus the optimisation of the degree of consumption of the existing IT infrastructure. Thanks to it, it is possible to simplify the existing IT environment, while creating a more dynamic and flexible data processing centre. There is also the ability to run several virtual machines on one server, flexibility of resource configuration, centralised management, less energy consumption by computers and cooling systems. The virtualisation of the IT environment has many advantages (Roszkowski, 2011) (Czajkowski, 2011):

- Consolidation of servers, and thus optimisation of the degree of computer hardware consumption as well as better use of computing assets by increasing the utilisation of virtual servers on physical servers.
- Reduction of the total cost of assets under the TCO (Total Cost of Ownership) model – the reduction takes place by increasing the use of equipment.
- Reducing the costs of the future development of the IT infrastructure – the need to expand the IT environment with new services that must be provided by the servers is associated only with the need to create a new virtual machine with a server.
- Lower capital expenditures CAPEX – savings are gained primarily due to the smaller number of physical servers, interfaces, network cabling and various network devices.
- Lower operating expenditures OPEX – these savings are due to, among others, reducing the demand for electricity, reducing service costs.
- Centralised infrastructure management – operating systems installed on virtual servers do not require creating backup copies, installing updates or numerous other activities. Operations that must be performed on virtual servers are ordered and supervised by one central management console.
- Increased security and reliability of the infrastructure due to the high availability properties of the virtualisation platform.
- Failure-free and continuous operation of IT systems – these systems can work in a continuous manner, without interference.
- The ability to build disaster recovery solutions.

Virtualisation allows for lowering investment and operational expenses as well as easier and cheaper management of IT infrastructure. Server virtualisation also brings increased security and reliability of the IT infrastructure.

3 VDI TECHNOLOGY – THE ARCHITECTURE AND MAIN BENEFITS

With the rapid development in computer technology in recent times, the personal computers have become so powerful that most of the users are not using the entire capabilities of such computer for their regular work. Because of this one can utilise the excess capabilities in one computer and share it with many other users. The concept of desktop virtualisation

implements this sharing of capabilities with the help of thin client and zero client machines which not only reduces the cost of infrastructure but also introduces green computing by limiting significantly energy consumption (Agrawal, Biswas, Nath, 2014).

VDI technology is the infrastructure of virtual stations and it is the next step in the virtualisation philosophy of workstations as well as placing them in centralised servers and making them available on zero client terminals. Zero client is a type of client device that does not contain a classic processor, disk storage or RAM. It is a compact terminal used in centralised computing infrastructure or VDI.

Each virtual workstation has allocated RAM memory, disk space, and the full installation of the operating system resides on a virtual disk. The user interacts with the virtual machine using the protocol of a remote graphic terminal. The key is the fact that the terminal is only a diskless thin client system, whose operation boils down to connecting with the VDI infrastructure.

Centralising the functions of desktops, at the same time it simplifies their administration and security and eliminates the need to perform basic work related to maintaining desktops. The power consumption is also reduced. The main benefits of virtual desktop infrastructure are (Chrobak, 2014):

- Management – using VDI technology allows to have central management of all 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.
- Security – with VDI technology, the users have greater control of how they secure their desktops. There is a possibility to lock down the image from external devices or prevent copying data from the image to your local machine.
- Operation systems migrations.
- VDI image – there is a possibility to create a library of VDI images to meet all of company needs.
- In addition, the VDI environment offers a number of additional features that allow the following: load balancing (immediate transfer of virtual systems to other servers in the cluster), disabling servers at lower loads, creating snapshots, and much more. Snapshot technology with VDI gives ability to roll back desktops to different states. This is a great feature, and it allows to give a lot of flexibility to end users.
- Lower power consumption – a thin client or zero client VDI session will use less electricity than a desktop computer.

4 BENEFITS RESULTING FROM THE IMPLEMENTATION OF VDI TECHNOLOGY IN STUDENTS LABORATORIES

Universities have a few reasons for deploying VDI in student laboratories. They can be divided in three main groups: economic, organizational and technological. In fact, almost all aspects have also the implied economic savings, so in the characteristics below we will focus on the economic and organizational aspects.

