Management of Virtual Desktops in Energy Efficient Office Environments Using Thin Clients

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***Abstract*—There are different approaches to make office computer environments more energy efficient: terminal server environments and virtual desktop infrastructures. While in both environments money saving thin clients are used to connect a server, this paper presents an alternative approach, that uses several distributed workstations instead of a server. Therefore, this topology allows some savings concerning power consumption, as well as procurement cost, because no centralized server is required. Theoretical consideration for a typical use case showed a potential for energy savings using this approach. Moreover, the model is especially interesting for small office environments. Existing workstation computers can be used and replaced step by step through thin clients without purchasing an expensive virtualization server.**

***Keywords*–VDI; virtualization; distributed hypervisors; thin client; virtual desktops; energy efficiency**

I. Introduction

In times of climate change, the energy demand of enterprises becomes a point of interest. Often the term Green IT is used with the goal to reduce CO_2 emissions. For modern office environments, this means reducing energy consumption and hence energy costs. Therefore, the approaches of terminal servers and virtualization are used to implement energy efficient infrastructures. Whereby, these environments are mainly using energy efficient and cost effective thin clients. Using terminal servers, end users are connected to a central server, where all the calculations are done. The other cost effective tool in computer technology is virtualization. Using this technique, user environments with operating system and all required applications are virtualized using virtual machines running on a centralized server with one hypervisor. Thus, the utilization rate of a server can be enhanced [1]. Nowadays, it is especially used in medium to large scale enterprises, in form of a Virtual Desktop Infrastructure (VDI) [2].

This paper presents an extended and distributed approach of the traditional VDI architecture. Here, virtual desktops are provided by several office workstation computers instead of a central server. Additionally, a set of workstation computers is also replaced by thin clients. Remaining workstations are used as user workspaces and virtualization platform (distributed hypervisors). The paper is focused on the concept of the Workstation based Virtual Desktop Infrastructure (WVDI) model. It covers the question, weather this approach may be used to achieve energy savings. Furthermore, a theoretical evaluation of this approach, using a typical use case in a small office environment, is presented. Thereby it is shown, that WVDI has a theoretical potential to reduce energy consumption within an office infrastructure.

This paper is organized as follows. In section II, the technical background and related work are given. Section III presents the concept of WVDI. Possible limitations of this approach are pointed out in section IV. A theoretical evaluation of the presented model is done in section V. Finally, in section VI we conclude the paper and indicate some further work.

II. Related Work

A. Terminal Servers

Applications installed on very powerful servers and providing user sessions for connected terminals are referred to as terminal servers. Usually, terminals are thin clients, which merely create remote connections to terminal server sessions. Since only a video stream, as well as mouse and keyboard input are transmitted over network, a higher degree of data security within an enterprise is reached. Attack surface via network is thus reduced significantly. Compared to environments using workstations or personal computers, terminal servers have many beneficial aspects. Due to centralization, PC maintenance costs decrease. All settings and software installations are accessed and applied centrally. Thus, applications are available to a large number of users. In large companies usage of terminal servers may reduce costs. Compared to a normal workplace, power consumption of a terminal server is only a 1/8th the amount. Further savings can be achieved by replacing expensive workstations with low-cost thin clients. Due to their structure, these environments are reliant on powerful servers [3] [4].

The thin clients and the use of remote display connections are important, but central servers are not used and not regarded further in this paper.

B. Virtualization Technologies

Another approach for energy efficient computer environments is virtualization. Many virtualization technologies, which differ with respect to the component to be virtualized exist. Below, two virtualization technologies are described.

1) Server Virtualization: On a physical server hardware a hypervisor, that distributes physical resources to Virtual Machines (VMs), is installed. Each virtual desktop can use physical hardware to a share determined by hypervisor, which ensures that VMs are separated logically and can not interfere or manipulate each other. Virtual desktops can be migrated between physical host systems dynamically, depending on hypervisor and any additional products, without being noticed by the user or operating system running in a VM. This virtualization technology offers greater flexibility, load distribution and reliability. It makes Data Centers (DCs) much more efficient and saves energy [5].

