CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Green Computing: Analysis of Power and Energy Consumption of Personal Computers

by

Baber Naeem

A thesis submitted in partial fulfillment for the degree of Master of Science

in the

Faculty of Computing
Department of Computer Science

2021

I dedicate my dissertation work to my family, teachers, and friends. The special feeling of gratitude to my loving parents for their love, endless support, and encouragement.

CERTIFICATE OF APPROVAL

Green Computing: Analysis of Power and Energy Consumption of Personal Computers

by

Baber Naeem

(MCS181015)

THESIS EXAMINING COMMITTEE

S. No.	Examiner	Name	Organization
(a)	External Examiner	Dr. Ayyaz Hussain	QAU, Islamabad
(b)	Internal Examiner	Dr. Mohammad Masroor Ahmed	CUST, Islamabad
(c)	Supervisor	Dr. Wazir Zada Khan	CUST, Islamabad

Dr. Wazir Zada Khan
Thesis Supervisor
May, 2021

Dr. Nayyer Masood
Head
Dept. of Computer Science
May, 2021

Dr. Muhammad Abdul Qadir
Dean
Faculty of Computing
May, 2021

Author's Declaration

I, **Baber Naeem** hereby state that my MS thesis titled "**Green Computing: Analysis of Power and Energy Consumption of Personal Computers**" is my own work and has not been submitted previously by me for taking any degree from Capital University of Science and Technology, Islamabad or anywhere else in the country/abroad.

At any time if my statement is found to be incorrect even after my graduation, the University has the right to withdraw my MS Degree.

(Baber Naeem)

Registration No: MCS181015

Plagiarism Undertaking

I solemnly declare that research work presented in this thesis titled "**Green Computing: Analysis of Power and Energy Consumption of Personal Computers**" is solely my research work with no significant contribution from any other person. Small contribution/help wherever taken has been duly acknowledged and that complete thesis has been written by me.

I understand the zero tolerance policy of the HEC and Capital University of Science and Technology towards plagiarism. Therefore, I as an author of the above titled thesis declare that no portion of my thesis has been plagiarized and any material used as reference is properly referred/cited.

I undertake that if I am found guilty of any formal plagiarism in the above titled thesis even after award of MS Degree, the University reserves the right to withdraw/revoke my MS degree and that HEC and the University have the right to publish my name on the HEC/University website on which names of students are placed who submitted plagiarized work.

(Baber Naeem)

Registration No: MCS181015

Acknowledgement

All praise is to ALLAH (S.W.T). The creator and Sustainer of all seen and unseen worlds. First and foremost, I would like to express my gratitude to ALLAH Almighty for his countless blessings upon me to complete this work. Secondly, I would like to express my sincerest thanks to my supervisor **Dr. Wazir Zada Khan** for her valuable guidance and assistance. I am sincerely grateful for her support, encouragement, and technical advice in the research area. She has taught me, both consciously and unconsciously, many techniques and strategies during my research. I pray for her well being and success in the future.

I am highly indebted to my parents and my family, for their support, assistance and encouragement throughout the completion of my degree. They form the most important part of my life after ALLAH (S.W.T). They are the sole source of my being in this world. No words can ever be sufficient for the gratitude I have for my parents and for my family. A special thanks to my sister for their support and encouragement during my studies. I express gratitude to **Dr. Yasir Noman Khalid**, Assistant Professor HITEC University Taxila for his assistance and cooperation throughout the Thesis. I would also like to extend my gratitude to **Mr. Muhammad Asif**, a Ph.D. Scholar at CUST and **Mr. Muhammad Usman**, Lecturer Fast University and a generous friend for his valuable support and guidance.

Finally, I am very thankfull to **Mr. Muhammad Nadeem Nadir**, and **Mr. Asad Hayat Khan** MS students at CUST, who are my research members and with whom I completed this thesis.

I pray to ALLAH (S.W.T) that may He bestow me with true success in all fields in both worlds and shower His blessings upon me for the betterment of all Muslims and the whole Mankind.

Ameen

Baber Naeem

Abstract

Green computing research is becoming a widespread research trend in research on the computing field. On the other hand, 30% of CO2 is carried into the planet by human activities and 50% by computing devices. We live in an Information Technology (IT) era where computers, data centers, servers, internet and other machines are often used in almost every industry. However, the high use of technology raises some concerns, such as extreme power consumption and a rising carbon footprint that has a negative effect on the environment. Many researchers have tried to solve this problem. In previous studies, different ways are used to meet this problem, by measuring the power consumption of data centre, HPC and many other computing devices. In this thesis, we focus on green computing measuring the power/energy of CPU, Disk, Main Memory and Screens of Six different types of personal computers (including desktops and laptops) using windows operating system. By using this experimental setup we analyse that CPU which consume more power can also execute the program into more parallel discipline. Moreover, SSD consumes more power as compared to HDD in read/write operations. Main memory of the same size with two number of slots can consume more power as compared to one slot.

Contents

List of Figures

List of Tables

Abbreviations

CPU	Central Processing Unit
GB	Gigabyte
HPC	High Performance Computing
HDD	Hard Disk Drive
ICT	Information and Communication Technologies
IT	Information Technology
LCD	Liquid Crystal Display
MB	Megabyte
SSD	Solid-State Drive
USB	Universal Serial Bus

Chapter 1

Introduction

We live in an age of Information Technology (IT) where in almost all industries computers, data centers, servers, internet and other machinery are used. The high use of technology, however, brings out some problems, such as extreme power usage and a growing carbon footprint that has a negative impact on the climate. These problems are increasingly causing demand for concerns about environmental change because of global public concerns about the use of energy, climate change, and the effects of these changes. The word Green IT was introduced in response to these problems in regard to projects that are based on reshaping IT into environmentally sustainable ways [1].

Green computing's aim is to reduce the practice of dangerous chemicals, allow the best use of resources over the entire product lifecycle and encourage the recycling of expired goods and factory waste. Computer peripheral devices are disposed of in the proper spot, otherwise they are polluted due to toxic chemicals. Lead, mercury and cadmium are the harmful chemicals. The lead used to solder the circuit board of the printer. The lead can affect our kidney, nervous and blood system. The mercury used to make batteries, switches. The mercury mixes with water to turn it as methylated maercury can damage our brain [2].

Green IT is a topic of research in computer science, but researchers have derived different Green IT concepts. Green IT or Green Computing is the process of

adopting policies and procedures that increase the performance of computing resources to minimize their use of energy usage and environmental effects [3] [4].
The amount of energy requirements for computing devices is increasing day by day as the number of these devices is growing. The rate for energy consumption of information and communication technologies (ICT) is increasing to its limits. It is estimated that ICT consumption will increase from 168 to 433 gigawatts (7% to 14.5%) by 2020 [5] . Hence, it is difficult to survive in future without focusing on the issue of growing energy consumption for computing devices. There is a sheer need to design the software and hardware in such a way that they consume less energy with increased throughput. This issue can be addressed by decreasing runtime of an application and designing energy efficient hardware.
According to Moore's law [6] the number of transistors will be double every 18 months. Furthermore, Moore's law for power consumption is describes as the power consumption of CPU is double every 18 months. It not only effects the temperature of but also increase the temperature of fans in computer system and total power of system.
Now a day's performance of computers has been advanced to the challenges that use computer daily life. Therefor heat issue is occurring on chip, circuit and CPU. Different types of cooling techniques are used to solve the problem and increase the performance of computer [7]. Currently, Energy consumption of applications have become a hot topic in research. An application is broken down into numerous chunks (functions or sets of functions within application) and each of the chunk is evaluated individually for energy consumption [5]. Moreover, researchers are also trying to introduce such tools which measure energy more accurately. These tools can help the developers to identify bottlenecks and hotspots in code. Consequently, they are able to enhance efficiency and optimize performance of software systems [8]. Monitoring the energy consumption of software system have gained considerable traction over last few years. Researchers are focusing on accurate model to estimate the energy consumption of software which sometimes use complex formulas or additional hardware resources [9]. According to research [10] any normal desktop with commonly used LCD (17 inches), consume 65-100 watts for system and 35 for screen. It consumed 874 kWh and it release 341 kg carbon

(CO2) in atmosphere, it is equal to driving 1312 km a normal car. Furthermore, techniques used by any OS to save power and energy consumption are not useful because systems can still consume energy while on any power saving mode like sleep mode, power saver and etc. On the other hand, 30% of CO2 is entered in planate by human's activities and 50% of caused by computing devices. Moreover, 90% Desktop Computers has lack of power management model Operating system should focus on green computing especially windows because there are 88-90% users use windows operating system.

In this study we use different types of personal computers, we can also use different types of energy profiling tools which are design to profile energy consumption of different components of a computer system. Moreover, we can run different types of software benchmark suits which are useful to utilize the specific components of a system. We analyze the results under windows platform because in previous studies no one can use windows OS and it is necessary because as discussed above 88-90% users use windows OS. The experiments are on intel processors which are commonly used.

1.1 Purpose

The purpose of this study is to make low power and energy consumption environment for computing and also resolve heat issue. Moreover, it will also focus on health issues.

1.2 Scope

The scope of this thesis is to investigate the bottlenecks of hardware and software which are cause of power wastage, heat issue and execution time in the domain of computer science. This study will help daily base computer users.

This study may also helpful to reduce the emission of heat which cause heat issues in the environment. Through this study we can build such a model which is helpful in power/energy consumption, Eco-friendly and environmental friendly.

1.3 Delimitations

The testing of three different benchmark suit application implementations will address in this thesis. This implies that there would not be any implementation from scratch. Also, to compare the effects of six different systems and find out what causes them, the study of the power/energy consumption will be carried out. The specific concentration is on the power/energy, for example.

1.4 Problem Statement

Current studies measured the power and energy consumption of the overall system during power-saving modes[10], power and energy consumption of the database system [11], power and energy consumption of different HPC applications, CPU GPU of HPC system [12], power and energy consumption of CPU, HDD and Memory in different VMs [13]. However, as identified from a critical assessment of literature, the current state-of-the-art studies haven't mapped the power and energy consumption of personal computers using windows operating system. Measurement of the power and energy consumption of CPU, HDD, Screen, and Main memory of personal computers will lead to identifying the power and energy wastage sources and bottlenecks causing energy and power wastages. Therefore, there is a need of a study to measure power and energy wastage in diverse personal computers and identify the probable bottlenecks that cause such wastages.

1.5 Research Question

Based on the research gap stated in the previous section, the following research questions were formulated in this thesis:

RQ1: Which component consumes more Power/Energy in personal computer CPU, HDD, Memory or Screen?

RQ2: Which processor architecture consume more power and what is the reason?

RQ3: How would you adapt your architecture to run with more energy efficiency?

Chapter 2

Backgroud

All theories concerning Power Consumption, Energy Consumption and features are discussed in this chapter.

2.1 Green Computing/Green IT/Green ICT

It is the study of designing, using and manufacturing of computer devices in a way that reduces environmental issues. Green Computing refers to durable computing of the environment. It is helpful to reduce the use of electricity as well as power and also for environmental waste by computing devices[14].

2.2 Green Computing Important

The world benefits from green computing. Reduced renewable energy use translates into lower emissions of carbon dioxide resulting from the reduction of fossil fuel used in power plants and transportation. It makes the environment pollution free from computer devices. It reduces the emission of dangerous gases in the earth. So it is necessary to implement those technologies in the environment which are designed according to green technology.

2.3 Power/Energy Profiling

Profile and monitor the usage of power and energy in a system. Different tools are designed for power/energy profiling[15] [16].

2.4 Power Consumption

In physics, power is the amount of energy transferred or converted per unit time. It is usually measured in watts or kilowatts. It is stated that used of electrical energy as per unit time, supplied to any electronic or electrical device [17].

2.5 Energy Consumption

Electric energy consumption is the form of energy consumption that uses electric energy. Electric energy consumption is the actual energy demand made on existing electricity supply[18] [19].

$$Energy = Time * Power$$

2.6 Green Software

The concept of green software is introduced in Energy Efficient Software as "Computer software that can be effectively and efficiently developed and used with minimal or no environmental impact".

2.7 Green Hardware

The concept of green hardware is introduced in Energy Efficient Software as "Computer hardware that can be effectively and efficiently developed and used with minimal or no environmental impact".

2.8 Hardware-Based-Tool

Monitor the power energy consumption of computing devices. These tools required some additional installation of hardware which are difficult to configure and also cost effective.

2.9 Software-Based-Tool

These tools are easy to use as compare to hardware-based. No need to install any hardware for this. Moreover, provides easy approach to all users and easy to configure.

2.10 Performance Monitoring

It is process of monitoring how applications are running on system and how much energy is consumed during execution. It is a set of tools and techniques to define how fast applications run[20].

2.11 Software Benchmarks

Benchmarks which are used to calculate and quantify the efficiency of certain elements of a given system; they are used generally to measure the performance on a wide variety of hardware platforms in combination with the power and energy usage of computations [21].

2.12 Power Monitoring Tools

Tools which are used to measure the power/energy of different components of computer devices. Some tools are hardware-based and some are software-based. Software base tools are easy to install and configured as compare to hardware [22].

2.13 Test System

Systems which are used to perform the experiments and running tools.

2.14 Linpack

LINPACK Benchmarks are a measure of the floating-point computing power of a device. It is designed to calculate the power consumption of CPU. The latest version of these benchmarks is used to build the TOP500 list, ranking the world's most powerful supercomputers [23].

2.15 Crystal DiskMar64

CrystalMark is a Storage benchmark and system information application from Crystal Dew World. CrystalDiskMark is designed to quickly test the performance of your hard drives to check power/energy consumption[24].

2.16 SpecView

The Standard Performance Evalution Corporation (SPEC) is a non-profit American corporation that seeks to "generate, create, maintain and endorse a standardized set " for computer devices, Founded in 1988. The SPEC CPU suites test CPU performance by measuring the run time of several programs such as the compiler GCC and the chemistry program games[25].

2.17 Joulemeter

It is a software-based tool which is used to monitor the power consumption of the system. It calculates the power of different computer resources such as screen brightness, CPU utilization and power usage. Power consumption is obtained by adding base power, CPU power, HDD power and screen power[26].

2.18 Intel Power Gadget

It is a software-based tool for windows platform it calculates the execution time of running application moreover, it calculates the average frequency used during execution as well as it calculates CPU power. Furthermore, it works only on intel-based systems[27].

2.19 Intel Vtune Amplifier

It is a software-based tool used to measure the processor utilization. For x86 based machines running Linux or Microsoft Windows operating systems, VTune Profiler (formerly VTune Amplifier) is a performance analytics tool.
On both Intel and AMD hardware, some features work on AMD, but advanced hardware-based sampling requires an Intel-manufactured CPU [28].

2.20 CPU

Central Processing Unit (CPU) is main component of the computer system that perform differently tasks. The CPU runs an operating system as well as different applications, also receiving the input from user and software programs [29].

