A STUDY ON THE PERFORMANCE OF VIRTUALIZATION PROGRAMS

by

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Signature: ______________________________

Amir Aghel Masjedi

Abstract

Virtualization has become a very popular research topic in recent years. Virtualization is used in varied applications such as e-Learning, business-to-business communication, social networking, computer simulation and enterprise development. These advances are due to the availability of high-speed computers, fiber-optic-enabled internet connections and advanced virtualization programs. However, only a very small amount of research has been conducted, most especially on the performance of virtualization programs. Thus little is known about the performance of the various virtualization programs such as VMware Workstation and VirtualBox. When dealing with virtualization, performance is of primary importance. This thesis reports on the performance of different virtualization programs, such as VMware Workstation 7 and Oracle VM VirtualBox 4 using MS Windows 7 guest-and host-operating systems. The chosen research methodology for this research is a mixed research methodology based on both qualitative and quantitative. A mixed research methodology allows the researcher to easily collect primary data via qualitative methods and then analyze the data using quantitative methods. The main purpose of this study is to find any performance differences in between VMware Workstation and VirtualBox based on Windows 7 guest and host OSs. Various experiments were conducted regarding the performance of VMware Workstation, VirtualBox and Microsoft Windows Virtual PC using Windows 7 and Linux Mint guest OSs and Windows 7 host OS. Findings of the experiments revealed that there are performance differences among VMware Workstation, VirtualBox and Virtual PC. In virtualization, it is generally thought that VMware Workstation is superior to other virtualization programs. However empirical results obtained from this study show that the performance of VMware Workstation and VirtualBox are similar. VMware Workstation has many features but its performance is not very different from VirtualBox. Virtual PC on the other hand is not a reliable product for serious virtualization as it lacks features, performance and support for different host and guest OSs. The overall findings of this study show that VMware Workstation and VirtualBox both meet performance and feature requirements for creating reliable virtual environments. This study opens a new path for research in the area related to performance of virtualization programs. Data gathered from this study was used to make meaningful conclusions in Chapter 6. The conclusion explores possible directions for future research on the performance of virtualization programs. Findings of this study may help businesses to select appropriate virtualization program as part of their information technology infrastructure and thereby benefit from using virtualization technology.

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List of Abbreviations and Acronyms

2D	Two-dimensional space
3D	Three-dimensional space
CPU	Central Processing Unit
GIMP	GNU Image Manipulation Program
Gbps	Gigabit Per Second
I/O	Input/Output
J2EE	Java Platform, Enterprise Edition
MS	Microsoft
MD5	Message-Digest Algorithm
MMIO	Memory-mapped I/O
MOSS	Microsoft Office SharePoint Server
OS	Operating System
PC	Personal Computer
P2V	Physical-to-Virtual
PSDK	Platform Software Development Kit
RAM	Random Access Memory
RDP	Remote Desktop Protocol
USB	Universal Serial Bus
VM	Virtual Machine
WDDM	Windows Display Driver Model

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Chapter 1: Introduction

Today almost all the businesses use information technology infrastructure to improve their productivity and resource management. However a lack of the proper technology to implement such systems will penalise businesses with increased cost and cause them to suffer technical difficulties. Older approaches are obsolete and may cause technical problems. New methods of computing which are based on a virtualized infrastructure will introduce smart management, encourage scalability and promote well organized resource usage.

Using virtualization programs such as VMware Workstation and VirtualBox will considerably improve use of network assets, increase network scalability, create a durable network which is easily managed, allow for the launching of new networks and services in a much shorter time span and, more importantly lower the cost of deployment. Virtualization can reduce the costs of managing a network in many different ways, for example, costs will initially drop by deploying fewer machines and, as a result, fewer machines require less power, meaning lower costs.

With virtualization, the cost of computer hardware will be reduced, as applications can run on a single machine without a need for multiple machines and constant hardware upgrades. Nowadays many enterprises are using the virtualization technologies to speed up their workload and promote scalability. The old way of using physical machines alone has become an obsolete and inefficient compared to a virtualized infrastructure which is very cheap to deploy and cost effective to maintain.

Enterprises have saved billions of dollars and resources such as electricity and manpower through using virtualized based infrastructure. They may have reduced their hardware but they are still able to reach their desired results as before with virtualization technologies. Unfortunately, many small businesses do not have enough financial resources, time and manpower to spend on researching performance of various virtualization programs available on the market before acquiring one.

1.1 Research Motivation

Motivation for doing this research was to examine and evaluate the performance of major virtualization programs on Windows 7. This research provides valuable information regarding performance differences of major virtualization programs such as VMware Workstation and VirtualBox on Windows 7.

1.2 Business Problem

Many small businesses are spending too much money on upgrading and managing their information technology infrastructure with little effect on productivity. System administrators are overwhelmed with constant hardware upgrades and the hours of work they entail. Managing and securing a physical network is a difficult and time-consuming job. However, with virtualization technologies, system administrators can easily create a virtual network and effortlessly manage it. For many businesses it is time-consuming to research the performance of major virtualization programs before choosing one. This study can provide the necessary feedback on the performance of the major virtualization programs available on the market today.

1.3 Research Design

The aim of this study is to evaluate the performance of various virtualization programs on Windows 7. To carry out this research successfully, it was necessary to study the literature and research papers related to this topic. To evaluate performance of different virtualization programs on Windows 7, different virtual environments using VMware Workstation, VirtualBox and Virtual PC were created on Windows 7.

1.4 Thesis Structure

Figure 1.1 shows the structure of this thesis.

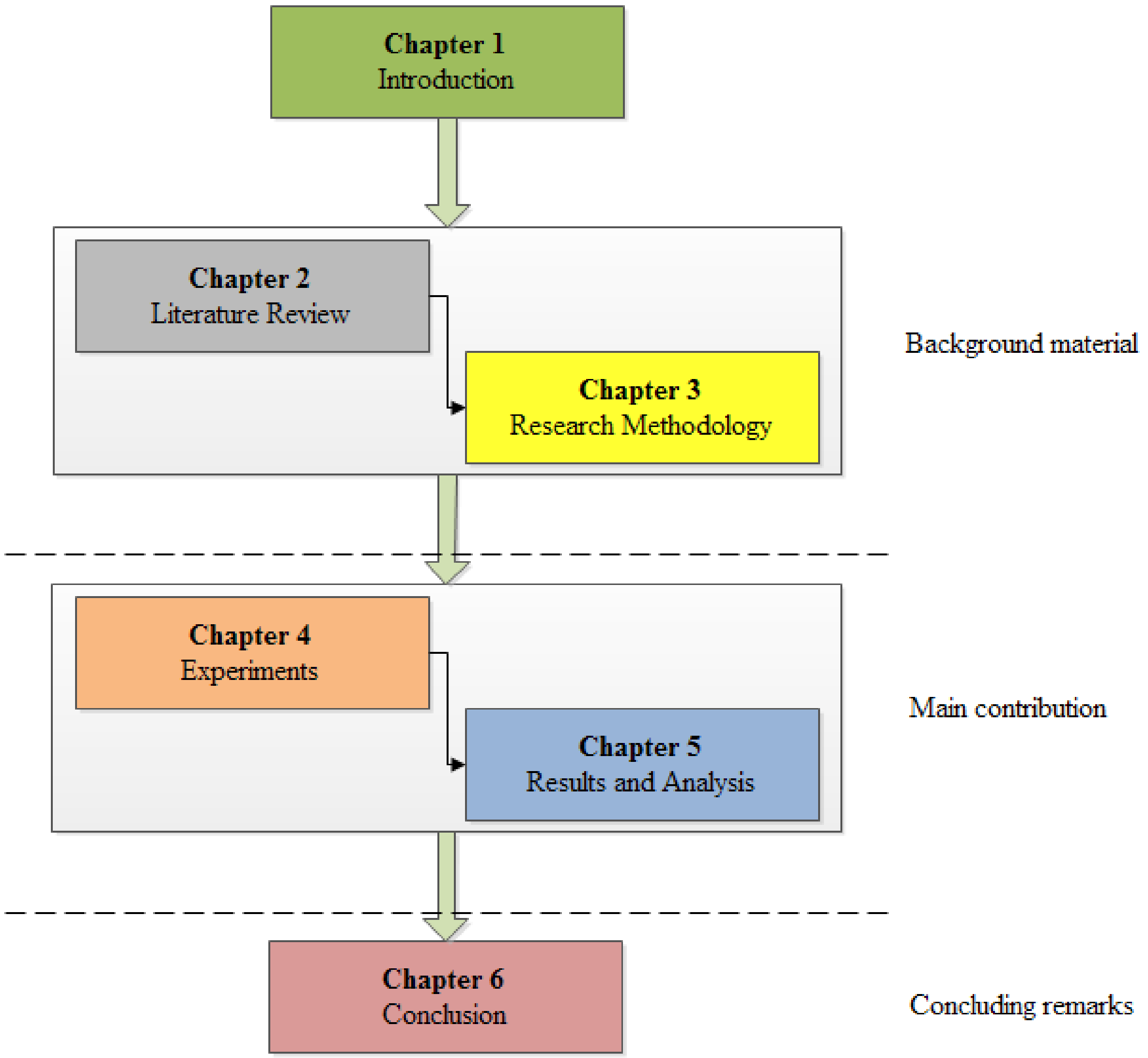

Figure 1.1: Structure of this thesis

Chapter 1 examines researcher motivation and provides an introduction for this research study. The researcher's interest in selecting this research is explained. The following chapters are structured in a manner to clearly present the background, contribution and conclusions of this research.

Chapter 2 reviews literature on the performance of virtualization programs, availability of virtual environments and virtualization technologies. The literature review chapter consists of a discussion of literature, research paper and online content related to virtualization and virtualization technologies. The literature review covered different studies in various areas of virtualization, including concept of virtualization, technologies, approaches and programs. Previous studies were reviewed and discussed. Gaps from the literature review were then noted.

Chapter 3 describes the research methodology adopted in this thesis. The reason for selecting the research methodology and the data gathering methods and data analysis techniques, are also discussed.

Chapter 4 presents the methods for studying the performance of different virtualization programs and describes the creation of the experiment environment. The experiments and their purpose are all explained in this chapter.

Chapter 5 contains the experimental results and analysis in tabular and graph form also in same chapter comparisons of the experiment results are made.

Chapter 6 concludes this research by summarizing the findings and making future recommendations.

Chapter 2: Literature Review

2.1 Introduction

In Chapter 1, introductory material on virtualization has been presented. In this chapter a detailed literature review on virtualization is presented and a history of virtualization and its highlights will be covered. Various types of virtualization methods and programs will be discussed and explained.

2.2 Virtualization

Virtualization is a relatively old concept but it has gained more popularity over recent years. Virtualization goes back to the year 1960's, when it was developed to solve problems arising at that time [1]. Virtual machines and virtual monitor concepts have existed since IBM's heyday. Back then virtualization was developed by IBM to provide timesharing of a mainframe computer [2]. However, nowadays many businesses are under pressure to achieve more with less. The same pressure is also affects system administrators all around the world. They are frequently asked to deliver more benefits to the organization with limited resources [3].

Virtualization is not only used in business-oriented environments but also in education. It is believed the use of virtualization in education dates back to as early as 2002. Virtualization will help education providers save money on maintenance and hardware, provide students with 24/7 access to lab resources and adopt new technologies in much sooner. Various studies prove that many already students use virtual machines to do their lab work instead of using a physical computer. In the beginning the use of virtualization was very costly, programs such as VMware Workstation were very expensive to deploy. Virtualization programs required computers with lots of memory and CPU power which they were very expensive at that time. Thus use of virtualization was only practiced by commercial enterprises. However nowadays computers can easily handle and run virtualization programs and, as a result, everyone with a personal computer can enjoy the benefit of virtualization [5].

To answer changing need, many organizations around the world are adopting a virtualized infrastructure and, as a result, the old way of computing is diminishing. For example, Kingston University in London is changing its information technology infrastructure by throwing away old computers in order to promote a virtualized infrastructure. According to the university it is trying to create a blueprint for virtualized education infrastructure and act as a pioneer for other universities around world which are willing to share the same cause and go virtualized [4].

Axon is a leader in information technology support. The company developed a system monitoring software for virtual based OSs. According to Axon's CEO Scott Green, Axon Performance Manager which is part of BMC tools can be easily integrated with virtual systems within a few days at a low cost. According to Green, virtualization has enormous potential advantages, however, virtual machines still require individual attention. Not having a proper monitoring system will put systems at risk. Green added that 80% of projects which Axon Corporation worked on involved virtualization technologies. Nowadays more businesses are using virtualization and virtualization technologies. Thus it can be said virtualization's popularity has dramatically increased in recent years [6].

Virtualization became a practical choice for system administrators to accomplish more with fewer resources. In computing, the term virtualization means to create a virtual version of a real entity. Applying virtualization to information technology infrastructure will reduce the quantity of unnecessary workstations to a minimum, which in turn will make management easier and costs lower [3], [7].

Stasiewicz [8] argues that virtualization is no longer a new phenomenon but a mature technology. Virtualization is accepted and integrated by many enterprises and it has been used for network infrastructure for many years. According to Stasiewicz, it can now be said that virtualization is not a fringe technology anymore but a technology which is adopted by the mainstream. According to Stasiewicz, virtualization has shown its benefits and advantages for a long time. Virtualization will provide security for network services by reducing the risk of host failure while reducing server resource consumption. Using virtualization and having a long term commitment to it, enterprises can now save money through lower energy costs and fewer hardware upgrades. According to Stasiewicz using virtualization in classrooms is not a new thing. Instructors have brought virtualization to students in many ways and have prepared them for the outside world. By using virtualization in networking classes and hardware classes, have became innovative and allowed students to create large, complex networks with fewer physical machines in a very short time [8].

2.3 Benefits of Virtualization

Virtualization can benefit businesses in many different ways by saving time, money and resources. With virtualization everyone can gain benefit, especially system administrators. System administrators can start thinking outside the box and not just focus on a few pieces of machinery. They can work on methods which will improve the quality of the services they offer. As virtualization becomes more popular, the use that comes to mind is to run multiple OSs at the same time. While this may be true it is not the main reason why businesses are moving toward virtualization. The true purpose behind this huge infrastructure change is to reduce server quantity and facilitate workload, thus saving space, power and time which leads to saving money.

Virtualization technologies offer the following main benefits [9]:

New way of disaster recovery: A virtualized information technology infrastructure will change the old way of disaster recovery by providing a fast, dependable and low budget disaster recovery plan through hardware independent, server consolidation and easy test scenarios.

Minimize system damage: Testing a new software in an OS can cause problems and cause file-system damage. With virtualization software developers can easily test new software in a virtualized environment and, if any damage is caused to the system, it is possible to rollback the system to its original state without any problems.

Reduce software clashes: Running multiple OSs on one machine sometimes causes' systems to crash. With virtualization it is possible to run multiple OSs on one machine without having a worry.

Easy cross-platform development: Software developers can easily test their products in different OSs with just a few clicks. Having all OSs up and running in one place is something which software developers can use to their advantage while saving time.

Save money: On most servers only one application can run because if an application crashes the whole system will crash and, if there are any other applications on that server, they will stop functioning as well. To solve that problem system administrators usually run each application individually on different servers to minimize system failure. This approach perhaps solves the problem but it is very costly and inconvenient, as most of a server's capacity will be left unused. More money is also required to acquire a new server for each new application. However, with virtualization, multiple applications can run at once on the virtual server. Thus businesses can save money and resources.

Save power: Businesses spend a lot of money for energy to run unnecessary servers. However with virtualization fewer physical servers are required thus energy requirements will be reduced to a minimum and less money will be spent.

Save time: With virtualization, fewer servers are required so system administrators can spend more time on performing tasks such as backup, maintenance, installation and recovery plans.

Improved security: With virtualization, system administrators can easily set up and manage honeypot traps.

Easy desktop management: Managing users' desktops can be a cumbersome task but with virtualization system administrator can more easily manage users' desktops.

Run multiple OSs: With virtualization, multiple OSs can run concurrently on a computer system.

2.4 Virtualization Approaches

The x86 is the most commonly used CPU architecture in industry. The x86 offers four different levels of protection from 0 to 3, which are described as rings. In this architecture, each ring provides a different level of privilege. Ring 0 is the innermost ring with complete control over hardware and system resources. Ring 3 is the outermost ring with the most limited privileges. Ring 0 is the place where the OS's kernel resides and it is in control of system resources. Applications which are relate to user's are always placed in Ring 3 which only provides limited access to system resources. If an application from Ring 3 tries to access system recourses which are only accessible through Ring 0 this creates an exception and consequently causes a catch. It will result in a change from unprivileged mode to privileged mode so the OS can execute the instruction and the afterward mode will return it to unprivileged while execution continues. The virtual machine monitor runs in Ring 0 which is in charge of virtual machines and system resources. Virtual machine behaviour is exactly the same as an unprivileged user trying to execute an instruction. When an instruction executed virtual machine monitor grabs the trap the instruction mode will change to privileged mode. A virtualization program will virtualize the CPU, I/O, memory and devices. Virtualization is achieved by actively contributing physical system recourses such as memory, CPU and devices to virtual machines. There are several approaches used for x86 CPU virtualization, but full virtualization, paravirtualization and hardware-assisted virtualization are the most common approaches which exist [2].

Full virtualization

In full virtualization a virtual machine fully simulates hardware behaviour and characteristics, which will allow a virtual OS to run in isolation. Full virtualization completely separates the guest OS from the physical hardware. The guest OS cannot determine that it is being virtualized and thus no modification is needed. Full virtualization is the only method of virtualization which does not require hardware or OS help to virtualize important and confidential instructions. Full virtualization provides the best security and isolation for virtual machines and allows easy migration and portability of the guest OS [10].

Paravirtualization

The word Para originates from a Greek word meaning alongside. Thus paravirtualization can be translated as alongside virtualization'. It simply means that the guest OS can communicate with a software layer which is called a hypervisor for better performance and efficiency. In paravirtualization, the hypervisor runs directly on top of the hardware. The hypervisor will automatically assign the necessary resources to the virtual machines. Paravirtualization is able to modify the OS's kernel to change non-virtualizable instructions to hypercalls which allow hypercalls to communicate directly with the hypervisor. The hypervisor is also involved in providing hypercall interfaces for important kernel operations such as interrupt handling, managing memory and time keeping. In paravirtualization the unmodified OS is not aware that it is being virtualized and important OS calls are trapped using binary translation [10].

Hardware-assisted virtualization

In hardware-assisted virtualization, the hardware provides the necessary support to create a virtual machine monitor which will allow a virtual OS to run in isolation. Hardware vendors are very interested in virtualization and are rapidly developing new products to make virtualization an easier task to achieve. Example of new improvements made by hardware vendors are Intel Virtualization Technology (VT-x) and AMD's AMD-V which both focuses on privileged instructions with a new CPU execution mode feature that allows the virtual machine manager to run below Ring 0. With hardware assisted virtualization, sensitive calls are automatically captured by the hypervisor, thus binary translation and paravirtualization are no longer required. The state of the guest OS is saved in Virtual Machine Control Blocks (AMD-V) or Virtual Machine Control Structures (VT-x). Intel VT and AMD-V CPU's became available since 2006 [10].

2.5 Types of Virtualization

Virtualization is just an abstraction of physical entity and system resources. The same concept will also apply to all different types of virtualization regardless of their type and purposes [11].

Server virtualization

Among the various types of virtualization, server virtualization is that on which most businesses are currently focussed. It is a fact that server virtualization is a big deal for businesses. Businesses can lose a lot of money and time if they choose to ignore it or can save money and time by adopting server virtualization. It is clear nowadays computer server have become huge space wasters and a cause of problems for businesses. Businesses are running out of empty space to place their servers. It seems obvious server virtualization has become a strong point of interest. Problems with servers are caused by their limitations and lack of ability to achieve multitasking. Servers can only serve one function, for instance a web server, file server, mail server, recourse management server and database server each only do one thing and, as a result, a lot of server resources are wasted. However servers can be in a multi-functioning state through the use of virtualization technologies. This will lead to less space required to house servers. Also the efficiency of existing servers will increase by 80-90 percent outranking previous estimations which were 8-14 percent due to server limitations. Server virtualization allows one server to do other servers' jobs by distributing server resources properly among different applications and platforms. Virtualization programs allow businesses to have various OSs and applications hosted locally or remotely, allowing users to access their work freely without being tied to a particular physical location [11].

Desktop virtualization

Desktop virtualization is concerned with workstations and end users. System administrators are often busy configuring, fixing and upgrading computers on a daily basis. The process is very time-consuming and an inefficient way to mange thousands of computers. This problem for system administrators can be a very cumbersome and onerous task, because each computer must be managed differently based on individual rules and regulations. Having open ports and slots for USB and DVD allows users to install unauthorized software onto their computer. Even an innocent user's computer can be prone to viruses and trojans through accessing the internet or other means. Thus new patches and antivirus updates need to be installed on computers from time to time and computers need to be scanned for viruses regularly. All these problems will make the system administrators' job very difficult. With desktop virtualization however, all these problems can easily be eliminated and the system administrator can focus more on productivity rather than performing time-consuming tasks [11].

There are three different types of desktop virtualization which are as follows [11]:

Remote virtualization: Remote virtualization is where the OS is hosted on a server and accessed remotely by users.

Local virtualization: This method of virtualization allows multiple OSs to run on the users' machine locally.

Application virtualization: Application virtualization is a virtualization method which uses a sandbox or wrapping technique to run applications on a user computer. Therefore the application will not make any changes to the OS's registry or files system. Virtualized applications will immediately work on the user's machine without any need for installation or configuration.

Storage virtualization: Storage virtualization is a virtualization technique which will separate logical storage from physical storage. Logical storage will act as a virtualized part of the hard drive.

Storage virtualization can be achieved through three different methods:

Direct Attached Storage: In this method data storage will be directly connected to the server. This is obviously the easiest method to perform but is very hard to manage.

Network-Attached Storage: In this method, one machine will be used in the network for data storage. This method is considered to be the first step towards storage virtualization. In network-attached storage, one machine acts as data storage simplifying the process of data backup.

Storage-Area Network: A specialized approach which changes how a simple hard drive works. This process is based on using special hardware and software which will convert an ordinary hard drive into a data solution. When businesses have realized that corporate data is a key asset, which needs to be accessible 24/7 they have shifted to storage area network.

2.6 VMware Workstation, VirtualBox & Virtual PC

Nowadays computers are powerful enough to run multiple virtualized OSs at the same time and so virtual OSs are more accessible than ever. Virtualization programs allow users to run a virtualized OS within a real OS. For example the main OS can be Windows 7, however with adequate hard disk space, RAM and CPU, users can run Microsoft Windows XP, Linux Mint, and Mac OS side-by-side in a virtualized environment on Windows 7 [12].

To successfully complete this study many factors such as compatibility, features, availability, support and cost were considered before selecting VMware Workstation and VirtualBox for this study:

- Compatibility
  - The best virtualization programs should be compatible with any host and guest OSs. For instance, virtualization programs should work on Microsoft Windows, Linux and Mac OSs and also, as far as compatibility goes, it should support many different guest OSs as well.
- Features
  - Having a list of adequate features will improve users' experience. Features such as export & import, cloning, networking, snapshots and shared folders are necessary and they should be supported by virtualization programs. Having more features is generally desirable.
- Availability
  - Provide easy and various methods for customers to obtain the product. Also provide long term commitment to developing the product further with updates and new versions.
- Support

    - Provide customers with 24/7 support. Provide customers with necessary helps such as documentation, guides and training.
- Cost
    - Cost and features are mixed together. If a free virtualization program comes with many features then that program is very desirable. However, most of the times that is not the case, thus the user's requirements, the list of features and the cost should be considered thoroughly.

VMware Workstation and VirtualBox are the best virtualization programs available today. VMware Workstation is feature-rich and compatible with many different host and guest OSs. VirtualBox has many features and supports many different host and guest OSs and moreover VirtualBox is free. Virtual PC is the Microsoft solution to virtualization. It is not as good as the VMware Workstation or VirtualBox, but it does allow users to run a virtualized OS inside the Microsoft Windows OSs. The majority of computers today use a Microsoft Windows OS, thus it is convenient to use Virtual PC as a virtualization solution and it is also free to use. However in this study VMware Workstation and VirtualBox were selected as the main virtualization programs on which to conduct experiments and Virtual PC was selected as an additional virtualization program to accompany VMware Workstation and VirtualBox in experiments.

VMware Workstation

In May 1999 VMware Corporation proudly launched VMware Workstation. VMware Workstation was developed based on ideas which were originally from a VM OS project by IBM back in 1960. VMware Workstation is a virtual machine which let users create numerous x86 or x64 virtual machines and concurrently host different types of OSs on each virtual machine [13]. VMware Workstation is used to create and operate various virtual machines. Beside the variety of guest OSs which are supported by VMware, it is also fully capable of supporting different host OSs. VMware is not a personal virtualization program, but is designed on such a scale that is can be used as a solution to problems concerning businesses. VMware can be used both for virtualization and para-virtualization, VMware supports both hosted and hypervisor architectures.

Of all virtualization programs which are available in the market today, VMware Workstation is the top ranking virtualization program available. VMware workstation is considered to be the most powerful virtualization program, it allows users to run both x86 and x64 OSs as guest machines. VMware Workstation is a paid virtualization program, but it also offers a free product called VMware Player to run the pre-configured guest OSs on host machines [14].

VMware Workstation is the most feature rich virtualization program available on the market. In fact, VMware Workstation is the first virtualization product, which VMware introduced to the public back in 1999. VMware Workstation has undergone many years of intense product development and improvement. VMware Workstation supports both Windows and Linux host OSs. For Mac users, VMware developed a similar product to VMware Workstation which is called VMware Fusion. VMware Workstation supports a range of 32-Bit and 64-bit guest OSs and it also provides fully emulated paravirtualized driver support for both Windows and Linux OSs [15].

According to Pozadzides "VMware *is the 900 pound gorilla of the Virtualization world*" [16]. VMware offers a free tool to run a pre-configured virtual machine which is called VMware Player, which works under both Windows and Linux. VMware Player can be obtained simply from VMware's website 'www.vmware.com/products/player/'. After the installation of VMware Player, the user can run pre-configured virtual machines which are also called ready-to-go virtual machines. Ready-to-go Virtual Machines are pre-made virtual machine images created from live virtual machines. These images can be obtained from "www.thoughtpolice.co.uk/vmware/", "www.vmware.com/appliances/" and "www.vmplanet.net/". After downloading virtual machine images, a user can run a virtual machine with VMware Player and start working with a virtual OS in no time. According to Pozadzides, the VMware Player works like magic but it has its downside, users can't create a new virtual machine and it is not a complete virtual machine solution. However advanced users could use VMware Server "www.vmware.com/products/server/" which was free to use, but unfortunately in January 2010, VMware announced the end of their support for VMware Server [16], [17].

VMware Workstation provides the following main features [15]:

Fullyparavirtualized: VMware Workstation provides VMware tools for Windows and Linux and limited emulated driver support for Solaris and FreeBSD. Emulated device drivers improve the performance of a virtualized mouse, input/output, video and networking.

Shared folder support: Shared folder support allows easy data exchange between host OS and guest OS. Shared folders from the host OS show as a mapped network drive in the guest OS.

Virtual USB controllers: VMware provides users with a USB 2.0 and USB 1.1 controller which allow users to connect any type of USB devices to virtual machines without the need to install device specific drivers on the host OS.

Sound driver support: VMware can emulate both Intel AC'97 and SoundBlaster 16.

Hardware virtualization support: VMware supports up to four virtual CPU's per virtual machine and 32GB of RAM for each virtual machine.

3D support: VMware provides accelerated 2D graphics and comprehensive 3D graphics support.

VMware can allocate 256MB of virtualized video RAM and it also fully supports Windows Direct3D, DirectX9.0c with Shader Model 3 support and OpenGL 2.13D.

Seamless desktop mode: Windows applications from the guest OS can easily be displayed on the host OS without showing the entire guest OS desktop. For instance, Microsoft Windows applications can run on Linux OS without showing the entire Microsoft Windows user interface.

Encryption: VMware Workstation supports encrypted virtual machines.

VirtualBox

VirtualBox is an x86 virtualization machine it was originally developed by Innotek GmbH and later on sold to Sun Microsystems. In January 2010 Sun Microsystems was purchased by Oracle Corporation which now makes VirtualBox an Oracle product. VirtualBox lets professional and home users create multiple virtual machines and host various OSs from Windows to Linux simultaneously on virtual machines. VirtualBox is a completely free virtualization program. It allows users to make, configure and run virtual machines on their physical machine. VirtualBox supports OS and virtual hard disk images made using VMware Workstation, thus VirtualBox can flawlessly run and integrate guest machines which were configured via VMware Workstation [14].

VirtualBox is a fantastic and easy-to-use open source software for creating virtual machines. VirtualBox is very intuitive and steps to create new virtual machine are very easy. VirtualBox works on Windows, Linux, Macintosh and OpenSolaris hosts and allows users to create a large number of guest OSs with Windows (NT 4.0, 2000, XP, Server 2003, Vista), DOS/Windows 3.x, Linux (2.4 and 2.6), and OpenBSD [16].

VirtualBox provides the following main features [15]:

Fully Paravirtualized: VirtualBox provides device drivers which will improve the performance of virtualized mouse, input/output, video and networking.

Shared folder support: Provides an easy-to-use data transfer method between guest OS and host OS. Shared folders from the host OS are shown as a mapped network drive in guest OSs.

Virtual USB controllers: VirtualBox provide users with USB 2.0 and USB 1.1 controllers which allow users to connect any type of USB devices to the virtual machines without the need to install device-specific drivers on the host OS.

Broad virtual network driver support: VirtualBox can emulate many different legacy Ethernet cards and many different types of Intel Pro/1000 chipsets for maximum OS compatibility.

Remote Desktop Protocol: VirtualBox is different from other virtualization software. VirtualBox completely supports standard Remote Desktop Protocol. VirtualBox allows a virtual machine to act as a Remote Desktop Protocol server, which will allow users to run the virtual machine remotely on a thin client that simply shows Remote Desktop Protocol data.

USB over RDP: With this feature a virtual machine which acts as a Remote Desktop Protocol server is able to access USB devices that are connected on the Remote Desktop Protocol client. With this method a server can virtualize a lot of thin clients that simply need to show Remote Desktop Protocol data and have USB devices plugged in.

Sound driver support: VirtualBox can emulate Intel AC'97 and SoundBlaster 16.

Hardware virtualization support: VirtualBox supports up to 16 virtual CPUs per virtual machine with 16GB of RAM for each virtual machine, and 32 virtual cores per host OS.

3D support: VirtualBox provides accelerated 2D graphics and experimental 3D graphics support for guest OSs. VirtualBox is able to allocate up to 128MB of virtualized video RAM.

Seamless Desktop Mode: Windows applications from guest OS can easily be displayed on host OS without showing the entire guest OS desktop. For instance, Microsoft Windows applications can run on Linux OS without showing the entire Microsoft Windows user interface.

Support for competing Virtual Disk formats: VirtualBox supports both VMware and Microsoft virtual disk formats.

VM Teleportation: VirtualBox supports live migration between VirtualBox hosts.

Experimental EFI Support: VirtualBox allow users to install Mac OS X on standard PC hardware which runs VirtualBox, unmodified.

Microsoft Windows Virtual PC

Windows Virtual PC is a virtualization program which allows users to host different type of OSs. Windows Virtual PC is an improved version Of Virtual PC which has been further developed by Microsoft especially for Microsoft Windows OSs. Virtual PC was initially developed by Connectix in 1997 for Macintosh-based computers. The first version of Virtual PC which supported Microsoft Windows OSs was version 4.0 and was released onto the market in 2001. In 2003 as market interest in virtualization technologies grew Microsoft purchased Virtual PC from Connectix. Since 2003 Microsoft has added many improvements to Virtual PC but has also removed many features which may have affected the popularity of Virtual PC among its users.