2) Desktop Virtualization: In general, desktop virtualization is similar to server virtualization. The difference is that VMs can be streamed across platforms such as personal computers, laptops or thin clients. Using hosted VDI-Desktops, users work with dedicated virtual desktops on a server. Each user has its work environment in an own VM, that can only be accessed via network. The user terminal serves only for input and output operations and needs almost no computing power. Depending on server performance and VM usage, a variable number of virtual desktops can be deployed on a hypervisor simultaneously [6].

In the approach presented in this paper, hypervisor based server virtualization shall be used on workstations. Therefore, it will be further developed in the course of this paper. Since thin clients can not provide the required computing performance, they are used in combination with hosted VDI-Desktops or VDIs, where programs are executed on a server centrally. Thus, usage of thin clients in VDI is possible, which is relevant for this work.

C. Virtual Desktop Infrastructure

In VDI, user desktop environments are virtualized and converted into VMs. Powerful central servers are equipped with a hypervisor to host and run virtual desktops. Workstations or desktops can be used as terminals on user side and are only used to establish a connection to VMs via a remote display protocol over network. To create a connection to a server hosted virtual machine little computing power is necessary. Hence, inexpensive and energy efficient thin clients are used instead of workstations or personal computers [7]. A central Connection Broker (CB) distributes requests for a remote connection from thin clients and forwards them to correct VMs. Users can login to any terminal device and work with their virtual desktop. VDIs are used in medium to large enterprises and are focused on virtualization of desktop PCs. Use of workstations and desktop computers requires an effort regarding installation, configuration, as well as high procurement and operating costs. Therefore, virtualization becomes interesting and its popularity increases. Usually, for a user it does not matter whether he is connected to a VM from a workstation, desktop or thin client. In case of failure or replacement of an end-device, it is easy to set up a replacement device, because no complex installation and configuration is necessary. The user can work almost seamlessly [8] [9] [10].

D. Virtual Desktop Infrastructure without central servers

Based on VDIs there is an approach without central servers [11] [12]. Here, hosting of VMs is done only on workstations and a software is utilized for virtualization. Employees may use a random workstation to connect to their virtual desktop over network. Virtual machines are located arbitrarily on workstations in an office environment. Depending on workload of individual workstations, virtual machines can be migrated dynamically between them. In this way, the highest possible energy efficiency can be achieved, which is the primary goal of this approach. This approach provides no infrastructure with servers in a server room or DC, but an office environment consisting exclusively of workstations. These are equipped with a hypervisor each, so that virtual desktops can be distributed to workstations variably.

Since thin clients are not yet used, an extension of this approach that allows their usage in such an environment, is presented in this paper. Thin clients have no hypervisor function, but use remote display protocols to connect to VMs hosted on workstations. As thin clients have a much lower power consumption than workstations, energy efficiency can be increased significantly. In addition, savings are possible with regard to cost of ownership, because thin clients are far more economically priced than workstations.

III. Workstation based Virtual Desktop Infrastructure

An extension for a VDI environment is the WVDI model, that uses the approach of replacing servers by workstations to take care of virtualization. In addition, to an environment composed of only workstations, a share of them is replaced by thin clients to achieve further energy savings and reduce procurement costs. Servers are not required, because already existing workstations are hosting VMs [11] [12].

A. Architecture

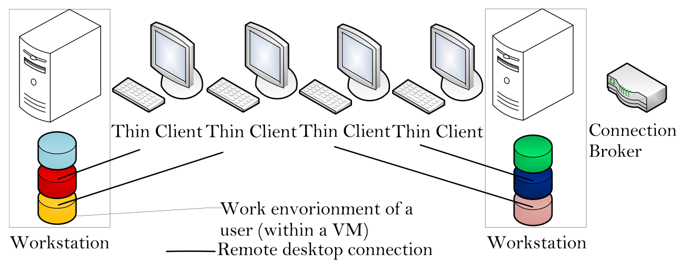

Figure 1. VDI-environment based on workstations

Figure 1 shows an abstract representation of an office environment including two workstations and four thin clients. Workstations provide users the same functionality as thin clients do, namely enable remote access to VMs. Further, there is a virtualization layer on each workstation, that provides virtual desktops (round hard disk icons). On the left and right, both VMs located on top illustrate a virtual desktop accessed via workstation. The other four are accessed via thin clients. Main task of a thin client is to create remote desktop connections to virtual desktops. A CB is illustrated, that takes care of management tasks. It is either implemented on an independent computer or run in a separate virtual machine on a workstation. This approach applies hypervisor based virtualization exactly like VDI, so users can choose their operating system individually. Maximum number of VMs on a workstation is limited by hardware performance. Thus, not as many as on a high performance server can be run. The number of hosted virtual desktops depends on processor performance, memory and hard disk space of a workstation. To run VMs in an office environment, it must consist of at least one workstation with hypervisor.

