A COMPARISON OF POWER CONSUMPTION BETWEEN MICROSOFT WINDOWS XP AND SUSE LINUX ON LAPTOP COMPUTERS

by

John Edward Meister, Jr.

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ABSTRACT

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Title: A Comparison of Power Consumption Between Microsoft Windows XP and SuSE Linux on Laptop Computers

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This study examines power consumption between Microsoft Windows XP and SuSE Linux on laptop computers through the proxy variable battery life. The experimental study evaluated battery life tests between the two operating systems on dual-booted laptop computers configured to use the same hardware and batteries. The tests determined that SuSE Linux is more efficient than Microsoft Windows XP on the tested laptop computers, realizing an overall average of 26.88% power savings. The researcher offers conclusions that may be useful to determine energy savings for organizations and provide mobile workers with longer battery life while maintaining interoperability.

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CHAPTER I

INTRODUCTION

Background of the Problem

The computing industry is facing a power crisis. Andy Karsner, a senior U.S. Energy Department official has taken note of the increasing consumption of energy by today's computing equipment (Shankland, 2006).

The focus of the industry has been on the hardware, and optimizing chips, display technology, and other hardware. Intel and IBM are working to reduce leakage current in the silicon oxide by using metal in the gates and by shrinking parts of the chip to 45 nanometers from the current 65-nanometers to further reduce energy loss as the technology shrinks to the atomic scale (Robertson, 2007). With hardware technology reaching the limits of physics and materiel science, another option that has not been considered: the efficiency of computer software. The primary software on any computer system is its operating system (OS). "An operating system is a program that manages the computer hardware" (Silberschatz, Galvin, & Gagne, 2002, p. 3).

There are two major operating systems that run on laptop computers using Intel architecture based CPUs: Microsoft Windows and Linux. Microsoft Windows XP (Microsoft, n.d.) is the most widely used version at the time of this research. "Linux is a free Unix-type operating system originally created by Linus Torvalds with the assistance of developers around the world. Developed under the GNU General Public License, the source code for Linux is freely available to everyone" (linux.org, n.d.).

The researcher observed a difference in battery life between Microsoft Windows XP and SuSE Linux on the same dual-booted HP Evo N-600C laptop during a round-trip flight between Seattle, Washington and Tokyo, Japan. When the laptop was operating in Windows XP the researcher realized three hours of battery life. The researcher realized five hours of battery life while operating in SuSE Linux. If these differences were repeatable and found on other laptop computers, then the potential for power savings might benefit others by allowing extended use of their laptop computers as they go from meeting to meeting, and also to reduce overall energy costs for the corporation and help the environment. When a computer uses power it creates heat, that heat is often removed by air conditioning in an office environment. If overall computing power consumption could be reduced by using a more efficient operating system then there will also be a reduction in energy required to cool the office.

The independent variable that was considered in this research is the OS, Microsoft Windows XP or SuSE Linux. The dependent variable is battery life.

History

Microsoft Windows XP was released on October 25, 2001. SuSE Linux was released in 1992; it was the first commercial Linux. It has remained one of the most popular and stable distributions. Oracle has supported SuSE and other versions of Linux since 1998 ("Oracle", 2007). There are hundreds of Linux distributions available today, all of them using the same underlying kernel and are compatible with each other. According to Distrowatch.com (n.d.), SuSE Linux is in the top ten distributions. Linux is a UNIX-like operating system developed by Linus Torvalds in 1991. Gumbel (2006 par. 1, 2.) describes Torvalds and Linux:

> Linus Torvalds was just 21 when he changed the world. Working out of his family's apartment in Helsinki in 1991, he wrote the kernel of a new computer

> operating system called Linux that he posted for free on the Internet — and invited anyone interested to help improve it.
>
> Today, 15 years later, Linux powers everything from supercomputers to mobile phones around the world, and Torvalds has achieved fame as the godfather of the open-source movement, in which software code is shared and developed in a collaborative effort rather than being kept locked up by a single owner.

The independent variables evaluated in this study are Microsoft Windows XP and SuSE Linux. The dependent variable under study is battery life. The measurement of battery life in minutes would allow the calculation of total power consumption by using the laptop battery rated value.

Operating Systems Functions

An operating system is the software required to operate a computer. It is the underlying program upon which applications will run. The efficiency of the operating system will affect power consumption and battery life. "Efficiency and functionality are key to an operating system's usefulness. The efficiency sets the stage for the performance of all software on a computer" (Nutt, 2003, p. 1).

Researchers Work Role and Setting

The researcher is the lab manager for a 787 software development and integration lab at Boeing, supporting over fifty Windows XP, Windows 2000, Windows 2003 Server, Linux and Windows Vista systems. He has experience as an electronics technician, circuit designer, and technical supervisor in telecommunications and data centers. He has worked as a Systems and Programmer Analyst, and has experience as a Windows, Linux and UNIX Systems Administrator. He has worked at Intel, ITT, Intermec, Merck, Boeing and the US Army. He has been a technical instructor teaching electronics, business management and computer science since 1979 at locations across the country. He travels nationwide to provide Linux and UNIX training through Clearview Consulting of Snohomish, WA. He is adjunct faculty at City University of Seattle in Bellevue, WA, teaching Operating Systems and other CS courses. He graduated in 1981 from the University of Maryland with a Bachelor of Science degree.

Statement of the Problem

Battery life, i.e., power consumption, has become a major issue for laptop users and corporations faced with escalating energy costs and availability. Workers are increasingly mobile, moving from conference room to conference room, and attending virtual meetings from all over the world. Battery life is an ongoing issue for users who require access to chargers after a few hours of use. The laptop is no longer just for the dedicated road warrior, but a common tool for office workers in cubicles. Many corporations have replaced desktop systems with laptop computers. Roseberry (2006) states that business class desktop replacements have been designed more for business users than home users. This provides access flexibility and the ability to work "virtually." Kanellos (2005) predicts an eight-hour notebook is moving closer to reality, with four hours the current standard, "although that allotment remains elusive in real life". Increasing battery life and reducing energy needs and costs would benefit laptop users, the corporations, and energy suppliers.