Virtual PC is a powerful virtualization program for Windows OSs, which allows users to run multiple versions of Windows simultaneously on one machine. Virtual PC manages all compatibility issues with legacy applications while users move to a new OS. With Virtual PC, reconfiguration time can be saved and users can work more efficiently. Virtual PC works on Windows XP Professional, Windows XP Tablet PC, Windows Server 2003, Windows Vista Business, Windows Vista Enterprise, Windows Vista Ultimate and Windows 7 [16].

Virtual PC provides the following main features [18]:

Integration with Windows XP Mode: Allow users to run many different Windows XP native applications in Windows XP Mode. Windows XP Mode is available to use in many different versions of Windows 7.

USB support: Provides USB support for a wide range of devices such as scanners, printers, flash memory and many more.

Seamless application publishing and launching: Users can run installed applications in Windows XP Mode directly from Windows 7.

Support for multi threads: Users can run multiple virtual machines simultaneously. Each virtual machine runs its own thread and, as a result, performance.will be enhanced

Clipboard sharing: Users can cut and paste between the virtual machine and the host OS.

Known folder integration between host and guest: Users can access Windows 7 folders such as My Documents, Pictures and Desktop from within a virtual machine.

Support for higher resolutions: Resolution can be extended up to 2048x1920.

According to Pozadzides, it is possible with virtualization to create a snapshot from of entire computer and easily copy or move data from an old machine to a new machine in just a few minutes and continue working immediately with no delay [16]. Pozadzides argues that there are many benefits to using virtualization technologies such as [16]:

Portable workspaces: Virtualization allows users to move easily entire workspaces from one physical machine to another physical machine. Users can even use an iPod or a USB flash drive to host a virtual machine.

Testing and training: Instead of installing all kinds of unknown applications into a safe computing environment, users can use.virtual machines for testing applications, playing games, personal work, and work related tasks.

Disaster recovery: Users can frequently backup virtual machines onto a USB flash drive and, in case of hardware failure or other sort of disaster, the user can easily restore the backup without having to reinstall everything.

Consolidation: System administrators can use virtual machines to consolidate many physical servers into fewer servers, which can then be used to host virtual machines. Each physical server is mirrored as a virtual machine and the guest OS is hosted on a virtual machine host system. This process also known as Physical-to-Virtual (P2V) transformation.

2.7 Examples of Virtualization

Republic Polytechnic (RP) of Singapore is a newly-built polytechnic with high ambitions. RP is the first polytechnic in Singapore which only uses the Problem-Based Learning (PBL) approach to teach its students. Students at RP are not required to attend various classes during day because the RP strategy in teaching differs from other education providers. RP's lecturers give students a practical problem for the day and students are obliged to find appropriate solutions for problem. RP's senior staff are happy to use new methods such as virtualization to benefit the students and the Polytechnic. As argued by Tay Kheng Tiong, director of School of Information and Communication Technology, RP is willing to deploy systems which will improve students study and allow RP to grow in a cost effective manner. As anticipated by RP's senior staff VMware had many benefits for RP such as: improved security, training and application development. Problems RP had encountered were a lack of space to create the required network for students which they could practice network security and also to create diverse platforms for the school's application developers to test their new software. According to Tay, VMware workstation and VMware ESX Server helped to create a large information technology infrastructure in the newly built campus. With the help of VMware's products the polytechnic saved money on hardware and space without taking high quality teaching away. Seow Khee Wei, Technology Development Manager at RP explained "We have compared both VMware Workstation and Virtual PC, but actually there wasn't any need for comparison. For sure we can say VMware Workstation was much superior to Virtual PC regarding functionality, feature and performance." Seow also added "VMware Workstation is more adaptable and a cost-effective solution compare to Virtual PC." Seow continued that RP's staff from the information technology department were able to deploy and configure VMware's products easily during class breaks and if there was any problem they were able find the solution from VMware's website easily [19].

Ringling College of Art and Design (RC) in US is a leading art and design college. Because of RC popularity, student numbers are increasing each year. For the last two years they have provided notebook computers for their students to work on. RC likes to be leading art college, however to provide high quality teaching, RC needs to upgrade their notebook computers. RC was not interested on spending more money on upgrading notebook computers but instead looked for an alternative solution to solve the problem. RC provided high quality workstations for their students, thus they needed to upgrade and change their notebook computers yearly which was very costly. RC's old strategy was to deploy new notebook computers across the campus and after a few years of usage the old computers were usually moved to the office area for office use only. RC has used this strategy for many years but they have found the result not very promising on cost effective. RC found that their strategy was not really useful because users couldn't completely benefit from computer recourses such as networks, memory, graphics and processors. RC realized they had to improve their strategy in hardware management. RC decided to use virtualization as a new strategy and as a result of the new solution, the problem with ageing computers was addressed. RC implemented desktop virtualization, thus notebook computers can now only be used to connect users remotely to server computers [1].

Bloomsburg University of Pennsylvania (BU) is a higher education organization in Pennsylvania State. The University has 7500 students, 900 personnel and 3200 back end computers spread across the university. The majority of the computers in BU are based on Microsoft Windows XP and a small ratio are based on Apple Mac OS. System administrators in BU locally install each user group's applications as a package on their computers. A common user's applications include but are not limited to: links to BU's services for students, Microsoft Office products, Antivirus, CD/DVD burners, Web browser and special software for a particular subject. BU staff's applications include only applications necessary such as: Microsoft Office, Web Browser and email client. However computers in classrooms include more than 200 applications. Applications in each classroom vary depending on semester and the papers covered. Staff at BU have an account with full administrative rights but students on the other hand have a limited account. At BU, system administrators use a variety of applications such as Microsoft's Software Management System (SMS) and SpecOps to deploy applications on users' computer, but there are a number of problems using such methods for installing or upgrading applications on workstations. For example the following problems may occur: configuration errors, windows registry errors and software conflicts. Problems which BU usually faced were based on software conflicts with new installations and upgrades. According to Vonblohn and Stahler, virtualization acts as a form of "bubble" or "box" which will allow each application to run independently in their own "box" or "bubble" without conflicting with other applications or Windows registry settings. It is argued by Vonblohn and Stahler that BU can use this strategy to reduce software conflicts and save money by purchasing fewer licenses required for each installation. Vonblohn and Stahler stated that BU used App-V which was formerly known as Microsoft Soft Grid to virtualize applications. BU believed by using App-V they have: decreased software crashes, introduced central upgrades, achieved easy to manage software licensing and achieved faster application distributions and upgrades [20].

Learning the theoretical aspects of networking and system administration at university is fun and challenging but not enough for someone who wishes to master in this field. One also needs to get involved in the practical aspects of system administration and practice the theoretical concepts as well. Unfortunately setting up networks for practice can be very expensive and may not seem practical, and so it is avoided by most universities around the world. However with recent advances in virtualization, universities can solve the above mentioned issues by creating virtual networks where students can practice what they have learned. This fact is not just theoretical but a reality and is practiced today by many different universities around the world such as the University of West Georgia. According to Yang, system and network administration requires a full understating of networking concepts and to be successful in this field one should have both theoretical awareness and practical expertise. As stressed by Yang, students should be given the opportunity to practice the practical aspects of networking. The practical aspects of networking are as important as the theoretical aspects. As described by Yang, the University of West Georgia have developed a program to teach students both the theoretical and practical aspects of system and network administration. The program provides the opportunity for students to learn theoretical aspects in the classroom and practice practical aspects by completing hands-on projects. The theoretical aspects of the program basically cover the fundamental information, theory and problems in system and network administration. The practical part covers hands-on exercises for students to practice. Yang argues that it is unrealistic and very expensive to waste hardware and lab space only for two courses at the university. To avoid creating sophisticated physical networks for student's hands-on project, the University of West Georgia used Virtual PC to create virtualized networks. Virtualization reduced cost, saved space and granted 24/7 access to networks. Students can access networks from any lab without any problem. The University used Virtual PC because it costs nothing and is very simple to use. According to the feedback which they have received from students, they have enjoyed classes and found hands-on projects challenging but useful. Virtual PC allowed the university to save money and provide services to students which improved their practical ability in the field of networking and system administration [21].

In 2002 Correia and Watson, lecturers from the School of Computing at Christchurch Polytechnic Institute of Technology, designed and implemented a local network for the Christchurch Polytechnic called Techlabs. Their newly created network was developed using virtualization technologies and programs. According to Correia and Watson, the newly built network is cost effective, flexible and a powerful learning environment for students. Correia and Watson published a paper about Techlabs and in it they have covered and discussed the background and reasons for creating and implementing Techlabs. In 2004 Correia and Watson summarized their ideas and reasons for using virtualization to create

Techlabs in a paper submitted to the National Advisory Committee on Computing Qualifications (NACCQ). In 2008 they have revised their paper and explained changes they have added to Techlabs over the past four years. Their new paper describes the latest Techlabs developments and widespread adoption of virtualization in industrial and academic sectors [22].

Jones uses VMware to create virtual machines for deploying different versions of Microsoft SQL Server. According to Jones, changes in the virtual machine can easily be made on desktop computer and then the virtual machines files can simply be copied to a laptop computer. Thus the same environment and settings can be ready on the laptop computer for presentations. Jones states that he has used virtualization for the past ten years and, according to him, virtualization is a fantastic tool for creating test environments. Jones can't imagine conducting presentations without the use of virtualization. Jones, states that he "*finds virtualization to be an amazing way to get more work done on a desktop, in a very stable manner*" [23]. Jones argues that it is possible to simply test an application on a virtual machine and then remove it or even delete the virtual machine if the application causes any sort of problem. Jones believes that during the next few years usage of virtualization will increase dramatically [23].

2.8 Literature Review Outline

In experiments conducted by virtualization specialist Brambley, the Easy Installer feature of VMware workstation was investigated. For the experiment Brambley downloaded Windows 7 beta from Microsoft's website and decided to use the company notebook for conducting the experiments.the company notebook is loaded with VMware Workstation and Microsoft Vista is the host OS. According to Brambley, the process of creating a new virtual machine on VMware Workstation was very easy. The Easy Installer feature on VMware Workstation automatically configured all necessary features for the new installation. The Experiment's result was satisfying and the whole process of creating a new virtual machine took less than an hour. Brambley stated that VMware Workstation's Easy Install feature was "*very impressive and makes building VMs so easy that even a caveman could do it*" [24].

Oracle and VMware released their newly built virtualization programs around May, 2010. To evaluate which program was better, Perlow conducted experiments on VirtualBox 3.2 and VMware Workstation 7.1. Perlow is a senior Technology Editor at "ZDNet.COM" and expert in virtualization technologies with decades of experience. For the experiment Perlow used a machine with the following features: dual quad-core 2.7Ghz AMD CPU, 16GB RAM, GeForce 9800 1GB DDR3 graphics card, 500GB SATA-2 hard disk, 100Mb cable modem link and Ubuntu LTS 10.04 64-bit edition as the host OS. To limit the scope of the experiments, Perlow decided to use only Windows XP, Windows 7 64-bit and 32-bit as guest OSs and only evaluate performance and usability. Perlow assigned two CPUs and 4GB RAM for 32-bit virtual machines and four CPUs and 4GB RAM for 64-bit virtual machines. The test results for Windows XP and Windows 7 32-bit and 64-bit OSs on VMware were excellent. Both OSs performed very well. As Perlow mentioned, when guest OSs were on full screen mode it was very difficult to realise they were virtualized [15].

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Figure 2.1: Test result of Windows XP 32-bit on VMwareWorkstation 7.1 [15]

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Figure 2.2: Test result of Windows 7 32-bit on VMwareWorkstation 7.1 [15]

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Figure 2.3: Test result of Windows 7 64-bit on VMwareWorkstation 7.1 [15]

Perlow noticed something odd about VMwareWorkstation 7.1. Test results based on VMwareWorkstation showed that applications in 32-bit OSs were only able to see 3GB of a total of 4GB RAM and changing the limit of RAM to 3GB or 4GB wasn't effective and the result was still the same as before. According to Perlow the problem was perhaps related to the Memory-Mapped (MMIO) method in Windows 7 32-bit version. However, in VirtualBox, applications were able to access RAM completely without any problem [15].

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Figure 2.4: Windows Experience Index test results for Windows 7 32-Bit on VMware Workstation 7.1 [15]

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Figure 2.5: Windows Experience Index test results for Windows 7 64-Bit on VMware Workstation 7.1 [15]

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Figure 2.6: 3DMark03 on VMware Workstation 7.1 using Direct3D and DirectX9 [15]

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Figure 2.7: 3DMark03 test results for Windows 7 32-Bit running on VMware Workstation 7.1 [15]

Both Windows 7 32-bit and 64-bit versions performed equally in tests. However Windows 64-bit was more efficient compared to Windows 32-bit version. The advantage of theWindows 64-bit version was that applications could access the full amount of the RAM even if it was bigger than 3GB [15].

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Figure 2.8: Test result of Windows XP 32-bit on VirtualBox [15]

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Figure 2.9: Test result of Windows 7 64-bit on VirtualBox [15]

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Figure 2.10: Windows Experience Index test results for Windows 7 64-Bit on VirtualBox [15]

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Figure 2.11: 3DMark03 on VirtualBox 3.20 [15]

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Figure 2.12: 3DMark03 test results for Windows XP 32-Bit running on VirtualBox 3.20 [15]

The biggest difference which was noticed between VMware and VirtualBox was that only VMware provided full 3D support so users can play 3D games in VMware. VirtualBox only supports very basic 3D which is not sufficient for 3D programs to run properly [15].

Jensen is a successful .Net developer. In the past he has used Virtual PC to create a virtual software development platform. Jensen used Windows Server and SQL Server, MOSS and Visual Studio as development tools. However because of performance issues the result was never satisfying. Thus Jensen decided to conduct an experiment on VMware Workstation 6.5 and Virtual PC 2007 to examine performance differences of both virtualization programs. For the experiments Jensen used a computer with the following specifications: an ASUS P5B Motherboard with Core 2 Duo 6600 CPU and 4GB of RAM. Jensen created virtual machines on both VMware Workstation and Virtual PC with Windows Server 2008 Standard x86 as guest OS and allocated 30GB of disk space and 1GB of RAM for each virtual machine. To test the performance of the guest OSs on VMware Workstation and Virtual PC, Jensen used PassMark PerformanceTest 6.1. For Jensen, CPU, 2D, memory, and disk performance and utilization were very important thus they were used as test criteria [25].

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Figure 2.13: VMware Workstation & Virtual PC Results [25]

Based on the experiments, results, VMware Workstation performed better than Virtual PC. Results showed that VMware Workstation work 2.9 times faster than Virtual PC. As argued by Jensen, the most important benefit of VMware Workstation over Virtual PC was VMware Workstation's ability to make use of both CPU cores whereas Virtual PC only supported one core. Based on the experiments' outcome Jensen decided to use VMware Workstation for creating virtual development platform's [25].

In a study conducted by VMware on VMware ESX Server 3.0.1 and open-source Xen 3.0.3, performance and scalability of VMware ESX Server and Xen were examined [10]. To conduct the study an IBM X3500 server was used with the following features: two VT-enabled dual core 3GHz Intel Woodcrest CPUs, 5GB of RAM, a dual port 1Gbps Ethernet adapter, two 146GB SAS disk drives and Windows Server 2003 Enterprise Edition 32-bit OS were used. The virtual machines each had assigned 1 CPU and 1GB of RAM. Only while testing the SPECjbb2005 the number of CPU's was changed to two or four and the amount of RAM to 1.6GB. For creating a guest OS, Windows Server 2003 Enterprise Edition 32-bit OS was used. To conduct the experiment properly VMware prepared a test workload list. The list contained information about benchmark tools and their components which were used to conduct a particular test. The created list is as follow:

- Integer component of SPECcpu2000 benchmark suite was used to simulate behaviour of CPU intensive applications
- Passmark was used to generate desktop workloads
- Netperf was used to simulate network activities
- SPECjbb2005 benchmark suite was used to simulate Java based applications which are typically used in data centres
- SPECcpu2000 INT package was used to demonstrate test usage in data centres

The experimental results collected showed that VMware ESX Server was superior to Xen. SPECcpu2000 test results which are demonstrated in Figure 2.14 shows that VMware ESX Server lagged 0 - 6 percent over the native OS and Xen lagged 1 - 12 percent behind the native OS. Based on the collected results it is clear that VMware ESX Server performed better than Xen.

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Figure 2.14: SPECcpu INT 2000 results [10]

Figure 2.15 shows the results acquired from the Passmark benchmark suite. The following CPUmark subsets such as IntMath, FPMath, MMX, SSE/3DNow, Compression, Encryption, ImageRotate, and StringSort were used during the test. VMware ESX Server lagged 14 - 18 percent behind the native OS and Xen lagged 6 - 41 percent behind the native OS. Based on the collected results it is clear that VMware ESX Server outperformed Xen.

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Figure 2.15: Passmark - CPU results [10]

According to the VMware test results of both SPECcpu2000 and Passmark, the VMware ESX Server is able to handle applications which are very highly demanding of the CPU.

Figure 2.16 shows the test results of the memory tests which were acquired from Memorymark, one of the Passmark benchmark suite's component. The following, Allocate SmallBlock, ReadCached, ReadUncached, and Write were carried out by Memorymark as part of the subtests during the experiment. The experimental results both showed that VMware ESX Server and Xen achieved the same performance.

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Figure 2.16: Passmark - Memory results [10]

To simulate development tasks in data centres SPECcpu2000 INT compile job was used. The workload which was created was based on Microsoft Visual C++ 2005 Express Edition compiler with Microsoft PSDK for Windows Server 2003 R2. The compile test on the native OS took 102 seconds, on the VMware ESX Server it took 113 seconds and on Xen took 149 seconds. Figure 2.17 shows the results.

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Figure 2.17: Compile workload result [10]

VMware tested the performance of connectivity on virtualization machines. The test was carried out between virtual machines and physical machines. To perform the experiment a physical ethernet adapter and port were used. For the experiment Netperf was used to simulate network activities and, to create test packets, Netperf TCP_STREAM was used. MessageSize and SocketSize were set to 8192 bytes and

65,536 bytes respectively. The results showed that VMware ESX Server performance was close to the native OS and Xen performance was poor. According to the results VMware ESX Server's performance in both one and two client tests was excellent. Test results for Xen wasn't good at all, Xen performed only to 3-6 percent of the native OS's performance level. As illustrated in Figure 2.18 VMware ESX Server can meet the requirements of data centre applications. However, Xen's lack of performance shows that it needs improvement.

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Figure 2.18: Netperf results [10]

To test Java Virtual Machine (JVM) performance the SPECjbb2005 benchmark was used. Unfortunately the test was only carried out on VMware ESX Server and the native OS. As discussed by VMware, Xen could not meet the necessary requirements to boot SMP Windows. Figure 2.19 shows the test results of SPECjbb2005 on VMware ESX Server and the native OS. As shown in Figure 2.19 VMware ESX Server performance is close to the native OS. As it is stressed by VMware, most enterprise applications such as J2EE application servers, file servers, mail servers and database servers, require extra CPU resources to work at their peak. Test results demonstrated in Figure 2.19 show that enterprise customers can rely on VMware ESX Server as an appropriate virtual environment to handle these sorts of applications.

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Figure 2.19: SPECjbb2005 results [10]

The VMware findings demonstrated that VMware ESX Server is more suitable than the Xen hypervisor and it is ready to meet the requirements of an enterprise data centre. As stated by VMware "*VMware ESX Server delivers the production-ready performance and scalability needed to implement an efficient and responsive data centre*" [10].

According to Matthews at el., in recent years many authors have compared the performance of different virtualization programs such as Xen, VMware Workstation and UML. However their work only covered a comparison of one virtual machine against the base OS. As discussed by Matthews at el. in their article the performance of virtual machines is a very important factor in the commercial environment such as Web Hosting providers. As stated by Matthews at el., Web Hosting customers who use the same physical host require acceptable performance from their virtual machine regardless of other virtual machines' workloads. According to Matthews at el., there is one more area of comparison which is missed by many studies and receives little attention which is "*how well do different virtualization environments protect or* *isolate one virtual machine from another?*" [26]. It is common sense to protect and separate sound virtual machines from harmful virtual machines, particularly in commercial environments. Being able to isolate CPU problems from network problems in virtual machines is an important factor in any virtualized system. To bridge the gap in the performance of virtualization programs Matthews at el., created a performance isolation benchmark and used the benchmark to evaluate the performance of VMware Workstation, Xen, Solaris Containers and OpenVZ. The benchmark included six various stress tests, the tests were as follows, memory test, disk test, CPU test, two network tests (send and receive) and fork bomb. To perform the experiments Matthews at el., decided to use a Web Server which they hosted on an IBM ThinkCentre with a Pentium 4 processor, 1 GB of memory and a gigabit Ethernet card. For the experiments five different virtualization programs were used: Xen 3.0, VMware Workstation 5.5, OpenVZ 2.6.18, an early release of OpenSolaris without additional resource controls and a recent release of OpenSolaris build 62 with additional resource controls. For Xen and VMware, a Linux server 2.6.12 was used for creating guest OSs and for OpenVZ, Linux 2.6.18 was used to create guest Oss. Virtual machines created in Xen and VMware Workstation were each assigned with 128 MB of memory. Vzsplit tool was used to assign physical machine resources equally between virtual machines created in OpenVZ, thus each machine received roughly 256 MB of memory. The experiment conducted by Matthews at el., produced very interesting outcomes. Outcomes of the study showed that VMware Workstation protected all sound virtual machines during stress tests and Xen acted similarly to VMware Workstation, however Xen showed a small amount of degradation, 1.7% during the disk intensive test and other tests. With OpenVZ and Solaris there was a need to implement resource controls otherwise both sound and harmful virtual machines could not perform well during stress tests. With resource control planned and implemented both OpenVZ and Solaris showed only a small amount of degradation during stress tests [26].

In a study which was conducted by Koe, capability and performance of VMware Workstation 6 Beta was tested. For testing the performance of VMware Workstation 6, Koe created two guest OSs with Ubuntu 6.10 and Mac OS X (Tiger) on VMware Workstation running on a Windows XP host OS. Koe assigned both virtual machines with 1GB of RAM and 6GB of hard disk space. As mentioned by Koe, the Mac OS X didn't work with two processors so only one processor were allocated to Mac OS X virtual machine and two processors was allocated to the Ubuntu virtual machine. Koe performed the study using a HP Compaq 8430 with 2.0Ghz dual-core CPU and 2GB of RAM. According to Koe the virtual machine which was created by Ubuntu worked very well and amazingly, VMware Workstation was also able to detect the laptop's dual core as two processors. However the Mac OS X virtual machine performed very poorly on VMware Workstation and it was slow. In a different experiment which Koe conducted on the VMware Server, Koe found that the VMware Server was unable to detect the laptop's two processors and only showed one processor, however the Mac OS X performed much faster on the VMware Server compared to the VMware Workstation [27].

In an experiment done by Mark on Virtual PC 2007 and VMware Workstation 6, performance of both virtualization programs was studied. For comparing the two products Mark used Dell Precision 390 machine with the following features: 4GB of RAM, Dual Core CPU @ 2.13GHZ, SATA II 160GB hard drive and virtualization support set to enabled. For this experiment Mark measured Windows Vista x86 load time on Virtual PC 2007 and VMware Workstation 6 and also measured Windows Vista x64 load time on Virtual PC 2007. Mark stated that the measurement duration started with the bios screen appearance until the Windows login screen appeared. According to Mark the load time of Windows Vista x86 on Virtual PC 2007 took approximately 1 minute and 27 seconds and on VMware Workstation 6 took about 48 seconds. Load time of Windows Vista x64 on Virtual PC 2007 took about 55 seconds. Mark argued VMware Workstation 6 is a better virtualization program compared to Virtual PC 2007 because VMware Workstation 6 offers many useful features which are not available on Virtual PC 2007. For example, to get virtual networks on Virtual PC 2007 it is necessary to install Virtual Server 2005. Based on the findings it seems using Virtual PC 2007 for virtualization is somewhat time-consuming and inconvenient [28].

Perera and Keppitiyagama performed an experimental study on the performance of 32bit Debian 6.0 Virtual Machines running on Xen and VMware Esxi. Their aim was to measure the virtual machines' performance based on network activity, file system I/O, CPU and memory. Benchmarks were performed on two servers with similar hardware. According to Perera and Keppitiyagama, benchmark results based on memory operations showed that on both hypervisors memory operations performance was roughly equal. Both Xen and VMware Esxi were able to perform equally while guest OSs were using high memory bandwidth. Benchmark results regarding network actives showed that both hypervisors performed very closely. However VMware Esxi performed to some extent better than Xen. Benchmark results regarding file system based activities shown that VMware Esxi performed better than Xen. Benchmark results showed that Xen's performance regarding writing to file system was poor. However benchmark results regarding CPU intensive applications shown that both Xen and VMware Esxi performed equally but Xen's performance was slightly better than VMware Esxi. Perera and Keppitiyagama's study showed that both hypervisors performed equally. However lack a of performance in the Xen platform was because "*Xen was designed to host Paravirtualized guest operating systems with less support to fully virtualized guests and VMware's Esxi was designed to host Fully Virtualized guest operating systems*" [29]. According to the findings, if support for Paravirtualization or Full virtualization is not required then Xen's performance was slightly better than VMware Esxi [29].

Findings from the literature review demonstrated that the use of virtualization technologies in any information technology infrastructure is essential and is needed to improve performance and save cost. It is believed many different businesses and universities use virtualization technologies and gain benefit from it. Various virtualization programs such VMware Workstation, VirtualBox and Virtual PC were reviewed and explained. Examples of the use of different virtualization technologies in various environments such as businesses and education were provided. Based on the literature review findings it is understood that most businesses use VMware to implement virtualized infrastructures. Many studies related to performance of virtualization programs were reviewed. In various experiments conducted by different researchers VMware and VirtualBox performed better than other virtualization programs. Table 2.1 lists key researchers and their main contributions on virtialization.

Table 2.1: Key researchers and their main findings on virtualization

Author	Theme	Description
Stasiewicz [8]	Introduced virtualization as a mature technology	Stasiewicz argued virtualization is no longer a new technology but instead a very mature concept. Stasiewicz believes that virtualization is being adopted by many in the mainstream and is gaining more popularity each day.
Correia & Watson [22]	Designed and implemented a virtual network for, Polytechnic	According to Correia and Watson their newly created network saved money and is a powerful learning environment for students.
Jones [23]	Used a virtual machine as a testing environment	Jones argued virtualization is a fascinating way to do more work on a desktop computer based on a stable platform.
Brambley [24]	Studied and tested the Easy Installer feature of VMware workstation	According to Brambley, the Easy Installer feature of VMware Workstation is an easy-to-use feature for novice to create new virtual machines on VMware Workstation.
Perlow [15]	Evaluated VMware Workstation, Oracle VM and VirtualBox performance	Perlow's experiments showed that Oracle VM VirtualBox only supports very basic 3D compared to VMware Workstation, however applications in VirtualBox can access RAM even it is more than 3GB.
Jensen [25]	Conducted experiments on VMware Workstation 6.5 & Virtual PC 2007	Jensen's findings demonstrated that VMware Workstation works 2.9 times faster than Virtual PC. Also, VMware Workstation supports both CPU cores whereas Virtual PC can only support one core.
VMware [10]	Examined performance of VMware ESX Server and Xen hypervisor	VMware's findings showed that VMware ESX Server performed better than Xen hypervisor. Furthermore it was observed that VMware ESX Server is ready to deal with enterprise data centres needs. However Xen needs more improvement.
Matthews [26]	Evaluated performance of VMware Workstation 5.5, Xen 3.0, OpenSolaris and OpenVZ 2.6.18 regarding protecting sound virtual machines from harmful virtual machines	Findings of this study showed that VMware Workstation protected all well behaving virtual machines and Xen also protected sound virtual machines but Xen shown a small amount of degradation. With OpenVZ and Solaris it was necessary to implement resource controls because both sound and harmful virtual machines were not able to perform well during tests. With resource control, both OpenVZ and Solaris only showed a small amount of degradation during tests.
Koe [27]	Tested performance of Ubuntu 6.10 and Mac OS X on VMware Workstation 6 Beta and VMware Server	Koe's findings illustrated that Ubuntu performed better than Mac OS X on VMware Workstation and Mac OS X performed better than Ubuntu on VMware Server. Interestingly Koe's experiments showed that Mac OS X on VMware Workstation wasn't able to work with two processors, thus only one processor was assigned to it. The experiments showed that VMware Server wasn't able to detect the laptop's two processors. However, VMware Workstation was able to detect the laptop's two processors.
Mark [28]	Performed a study on Virtual PC 2007 and VMware Workstation 6	Mark's findings demonstrated that if a user needs virtual networks on Virtual PC 2007 it is necessary to install additional programs such as Virtual Server 2005. Mark's study also showed that Windows Vista's load time on VMware Workstation 6 took less time compare to Virtual PC 2007.
Perera and Keppitiyagama [29]	Studied performance of 32bit Debian on Xen and VMware Esxi	Perera and Keppitiyagama's study outcomes showed that both Xen and VMware Esxi performed somewhat similarly. However if support for Paravirtualization or Full virtualization were not part of the test criteria then it can be concluded that Xen's performance was slightly better than VMware Esxi's.

2.9 Summary

In this chapter literature and studies related to virtualization were presented. Various virtualization techniques, approaches and programs were covered and explained thoroughly. The objective of this research is to evaluate the performance of various virtualization programs. A mixed research methodology based on quantitative and qualitative methodologies is used to perform this study. The research methodology and data collection methods are thoroughly discussed in Chapter 3.

Chapter 3: Research Methodology

3.1 Introduction

Chapter 2 reviewed literature on virtualizations. The research methods which were used in this study are covered in this chapter. The objective of this research is to study and investigate the performance of different virtualization programs. Various experiments regarding performance were performed on different virtualization programs. The quantitative data collected from the experiments were converted into graphs and the qualitative results were thoroughly studied.

3.2 Research Question

The following research question has been considered in this thesis:

How virtualization programs can be evaluated in terms of performance and cost effectiveness?

3.3 Hypothesis

According to Kumar hypotheses bring unambiguousness and a focus to a research problem. The research hypothesis will help to understand the research problems.[30].

The following hypothesis is used in this study:

There are performance differences between VMware Workstation and VirtualBox.

3.4 Methodology

According to Kothari research methodology is an approach for systematically solving research problems. Research methodology can be categorized as a science which allows the undertaking of studying research scientifically. In research methodology various steps are discussed which will be used to carry out research successfully. Research methodology is not just about choosing an appropriate method for study but it is also about covering the reasons and logic behind choosing a particular method. Kothari argues that research methods are methods and techniques which are used by researchers to conduct research.

Research methods are limited in scope compared to research methodology and are simply used by a researcher to perform research operations and should not be mistaken for research methodology [31].

Research methodology is a tool which will systematically explain a research phenomenon. A research methodology has many parts, the most important part is to design research steps with appropriate research methods. According to Yin, research design is mostly concern with logical problems rather than logistical problems [32]. According to Kumar research methodology is a technique to systematically explain research problems. Research methodology allows a researcher to study and perform research in a scientific manner. Kumar argues that research methodology has many dimensions and research methods represent a part of research methodology. According to Kumar the scope of research methodology is broader than research methods, therefore research methodology not only covers research methods but it also covers logic behind choosing a particular research method [33].

For this research the empirical approach was used. According to Marczyk, DeMatteo and Festinger the scientific method is strongly based on the empirical approach. The empirical approach is based on evidence, which means to gain new knowledge it is necessary to observe and experiment. In the empirical approach the researcher makes scientific decisions based on information which is gained from observation and experimentation [34]. According to nsu.edu empirical research is supported by observation and measured phenomena [35]. Results of empirical research based on observations or experimentations use quantitative research methods. According to Henrichsen, Smith and Baker there are many different ways to conduct empirical research such as [36]:

- Questioning
- Studying behaviour
- Observing and explaining
- Experimenting

In this study experimenting, observing and explaining were used. Kothari describes empirical research as a type of research which relies on experiment and observation. Conclusions which are made through empirical research can be validated by observation or experiment. According to Kothari it is possible to call empirical research an experimental type of research. In empirical research it is required that the researcher makes a hypothesis first and then proves or disproves the hypothesis by collecting the necessary information. After researcher has collected enough information, the researcher can then create an experimental environment and manipulate environmental variables to change the experiment results. information which is obtained by means of experiments are the best source of support for the given hypothesis [31].