The economic and organisational benefits, resulting from the use of the discussed solutions can be, among others, the following:

- Administrative maintenance costs – the implementation of VDI architecture allows to significantly simplify the process of administering, maintaining laboratories and computer stations.
- Operating costs – a typical terminal integrated with a LED monitor created in zero client technology consumes an average of 40-50W of electricity, which is a fourfold lower consumption than a typical workstation (which consumes, with the monitor, about 200W). Of course, the VDI infrastructure also includes a set of servers and a disk array, therefore while averaging the results for a typical example of ten 30-position laboratories, one can estimate energy savings of about 50%.
- Hardware replacement costs – it is estimated that the average time of depreciation of the workstation is three years, while in the academic practice this time is estimated to be five years. Manufacturers of VDI equipment indicate a double-long period of depreciation of the VDI client from a typical workstation as one of the advantages of VDI. The key fact is that the VDI terminal does not contain any components that determine the contractual aging of the equipment. VDI terminals do not have any mechanical parts, not even fans, therefore MTBF (Mean Time Between Failures) is about 70,000 hours for them, which is more than twice than in the case of a

typical workstation (MTBF = 30,000 hours). It should also be noted that the cost of the VDI terminal itself is about 25% lower than the average computer set for the laboratory.

The VDI infrastructure provides the IT administrators in higher education institutions with an efficient and stable environment for managing didactic laboratories, automating a number of processes, and improving the reliability of the entire solution. The main aspects improving the work of administrators are following:

- Central implementation and maintenance of virtual systems – the administrator prepares one system image (golden image), which will be read-only, while each cloning of the image and creating a virtual system will not copy the whole image. The system reads data from the golden image and all changes made in the virtual system are saved in so-called linked clone images. The space saving is relatively high and it increases with the increase in the number of workstations (Lowe, Marshall, 2013).
- Instant refreshing of virtual systems – one of the implications of golden images is the fact that if the virtual operating system only reads the data from the golden image and saves all the differential changes to a linked clone, then deleting the data in that place immediately causes the clean operating system image to be restored. The system automatically disconnects the user session after 15 minutes of inactivity and it immediately refreshes the image of the virtual system, which restores it to the initial state (this process takes several seconds for each system) (Asselin, O'Doherty, 2014).
- Continuity of the laboratory's operation – the user cannot configure any settings to disrupt the continuity of the terminals' operation.
- Security policy – it is possible to install one central antivirus program with agents for individual virtual systems or even opt out of antivirus software on workstations, based on the assumption that computers will be restored to the initial state anyway.

Benefits of implementation of 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 zero-clients could introduce energy savings and reduce physical desktop replacement costs. Virtualized desktops can be also delivered to numerous devices, particularly student's personal laptops. However, there are many benefits of desktop virtualization, there are also many barriers to implementation (Erskine, Füstös, 2013).

5 MAJOR DISADVANTAGES, LIMITATIONS AND CHALLENGES OF VDI TECHNOLOGY

Enterprises should consider the benefits and drawbacks of Virtual Desktop Infrastructure (VDI) before deciding to switch. The main disadvantages and limitations of this technology are (Schmidt, 2015):

- The initial cost of VDI hardware exceeds the cost of purchasing new PCs for the company. There is a lot of new equipment company needs to purchase before and after implementation.
- Another issue, which prevents organisations from using VDI, is long-term pricing. The initial price often only covers a very rudimentary resource profile for nothing more than OS or workspace hosting. VDI is particularly suitable for agile computer demand, but it currently does not yet pay off when replacing the average desktop. However, for certain organisations, VDI brings real benefits. Higher education can for example offer their students a work environment via DaaS (Oneclick, 2017).
- VDI runs the risk of more costly changes and unforeseen costs are a danger to new VDI projects.
- Software licensing is different with VDI technology and often costs a lot of money, so companies should consider the right licensing approach.
- Specialized software and applications that require modifications or special parameters are sometimes very difficult to virtualize and some of them are generally unable to be virtualized.
- It appears to be practical to administer and maintain hardware and software thanks VDI technology, however VDI systems require committed IT staff (Oneclick, 2017).
- The implementation of VDI technology requires initial training for users, they need to

learn new technology with its terminology, functionality and operations, work with different interface and with different troubleshooting solutions.

- Outages occur more frequently during the rollout of VDI and they can be more impactful under VDI technology because everything is centralized on a single system. That is why new contingency plans have to be created to deal with these problems.
- VDI is dynamic and this can cause problems for the system. There is less dependency on hardware, that is why software attacks are more likely. In the rollout, isolation of problems are more difficult and the chances of attack increase.
- Increased Network Requirements – for office applications like word processing or spreadsheet applications, VDI network requirements are minimal. However, if a large percentage of workforce needs graphics rendering capabilities or video streaming, administrators need to know that server can handle the whole traffic. The solution of this problem may be very expensive (Mavenspire, 2018).