B. Management concept

A CB is responsible for maintenance of connection requests from the user side. For correct transfer to an appropriate virtual desktop, each user is assigned to a personal VM. The CB knows which hypervisor hosts a proper virtual desktop and manages migrations between workstations centrally, to allow a uniform, but also energy efficient, load distribution.

Goal is to adapt the CB, so that workstations are always utilized to their capacity and also without performance losses, to require less workstations with hypervisor. Remaining workstations can be shut down, but local working users should be considered. Moreover, migration is done in off or on state (Live-Migration). By monitoring utilization of all virtual desktops and workstations, it is decided whether to migrate VMs to another workstation for better performance. This is done completely autonomous and remains unnoticed by users. If a virtual machine has to be run, the respective workstation is woken up via Wake-On-LAN.

C. Assignment of virtual machines

The approach works with static and dynamic assignment of VMs, that can be moved manually, e.g. replace workstations or perform maintenance work. Using static assignment a certain virtual desktop always remains on a specific, previous defined host and is migrated independently of the load level of a workstation. Worst case is if all workstations are switched on and only one virtual desktop is run on each. This is not particularly energy efficient, but implementation is simpler and the CB can be omitted, because organizing and monitoring of dynamic migration is not needed. Alternatively, virtual desktops can be migrated dynamically. Migration can take place at any time, regardless whether a VM is running or not. A CB initiates and monitors all migrations. It is always aware, which workstation is hosting a certain virtual desktop and brokers connection requests accordingly. Migration should be performed in following cases:

1) Start and end of work: At start of work, in most cases, VMs are scattered on switched off workstations. For each additional user who begins to work, the corresponding virtual desktop and hosting workstation are localized and started if necessary. The more users start working, the more workstations have to be run. Depending on the number of VMs run in total and their load, a consolidation on a few or distribution to several workstations, may be useful. If users shut down their virtual desktops or place them in idle state, workstations without running VMs are shut down, unless migrations or backup tasks are pending. Not all users stop working at once. Usually, this extends over a longer period of time. Migration is useful to consolidate still running VMs to as few workstations as possible at an early stage. Thus, energy efficiency increases.

2) Lack of hard disk space: One or more VMs must be migrated to another workstation, if the amount of free disk space of the workstation decreases. Particularly in case of thin-provisioning, where hard disk space for virtual desktops is assured but not physical available at all.

3) High and low utilization: For high workstation utilization in form of processor and memory utilization, it is advisable to migrate VMs to another workstation in order to provide sufficient performance for all users. If necessary, a switched off workstation has to be started. If utilization of workstations is low, it may be advisable to consolidate VMs on less workstations. This increases energy efficiency, because remaining workstations are utilized more efficiently and others are released from their current work and can thus be switched off.

D. Energy savings

In principle, two things establish energy savings using WVDI in office environments. First, many workstations are replaced by energy saving thin clients. Secondly, an intelligent management uses dynamic migration. Resources of workstations are exploited as efficient as possible by running as many VMs per host as feasible. Maximum of hosted VMs are determined by utilization and performance of physical available hardware. In case of high utilization rates of individual workstations, remaining ones, which are not used, can be switched off automatically. Overall, energy savings are achieved through non running workstations. In a scenario where one workstation and three thin clients are used, possible energy saving is theoretical 50% compared to an environment with workstations alone, since mainly thin clients are used for better utilization of workstations. In order to achieve high energy efficiency, just as many workstations as required are switch on. This is possible if running workstations are well utilized, but limitation of performance is reasonable for users.

IV. Possible limitations of WVDI

WVDI enables virtualized office environments to be run energy efficient without a server infrastructure, by using energy saving thin clients and existing workstations with hypervisors to provide VMs. Therefore, energy savings are achieved by replacing some workstations with energy saving thin clients. Analyzing WVDI, possible problems can be identified for practical implementation. Some of these are presented and discussed below.