In order to carry out this research successfully certain steps were followed. As posited by Kothari, the research process consists of many different steps or actions which are necessary to effectively carry out research [31]. Figure 3.1 shows the research processes.

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Figure 3.1: Kothari - Research Processes [31]

This research was executed in the following order:

1. Study research problem
2. Carry out literature review
3. Study previous research
4. Make hypothesis
5. Create research objectives/goals
6. Proceed with research design
7. Choose appropriate research methods
8. Conduct experiments
9. Collect data
10. Analyze collected data
11. Formulate meaningful conclusions
12. Write up the results

According to Creswell research design consists of plans and procedures designed to be integrated with the research and will cover all processes of assumption making, data gathering and analysis. As Creswell argues, planning is all about making many different decisions. Decisions will guide the researcher throughout research . Creswell simplifies the decision-making process by providing the researcher with a simple question: which design should be used to study a topic? By answering this simple question the researcher will bring new ideas, possibilities and assumptions to the research, which will consequently lead to strategies and methods such as data gathering and data analysis. However, having said that, choosing an appropriate research design is also related to the nature of the research and other factors such as the researcher's experience, type of research problem and the participants involved in a study [37]. Creswell defines research design as "*the plan or proposal to conduct research, involves the intersection of philosophy, strategies of inquiry, and specific methods*" [37].

Creswell describes three different types of research design: qualitative, quantitative, and mixed method. Creswell suggests that quantitative and qualitative are not polar opposites or dichotomies, rather they signify different ends on a continuum. A research study can be more quantitative than qualitative or the other way around. On the other hand a mixed research method lies on the middle of the continuum because it integrates elements of both the quantitative and qualitative methods [37].

Creswell describes qualitative research as a means for researching and understanding social problems of an individual or a group. The process of qualitative research involves creating questions and presenting them in a group environment and analyzing the collected data. In the final process of qualitative research, the researcher can document the findings and make suggestions based on them. Quantitative research however, is a process of examining the relationships between variables. Variables are usually numerical data and analysis is conducted based on collected statistical data from participants or environments. The quantitative research report structure consists of an introduction, literature review, methods, findings, analysis and conclusion. Interestingly, mixed research methods combine both qualitative and quantitative research methods. It is based on philosophical assumptions and applies both qualitative and quantitative research approaches to a study, thus the strength of the mixed research method is greater than both the qualitative and quantitative methods [37].

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Figure 3.2: Creswell - The Framework of Research Design [37]

According to Creswell strategies of inquiry are important in a research study, because they provide the exact route for the procedures of a research design. The researcher must choose a type of study which is a qualitative, quantitative or mixed methods study. Strategies of inquiry are methods belonging to qualitative, quantitative or mixed methods. Some authors call them approaches to inquiry while others called them research methodologies [37].

Research Strategies

- Quantitative Strategies
  - Experimental research - seeks to discover if a specific action changes the result [37]. It is a research design approach which uses manipulation and controlled results from a testing environment to understand a particular process [38].
- Qualitative Strategies

  - Case study - is a strategy in which the researcher investigates in-depth "*a program, event, activity, process, or one or more individuals"[37]*.
  - Literature review - is a strategy for finding and summarizing studies about a particular research topic.
- Mixed Methods Strategies
  - Sequential mixed methods - this process consist of elaborating on or expanding on outcomes of one method with another method. The researcher begins the study with a qualitative method and then advances the study with a quantitative method. Alternatively, the researcher can start the study with a quantitative method and then use qualitative methods [37].

Qualitative Research

The qualitative research methodology is traditionally used in the social science field and market research. However, nowadays more researchers in different fields use qualitative research methodology. Qualitative research methodology is about distinguishing qualities, thus it is usually used to describe the why and how of a situation or fact, instead of describing what/where and when. As stated by Patton, qualitative data are "*detailed descriptions of situations, events, people, interactions, observed behaviors, direct quotations from people about their experiences, attitudes, beliefs and thoughts and excerpts or entire passages from documents, correspondence, records, and case histories*" [39]. Qualitative research is an appropriate methodology in situations where collected data via the quantitative approach alone cannot provide enough information for a study due it's numerical nature.

The scientific nature of the qualitative research methodology allows the researcher to find legitimate answer for research questions. The researcher can find answers to the research questions by completing the required steps. Steps are defined as the experimentation and study of gathered material during the experimental phase. Denzin and Lincoln argued that researchers must exercise experiments the subjects normal environment so they can achieve optimum results [40]. According to Creswell, if a problem requires a better understanding due to lack of proper research, then it is worthwhile carrying out research based on the qualitative research methodology to deepen our understanding [41].

Qualitative research methodology is an appropriate solution for studying raw information. A variety of sources such as literature review, case studies, experiments and analysis will supply the required qualitative input for this study. Useful literature regarding virtualization will be studied to gain the necessary knowledge required for this research. The research will proceed by studying case studies, conducting experiments and analysing data, and in this way the research question can be answered.

According to Thomas, in a quantitative research study different types of methods can be used, experimental and descriptive [42]. The main source of data collection for this research study is based on experiments, thus the experimental method has been chosen. The descriptive method is also used for analysis of the gathered data.

According to the Marczyk et al., there are two types of research methods with which researchers need to be familiar: quantitative and qualitative research methods. Quantitative research is concerned with studies which use statistical analysis to acquire their results. Key characteristics of quantitative research consist of formal and systematic measurement and the use of statistics. Qualitative research on the other hand is concern with studies which do not use numbers to the same degree. Qualitative research, in general, is mostly concerned with observation [34].

Myers argues that qualitative research methods were first used by researchers in social sciences to help them study social and cultural phenomena. The main sources of data for qualitative research methods are fieldwork, observation interviews, survey, documents and texts, and the researcher's impressions and reactions [43].

The qualitative research methodology is considered to be a scientific research approach. In scientific research, the researcher will solve the research problem by conducting studies to answer the research questions. To answer the research questions, the researcher will follow a set of plans and procedures. The plans and procedures can be defined as conducting a literature review, performing experiments, surveying and analyzing results gathered from experiments or other sources. These plans and procedures are approaches which will be used in the qualitative research by the researcher. The qualitative research methodology helps the researcher to discover solutions for problems which are faced in a particular field of study. The qualitative research methodology aims to study human behaviour and discover why human act the way they do. The qualitative research methodology also allows the researcher to study various phenomena, not just human behaviour, and find out what is happing in that phenomenon [44] & [45].

Quantitative Research

Quantitative research is used to measure quantity or amount. It is appropriate to use quantitative research when dealing with concepts which are expressed in terms of numbers or quantity. Qualitative research however is used in research which deals with qualitative phenomenon [31].

The main goal of quantitative research is to make use of numbers to create new information. The Gathering of quantitative data is vital for this type of research. In this research the researcher will analyze data gathered from experiments so the performance of different virtualization programs can be evaluated.

Quantitative research methods were first used in the natural sciences to help scientists study natural phenomena. According to Myers, quantitative research methods are now widely adopted and used in social sciences. Quantitative research methods include but are not limited to; laboratory experiments, econometrics, surveys and questionnaires, and numerical analysis [43].

Quantitative research methods focus less on questionnaires and interviews and more on the gathering and examination of statistical data. The quantitative methodology chosen for studying the performance of various virtualization programs on Windows 7 will generally focus on gathering and collecting numerical data. The main purpose of the quantitative research methodology is to make use of numbers to gain necessary information. Quantitative information will play an important role in this study. Data gathered from experiments are analyzed in order to assess the performance of virtualization programs on Windows 7.

In a quantitative research study four approaches can be used; ecologic studies, phone-based surveys, quantitative information studies and experimental studies [42]. Because the main source of data collection for this study is based on experiments, the experimental approach has been chosen as the main approach for this study. A performance evaluation of various virtualization programs on Windows 7 is the key goal of this research study, which will require repeated evaluation of virtualization programs on Windows 7. A descriptive approach will be used for the analysis of the data gathered.

Mixed Research Methodology

The research methodology selected for this study is a mixed research methodology. It is called a mixed research methodology because qualitative and quantitative research methodologies were combined together and used in this study. The qualitative research methodology was used in this research to gather information and perform a literature review which helped to deepen the researcher's knowledge regarding virtualization and the research problem. The quantitative research methodology was used to analyze results which were obtained through the experiments. By using the quantitative research methodology, the researcher was able to evaluate the results and document dissimilarities which helped to form meaningful conclusions based on the findings.

Johnson & Onwuegbuzie define mixed methods research as the "*class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study*" [46].

According to Creswell quantitative, qualitative and mixed methods are the three main approaches used in research design. Quantitative and qualitative approaches have been used by researchers for many years in research design, but recently mixed methods have gained more popularity [41]. According to Myers research methods can be categorized in different ways, but one of the most general differences is between qualitative and quantitative research methods [43].

Mixed research methodology is an ideal research methodology for this study. Qualitative methods were used to gather required data for research and carrying out the literature review. An in-depth research literature review was conducted at the beginning of the research to improve the researcher's knowledge regarding the research topic. The data collected from experiments were analyzed based on quantitative methods, then results were evaluated and dissimilarities were documented.

3.5 Data Gathering

Data collection is divided into many different aspects such as literature review, examination, experimentation, interview and survey. In this study literature review, experimentation and examination were used. This study uses a mixed research methodology thus methods of data collection are based on a mixed research methodology. The primary sources of data for this study were a literature review, a review of past studies and collecting experimental results. Data gathering is concept which uses different techniques and methods. Data gathering has many steps which include:

Step 1: set the boundary of study.

Step 2: gather necessary information through different means such as; survey, interview, experiments, literature review and texts.

Step 3: design appropriate methods for documenting and representing data.

According to Creswell the process of data gathering begins with studying the collected data and trying to make sense of it [41]. The researcher can study his/her logbook and try to compare data and come to some sort of understanding. After the researcher becomes properly familiar with the collected data then he/she can categorize data into an appropriate format. The researcher can insert results of the analysis in each created category, using graphs, figures and other sorts of illustration to enhance presentation of the data. Illustrated materials help to better and more clearly understand information. To complete the data gathering process the researcher can present conclusions based on his/her understanding and suggest solutions to the research problems. The steps below explain the data gathering process in this study:

Step 1: This study aims to evaluate and examine the performance of various virtualization programs such as VMware Workstation and VirtualBox on Windows 7.

Step 2: Methods which were used in this study to gather required data were based on a literature review and experimental results. Data collected through the literature review were very extensive. The literature review created the foundation of this study and allowed the researcher to increase his knowledge about the research problem by studying related studies and literature. The literature review covered various topics regarding virtualization concepts, technologies and programs. In the literature review, studies with similar topics were also covered. The literature review phase included searching online databases such as Google Scholar, ProQuest Computing, IEEE Xplore and ACM Digital Library, using the World Wide Web and AUT library to obtain information about virtualization and previous studies about it. The literature review helped the researcher to find information related to this research and understand and discover other researchers' opinion about this topic. The main sources for literature were academic papers, articles, journals, reports, conference papers, books and reliable technology-related websites.

Step 3: Various experiments were conducted on the performance of virtualization programs and the results collected from the experiments were documented. The results gathered from the experiments played an important role in providing necessary information to answer the research question. The experiment process involved setting up the experimental environment on Windows 7, creating test criteria, conducting the experiments, and evaluating the performance of the various virtualization programs on Windows 7.

Step 4: The data collected from the experiments were converted into graphs for better evaluation. Microsoft Excel was used to create the graphs. The graphs created helped to highlight the differences in the results and provide meaningful analysis.

Step 5: Conclusions were made based on the results of the analysis.

3.6 Data Analysis

According to Creswell the data analysis process is about creating understanding from images and text-based content. The data analysis process involves repeatedly analyzing and comparing collected data [41]. The data analysis process includes many steps all of which are covered thoroughly in the following paragraphs:

Categorize and manage data for analysis: Data preparation is the most important step of all. In this step the researcher will organize and prepare the data gathered. The data preparation process involves organizing the literature review and experimental results. Inspect the gathered data and organize them into their related categories, this will allow the researcher to gain a good understanding of data hierarchy and their relation to each other.

Read the collected data thoroughly: In this step the researcher will read all data collected thorough the qualitative and quantitative methods. Reading data will allow the researcher to realise which data are important and the researcher can also make comments about the data and create new ideas.

In depth analysis and coding data: In this step the researcher will start the coding process. Techniques and tools which were used during data analysis will be explained here. In the coding stage the researcher will convert collected data into different chunks. The process is based on organizing images, text and paragraphs into categories. Categories can be marked to make them easier to find; colouring coding different categories to make them more easily accessible. The researcher can use computer software to improve the coding process. In this study Microsoft Excel was used to code the data. Excel was used to generate graphs from quantitative data collected from the experiments. Each experimental result was entered into an Excel spreadsheet and each data coloured differently for coding purposes. The graphs helped the researcher to distinguish differences between collected data and make analysis easier. After data were converted to graphs and each separated and coded, the researcher used Microsoft Word to document data and organizes them in various categories. Different sections were created in Microsoft Word for writing study findings and explaining graphs.

Using a coding process to describe the research environment: In this step the researcher created necessary descriptive data within the coding process. Descriptive data contained information about the research study. The researcher used the coding process to create different categories or topics. The categories and topics created are main part of the research study.

Describe categories and topics in the form of narrative: In this step the researcher used figures or examples to relate descriptions and study findings together. The results of the data analysis provided answers to the research question.

Make sense of the data: The researcher created meaningful links and made clear understandings of the research outcomes based on the literature review and the experimentations.

3.7 Summary

In this chapter, the research methodology chosen for this research study was explained. The researcher explained the reasons behind the mixed research methodology being the main research methodology for this study. Different approaches and methods to performing this study were explained and suitable methods were highlighted. The next chapter covers information on creating the experimental environment and the experiments.

Chapter 4: Experimental Design

4.1 Introduction

Previous chapter covered in depth information about chosen research methodology for this study. In this chapter a detailed explanation of the experimental environment is discussed. This chapter also contains information regarding the experiments carried out in order to complete this study. The objective and description of each experiment is documented in detail.

4.2 Experimental Environment

Physical Machine

The experimental environment is based on a personal, desktop computer with the following hardware and software features:

- Hardware
    - Intel(R) Dual-Core CPU 3.00GHz
    - 2.00 GB of Memory
    - 500 GB Hard Disk Space
    - NVIDIA GeForce 9600 GT Graphic Card
- Software
    - Windows 7 Ultimate 32-bit Edition OS
    - VMware Workstation 7
    - Oracle VM VirtualBox 4
    - Microsoft Windows Virtual PC

The experimental environment is organized into two different layers: the physical layer and the virtual layer. The physical layer consists of the physical hardware, the host OS and the virtualization programs. The virtual layer on the other hand consists of virtual hardware, guest OSs and third party applications. Table 4.1 shows hardware, software and the order in which the experimental environment's layers are organized.

Table 4.1: Experimental Environment Layers

<table>
<tr><td rowspan="3">Virtual Layer</td><td>Third Party Applications (GNU Image Manipulation Program, Mozilla Thunderbird and Pidgin)</td></tr>
<tr><td>Guest OSs (Windows 7 Ultimate 32-bit Edition OS and Linux Mint 32-bit OS)</td></tr>
<tr><td>Virtual Hardware (CPU, Memory, Network Interface Controller and Hard Disk)</td></tr>
<tr><td rowspan="3">Physical Layer</td><td>Virtualization programs (VMware Workstation, VirtualBox and Virtual PC)</td></tr>
<tr><td>Host OS (Windows 7 Ultimate 32-bit Edition OS)</td></tr>
<tr><td>Physical Hardware (CPU, Memory, Network Interface Controller and Hard Disk)</td></tr>
</table>

VMware Workstation, VirtualBox and Virtual PC each consists of two guest operating systems: Windows 7 Ultimate 32-bit Edition and Linux Mint 32-bit Edition. For testing purposes, each guest operating system will be configured and allocated the same amount of virtual system resources. Table 4.2 shows the resource distribution plan for the host and guest operating systems.

Table 4.2: Resource Distribution Plan

Resource Distribution Plan			
	Hard Disk	**Memory**	**Processor**
Windows 7 Host OS	500 GB	2 GB	2
VMware Workstation Windows 7 guest OS	20 GB	1 GB	1
VMware Workstation Linux Mint guest OS	20 GB	1 GB	1
VirtualBox Windows 7 guest OS	20 GB	1 GB	1
VirtualBox Linux Mint guest OS	20 GB	1 GB	1
Virtual PC Windows 7 guest OS	20 GB	1 GB	1
Virtual PC Linux Mint guest OS	20 GB	1 GB	1

To successfully complete the experiments the following hardware and software were used:

- A personal computer with Windows 7 as host OS
- A virtual machine created by VMware Workstation with Windows 7 as guest OS
- A virtual machine created by VMware Workstation with Linux Mint as guest OS
- A virtual machine created by VirtualBox with Windows 7 as guest OS
- A virtual machine created by VirtualBox with Linux Mint as guest OS
- A virtual machine created by Virtual PC with Windows 7 as guest OS
- A virtual machine created by Virtual PC with Linux Mint as guest OS
- Microsoft Windows Task Manager
- Linux Mint System Monitor
- NovaBench 3.0.4
- 7-Zip 9.20

- Linux Mint 11, Katya
- Microsoft Windows 7 SP1
- VMware Workstation 7
- Oracle VM VirtualBox 4
- Microsoft Windows Virtual PC
- A digital stopwatch

Installing Host OS

In this section information about installing the host OS on the physical machine is covered. To install Windows 7 on a physical machine first it is necessary to evaluate the whole process before starting installation. When Windows 7 setup is started it is necessary to supply the setup screen with necessary information regarding installation. Careful planning will make installing Windows 7 a breeze, and it will reduce common errors during the installation process. Moreover having the necessary knowledge about setup configuration will smooth the path to a successful installation. There are some important aspects of installation which require some thought before beginning the installation process: Verify system requirements, complete a hardware and software compatibility check and work out disk partitioning options.

According to Microsoft the minimum system requirements for installing Windows 7 are as follows: 1 gigahertz (GHz) or faster 32-bit (x86) processor, 1 gigabyte (GB) RAM (32-bit), 16 GB available hard disk space (32-bit) and a DirectX 9 graphics device with WDDM 1.0 or higher driver. Considering the minimum system requirements for installing Windows 7 mentioned by Microsoft, the physical machine used in this study to install Windows 7 is quite capable to run Windows 7 properly.

Furthermore there are two methods to install Windows 7:

Upgrade: In this method setup will replace the previous version of Windows with Windows 7, however, the user's files, folders, OS settings and applications stay exactly the same as before on the computer.

Custom: In this method setup will replace the previous version of Windows with Windows 7, however in this case, setup won't keep the user's files, folders, OS settings or applications on the computer.

For purposes of this experiment and to ensure an error free experimental environment, the custom method in the setup window was selected to install Windows 7 on the physical machine. In order to reduce errors further, the Hard Disk was carefully formatted before starting the installation process. To begin the Windows 7 installation process, the Windows 7 DVD was inserted into the DVD Drive and the computer was rebooted and, as a result, a black window temporally appeared while the contents of the DVD were loading. After a few seconds the "Starting Windows" screen showed up. After the "Starting Windows" screen the “Regional Setting” screens appeared. No changes were made and the installation proceeded by clicking the “Next” button. In the next screen the “Install now” button was clicked to begin the installation process. In the next screen the license terms were carefully read and accepted. Then “Next” button was clicked to proceed with the installation. In the next screen the “Custom” option from type of installation was clicked to install a fresh copy of Windows 7. On the next screen, a partition for installing windows was selected and then formatted. The “Next” button was clicked to proceed with the installation. On the next screen the setup copied Windows files from the installation disk to the hard disk. After all necessary files were copied to the hard Disk the “Set up Windows” screen appeared. On this screen the user name was entered, then the “Next” button was clicked to continue. On the next screens, the password, network type and other features were configured. After Windows finalized the OS, Windows appeared. Figure 4.1 shows the successful installation of Windows 7 on the physical machine.

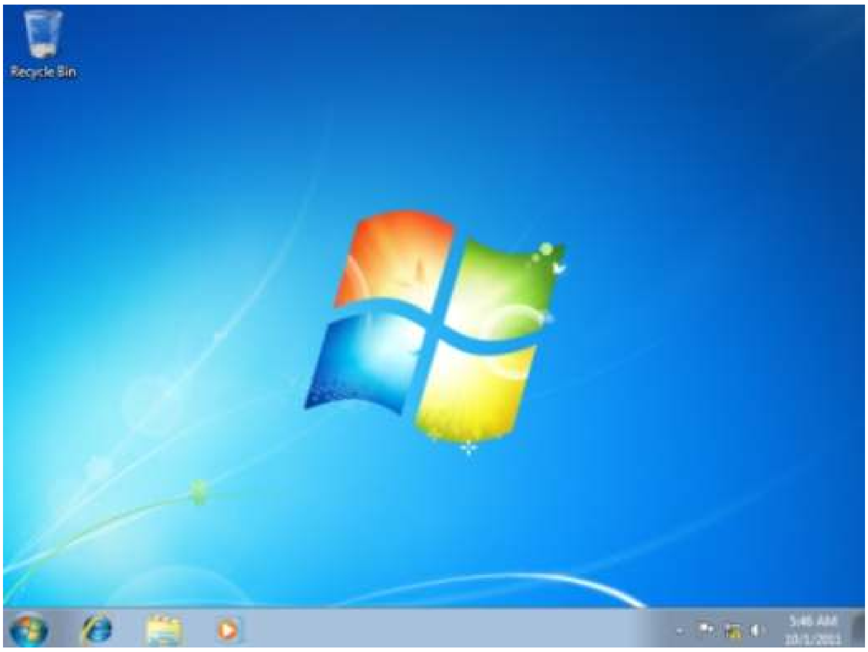

Figure 4.1: Microsoft Windows OS (Host)

Installing Virtualization Programs

VMware Workstation: VMware Workstation for windows was obtained from “www.vmware.com”. After the download was completed, the installation process began by running the setup file. An “Installation Wizard” screen followed to successfully install VMware Workstation on the Windows 7 Host OS. Figure 4.2 shows the VMware Workstation successfully installed on the Windows 7 Host OS.

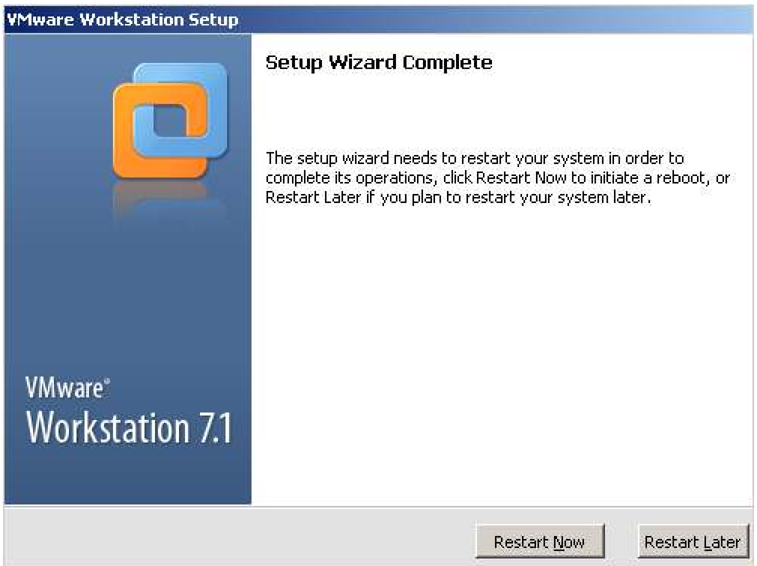

Figure 4.2: VMware Workstation - Setup Wizard Complete

VirtualBox: VirtualBox was downloaded from "www.virtualbox.org" after the download was completed the setup file was launched to begin the installation process. Next the "Installation Wizard" screen followed to install VirtualBox on the Windows 7 Host OS. Figure 4.3 shows the successful installation of VirtualBox on the Windows 7 Host OS.

Figure 4.3: VirtualBox - Installation Complete

Virtual PC: Virtual PC was downloaded from "www.microsoft.com/windows/virtual-pc/" and the download completed. The update file was launched to begin the Virtual PC installation process. The prompts on screen were followed to successfully install Virtual PC on the Windows 7 Host OS. Figure 4.4 shows Virtual PC successfully installed on the Windows 7 Host OS.

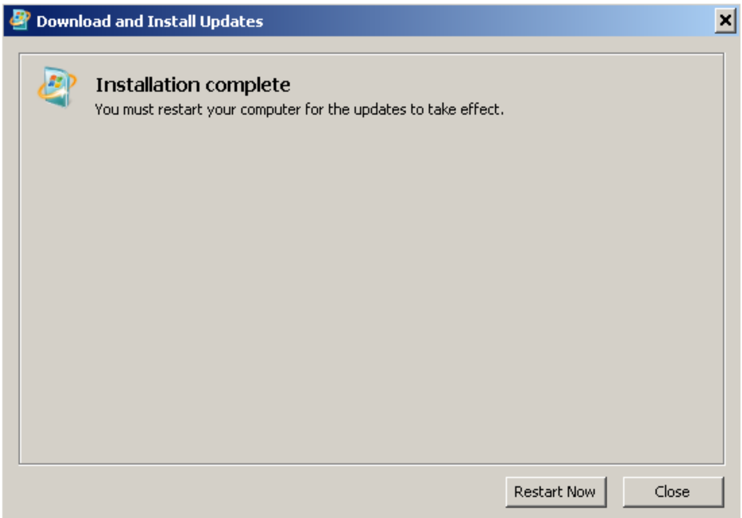

Figure 4.4: Virtual PC - Installation complete

Installing Guest Operating Systems

Choosing the right operating system as guest OS was essential. That is why many factors such as: operating system availability, cost, features and performance were considered before selecting an OS as a guest OS. As a result, for this study, Windows 7 Ultimate 32-bit Edition was selected as the main guest OS. In addition, Linux Mint 32-bit Edition was selected as an extra guest OS. It was appropriate to use Windows 7 as the main guest OS because Windows 7 is a dominant OS available on the market and it is used by many businesses all round the world. Windows 7 will not slow down virtual machines, thus virtual machines can run smoothly and error free. Nonetheless the Linux operating system is also used by some small businesses. Thus Linux Mint was selected as an additional OS to conduct experiments on. However the main goal of this study was to conduct experiments using Windows 7 on VMware Workstation and VirtualBox. But because some businesses are using Linux OS, some experiments were also carried out using the Linux Mint guest OS.

Installing Guest Operating Systems on VMware Workstation: To install Windows 7 and Linux Mint OSs on VMware Workstation it was necessary to create a new virtual machine on VMware Workstation for each OS. The process of creating virtual machines for Windows 7 and Linux Mint OSs occurred separately. In order to create a new virtual machine in VMware Workstation the "New Virtual Machine" icon was clicked. After the "New Virtual Machine" icon was clicked the "New Virtual Machine Wizard" screen appeared. The "New Virtual Machine Wizard" screen helps users to create a new virtual machine on VMware Workstation using either "Typical" or "Custom" options. The "New Virtual Machine Wizard" provides the necessary help to users throughout the process, so users can easily create and configure a new virtual machine on VMware Workstation without any problem. For this study the "Typical" option from the "New Virtual Machine Wizard" screen was selected to create a new virtual machine and the "Next" button was clicked to proceed with creating a new virtual machine. On the next screen the location of the OS image files was provided to the "New Virtual Machine Wizard" and the "Next" button was clicked. Next the "Wizard's Easy Install Information" screen appeared which allows users to enter information required for the new OS. On the "Easy Install Information" screen for Windows 7, from "Version of Windows to install" "Windows 7 Ultimate Edition" was selected and "user1" entered as the username for the OS and for Linux Mint, from "Guest OS" option "Linux" was selected and the "Version" of Linux was set to "Other Linux 2.6.x kernel". On the "Name the Virtual Machine" screen "Windows 7"and "Linux Mint" were entered as the "Virtual machine names" for Windows 7 and Linux Mint respectively. On the "Specify Disk Capacity" screen for both Windows 7 and Linux Mint virtual machines "Maximum disk size" was set to 20 GB and the "Store virtual disk as a single file" option was selected. In "Ready to Create Virtual Machine" screen the "Customize Hardware" button was clicked to modify the virtual machine Memory to 1024 MB and Processor to 1. Finally the finish button was clicked to create a new virtual machine. Figures 4.5 and 4.6 show summaries of the new virtual machines on VMware Workstation.

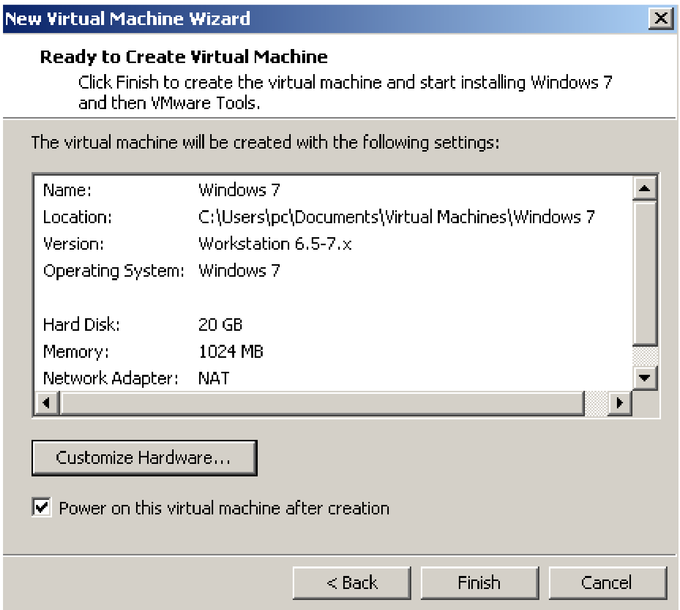

Figure 4.5: VMware Workstation - Windows 7

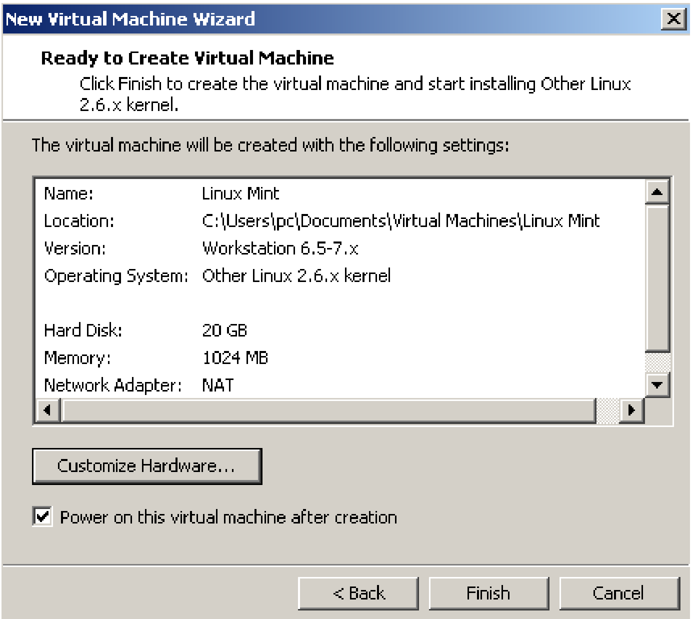

Figure 4.6: VMware Workstation - Linux Mint

Installing Guest Operating Systems on VirtualBox: To install a new guest OS on VirtualBox it is necessary to first create a virtual new machine. The process of creating virtual machines for Windows 7 and Linux Mint OSs each occurred separately. In order to create a new virtual machine on VirtualBox the "New" icon on the "VirtualBox Manager" was clicked. Next the "New Virtual Machine Wizard" screen appeared, on this screen the “Next” button was clicked to proceed with the creation of the new virtual machine. In “VM Name and OS Type” the name of the virtual machine for Windows 7 was defined as Windows 7 and the name of the virtual machine for Linux Mint was defined as Linux Mint, on the same screen the OS type for Windows 7 was set to Microsoft Windows and the OS type for Linux Mint was set to Linux. Next on the “Memory” screen, the amount of memory for Windows 7 and Linux Mint was set to 1024 MB. Next on the “Virtual Hard Disk” screen the “Create new hard disk” was selected and the next button clicked to proceed. On the next screen “VirtualBox Disk Image” was selected for creating a new virtual disk. On the next screen the type of virtual hard disk was set to “Fixed size”. On the next screen the Windows 7 virtual disk file was named Windows 7 and the virtual disk location set to the default location and the Linux Mint virtual disk file was named Linux Mint and the virtual disk location set to the default location. For both Windows 7 and Linux Mint the size of the virtual disk was set to 20 GB. After all required information was provided, the Wizard was ready to create new virtual machines. The create button was clicked to proceed with the creation of the new virtual machines. Figures 4.7 and 4.8 shows summaries of the creation of the new virtual machines on VirtualBox.