There are also lots of different challenges connected with VDI technology (Bowker, Matuson, 2016). The main challenges include following issues:

- Complex infrastructure is difficult to plan, configure, manage, and maintain.
- Unfavorable economics with heavily weighted upfront invest costs, and cumbersome IT operations.
- Unpredictable global access based on the proximity of users due to low network bandwidth and unacceptable latency.
- Time-consuming implementations and months of planning, testing, and staging of the infrastructure.
- Difficult root cause analysis and troubleshooting among multiple IT teams (server, storage, networking, endpoint, and security) leading to prolonged troubleshooting.
- VDI can complicate software licensing and support, because some licensing and support agreements do not allow for software to be shared among multiple devices or users.
- VDI's reliance on network connectivity presents another challenge. Users can't access their virtual desktops without a network connection, and weak connectivity can hinder desktop performance. This problem is especially common with graphics-intensive applications and other software with high processing demands. Although the systems used for student laboratories are not especially graphically demanding (not taking into consideration specific graphics applications), the administrators should be aware that the real-time transmission of multiple video streams can cause performance problems for the entire ecosystem of VDI solution. 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 (Chrobak, 2014).

VDI has multiple advantages. While some companies have recognized the value of VDI, the complexity and cost of VDI has limited the usage and full potential of this solution. The described technology has a lot of difficulties at the beginning, but VDI leads to more efficiency in the long run. Generally, companies need to decide if they have the resources to bear the implementation expenses and solve the problems and limitations of VDI to achieve the described benefits (Schmidt, 2015).

6 PRACTICAL IMPLEMENTATION

The concept of rebuilding IT Infrastructure on 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 begin the process of public procurement and project was run in early 2012. The University of Economics was the first university in Poland, which has implemented such new solutions on such a large scale. The authors of the article were the authors of the concept of reconstruction of the IT infrastructure at the Wroclaw University of Economics, as well as the creation of a private cloud there.

Before the project started, a detailed comparative analysis of the costs of VDI technology and previous, previous (PC) solutions was made. The figures 1-3 present a comparison of costs for VDI infrastructure and previous solutions (PC) (in Polish Zloty – PLN).

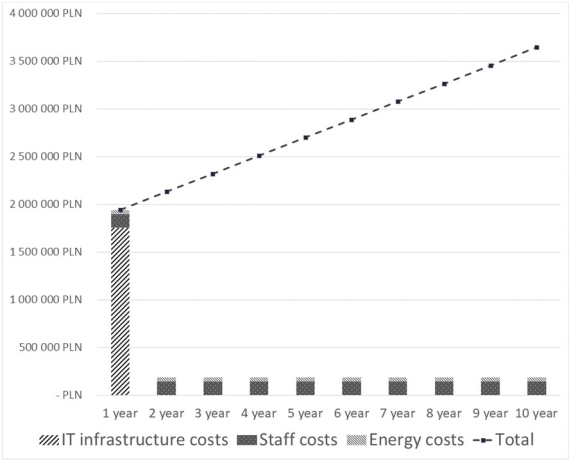

Figure 1: The estimated TCO for VDI implementation at Wroclaw University of Economics.

Initial costs of implementing VDI are higher than traditional solutions (PC), but as you can see from the chart, from the fourth year, VDI implementation brings significant savings. The total costs include infrastructure purchase costs, Help-Desk remuneration costs, electricity costs (standard office work conditions in an air-conditioned facility have been assumed).

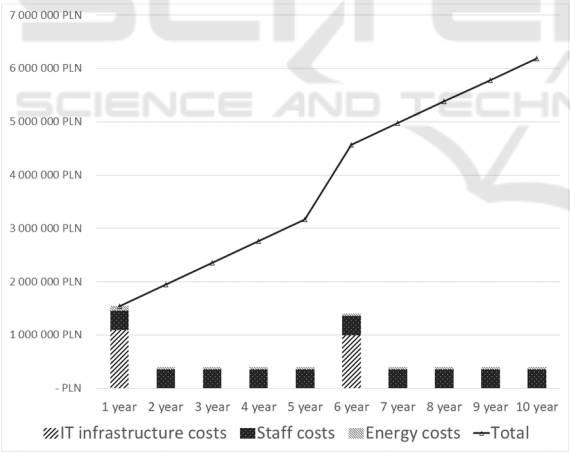

Figure 2: The estimated TCO for previous solution (PC) at Wroclaw University of Economics.