Assumptions

This study did not consider actual energy costs, as that varies by location. This study did not seek to analyze actual power consumption by models. This study was intended to determine the difference in the efficiency of the operating systems by determining battery life measured in minutes of each OS. Systems were not optimized for the tests to eliminate other variables. The assumption for the tests were that the vendors had optimized these operating systems for the most stable, efficient and useful configuration; therefore, default installations and options were selected during installation.

Limitations

This study was limited to a test of Microsoft Windows XP and SuSE Linux operating systems to reduce the variables associated with other distributions of Linux and versions of Microsoft Windows. The tests were conducted with the default installations of the operating systems, no user interaction and no applications running.

Definition of Terms

Ampere -hour (Ah) capacity – "The measure of the total quantity of electricity which can be delivered by a battery from the fully charged condition until its terminal voltage drops to the lowest permitted limit" (Tranter, 1983, p. 27).

Power - "Power measures the rate at which energy is transformed. The transformation of 1 joule of energy in 1 second represents an average power of 1 watt" (Smith, 1984, p. 8).

Acronyms

CPU	Central Processing Unit
CS	Computer Science
DLL	Dynamic Link Library
GNU	A recursive acronym meaning: "GNU is Not Unix", the name provided by Richard Stallman, founder of the Open Source movement.
I/O	input/output
IT	Information Technology
OS	Operating System
SuSE	"Software- und System-Entwicklung" was founded in late 1992 as a UNIX consulting group.
Wine	Wine Is Not a (CPU) Emulator. (Wine HQ, n.d., par. 2.2).
XP	A Microsoft Windows version released in October 2001.

CHAPTER II

REVIEW OF RELEVANT LITERATURE AND RESEARCH

Power Consumption

"A Google engineer has warned that if the performance per watt of today's computers doesn't improve, the electrical costs of running them could end up far greater than the initial hardware price tag" (Shankland, 2005). "The possibility of computer equipment power consumption spiraling out of control could have serious consequences for the overall affordability of computing, not to mention the overall health of the planet" Barroso, 2005). Bangeman (2007) reports that the EPA will begin a six-month study of power consumption in the data center with the goal of encouraging the deployment of more energy-efficient hardware.

Bangeman (2007) identifies the additional power consumption of computers:

> Energy costs can account for up to 30 percent of a company's IT budget. Power consumption figures include not only the servers themselves, but uninterruptable (sic) power supplies, switches, NAS devices, and air conditioning. Those energy bills have grabbed the attention of enterprise IT managers. At last fall's Intel Developer Forum, Google Fellow Luis Barroso said that his company believed that 30 to 45 percent of a PSU's input power is wasted. Given the scope of Google's data centers, that's a significant figure.

Bangeman (2007) summarizes the problem and the overall impact:

> With rising energy prices and concerns over the impact of greenhouse gases on the Earth's climate, the private sector is already feeling the need to slash IT energy costs. The EPA's study may serve to reinforce such attitudes in the private sector while providing a mandate for federal agencies to cut IT energy costs with more energy-efficient equipment.

In a CNET News.com article, Shankland (2006) reported:

> But it's in the interest of anyone consuming power to improve efficiency, argued Andrew Fanara of the EPA's Energy Star program. "Companies have to ask themselves, 'Am I willing to bet the cost of energy is going to go down?' That's the cost of doing nothing," Fanara said.

Power consumption is a major industry concern. The focus has been on the improvement of hardware. The operating system and software run on the hardware must also be considered.

Computer Operating Systems

An operating system is part of every computer system. A computer system has four major components: the hardware, the operating system, the application programs and the users. (Silberschatz, Galvin, & Gagne, 2002).

Computer Hardware

The hardware components include the CPU, memory, disk drivers, video displays, keyboard and graphical user interfaces. (O'Brien, 2002). There are two major operating systems available for laptop computers and desktops using Intel architecture: Microsoft Windows and Linux. Microsoft Windows and Linux are compatible on the same hardware and may be loaded on the same system and on the same disk drive, although they can not run concurrently. Having the operating systems loaded on the same system in a dual-boot configuration would allow the user to have the benefits of both.

Monolithic Kernels

Both Linux and Windows are monolithic kernels operating systems. "In a monolithic kernel, all software and data structures are placed in one logical module…and they can be very efficient if they are well implemented" (Nutt, 2004, p. 778). Both Windows and Linux have all core operating systems services running in shared address space in kernel-mode. (Solomon & Russinovich, 2006). Figure 1 graphically represents the similarity of the architectures.