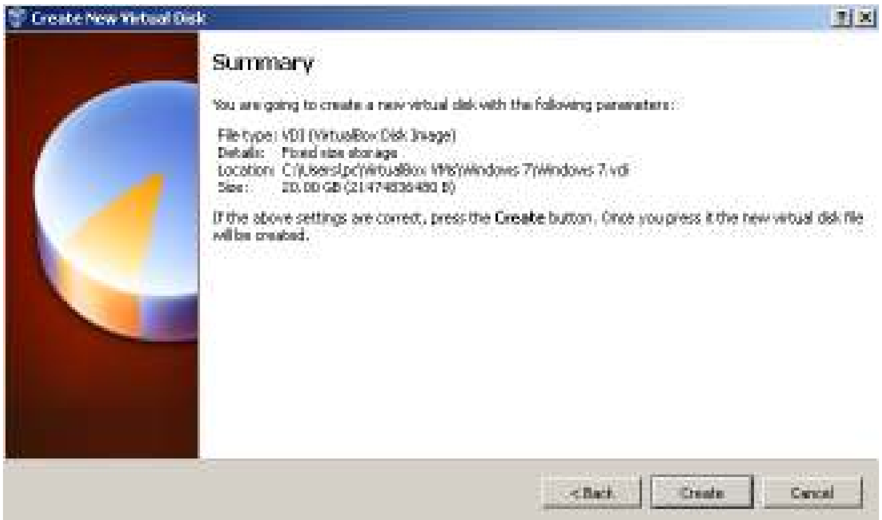

Figure 4.7: VirtualBox - Windows 7

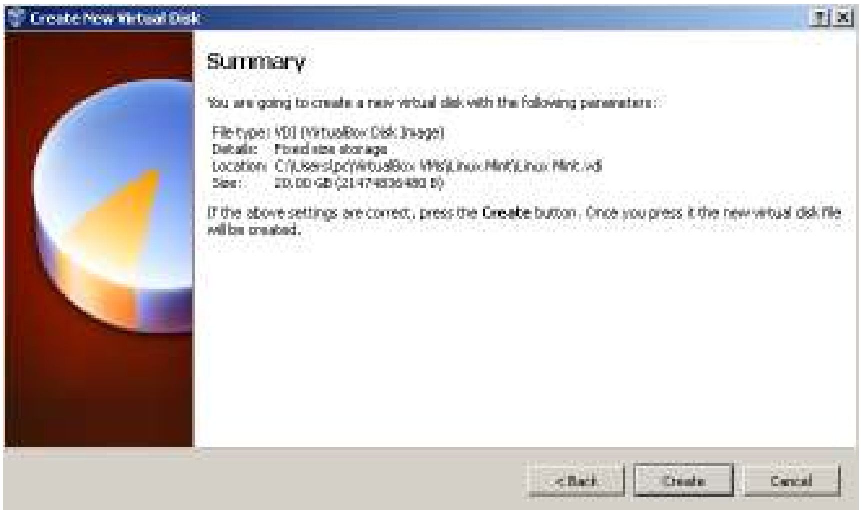

Figure 4.8: VirtualBox - Linux Mint

Installing Guest Operating Systems on Virtual PC: To create a virtual OS on Virtual PC first it is necessary to create a virtual machine. The process of creating virtual machines for Windows 7 and Linux Mint OSs each occurred separately. To create a new virtual machine in Virtual PC the “Create virtual machine” button was clicked. On the next screen, the virtual machine name for Windows 7 was entered as Windows 7 and for Linux Mint it was entered as Linux Mint. Both Windows 7 and Linux Mint virtual machines locations were set to the default location. On the next screen, both Windows 7 and Linux Mint memory was set to 1024 MB. On the “Add a virtual hard disk” screen “Create a virtual hard disk using advanced options” was selected and the “Next” button clicked to proceed. Next the type of virtual hard disk for both Windows 7 and Linux Mint was set to “Fixed size”. On the next screen the name of the Windows 7 virtual hard disk file was set to Windows 7 and the name of the Linux Mint virtual hard disk file was set to Linux Mint. On the “specify size of virtual hard disk” screen, the virtual hard disk size for Windows 7 was set to 20000 MB and the virtual hard disk size for Linux Mint was also set to 20000 MB. Finally, using the “Settings” option on the virtual machine, the location of OS the image file was given to the virtual machine. Figure 4.9 shows the successful creation of both Windows 7 and Linux Mint virtual machines.

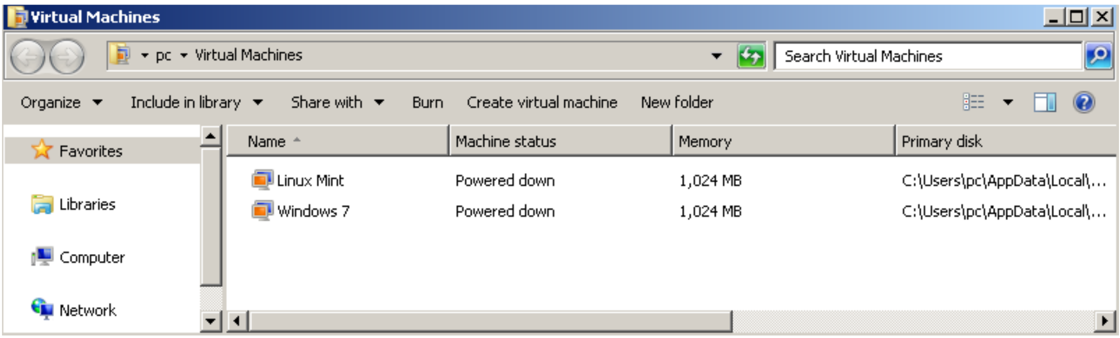

Figure 4.9: Virtual PC - Virtual Machines

Successful Installation of Guest Operating Systems

Figure 4.10: Windows 7 guest OS on VirtualBox

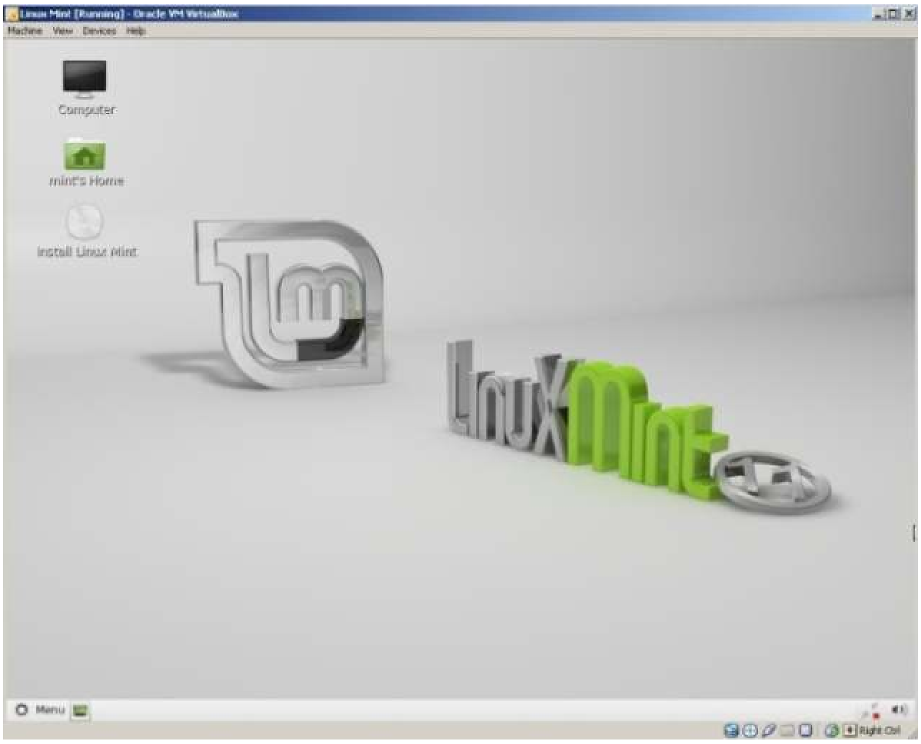

Figure 4.11: Linux Mint guest OS on VirtualBox

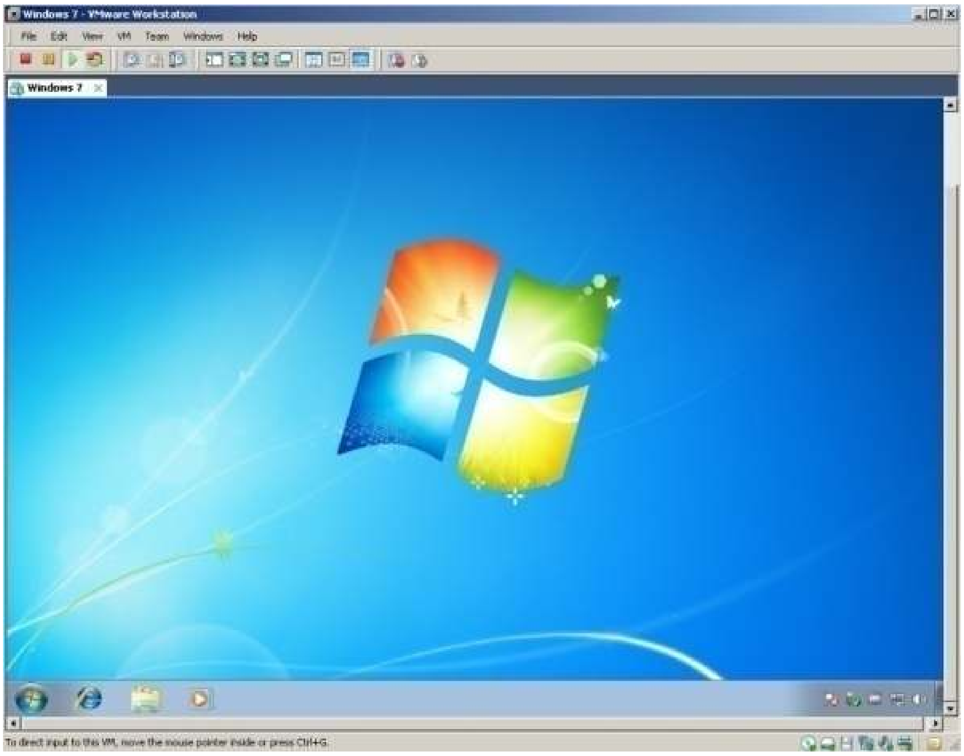

Figure 4.12: Windows 7 guest OS on VMware Workstation

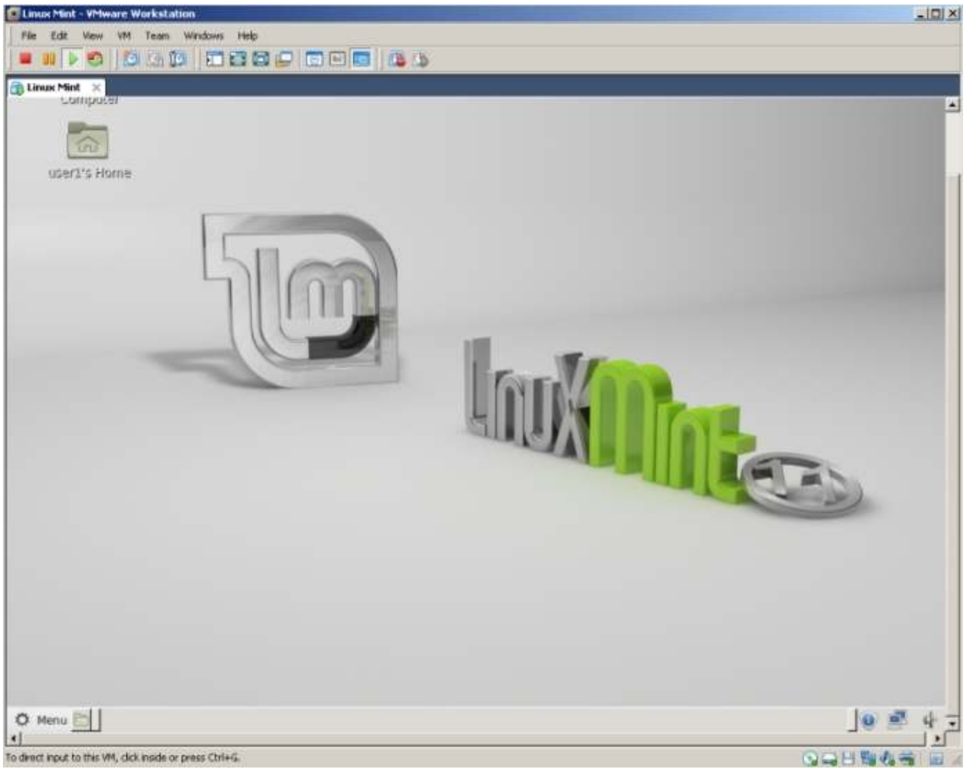

Figure 4.13: Linux Mint guest OS on VMware Workstation

Figure 4.14: Windows 7 guest OS on Virtual PC

Figure 4.15: Linux Mint guest OS on Virtual PC

4.3 Experiments

Experiment 1: Guest operating systems installation time

The purpose of this experiment was to measure Windows 7 and Linux Mint OSs installation time on the virtual machines created by VMware Workstation, VirtualBox and Virtual PC. Each installation was performed separately, not concurrently. During the experiment a digital stopwatch was used to measure the OSs installation times on the virtual machines. To capture the exact installation time of the operating systems on the virtual machines, the digital stopwatch started at the same time as the installation procedure.

Experiment 2: Guest operating system boot time

The purpose of this experiment was to measure the boot time of Windows 7 and Linux Mint guest operating systems based on VMware Workstation, VirtualBox and Virtual PC. Each test was performed separately, not concurrently. To capture the boot time of the guest operating systems, a digital stopwatch was used during the experimental procedure. For accuracy, the digital stopwatch started at the same time as the boot sequence. The test repeated for three different times on each guest operating system. Between each test there was a system reboot and a few minutes delay. This method was used to allow system resources to be restored to their normal state and system becomes stabilized. During the experiment the use of the host OS was reduced to a minimum level and resources such as memory and CPU were kept under an optimum level and unnecessary applications were closed prior to starting the experiment.

Experiment 3: Guest operating system shutdown time

This experiment was designed to measure Windows 7 and Linux Mint guest operating systems shutdown time based on VMware Workstation, VirtualBox and Virtual PC. For this experiment a digital stopwatch was used to capture the guest operating systems shutdown time. Each test was performed separately, not concurrently. To capture the exact shutdown time of the guest operating systems the shutdown operation began at the same time as the digital stopwatch. The test was repeated three times on each guest operating system. Between each test there was a system reboot and a few minutes delay. This method was used to allow the system resources return to their normal state, therefore accurate shutdown duration of the guest operating systems could be obtained. During the experiment use of the host OS was reduced to a minimum level and resources such as memory and CPU kept under an optimum level and any unnecessary applications were closed prior to starting the experiment.

Experiment 4: Guest operating systems' restart time

The aim of this experiment was to measure the restart time of Windows 7 and Linux Mint guest operating systems based on VMware Workstation, VirtualBox and Virtual PC. Each test was performed separately, not concurrently. To capture the restart time of guest operating systems, a digital stopwatch was used throughout the experimental procedure. To accurately obtain the restart times of the guest operating systems, restart operation started at the same time as the digital stopwatch. A system reboot and a few minutes delay were used between each restart test. This method was used to allow the system resources to return a normal state. During the experiment use of the host OS was reduced to a minimum level and resources such as memory and CPU were kept under an optimum level and any unnecessary applications were closed prior to starting the experiment.

Experiment 5: CPU usage of virtualization programs on host OS

In this experiment CPU usage of VMware Workstation, VirtualBox and Virtual PC were monitored on the host OS. The experiment process began by executing VMware Workstation, VirtualBox and Virtual PC and powering up guest operating systems in order to perform the experiment. Each test was performed separately, not concurrently. CPU usage of the host OS kept at a minimum level. Unrelated applications to this experiment were closed before starting the experiment. To measure the CPU usage of VMware Workstation, VirtualBox and Virtual PC on Win 7, Microsoft Windows Task Manger was used on the host OS. Between each test a few minutes delay was used and system rebooted so the CPU and memory resources of the host OS could return to a normal state.

Experiment 6: Memory usage of virtualization programs on host OS

In this experiment memory usage of VMware Workstation, VirtualBox and Virtual PC were monitored on the host OS. The experimental process began by executing VMware Workstation, VirtualBox and Virtual PC and powering up guest operating systems in order to perform the experiment. Each test was performed separately, not concurrently. Memory usage of the host OS was kept at a minimum level. Applications unrelated to this experiment were closed before starting the experiment. To measure memory usage of VMware Workstation, VirtualBox and Virtual PC on Win 7, Microsoft Windows Task Manger was used on the host OS. Between each test there was a few minutes delay and a system reboot. This method was used to allow the CPU and memory of the host OS could return to a normal state.

Experiment 7: Load time of third party applications on guest operating systems

The purpose of this experiment was to measure the load time of third party applications such as GNU Image Manipulation Program, Mozilla Thunderbird and Pidgin on the Windows 7 and Linux Mint guest operating systems based on VMware Workstation, VirtualBox and Virtual PC. Each third party application was executed on the guest operating systems separately. Each test was performed separately, not concurrently. Each third party application was executed three separate times on the guest operating systems and between each execution there was a few minutes delay and a system reboot. This approach was used so the CPU and Memory resources of the host OS could get back to a normal state. Normal usage of both guest operating systems and the host OS were considered during the tests. A digital stopwatch used in this experiment to record the load time of third party applications. Digital stopwatch started at the same time as the execution of the third party applications thus an accurate load time of the third party applications was obtained.

Experiment 8: CPU usage of third party applications on guest operating systems

In this experiment the CPU usage of third party applications such as GNU Image Manipulation Program, Mozilla Thunderbird and Pidgin on guest operating systems was monitored and recorded. For this experiment Windows 7 and Linux Mint guest operating systems were used based on VMware Workstation, VirtualBox and Virtual PC. Each third party application was executed on each guest operating system three separate times. Each test was undertaken separately. Between each execution there was a few minutes delay and a system reboot. This method allowed the system resources such as the CPU and memory to return to a normal state after each test. For this experiment Microsoft Windows Task Manager and Linux Mint System Monitor were used to monitor CPU usage of third party applications on guest operating systems. During the experiment the use of the host OS and guest operating systems were reduced to a minimum level.

Experiment 9: Memory usage of third party applications on guest operating systems

In this experiment memory usage of third party applications such as GNU Image Manipulation Program, Mozilla Thunderbird and Pidgin on the guest operating systems were monitored and recorded. For the experiment Windows 7 and Linux Mint guest operating systems were used based on VMware Workstation, VirtualBox and Virtual PC. Each third party application was executed on each guest operating system three times. All tests were performed separately, not concurrently. Between each test there was a few minutes delay and a system reboot, this method was used to allow the usage of system resources such as CPU and Memory to come back to a normal state after each test. For this experiment Microsoft Windows Task Manager and Linux Mint System Monitor were used to monitor memory usage of the third party applications on the guest operating systems. During the experiment, use of the host OS and the guest operating systems were reduced to a minimum.

Experiment 10: Guest operating systems log off time

The purpose of this experiment was to evaluate guest operating systems, log off time. Windows 7 and Linux Mint guest operating systems were used based on VMware Workstation, VirtualBox and Virtual PC. All tests were performed independently. The log off time test was repeated three times on each guest operating system and between each test there was a few minutes delay and a system reboot. A digital stopwatch was used to record the log off time of the guest operating systems. For accuracy, the digital stopwatch started at the same time as the log off procedure. Thus an accurate log off time for the guest operating systems on VMware Workstation, VirtualBox and Virtual PC was obtained. During the experiment use of system resources on guest and host OSs was reduced to a minimum level.

Experiment 11: Guest operating systems log on time

The purpose of this experiment was to evaluate guest operating systems, log on time. Windows 7 and Linux Mint guest operating systems were used based on VMware Workstation, VirtualBox and Virtual PC. Each test was performed separately, not concurrently. The log on time test was repeated three separate times on each guest operating system and between each test there was a few minutes delay with a system reboot. A digital stopwatch used to record log on times of guest operating systems. For accuracy the digital stopwatch started at the same time as the log on procedure. Thus accurate log on times of the guest operating systems on VMware Workstation, VirtualBox and Virtual PC were obtained. During the experiment use of system resources was reduced to a minimum level.

Experiment 12: Guest operating systems switch user time

The purpose of this experiment was to find out how fast a user on VMware Workstation, VirtualBox and Virtual PC using Windows 7 and Linux Mint guest operating systems can a perform switch user. Each test was performed separately, not concurrently. During the experiment use of the host and guest operating systems was reduced to a minimum level. In this experiment a digital stopwatch was used to record the time. To collect accurate results the digital stopwatch started at the same time as the switch operation. The test was repeated for three times on each guest operating system. Between each test there was a few minutes delay and a system reboot. This was done to allow system resources such as CPU and memory use to return to a normal state after each test.

Experiment 13: Time for a guest operating system to go to a sleep state

The aim of this experiment was to test how fast Windows 7 and Linux Mint guest operating systems based on VMware Workstation, VirtualBox and Virtual PC can go to a sleep state. Each test was performed separately, not concurrently. During the experiment use of the host and guest operating systems was reduced to a minimum level. In this experiment a digital stopwatch was used to record the time. To collect accurate results the digital stopwatch started at the same time as the sleep operation. The test was repeated for three different times on each guest operating system. Between each test there was a few minutes delay and a system reboot. This was done to allow system resources such as CPU and memory use return to a normal state after each test.

Experiment 14: Time for a guest operating system to recover from a sleep state

The aim of this experiment was to test how fast Windows 7 and Linux Mint guest operating systems based on VMware Workstation, VirtualBox and Virtual PC can recover from a sleep state. Each test was performed separately, not concurrently. During the experiment, use of host and guest operating systems was reduced to a minimum level. In this experiment a digital stopwatch was used to record the time. To collect accurate results the digital stopwatch started at the same time as the wakeup operation. The test was repeated three different times on each guest operating system. Between each test there were a few minutes delay and a system reboot. This method was used to allow system resources such as CPU and Memory to return to a normal state.

Experiment 15: Time taken for a guest operating system to go to a state of hibernation

The purpose of this experiment was to test how fast Windows 7 and Linux Mint guest operating systems based on VMware Workstation, VirtualBox and Virtual PC can go to a state of hibernation. Each test was performed separately, not concurrently. During the experiment use of host and guest operating systems was reduced to a minimum level. In this experiment a digital stopwatch was used to record the time. To collect accurate results the digital stopwatch was started at the same time as the hibernate operation. The test was repeated for three different times on each guest operating system. Between each test there were a few minutes delay and a system reboot. This was done to allow system resources such as CPU and memory to return to a normal state.

Experiment 16: Time taken for a guest operating system to recover from a state of hibernation

The objective of this experiment was to test how fast Windows 7 and Linux Mint guest operating systems based on VMware Workstation, VirtualBox and Virtual PC can recover from a state of hibernation. All tests were performed separately, not concurrently. During the experiment use of the host and guest operating systems was reduced to a minimum level. In this experiment a digital stopwatch was used to record the time. To collect accurate results the digital stopwatch was started at the same time as the turn on operation. The test was repeated three times on each guest operating system. Between each test there were a few minutes delay and a system reboot. This approach was used to allow system resources such as CPU and Memory to come to a normal state after each test.

Experiment 17: Time taken to compressed file on guest operating systems

The aim of this experiment was to evaluate how fast a compressed file can be unpacked on VMware Workstation, VirtualBox and Virtual PC using Windows 7 and Linux Mint guest operating systems. Each test was performed separately, not concurrently. During the experiment use of the host and guest operating systems was reduced to a minimum level. In this experiment a digital stopwatch was used to measure the unpacking time. To obtain the exact time, a digital stopwatch started at the same time as the unpacking operation. On each guest operating system the test was repeated for three different times. Between each test there was a few minutes delay and a system reboot. This technique was used to allow usage of system resources such as CPU and Memory to return to a normal state after each test. The unpacking procedure was performed on a compressed file called File.7z. File.7z was created with the 7-Zip program on Win 7. To create the File.7z, following configurations on 7-Zip were used: Archive format: 7z | Compression level: Normal | Compression method: LZMA | Dictionary size: 16 MB | Word size: 32 | Solid Block size: 2 GB | Number of CPU threads: 1 | Update mode: Add and replace files. File.7z contained four sample PDF files. Size of each PDF file was approximately 107.5 MB. The size of the file.7z was approximately 430 MB. To extract File.7z no graphical user interface was used. To extract File.7z using 7-Zip on Windows 7 and Linux Mint the following commands (“>7z x C:\Users\user1\Desktop\File.7z-oC:\Users\user1\Desktop\” and “~ $ 7z x /home/user1/Desktop/File.7z -o/home/user1/Desktop/”) were used in Windows 7’s Command Prompt and Linux Mint’s Terminal respectively.

Experiment 18: Drive/HDD Write Speed on guest operating systems

The objective of this experiment was to analyse drive write speeds on VMware Workstation, VirtualBox and Virtual PC using the Windows 7 guest operating system. Each test was performed separately not concurrently. To perform the experiment the NovaBench benchmarking suite was used. The experiment was carried out by running the "Drive/HDD Write Speed" component of NovaBench. This component tested the drive write speed on guest operating systems running on VMware Workstation, VirtualBox and Virtual PC. During the experiment use of the host and guest operating systems was reduced to a minimum level. To obtain accurate results the experiment was repeated for three different times. Between each repetition there was a few minutes delay and a system reboot. This method was used to allow system resources such as CPU and Memory to return to a normal state after each test.

Experiment 19: CPU - Floating Point Operations on guest operating systems

The purpose of this experiment was to investigate how many floating point operations can be executed on the Windows 7 guest operating system based on VMware Workstation, VirtualBox and Virtual PC. Each test was performed separately, not concurrently. To perform the experiment, the NovaBench benchmarking suite was used. The experiment was carried out by running the "CPU - Floating Point Operations" component of NovaBench. This component executed repetitive floating point operations on the guest operating systems running on VMware Workstation, VirtualBox and Virtual PC. During the experiment usage of host and guest operating system was reduced to a minimum level. To obtain accurate results the experiment was repeated for three times. Between each test there was a few minutes delay and a system reboot. This was done to allow system resources such as CPU and memory to come back to a normal state after each test.

Experiment 20: CPU - Integer Operations on guest operating systems

The purpose of this experiment was to investigate how many integer operations can be executed on the windows 7 guest operating system based on VMware Workstation, VirtualBox and Virtual PC. Each test was performed separately, not concurrently. To perform the experiment the NovaBench benchmarking suite was used. The experiment was carried out by running the "CPU - Integer Operations" component of NovaBench. This component executed repetitive integer operations on the guest operating systems running on VMware Workstation, VirtualBox and Virtual PC. During the experiment usage of host and guest operating systems resources was reduced to a minimum level. To obtain accurate results the experiment was repeated for three times. Between each repetition there was a few minutes delay and a system reboot. This method was used to allow system resources such as CPU and memory to come back to a normal state after each test.

Experiment 21: CPU - MD5 Hashing on guest operating systems

The aim of this experiment was to investigate how many MD5 hashing operations can be generated on the windows 7 guest operating system based on VMware Workstation, VirtualBox and Virtual PC. Each test was performed separately, not concurrently. To perform the experiment the NovaBench benchmarking suite was used. The experiment was carried out by running the "CPU - MD5 Hashing" component of NovaBench. This component generated repetitive MD5 Hashes on the guest operating systems running on VMware Workstation, VirtualBox and Virtual PC. During the experiment usage of host and guest operating systems resources was reduced to a minimum level. To obtain accurate results the experiment was repeated for three different times. Between each repetition there was a few minutes delay and a system reboot. This technique was used to allow system resources such as CPU and Memory to return to a normal state after each test.

Experiment 22: RAM Transfer Speed on guest operating systems

The intent of this experiment was to measure RAM transfer speed on the windows 7 guest operating system based on VMware Workstation, VirtualBox and Virtual PC running on the Win 7 host OS. Each test was performed separately, not concurrently. To perform the experiment the NovaBench benchmarking suite was used. The experiment was carried out by running the "RAM Transfer Speed" component of NovaBench. This component measured RAM transfer speed on the guest operating systems running on VMware Workstation, VirtualBox and Virtual PC. During the experiment usage of host and guest operating systems resources was reduced to a minimum. To obtain accurate results the experiment was repeated three times. Between each test there was a few minutes delay and a system reboot. This method was used to allow system resources such as CPU and Memory to return to a normal state after each test.

4.4 Summary

This chapter contained the necessary information about the creation of the experimental environment and the experiments themselves. The information provided covered all the processes such as preparing the host OS, installing the virtual platforms, creating the virtual machines and installing the guest OSs on the virtual machines. This chapter provided information on all the experiments conducted by the researcher, experiments were clearly explained. The next chapter focuses on the results and analysis of the experiments which were carried out by the researcher.

Chapter 5: Results and Analysis

5.1 Introduction

In previous chapter experiments were discussed and explained. In this chapter experiment results are thoroughly analyzed and explained.

5.2 Analysis of Experiments

Analysis of Experiment 1: Guest operating system installation time

Table 5.1: Experiment 1 - Guest operating systems installation time

	Win 7	Mint
Native	486 Seconds	290 Seconds
VMware Workstation	497 Seconds	310 Seconds
VirtualBox	581 Seconds	341 Seconds
Virtual PC	610 Seconds	296 Seconds

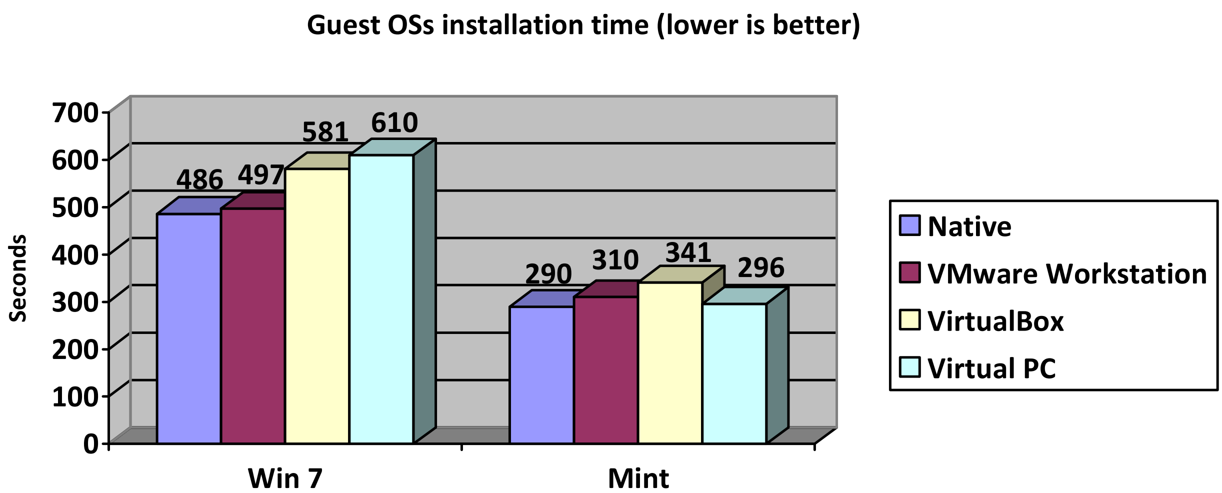

Figure 5.1: Experiment 1 - Guest operating system installation time

Figure 5.1 presents the results for experiment 1. In this experiment, three different virtual platforms (VMware Workstation, VirtualBox and Virtual PC) were tested based on two different operating systems, Windows 7 and Linux Mint. This graph focuses on the time each operating system took to install. As visible in the figure above, more time was taken to install the Windows 7 guest OS while the Linux Mint guest OS took less time to install.