A 10-year cycle was adopted, the total infrastructure cost was compared, excluding operation systems licensing of virtual systems, anti-viruses software, Office systems etc. (for both cases). The comparison concerns 400 computers and accompanying infrastructure servers.

The first phase of the project covered the installation and configuration of seven laboratories with 175 zero client terminals (Samsung NC240) and a new server room based on DELL Blade servers, where a total of 6 two-processor servers were installed, with the possibility of fast scaling up to 16 servers. Six two-processor servers, with a total of 1.27 TB RAM, are allocated for VDI solution.

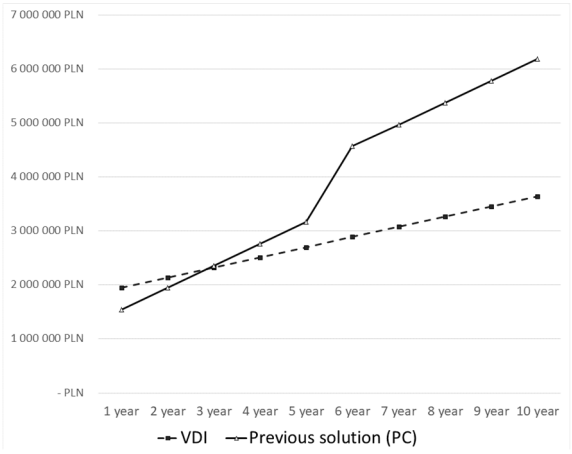

Figure 3: Comparison of estimated TCO of VDI and previous solution (PC) for the Wroclaw University of Economics.

The disk array and some servers are equipped with an SSD-based cache. One of the servers is equipped with an nVidia card GRID K1 and streaming card supporting hardware PCoIP (Apex 2800). As storage is used EMC disk array with a total of 20 Tb working gross capacity.

After three months from the start-up of the infrastructure, 60 servers were already working in the server pool – the majority of existing servers servicing the university were virtualised (including e-mail and www servers). The cost of the project was around 1.3 million PLN.

A year after the implementation, due to the fact that the project met all the requirements, the database of VDI labs was expanded. There are currently almost 400 terminals (Samsung NC240 terminals), over 500 virtual systems, and students can connect to one of right available images, depending on the course and the necessary configuration.

Hardware and software solutions implemented at the Wroclaw University of Economics facilitated the use of the latest tools in the didactic process. The purchase of modern equipment allowed to implement a much richer range of scenarios in the laboratory program. At the same time, the flexibility of the hardware facilities allowed the academic staff to choose student laboratory configurations in such a way as to cover as wide a range of issues as

possible. This form of classes is conducted in a number of project tasks, in particular group projects characterised by greatest freedom in independent decision-making and proposing solutions. Figure 4 presents a major fragment of the implemented network infrastructure for the Wroclaw University of Economics with the student laboratories (currently there are 12 `students laboratories in this technology) and its connection to Wroclaw Centre for Networking and Supercomputing at Wroclaw University of Science and Technology. The whole infrastructure at the University includes almost 400 zero client terminals and over 500 virtualised systems, which are available to students in laboratories.

As it was already mentioned in the article, the implementation of zero client solution has reduced the cost of maintaining the infrastructure compared to a traditional workstation equipped with a PC and monitor. The zero client consumes much less power than a traditional workstation and reduces the number of installed devices, thanks to which it can reduce energy consumption several times. It is also completely quiet and extremely reliable. Thanks to the implementation of VDI, mechanical faults are no longer an issue, thus reducing the downtime and eliminating maintenance costs. Users no longer have to worry about system failures on their devices. Currently, terminals have a smaller administrative workload compared to classic PCs, because the proposed architecture is, to a large extent, very centralised, and workstation support can be performed by one person. In a simple and quick way, it is possible to personalise specific groups of terminals, for example for specific classes; it is easy to maintain the application order, and it is possible to quickly restore the master workstation.