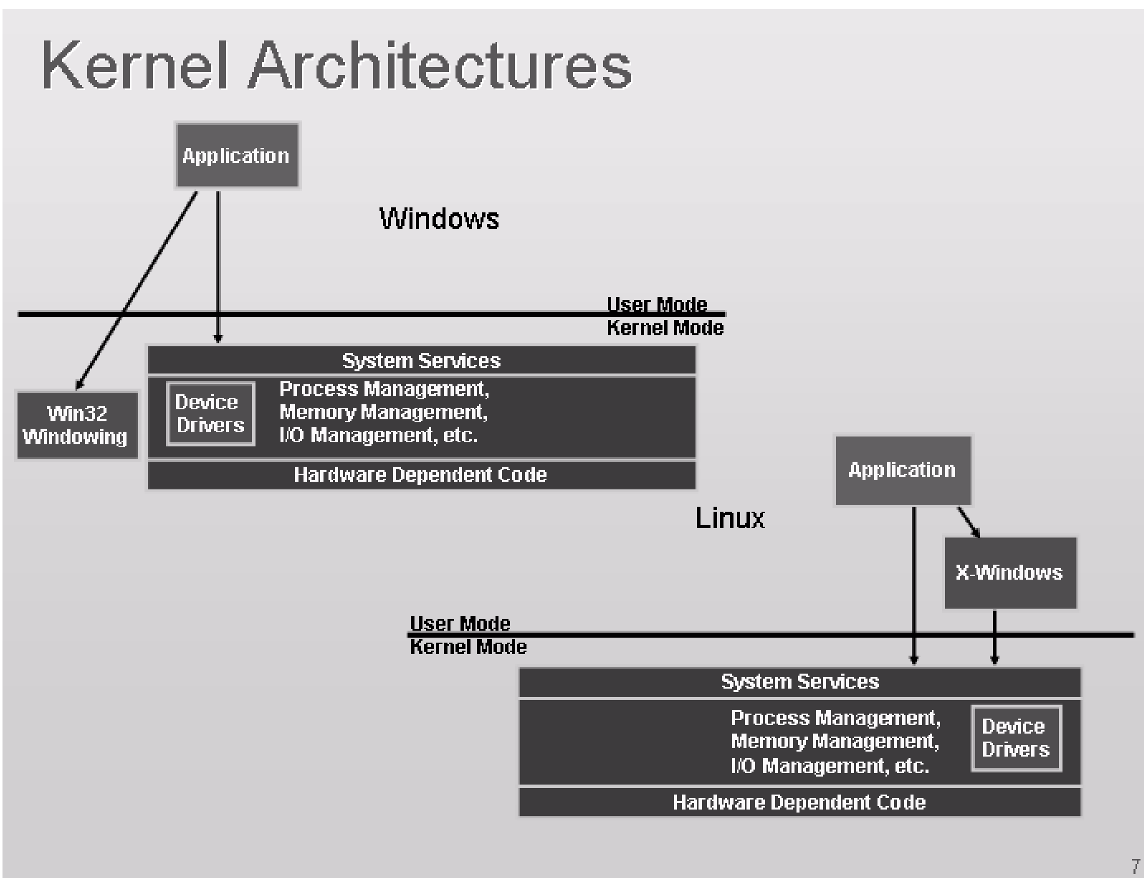

Figure 1. Kernel architectures. *Note.* From Solomon & Russinovich (2006).

Operating Systems Efficiency

The efficiency of the operating system and the hardware will determine the total power consumption. According to Brooks (1995) a software development project will grow in size. This growth often translates to increased program size, additional lines of code that are executed by the CPU during program execution and as a result increased power consumption. Inefficient code and a lack of optimization will result in poor user performance, this leads to the acquisition of faster, more powerful hardware, which leads to increased power consumption.

Lines of Source Code

Dvorak (2004) reported that there are now so many millions of lines of code that he was told nobody at Microsoft has a handle on it. Lohr and Markoff (2006) estimate that Windows XP has more than 20 million lines of code. Wheeler (2004) estimated that a GNU/Linux distribution includes well over 17 million lines of physical source code, representing 4,500 person-years of development time.

Both operating systems appear to have similar lines of code in their distribution, XP with 20 million and Linux with 17 million. However, it may be inferred, based on the Linux paradigm, that the code used in Linux having been reviewed by the open source community might be more efficient. Linux is designed after the same philosophy as UNIX. Because of the modularity of this philosophy, the lines of code may not be directly comparable. The lines of code used in XP would be loaded with the operating system while much of the code in Linux would sit waiting to be called to service as evidenced by the second of the nine precepts put forward by Gancarz (1995, 2003) that states that each program should be made to do one thing well.

Laptop Batteries and Power Consumption

The issue of power is of even more concern to the mobile worker. The total time that the battery provides power to the portable computer permits the user to engage in productive work. Miles (1999) notes:

> As notebooks drop in price and increase in performance, they've finally become a viable option as a primary computer for millions of users. But those with the fanciest chips and multimedia options typically offer less than stellar battery life--about an hour for many systems--which leaves many nervous users scrambling for an electrical outlet.

Current battery technology has improved the life of many systems, but even today the larger notebook systems provide battery life that is not much more than an hour. Typical battery life while running Microsoft Windows is in the two to three hour range. This limits the mobility of workers and requires carrying a charger or spare battery. If the operating system could provide additional battery life this would not only save energy but benefit the users. In addition, the dangers associated with the Lithium-Ion batteries contained in most portable computers increase with additional power requirements and possible internal shorts ("PC Pitstop PC Safety", n.d.). Between 2004 and 2006, Dell Computers, along with other vendors, had battery recalls due to the danger of defective batteries having an internal short, "Under rare conditions, it is possible for these batteries to overheat, which could pose a risk of fire" ("Battery", Dell, 2006). Lithium-Ion is a flammable liquid, and in the event of a short, a chemical reaction occurs that can melt the battery or cause it to explode, Kanellos (2006) reports, while presenting an argument for the use of zinc-based batteries:

> Lithium ion batteries, which came out in 1990, are the surly child prodigy of portable electronics. These batteries can hold far more energy than conventional rechargeable batteries and generally weigh less than traditional rechargeables. Notebook makers and cell phone manufacturers have used these properties to create fairly light devices that can run for several hours on a single battery charge.
>
> Unfortunately, a short circuit inside a lithium ion battery can lead to what's known in the industry as a "runaway thermal reaction." The reaction can cause the battery case to melt and spew hot liquids, or explode due to pressure and heat. Injuries have been reported around the globe.
>
> To make matters worse, manufacturers have continued to increase the energy density--or the amount of energy the battery can hold--of lithium ion batteries by thinning out separators (which keep the electrodes apart) and changing other components. These changes lead to longer run times--something consumers are demanding--but also raise the potential that something can go wrong.
>
> "The root cause is more and more energy required in a limited volume. You aggravate the safety issues," said Rick Cooper, vice president of business development at PolyFuel, which makes membranes for direct methanol fuel cells.

The use of laptop computer batteries provide a finite source of power by which to evaluate the total power consumption and determine which OS is more efficient. Reducing power consumption on existing hardware will help to offset the continuing growth in power use. The more efficient the operating system, the longer it will operate on the same battery and hardware.