Based on the graph above, the longest amount of time to install the Windows 7 guest OS was taken by Virtual PC at approximately 610 seconds, while shortest amount of time to install the Windows 7 guest OS was taken by the VMware Workstation at approximately 497 seconds. However, the lowest time to install the Linux Mint guest OS was taken by Virtual PC at approximately 296 seconds, whereas the highest amount of time to install the Linux Mint guest OS was taken by VirtualBox at approximately 341 seconds.

A comparison of the results shows that the best performance of to Windows 7 installation was observed on the VMware Workstation, as it took 497 seconds to install, while on the other two virtualization programs, VirtualBox and Virtual PC, installation of the OS took longer than 497 seconds. The best performance of Linux Mint installation was observed Virtual PC, taking approximately 296 seconds to install, while on the other two virtualization programs, VMware Workstation and VirtualBox, installation of the OS took more than 296 seconds.

As shown in the figure above the virtual platforms took longer time to install Windows 7 OS. It took, 200 fewer seconds by all three virtual platforms to install Linux Mint OS.

An overall evaluation of the results shows that the average time to install the guest OSs on the VMware Workstation was approximately 403.5 seconds while the average time to install the guest OSs on VirtualBox was approximately 461 seconds and the average time to install the guest OSs on the Virtual PC was approximately 453 seconds. According to these findings the VMware Workstation performed better than the other two virtualization platforms.

Analysis of Experiment 2: Guest operating system boot time

Table 5.2: Experiment 2 - Guest operating system boot time

	Win 7 1st	**Win 7 2nd**	**Win 7 3rd**	**Mint 1st**	**Mint 2nd**	**Mint 3rd**
Native	32.40 seconds	32.21 seconds	32.49 seconds	26.30 seconds	25.05 seconds	25.30 seconds
VMware Workstation	42.33 seconds	44.41 seconds	41.29 seconds	35.20 seconds	33.38 seconds	33.34 seconds
VirtualBox	33.52 seconds	32.47 seconds	32.63 seconds	34.09 seconds	23.34 seconds	23.15 seconds
Virtual PC	42.29 seconds	30.81 seconds	30.76 seconds	27.10 seconds	25.26 seconds	25.45 seconds

Table 5.3: Experiment 2 - Guest operating system boot time (average results)

	Win 7	**Mint**
Native	32.36 seconds	25.55 seconds
VMware Workstation	42.67 seconds	33.97 seconds
VirtualBox	32.87 seconds	26.86 seconds
Virtual PC	34.62 seconds	25.93 seconds

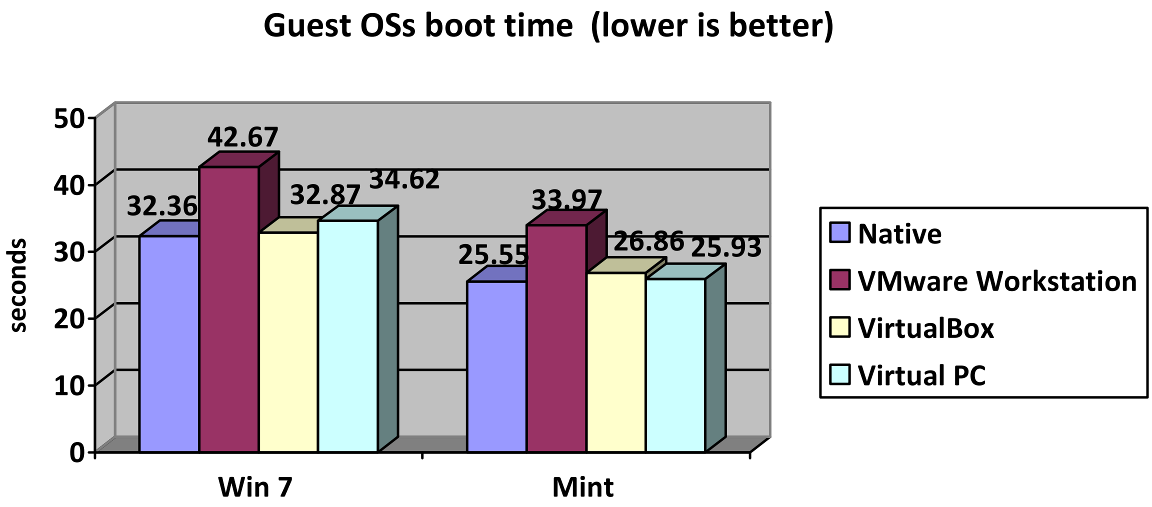

Figure 5.2: Experiment 2 - Guest operating system boot time

Figure 5.2 presents the results for Experiment 2. This experiment focused on the virtual operating system's booting performance. Hence, two different operating systems, Windows 7 and Linux Mint booting performance were necessary based on the three different virtual operating systems (VMware Workstation, VirtualBox and Virtual PC). The graph above shows the average time each virtual operating system took to boot up. As shown in the figure above more time was taken to start-up Windows 7 on the three of the virtual while Linux Mint performed slightly better on these three virtual operating systems.

The highest amount of time was observed on the VMware Workstation using Windows 7 guest OS at approximately 42.67 seconds. The least amount of time was observed on Virtual PC using the Linux Mint guest OS at approximately 25.93 seconds. The second highest amount of time was observed on Virtual PC using the Windows 7 guest OS taking approximately 34.62 seconds to boot up.

The best performance was observed on Virtual PC using Linux Mint as the guest OS, as it took approximately 25.93 seconds to boot up, whereas on VirtualBox using Linux Mint guest OS took approximately 26.86 seconds to boot up. Both virtualization platforms had a 0.93 second difference while VMware platform took 7.11 more seconds than VirtualBox to boot up.

Furthermore, it was observed from these results that each virtualization platform took a different amount of time to boot up. Overall comparison among the three virtualization platforms using Windows 7 and Linux Mint guest OSs showed that virtualization platforms using the Linux Mint guest OSs took less time to boot up while virtualization platforms using Windows 7 took slightly longer to boot up.

Overall evaluation of the results shows that the average time VMware Workstation took to boot up the guest OSs was approximately 38.32 seconds while the average time on VirtualBox was approximately

29.865 seconds and the average time on Virtual PC was approximately 30.275 seconds. According to these findings, VirtualBox performed better than the other two virtualization platforms.

Analysis of Experiment 3: Guest operating system shutdown time

Table 5.4: Experiment 3 - Guest operating system shutdown time

	Win 7 1st	**Win 7 2nd**	**Win 7 3rd**	**Mint 1st**	**Mint 2nd**	**Mint 3rd**
Native	05.30 seconds	05.49 seconds	05.27 seconds	04.10 seconds	04.24 seconds	04.08 seconds
VMware Workstation	10.41 seconds	10.69 seconds	10.35 seconds	05.12 seconds	05.39 seconds	05.56 seconds
VirtualBox	06.29 seconds	07.13 seconds	06.04 seconds	07.23 seconds	06.35 seconds	06.66 seconds
Virtual PC	06.20 seconds	05.74 seconds	05.38 seconds	04.20 seconds	04.34 seconds	04.12 seconds

Table 5.5: Experiment 3 - Guest operating system shutdown time (average results)

	Win 7	**Mint**
Native	05.35 seconds	04.14 seconds
VMware Workstation	10.48 seconds	05.35 seconds
VirtualBox	06.48 seconds	06.74 seconds
Virtual PC	05.77 seconds	04.22 seconds

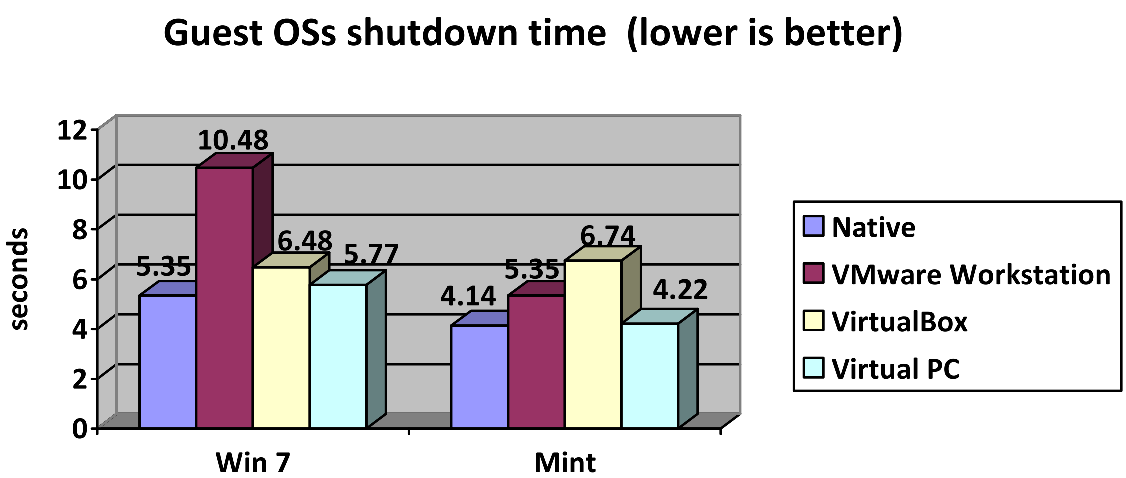

Figure 5.3: Experiment 3 - Guest operating system shutdown time

Figure 5.3 presents the results for Experiment 3. This experiment focused on the virtual operating systems, shutdown performance. In this experiment two different operating systems, Windows 7 and Linux Mint, were included to test their shutdown performance based on three different virtual operating systems (VMware Workstation, VirtualBox and Virtual PC). The graph shows the average time each virtual operating system took to shutdown. As shown in the figure above, nearly the same amount of time was taken to shutdown both operating systems (Windows 7 & Linux Mint) on VirtualBox.

The highest amount of time was measured on the VMware Workstation using Windows 7 at approximately 10.48 seconds. The lowest amount of time was taken by Virtual PC using Linux Mint at approximately 4.22 seconds. The second lowest amount of time was measured on the VMware Workstation using Linux Mint taking approximately 5.35 seconds to shutdown.

The best performance was observed on Virtual PC using the Linux Mint guest OS taking approximately 4.22 seconds to shutdown, while Virtual PC using the Windows 7 guest OS took approximately 5.77 seconds to shutdown. Both virtualization platforms had 1.55 seconds difference between each other whereas on VMware Workstation using Windows 7 the shutdown process took 5.13 seconds more compared to VMware Workstation using the Linux Mint guest OS.

Moreover, it was observed from these results that each virtual platform took a different amount of time to shutdown the two OS's except for VirtualBox. An overall comparison between Windows 7 and Linux Mint based on the three virtual platforms shows that Linux Mint took less time to shutdown but VirtualBox took a similar amount of time with both guest operating systems (Windows 7 & Mint).

An overall evaluation of the results shows that the average time for the VMware Workstation to shutdown the guest OSs was approximately 7.915 seconds while the average time on VirtualBox was approximately 6.61 seconds and the average time on Virtual PC was approximately 4.995 seconds. According to these findings, Virtual PC performed better than the other two virtualization platforms.

Analysis of Experiment 4: Guest operating systems' restart time

Table 5.6: Experiment 4 - Guest operating systems' restart time

	Win 7 1st	**Win 7 2nd**	**Win 7 3rd**	**Mint 1st**	**Mint 2nd**	**Mint 3rd**
Native	29.28 seconds	29.30 seconds	30.10 seconds	28.37 seconds	29.10 seconds	28.30 seconds
VMware Workstation	60.09 seconds	50.18 seconds	51.27 seconds	30.79 seconds	37.12 seconds	35.36 seconds
VirtualBox	51.17 seconds	49.38 seconds	48.19 seconds	29.46 seconds	29.17 seconds	29.35 seconds
Virtual PC	30.29 seconds	31.43 seconds	30.37 seconds	29.30 seconds	29.39 seconds	29.18 seconds

Table 5.7: Experiment 4 - Guest operating systems' restart time (average results)

	Win 7	Mint
Native	29.56 seconds	28.59 seconds
VMware Workstation	53.84 seconds	34.42 seconds
VirtualBox	49.58 seconds	29.32 seconds
Virtual PC	30.69 seconds	29.29 seconds

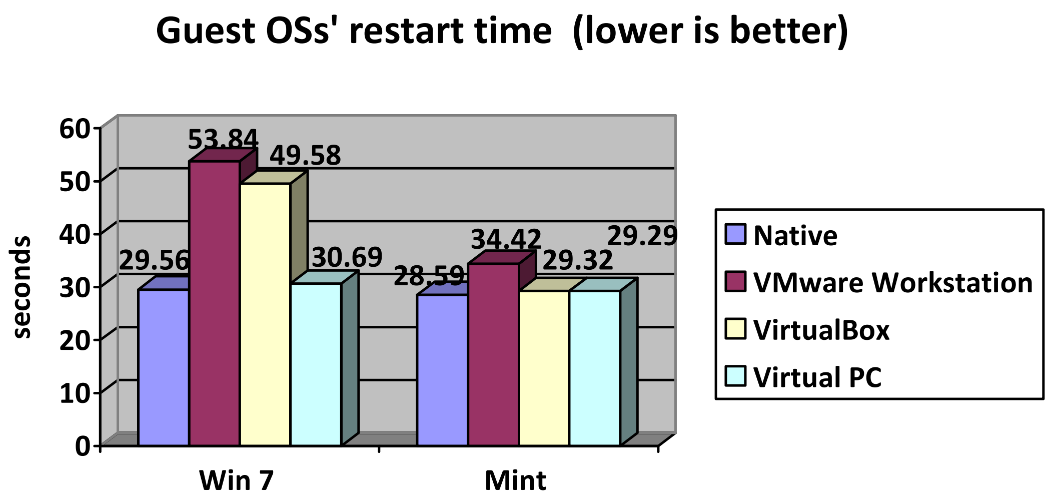

Figure 5.4: Experiment 4 - Guest operating systems' restart time

Figure 5.4 presents the results for experiment 4. This experiment focused on the virtual operating systems, restart performance. In this experiment two different operating systems, Windows 7 and Linux Mint were used to test the restart performance of the guest operating systems based on three different virtual operating systems (VMware Workstation, VirtualBox and Virtual PC). The graph shows the average time each operating system took to restart. As visible in the figure above the same amount of time was taken to restart Linux Mint guest operating systems on both VirtualBox and Virtual PC.

The highest amount of time was observed on VMware Workstation using Windows 7 at approximately 53.84 seconds. The least amount of time was seen on Virtual PC and VirtualBox using the Linux Mint guest OS at approximately 29.30 seconds. The second highest amount of time was observed on VirtualBox using Windows 7 taking approximately 49.58 seconds to restart.

The best performance was observed on Virtual PC and VirtualBox using the Linux Mint guest OS as both took approximately 29.30 seconds to restart, whereas on Virtual PC using Windows 7 the restart took approximately 30.69 seconds. On Virtual PC theWindows 7 and Linux Mint guest OSs had 1.40 seconds difference whereas on VMware Workstation using the Windows 7 the restart took 19.42 more seconds than on other using the Linux Mint guest OS.

Moreover, it was noticed from these results that each virtualization platform took a different amount of time to restart, apart from VirtualBox and Virtual PC using the Linux Mint guest OS which took the same amount of time. Overall the comparison between Windows 7 and Linux Mint guest OSs based on the three virtualization platforms showed that the Linux Mint guest OS took less time to restart except on VMware Workstation.

An overall evaluation of the results shows that the average time for the VMware Workstation to restart the guest OSs was approximately 44.13 seconds while the average time for VirtualBox to restart the guest OSs was approximately 39.45 seconds and the average time for Virtual PC to restart the guest OSs was approximately 29.99 seconds. According to these findings, Virtual PC performed better than the other two virtualization platforms.

Analysis of Experiment 5: CPU usage of virtualization programs on host OS

Table 5.8: Experiment 5 - CPU usage of virtualization programs on host OS

	Win 7 1st	**Win 7 2nd**	**Win 7 3rd**	**Mint 1st**	**Mint 2nd**	**Mint 3rd**
VMware Workstation	63%	59%	60%	58%	58%	60%
VirtualBox	50%	57%	56%	56%	60%	52%
Virtual PC	70%	60%	75%	60%	63%	65%

Table 5.9: Experiment 5 - CPU usage of virtualization programs on host OS (average results)

	Win 7	**Mint**
VMware Workstation	61%	59%
VirtualBox	54%	56%
Virtual PC	68%	63%

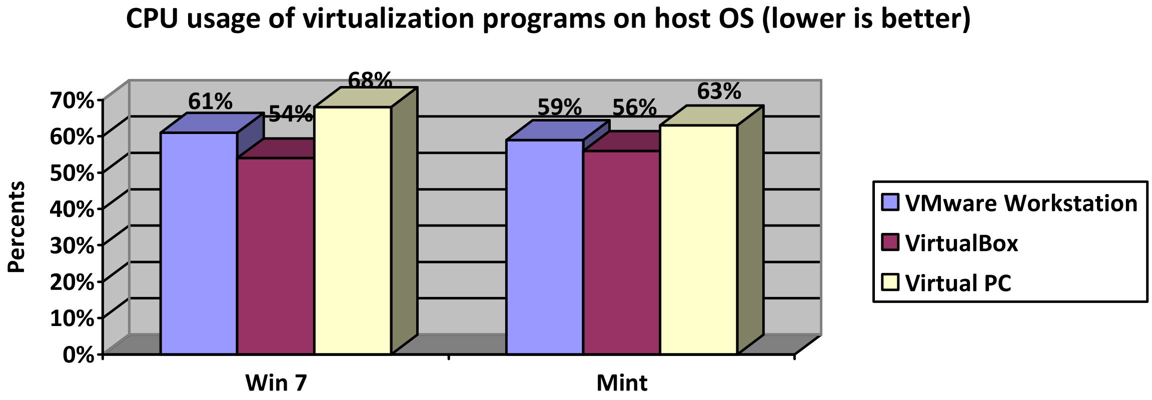

Figure 5.5: Experiment 5 - CPU usage of virtualization programs on host OS

Figure 5.5 presents the results for Experiment 5. Experiment 5 is focused on the CPU usage of virtualization platforms on the host OS while running the guest OS. For this experiment Windows 7 and Linux Mint were used as the guest operating systems on VMware Workstation, VirtualBox and Virtual PC. The guest OS was powered on and the average CPU usage on the host operating system was observed in order to identify the CPU usage required by the virtualization platform.

As shown in the figure 5.5, for Virtual PC using Windows 7 guest OS the CPU usage is high at approximately 68% while on other virtualization platforms with Windows 7 as the guest OS CPU usage is less.

The lowest amount of CPU usage was observed on VirtualBox using the Windows 7 guest OS at approximately 54%, whereas the highest amount of CPU usage was observed on Virtual PC using the Windows 7 guest OS at approximately 68%. Interestingly, Virtual PC using the Linux Mint guest OS also used the highest amount of CPU at approximately 63%.

The best performance was noticed on VirtualBox using both Windows 7 and Linux Mint guest OSs as they were 54% to 56% respectively. The second best performance was observed on VMware Workstation using both Windows 7 and Linux Mint guest OS as they used 59% to 61% CPU respectively. The worst performance was measured on Virtual PC using both Windows 7 and Linux Mint guest OS with 63% to 68% CPU usage respectively.

Furthermore, it was observed from these results that on all three virtualization platforms except on VirtualBox, Linux Mint guest OS used less CPU compared with the Windows 7 guest OS. VirtualBox using the Linux Mint guest OS used only slightly more CPU at approximately 2% than VirtualBox using the Windows 7 guest OS.

An overall evaluation of the results shows that on VMware Workstation average CPU usage of the guest OSs was approximately 60% while on VirtualBox, the average CPU usage of the guest OSs was approximately 55% and on Virtual PC the average CPU usage of the guest OSs was approximately 66%. According to these findings the VirtualBox performed better than the other two virtualization platforms.

Analysis of Experiment 6: Memory usage of virtualization programs on host OS

Table 5.10: Experiment 6 - Memory usage of virtualization programs on host OS

	Win 7 1st	**Win 7 2nd**	**Win 7 3rd**	**Mint 1st**	**Mint 2nd**	**Mint 3rd**
VMware Workstation	488 K 35,804 K 692 K 16,544 K 24,656 K 3,676 K (81,860 K)	500 K 35,780 K 692 K 16,552 K 21,176 K 3,772 K (78,472 K)	496 K 35,728 K 700 K 16,544 K 24,496 K 3,660 K (81,624 K)	492 K 31,960 K 712 K 16,548 K 28,660 K 3,184 K (81,556 K)	496 K 25,428 K 712 K 16,548 K 28,324 K 3,188 K (74,696 K)	488 K 31,788 K 712 K 16,572 K 28,232 K 3,184 K (80,976 K)
VirtualBox	4,448 K 11,369 K 35,828 K (51,645 K)	4,620 K 10,728 K 37,384 K (52,732 K)	4,696 K 11,160 K 36,032 K (51,888 K)	4,412 K 11,044 K 27,000 K (42,456 K)	4,512 K 11,144 K 26,968 K (42,624 K)	4,472 K 11,192 K 26,916 K (42,580 K)
Virtual PC	4,904 K 6,608 K (11,512 K)	4,908 K 6,736 K (11,644 K)	4,904 K 6,664 K (11,568 K)	3,336 K 6,760 K (10,069 K)	3,328 K 6,736 K (10,064 K)	3,316 K 6,768 K (10,084 K)

Table 5.11: Experiment 6 - Memory usage of virtualization programs on host OS (average results)

	Win 7	**Mint**
VMware Workstation	80,652 K	79,076 K
VirtualBox	52,088 K	42,553 K
Virtual PC	11,575 K	10,072 K

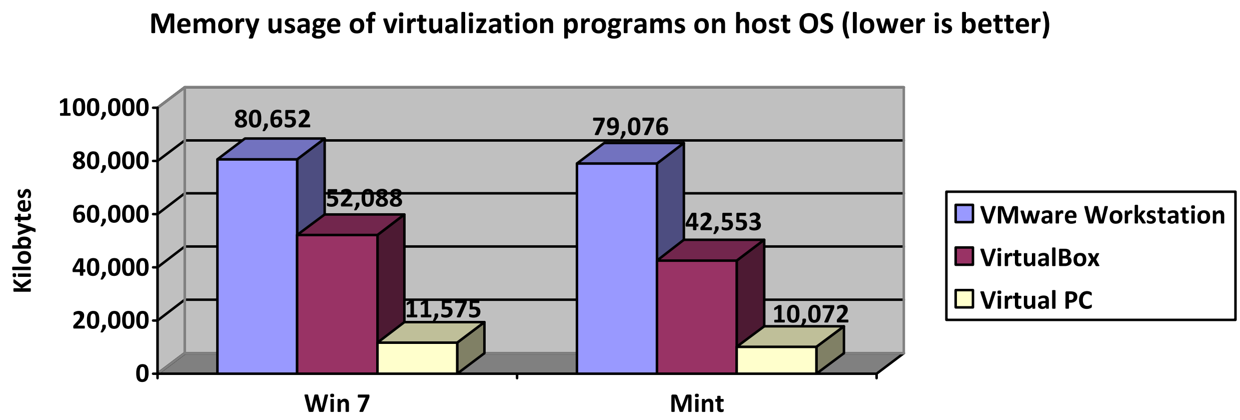

Figure 5.6: Experiment 6 - Memory usage of virtualization programs on host OS

Figure 5.6 presents the results for Experiment 6. Experiment 6 is focused on memory usage of virtualization platforms on the host OS while running a guest operating system. Windows 7 and Linux Mint were used as the guest operating systems. To perform the experiment, the guest OS powered on and memory usage of the virtualization platform measured on the host operating system. Figure 5.6 shows that VMware Workstation requires more memory compared to the other two virtualization platforms, VirtualBox and Virtual PC.

The highest amount of memory usage was observed on VMware Workstation using Windows 7 guest OS at approximately 80,652K. The second highest amount of memory usage was observed on VMware Workstation using Linux Mint guest OS at approximately 79,076 K. The least amount of memory usage was observed on Virtual PC using Linux Mint guest OS at approximately 10,072 K while the second lowest performance was measured on Virtual PC using Windows 7 guest OS at approximately 11,575 K.

Comparison among the three virtual platforms show that on all three virtualization platforms using the Linux Mint guest OS performance was slightly better than using Windows 7 guest OS. Comparisons between the three virtualization platforms indicate that Virtual PC used the least amount of memory while VirtualBox performed slightly better than VMware Workstation as it used less memory. However VMware Workstation had the worst performance as it used higher amounts of memory than both of the other platforms.

An overall evaluation of the results shows that on the VMware Workstation average memory use of the guest OSs was approximately 79,864 K while on VirtualBox average memory use of the guest OSs was approximately 47,320.5 K and on Virtual PC average Memory use of the guest OSs was approximately 10,823.5 K. According to these findings the Virtual PC performed better than the other two virtualization platforms.

Analysis of Experiment 7: Load time of third party applications on guest operating systems

The aim of Experiment 7 is to identify the loading time for an application using a guest operating system based on a virtual platform. Therefore, three applications were selected; GIMP, Thunderbird and Pidgin. The guest operating systems used were Windows 7 and Linux Mint while the three virtual platforms were VMware Workstation, VirtualBox and Virtual PC. The tests were run multiple times and their average results were obtained. The tables below illustrate the loading time for these applications.

Table 5.12: Experiment 7 - Load time of GIMP on guest operating systems

	Win 7 1st	**Win 7 2nd**	**Win 7 3rd**	**Mint 1st**	**Mint 2nd**	**Mint 3rd**
VMware Workstation	04.45 seconds	04.44 seconds	04.47 seconds	03.22 seconds	03.11 seconds	03.17 seconds
VirtualBox	04.58 seconds	04.77 seconds	04.75 seconds	02.98 seconds	02.87 seconds	02.88 seconds
Virtual PC	04.84 seconds	04.94 seconds	04.54 seconds	03.25 seconds	03.50 seconds	03.54 seconds

Table 5.13: Experiment 7 - Load time of GIMP on guest operating systems (average results)

	Win 7	**Mint**
VMware Workstation	04.45 seconds	03.16 seconds
VirtualBox	04.70 seconds	02.91 seconds
Virtual PC	04.77 seconds	03.43 seconds

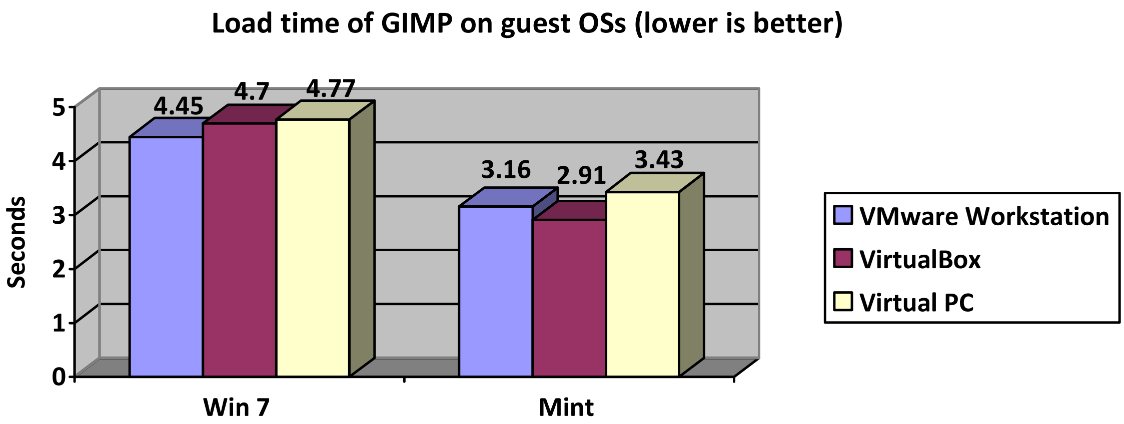

Figure 5.7: Experiment 7 - Load time of GIMP on guest operating systems

Figure 5.7 presents the results for Experiment 7. Experiment 7 focused on the loading time for an application called GIMP on three different virtual platforms, VMware Workstation, VirtualBox and Virtual PC using Windows 7 and Linux Mint guest OSs.

Figure 5.7 indicates that GIMP on all three virtual platforms using the Windows 7 guest OS took more time to load compared to the Linux Mint guest OS. The longest loading time was taken by Virtual PC using Windows 7 guest OS at approximately 4.77 seconds whereas, VirtualBox using Windows 7 guest OS took 4.70 seconds to load the GIMP application. The shortest loading time was on VirtualBox using the Linux Mint guest OS at approximately 2.91 seconds. The second shortest loading time was measured on VMware Workstation using the Linux Mint guest OS at approximately 3.16 seconds.

A comparison between the two guest operating systems based on the three virtual platforms shows that the Linux Mint guest operating system performed marginally better than Windows 7 guest operating systems on all three virtual platforms tested.

A comparison among the three virtual platforms showed that GIMP on Virtual PC using the Linux Mint guest OS used approximately 1.34 seconds less compared to Windows 7 guest OS on Virtual PC. GIMP on VMware Workstation using the Linux Mint guest OS used approximately 1.29 seconds less loading time when compared to GIMP on VMware Workstation using the Windows 7 guest OS. However GIMP on VirtualBox using Linux Mint took approximately 1.79 fewer seconds than GIMP on VirtualBox using the Windows 7 guest OS. Overall, GIMP on VirtualBox using the Linux Mint guest OS had the best performance.

An overall evaluation of the results shows that on VMware Workstation the average load time of GIMP was approximately 3.805 seconds while on VirtualBox GIMP's average load time of was also approximately 3.805 seconds, whereas on Virtual PC GIMP's average load time was approximately 4.1 seconds. According to these findings VMware Workstation and VirtualBox performed better than Virtual PC.

Table 5.14 - Experiment 7: Load time of Thunderbird on guest operating systems

	Win 7 1st	**Win 7 2nd**	**Win 7 3rd**	**Mint 1st**	**Mint 2nd**	**Mint 3rd**
VMware Workstation	01.42 seconds	01.32 seconds	01.38 seconds	01.54 seconds	01.70 seconds	01.34 seconds
VirtualBox	01.96 seconds	01.65 seconds	01.63 seconds	01.64 seconds	01.65 seconds	01.59 seconds
Virtual PC	01.56 seconds	01.52 seconds	01.54 seconds	01.90 seconds	01.90 seconds	01.96 seconds

Table 5.15 - Experiment 7: Load time of Thunderbird on guest operating systems (average results)

	Win 7	**Mint**
VMware Workstation	01.37 seconds	01.52 seconds
VirtualBox	01.74 seconds	01.62 seconds
Virtual PC	01.54 seconds	01.92 seconds

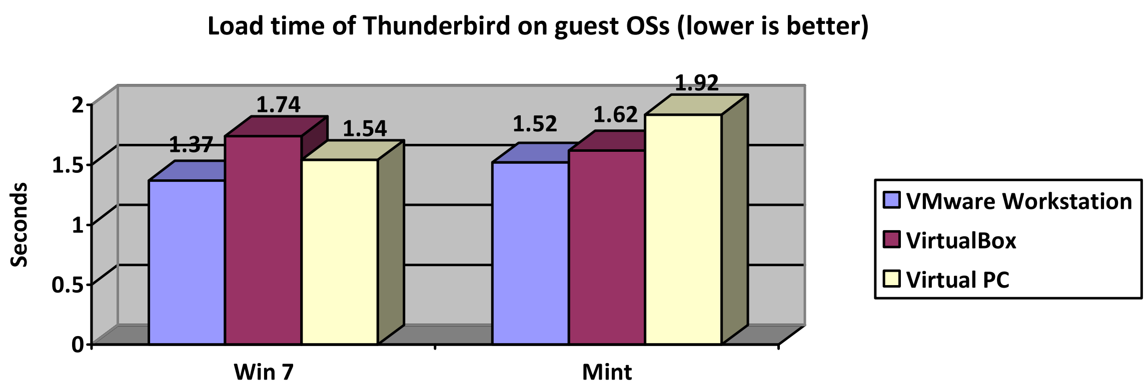

Figure 5.8: Experiment 7 - Load time of Thunderbird on guest operating systems

Figure 5.8 presents the results for Experiment 7, measuring the load time for an application called Mozilla Thunderbird on the three different virtual platforms VMware Workstation, VirtualBox and Virtual PC using Windows 7 and Linux Mint guest OSs.