2.21 Disk

It is a device that reads and/or writes data to a disk. Most common type of disk is hard disk drive but also exists other disk like a floppy. Data is permanently stored in disk, only removed when user remove it. There is a new version of the disk is SSD which is most faster then HDD [30].

2.22 Main Memory

It is just like a human brain to store data and information temporarily. Data is removed when computer powered off [31].

2.23 Monitor/Screen

It is an output device which is used to display the information to the users [32].

2.24 Personal Computer

A personal computer is a multi-purpose computer that is made possible for individual use by its size, capabilities, and price. Instead of a technical specialist or technician, personal computers are meant to be controlled directly by an end user.

2.25 Desktop

A desktop computer is a type of personal computer. Due to its size and power requirements, it is designed for regular use at a single location on or near a desk or table.

2.26 Laptop

A laptop or laptop computer is a small, portable personal computer, also known as notebooks, with a thin LCD or LED computer screen and an alphanumeric keyboard on the inside of the lower lid. They, with many of the same abilities, are designed to be more compact than conventional desktop computers. New laptops are ultra slim and these are very fast laptop. Laptop is easy to use as compare to desktop and one more advantage is that laptop never turn off while down the supply because of its battery backup.

2.27 Techniques for Managing Power Consumption

It is important to understand the ways in which energy consumption affects the greenness of any technology, especially computer technology, in order to find ways to reduce that consumption. There are a number of methods available that are common on most computers on the market today to control power consumption. These methods include adjusting the settings that control the actions of different software and hardware components, and thus power consumption.

2.27.1 Screen Savers

In green computing, screen savers are a bit of a misnomer. A common belief is that less energy is being used by screen savers. Actually, this is far from true. Screen savers can use as much or more power as if they were idle on your device. A complex screen saver or a 3D screen saver can often use more power than would usually be used by your device while idling. Screen savers can avoid sleep of the computer and CPU, which can waste a large amount of electricity.

2.27.2 Monitor Sleep Mode

It is a good start to increase energy efficiency by allowing the monitor to fall asleep after idling for a certain amount of time. Generally, a monitor falling asleep or joining the stand means the same thing.

The computer panel will go blank and there will be no light emitted from the display. On the display, there is normally a green light that tells the user that the monitor is switched on. The green light usually becomes amber when the monitor is in sleep mode. These modes are not helpful to save the power and energy of monitor because it just blank the screen of monitor nothing else. Monitor can only save the power and energy by using in on the low brightness mode. Operating system should focus on the power and energy consumption of monitor screen because it is also very important in power energy consumption area.

2.27.3 Hard Disk Sleep Mode

Similar to the sleep mode of the monitor, when not in use, a computer may place its hard disk drives in sleep mode. Hard drives on laptop computers tend to use less than desktop computers, but even more important are the energy savings on a laptop, particularly when the laptop is operating on battery power. There are several hard disk drives on certain desktops, workstations, and servers. It is possible to put hard disk drives that are not in use in Stand by Mode, while hard disk drives that are in use can be left on. This is controlled automatically for the user by the operating system.

2.27.4 System Stand By

One of the most valuable power-saving features computers have to offer is Machine Stand by. A machine would shut down most of its components after a pre-set duration of idling, giving us considerable energy savings. The memory will stay active so that when the device wakes up from Stand By mode, whatever the user was working on will still be there. That's more than 20 times less power used when idling than when idling. Another benefit of the Stand by Mode system is that the machine will wake up in a couple of seconds.
This is much quicker than fully shutting down a computer and booting it back up. Another convenient way to use Stand by is to customize the power button of the machine to send the computer into Stand by mode rather than shut it down. This feature would allow a user to instantly send a device to Stand by, instead of waiting for some time to idle until it is automatically placed into Stand by mode. Configuring the power button of a device to serve as a stand-by button can be done by adjusting the power options of the computer in the control panel. But in stand by mode system continuously consumes some part of power and energy with respect to time. Stand by modes are some how beneficiary in power and energy consumption scheme but not fully helpful in power and energy consumption. Standby is not much better technique but little bit helpful.

2.27.5 Hibernate

The Hibernate functionality is comparable to the Stand by mode system. Hibernate goes a step better than Stand By and turns the machine off completely. The Hibernate function will save the memory state on the hard disk drive prior to turning the device off.

2.28 Summary

The chapter has been started from the introduction of green computing. After defining the green computing importance of green computing also discussed in the same chapter. Moreover to this define power and energy consumption and tools used to measure the power and energy consumption also discussed. Benchmarks which are used to measure the power and energy consumption are defined. Techniques which are used to map the power consumption are discussed at the end of the chapter.

Chapter 3

Green Computing Types and Advantages

In this chapter history of green computing, types of green computing, goals of green computing, importance of green computing and etc are discussed

3.1 What is Green Computing

Green Computing refers to sustainable computing that is stable. This eliminates the use of power as well as electricity, because when we use a machine, it reduces environmental waste. It is similar to igreen chemistry, which has become the life of the product and makes the product more energy efficient, the abandoned product and industrial waste are easier to recycle and biodegrade, less harmful use material, it has the same purpose.

3.2 History of Green Computing

Do you aware of how much energy your computer uses? If you do research, you probably don't know, then you will realize that green computing is more important for saving the energy of your computer. The beginning of Green Computing was named Energy Star, and it originated in 1992. This Energy Star was used in all electronic products, such as printers, televisions, and refrigerators, saving more energy in that period, but not in computers. When this term used in computing, it becomes green computing.

3.3 Green Computing's Objectives

The aims of green computing are different:

- More Energy Efficiency Production.
- To make use of the recyclability of waste materials and wasted products from factories.
- Designing proper algorithms to increase the performance of the computer
- Designing proper energy efficient software.

3.4 Types of Green Computing

3.4.1 Solar Power System

We use sunlight in this program and generate solar power for personal and commercial use. For the introduction of this technology, Canada, Spain and California have the first place. For green technology, this is an outstanding accomplishment. When we talk about green computing, photovoltaic solar panels are the most miraculous example, since energy is easily transformed into electricity.

3.4.2 Wind Turbine Program

Another great type is the wind turbine system, since everyone can produce electricity with the aid of this system. There is no bad effects on the atmosphere after the wind turbine is built. It lowers emissions of carbon dioxide. But you need a massive amount of money to set up a wind turbine, so it's not possible for everybody.

3.4.3 Geothermal Power

This is also exclusive type of green technology. With the help of this Geothermal plant can be generated electricity, and people can utilize of this power in daily usage such s heating and cooling house.

3.5 Need of Green Computing

- Save large amounts of money
- Save the atmosphere
- Reduce the risks of other lives
- For Waste Product Recycling

3.6 Green Computing Applications

There are several places where green computing applications are used:

- Manage the energy in Data Centers
- Green Cloud Computing in Energy Efficiency
- Green Wireless Network
- With Big Data Structures, Green Parallel Computing
- Green Parallel Computation, with Large Data Structures

3.7 Green Computing Examples

- Renewable Energy Sources
- Renewable sources of energy, do not use fossil fuels.

They are readily available, are eco-friendly and produce less emissions. Apple, which is constructing a new corporate center, is preparing to use much of the wind turbine technology in the building, and a wind-powered data center has already been built by Google.

3.8 Approaches to Green Computing

3.8.1 Power Management

Computer modules consume more power in old technology in which there is no proper control to supply power to all parts of the computer.

3.8.2 Power Supply

In our old computer system, 60 percent of the power supply is used, and 40 percent is lost, but now in green computer technology, PC performance is increased.

3.8.3 Storage

To store some data, our hard drive consumes more power, so now you need the new technology.

3.9 Green Computing Advantages

- Save Energy Money and Resource

- Increase performance
- Resource management means that manufacturing, using and disposing of goods requires less energy
- Reduce of carbon Dioxide, which is harmful
- Reduce Environmental pollution, save environment

3.10 Conclusion of Green Computing

At the simplest stage, in the case of upfront investment, green computing is not a rocket science and definitely does not involve massive sums of cash.

3.11 Summary

Chapter 3 explains the green computing, its history, objectives, types and advantages of green computing in details. It also contains applications, examples and approaches of green computing

Chapter 4

Literature Review

Green IT (GIT) is an example of a green growth program aimed at improving efficiency and productivity Via sustainable consumption and growth of the resources of organizations and society. With GIT, organizations in Information Technology (IT) have achieved successful processes with minimal carbon wastage. The short life of IT products, however, as well as some production and disposal processes, have led to widely reported concerns about negative impacts, such as increased use of energy by organizations. Moreover, the carbon emissions of IT products and systems also surpasses that of the pollution of the aviation industry. Green computing solves environmental concerns[33][34].

We have conducted a detailed literature review on energy consumption devices. Our analysis suggests that recent work done by the experts in field of Energy Consumption is divided into two main strains of research 1) Hardware 2) Software. There are mainly two major ways to calculate the measure of energy consumption of a computing device i.e. hardware and software. In the following Section we discuss the state-of-the-art techniques used in recent literature from these two domains.

Hardware monitoring is achieved with the help of using different additional hardware components e.g. multimeters or specialize integrated circuits. Moreover, such hardware solutions include power meter [35] and specific circuits or sensors. Through these approaches we can calculate the exact and accurate measurement of energy consumed by hardware component. The energy consumption solution based on hardware have more cons than pros. These solutions provide us with fruitful results however they require additional investment and difficult installations [36] [37]. Hardware devices, such as hard disk or network interface which are available in different varieties, run on different power modes [9]. It is not always enough to estimate the energy consumption of hardware devices based on a specific workload we also need to measure the energy which is consumed by the drivers associated with a specific hardware component. Moreover, It is also possible that a low power device consumes more energy than operating device in case if we allow CPU and drivers to interrupt. Now a day, running average power limit (RAPL) feature is available in Intel Sandy Bridge and Ivy Bridge CPUs that uses the concept of optimizing energy by using hardware systems [38]. As it gives us permission to monitoring the power consumption of the whole CPU package.

Similarly, PowerMon2 [39] is a micro-control-based device which can estimate power up to eight power channels of power supply. PowerMon2 makes use of digital power meter to estimate power consumption. It is connected via USB and installed in 3.5” drive bay to collect the sample of power via API. Finally, the results are provided to the end user with a maximum frequency measure up to 3khz.

PowerPack [40] is an NL-Based model which can measure the hardware power. It is accompanied by a software which is working on backend which can support more power measurement devices such as Watt’s Up Pro, NL and Radio Stack. This approach tends measure the energy consumption of specific code segments with the help of additional software component. However, the main problem with this type of devices is cost of these devices.

As energy monitoring is usually measured by hardware monitoring tools, such as power meter or custom-made circuits. But these models/devices are not successful on large scale because these are too much expensive. Moreover, these models can consume the power of whole system rather than a single software component or current applications being executed.

As mentioned earlier, there are more cons than pros of hardware-based energy consumption measurement tools. Hence, in this research our focus is on measuring energy consumption based on software tools. Software based techniques are quite better than hardware approaches as it could not require any additional hardware. These tools provide us software energy measurement such that how much energy is consumed by software? Consequently, this task is done in minimized cost as compared to hardware. But some tools use power meter to introduced their models and some tools start estimating of energy measurement of the application when the application is executed. Whereas, some tools make changes in the source code of applications to estimate the power consumption.

Songkran et al [7] they experimentality study thermal cooling enhancement. They monitor the system with and without using thermal system. They conclude the result that by using thermo-electric air cooler module the temperature of CPU is reduced very fast and performance is increased but also increase the power consumption due to extra equipment added in system. They performed their experiments on dual processor computer.

Guohui et al [6] introduced a 1-mm-thick miniature loop heat pipe (mLHP), this design for ultra slim laptop, this technique is used to solve heath issue of CPU and performance. Moreover, it is required to install extra hardware in system

Jolinar [41] is one of the best tools for measure energy consumption. It requires low space and is easy to install. Moreover, it is not dependent on any hardware component and does not interfere or modify the source code of an application. It can provide accurate information and any one can understand it easily. Further Joulemeter (windows based) [42] and PowerTop (Linux based) [43] are also some examples of popular energy measurement software tools.

Adel et al [44], in their research with the help of jolinar they discuss the energy consumed by algorithms depending on their run time activities. They selected Chudnovsky's algorithm and Ramanujan's algorithm which are used to calculate the numbers of digits in Pi. The digits range for Pi was set in a range from 10 to 100 million digits. According to their analysis, Chudnovsky's algorithm consumes less energy as compared to Ramanujan's algorithm. Adel et al [36], measured the energy consumption for the FileZilla server. FileZilla consumed 6.73 Joules in a benchmark run consisting of sending and receiving 5 files to an FTP server, with most of that energy (5.85 Joules) being consumed by the processor (86% of the total energy of the application).

Von et al [45] measure energy of different CPU's and systems. For this purpose, they select three different types of systems, one is older and others with new technology. Moreover, they run test with turbo on and off. They also run tests on more than one samples of same processor and find the variation of result. They find that idle is the most extreme case for results, also find that LINPACK and LU consume more energy rather than others.

Chen et. Al. [46] profile energy consumption of different virtual machines and a host with three parameters i.e. power, efficiency and energy. They build a power model on single cluster node which profile power consumption of CPU, HDD and Memory of single work node. They run different benchmarks on host and vCPUs (all have same specifications, only vCPUs have different numbers of cores) and show the differences in results.

Ibrahim et al [47] monitor the performance and power consumption in Hadoop clusters. They measure the power and performance of MapReduce, how over they focus on MapReduce processing and impact of dynamical scaling on power and performance. They use Grid' 5000 cluster and PI, Grep, Sort as a benchmark. They do experiments under different DVFS settings (i.e. different CPU frequencies). They also show results that CPU bounded applications utilized more energy, as compare to others. Also show that memory bounded applications give same response on high frequency as well as on low. They conclude result that these changes in frequencies are not affected on Hadoop power saving.

Dimitris et al [11] measure the energy consumption of database system, scale-out(shared-nothing) single date base node. They developed their own set of micro-benchmarks like hashing, sorting and scans moreover, these benchmarks hit the all cores as well as other shared resources. They conclude a result in most of experiments that best performance is also the most energy efficient. They run mostly programs in parallel as well as in linear, in linear execution less energy used.

Enida et al [12] briefly surveyed different models and techniques which are developed to monitor power and energy consumption of different HPC. The best thing in the survey is that they classified their survey into power consumption of different components like CPU, GPU, XEON PHI and FGPA and High-Performance Computing Applications (Interconnects and communications). They also conclude that these apps consumed 30-40% energy of system. They also show that dynamical models are best, and for batter power consumption monitoring long execution applications are best.

Joulemeter [48] is a software tool which is used to monitor the power consumption of system. It calculates power of different computer resources such as screen brightness, CPU utilization and power usage. Power consumption is obtained by adding base power, CPU power, HDD power and screen power.

In [10] paper the survey on different energy saving techniques in OS like power saver, screen saver and etc.