Summary

Both Microsoft Windows XP and SuSE Linux use similar kernel architecture and operate on the same hardware platform. They both have millions of lines of code.

Statement of the Hypothesis

Based on the review of literature and the experience of the researcher, the following hypothesis was posited for this study.

It is hypothesized that there is no significant statistical difference ($\alpha = .05$) in power consumption between Microsoft Windows XP and SuSE Linux on laptop computers.

CHAPTER III

RESEARCH METHODS

The researcher gathered qualitative and quantitative data to explore the research hypothesis. An experimental study was completed to test battery life on laptop computers loaded with default installations of Microsoft Windows XP and SuSE Linux.

Research Model

The differences in battery life between Microsoft Windows XP and SuSE Linux were examined in an experimental study. The test was designed to isolate the one dependent variable: battery life. A variety of laptop computer models were tested to eliminate any advantage that one model might offer one operating system over another. The test design required the use of the same physical hard drive for the comparative tests. This ensured no difference in physical I/O, system interfaces or physical differences in disk drives.

To ensure that a valid comparison was made between the two operating systems, the laptop computers were configured to "dual-boot", this means that both operating systems are loaded and configured to run separately on the same computer and the same physical hard drive. This allowed the consistent testing of the dependent variable, battery life. By using the same exact hardware the independent variable was the only item changed during the test. Battery life is a proxy variable for power consumption. The use of a battery provided a finite quantity of energy. Both independent variables were tested with the same physical battery. The operating system that ran the longest on the same battery was the most efficient.

Tests conducted on a subject laptop computer used the exact same hardware for each test, including but not limited to any attached keyboards, USB devices, graphical input devices, i.e., mice, or attached video displays. As long as the system was tested in the same physical configuration for both tests on each laptop computer the battery life data were considered valid. The specific battery type or laptop computer model was irrelevant as the test was intended to show the difference in overall power consumption between Microsoft Windows XP and SuSE Linux.

The only independent variable was the operating system for each laptop computer under test. The test of battery life was conducted after the operating system was fully loaded on the system and fully operational. Having the operating system fully booted and functioning ensured that the battery and computer were at operating temperature and that only the quiescent states of the operating systems were compared. No applications were loaded or operated during the test cycles. The use of even similar applications could not ensure that the same code would be executed, resulting in dissimilar system activity and invalidating the test results. Therefore, the researcher only tested the operating systems without applications running. User interaction during the test was limited to observing the remaining battery life by viewing the power meter or battery life indicator in each operating system.

The quantitative data were gathered from a variety of laptop models and makes configured with the default installations of Microsoft Windows XP and SuSE Linux. The operating systems were loaded on the same hardware, including the same hard drive, and used the same battery for each test cycle. The battery life times in minutes was collected for the study. The independent variable for this research project was the operating system. The dependent variable was the battery life.

The battery life test event began when the tester had the operating system up and running, was logged in, had turned off all applications, turned off the screen saver and opened the power meter or battery indicator utility. Then the tester noted the time and removed the power plug from the laptop computer. When the battery was discharged so that the laptop computer would no longer function and turned off the display, the tester recorded the time. The tester recorded the total time of operation in minutes.

Population

The population for the study was the laptop computers configured and used for testing found in Appendix B. Multiple tests of each OS on selected laptop computers were conducted to ensure validity of results. In addition, a wide range of laptop computers was tested at least twice in each OS to reduce the variability of the hardware. The battery tests are easily replicated on any laptop that will operate with Microsoft Windows or Linux. Due to time and resource constraints this study was limited to systems that were accessible to the researcher and test volunteers, sufficient numbers were tested to help ensure statistical validity. The tester noted the time, removed the battery charger or power cord and observed the laptop until the system shut down or turned off, then noted the time and recorded the total battery life in minutes for the operating system that was tested. The tester reattached the power to the system, recharged the battery, and booted into the other operating system. Once the battery was fully charged, the tester repeated the process for the other operating system. Each laptop computer test cycle has two data points, one for Microsoft Windows XP and one for SuSE Linux.

The Data Collection Device

The battery life data collected from each laptop computer were collected and loaded into a spreadsheet. The data recorded included the laptop make and model, the battery life for Microsoft Windows XP and SuSE Linux in minutes, and indicated the differences in percentages between the two operating systems. The parametric data from the spreadsheet were analyzed using a *t*-test for independent samples to determine if a statistical significance difference existed between the two groups.

Reliability and Validity

Each laptop computer had Microsoft XP and SuSE Linux loaded. Each operating system used the default installation for the test. The systems were not tuned for power-savings. Hard disks and monitors were not turned off during the tests and the laptop computers were not permitted to enter sleep mode. The operating systems operated in their quiescent states with no applications running and no user interaction. By conducting the tests with no applications and no user interaction, each operating system was tested independently and a reasonable comparison can be made. It is also expected that, in general practice, users will not modify the system parameters and their expected battery life will parallel that of these tests. Multiple vendors and models were tested to eliminate the possibility that one model might be optimized for one operating system or the other. Testing multiple models also eliminated specific hardware features that might benefit one operating system over the other. Variables might include memory chips, CPU types, disk types and other equipment that were not considered part of this test. By testing multiple laptop computers the researcher was able to gather valid and reliable data.

Treatment of the Data and Procedures

The data gathered on battery life were evaluated using a *t*-test for paired samples. (Cooper & Schindler, 2006). The level of significance was $p < .05$. The null hypothesis was that there is no statistical significant difference in battery life between Windows XP and SuSE Linux.

CHAPTER IV

RESULTS

Eighty-eight battery life tests were conducted on eleven different laptop computers identified in Appendix B. The laptop computers were categorized into four different CPU types. The collected data, in minutes, from each battery test were organized by the independent variable, the operating systems Microsoft Windows XP and SuSE Linux.