Figure 5.8 indicated that Mozilla Thunderbird on VMware Workstation and Virtual PC using the Windows 7 guest OS performed slightly better than Mozilla Thunderbird on Workstation and Virtual PC using the Linux Mint guest OS. The performance of Mozilla Thunderbird on VirtualBox using the Linux Mint guest OS was better than Mozilla Thunderbird on VirtualBox using the Windows 7 guest OS.

The shortest time was observed using Mozilla Thunderbird on VMware Workstation using the Windows 7 guest OS at approximately 1.37 seconds, while the second shortest load time was observed on Mozilla Thunderbird on VMware Workstation using the Linux Mint guest OS at approximately 1.52 seconds. The longest load time was taken using Mozilla Thunderbird on Virtual PC using the Linux Mint guest OS at approximately 1.92 seconds, whereas Mozilla Thunderbird on VirtualBox using the Windows 7 guest OS took 1.74 seconds to load.

A comparison among the three virtual platforms revealed that Mozilla Thunderbird performed differently on each virtual platform. VMware Workstation and Virtual PC performed slightly better using the Windows 7 guest OS, whereas VirtualBox performed slightly better using the Linux Mint guest OS.

Also a comparison among the three virtual platforms revealed that VirtualBox using Linux Mint guest OS used approximately 0.12 second less time than the Windows 7 guest OS. However, the longest load time was observed on Virtual PC using the Linux Mint guest OSs at approximately 0.38 second more than when using the Windows 7 guest OS. Moreover, VMware Workstation using the Windows 7 guest OS used approximately 0.15 second less time than VMware Workstation using the Linux Mint guest OS. Overall, Virtual PC using the Linux Mint guest OS had the worst performance.

An overall evaluation of the results shows that on the VMware Workstation the average load time of Mozilla Thunderbird was approximately 1.445 seconds while on VirtualBox the average load time of Mozilla Thunderbird was approximately 1.68 seconds and on Virtual PC the average load time of Mozilla Thunderbird was approximately 1.73 seconds. According to these findings VirtualBox performed better than VMware Workstation on Virtual PC.

Table 5.16 - Experiment 7: Load time of Pidgin on guest operating systems

	Win 7 1st	Win 7 2nd	Win 7 3rd	Mint 1st	Mint 2nd	Mint 3rd
VMware Workstation	01.10 seconds	01.06 seconds	01.06 seconds	01.50 seconds	01.50 seconds	01.56 seconds
VirtualBox	01.14 seconds	01.04 seconds	01.05 seconds	02.18 seconds	02.06 seconds	02.10 seconds
Virtual PC	01.22 seconds	01.22 seconds	01.22 seconds	02.12 seconds	02.19 seconds	02.29 seconds

Table 5.17 - Experiment 7: Load time of Pidgin on guest operating systems (average results)

	Win 7	Mint
VMware Workstation	01.07 seconds	01.52 seconds
VirtualBox	01.07 seconds	02.11 seconds
Virtual PC	01.22 seconds	02.20 seconds

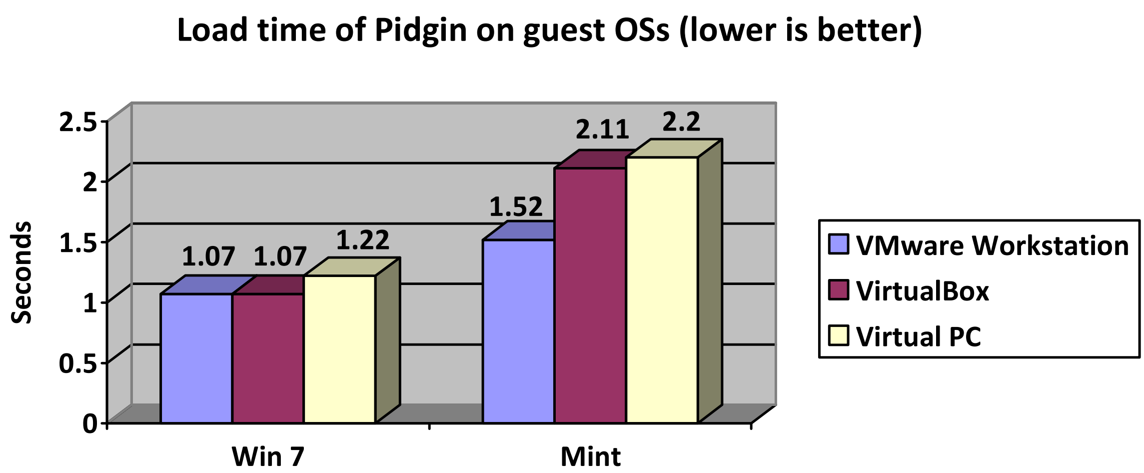

Figure 5.9: Experiment 7 - Load time of Pidgin on guest operating systems

Figure 5.9 presents the results for Experiment 7. Where the load time for an application called Pidgin on VMware Workstation, VirtualBox and Virtual PC using the OSs guest Windows 7 and Linux Mint was measured.

Figure 5.9 reveals that Pidgin on all three virtual platforms using the Windows 7 guest OS performed better than when using the Linux Mint guest OS. The shortest load time was measured using Pidgin on VMware Workstation and VirtualBox using the Windows 7 guest OS at approximately 1.07 seconds, while the load time of Pidgin on Virtual PC using Windows 7 guest OS took approximately 1.22 seconds. The longest load time was on Virtual PC using the Linux Mint guest OS at approximately 2.20 seconds, whereas the second longest load time was measured using Pidgin on VirtualBox using the Linux Mint guest OS at approximately 2.11 seconds.

A comparison between the two guest operating systems based on the three virtual platforms indicates that virtual platforms which used the Windows 7 guest OS performed marginally better than the virtual platforms using the Linux Mint guest OS. Virtual PC using either Windows 7 or Linux Mint guest operating systems had longer loading times.

A comparison among the three virtual platforms showed that Pidgin on VMware Workstation using Windows 7 guest OS used approximately 0.45 second less load time than using the Linux Mint guest OS. However the longest load time was observed on VirtualBox using the Linux Mint guest OSs at approximately 1.04 seconds more than when using Windows 7. Furthermore Pidgin on Virtual PC using the Windows 7 guest OS used approximately 0.98 second less load time than when using the Linux Mint guest OS. Overall Pidgin on VMware Workstation using both the Windows 7 and Linux Mint guest OSs had the best performance.

An overall evaluation of the results shows that on VMware Workstation the average load time of Pidgin was approximately 1.295 seconds while on VirtualBox the average load time of Pidgin was approximately 1.59 seconds whereas on Virtual PC the average load time of Pidgin was approximately 1.71 seconds. According to these findings VirtualBox performed better than VMware Workstation and Virtual PC.

Analysis of Experiment 8: CPU usage of third party applications on guest operating systems

The goal of Experiment 8 was to identify CPU performance while running applications on a guest operating system. Thus, each virtual operating system (Windows 7 & Linux Mint) was based on three different virtual platforms; VMware Workstation, VirtualBox and Virtual PC. In this experiment a virtual platform was installed and on top of that a guest operating system was installed. Then applications; GIMP, Mozilla Thunderbird and Pidgin were installed. The CPU usage of each application was measured and the average results were calculated. Figures 5.10, 5.11 and 5.12 illustrate the results for these applications.

Table 5.18: Experiment 8 - CPU usage of GIMP on guest operating systems

	Win 7 1st	Win 7 2nd	Win 7 3rd	Mint 1st	Mint 2nd	Mint 3rd
VMware Workstation	100%	100%	100%	100%	100%	100%
VirtualBox	100%	100%	100%	92%	100%	100%
Virtual PC	100%	100%	100%	100%	100%	100%

Table 5.19: Experiment 8 - CPU usage of GIMP on guest operating systems (average results)

	Win 7	Mint
VMware Workstation	100%	100%
VirtualBox	100%	97%
Virtual PC	100%	100%

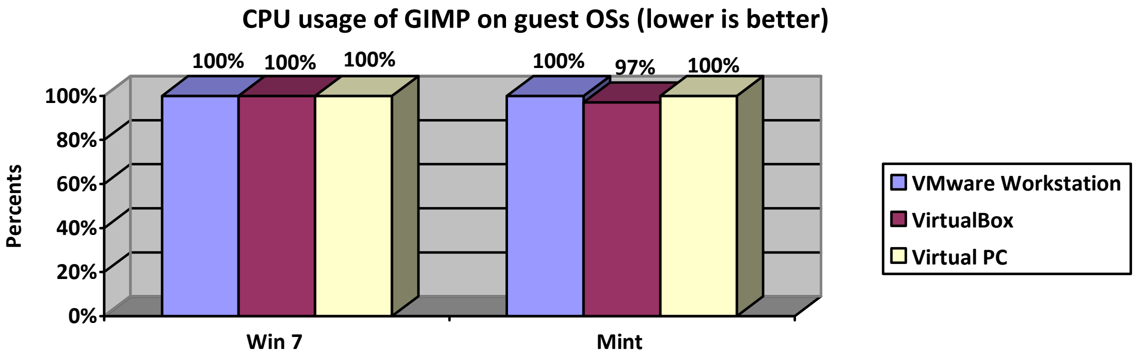

Figure 5.10: Experiment 8 - CPU usage of GIMP on guest operating systems

This part of Experiment 8 aimed to identify the CPU usage of running an application known as GIMP on the guest OSs. Thus, each guest OS Windows 7 and Linux Mint,was based on the three different virtual platforms, VMware Workstation, VirtualBox and Virtual PC. CPU usage of the GIMP application was measured and the average results were calculated.

As shown in Figure 5.10 the GIMP application on all three virtual platforms using the Windows 7 and Linux Mint guest OSs performed very closely, as they all used approximately 100% of the CPU except for VirtualBox using the Linux Mint guest OS. The smallest amount of CPU usage was observed on VirtualBox using the Linux Mint guest OS at approximately 97%.

An overall evaluation of the results shows that on the VMware Workstation average CPU use of GIMP was approximately 100% while on VirtualBox the average CPU use of GIMP was approximately 99% whereas on Virtual PC, the average CPU use of GIMP was approximately 100%. According to these findings VirtualBox performed slightly better than VMware Workstation and Virtual PC.

Table 5.20: Experiment 8 - CPU usage of Thunderbird on guest operating systems

	Win 7 1st	**Win 7 2nd**	**Win 7 3rd**	**Mint 1st**	**Mint 2nd**	**Mint 3rd**
VMware Workstation	100%	100%	100%	80%	70%	100%
VirtualBox	78%	100%	100%	80%	90%	100%
Virtual PC	72%	100%	100%	100%	100%	100%

Table 5.21: Experiment 8 - CPU usage of Thunderbird on guest operating systems (average results)

	Win 7	**Mint**
VMware Workstation	100%	83%
VirtualBox	93%	90%
Virtual PC	91%	100%

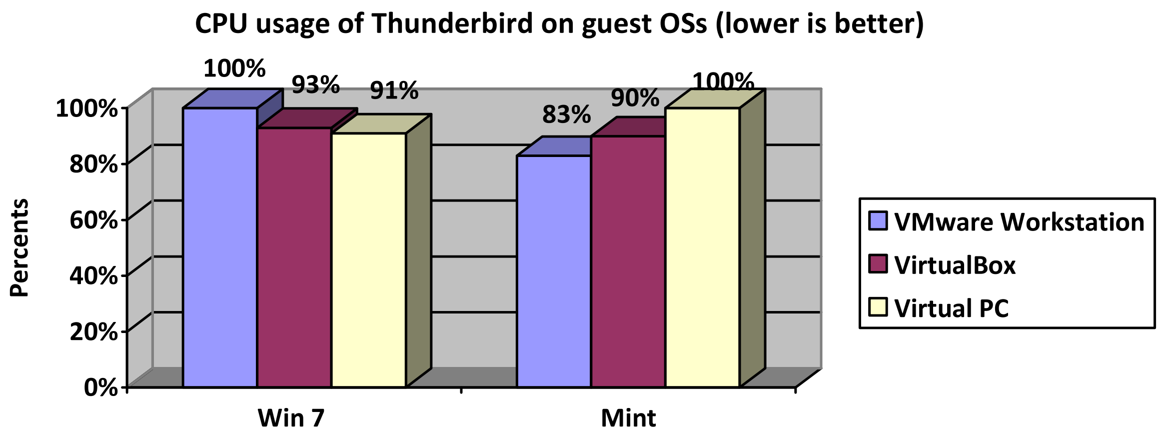

Figure 5.11: Experiment 8 - CPU usage of Thunderbird on guest operating systems

This part of Experiment 8 aimed to identify CPU usage while running an application known as Mozilla Thunderbird on the guest OSs. Thus, each guest OS, Windows 7 and Linux Mint was based on the three different virtual platforms; VMware Workstation, VirtualBox and Virtual PC. CPU usage of the Mozilla Thunderbird application was measured and the average results were calculated.

Figure 5.11 indicates that Mozilla Thunderbird on VMware Workstation using Windows 7 requires more CPU use compared to the other two virtual platforms, VirtualBox and Virtual PC using the Windows 7 guest OS. However, results for the Linux Mint guest OS showed that Mozilla Thunderbird on Virtual PC using Linux Mint guest OS requires more CPU usage than the other two virtual platforms, VMware Workstation and VirtualBox.

The highest amount of CPU usage was observed on VMware Workstation using the Windows 7 guest OS at approximately 100% while the same amount of CPU usage was noticed on Virtual PC using the Linux Mint guest OS. The least amount of CPU usage was observed on VMware Workstation using the Linux Mint guest OS at approximately 83%. Second lowest amount of CPU usage was observed on VirtualBox using Linux Mint guest OS at approximately 90%.

A comparison between the two guest operating systems based on the three virtual platforms showed that VMware Workstation and VirtualBox performed better using the Linux Mint guest OS whereas, Virtual PC performed slightly better using the Windows 7 guest OS.

A comparison between the three virtual platforms showed that VirtualBox had constant CPU usage while the other two virtual platforms were not stable. Virtual PC using the Linux Mint guest OS used the maximum amount of CPU while Virtual PC using Windows 7 guest OS used approximately 9% less. However, VMware Workstation performed conversely to Virtual PC, as VMware Workstation using the Windows 7 guest OS used the maximum amount of CPU whereas using the Linux guest OS it used approximately 17% less CPU.

An overall evaluation of the results shows that on the VMware Workstation the average CPU usage of Mozilla Thunderbird was approximately 92% while on VirtualBox the average CPU usage of Mozilla Thunderbird was approximately 92% whereas on Virtual PC the average CPU usage of Mozilla Thunderbird was approximately 96%. According to these findings VMware Workstation and VirtualBox performed slightly better than Virtual PC.

Table 5.22: Experiment 8 - CPU usage of Pidgin on guest operating systems

	Win 7 1st	**Win 7 2nd**	**Win 7 3rd**	**Mint 1st**	**Mint 2nd**	**Mint 3rd**
VMware Workstation	41%	57%	78%	98%	72%	81%
VirtualBox	40%	40%	39%	98%	100%	100%
Virtual PC	100%	100%	100%	100%	100%	100%

Table 5.23: Experiment 8 - CPU usage of Pidgin on guest operating systems (average results)

	Win 7	**Mint**
VMware Workstation	59%	84%
VirtualBox	40%	99%
Virtual PC	100%	100%

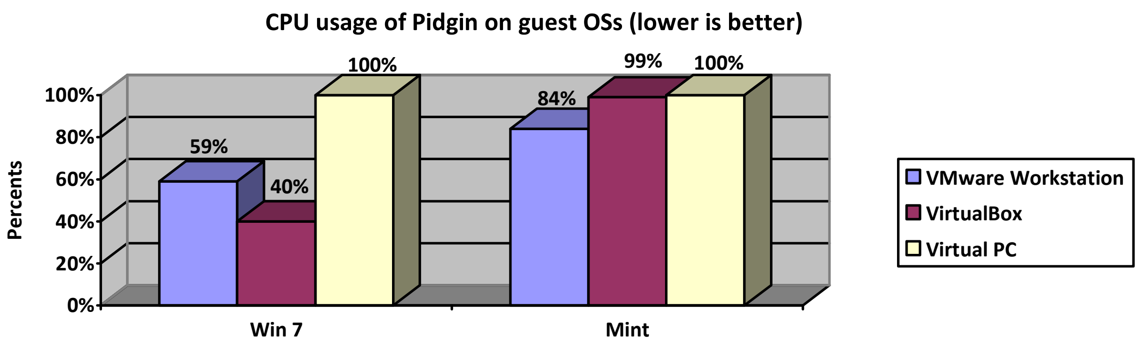

Figure 5.12: Experiment 8 - CPU usage of Pidgin on guest operating systems

This part of Experiment 8 aimed to identify the CPU usage of running an application known as Pidgin on the guest OSs. Thus, each guest OS, Windows 7 and Linux Mint, was based on the three different virtual platforms; VMware Workstation, VirtualBox and Virtual PC. CPU usage of the Pidgin application was measured and average results were calculated.

Figure 5.12 shows that Pidgin on Virtual PC requires more CPU usage compared to the other two virtual platforms, VMware Workstation and VirtualBox using either Windows 7 or Linux Mint guest OSs.

The least amount of CPU usage was observed on VirtualBox using the Windows 7 guest OS at approximately 40%. The second lowest amount of CPU usage was observed on VMware Workstation using the Windows 7 guest OS at approximately 59%. The highest amount of CPU usage was observed on Virtual PC using Windows 7 guest OS at approximately 100% and same amount of CPU usage was observed on Virtual PC using the Linux Mint guest OS. The second highest amount of CPU usage was observed on VirtualBox using the Linux Mint guest OS at approximately 99%.

A comparison between the two guest operating systems based on the three virtual platforms indicated that VMware Workstation performed better than Virtual PC and VirtualBox using the Linux Mint guest OS whereas VirtualBox performed slightly better than Virtual PC and VMware using the Windows 7 guest OS.

A comparison among the three virtual platforms indicated that VirtualBox used 60% lesser CPU than Virtual PC and 41% less than VMware Workstation using the Windows 7 guest OS. However, Pidgin using the Linux Mint guest OS based on VMware Workstation was observed to use approximately 16% less CPU than Virtual PC and 15% lesser than VirtualBox.

An overall evaluation of the results shows that on VMware Workstation average CPU usage of Pidgin was approximately 72% while on VirtualBox average CPU usage of Pidgin was approximately 70%

whereas on Virtual PC the average CPU usage of Pidgin was approximately 100%. According to these findings VirtualBox performed slightly better than VMware Workstation and Virtual PC.

Analysis of Experiment 9: Memory usage of third party applications on guest operating systems

The goal of experiment 9 was to identify memory performance while running applications on a guest operating system. Thus, each virtual operating system (Windows 7 & Linux Mint) was based on the three different virtual platforms, VMware Workstation, VirtualBox and Virtual PC. In this experiment a virtual platform was installed first and on top of that a guest operating system was installed. Then applications; GIMP, Mozilla Thunderbird and Pidgin were installed. Memory usage of each application was measured and the average results were calculated. Figures 5.13, 5.14 and 5.15 illustrate the results for these applications.

Table 5.24: Experiment 9 - Memory usage of GIMP on guest operating systems

	Win 7 1st	**Win 7 2nd**	**Win 7 3rd**	**Mint 1st**	**Mint 2nd**	**Mint 3rd**
VMware Workstation	23,360 K 6,484 K (29,844 K)	23,492 K 6,484 K (29,976 K)	23,372 K 6,484 K (29,856 K)	18.9 MiB (19353.6 K) 2.1 MiB (2150.4 K) (21,504 K)	18.9 MiB (19353.6 K) 2.1 MiB (2150.4 K) (21,504 K)	18.9 MiB (19353.6 K) 2.1 MiB (2150.4 K) (21,504 K)
VirtualBox	24,020 K 6,860 K (30,880 K)	23,256 K 6,412 K (29,668 K)	23,180 K 6,408 K (29,588 K)	19.0 MiB (19456 K) 2.1 MiB (2150.4 K) (21,606.4)	18.9 MiB (19353.6 K) 2.1 MiB (2150.4 K) (21,504 K)	18.9 MiB (19353.6 K) 2.1 MiB (2150.4 K) (21,504 K)
Virtual PC	23,468 K 6,476 K (29,944 K)	23,528 K 6,480 K (30,008 K)	23,508 K 6,480 K (29,988 K)	19.8 MiB (20275.2 K) 2.1 MiB (2150.4 K) (22,425.6 K)	19.7 MiB (20172.8 K) 2.1 MiB (2150.4 K) (22,323.2)	19.7 MiB (20172.8 K) 2.1 MiB (2150.4 K) (22,323.2)

Table 5.25: Experiment 9 - Memory usage of GIMP on guest operating systems (average results)

	Win 7	**Mint**
VMware Workstation	29,892 K	21,504 K
VirtualBox	30,045 K	21,538.13 K
Virtual PC	29,980 K	22,357.33 K

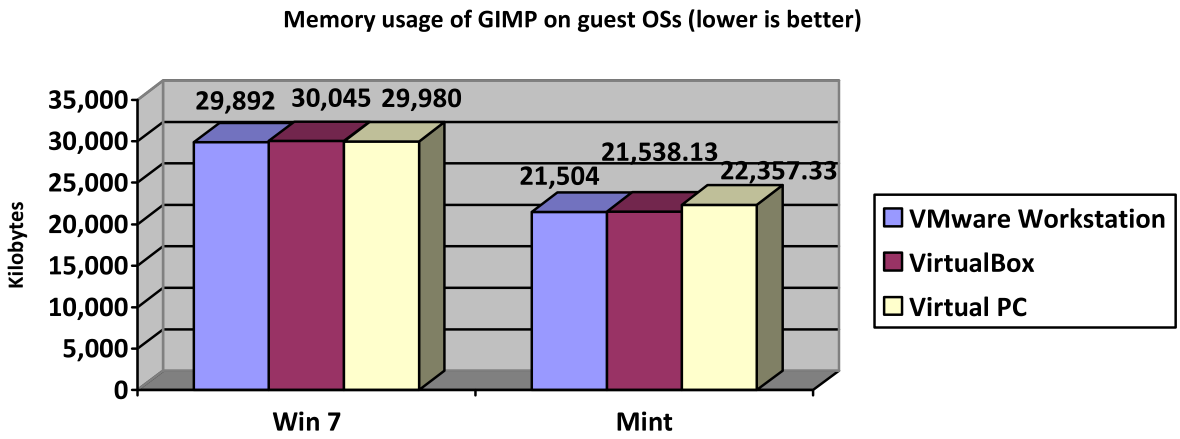

Figure 5.13: Experiment 9 - Memory usage of GIMP on guest operating systems

This part of Experiment 9 aimed to identify memory use while running an application known as GIMP on the guest OSs. Thus, each guest OS, Windows 7 and Linux Mint was based on the three different virtual platforms; VMware Workstation, VirtualBox and Virtual PC. Memory usage of the GIMP application was measured and average results were calculated.

Figure 5.13 shows that the GIMP application on VMware Workstation, VirtualBox and Virtual PC using the Linux Mint guest OS required less memory. However, results for VMware Workstation, VirtualBox and Virtual PC using the Windows 7 guest OS showed that the GIMP application require approximately 7500 K more memory.

The highest amount of memory use was observed on VirtualBox using the Windows 7 guest OS at approximately 30,045 K, while similar amount of memory usage was noticed on VMware Workstation and Virtual PC using the Windows 7 guest OS at approximately 29,892 K and 29,980 K respectively. However the lowest amount of memory use was observed on VMware Workstation using the Linux Mint guest OS at approximately 21,504 K, the second lowest amount of memory use was detected on VirtualBox using the Linux Mint guest OS at approximately 21,538.13 K.

A comparison between the two guest operating systems based on the three virtual platforms indicated that the Linux Mint guest OS based on all three virtual platforms; VMware Workstation, VirtualBox and Virtual PC performed much better than the Windows 7 guest OS.

A comparison between the three virtual platforms showed that VirtualBox using the Windows 7 guest OS used highest amount of memory use while VirtualBox using the Linux Mint guest OS used approximately 8,506.87 K less memory. VMware Workstation using the Linux Mint guest OS used approximately 8,388

K less memory than on the Windows 7 guest OS, while Virtual PC using the Linux Mint guest OS used approximately 7,622.67 K less memory than on the Windows 7 guest OS.

An overall evaluation of the results shows that on VMware Workstation, average memory usage of GIMP was approximately 25,698 K while on VirtualBox average memory usage of GIMP was approximately 25,791.565 K whereas on Virtual PC, average memory usage of GIMP was approximately 26,168.665 K. According to these findings VMware Workstation performed better than VirtualBox or Virtual PC.

Table 5.26: Experiment 9 - Memory usage of Thunderbird on guest operating systems

	Win 7 1st	**Win 7 2nd**	**Win 7 3rd**	**Mint 1st**	**Mint 2nd**	**Mint 3rd**
VMware Workstation	30,380 K	30,256 K	30,260 K	72.0 KiB (72 K) 19.8 MiB (20275.2 K) (20,347.2 K)	72.0 KiB (72 K) 19.8 MiB (20275.2 K) (20,347.2 K)	72.0 KiB (72 K) 19.8 MiB (20275.2 K) (20,347.2 K)
VirtualBox	30,068 K	30,068 K	30,068 K	76.0 KiB (76 K) 18.6 MiB (19046.4 K) (19,122.4 K)	76.0 KiB (76 K) 18.6 MiB (19046.4 K) (19,122.4 K)	76.0 KiB (76 K) 18.7 MiB (19148.8 K) (19,224.8 K)
Virtual PC	29,868 K	30,232 K	30,272 K	72.0 KiB (72 K) 20.8 MiB (21299.2 K) (21,371.2 K)	72.0 KiB (72 K) 20.6 MiB (21094.4 K) (21,166.4 K)	72.0 KiB (72 K) 19.6 MiB (20070.4 K) (20,142.4 K)

Table 5.27: Experiment 9 - Memory usage of Thunderbird on guest operating systems (average results)

	Win 7	**Mint**
VMware Workstation	30,299 K	20,347.2 K
VirtualBox	30,068 K	19,156.53 K
Virtual PC	30,124 K	20,893.33 K

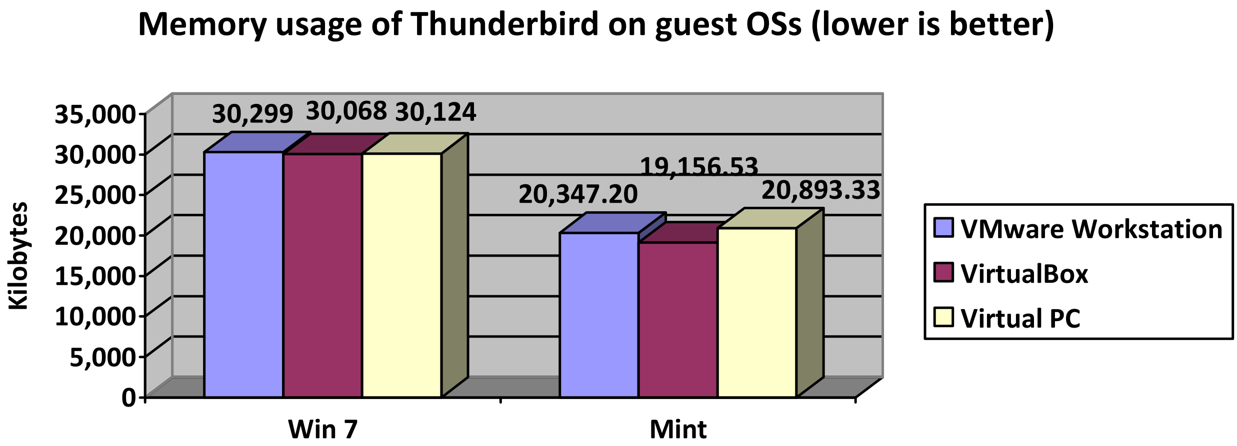

Figure 5.14: Experiment 9 - Memory usage of Thunderbird on guest operating systems

This part of Experiment 9 aimed to identify memory use while running an application known as Mozilla Thunderbird on the guest OSs. Thus, each guest OS Windows 7 and Linux Mint, was based on the three different virtual platforms, VMware Workstation, VirtualBox and Virtual PC. Memory usage of the Mozilla Thunderbird application was measured and the average results were calculated.

The results shown above indicate that Mozilla Thunderbird on VMware Workstation, VirtualBox and Virtual PC using the Windows 7 guest OS required more memory. The highest amount of memory usage was observed on VMware Workstation using the Windows 7 guest OS at approximately 30,299 K while Virtual PC using the Windows 7 guest OS performed closely, as it used approximately 30,124 K. The lowest amount of memory usage was observed on VirtualBox using the Linux Mint guest OS at approximately 19,156.53 K while the second lowest amount of memory usage was noticed on VMware Workstation using the Linux Mint guest OS at approximately 20,347.20 K.

A comparison between the two guest operating systems based on the three virtual platforms indicates that the Linux Mint guest OS based on all three virtual platforms, VMware Workstation, VirtualBox and Virtual PC performed much better than the Windows 7 guest OS. The difference between the Windows 7 guest OS and the Linux Mint guest OS on all three virtual platforms was more than 9,000 K.

A comparison among the three virtual platforms shows that Virtual PC using the Linux Mint guest OS used approximately 9,230.67 K less memory than on the Windows 7 guest OS based on Virtual PC. VMware Workstation using the Linux Mint guest OS used approximately 9,951.8 K less memory than on the Windows 7 guest OS, while VirtualBox using the Linux Mint guest OS used approximately 10,911.47 K less memory than on the Windows 7 guest OS.

An overall evaluation of the results shows that on VMware Workstation, average memory use of Mozilla Thunderbird was approximately 25,323.1 K while on VirtualBox average memory use of Mozilla Thunderbird was approximately 24,612.265 K whereas on Virtual PC average memory use of Mozilla Thunderbird was approximately 25,508.665 K. According to these findings VirtualBox performed better than VMware Workstation and Virtual PC.