They measure power consumption of system while it is on sleep mode or following any other power saving mechanism and conclude a result that during activation of these power saving techniques system can also consume the energy, it is also because of time-out based so it is not enough for minimizing the power consumption. OS should develop intelligence scheme to sense human inactivity.

Girish et al[13] the yearly energy consumption of a data is equal to 120 million of houses, due to this heat dissipation increase and CO2 released due to this more energy consumed, environmental issues also increased.

Nguyen et al[49] the relevance of Green Computing is seen in this research paper. We should recognize the need for green computing, and the appropriate steps for a sustainable environment should be taken:

1. Use LCD instead of CRT Monitor.
2. Turn screen brightness on low power.
3. When made, computers and their components use hazardous chemicals and when we use informal disposal, they have adverse effects on our environment. But we have to use formal disposal to mitigate or decrease these damaging impacts.
4. Screen savers often absorb power even though a system is not in operation. A picture, text or image can be a screen saver that displays.
5. Screen saver mode is not helpful.
6. Turn screen brightness on high power consumes more energy.
7. It is important to use monitor on low brightness.

If not, we will suffer from air pollution. So we should take the steps of understanding the significance and need of Green Computing with a little sense of understanding.

Pham et al[13] In embedded microprocessors, this paper deals with the reduction of power consumption. For embedded device applications, computing power and energy conservation are becoming the key challenges. A significant requirement for these systems is the long service life when the power supply is provided by batteries. This work explores a method for minimizing energy consumption for microprocessors, based on the use of hardware accelerators. Their usage allows the execution time to be reduced and the clock frequency to be reduced, thus reducing the consumption of power. The experimental results show that the use of a hardware accelerator dramatically reduces the consumption of fuel.

4.1 Summary

The critical review depicts through table 3.1. There was no evidence of these analysis in previously done work. Due to the absence of these analysis in review of literature we chose these analyses for study where we analyzed that these analyses doing work on datacenter, clusters and virtual machines. Moreover, in the case of personal computers power/energy consumption have been done with Linux operating system, windows is commonly used operating system in the world so researchers should gave attention to this side.

One more thing is that most power monitoring tools are hardware-based which are cost effected and difficult to install. Software based tools are better then hardware. So it is batter that we can use software tools as compare to hardware tools because of its difficulties in installation and configuration.

On the other hand software tool is very comfortable and reliable as it is available at very low cost and mostly avaiable on internet free of cost. But hardware based tools are available on very high cost and difficult to install. As these are easy to install and also easy to usable.

TABLE 4.1: Critical Table of Literature

Ref	Tool	Operating System	Components	Bench Mark	Software/ Hardware	System	Remark
[39]	PowerMon2	N/A	CPU, Applications	NAS, BT and SP	Hardware	Computer	Cost Effective
[40]	PowerPack	N/A	CPU, Disk, Memory, CPU Fan and Motherboard	NPB, Spec, NAS	Hardware, Software	Cluster	Cost effective
[41]	Jolinar	Linux	CPU, Disk	Chudnovsky's algorithm and Ramanujan's algorithm	Software	Computer	Easy to use
[46]	Data logger,	Cent OS	CPU, Disk,	Linpack, Dhrystones and Fhourstones benchmarks	Hardware	VMs on Cluster	Cost effective
[11]	BrandElectronics 20-1850 CI	N/A	CPU, Disk	Own benchmarks (hashing, sorting)	Hardware	Data base	Cost effective
Prop-osed	Joulemeter, PowerGadget, VtuneAmplifier	Windows	CPU, Disk, Memory, Screen	Linpack, Specviiew, CrystalDisk Mark	Software	Personal	Easy to use

Chapter 5

Research Methodology

The systems used in the research project are mentioned in chapter three. The research methodology used in this report, the research design, the data collection process, specifics of the analysis and ethical approvals needed for the research purpose to be obtained are included in this research design chapter. Green computing's aims are similar to green chemistry: reducing the use of toxic chemicals, optimizing energy production over the life of the device. The goal of this research is to develop an energy-efficient system, protect the environment with pollution, improve the use of computer equipment, and develop environmentally friendly production practices.

Our tests are made up of benchmarking suites that are designed to calculate the power of various components of the device. We used two desktops and four laptops from different vendors with different specifications in this report, one more thing is that two laptops are equipped with new hard drive technology called SSD and the remaining four PCs(two laptops and two desktops) are equipped with HDD(which is old).

We mounted Windows 10 on all of the test systems. On each device, we configure three different power monitoring tools and install the three different benchmarks on them as well. On six different systems, we ran each benchmark, each benchmark is tested with three different power monitoring tools, Intel Vtune amplifier, Intel power gadget, core temp and joulemeter. Intel Vtune is used to collect CPU time and parallelism in a program. Intel power gadget is used to collect elapsed time, CPU utilization, CPU temperature and main memory power. Joulemeter is used to collect the power of hard disk, CPU and screen. Coretemp is used to calculate the numbers of processor cores and their max/min temperature.

Systems which are used for experiments are listed below with specifications.

TABLE 5.1: Test System #1 - Laptop

Brand	**SAMSUNG ELECTRONICS CO., LTD.**
Operating system	Microsoft Windows 10 Pro
Processor	Intel(R) Core(TM) i5-2450M CPU @ 2.50GHz, 2501 Mhz, 2 Core(s), 4 Logical Processor(s)
Memory	2X 4.00 GB
Hard disk	ST500LM012 HN-M500MBB Type: HDD
Optical drives	DVD Writer
Power supply	N/A
USB devices	N/A
Screen	LED backlight widescreen 12.5” HD display
Display	Intel(R) HD Graphics 3000 2.00 GB RAM

TABLE 5.2: Test System #2 - Laptop

Brand	**Hewlett-Packard**
Operating system	Microsoft Windows 10 Pro
Processor	Intel(R) Core(TM) i3-4030U CPU @ 1.90GHz, 1901 Mhz, 2 Core(s), 4 Logical Processor(s)
Memory	2X 4.00 GB
Hard disk	TOSHIBA MQ01ABD050V Type: SSD
Optical drives	N/A
Power supply	N/A
USB devices	N/A
Screen	LCD Screen 15.6” WideScreen HD (1366x768) New Grade A+
Display	Intel(R) HD Graphics Family, Intel Corporation compatible 1.00 GB RAM

Table 5.3: Test System #3 - Laptop

Brand	Hewlett-Packard
Operating system	Microsoft Windows 10 Pro
Processor	Intel(R) Core(TM) i3-4030U CPU @ 1.90GHz, 1901 Mhz, 2 Core(s), 4 Logical Processor(s)
Memory	2X 4.00 GB
Hard disk	TOSHIBA MQ01ABD050V Type: HDD
Optical drives	N/A
Power supply	N/A
USB devices	N/A
Screen	LCD Screen 15.6" WideScreen HD (1366x768) New Grade A+
Display	Intel(R) HD Graphics Family, Intel Corporation compatible 1.00 GB RAM

Table 5.4: Test System #4 - Laptop

Brand	Hewlett-Packard
Operating system	Microsoft Windows 10 Pro
Processor	Intel(R) Core(TM) i9-9880H CPU @ 2.30GHz, 2304 Mhz, 8 Core(s), 16 Logical Processor(s)
Memory	32 GB
Hard disk	ST1000LM049-2GH172 Type: SSD
Optical drives	N/A
Power supply	N/A
USB devices	N/A
Screen	15" diagonal FHD IPS Anti-Glare micro-edge WLED-backlit Display (1920 x 1080) with 144Hz refresh
Display	N/A

All the Test Systems are equipped with different types of processor, main memory, hard disk and screens. Moreover, Test System # 2 and 3 are equipped with SSD and remaining Test Systems are equipped with HDD.
The difference between these system is only that some Test systems are equipped with same one memory slot and some are equipped with two.Moreover, Test systems are equipped with different type of LCD screen according to the manufacturing of Test System some are good and some are bad in performance.

All the Test Systems are equipped with different types of processor, main mem-

Table 5.5: Test System #5 - Laptop

Brand	**LENOVO**
Operating system	Microsoft Windows 10 Pro
Processor	Intel(R) Core(TM) i5-8500 CPU @ 3.00GHz, 3000 Mhz, 6 Core(s), 6 Logical Processor(s)
Memory	8 GB
Hard disk	WDC WD10EZEX-08WN4A0 Type: HDD
Optical drives	DVD Writer
Power supply	PS3 180W 70+ (Worldwide) 280 Watt (Japan), 80% plus, auto-sensing power supply unit 110/220 volt (50/60Hz)
USB devices	Keyboard, Mouse
Screen	15” diagonal FHD IPS Anti-Glare micro-edge WLED-backlit Display (1920 x 1080) with 144Hz refresh
Display	Intel(R) UHD Graphics 630 Adapter 1.00 GB RAM

ory, hard disk and screens. Moreover, Test System # 2 and 3 are equipped with SSD and remaining Test Systems are equipped with HDD.
The difference between these system is only that some Test systems are equipped with same one memory slot and some are equipped with two.

Table 5.6: Test System #6 - Laptop

Brand	**DELL**
Operating system	Microsoft Windows 10 Pro
Processor	Intel(R) Core(TM) i3-4130 CPU @ 3.40GHz, 3400 Mhz, 2 Core(s), 4 Logical Processor(s)
Memory	2X 4.00 GB
Hard disk	ST500DM002-1BD142 Type: HDD
Optical drives	DVD Writer
Power supply	N/A
USB devices	Keyboard, Mouse
Screen	15” diagonal FHD IPS Anti-Glare micro-edge WLED-backlit Display (1920 x 1080) with 144Hz refresh
Display	Intel(R) HD Graphics 4400 1.00 GB RAM

5.1 Diagram

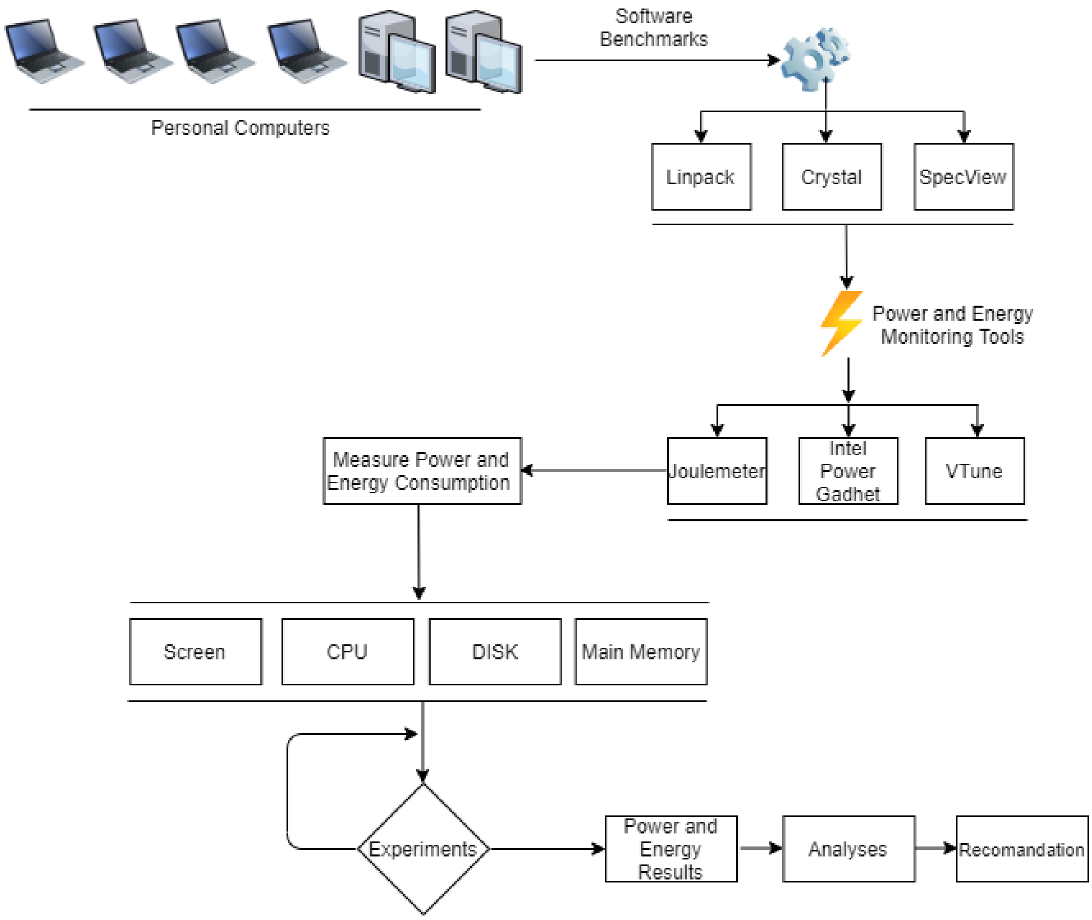

FIGURE 5.1: Methodology Diagram

5.1.1 Systems Under Test

In this thesis, we used six different personal computers as a test system. Four laptops and two desktops, two laptops are the same in specifications but different in secondary storage i.e one laptop is equipped with HDD and other is equipped with SSD. Remaining systems are different from each other. The system under test # 2 and 4 are equipped with SSD and system under test # 1,3,5 and 6 are equipped with HDD which is old technology. Furthermore, system under test # 1 and 5 are equipped with Core i5 processor, system under test # 2,3 and 6 are equipped with Core i3 processor and system under test # 4 is equipped with Core i9 processor. Moreover, system under test # 1 is 2nd generation and system under test # 2,3 and 6 are 4th generation and all are equipped with 2x 4GB RAM,

system under test # 4 is 9th generation and equipped with 1x 32GB RAM and system under test # 5 is 8th generation and equipped with 1x 8GB RAM.
Only one system is equipped with 32GB RAM. All the system under test are based on intel architecture.

5.1.2 Benchmark selection

In benchmark selection, we select three standard benchmarks i.e Linpack, Crystal, and Specview. These benchmarks are used to utilize the power and analyses the system performance of different components of a system.

5.1.2.1 Linkpack

Linpack Benchmarks are used to measure the system floating-point value. In 1979, the LINPACK benchmark study first appeared as an appendix to the user's manual for LINPACK. In the late 1980s, LINPACK Parallel benchmark also implemented parallel processing.
The latest version of these benchmarks is used to build the list of TOP500, ranking the most powerful supercomputers in the world. In this thesis, this benchmark is used to calculate the CPU power of various systems under test.

5.1.2.2 CrystalDiskMark

It is an open-source disk drive benchmark tool for Microsoft Windows. It works by reading and writing through the filesystem in a volume-dependent way. CrystalMark is a Storage benchmark and system information application from Crystal Dew World.
CrystalDiskMark is designed to quickly test the performance of hard drives. In this thesis, CrystalDiskMark is used to measure the power of HardDisks.
CrystalDiskMark is one of very best benchmark for read/write operation.
It is designed to perform read write operations and check the performance of read/write operation of a disk.