Each test was started with a fully charged battery in either Windows XP or SuSE Linux. The tests were conducted without using applications, without user interaction and at the same ambient temperature. Static tests in each operating system were conducted to ensure that the researcher was not a variable in the depletion of the battery. Default configurations were used in both operating systems on the laptops to eliminate the variables associated with customization and optimization. Screen savers were not used and monitors and disks were not turned off by the system. The same ambient temperature was used to eliminate battery temperature as a variable.

The data collected were broken into four CPU types. The first CPU group was the Intel Pentium 4. Laptop computers tested in this group were a Fujitsu Lifebook C-2240, a Toshiba Satellite S20-A207 and an IBM A31p. The second CPU group was the Intel Pentium M. Laptop computers tested in this group were two different Dell 610s. The third CPU group was the Intel Centrino. Laptop computers tested in this group were a Dell 510, a Sony Vaio PCG-9231 and an IBM R50p. The fourth CPU group was the Intel Pentium III. Laptop computers tested in this group were an HP EVO N-600C, and an HP Pavilion N5350 tested with two different battery capacity types.

In the Intel Pentium 4 CPU group, a statistically significant difference existed; $t(22) = 2.93$, $p = 0.008$, Pentium 4 SuSE mean ($\bar{x}$ = 180.67 and σ = 61.18) were significantly higher than Pentium 4 Windows XP mean ($\bar{x}$ = 116.92 and σ = 44.16). The overall expected power savings of Linux over Windows using a Pentium 4 CPU was 35.93%(σ = 6.07).

Levene's test for equality of variances for the Pentium 4 CPU group was significant ($p < .001$), indicating that the variances were not the same, this may be the result of one sample laptop computer only having two test cycles. A separate *t*-test calculation showed that variances were equal with $t(22) = -2.92$, $p = 0.0078$. The calculated average power savings of Linux for all Pentium 4 CPU laptop computers was 35.93%. These data are shown in Table 1.

Table 1

Battery Life for XP and Linux on Pentium 4 CPUs

Pentium 4 CPUs	XP	SuSE
Mean (in minutes)	116.92	180.67
Observations	12	12
XP / SuSE	64.07%	
Linux Power Savings	35.93%	

In the Intel Pentium M CPU group, a statistically significant difference existed; $t(14) = 4.12$, $p = 0.001$, Pentium M SuSE mean ($\bar{x}$ = 180.25 and σ = 20.25) were significantly higher than Pentium M Windows XP mean ($\bar{x}$ = 143.50 and σ = 15.06).

The overall expected power savings of Linux over Windows using a Pentium M CPU was 20.25%, ($\sigma = 4.42$).

Levene's test for equality of variances for the Pentium M CPU group was not significant ($p > .05$). The calculated average power savings of Linux for all Pentium M CPU laptop computers was 20.24%. These data are shown in Table 2.

Table 2

Battery Life for XP and Linux on Pentium M CPUs

Pentium M CPUs	XP	SuSE
Mean (in minutes)	143.50	180.25
Observations	8	8
XP / SuSE	79.76%	
Linux Power Savings	20.24%	

In the Intel Centrino CPU group, a statistically significant difference existed; $t(22) = 2.77$, $p = 0.0110$, Centrino SuSE mean ($\bar{x} = 226.33$ and $\sigma = 42.82$) were significantly higher than Centrino Windows XP mean ($\bar{x} = 179.33$ and $\sigma = 40.38$). The overall expected power savings of Linux over Windows using a Centrino CPU was 21.14%, ($\sigma = 6.58$).

Levene's test for equality of variances for the Centrino CPU group was not significant ($p > .05$). The calculated average power savings of Linux for all Centrino CPU laptop computers was 21.24%. These data are shown in Table 3.

Table 3

Battery Life for XP and Linux on Centrino CPUs

Centrino CPUs	XP	SuSE
Mean (in minutes)	179.33	226.33
Observations	12	12
XP / SuSE	78.76%	
Linux Power Savings	21.24%	

In the Intel Pentium III CPU group, a statistically significant difference did not exist; $t(22) = 1.39$, $p = 0.18$, Pentium III SuSE mean ($\bar{x} = 266.25$ and $\sigma = 143.18$) were higher than Pentium III Windows XP mean ($\bar{x} = 193.50$ and $\sigma = 112.09$). The large difference in battery size on the HP Pavilion tests resulted in a large standard deviation that reduced the statistical significance. The net expected power savings of SuSE Linux over Windows XP was substantial at an estimated 27.88%, ($\sigma = 10.31$).

Levene's test for equality of variances for the Pentium III CPU group was not significant ($p > .05$). The calculated average power savings of Linux for all Pentium III CPU laptop computers was 27.88%. These data are shown in Table 4.

Table 4

Battery Life for XP and Linux on Pentium III CPUs

Pentium III CPUs	XP	SuSE
Mean (in minutes)	193.50	266.25
Observations	12	12
XP / SuSE	72.12%	
Linux Power Savings	27.88%	

The *t*-test analysis for all data on the dual-booted laptop computer data is listed in Table 5. The overall power savings across all four CPU groups was 26.88%.

Table 5

t-test Results of the Battery Life for XP and Linux

	XP	SuSE
Mean (in minutes)	159.66	216.39
Observations	44	44
df	86	
t stat	-3.27	
p	0.0015	

Across all gathered data, a statistically significant difference existed; $t(86) = -3.27$, $p = 0.0015$, the SuSE Linux mean ($\bar{x}$ = 216.39 and σ = 89.77) was significantly higher than Windows XP mean ($\bar{x}$ = 159.66 and σ = 71.78). The overall power savings of SuSE Linux over Windows XP across all tested laptop computers was ($\bar{x}$ = 26.88% and σ = 9.54).

CHAPTER V

DISCUSSION

The null hypothesis was rejected as $p < 0.5$; a $t(86) = -3.27$, $p = 0.0015$ was calculated across all laptop computer model battery life data. There was a significant difference in battery life between Microsoft Windows XP and SuSE Linux across all of the tested laptop computers. Eighty-eight tests on eleven laptop computers from four different CPU categories were tested. There was a significant difference in power consumption between Microsoft Windows XP and SuSE Linux.