Table 5.28: Experiment 9 - Memory usage of Pidgin on guest operating systems

	Win 7 1st	**Win 7 2nd**	**Win 7 3rd**	**Mint 1st**	**Mint 2nd**	**Mint 3rd**
VMware Workstation	11,128 K	11,208 K	11,156 K	10.0 MiB (10,240 K)	10.1 MiB (10,342.4 K)	10.1 MiB (10,342.4 K)
VirtualBox	9,364 K	9,556 K	9,388 K	9.5 MiB (9,728 K)	9.5 MiB (9,728 K)	9.5 MiB (9,728 K)
Virtual PC	10,092 K	9,536 K	9,548 K	10.0 MiB (10,240 K)	10.0 MiB (10,240 K)	10.0 MiB (10,240 K)

Table 5.29: Experiment 9: -Memory usage of Pidgin on guest operating systems (average results)

	Win 7	**Mint**
VMware Workstation	11,164 K	10,308.26 K
VirtualBox	9,436 K	9,728 K
Virtual PC	9,725 K	10,240 K

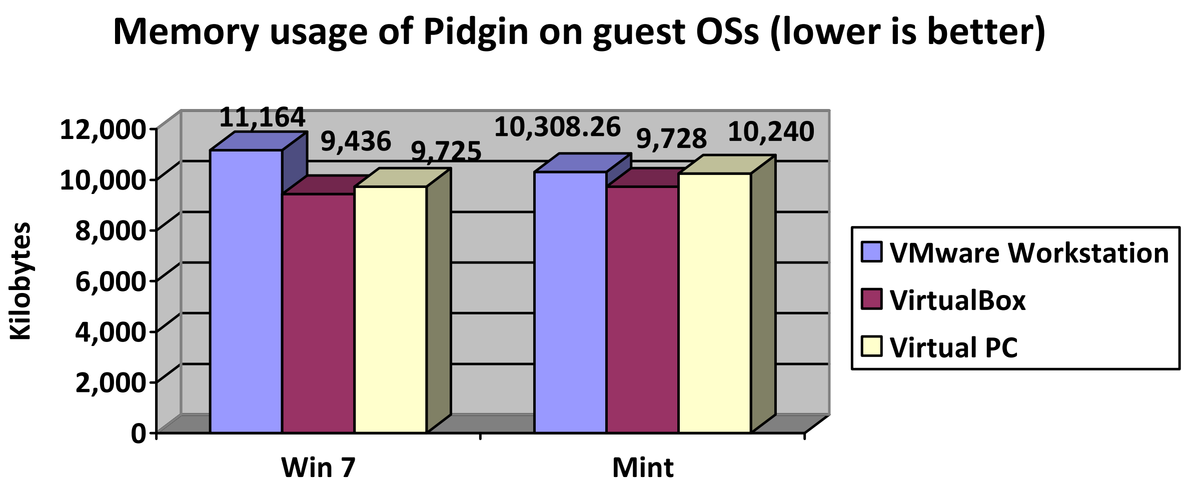

Figure 5.15: Experiment 9 - Memory usage of Pidgin on guest operating systems

This part of Experiment 9 aimed to identify memory usage while running an application known as Pidgin on the guest OSs. Thus, each guest OS, Windows 7 and Linux Mint, was based on the three different virtual platforms; VMware Workstation, VirtualBox and Virtual PC. Memory use of the Pidgin application was measured and the average results were calculated.

The results shown above indicate that Pidgin required different amounts of memory on each of the virtual platforms. The highest amount of memory usage was observed on VMware Workstation using the Windows 7 guest OS at approximately 11,164 K while VMware Workstation using the Linux Mint guest OS the memory usage was approximately 10,308.26 K. The least amount of memory usage was observed on VirtualBox using the Windows 7 guest OS at approximately 9,436 K while the second lowest amount of memory usage was seen on Virtual PC using the Windows 7 guest OS at approximately 9,725 K.

A comparison between the two guest operating systems based on the three virtual platforms indicates that each guest OS based on all three virtual platforms, VMware Workstation, VirtualBox and Virtual PC, performed differently. VMware Workstation using the Linux Mint guest OS performed much better than on the Windows 7 guest OS while the Windows 7 guest OS on Virtual PC and VirtualBox performed slightly better than the Linux Mint guest OS on Virtual PC and VirtualBox.

A comparison between the three virtual platforms revealed that VMware Workstation using the Linux Mint guest OS used approximately 855.74 K less memory than the Windows 7 guest OS based on VMware Workstation. While Virtual PC using the Windows 7 guest OS used approximately 515 K less memory than the Linux Mint guest OS. Moreover, the results for the VirtualBox platform revealed that VirtualBox using Windows 7 guest OS used approximately 292 K lesser memory than on the Linux Mint guest OS. Overall, VirtualBox performed much better than the other two virtual platforms, VMware Workstation and Virtual PC.

An overall evaluation of the results shows that on VMware Workstation average memory usage of Pidgin was approximately 10,736.13 K while on VirtualBox average memory usage of Pidgin was approximately 9,582 K whereas on Virtual PC average memory usage of Pidgin was approximately 9,982.5 K. According to these findings VirtualBox performed better than VMware Workstation and Virtual PC.

Analysis of Experiment 10: Guest operating systems log off time

Table 5.30: Experiment 10 - Guest operating systems log off time

	Win 7 1st	Win 7 2nd	Win 7 3rd	Mint 1st	Mint 2nd	Mint 3rd
Native	03.30 seconds	03.29 seconds	03.40 seconds	03.80 seconds	04.20 seconds	03.10 seconds
VMware Workstation	05.20 seconds	04.83 seconds	04.80 seconds	04.99 seconds	05.08 seconds	04.46 seconds
VirtualBox	05.04 seconds	04.47 seconds	04.45 seconds	04.90 seconds	04.93 seconds	04.90 seconds
Virtual PC	03.55 seconds	03.29 seconds	03.32 seconds	04.60 seconds	03.66 seconds	03.70 seconds

Table 5.31: Experiment 10 - Guest operating systems log off time (average results)

	Win 7	Mint
Native	03.33 seconds	03.70 seconds
VMware Workstation	04.94 seconds	04.84 seconds
VirtualBox	04.65 seconds	04.91 seconds
Virtual PC	03.38 seconds	03.98 seconds

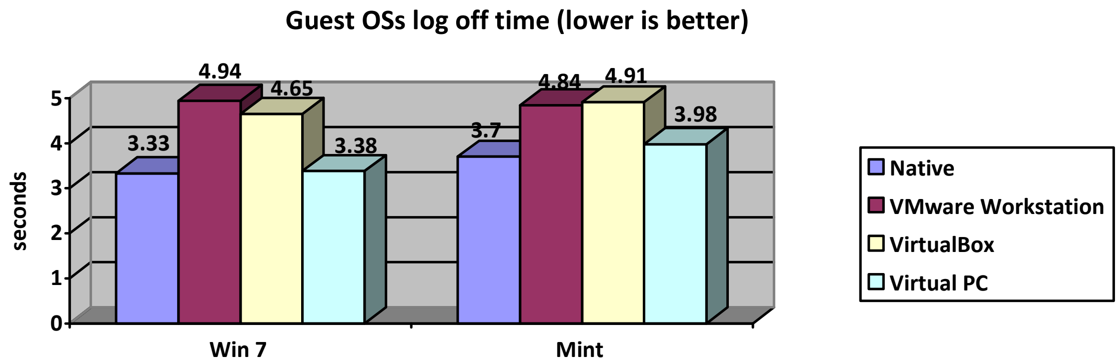

Figure 5.16: Experiment 10 - Guest operating systems log off time

Figure 5.16 presents the results for Experiment 10. This experiment focused on guest operating systems log off time. To measure guest operating system log off time two different guest operating systems were used, Windows 7 and Linux Mint. These two operating systems were installed on three virtual platforms; VMware Workstation, VirtualBox and Virtual PC. The graph above shows the time each guest operating system took to log off and their average results were observed and presented in seconds.

The longest amount of time was observed on VMware Workstation using Windows 7 at approximately 4.94 seconds, while the second longest amount of time was observed on VirtualBox using the Linux Mint guest OS at approximately 4.91 seconds. The least amount of time was noticed on Virtual PC using the

Windows 7 guest OS at approximately 3.38 seconds. The seconds shortest amount of time was observed on Virtual PC using the Linux Mint guest OS at approximately 3.98 seconds.

A comparison between the two guest operating systems showed that the Windows 7 guest operating system performed better than Linux Mint on Virtual PC and VirtualBox. However, Linux Mint on VMware Workstation performed better than the Windows 7 guest OS.

A comparison between the three virtual platforms showed that Virtual PC took the least amount of time to log off compared with the other two virtual platforms, VMware Workstation and VirtualBox. Virtual PC using the Windows 7 guest OS took 0.6 second less time to log off than the Linux Mint guest OS while VirtualBox using Windows 7 guest OS took 0.26 second less time to log off than the Linux Mint guest OS. However, VMware Workstation using the Linux Mint guest OS took 0.1 second less time to log off than the Windows 7 guest OS.

An overall evaluation of the results shows that on VMware Workstation the average log off time of guest OSs was approximately 4.89 seconds while on VirtualBox the average log off time of guest OSs was approximately 4.78 seconds whereas on Virtual PC the average log off time of guest OSs was approximately 3.68 seconds. According to these findings Virtual PC performed better than VMware Workstation and VirtualBox.

Analysis of Experiment 11: Guest operating systems' log on time

Table 5.32: Experiment 11 - Guest operating systems' log on time

	Win 7 1st	**Win 7 2nd**	**Win 7 3rd**	**Mint 1st**	**Mint 2nd**	**Mint 3rd**
Native	02.10 seconds	02.28 seconds	02.05 seconds	06.40 seconds	06.24 seconds	06.35 seconds
VMware Workstation	06.44 seconds	05.40 seconds	05.98 seconds	08.96 seconds	08.90 seconds	08.72 seconds
VirtualBox	03.46 seconds	02.93 seconds	02.80 seconds	11.46 seconds	10.80 seconds	10.94 seconds
Virtual PC	02.84 seconds	02.70 seconds	02.75 seconds	12.50 seconds	11.28 seconds	11.29 seconds

Table 5.33: Experiment 11 - Guest operating systems' log on time (average results)

	Win 7	**Mint**
Native	02.14 seconds	06.33 seconds
VMware Workstation	05.94 seconds	08.86 seconds
VirtualBox	03.06 seconds	11.06 seconds
Virtual PC	02.76 seconds	11.69 seconds

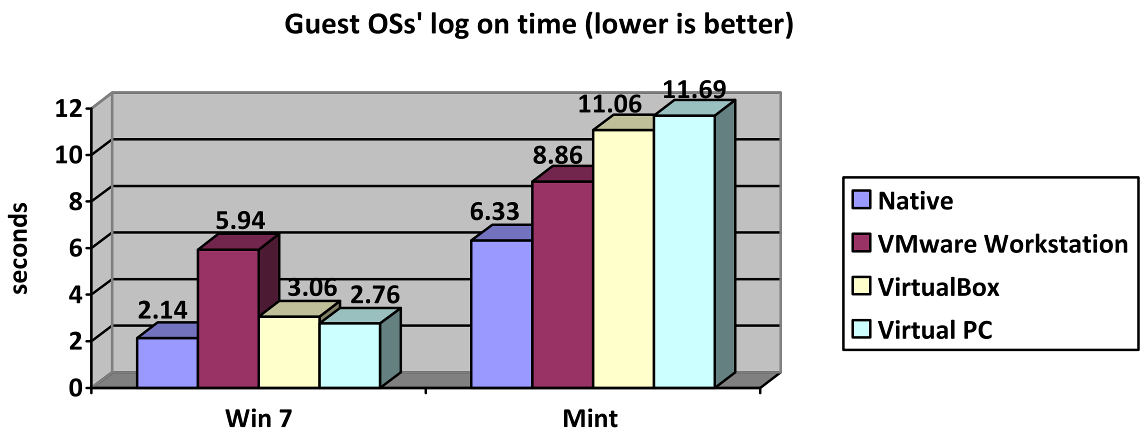

Figure 5.17: Experiment 11 - Guest operating systems, log on time

Figure 5.17 presents the results for Experiment 11which focused on guest operating systems, log on time. To measure guest operating system log on time, two different guest operating systems were used, Microsoft Windows 7 and Linux Mint. These two operating systems were installed on the three virtual platforms; VMware Workstation, VirtualBox and Virtual PC. The graph above shows the time each guest operating system took to log on and their average results were noted and presented in seconds.

The highest amount of time was observed on Virtual PC using the Linux Mint guest OS at approximately 11.69 seconds, whereas the second highest amount of time was observed on VirtualBox on the Linux Mint guest OS at approximately 11.06 seconds. The shortest amount of time was observed on Virtual PC using the Windows 7 guest OS at approximately 2.76 seconds. The second shortest amount of time was observed on VirtualBox using the Windows 7 guest OS at approximately 3.06 seconds.

A comparison between the two guest operating systems shows that the Windows 7 guest operating system performed much better than Linux Mint on all three virtual platforms (VMware Workstation, VirtualBox and Virtual PC). The difference between the Windows 7 guest OS and the Linux Mint guest OS on VMware was more than 2 seconds while Virtual PC and VirtualBox had more than 7 seconds, difference between both guest operating systems (Windows 7 & Linux Mint).

A comparison between the three virtual platforms indicates that VMware Workstation had a more stable performance on both guest OSs. VMware Workstation using the Windows 7 guest OS took 2.92 seconds less time to log on compared to VMware Workstation using the Linux Mint guest OS. While Virtual PC using Windows 7 guest OS took 8.93 seconds less time to log on compared to using the Linux Mint guest OS. VirtualBox using the Windows 7 guest OS took 8.0 seconds less to log on compared to VirtualBox using the Linux Mint guest OS. Overall Virtual PC had the best performance using the Windows 7 guest OS.

A comparison among the three virtual platforms indicated that VMware Workstation had a stable performance on both guest operating systems. VMware Workstation using the Windows 7 guest OS took 2.92 seconds less time to log on compare to VMware Workstation using Linux Mint. While Virtual PC using Windows 7 guest OS took 8.93 seconds lesser time to log on compare to Virtual PC using Linux Mint guest OS. VirtualBox using Windows 7 guest OS took 8.0 seconds lesser time to log on compare to VirtualBox using Linux Mint guest OS. Overall, Virtual PC had the best performance using Windows 7 guest OS.

An overall evaluation of the results shows that on VMware Workstation the average log on time of the guest operating systems was approximately 7.40 seconds while on VirtualBox the average log on time of the guest operating systems was approximately 7.06 seconds whereas on Virtual PC the average log on time of the guest operating systems was approximately 7.222 seconds. According to these findings VirtualBox performed better than VMware Workstation or Virtual PC.

Analysis of Experiment 12: Guest operating systems' switch user time

Table 5.34 - Experiment 12 - Guest operating systems' switch user time

	Win 7 1st	**Win 7 2nd**	**Win 7 3rd**	**Mint 1st**	**Mint 2nd**	**Mint 3rd**
Native	03.30 seconds	03.35 seconds	03.20 seconds	04.80 seconds	04.85 seconds	04.65 seconds
VMware Workstation	03.34 seconds	03.04 seconds	03.93 seconds	08.10 seconds	07.80 seconds	07.76 seconds
VirtualBox	04.60 seconds	04.43 seconds	04.76 seconds	06.05 seconds	06.27 seconds	06.99 seconds
Virtual PC	03.49 seconds	03.30 seconds	03.78 seconds	04.84 seconds	05.01 seconds	04.76 seconds

Table 5.35 - Experiment 12 - Guest operating systems' switch user time (average results)

	Win 7	**Mint**
Native	03.28 seconds	04.76 seconds
VMware Workstation	03.43 seconds	07.88 seconds
VirtualBox	04.59 seconds	06.43 seconds
Virtual PC	03.52 seconds	04.87 seconds

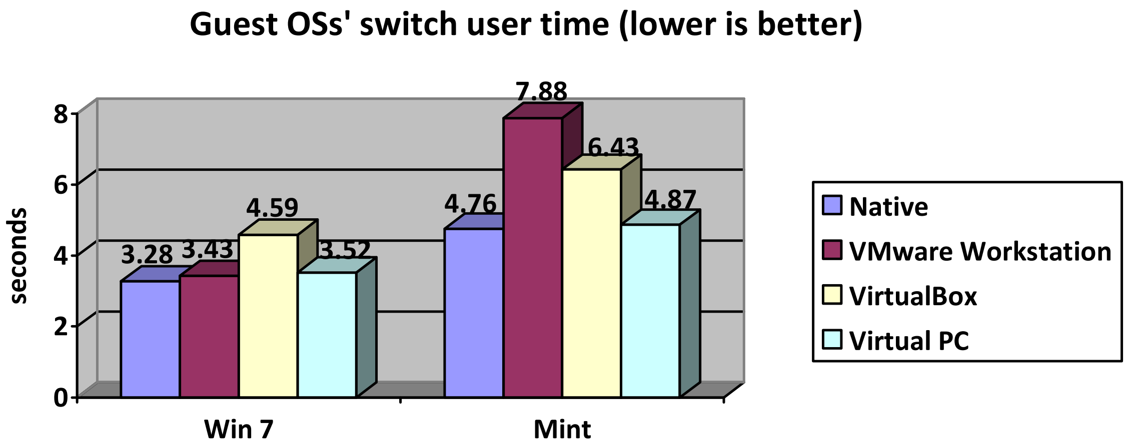

Figure 5.18 - Experiment 12 - Guest operating systems, switch user time

Figure 5.18 presents the results for the Experiment 12 which focused on guest operating systems' "switch user" time. To measure the guest operating system "switch user" duration, two different guest operating systems were used, Windows 7 and Linux Mint. These two operating systems were installed on the three virtual platforms; VMware Workstation, VirtualBox and Virtual PC. The graph above shows the time each guest operating system took to "switch user" and their average results were obtained and presented in seconds.

The lowest amount of time was observed on VMware Workstation using the Windows 7 guest OS at approximately 3.43 seconds, while the second lowest amount of time was observed on Virtual PC using the Windows 7 guest OS at approximately 3.52 seconds. The highest amount of time was observed on VMware Workstation using the Linux Mint guest OS at approximately 7.88 seconds, while the second highest amount of time was observed on VirtualBox using the Linux Mint guest OS at approximately 6.43 seconds.

A comparison between the two guest operating systems indicated that the Windows 7 guest OS performed much better than the Linux Mint guest operating system on all three virtual platforms (VMware Workstation, VirtualBox and Virtual PC). The smallest time difference between the Windows 7 guest OS and the Linux Mint guest OS was observed on Virtual PC at approximately 1.35 seconds. The second lowest time difference between the Windows 7 guest OS and the Linux Mint guest OS was seen on VirtualBox at approximately 1.84 seconds, whereas VMware Workstation had more than 4 seconds difference between both the Windows 7 and Linux Mint guest OSs.

Comparison of the three virtual platforms indicates that VMware Workstation using Windows 7 guest OS took 4.45 seconds less time to "switch user" compared to Linux Mint guest OS. Virtual PC using the

Windows 7 guest OS took 1.35 seconds less time to "switch user" compared to the Linux Mint guest OS. VirtualBox using the Windows 7 guest OS took 1.84 seconds less time to "switch user" compared to the Linux Mint guest OS. Overall, VMware Workstation had the best performance using the Windows 7 guest OS.

An overall evaluation of the results shows that on VMware Workstation the average "switch user" time on the guest OSs took approximately 5.655 seconds while on VirtualBox the average "switch user" time on the guest OSs took approximately 5.51 seconds whereas on Virtual PC the average "switch user" time on the guest OSs took approximately 4.195 seconds. According to these findings Virtual PC performed better than VMware Workstation or VirtualBox.

Analysis of Experiment 13: Time for a guest operating system to go to a sleep state

Table 5.36: Experiment 13 – Time for a guest operating system to go to a sleep state

	Win 7 1st	**Win 7 2nd**	**Win 7 3rd**	**Mint 1st**	**Mint 2nd**	**Mint 3rd**
Native	09.35 seconds	09.30 seconds	09.35 seconds	05.20 seconds	05.05 seconds	05.20 seconds
VMware Workstation	10.44 seconds	10.35 seconds	10.40 seconds	06.24 seconds	06.30 seconds	06.45 seconds
VirtualBox	n/a	n/a	n/a	n/a	n/a	n/a
Virtual PC	n/a	n/a	n/a	n/a	n/a	n/a

Table 5.37: Experiment 13 – Time for a guest operating system to go to a sleep state (average results)

	Win 7	**Mint**
Native	09.33 seconds	05.15 seconds
VMware Workstation	10.39 seconds	6.33 seconds
VirtualBox	n/a	n/a
Virtual PC	n/a	n/a

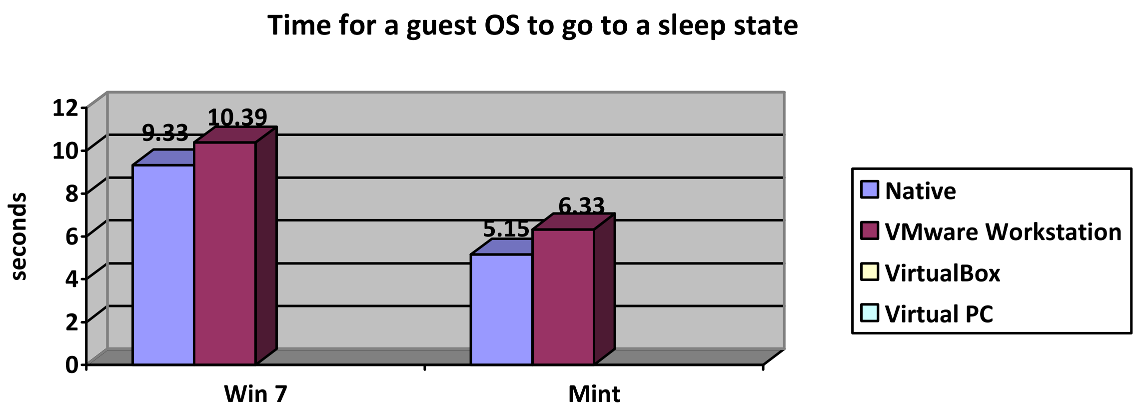

Figure 5.19: Experiment 13 – Time for a guest operating system to go to a sleep state

Figure 5.19 shows the results for Experiment 13. This experiment measured the amount of time a guest OSs took to go to a "sleep" state. For this experiment Windows 7 and Linux Mint were installed on VMware Workstation, VirtualBox and Virtual PC. The graph above shows the time each guest OS took on VMware Workstation, VirtualBox and Virtual PC to go to a "sleep" state.

Unfortunately the "sleep" feature was not available on the guest OSs based on VirtualBox and Virtual PC. Thus the tests were only performed on VMware Workstation using the Windows 7 and Linux Mint guest OSs. Evaluation of VMware Workstation using Windows 7 and Linux Mint guest OSs indicated that lowest amount of time was observed on VMware Workstation using the Linux Mint guest OS at approximately 6.33 seconds. The amount of time observed of VMware Workstation using the Windows 7 guest OS was approximately 10.39 seconds. A comparison on VMware Workstation using both Windows 7 and Linux Mint guest OSs shows that VMware Workstation using the Linux Mint guest OS took approximately 4.06 seconds less to go to a "sleep" state compared to the Windows 7 guest OS.

An overall comparison of the results shows that the average time for the guest OS to go to a "sleep" state on VMware Workstation is approximately 8.36 seconds.

Analysis of Experiment 14: Time for a guest operating system to recover from a sleep state

Table 5.38: Experiment 14 – Time for a guest operating system to recover from a sleep state

	Win 7 1st	**Win 7 2nd**	**Win 3rd**	**Mint 1st**	**Mint 2nd**	**Mint 3rd**
Native	16.45 seconds	16.40 seconds	16.46 seconds	10.20 seconds	10.25 seconds	10.26 seconds
VMware Workstation	18.65 seconds	18.30 seconds	17.58 seconds	12.88 seconds	12.45 seconds	12.92 seconds
VirtualBox	n/a	n/a	n/a	n/a	n/a	n/a
Virtual PC	n/a	n/a	n/a	n/a	n/a	n/a

Table 5.39: Experiment 14 – Time for a guest operating system to recover from a sleep state (average results)

	Win 7	**Mint**
Native	16.43 seconds	10.23 seconds
VMware Workstation	18.17 seconds	12.75 seconds
VirtualBox	n/a	n/a
Virtual PC	n/a	n/a

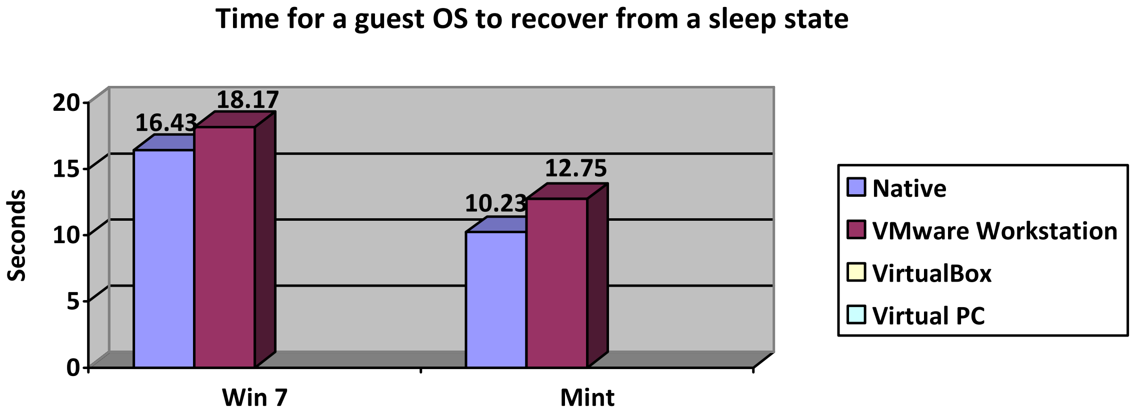

Figure 5.20: Experiment 14 – Time for a guest operating system to recover from a sleep state

Figure 5.20 shows the results for Experiment 14. This experiment measured the time a guest OS took to recover from a "sleep" state. For this experiment Windows 7 and Linux Mint were installed on VMware Workstation, VirtualBox and Virtual PC. The graph above shows the time each guest OS took on VMware Workstation, VirtualBox and Virtual PC to recover from a "sleep" state.

Unfortunately the sleep feature was not available on guest OSs based on VirtualBox and Virtual PC. Thus the tests were only performed on VMware Workstation using Windows 7 and Linux Mint guest OSs. An evaluation on VMware Workstation using the Windows 7 and Linux Mint guest OSs indicated that the lowest amount of time was observed on the Linux Mint guest OS at approximately 12.75 seconds. VMware Workstation using Windows 7 took approximately 18.17 seconds. A comparison of VMware Workstation using both Windows 7 and Linux Mint guest OSs showed that VMware Workstation using the Linux Mint guest OS took 5.42 seconds less time to recover from the sleep state compared to the Windows 7 guest OS.

An overall comparison of the results show that the average time to recover from the "sleep" state on VMware Workstation is approximately 15.46 seconds.

Analysis of Experiment 15: Time for a guest operating system to go into a state of hibernation

Table 5.40: Experiment 15 – Time for a guest operating system to go into a state of hibernation

	Win 7 1st	**Win 7 2nd**	**Win 7 3rd**	**Mint 1st**	**Mint 2nd**	**Mint 3rd**
Native	19.30 seconds	19.35 seconds	19.38 seconds	29.22 seconds	29.25 seconds	29.30 seconds
VMware Workstation	21.37 seconds	20.75 seconds	21.56 seconds	30.33 seconds	30.30 seconds	30.48 seconds
VirtualBox	n/a	n/a	n/a	n/a	n/a	n/a
Virtual PC	n/a	n/a	n/a	n/a	n/a	n/a

Table 5.41: Experiment 15 – Time for a guest operating system to go into a state of hibernation (average results)

	Win 7	Mint
Native	19.34 seconds	29.25 seconds
VMware Workstation	21.22 seconds	30.37 seconds
VirtualBox	n/a	n/a
Virtual PC	n/a	n/a

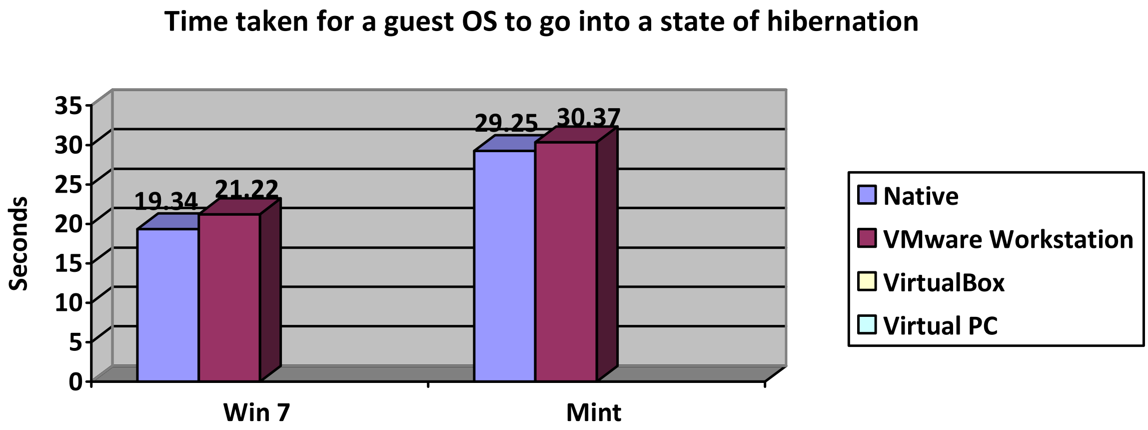

Figure 5.21: Experiment 15 – Time taken for a guest operating system to go into a state of hibernation

Figure 5.21 shows the results for the Experiment 15 which focused on the period of time it took for a guest OS to go into a "hibernate" state. To test the time taken for a guest OS to go into a "hibernate" state, Windows 7 and Linux Mint were used. Windows 7 and Linux Mint were installed on VMware Workstation, VirtualBox and Virtual PC. The graph above shows the time each guest OS took to go into a "hibernate" state and their average results were obtained and presented in seconds.

Unfortunately the "hibernate" feature for OSs was not available on VirtualBox and Virtual PC. Thus the tests were only performed on VMware Workstation using Windows 7 and Linux Mint guest OSs. An evaluation on VMware Workstation using Windows 7 and Linux Mint guest OSs indicated that the shortest amount of time was observed on VMware Workstation using Windows 7 at approximately 21.22 seconds; while the amount of time VMware Workstation took using the Linux Mint guest OS was approximately 30.37 seconds. A comparison of VMware Workstation using both Windows 7 and Linux Mint guest OSs shows that VMware Workstation using the Windows 7 guest OS took 9.15 seconds less than on the Linux Mint guest OS.

An overall comparison of the results shows that the average time for the OS to go into a "hibernate" state on VMware Workstation is approximately 25.795 seconds.

Analysis of Experiment 16: Time taken for a guest operating system to recover from a state of hibernation

Table 5.42: Experiment 16 – Time taken for a guest operating system to recover from a state of hibernation

	Win 7 1st	Win 7 2nd	Win 7 3rd	Mint 1st	Mint 2nd	Mint 3rd
Native	14.24 seconds	14.25 seconds	14.25 seconds	19.65 seconds	19.61 seconds	19.75 seconds
VMware Workstation	15.57 seconds	15.49 seconds	14.80 seconds	22.70 seconds	22.30 seconds	23.28 seconds
VirtualBox	n/a	n/a	n/a	n/a	n/a	n/a
Virtual PC	n/a	n/a	n/a	n/a	n/a	n/a

Table 5.43: Experiment 16 - Time taken for a guest operating system to recover from a state of hibernation (average results)

	Win 7	Mint
Native	14.24 Seconds	19.67 Seconds
VMware Workstation	15.28 Seconds	22.76 Seconds
VirtualBox	n/a	n/a
Virtual PC	n/a	n/a

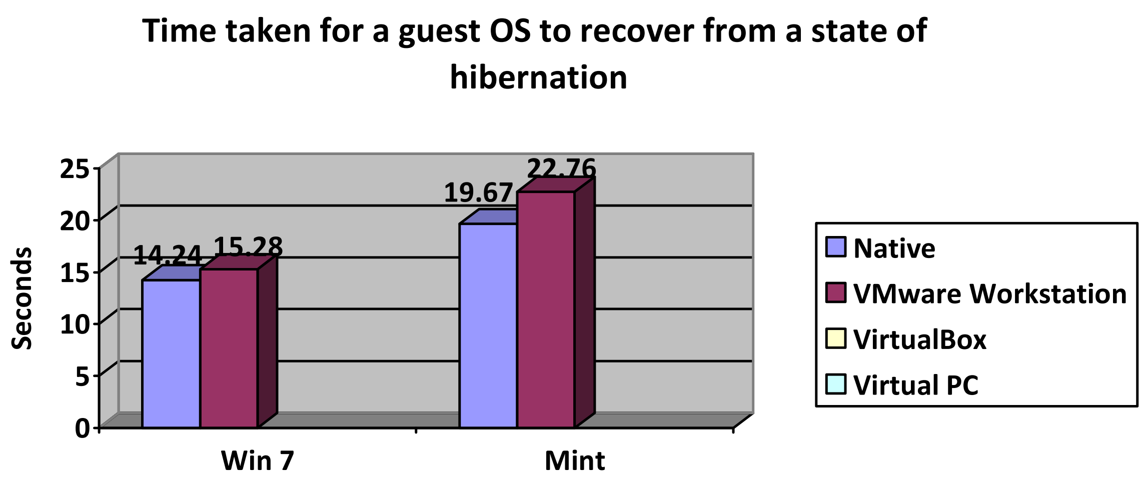

Figure 5.22: Experiment 16 - Duration of guest operating systems recovers from a hibernate state

Figure 5.22 shows the results for Experiment 16. This experiment focused on the time taken for a guest OSs to recover from a "hibernate" state. To test the time for a guest OS to recover from a "hibernate" state, Windows 7 and Linux Mint were used. Windows 7 and Linux Mint OSs were installed on the three virtual platforms; VMware Workstation, VirtualBox and Virtual PC. The graph above shows the time each guest OS took to recover from a "hibernate" state and their average results were obtained and presented in seconds.