5.1.2.3 SpecView

The SPEC CPU suites test CPU performance by measuring the run time of several programs such as the compiler GCC and the chemistry program games. SPECviewperf 7.0 provides new functionality to capture graphics features from actual applications more accurately. It is a project group of the Graphics Performance Characterization (GPC) Group, part of Standard Performance Evaluation Corp. (SPEC).

5.1.3 Power and Energy Monitoring Tools

In this section, we used different power and energy monitoring tools. These tools are designed to measure the power and energy consumption of different components of windows based personal computers. Moreover, these tools are designed for Intel processors, and only configured on windows.

5.1.3.1 JouleMeter

JouleMeter is a software-based tool which is used to monitor the power consumption of the system. It calculates the power of different computer resources such as screen brightness, CPU utilization and power usage. Power consumption is obtained by adding base power, CPU power, HDD power and screen power.

5.1.3.2 Intel Power Gadget

Intel power gadget is a software-based tool for windows platform it calculates the execution time of running application moreover, it calculates the average frequency used during execution as well as it calculates CPU power. It is only designed for intel systems.
Furthermore, it works only on Intel-based systems. It is designed for windows operating system.
Windows tools are very helpful because mostly users use the windows operating system.

5.1.3.3 Intel Vtune Amplifier

Intel vtune amplifier is a software-based tool used to measure the processor utilization. It also works only on Intel based systems. Moreover, this tool is also used to check parallelism in a program.

5.1.4 Measure Power and Energy Consumption

in this section, we measure the power and energy consumption of different components of systems. We measure the power and energy of Disk, CPU, Screen and RAM. One by one we measure the power and energy consumption of all systems. In the next session, we discussed how we can measure the power and energy consumption of these components.

5.1.5 Experiments

In this session, we do experiments on different systems, ran different software benchmarks and power and energy monitoring tools as discussed previously. We ran these software benchmarks various times on each system. We ran Linpack benchmark one to five time with 15000 numbers of equations and also ran it again with one to five time with 20000 numbers of equations. This is specifically used to measure the power and energy of CPU.

We ran Crystal diskmark on each system with different numbers of times to measure the power and energy consumption of disk. We also ran this benchmark with different data size, performed read and write operations. We ran this benchmark one number of time with different test size i.e. 16MB, 32MB, ..., 8GB and set MB/s as a test unit.

First, we ran this benchmarks with joulemeter, intel power gadget and CoreTemp to measure the power and energy of RAM, CPU, Disk, and Screen we also measured the CPU utilization, Cpu temperature, Numbers of cores and there min/max temperature and elapsed time of the total process. Secondly, we ran benchmark with Vtune amplifier to calculate CPU time and parallelism in program.

5.1.6 Results

In this session, all of the benchmarks are run on all test systems using windows 10. These benchmarks are run using instructions which are discussed previously. Each benchmark is discussing in the previous section and results will b discussed in the upcoming section.

5.1.7 Analyses

Some of our results are expected and some surprised us. Laptops consume less power as compare to desktop. One more surprising thing is that SSD consumes more power than HDD. Further analyses are discussed in detail in the next chapter.

5.1.8 Recommendation

It will be discussed in the next chapter.

5.2 Summary

Research Methodology is discussed in chapter 5. All the benchmarks and power monitoring tools are ran on the system under test and Power/Energy consumption of CPU, Disk, Screen and main memory is measured.

Chapter 6

Results and Analysis

All of the benchmarks were run against on all systems. We ran three different benchmarks on all of the systems which are specifically designed to utilize the power of the specific component, for example, we use Linpack benchmark which is used to utilize CPU similarly we also use the SpecView benchmark which is also used to utilize the processor power, the third benchmark which we use is Crystal, it is design to test the power of Disks, it performs read/write operations. These benchmarks are run with power/energy monitoring tools, which are Intel power gadget, Joulemeter and Intel Vtune amplifier. These tools can monitor the power/energy of different components like Disk, Cpu, Screen and RAM, additionally, they also measure the CPU utilization, elapsed time and temperature of CPU. We can describe the results of our experiments below.

6.1 Linpack Results

We ran Linpack on all system under test with different numbers of time and input size. We ran this benchmarks on each system one time and measure the result, then we ran it again two-time, three-time, four-time and five-time, then measure the results. We measure Power/Energy with 1 to 5 different number of test and data size which is Quick 2GB and Standard 3GB.

6.1.1 Quick 2GB

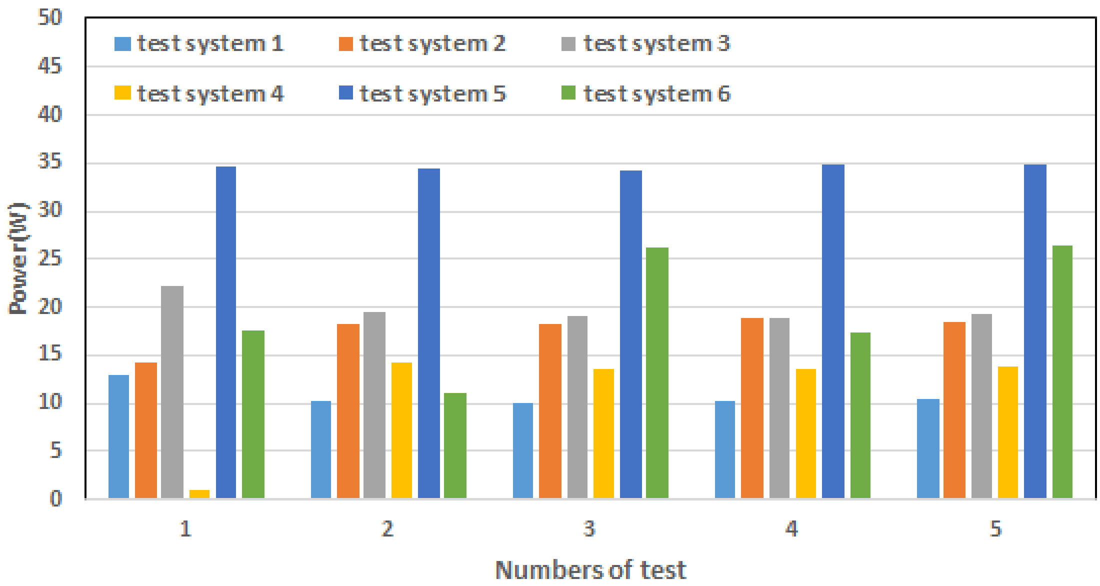

Figure 6.1: Power Consumption with Quick 2GB

Fig 6.1 depicts the scenario of power consumption of all the test systems. In the above figure, we can see the difference in the power consumption of all the systems. In the figure, we can see that test system 1 consume less power as compare to the test system 3,5 and 6, this is because of the clock speed of CPU's, CPU with high clock speed consume less power as compare to low clock speed CPU.

We compare test system 1,3,5,6 because these are equipped with HDD, we can compare the results of test system 2 and 4 which are equipped with SSD, in this scenario the result is same that CPU with high clock speed CPU can consume less power as compared to CPU with low clock speed. The other thing we observe in the result is that test system with the same specification but the difference in Disks(test system1 is equipped with SSD and 2 is equipped with HDD), test system with HDD consumes more power as compared to test system with SSD.

Fig 6.2 depicts the execution time of all the systems. We observed that test system which consumes high power can also take less time to execute the programs and test systems which consumes low power can take much time. Moreover, in the

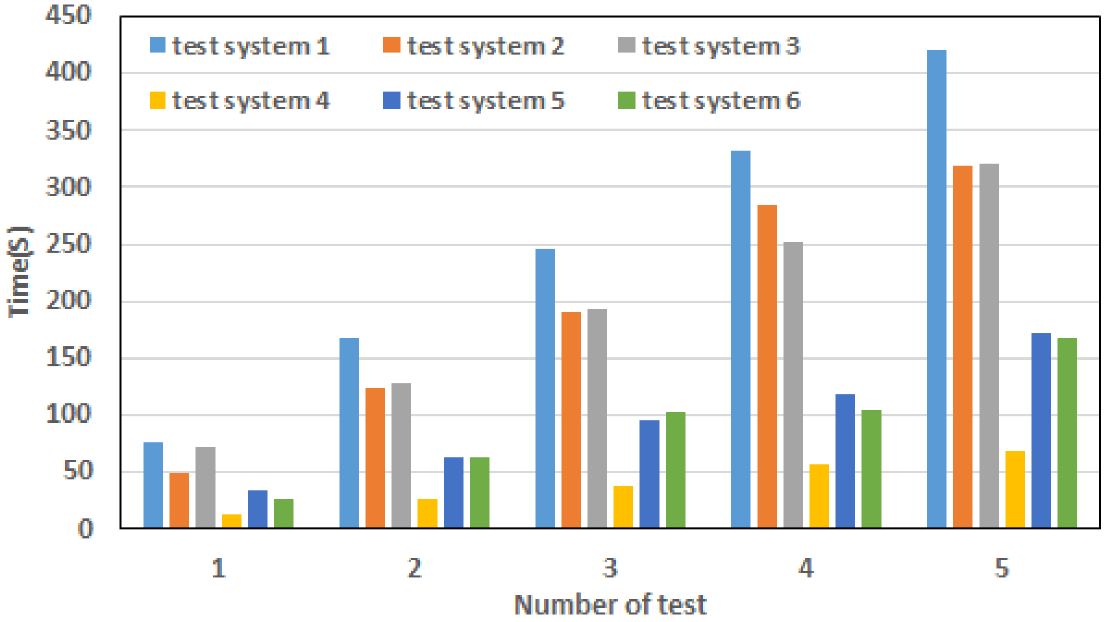

Figure 6.2: Time Taken by Quick 2GB

case of SSD the scenario is same.

Fig 6.3 shows the graph of energy consumed by Quick 2GB. In this scenario, the

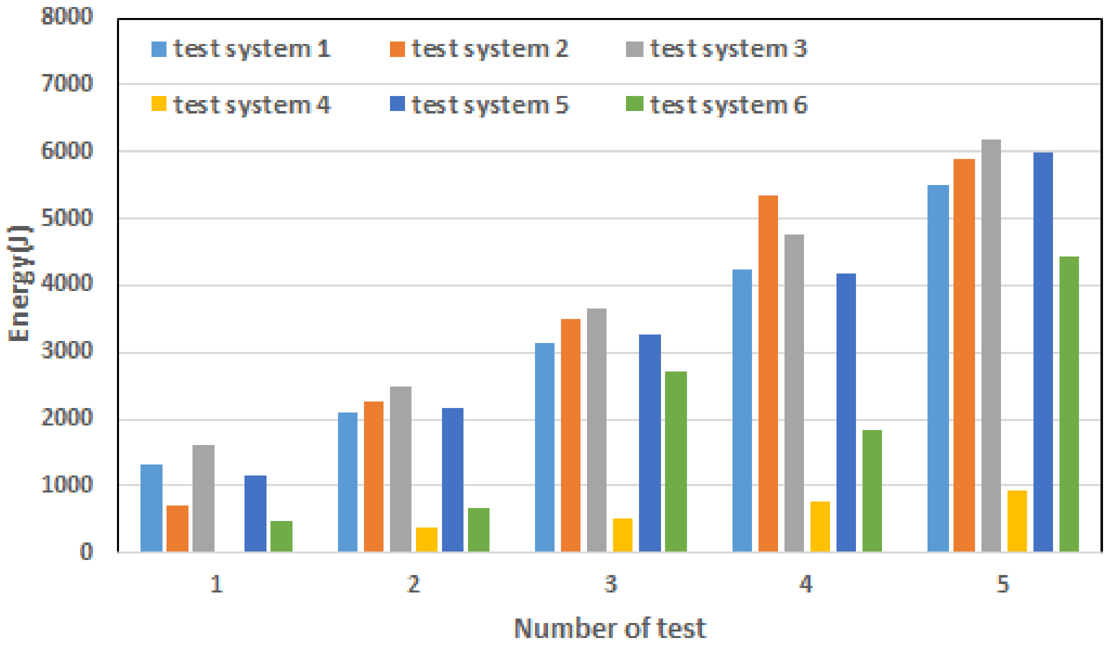

Figure 6.3: Energy Consumption with Quick 2GB

results amazed us that we thought systems which consume less power are energy efficient but, our assumption is wrong when we find out that there is not such a big difference in energy consumption of all of the systems because the systems which consume less power can take more time to execute and the system which consume more power they also take less time to execute the program. However, in the case of SSD, we find that processor speed is good in some cases and some cases very good.

6.1.2 Quick 3GB

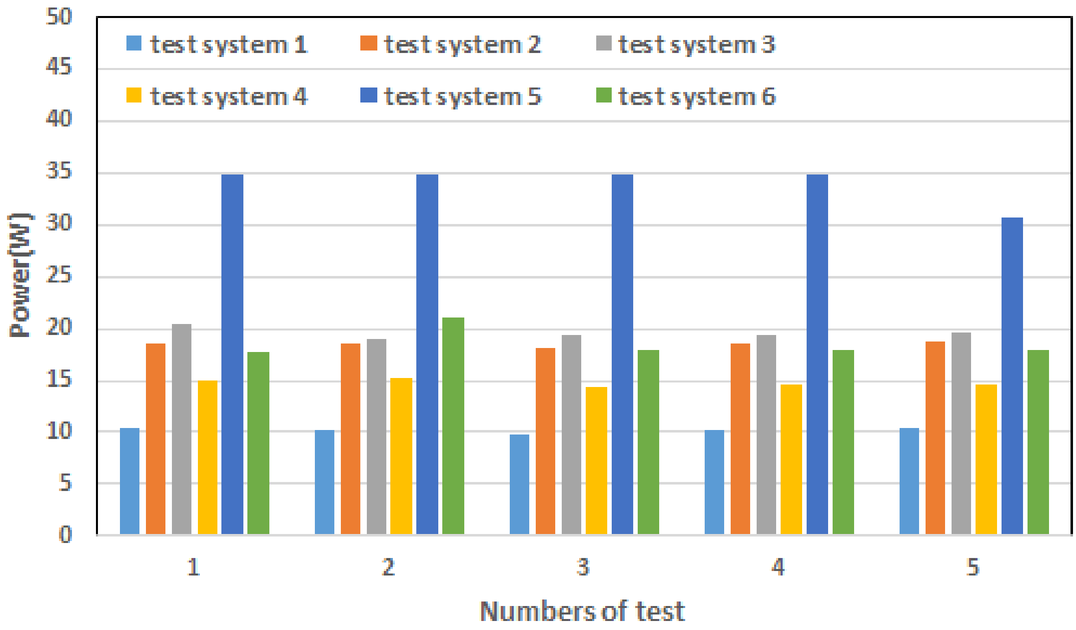

Figure 6.4: Power Consumption with Standard 3GB

We ran a standard 3GB program of Linpack on all of the test systems which are used in this thesis. We observed some minor changings in the power consumption of systems but mostly the scenario is same as Fig 6.1, 6.4 depicts the whole scenario. We observe that when we run number of test 1 time first system increased the power consumption a little bit test system 2 decreased the power consumption a little bit, system 4 increased power valuable power consumption and remaining two systems lie in same category. But in other numbers of test the result of power consumption of test system 1,2,3,4 and 5 is almost near to same but test system 6 increase the power consumption on 2,3 and 5 numbers of tests.