Additionally, basic administrative tasks, such as system upgrade, software upgrade or installation of additional software, can be performed remotely and automatically by one person on numerous computers at the same time. Replacing computers with terminals allows to delay the aging process of equipment and reduce the costs of its modernisation. While a classic computer requires modernisation (in the academic environment it practically means an exchange for a newer model) about every four, maximum five years, the use of terminals means that they are technologically aging much slower.

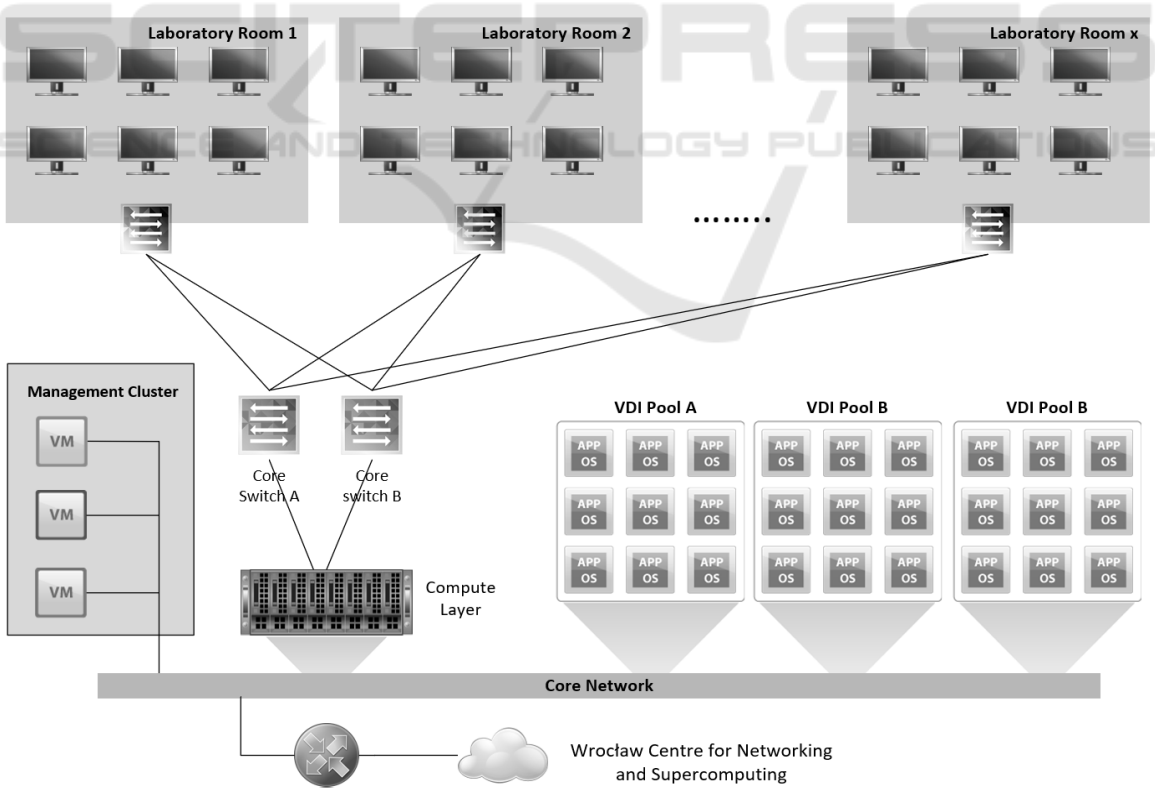

Figure 4: VDI network infrastructure for the Wroclaw University of Economics.

Thanks to the centralisation of computing power and virtualisation, it is possible to estimate that the life cycle of terminals at the Wroclaw University of Economics will reach about seven-right years, and the cost of replacing them will be about 50% lower than that of classic computers. The proposed solution is worth implementing primarily for the reasons of cost-effectiveness, but also due to the possibility of expansion and the simplicity of maintenance.

7 CONCLUSIONS

Virtualisation seems to be one of the most promising technological innovations in the field of computer science. The implementation of the VDI architecture can significantly simplify the process of administration and maintaining laboratories and computer workstations. It offers multiple benefits, as these solutions provide new opportunities, lead to the optimal use of existing resources, and contribute to significant savings, as evidenced by its implementation at the Wroclaw University of Economics.

After four years since implementing VDI at Wroclaw 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 anywhere. We do not at present provide access from anywhere for students (only for teachers and some students involved in the student organizations), but it is considered as a next step in the near future.

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