A. Wake up of Workstations

A CB decides if a workstation is woken up, to serve as hypervisor. This can be done via Wake-On-LAN by sending a magic packet, to give the boot command. A problem cloud be that in an already existing office environment workstations may not be Wake-On-LAN capable or behave incorrectly, e.g. do not follow the usual boot sequence.

B. Properties of virtual desktops

A virtual desktop is located in a VM. Size of a VM can vary arbitrarily, but it must not exceed the local hard disk size, even if thin-provisioning is used, that allows to allocate more hard disk space, than physically available. If allocated memory, that is not physically present, is used entirely, it may lead to a destruction of the VM. Using dynamic migration, maximum hard disk size should be equal to storage capacity of the smallest hard disk integrated in all workstations. Alternatively, VMs, that have not as much physical disk space as allocated, can be prevented from being copied. Depending on virtualization degree, several VMs located on a workstation share space. The size of a virtual machine has a direct impact on migration duration. Further, no special requirements are imposed on the operating system of a virtual desktop, but it has to be supported by hypervisor.

C. Exceeding maximum storage capacity of a workstation

In WVDI, hard disk space can not be added easily. Depletion of storage capacity depends on physical available hard disk space and space already occupied by other VMs. Both values are variable since each workstation can have a different hard disk size and VMs with different virtual disks. Here, an optimization by the CB is necessary, to migrate virtual desktops to other workstations in time and thus an overflow of hard disk is avoided. For static allocation of VMs, it should

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be sufficient to allocate as much virtual disk space as physical available.

D. Simultaneous start and end of work at all workplaces

If many users start their VMs simultaneously (for example at start of work), virtual desktops must be deployed or upgraded. Because simultaneous switching on/off of multiple VMs requires more hardware performance, this may lead to initial performance limitations. In case of static distribution of virtual machines, this performance limitation is restricted to its boot time. Using (dynamic) migration can cause more limitations. If many migrations take place simultaneously, network load is high correspondingly and depending on network hardware, performance bottlenecks can occur. In the worst case, all VMs are on a single workstation initially and requested concurrently. Then, a majority of VMs is migrated to other workstations, to make the same amount of hardware available for each virtual desktop. To prevent this scenario, the CB has to be parameterized with a maximum number of storable VMs, for each workstation. This number should be chosen individually, depending on the available hardware resources. Virtual desktops have to be distributed to workstations in roughly equal proportions, so that no performance losses occur due to a simultaneous start of all workstations. It is similar if all employees go off duty simultaneously, but do not have to wait for shut down or migration. Instead, this is done in background autonomously, after office hours.

E. Hardware failure of a workstation

If a workstation crashes e.g. due to a disk defect, all stored data and VMs are lost. A backup strategy should be designed, that regular backs up all virtual desktops to a Network Attached Storage (NAS), to prevent data loss. This could be performed every night, when network load is low anyway. Alternatively, VMs could always be migrated to at least two workstations to ensure redundancy. This could be done automated, always after a virtual desktop is shut down. However, this would require additional memory and thus limit the total number of VMs. In addition, network traffic is increased each time a VM is shut down or copied to an additional workstation.

F. Integration of a central management unit for WVDI

A centralized management is necessary to manage VMs and to perform and monitor dynamic migration. This can be implemented on a small computer with low computing power, since high performance is not required for its tasks. Alternatively, a management unit can also be installed on an existing workstation. However, this workstation must be active at all times or at least for the time when a workstation or a thin client is to be used, because it handles incoming connection requests and manages migration processes. Alternatively, an allocation table of VMs could be stored in thin clients and workstations permanently. This may result in a greater administrative management if a device needs to be replaced.

G. Data security and safety

Using WVDI, implementations for physical access protection like in conventional offices are far more difficult, because data is stored in users VMs, that are located on workstations and are thus exposed to third party access. In order to ensure data security, encryption should be used. The best case is to encrypt all VMs entirely if possible and appropriate regarding performance. Further, communication between user workplaces and VMs shall be encrypted.