Fig 6.5 we observed the same results as we observed in Fig 6.2 that test systems which consume less power mostly they take more time to execute the benchmark. One more thing we observed that both test system 1 and 2 which are same in specifications but the only difference in their Disks, in Quick 2GB benchmark there

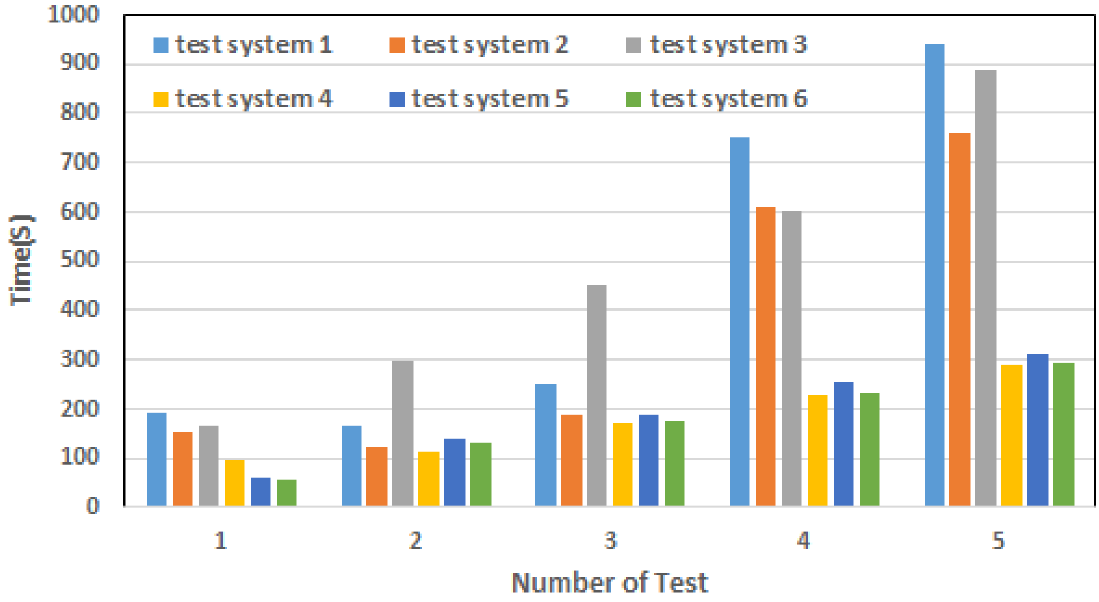

FIGURE 6.5: Time Taken by Standard 3GB

is nearly half of time difference in first three numbers of test but when the data size increased and numbers of test increased the time ratio between them is same. Fig 6.6we again observed that system which takes much time also consumed much

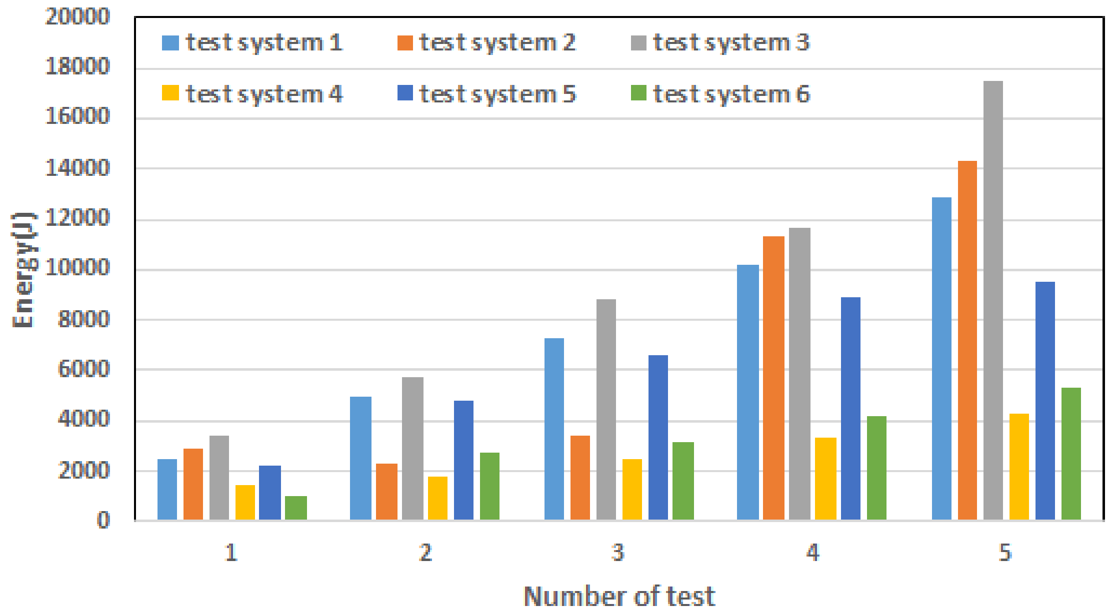

FIGURE 6.6: Energy Consumption with Standard 3GB

energy, and system which takes less time also consumes less energy. Moreover, we also compare the results of SSD based system and HDD based system of same specification, at small numbers of test SSD's equipped system consumes half of

HDD's but when the numbers of test increased the energy consumption is nearly same and in 1 or 2 cases it is greater the HDD's.

6.2 SpecView

SpecView is also a benchmark which is designed to utilize the CPU power. We ran this benchmark on all the test system one time and calculate the power/energy consumption of the systems.

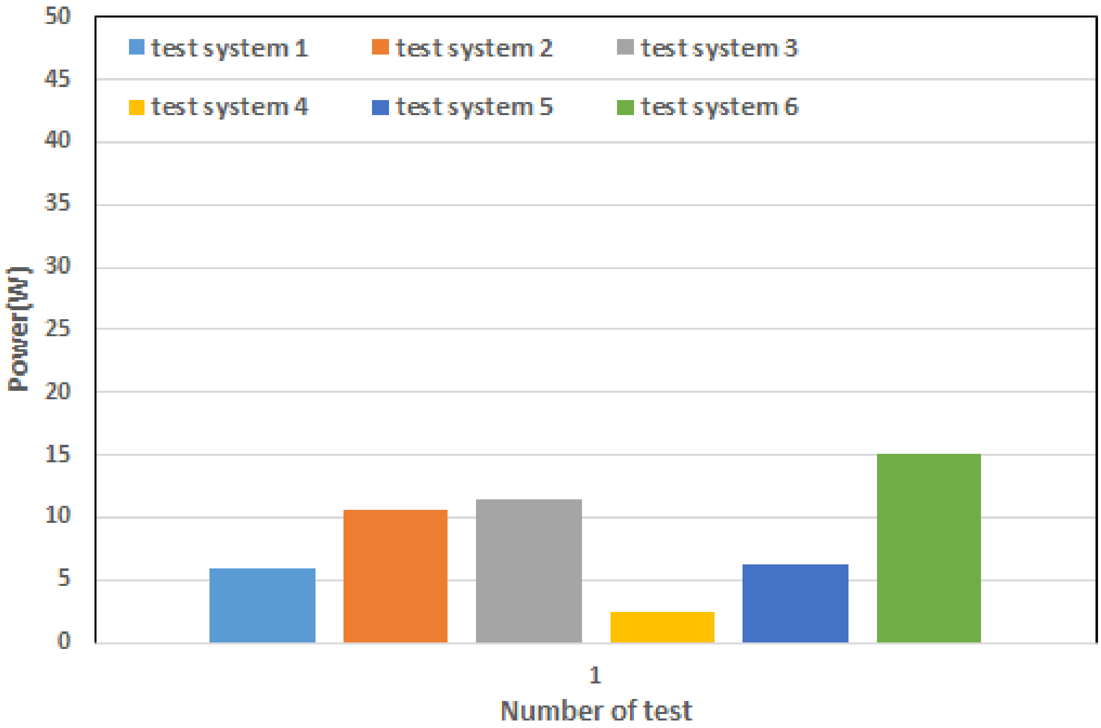

FIGURE 6.7: Power Consumption of Specview

Fig 6.7 show the power consumption of specview benchmark. Our observation is same as for Linpack that CPU with high clock speed consumes less power as compared to CPU with low clock speed. Moreover, test system with same specification but difference in Disk, have a little bit different in power consumption.

In the case of Specview benchmark we observe same thing as in Linpack that those test system which consumes less power can take more time as compared to those test system which consumes more power. There is also a little bit difference

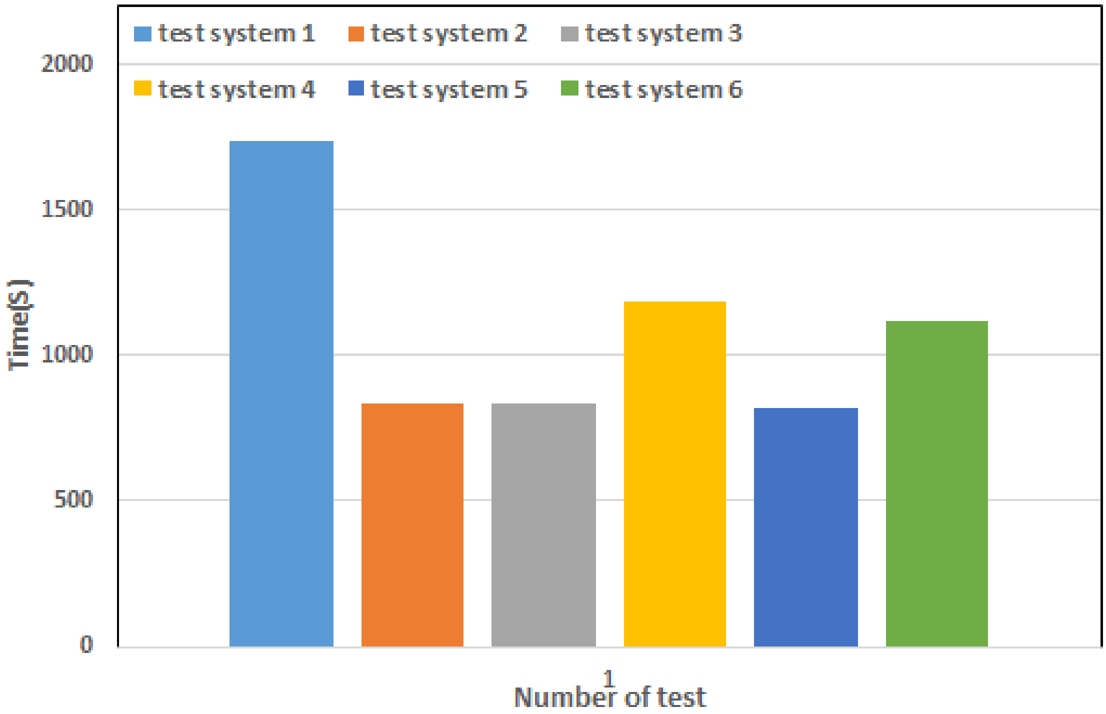

FIGURE 6.8: Time Taken by Specview

between the execution time of test system 1 and 2(which are same in specification but Disk are different), Fig 6.8 depicts the whole scenario.

Once again the results are amazing that test systems which consume less power are not energy efficient as compare to test system which consumes more power. Moreover, in the case of test system 2 and 3(which are same in specification but different Disk) there is no valuable different of energy consumption.

Fig 6.9 depicts the scenario. One more observation is that test system which consumes less power can execute the program in less parallel mechanism.

Fig 6.10 depicts the scenario. Moreover, there is no difference in parallelism of same test system with different Disk.

Once again the results are amazing that test systems which consume less power are not energy efficient as compare to test system which consumes more power. The above results amazed us in different stages.

Another finding of this thesis is that the utilization of CPU is affected by the parallelism in program. Fig 6.11 depicts the scenario that CPU utilization is affected by how parallel a program is executed. It is also effected on the power consumption of the CPU.

In CPU bounded applications mostly power is used by Central Processing Unit.