The first CPU group was the Intel Pentium 4. Laptop computers tested in this group were a Fujitsu Lifebook C-2240, a Toshiba Satellite S20-A207 and an IBM A31p. The average power savings of SuSE Linux in the third CPU group was 35.93%, with a low of 26.83% on the Toshiba Satellite and a high of 38.66% on the Fujitsu Lifebook.

The second CPU group was the Intel Pentium M. Laptop computers tested in this group were two different Dell 610s. The average power savings of SuSE Linux in the fourth CPU group was 20.24%, with a low of 18.51% on the first Dell 610 and a high of 21.98% on the second Dell 610.

The third CPU group was the Intel Centrino. Laptop computers tested in this group were a Dell 510, a Sony Vaio PCG-9231 and an IBM R50p. The average power savings of SuSE Linux in the first CPU group was 21.24%, with a low of 18.82% on the IBM R50p and a high of 30.06% on the Sony Vaio.

The fourth CPU group was the Intel Pentium III. Laptop computers tested in this group were an HP EVO N-600C, and an HP Pavilion N5350 tested with two different battery capacity types. The average power savings of SuSE Linux in the second CPU group was 27.88%, with a low of 22.64% on the HP N5350 with a 6600 mAH battery and a high of 39.98% on the HP N-600C.

The collected data revealed that the Linux operating system was significantly more efficient than Microsoft Windows XP. This efficiency translated to extended battery life and reduced power consumption for SuSE Linux on all tested laptop computers. The issues of battery life and power consumption affect users and their organizations in a multitude of ways. Decreased battery life requires more frequent battery changes, more frequent charges, or the purchase of a larger capacity battery to make it through a work day or an airplane flight. Increased power consumption by Microsoft Windows XP results in higher energy costs, the necessity for additional power sources and increased heat.

The literature review revealed that both operating systems have similar lines of code; however, the Linux philosophy appears to result in better use of those lines of code, possibly by not loading them into memory until called. Observations made using system tools indicate that Microsoft Windows XP accesses the CPU more often than does SuSE Linux while in a quiescent state. The increased frequency of CPU activity, activation of unneeded services, and unused functions loaded into memory, may be factors associated with the decreased battery life and increased power consumption of Microsoft Windows XP. The Windows operating system appears to use a fixed polling schedule to monitor the system, while the Linux operating system may use an interrupt method, waiting for a system call by an application or intervention by the user. The specific differences in the operating systems would require further analysis to determine the specific underlying causes of Microsoft's increased power consumption and decreased battery life.

CHAPTER VI

CONCLUSION

The null hypothesis was rejected as $p < 0.5$. There is a significant difference in battery life between Microsoft Windows XP and SuSE Linux on the tested laptop computers. The estimated average savings of SuSE Linux averaging 26.88% was about 56.4 minutes of additional laptop computer use based on the mean data collected.

The difference in battery life between Microsoft Windows XP and SuSE Linux was significant and revealed the efficiency of Linux over Microsoft. The power savings of Linux ranged from 18.51% to 39.98%. Corporations would realize noticeable power savings by using Linux over Windows as demonstrated by these tests.

With the current worldwide political emphasis on reducing greenhouse gases and heat, it is clear that the use of SuSE Linux would significantly reduce power consumption and especially help to reduce these gases in areas that use coal for power production. The reduction of power consumption elsewhere would reduce the need for additional power plants and extend the viability of our existing infrastructure. The extended battery life of Linux will permit laptop computer users longer periods of productive work.

CHAPTER VII

RECOMMENDATIONS

The use of Linux over Microsoft Windows is highly recommended to reduce energy consumption, reduce heat, and in doing so, reduce dependency on foreign oil, reduce the production of "greenhouse gases" and other waste products from coal burning plants, and reduce the need for additional power generating resources. Linux will reduce unnecessary heat from the computer through reduced power consumption, which reduces the need for additional air conditioning, and further reducing green house gases and power consumption. It is expected that these power savings will be realized by desktop systems as well, as the test was for the efficiency of the operating systems and not the specific computer type.

It is recommended that Linux be used with interoperable tools like OpenOffice, Mozilla Thunderbird, and Mozilla Firefox. Using a dual-booted laptop would allow the user to switch to Microsoft Windows when WINE, Code Weavers Cross Over, VMware, or Citrix would not work or are unavailable and a Microsoft Windows proprietary application had to be used. Large scale proprietary applications could be run on Citrix, permitting users to experience the power savings and extended battery life of Linux, while also reducing overall software license costs by having fewer licensed applications.

The researcher recommends research into the power savings while using applications. Both SuSE Linux and Microsoft Windows use the application OpenOffice. The use of OpenOffice would provide the tools necessary for workers to be productive while maintaining interoperability with the Microsoft Office suite. The tests would be tailored to the particular environment used in a corporate environment. Comparisons of file creation, opens, saves and edit times would be monitored and tested on both operating systems and also compared with Microsoft Office on Windows to see if there are measurable differences in power consumption as well as performance. Additional tests would be conducted to ensure full interoperability between the two applications to determine if files created in either may be opened, edited and saved across both applications without file corruption or data loss.

In addition to the power savings and extended battery life of Linux, the total costs of operation and ownership should be evaluated, such as the operating systems acquisition costs, installation times, time spent configuring the operating system for useful work, the installation of all applications to be used, the time spent dealing with malware, worms, viruses, Trojan horses and other destructive software, and their removal and restoration to normal operating, that currently plagues the Microsoft Windows operating systems.

In addition to power, and costs, the performance of the operating systems should be monitored. It is likely that there will be performance benefits using Linux as the efficiency demonstrated in these battery life tests would also indicate more responsive user interaction with applications and the system. Specific tests with known file size documents or spreadsheets could be used and timed. The files would need to be of sufficient size to make any differences more noticeable and measurable.