H. Flexible selection of workplace and telework

The approach allows users to work from home via remote desktop connections. Energy savings are achieved by not running a dedicated workstation for each user separately. A further advantage is, that it is not required to shut down a VM when leaving, but calculations are still pending. Users simply turn off thin clients while virtual desktops are running in background. When working within a virtualized infrastructure, opportunity to change the workspace and continue working is given. Here, the VM continues to run on a respective hypervisor without interruption and only the connection is established from another end device, which may be a thin client, workstation or a computer at home.

I. Operating conditions of a virtual machine

If a VM is paused, the current system state is frozen and written to hard disk. After this, a virtual desktop no longer needs any resources. Power consumption in this state corresponds to a proper turned off VM. A user only has to turn off thin client and peripheral devices, such as a screen or printer. Returning from break, a user starts his thin client and the virtual desktop is woken up, that is again in exact the same state, as left previously so work can be continued seamlessly. This can be problematic if application programs are connected to a central database server directly. It can lead to unwanted results if the database server is disconnected due to timeout, resulting in inconsistencies within database. Another option is to continue to run VMs if a user disconnects and turns off thin client. Time exposure is equal to the other option here. Any further calculations can be continued or database connections maintained. Energy savings are only possible if thin client and its peripherals are turned off. On hypervisor side, no savings can be achieved as the VM is continues running. When returning to work, a user only needs to restart his thin client and the corresponding remote connection.

V. Evaluation of WVDI

To evaluate WVDI, its energy efficiency is compared with conventional workstation or desktop PC solutions. For calculations, power consumption values of respective components were taken into account. The purpose is to determine whether the use of WVDI can save energy or not. The number of necessary workstations and thin clients is determined by the virtualization rate and total number of required workspaces.

Definition: *The **virtualization rate** specifies the maximum number of VMs that can be run on a hypervisor.*

According to this definition, a virtualization rate of three means, on a hypervisor (up to) three VMs can be run. In WVDI a hypervisor runs on a workstation and a user can work with the virtual desktop on it directly. A virtualization rate of three in WVDI means there are a workstation and two thin clients. A virtualization rate of three is noted in this work as VR = 3.

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A. General conditions

Certain reference hardware and their parameters (power consumption) are used for a simplified and theoretical evaluation. A workstation serves as a hypervisor and is available to a user as workplace. For remote connection to a VM, a thin client is used as local end device. A desktop computer and workstation (without hypervisor) are used for comparison with conventional desktop PC or workstation based solutions. Performance of all considered components is interpreted for an average user type called ”medium user”. This user is characterized by using two or three applications at the same time, including e.g. word processing, spreadsheet, database or client/server applications [13]. In order to obtain concrete and realistic performance data, widely used and adapted hardware components for this user type are considered.

1) Workstation: The Fujitsu’s CELSIUS W530 Premium Selection workstation with a power consumption of 38 Watts in IdleMode, 100 Watts in Maximum and 44 Watts in OnMode is used as a reference workstation. This workstation is recommended for virtualization tasks by the manufacturer. Values for power consumption (IdleMode and Maximum) were given by the ECO Declaration Sheet [14]. Power consumption of 44 W in OnMode was calculated and rounded using the formula defined in the Product Cases Report of the European Commission [15]:

$$OnMode[W] = 0,9 \cdot IdleMode[W] + 0,1 \cdot Maximum[W]$$

A fixed (38 Watts in IdleMode) and a variable power consumption are included in the total power requirement for each workstation. Variable power consumption is determined by the number of VMs run. A virtual desktop causes an additional power consumption on the host system of up to about five watts [16]. Since they are not always run under full load, an additional power consumption of four watts is assumed for each additional VM. The fact that power consumption is nonlinear according to processor utilization, is neglected, because deviations are minimal to the final result but would increase calculation effort considerably.

2) Thin Client: The Igel UD5-LX thin client with following data is used as a reference device. It has a typical power consumption of 11 Watts. No distinction is made between IdleMode, OnMode and Maximum, since no calculations are performed by thin clients in the actual sense, only a remote session is provided. Hence, utilization is almost always the same.

3) Desktop PC: The Fujitsu’s ESPRIMO P720 E90+ desktop PC with following data is used for comparison with WVDI. For each PC a power consumption of 24,2 Watts in OnMode is assumed [17]. It is an all-round PC, dimensioned for conventional office work and has been selected for this reason. For following calculations, a rounded value of 25 watts (OnMode) is used for its power consumption.