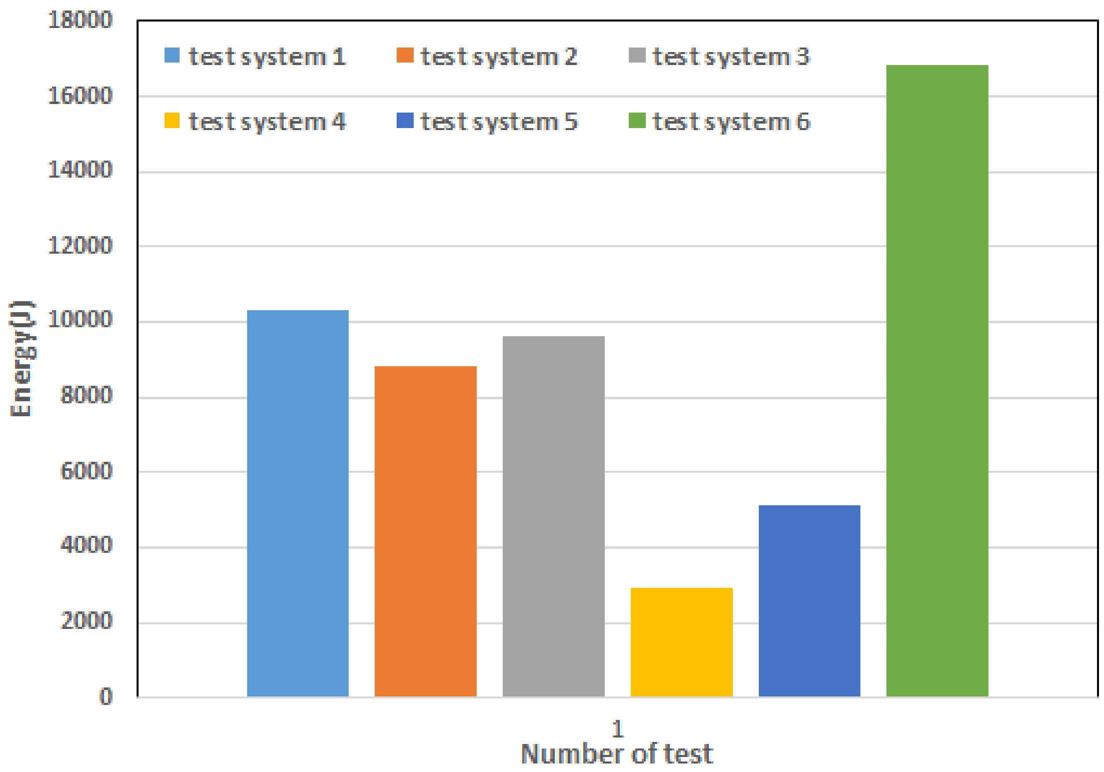

FIGURE 6.9: Energy Consumption of Specview

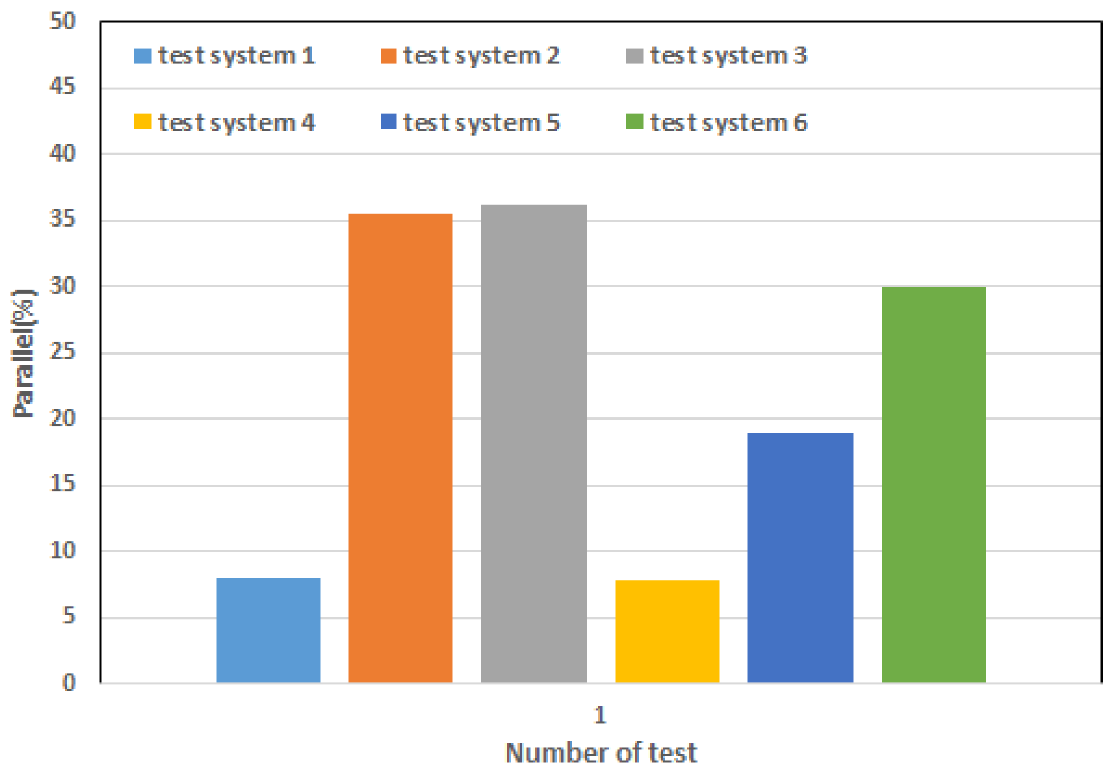

FIGURE 6.10: Parallelism

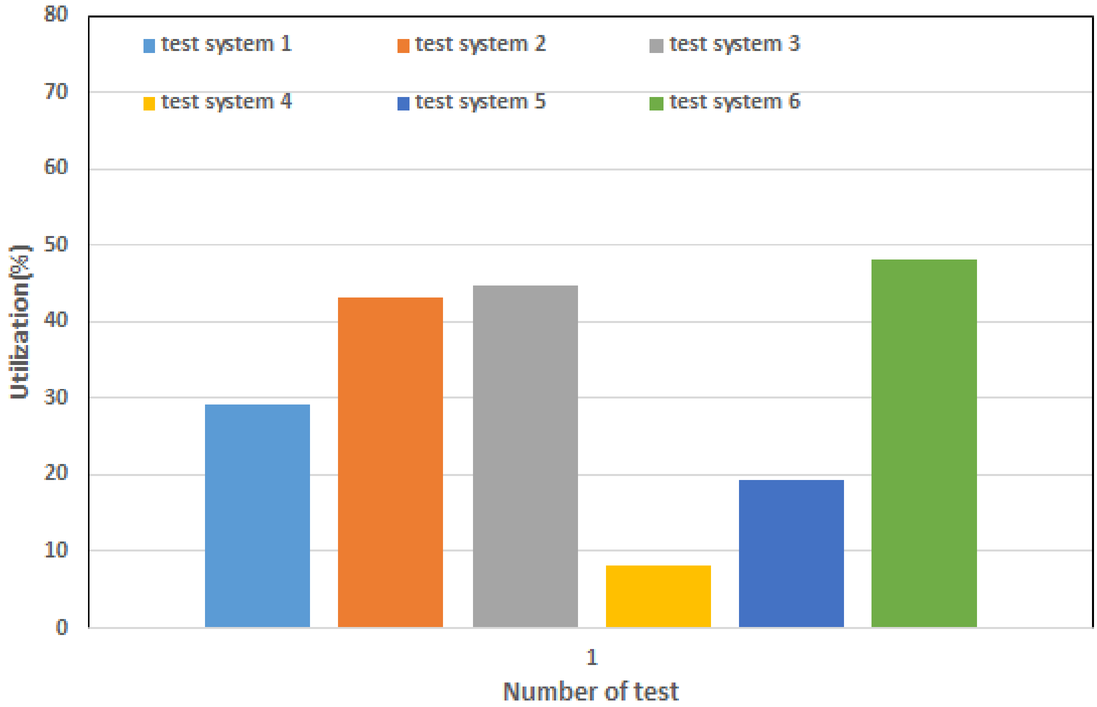

FIGURE 6.11: CPU Utilization With Specview

6.3 CrystalDiskMark

Crystal benchmark is an open-source disk drive benchmark tool for Microsoft Windows. It is used to test the read/write operation of Disk. In this thesis, we run this benchmark to utilize the power/energy of Disk. In this work, crystal benchmark is tested with nine different sizes of data sets, with MB/s as a test unit. All the tests are performed on each test system used in this thesis. The results of these tests are given below.

Fig 6.12 depicts the power consumption of Disk with Crystal benchmark. This figure shows an amazing result, in this figure the power consumption of SSD is very high as compared to HDD. Power consumption of HDD with different space lies in same range, but in the case of SSD the scenario is opposite. Power consumption of SSD is increased with the size of SSD. In HDD's case, all the Disks with different size consume the power below then 3 watts but in case of SSD, test system 2's disk consume average power of 4 watts in all scenarios and test system 4's disk consumes power of more then 20 watts in first six tests and more the 17 watts in last four watts.

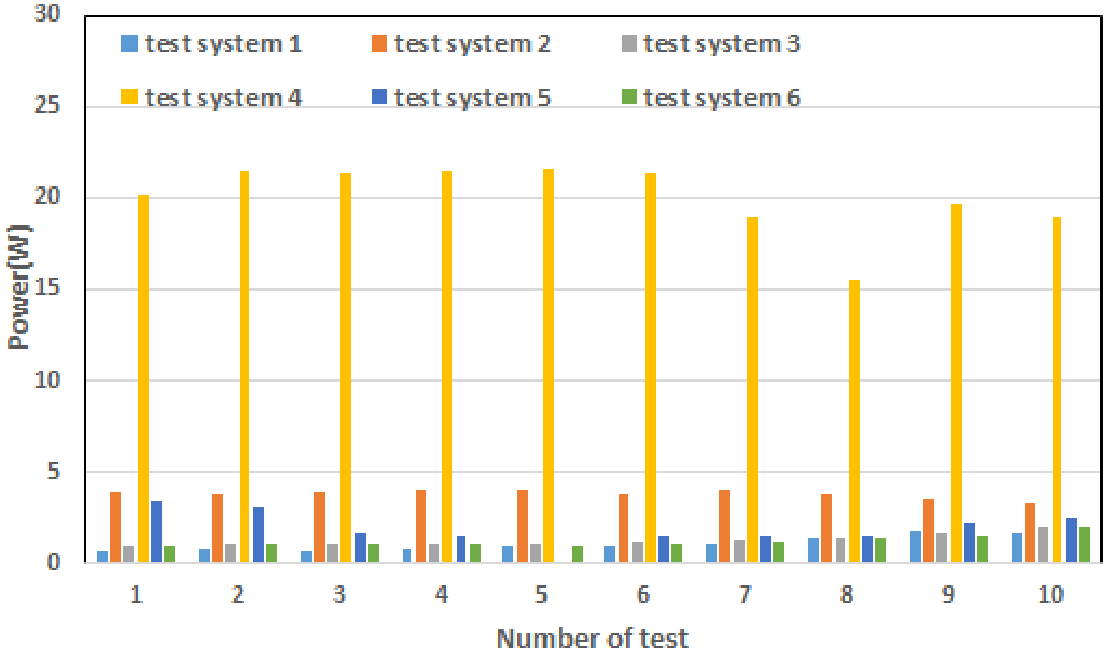

FIGURE 6.12: Power Consumption of Crystal

In Fig 6.13 shows the execution time of crystal benchmark which gives another amazing result. When we execute all the number of tests on each test system the execution time is almost same in all scenarios there is no big difference of execution neither in HDD nor in SSD. SSD takes almost same time as compared to HDD in the read/write operation.

In energy consumption scenario the results are again amazing, SSD's consumes more energy as compared to HDD. SSD with small size i.e.test system 2's SSD consume energy between 400 to 700 joules and SSD with large size consume energy between 2300 to 2700 joules, in all of the scenarios.

In case of small size SSD, it consumes two times more energy than normal HDD's but in the case of large size SSD, it consumes approximately four to five times more energy then smallest SSD Fig 6.14 depicts the Scenario.

6.4 Main Memory

In this portion of thesis main memory power consumption is discussed that how much power is consumed by the main memory. Also measured the main memory power/energy consumption during the execution of Linpack. Moreover, in four

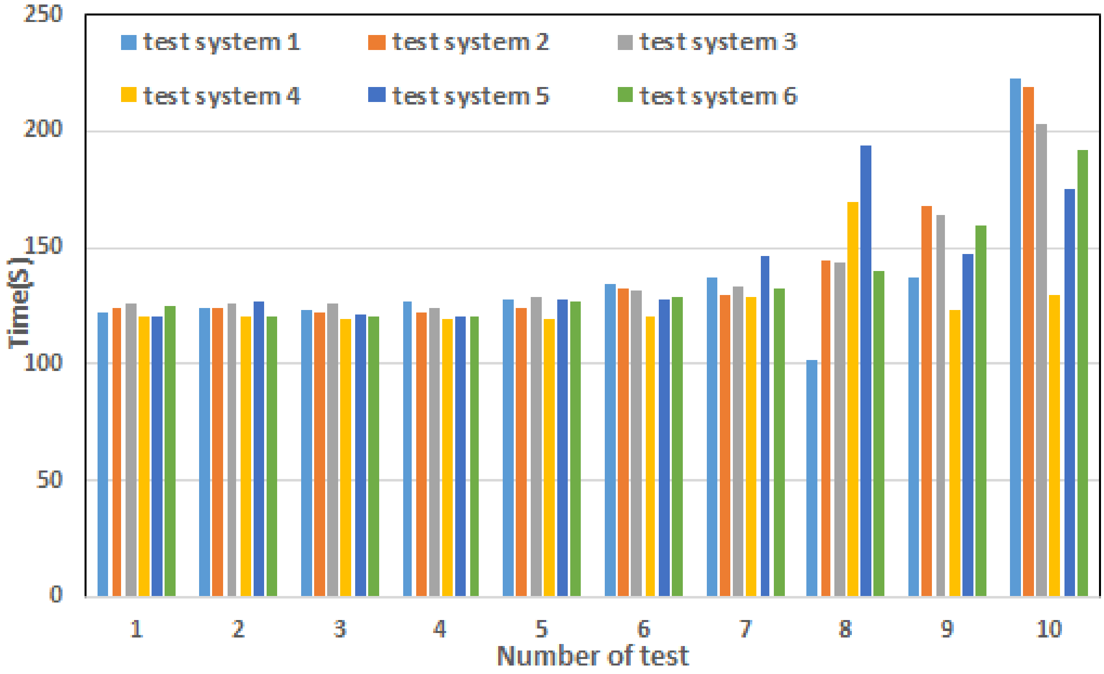

FIGURE 6.13: Time Taken by Crystal

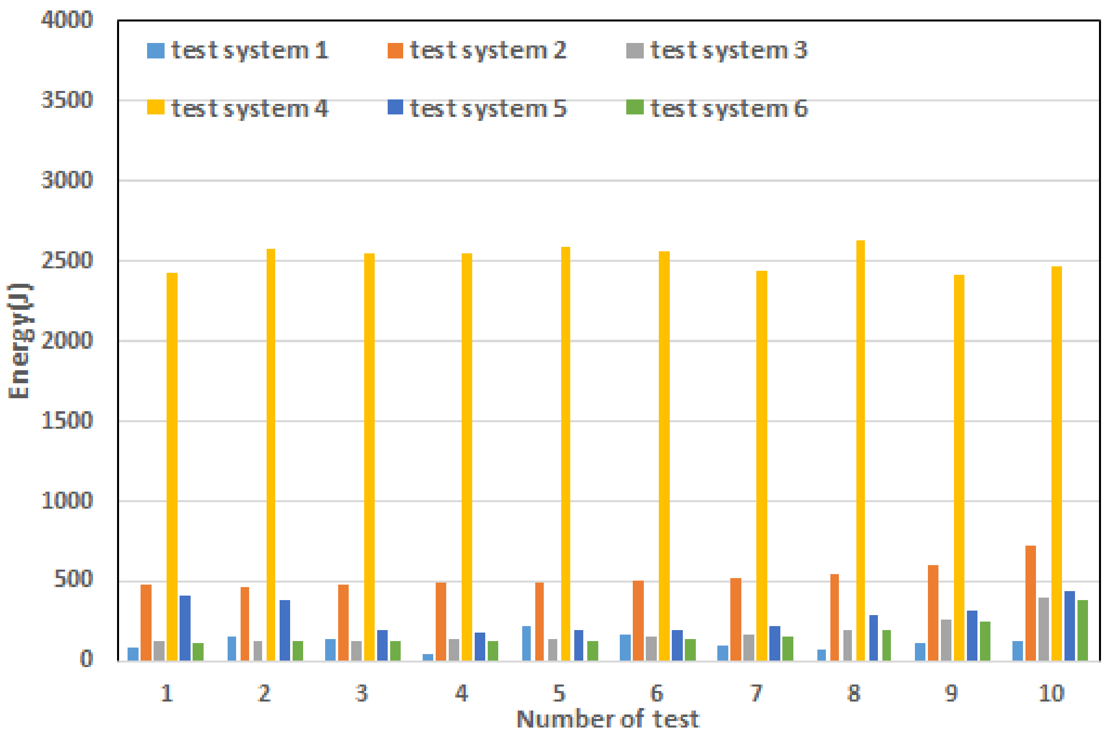

FIGURE 6.14: Energy Consumption of Crystal

of our test systems there are two memory chips of 2X4GB, one is equipped with 1X8GB and one is equipped with 1X32GB. Quick 2GB and Standard 3GB results are shown below.