There are no results for VirtualBox or Virtual PC. The "hibernate" feature was not available on guest OSs on VirtualBox and Virtual PC. Thus the tests were only performed on VMware Workstation using the Windows 7 and Linux Mint guest OSs.

A comparison of VMware Workstation using Windows 7 and Linux Mint guest OSs indicated that the least amount of time taken to recover from a "hibernate" state was observed on VMware Workstation using the Windows 7 guest OS at approximately 15.28 seconds. The longest amount of time to recover from a "hibernate" state was observed on VMware Workstation using the Linux Mint guest OS at approximately 22.76 seconds.

A comparison of VMware Workstation using Windows 7 and Linux Mint guest OSs show that to recover from a "hibernate" state using the Windows 7 guest OS took approximately 7.48 seconds less time than when using the Linux Mint guest OS.

An overall comparison of the results show that the average time taken to recover from the "hibernate" state on VMware Workstation was approximately 19.02 seconds.

Analysis of Experiment 17: Time taken to unpack a compressed file on guest operating systems

Table 5.44: Experiment 17 – Time taken to unpack a compressed file on guest operating systems

	Win 7 1st	**Win 7 2nd**	**Win 7 3rd**	**Mint 1st**	**Mint 2nd**	**Mint 3rd**
Native	35 seconds	36 seconds	35 seconds	46 seconds	48 seconds	45 seconds
VMware Workstation	61 seconds	49 seconds	50 seconds	75 seconds	61 seconds	61 seconds
VirtualBox	51 seconds	49 seconds	49 seconds	56 seconds	56 seconds	56 seconds
Virtual PC	48 seconds	47 seconds	47 seconds	64 seconds	64 seconds	64 seconds

Table 5.45: Experiment 17 – Time taken to unpack a compressed file on guest operating systems (average results)

	Win 7	**Mint**
Native	35.33 seconds	46.33 seconds
VMware Workstation	53.33 seconds	65.66 seconds
VirtualBox	49.66 seconds	56 seconds
Virtual PC	47.33 seconds	64 seconds

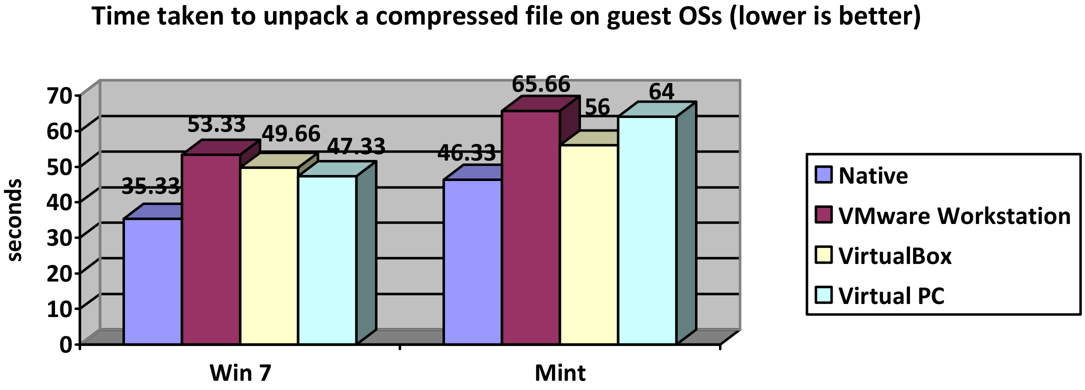

Figure 5.23: Experiment 17: Time taken to unpack a compressed file on guest operating systems

Figure 5.23 shows the results for Experiment 17 which focused on discovering the time it takes to unpack a compressed file based on the different virtualization programs; VMware Workstation, VirtualBox and Virtual PC. To test unpacking time a compressed file, two different guest operating systems, Windows 7 and Linux Mint, were used. Windows 7 and Linux Mint OSs were used on the three different virtualization programs; VMware Workstation, VirtualBox and Virtual PC. The graph above shows the time the unpacking procedure took on each virtualization program and their average results were obtained and presented in seconds.

An evaluation of VMware Workstation, VirtualBox and Virtual PC indicated that the shortest amount of time was observed on Virtual PC using the Windows 7 guest OS, at approximately 47.33 seconds, while the highest amount of time was observed on VMware Workstation using the Linux Mint guest OS, at approximately 65.66 seconds. A comparison of the two virtualization programs, VMware Workstation and Virtual PC shows that unpacking the compressed file on Virtual PC using the Windows 7 guest OS took 18.33 seconds less compared with VMware Workstation using the Linux Mint guest OS.

The second shortest amount of time was observed on VirtualBox using the Windows 7 guest OS at approximately 49.66 seconds and the second highest amount of time was observed on Virtual PC using the Linux Mint guest OS at approximately 64 seconds. A comparison between the two virtualization programs, VirtualBox and Virtual PC, shows that unpacking a compressed file on VirtualBox using the Windows 7 guest OS took 14.34 seconds less time compared to Virtual PC using the Linux Mint guest OS.

The third lowest time taken was observed on VMware Workstation using the Windows 7 guest OS at approximately 53.33 seconds and the third highest amount of time was observed on VirtualBox using the Linux Mint guest OS, at approximately 56 seconds. A comparison between VMware Workstation and

VirtualBox shows that unpacking the compressed file on the VMware Workstation using the Windows 7 guest OS took 2.67 seconds less time compared to VirtualBox using the Linux Mint guest OS.

A comparison between the two guest operating systems indicated that the Windows 7 guest OS performed much better than the Linux Mint guest operating system on all three virtualization (VMware Workstation, VirtualBox and Virtual PC).

A comparison between the three virtualization programs VMware Workstation, VirtualBox and Virtual PC shows that Virtual PC took the least amount of time to unpack the compressed file compared to the other two virtual platforms, VMware Workstation and VirtualBox. Virtual PC using the Windows 7 guest OS took 16.67 second less time to unpack compared with the Linux Mint guest OS while VirtualBox using the Windows 7 guest OS took 6.34 second less time decompress the file than on the Linux Mint guest OS. However, VMware Workstation, using the Windows 7 guest OS, took 12.33 second less time to unpack the compressed file compared to the Linux Mint guest OS.

An overall comparison of the results shows that the average time on VMware Workstation using Windows 7 and Linux Mint guest OSs, to unpack the compressed file is approximately 59.495 seconds while the average time on VirtualBox using Windows 7 and Linux Mint guest OSs to unpack the compressed file is approximately 52.83 seconds, whereas the average time on Virtual PC using the Windows 7 and Linux Mint guest OSs to unpack the compressed file is approximately 55.665 seconds. According to these findings the VirtualBox performed better than the other two virtualization programs.

Analysis of Experiment 18: Drive/HDD write speed on guest operating systems

Table 5.46: Experiment 18 - Drive/HDD write speed on guest operating systems

	Win 7 1st	**Win 7 2nd**	**Win 7 3rd**
Native	70 MB/Second	68 MB/Second	62 MB/Second
VMware Workstation	53 MB/Second	38 MB/Second	33 MB/Second
VirtualBox	44 MB/Second	43 MB/Second	41 MB/Second
Virtual PC	66 MB/Second	57 MB/Second	54 MB/Second

Table 5.47: Experiment 18 - Drive/HDD write speed on guest operating systems (average results)

	Win 7
Native	66.66 MB/Second
VMware Workstation	41.33 MB/Second
VirtualBox	42.66 MB/Second
Virtual PC	59 MB/Second

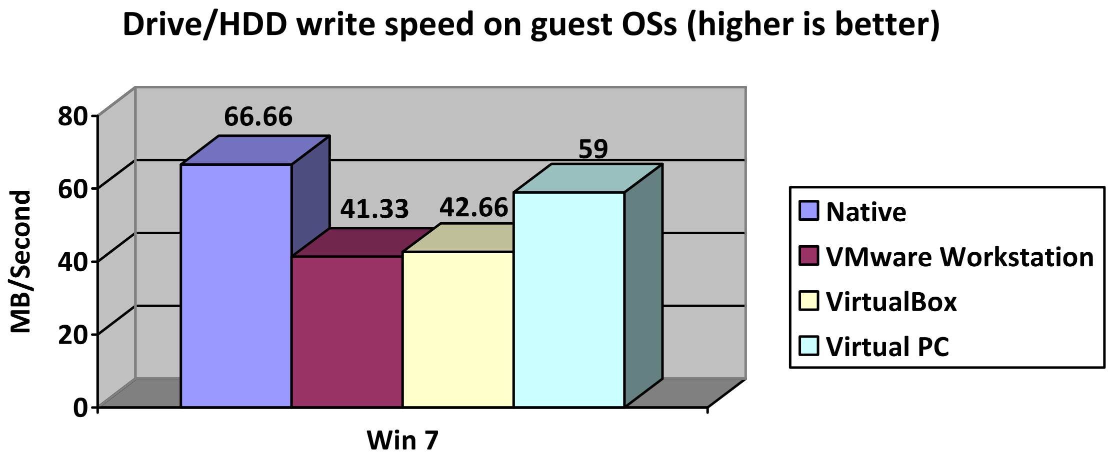

Figure 5.24: Experiment 18 - Drive/HDD write speed on guest operating systems

Figure 5.24 presents the results for Experiment 18. This experiment focused on the drive write speed on the guest operating systems. To measure the drive write speed on the guest operating systems, Windows 7 was used as the guest operating system. Windows 7 was installed on the three different virtualization platforms, VMware Workstation, VirtualBox and Virtual PC. The graph above shows the drive write speed on the guest operating system and their average results were noted and presented in MB/Second.

The best write speed was observed on Virtual PC at approximately 59 MB/Second, while the second best write speed was on VirtualBox at approximately 42.66 MB/Second. The worst write speed was observed on VMware Workstation at approximately 41.33 MB/Second.

A comparison among the three virtual platforms showed that Virtual PC performed better than the other two virtualization platforms, VMware Workstation and VirtualBox. The results show that Virtual PC performed better than VirtualBox and VMware Workstation by 16.34 MB/Second and 17.67 MB/Second respectively. VirtualBox performed better than VMware Workstation by 1.33 MB/Second.

Analysis of Experiment 19: CPU - Floating Point Operations on guest operating systems

Table 5.48: Experiment 19 - Floating Point Operations on guest operating systems

	Win 7 1st	**Win 7 2nd**	**Win 7 3rd**
Native	26698896 Floating Point Operations/Second	26687987 Floating Point Operations/Second	26694964 Floating Point Operations/Second
VMware Workstation	25535669 Floating Point Operations/Second	25521826 Floating Point Operations/Second	25544186 Floating Point Operations/Second
VirtualBox	25542419 Floating Point	25523575 Floating Point	25517684 Floating Point

	Operations/Second	Operations/Second	Operations/Second
Virtual PC	25530807 Floating Point Operations/Second	6600308 Floating Point Operations/Second	14031257 Floating Point Operations/Second

Table 5.49: Experiment 19 - Floating Point Operations on guest operating systems (average results)

	Win 7
Native	26693949 Floating Point Operations/Second
VMware Workstation	25533894 Floating Point Operations/Second
VirtualBox	25527893 Floating Point Operations/Second
Virtual PC	15387457 Floating Point Operations/Second

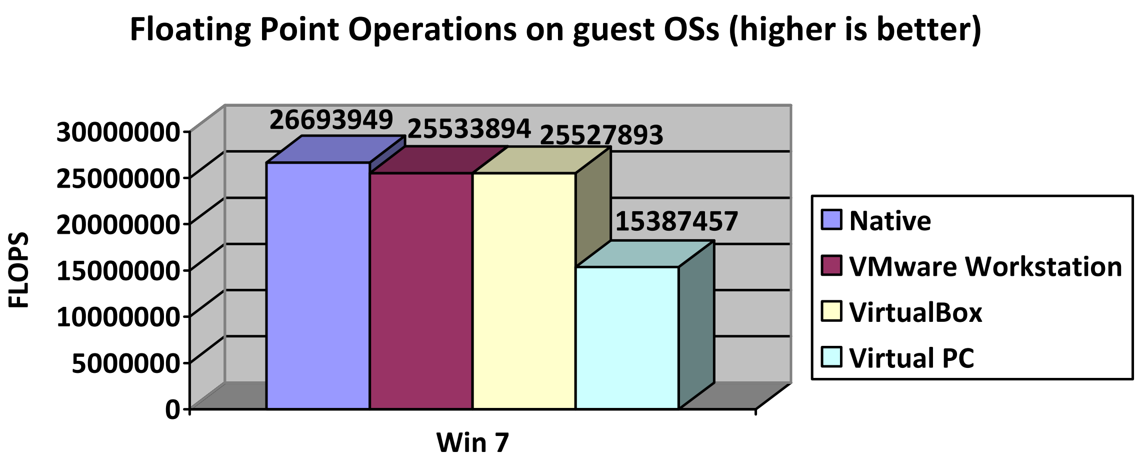

Figure 5.25: Experiment 19 - Floating Point Operations on guest operating systems

Figure 5.25 presents the results for Experiment 19. This experiment focused on CPU floating point operations on the guest operating system. To measure the CPU floating point operations Windows 7 was used as the guest operating system. Windows 7 was installed on the three different virtual platforms; VMware Workstation, VirtualBox and Virtual PC. The graph above shows the CPU floating point operations on the guest operating system and their average results were noted and presented in Floating Point Operations/Second.

The highest number of floating point operations were observed on VMware Workstation at approximately 25,533,894 Floating Point Operations/Second, while the second highest number of floating point operations were observed on VirtualBox at approximately 25,527,893 Floating Point Operations/Second.

The he lowest number of floating point operations were observed on Virtual PC at approximately 15,387,457 Floating Point Operations/Second.

A comparison between the three virtualization platforms showed that VMware Workstation outperformed better the other two virtualization platforms, VirtualBox and Virtual PC. The results showed that VMware Workstation performed better than VirtualBox and Virtual PC by 6001 Floating Point Operations/Second and 10,146,437 Floating Point Operations/Second respectively. VirtualBox performed better than Virtual PC by 10,140,436 Floating Point Operations/Second.

Analysis of Experiment 20: CPU - Integer Operations on guest operating systems

Table 5.50: Experiment 20 - Integer Operations on guest operating systems

	Win 7 1st	**Win 7 2nd**	**Win 7 3rd**
Native	99,989,897 Integer Operations/Second	98,846,867 Integer Operations/Second	99,289,929 Integer Operations/Second
VMware Workstation	84,199,715 Integer Operations/Second	83,783,935 Integer Operations/Second	84,459,794 Integer Operations/Second
VirtualBox	83,109,965 Integer Operations/Second	83,666,738 Integer Operations/Second	81,240,818 Integer Operations/Second
Virtual PC	81,404,476 Integer Operations/Second	55,069,424 Integer Operations/Second	79,154,399 Integer Operations/Second

Table 5.51: Experiment 20 - Integer Operations on guest operating systems (average results)

	Win 7
Native	99,375,564.33 Integer Operations/Second
VMware Workstation	84,147,815 Integer Operations/Second
VirtualBox	82,672,507 Integer Operations/Second
Virtual PC	71,876,100 Integer Operations/Second

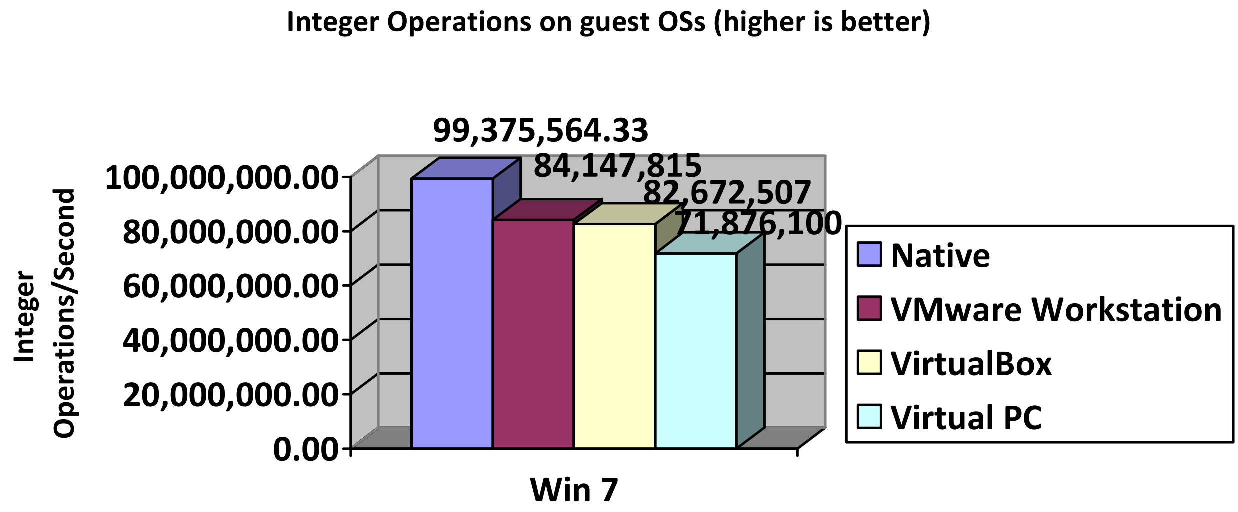

Figure 5.26: Experiment 20 - Integer Operations on guest operating systems

Figure 5.26 presents the results for Experiment 20. This experiment focused on CPU integer operations on the guest operating system. To measure the CPU integer operations on the guest operating systems, Windows 7 was used. Windows 7 was installed on the three different virtual platforms such as VMware Workstation, VirtualBox and Virtual PC. The graph above shows the CPU integer operations on the guest operating system and their average results were noted and presented in Integer Operations/Second.

The highest numbers of integer operations were observed on VMware Workstation at approximately 84,147,815 Integer Operations/Second, while the second highest numbers of integer operations were observed on VirtualBox at approximately 82,672,507 Integer Operations/Second. The lowest numbers of integer operations were observed on Virtual PC at approximately 71,876,100 Integer Operations/Second.

A comparison between the three virtual platforms showed that VMware Workstation performed better than the other two virtualization platforms. Results show that VMware Workstation performed better than VirtualBox and Virtual PC by 1,475.308 Integer Operations/Second and 12,271,715 Integer Operations/Second respectively. VirtualBox performed better than Virtual PC by 10,796,407 Integer Operations/Second.

Analysis of Experiment 21: CPU - MD5 Hashing on guest operating systems

Table 5.52: Experiment 21- MD5 Hashing on guest operating systems

	Win 7 1st	Win 7 2nd	Win 7 3rd
Native	998,126 MD5 Hashes Generated/Second	994,324 MD5 Hashes Generated/Second	999,740 MD5 Hashes Generated/Second
VMware Workstation	957,025 MD5 Hashes Generated/Second	945,246 MD5 Hashes Generated/Second	936,964 MD5 Hashes Generated/Second
VirtualBox	825,068 MD5 Hashes Generated/Second	835,633 MD5 Hashes Generated/Second	845,561 MD5 Hashes Generated/Second
Virtual PC	893,405 MD5 Hashes Generated/Second	315,284 MD5 Hashes Generated/Second	857,468 MD5 Hashes Generated/Second

Table 5.53: Experiment 21 - MD5 Hashing on guest operating systems (average results)

	Win 7
Native	997,396.66 MD5 Hashes Generated/Second
VMware Workstation	946,411.7 MD5 Hashes Generated/Second
VirtualBox	835,420.7 MD5 Hashes Generated/Second
Virtual PC	688,719 MD5 Hashes Generated/Second

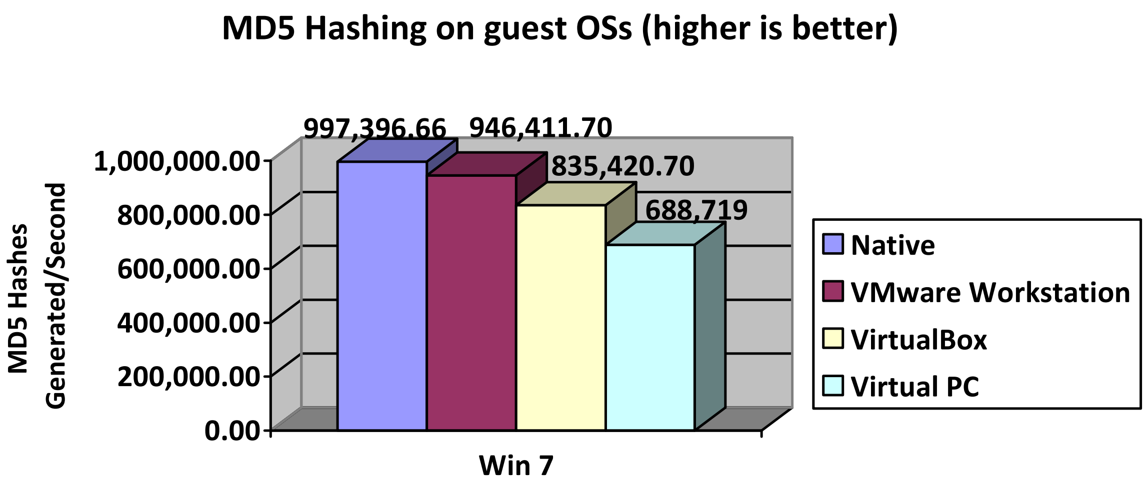

Figure 5.27: Experiment 21 - MD5 Hashing on guest operating systems

Figure 5.27 presents the results for Experiment 21. This experiment focused on the MD5 hashing rate on the guest operating system. To measure this, Windows 7 was used as the guest operating system. Windows 7 was installed on the three different virtualization platforms; VMware Workstation, VirtualBox and Virtual PC. The graph above shows the number of MD5 hashes generated on the guest operating system and the average results were noted and presented as MD5 Hashes Generated/Second.

The highest number MD5 hashes generated was observed on VMware Workstation at approximately 946,411.7 MD5 Hashes Generated/Second, while the second highest number of MD5 hashes generated was observed on VirtualBox at approximately 835,420.7 MD5 Hashes Generated/Second. The lowest number of MD5 hashes generated was observed on Virtual PC at approximately 688,719 MD5 Hashes Generated/Second.

A comparison between the three virtual platforms showed that VMware Workstation outperformed the other two virtualization platforms, VirtualBox and Virtual PC. The results show that VMware Workstation performed better than VirtualBox and Virtual PC by 110,991 MD5 Hashes Generated/Second and 257,692.7 MD5 Hashes Generated/Second respectively. VirtualBox performed better than Virtual PC by 146,701.7 MD5 Hashes Generated/Second.

Analysis of Experiment 22: RAM Transfer Speed on guest operating systems

Table 5.54: Experiment 22 - RAM Transfer Speed on guest operating systems

	Win 7 1st	**Win 7 2nd**	**Win 7 3rd**
Native	4097 MB/s	4098 MB/s	4079 MB/s
VMware Workstation	3096 MB/s	3088 MB/s	3057 MB/s
VirtualBox	2987 MB/s	2974 MB/s	2902 MB/s
Virtual PC	1392 MB/s	1403 MB/s	1401 MB/s

Table 5.55: Experiment 22 - RAM Transfer Speed on guest operating systems (average results)

	Win 7
Native	4091.33 MB/s
VMware Workstation	3080.33 MB/s
VirtualBox	2954.33 MB/s
Virtual PC	1398.67 MB/s

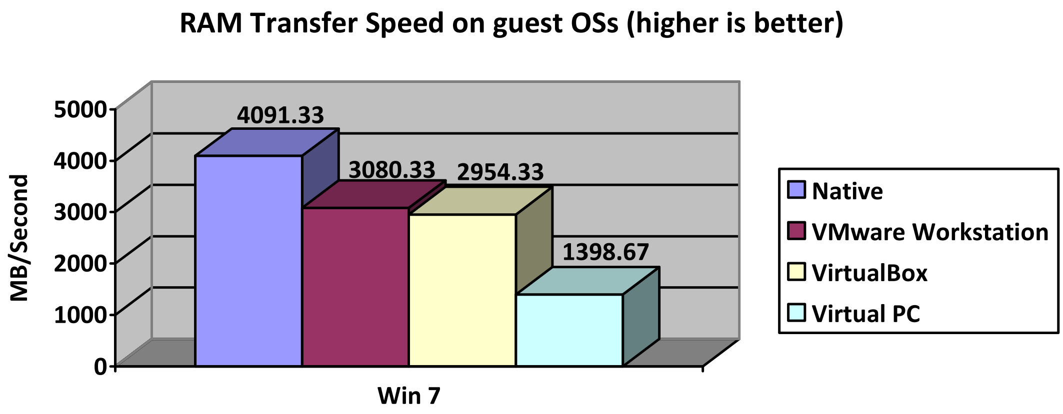

Figure 5.28: Experiment 22 - RAM Transfer Speed on guest operating systems

Figure 5.28 presents the results for Experiment 22.which measured RAM transfer speed on the guest operating system. Windows 7 was used as the guest operating system. Windows 7 was installed on the three different virtualization platforms; VMware Workstation, VirtualBox and Virtual PC. The graph above shows the RAM transfer speed on the guest operating system and the average results were noted and presented in MB/Second.

The highest RAM transfer speed was observed on VMware Workstation at approximately 3080.33 MB/s, while the second highest was observed on VirtualBox at approximately 2954.33 MB/s. The lowest RAM transfer speed was observed on Virtual PC at approximately 1398.67 MB/s.

A comparison between the three virtualization platforms showed that VMware Workstation performed better than the other two virtualization platforms. The results show that VMware Workstation performed better than VirtualBox and Virtual PC by 126 MB/s and 1681.66 MB/s respectively. VirtualBox performed better than Virtual PC by 1555.66 MB/s.

Virtualization Programs and Their Rankings

Table 5.56 shows virtualization program with their ranking. Each virtualization program received an asterisk mark for performing well in each experiment.

Table 5.56: Virtualization Programs and Their Rankings

	VMware Workstation	VirtualBox	Virtual PC
Experiment 1	*		
Experiment 2		*	
Experiment 3			*
Experiment 4			*
Experiment 5		*	
Experiment 6			*
Experiment 7	*	* * *	
Experiment 8	*	* * *	
Experiment 9	*	* *	
Experiment 10			*
Experiment 11		*	
Experiment 12			*
Experiment 13	*		
Experiment 14	*		
Experiment 15	*		
Experiment 16	*		
Experiment 17		*	
Experiment 18			*
Experiment 19	*		
Experiment 20	*		
Experiment 21	*		
Experiment 22	*		
Total Points	12	12	6

5.3 Summary

This chapter presented the experimental results of the performance of the various virtualization programs. A detailed analysis of the experimental results which were obtained through conducting the experiments as presented in Chapter 4 were was performed. The results obtained from the analysis show that there are significant performance differences between VMware Workstation, VirtualBox and Virtual PC. The conclusion of the research and future research are presented in Chapter 6.

Chapter 6: Conclusions and Directions for Future Research

This chapter presents the findings with relation to answering the research question. A summary of each chapter is also presented. Recommendations are provided based on the experiments conducted and the findings. Directions for future research and further development are also discussed.

Chapter 1 served as a basis for this research. The research objectives, aims and organizational structure are described in this chapter. Chapter 2 covered and discussed various literature regarding virtualization. In Chapter 2 virtualization technologies, their usage and current research in the field of virtualization were thoroughly covered and explained. According to the findings in Chapter 2, it is understood that use of virtualization technology in information technology infrastructure is essential and it is being widely adopted by many organizations. The findings in Chapter 2 helped to shape this research study. Based on the findings of the literature review and considering factors such as cost, compatibility and features, VMware Workstation VirtualBox and VirtualPC were selected for study and experimentation.

Chapter 3 discussed the methodology used in this research study. To obtain accurate and relevant results from this research, a mixed research methodology was adopted. Mixed research methodology is based on both quantitative and qualitative research methodologies. Qualitative research methodology was used to obtain qualitative data from the literature and make qualitative comparisons. However, quantitative research methodology was used to obtain quantitative data and make quantitative comparison. The mixed research methodology allowed the researcher to study and analyse performance of VMware Workstation and VirtualBox and VirtualPC on Windows 7. Chapter 4 presented the detailed experimental design. The process, objectives and description of the experiments are covered and discussed in Chapter 4. Chapter 5 contains the experimental results and an analysis on performance of VMware Workstation and VirtualBox and VirtualPC on Windows 7 host OS.

This research study provided satisfactory results by answering the research question. Based on the research outcome it is understood that the use of virtualization technologies and programs is necessary to overcome common problems and barriers in implementation of scalable information technology infrastructure. Performance differences were observed in the different virtualizations programs. The advantages and benefits of VMware Workstation and VirtualBox over Virtual PC were noticed. With regard to the question of cost of virtualization programs available on the market, the results of this research study show that VirtualBox has demonstrated itself to be a successful virtualization program in relation to both cost and performance. Over recent years, implementation of VirtualBox in different environments is rapidly increasing. However, still the majority of businesses use VMware products because of its support for vast range of virtualization programs available for different purposes and its long standing commercial support. As more businesses and organizations use virtualization programs, rapid development and improvement are observed from different vendors.

Through the conducting of various experiments on the virtualization programs, a deeper understanding of the performance of various virtualization programs such as VMware Workstation, VirtualBox and Virtual PC has been obtained. The preliminary results gave a clear indication of which virtualization program performed better on Windows 7. Based on the results it was observed that, VMware Workstation and VirtualBox performed close to each other and better than Virtual PC. The discussion in Chapter 5 indicated the performance differences between VMware Workstation, VirtualBox and Virtual PC. The findings demonstrated that, Virtual PC lacks both features and performance, but it is a very good product for home users who may like to use different versions of Windows OS together.

Some minor limitations were observed with VirtualBox and Virtual PC. Both VirtualBox and Virtual PC did not support hibernate and sleep features on guest OSs.

6.1 Future research directions

This research study provides a necessary baseline for conducting further studies in the area of virtualization performance. Use of virtualization technology in information technology infrastructure is increasing rapidly and adoption of virtualization technology in different environments and settings is becoming a very challenging task. Future research may include the following:

Use of 64-bit guest and host operating systems: In this study only 32-bit guest and host operating systems were used. However, nowadays new laptops usually use 64-bit operating systems. Thus it is worthwhile to study the performance of virtualization programs using 64-bit host and guest OSs. Also, it is important to know some businesses use 64-bit guest operating system as part of their information technology infrastructure. Studying performance of virtualization programs using 64-bit guest operating systems can produce promising results and also guide businesses to select the most appropriate 64-bit host and guest operating systems for better performance.

Conducting experiments using different type of workloads: In this study workloads of GIMP, Pidgin and Mozilla Thunderbird on virtualization programs were measured. Future experiments could include other types of workloads. Future experiments could focus on measuring the workloads of Java based applications, web servers, mail servers and database servers on virtualization programs. For instance, evaluating workloads of Java based applications on virtualization programs is helpful because many businesses use Java based applications. Knowing on which virtualization program, Java based applications can perform well, can guide businesses to select the most appropriate virtualization program to use.

Use diverse host and guest operating systems: In this study Windows 7 was used as host and guest operating systems. However, for future experiments Linux and Mac OS X operating systems could be used as host and guest operating systems. Studying diverse host and guest operating systems are important because better performance results can be obtained by using a particular operating system. There are many different operating systems available to use, however each can have different performance. Studying performance of diverse host and guest operating systems with virtualization programs can produce interesting results regarding OS performance in relation to virtualization program and can guide businesses to choose the most appropriate guest and host operating systems to use with the virtualization program.

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