The researcher also suggests further testing of the difference between the latest release of Microsoft Windows Vista and SuSE Linux to see if there is even further power savings available by using SuSE Linux, as this would most likely be the case considering the additional lines of code and DLLs used in Vista over XP.

The researcher conducted two tests of Vista Enterprise Edition on the IBM R50p used in the tests conducted for this study. Vista lasted 113 minutes in one test and 128 minutes in another. The mean time on the same IBM R50p for Linux was 266.2 minutes, $\sigma = 14.906$. The two tests of Microsoft Vista on the IBM R50p indicate that SuSE Linux would save an average of 57% over Microsoft Vista, where only 19% savings were realized over Microsoft Windows XP. The power consumed on the IBM R50p was estimated to be 16.07 Watts for SuSE Linux, 19.82 Watts for Microsoft Windows XP, and 35.49 Watts for Windows Vista Enterprise (See Figure 6, Appendix D). This startling and significant increased power consumption by Windows Vista is disturbing considering the claims of power savings presented by Microsoft. A savings of 57% of SuSE Linux over Microsoft Vista exceeds any of the systems tested using Microsoft XP and opens up the question of how much more savings might be realized on systems that showed more power savings over Windows XP. This should be an area for expanded research.

There are a number of commercial and Open Source applications that work the same on Microsoft Windows and Linux. Some of these applications are web browsers, such as Mozilla Firefox and Opera, email clients, such as Mozilla Thunderbird, and of course the OpenOffice office suite that provides comparable tools to Microsoft Office at no cost, and StarOffice, which is one version newer than the free OpenOffice and supported through purchase by Sun Microsystems. There are specific commercially available products that permit the use of Microsoft applications directly in Linux. CodeWeavers "CrossOver" is one such product. (CodeWeavers, 2007) The Xandros distribution of Linux includes the CodeWeavers application CrossOver. (Xandros, 2007) Many of these applications are built on or use Wine.

> Wine is a translation layer (a program loader) capable of running Windows applications on Linux and other POSIX compatible operating systems. Windows programs running in Wine act as native programs would, running without the performance or memory usage penalties of an emulator, with a similar look and feel to other applications on your desktop.
>
> The Wine project started in 1993 as a way to support running Windows 3.1 programs on Linux. Bob Amstadt was the original coordinator, but turned it over fairly early on to Alexandre Julliard, who has run it ever since. Over the years, ports for other Unixes have been added, along with support for Win32 as Win32 applications became popular. (winehq, n.d.).

There are websites dedicated to providing useful "crossover" information, one such site is http://www.grokdoc.net/index.php/Application_Crossover_Chart provided by groklaw.net's grokdoc.net page, which cites, "There are three basic free office packages available for Linux. KOffice for KDE, GNOME Office for GNOME or OpenOffice (OpenOffice.org, 2007) for any Linux".

The researcher recommends further research into the issues of interoperability and power savings. Another area of research would be the use of a Citrix client on a Linux laptop. This would allow a user to reduce power consumption on the client laptop computer while operating in a Microsoft environment that is running on a server. The use of one server by several laptop users would reduce the power consumption on several laptops with negligible increase in power use on that one server. This would benefit an organization in other ways, such as reducing the software application support on the client laptops as all updates would occur on the one Citrix server. The power savings on the laptops may not offset the license costs of the Citrix server, and further analysis is recommended.

The observed differences in the operating system battery life reveal that there is a difference in program efficiency. Improvement of application and operating system code should be considered as a means of reducing power consumption. This study quantitatively showed the difference in power savings of SuSE Linux over Microsoft Windows XP. The researcher recommends further analysis towards applying the use of Linux in the corporate environment as a means of reducing power consumption and unnecessary heat while improving computing efficiency.

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APPENDIX A

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APPENDIX B

RECORDED TEST RESULTS

Figure 2 Recorded test results by CPU types

Minutes of battery life using the same hardware and battery. *t*-test entry values:

laptop tested	XP minutes	SuSE minutes	XP / SuSE	Linux Power Savings
Fujitsu 2240 test 1	71	121	58.7%	41.3%
Fujitsu 2240 test 2	73	131	55.7%	44.3%
Fujitsu 2240 test 3	79	115	68.7%	31.3%
Fujitsu 2240 test 4	74	131	56.5%	43.5%
Fujitsu 2240 test 5	77	112	68.8%	31.3%
Fujitsu 2240 test 6	77	129	59.7%	40.3%
Toshiba Satellite test 1	161	216	74.5%	25.5%
Toshiba Satellite test 2	175	244	71.7%	28.3%
IBM A31p test 1	146	225	64.9%	35.1%
IBM A31p test 2	161	254	63.4%	36.6%
IBM A31p test 3	152	252	60.3%	39.7%
IBM A31p test 4	157	238	66.0%	34.0%
		Pentium 4 CPU average:		35.9%

laptop tested	XP minutes	SuSE minutes	XP / SuSE	Linux Power Savings
Dell 610a test 1	117	157	74.5%	25.5%
Dell 610a test 2	127	159	79.9%	20.1%
Dell 610a test 3	137	161	85.1%	14.9%
Dell 610a test 4	147	170	86.5%	13.5%
Dell 610b test 1	158	195	81.0%	19.0%
Dell 610b test 2	154	202	76.2%	23.8%
Dell 610b test 3	157	197	79.7%	20.3%
Dell 610b test 4	151	201	75.1%	24.9%
		Pentium M CPU average:		20.2%