Fig 6.15 depicts the scenario of power consumed by main-memory of different test

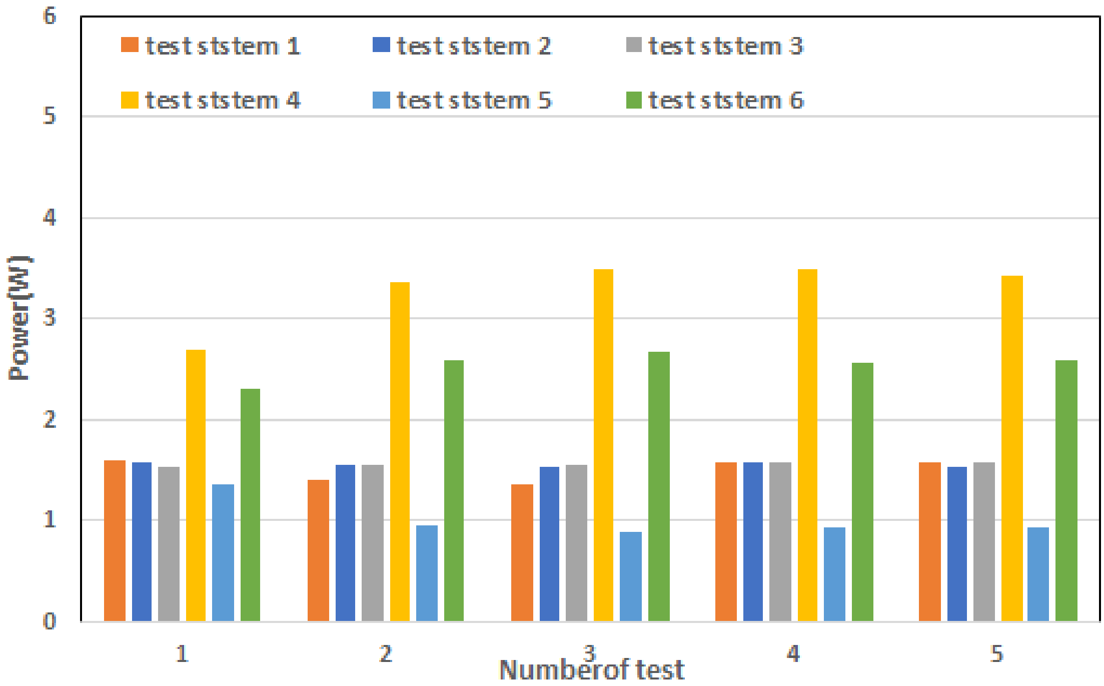

FIGURE 6.15: Power Consumption with Quick 2GB

systems which are used in this research work. Power consumption of main memory is measured by running five different numbers of test of Linpack quick 2GB. Observation is that the power consumption of main memory of all test system remains constant at all stages or slightly different somehow. Another observation is that power consumption is also depended on size of main memory. As previously described that test system 5 and 6 are two desktops, test system 5 is equipped with 1X8GB main memory and test system 6 is equipped with 2X4GB main memory, observation is that test system which contains two chips of main memory consumes double or more than double power as compare to test system which contains only one main memory.

Fig 6.16 depicts the execution time of different test system. This execution is not depending on main memory but depending on the CPU architecture which was discussed previously. This time execution is used to know the energy consumption of the test system.

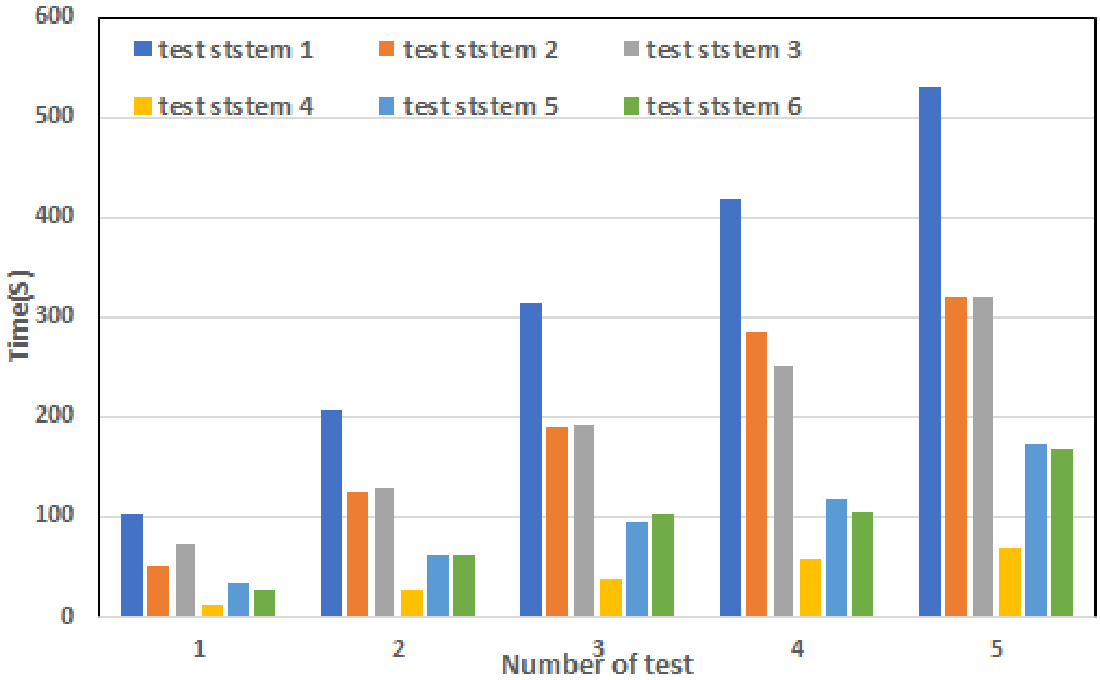

FIGURE 6.16: Time Taken with Quick 2GB

Fig 6.17 depicts the scenario that energy consumption of main memory is also related to CPU performance because it depends on the execution time of a program, that how fast CPU executes the program. If CPU takes a lot of time to execute the program then energy consumption of main memory is greater as compared to CPU which executes it faster.

Fig 6.18 depicts the scenario of power consumed by main-memory of different test systems which are used in this research work. Power consumption of main memory is measured by running five different numbers of test of Linpack standard 3GB. Observation is that the power consumption of main memory of all test system remains constant at all stages or slightly different somehow. Another observation is that power consumption is also depended on size of main memory. As previously described that test system 5 and 6 are two desktops, test system 5 is equipped with 1X8GB main memory and test system 6 is equipped with 2X4GB main memory, observation is that test system which contains two chips of main memory consumes double or more than double power as compare to test system which contains only one main memory.

Main memory consumes power/energy according to size, it takes power/energy time to time. One more thing is that when we ran different slots of same memory.

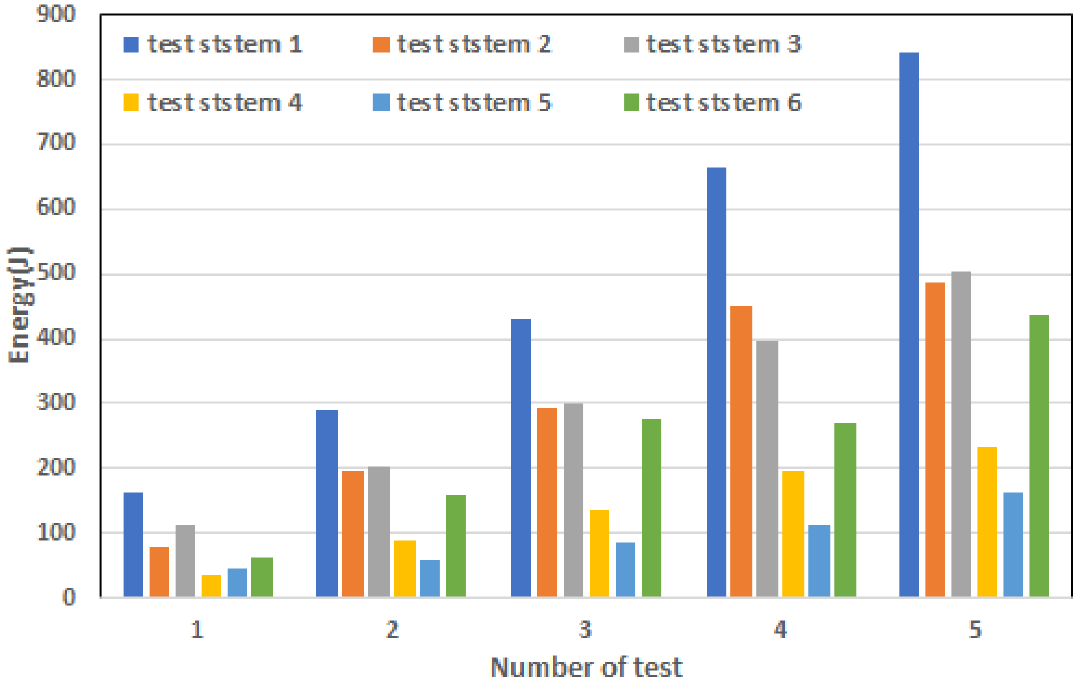

FIGURE 6.17: Energy Consumption with Quick 2GB

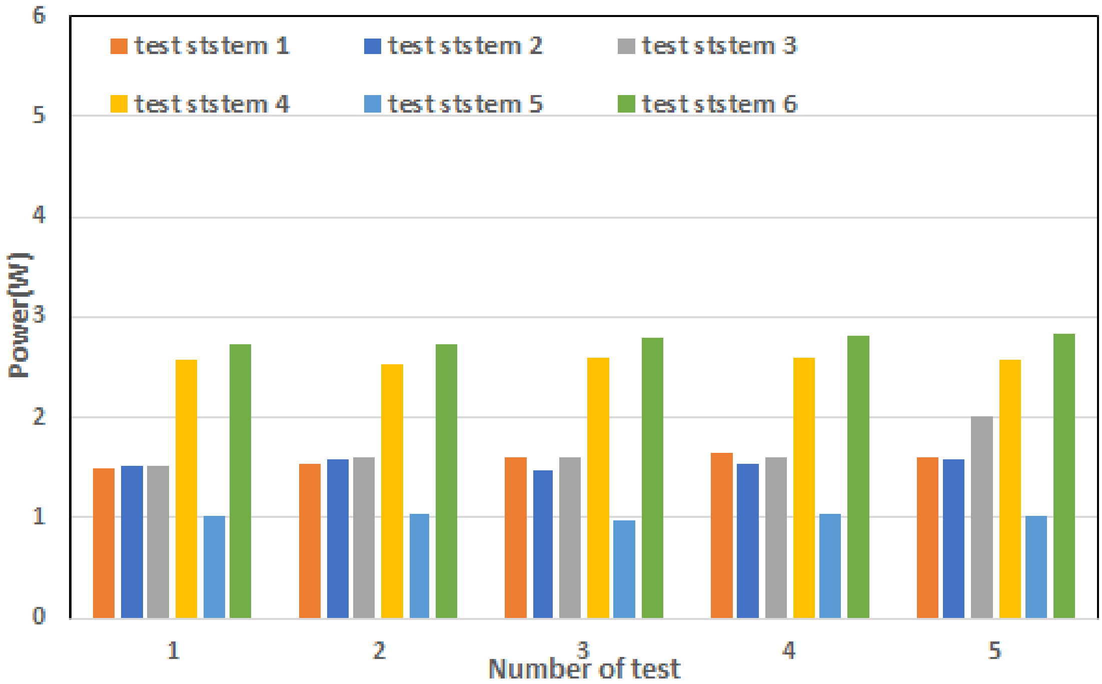

FIGURE 6.18: Power Consumption of Standard 3GB

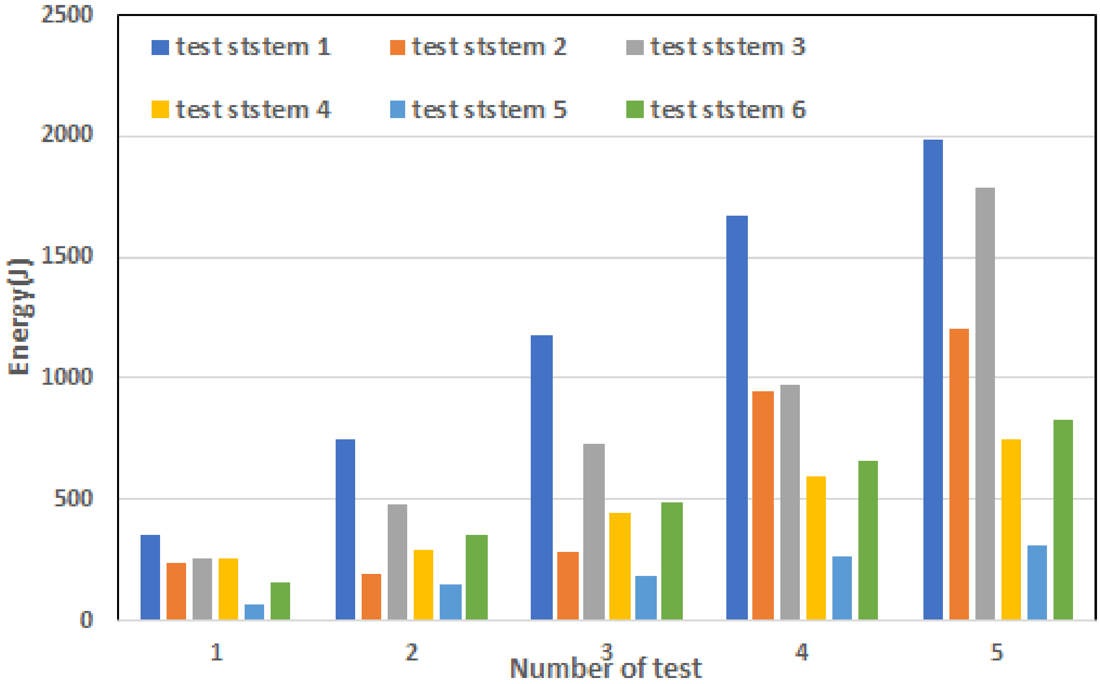

FIGURE 6.19: Energy Consumption with Standard 3GB

it takes more power/energy as compare to one. Fig 6.20 depicts the execution time of different test system. This execution is not depending on main memory but depending on the CPU architecture which was discussed previously. This time execution is used to know the energy consumption of the test system. Energy consumption of main memory is also related to CPU performance because it depends on the execution time of a program, that how fast CPU executes the program. If CPU takes a lot of time to execute the program then energy consumption of main memory is greater as compared to CPU which executes it faster. Fig 6.19 depicts the whole scenario. As time we increase the data size which is standard 3GB of Linpack. It takes more time to execute and also consume more energy because of time. Beside standard 3GB, 2GB takes less time in execution.