In addition, the CB (to manage host assignments of VMs) is not regarded. Since this is only a single small computer or even a single virtual desktop, it is hardly important here. In addition, higher network traffic resulting from a dynamic migration of VMs is not taken into account. Dynamic migration is shown in the best case scenario. With dynamic migration it is possible to cause and approximate the best case. Power consumption of peripheral components are not included here, because these are required in any case, regardless of whether a conventional installation or WVDI is implemented.

B. Energy efficiency in an office environment model

WVDI was designed to enable small enterprises usage of VDI without a dedicated server. Small enterprises typically consist of up to 50 employees. Since in most cases not all users are present at the same time and there are part time employees, this evaluation is based on a more realistic scenario with 30 workplaces. Power consumption is calculated at different virtualization rates. Virtualisation rates of two, four, eight and ten were chosen, since these appear reasonable and realistic. The goal is to determine whether WVDI allows energy savings. For the sake of a clear presentation, an evaluation of the virtualization rates was relinquished. A specific number of workstations and thin clients is required for each virtualization rate. Table I shows how many workstations and thin clients are required for several numbers of virtualization rates.

TABLE I. REQUIRED NUMBER OF WORKSTATIONS AND THIN CLIENTS PER TOTAL NUMBER OF WORKPLACES AND VIRTUALIZATION RATE

	30 Workplaces	
	Workstations	Thin Clients
VR=2	15	15
VR=4	8	22
VR=8	4	26
VR=10	3	27

1) Worst case scenario: Users work on thin clients only and use VMs, which are hosted on different workstations. For each user a thin client and a workstation has to be started. Power consumption is thus higher compared to solutions using only workstations or thin clients. When all workstations have started, only power consumption of thin clients and VMs are added for each additional user. This problem could be solved by organizational measures in the company or by usage of dynamic migration of VMs, but this is not taken into account here. Figure 2 shows that at first, power consumption

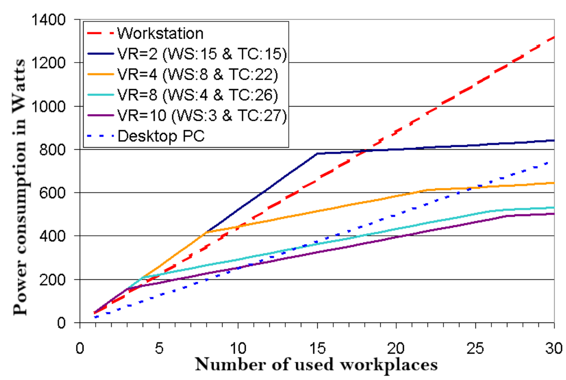

Figure 2. Worst case with 30 workplaces

for all virtualization rates is slightly above the conventional workstation solution. This is due to the fact, that not only a workstation but also a thin client and a VM have to be run per user. Starting from VR=4, it can be seen that even in the worst case, power consumption for ten workplaces is below a workstation solution. Starting from 25 workplaces, power consumption is even below that of a pure desktop computer solution. This is analogous to other virtualization rates. Using a virtualization rate of VR=2, more than 18 workplaces have to be used in order to achieve energy savings

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compared to a pure workstation solution. Using 30 workplaces power consumption in WVDI is about 400 Watts lesser than the workstation solution. Even if 30 workplaces are used, power consumption of a desktop computer solution is about 100 Watts below the WVDI solution.

2) Best case scenario: The most favorable and thus most energy efficient situation when using WVDI is represented. In this case, it is assumed that users are distributed at their workplaces, so that as few workstations as possible have to be run. This can be done in two ways: Firstly, users are organized in such a way that certain groups of users work with their VMs on the same workstation simultaneously. Thus, only as few workstations as necessary are run. However, this could be difficult to implement, because of a significant reduction in flexibility and higher administrative and organizational effort. Secondly, dynamic migration is implemented. All required VMs are moved dynamically to as few workstations as possible during operation, so that as many workstations as possible can be switched off. This option is much more complex regarding implementation on technical side, but is hardly noticeable to users. Here, the maximum number of VMs per workstation is utilized fully and as few workstations as possible are run. In Figure 3 curves for workstation and desktop computer