Minutes of battery life using the same hardware and battery. *t*-test entry values:

laptop tested	XP minutes	SuSE minutes	XP / SuSE	Linux Power Savings
Dell 510 test 1	181	236	76.7%	23.3%
Dell 510 test 2	157	220	71.4%	28.6%
Dell 510 test 3	176	208	84.6%	15.4%
Dell 510 test 4	180	207	87.0%	13.0%
Dell 510 test 5	161	202	79.7%	20.3%
Sony PCG-9W31 test 1	116	154	75.3%	24.7%
Sony PCG-9W31 test 2	102	158	64.6%	35.4%
IBM R50p test 1 a	201	251	80.1%	19.9%
IBM R50p test 2 b	226	272	83.1%	16.9%
IBM R50p test 3 a	226	266	85.0%	15.0%
IBM R50p test 4 b	212	254	83.5%	16.5%
IBM R50p test 5 a	214	288	74.3%	25.7%
		Centrino CPU average:		21.2%

laptop tested	XP minutes	SuSE minutes	XP / SuSE	Linux Power Savings
HP EVO N-600C test 1	174	299	58.2%	41.8%
HP EVO N-600C test 2	188	304	61.8%	38.2%
HP N5350 3600 1xs	72	130	55.4%	44.6%
HP N5350 3600 2xs	76	113	67.3%	32.7%
HP N5350 3600 3sx	80	107	74.8%	25.2%
HP N5350 3600 4sx	88	106	83.0%	17.0%
HP N5350 3600 5sx	79	101	78.2%	21.8%
HP N5350 6600 1sx	332	386	86.0%	14.0%
HP N5350 6600 2xs	318	388	82.0%	18.0%
HP N5350 6600 3sx	311	382	81.4%	18.6%
HP N5350 6600 4xs	308	441	69.8%	30.2%
HP N5350 6600 5xs	296	438	67.6%	32.4%
		Pentium III CPU average:		27.9%

	XP	SuSE	XP / SuSE	savings:
MEAN across CPUs:	159.7 minutes	216.4 minutes	73.12%	26.88%

Overall power saving of SuSE LINUX across all CPU types tested:	26.88%

APPENDIX C

CPU STATISTICAL DATA

Figure 3 CPU statistical data

All CPU types

Data for all CPU types:	mean XP	std dev XP	mean SuSE	std dev SuSE	mean Power Savings	std dev Power Savings
	159.659	71.784	216.386	89.765	26.875%	9.541%

Pentium 4 Laptop Computers

Pentium 4	mean XP	std dev XP	mean SuSE	std dev SuSE	mean Power Savings	std dev Power Savings
t(22)=2.927, p=0.008	116.917	44.156	180.667	61.177	35.930%	6.072%
Fujitsu 2240	75.167	2.994	123.167	8.400	38.662%	5.897%
Toshiba Satellite	168.000	9.899	230.000	19.799	26.871%	1.991%
IBM A31p	154.000	6.481	242.250	13.525	36.360%	2.455%

Pentium M Laptop Computers

Pentium M	mean XP	std dev XP	mean SuSE	std dev SuSE	mean Power Savings	std dev Power Savings
t(14)=4.119, p=0.001	143.500	15.062	180.250	20.247	20.245%	4.415%
Dell 610a	132.000	12.910	161.750	5.737	18.510%	5.445%
Dell 610b	155.000	3.162	198.750	3.304	21.979%	2.793%

Centrino Laptop Computers

Centrino	mean XP	std dev XP	mean SuSE	std dev SuSE	mean Power Savings	std dev Power Savings
t(22)=2.766, p=0.011	179.333	40.379	226.333	42.824	21.240%	6.577%
Dell 510	171.000	11.203	214.600	13.667	20.133%	6.229%
Sony PCG-9W31	109.000	9.899	156.000	2.828	30.059%	7.614%
IBM R50p	215.800	10.545	266.200	14.906	18.820%	4.232%

Pentium III Laptop Computers

Pentium III	mean XP	std dev XP	mean SuSE	std dev SuSE	mean Power Savings	std dev Power Savings
t(22)=1.386, p=0.180	193.500	112.090	266.250	143.176	27.876%	10.305%
HP EVO N-600C	181.000	9.899	301.500	3.536	39.982%	2.580%
HP Pavilion N5350 3600	79.000	5.916	111.400	11.238	28.271%	10.793%
HP Pavilion N5350 6600	313.000	13.266	407.000	29.766	22.639%	8.133%

APPENDIX D

POWER SAVINGS BY MODEL

Figure 4 Power savings of Linux by laptop computer model

Linux Power Savings by Laptop	
Dell 610 #1	18.51%
R50p	18.82%
Dell 510	20.13%
Dell 610 #2	21.98%
HP N5350 6600	22.64%
Toshiba S20-A207	26.87%
HP N5350 3600	28.27%
Sony PCG-9W31	30.06%
IBM A31p	36.36%
Fujitsu C-2240	38.66%
HP N-600C	39.98%

Figure 5 Estimated power consumption for XP and SuSE

Laptop Computer	mAh battery	voltage	avg XP minutes	avg **XP Watts**	avg SuSE minutes	avg **SuSE Watts**	Linux power savings
Dell 610	4700	11.1	132	23.71	161.8	19.35	18.51%
R50p	6600	10.8	216	19.82	266	16.07	18.82%
Dell 510	4700	11.1	171	18.31	215	14.59	20.13%
Dell 610	4700	11.1	155	20.20	198.8	15.75	21.98%
HP N5350	6600	11.1	313	14.04	407	10.80	22.64%
Toshiba	8400	10.8	168	32.40	230	23.67	26.87%
HP N5350	3600	11.1	79	30.35	111	21.52	28.27%
Sony	4000	11.1	109	24.44	156	17.08	30.06%
A31p	7600	10.8	154	31.98	242	20.33	36.36%
Fujitsu	3600	14.4	75	41.38	123	25.25	38.66%
HP N-600C	4400	14.8	181	21.59	302	12.96	39.98%

Figure 6 R50p power comparison: SuSE, XP, and Vista

Laptop computer	**OS**	mAh	voltage	minutes	**WATTS**
IBM R50p	**SuSE**	6600	10.8	266	**16.07**
IBM R50p	**XP**	6600	10.8	216	**19.82**
IBM R50p	**Vista**	6600	10.8	121	**35.49**