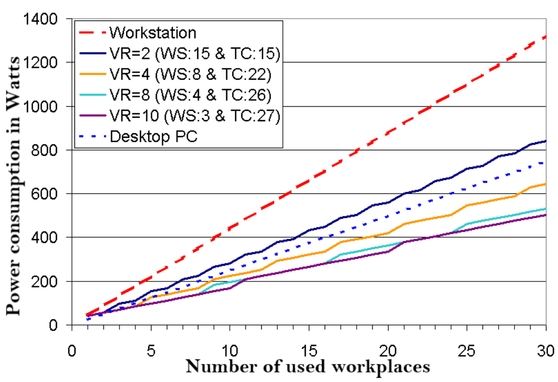

Figure 3. Best case with 30 workplaces

solutions are exactly the same as in the worst case scenario. A further workstation is switched on for each significant increase of a WVDI curve. The Figure shows that using WVDI with the lowest virtualization rate of VR=2, power consumption is below a workstation solution. Using a virtualization rate of VR=3, power consumption is below the desktop PC solution. With a virtualization rate of VR=4, power consumption is half as much compared to a workstation solution. If a best case distribution is ensured by organizational measures or dynamic migration, energy efficiency can be increased significantly, as well as energy savings. It is analogous to other virtualization rates. The best case scenario shows that power consumption of WVDI using a virtualization rate of VR=2 with 30 workplaces is about 400 Watts below a pure workstation solution. Further, the desktop computer solution is about 100 Watts below the WVDI solution. This is the same as in the worst case scenario. Starting with a virtualization rate of VR=4 in the best case, power consumption in WVDI is below a desktop computer solution whereas in the worst case power consumption is lesser than a desktop computer solution if more than 25 workplaces are used.

VI. CONCLUSION

Using WVDI compared to conventional solutions, energy savings, as well as lower procurement costs are possible. Compared to a solution consisting of only workstations, procurement cost savings are already achieved using a virtualization rate of VR=2. Using a virtualization rate of VR=4, procurement costs are already half as much. Even in the worst case scenario, the power consumption of WVDI is below a pure workstation solution, if a minimum virtualization rate of VR=4 with ten workplaces is used. Starting form 25 workplaces, power consumption is also below a desktop computer solution. In the best case, power consumption is already below a pure workstation solution using a virtualization rate of VR=2. This solution is suitable particularly for small office environments, where procurement and maintenance of a large and cost intensive server infrastructure is not worthwhile. Using WVDI, small office infrastructures can still benefit from the advantage of virtualization and increase energy efficiency. Energy savings in WVDI are theoretically determined and illustrated using specific power consumption values for exemplary hardware components (workstations, thin clients and desktop PCs). It is assumed, that execution time is nearly the same in both cases, therefore the decline in power consumption translates to energy savings. Which solution is the one with highest energy efficiency for a respective IT environment, depends on the number of devices, but also on their power consumption.

The result of the research question shows, that WVDI can save energy in theory. Further, the following points have to be considered within the next steps. This paper provides only theoretical calculations, hence, the real number of possible VMs on a host is not considered. Therefore, further steps will be required to evaluate possible limitations of the WVDI model, such as communication and load balancing. Since WVDI is an distributed hypervisor system, network traffic may rise due to an increasing number of required migration processes for consolidation. This may also lead to potential performance cost if those migrations become more frequent. But it must also been taken into account, that a high consolidation rate may decrease performance, because workstations are not as powerful as servers. Another important aspect to be worked on regards data security and privacy assurance in WVDI. Finally, potential drawbacks of WVDI have to be analyzed further, to substantiate energy savings.

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REFERENCES

[1] S. Dutta and A. K. Gupta, “Green computing: A greener approach towards IT,” in 2016 3rd International Conference on Computing for Sustainable Global Development (INDIACom), Mar. 2016, pp. 50–53.

[2] M. Plettenberg and R. Spruijt, “State of the VDI and SBC Survey 2017 Edition,” Login VSI und VDI Like A Pro, Tech. Rep., Jun. 2017.

[3] C. Kehl and N. Frangos, “The Efficient Installation and Operation of Terminal Server Farms (original title: Die effiziente Installation und der Betrieb von Terminalserverfarmen),” visionapp GmbH, White Paper, April 2007, URL: https://slidedocument.com/die-effiziente-installation-und-der-betrieb-von-terminalserverfarmen [accessed: 2017-12-19].

[4] K. Usvub, A. M. Farooqi, and M. A. Alam, “Edge Up Green Computing In Cloud Data Centers - ProQuest,” International Journal of Advanced Research in Computer Science, Tech. Rep., Mar. 2017, URL: https://search.proquest.com/openview/8ad22aad54ab6364be896bb80aaf46d8/1?pq-origsite=gscholar&cbl=1606379 [accessed: 2017-12-12].

[5] VMware, “Virtualization Overview,” VMware Inc., White Paper, 2006, URL: http://www.vmware.com/pdf/virtualization.pdf [accessed: 2017-12-20].

[6] D. K. Sachsenmaier, “Energy-efficient Computer Workstations in Office Environments: Technologies and Comparison (original title: Energieeffziente Computerarbeitsplaetze in Bueroumgebungen: Technologien und Vergleich),” Bachelor thesis, University of Passau, September 2013.

[7] L. Casanova, Marcel, and E. Kristianto, “Comparing RDP and PcoIP protocols for desktop virtualization inVMware enviroment,” in 2017 5th International Conference on Cyber and IT Service Management (CITSM), Aug. 2017, pp. 1–4.

[8] K. Feldhusen, “Sizing of Virtual Desktop Infrastructures,” Whitepaper, Fujitsu Technology Solutions GmbH, White Paper, 2011, URL: http://www.fujitsu.com/downloads/HK/wp-vdi-sizing.pdf [accessed: 2017-12-20].

[9] A. Murphy, “Optimizing VMware View VDI Deployments with F5,” F5 Networks Inc., White Paper, 2009, URL: https://www.pei.com/wp-content/uploads/2013/01/Optimizing-VMware-VDI.pdf [accessed:2047-12-19].

[10] E. VMware, Cisco, “Enterprise Virtual Desktop Infrastructure: Design for Performance and Reliability,” VMware, Cisco, EMC, White Paper, 2009, URL: http://www.emc.com/collateral/hardware/white-papers/white-paper-vdi.pdf [accessed: 2017-12-20].

[11] A. Berl and H. de Meer, “An Energy Consumption Model for Virtualized Office Environments,” Future Generation Computer Systems, vol. 27, no. 8, Oct. 2011, pp. 1047–1055, URL: http://www.net.fim.uni-passau.de/pdf/Berl2011b.pdf http://linkinghub.elsevier.com/retrieve/pii/S0167739X11000616 [accessed: 2017-12-20].

[12] A. Berl, N. Race, J. Ishmael, and H. de Meer, “Network Virtualization in Energy-Efficient Office Environments,” Computer Networks, vol. 54, no. 16, Nov. 2010, pp. 2856–2868, URL: http://www.net.fim.uni-passau.de/pdf/Berl2010d.pdf http://linkinghub.elsevier.com/retrieve/pii/S1389128610002513 [accessed: 2017-12-20].

[13] E. Weidner et al., “Ecological Comparison of PC and Thin Client Workplace Devices (original title: Oekologischer Vergleich von PC und Thin Client Arbeitsplatzgeraeten),” Fraunhofer-Institut fuer Umwelt-, Sicherheits-, Energietechnik UMSICHT, Oberhausen, Tech. Rep., Dec. 2006.

[14] D. Feuerer, “Product environmental attributes - THE ECO DECLARATION - Workstation CELSIUS W530,” Fujitsu Technology Solutions GmbH, ECO Declaration, Juli 2013.

[15] R. Kemna, M. van Elburg, W. Li, and R. van Holsteijn, “Methodology Study Eco-design of Energy-using Products (MEEUP): product cases report,” Delft, Netherlands: VHK-Van Holsteijn en Kemna BV, 2005.

[16] Q. Chen et al., “Profiling Energy Consumption of VMs for Green Cloud Computing.”

[17] Fujitsu Technology Solutions GmbH, “Energy Consumption ESPRIMO P720 E90+,” White Paper, Fujitsu Technology Solutions GmbH, White Paper, June 2013.

[18] J. Willerding, “Management of Virtual Desktops in Energy Efficient Office Environments Using Thin Clients (original title: Management von virtuellen Desktops in energieeffizienten Broumgebungen unter Verwendung von Thin Clients),” Master thesis, University of Passau, December 2014.