6.5 Screen

In this portion of the thesis, power/energy consumption of LCD Screen of the different test system is discussed did not used any specific benchmark on to measure power/energy consumption of Screen. Because screen takes power according to its use no power saving in any power saving mode. Screen saving mode providing

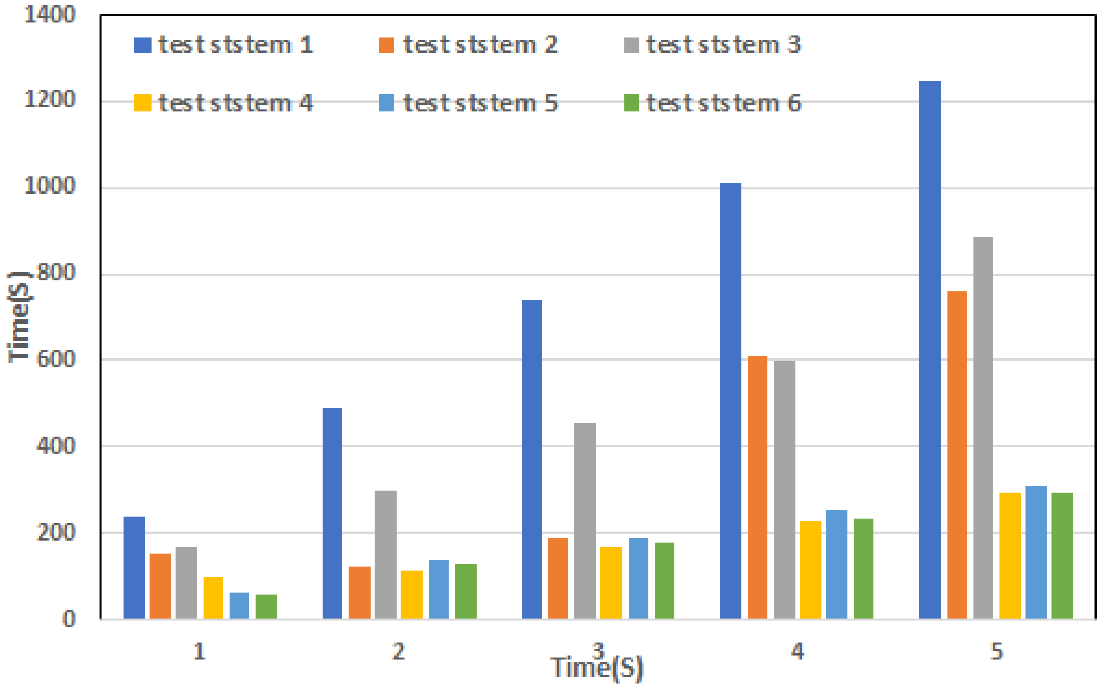

FIGURE 6.20: Time Taken by Standard 3GB

by operating systems are never useful. Screen power is only saved by using it on low brightness. Moreover, also measured the power/energy consumption of Screen with windows power-saving techniques but could not found any difference because it just turns the screen black, screen consume the same power as on working. Only Screen's brightness setting can affect power consumption.

All the test system ran one minute and power consumption is measured. Fig 6.21 shows the power consumption of different test system's Screen. An observation is that Screen continuously consumes same power, it doesn't change at any stage. Moreover, Screen of test system 2 and 3 which are same consumes same power. Fig 6.22 shows the time of Screen.

As previously discussed that in this research power consumption of Screen was measured one minute.

As shown in Fig 6.23 energy graph of all the Screen of test system is same as power because all the test systems ran for one minute time.

As screen consumes power according to its brightness and how much time the program executes. In this thesis we ran all the screens one minute time and find out and monitor the power and energy consumption. It is very important to save the power and energy of monitor to save the whole system power.

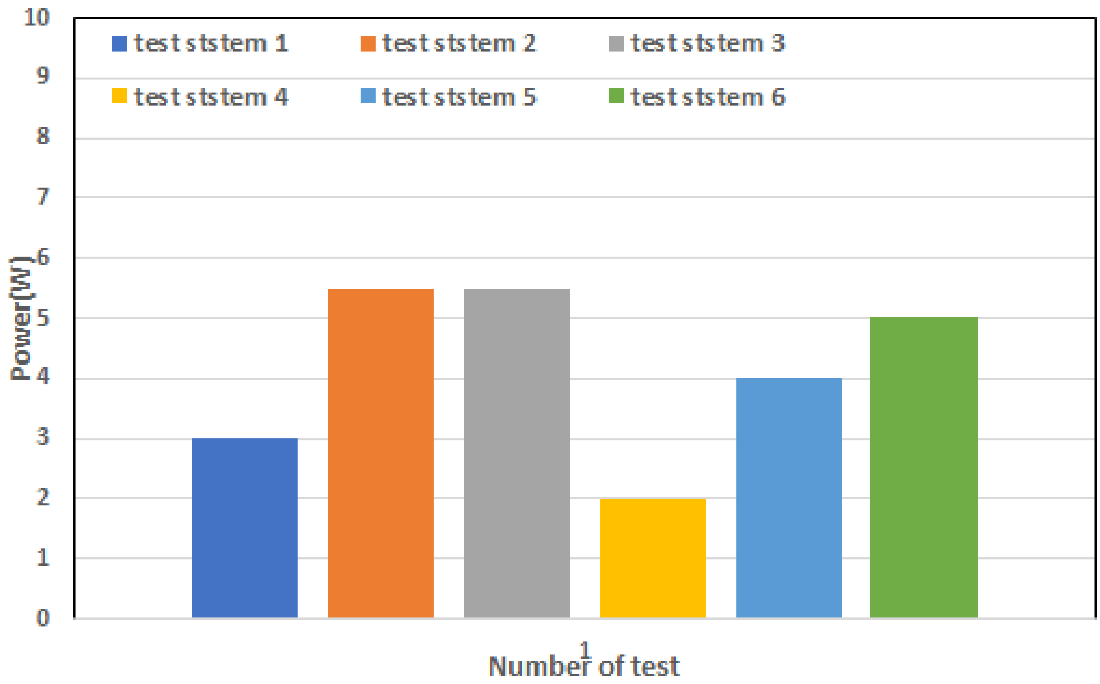

Figure 6.21: Power Consumption

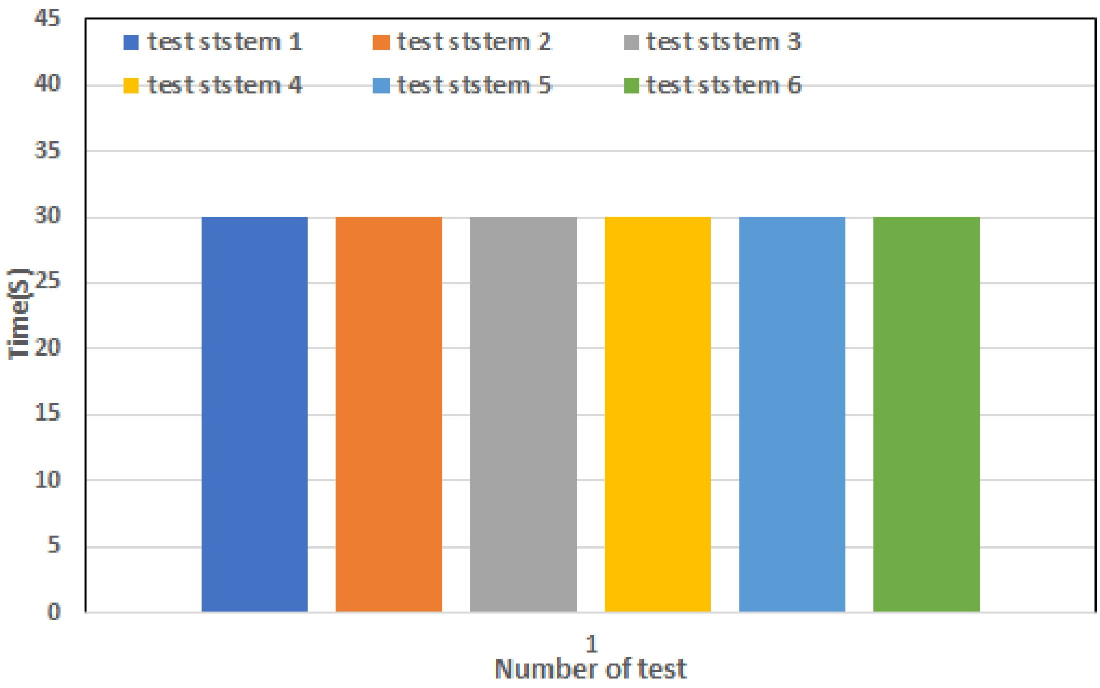

Figure 6.22: Time

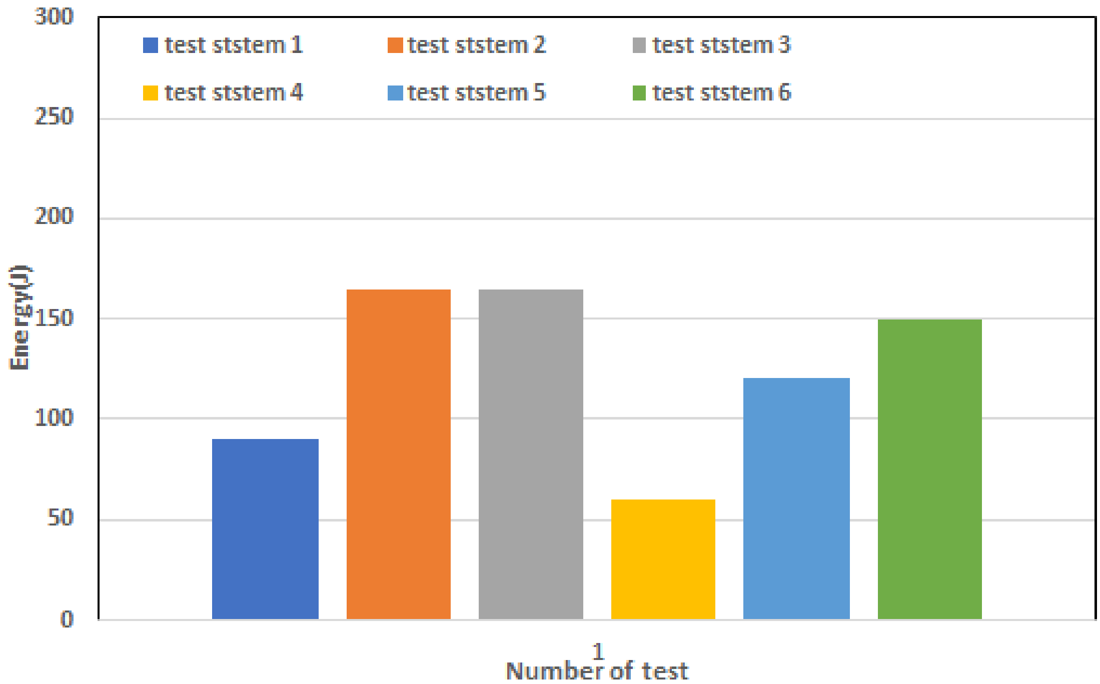

FIGURE 6.23: Energy Consumption

6.6 Result Summary

In this work analysis of the different nature of power/energy consumption of six different personal computers is done by executing different benchmark suits i.e Linpack, Specview and Crystal. Also used the power/energy monitoring tools to monitor the power/energy consumption of different components i.e CPU, Disk, Mainmemorry and Screen. Power/energy consumption is measured by executing benchmarks suits with power/energy monitoring tools. CPU power/energy consumption is monitoring by executing the Linpack and Spec benchmarks, Linpack benchmark is executing with two different versions Quick 2GB and Standard 3GB with five numbers of test i.e one time, two times,. . . ., five times. After running these test we conclude a result that test system which consumes more power can execute the program in more parallel manners and takes less time, on other hand test system which consumes less power takes more time to execute the application and done with less parallel way. Specview benchmark is also designed to utilize the power of CPU we ran the Specview benchmark with the same tools on all the test system which are previously mentioned, the result is same as in the case of Linpack that test system which consumes more power can execute the program in more parallel manners and takes less time, on other hand test system which consumes less power takes more time to execute the application and done with less parallel way.

Power/energy consumption of Disk is consumed by executing the read/write tests with power/energy monitoring tools. We ran the 10 different tests with different data size i.e 16MB, 32MB,. . . ., 8GB. An amazing thing is discovered that power/energy consumption of SSD is high as compared to HDD. Moreover, the execution time is same as taken by HDD, and HDD of different size consuming nearly same power but as SSD,s size increased the power consumption is also increased. Main memory power/energy consumption is also monitored while executing the Linpack benchmark. An observation is that main memory of the same size but different numbers of slots consume different power. 2X4 8GB main memory consumes more power and 1X1 8GB main memory consumes less power. Screen power/energy consumption is measured by power on the Screen for one minute. All the Screens consume the same power/energy while using different screen savers and playing videos. If we use the brightness settings then it will be useful to save power. Another thing is analyzed that CPU bounded applications consume more power of CPU and memory bounded applications consume more power of memory.

6.7 Analysis

Some of our results were expected and some surprised us. In the case of CPU, one amazing thing is that CPU which consumes less power can take greater time to executes the program as compared to CPU which consume more power. Moreover, CPU which consume more power can be executed the program better parallel way, and it takes less time to execute the program, as the CPU consumes more power it can execute the program in a more parallel way. Furthermore, CPU utilization is also increased. Due to this a meaningful effect on energy consumption of the CPU. Additionally, all the CPU's used in this thesis executes the benchmark program with less than 56% parallelism, architecture should be able to execute the program with 100% parallelism to save the time as well as energy.

Another surprising result is in the section of Disk. As we know that a new Disk technology name as SSD introduced which is faster than the old's HDD. But surprising thing is that in read/write operations which are performed in this thesis for power consumption of Disk, HDD gives an amazing result, HDD consumes very low power to perform these operations and SSD perform these operations at very high power consumption. Moreover, in the case of HDD there is no as such difference in power consumption according to size but it is a huge power consumption difference in SSD according to size. Another shocking result is that the execution time of these read/write operations are same, there is no such a meaningful difference between the execution time of these operations on HDD and SSD.

Main memory can also affect the power consumption of a system but a little bit because of its small size. Observation is that main memory consumes constantly consumes same power on each stage or little bit variation. Another observation is that 1X8GB memory consumes less power as compare to 2X4GB. In case of Screen, observation is that Screen usually consumes same power both on screen savers designed by operating systems as well as on normal screen. But if we use Screen brightness setting on low then it will be helpful in power consumption mechanism. Different Screen consumes the different value of power consumption. The results collectively indicate that the benchmarks we have used are repeatable as well as practical. They closely approximate how much power would be used during real world tasks. This is an important feat because we have a free toolkit to offer anyone which can help show a computers power consumption. This can lead to more efficient computing design by having regular people be able to see results of these benchmarks and understand in simple terms how much power their devices use. In our capitalistic society consumer purchases have an impact on the designs computer manufacturers employ. If consumers demand energy efficient products, computer companies will have to employ energy efficient designs so that they do not lose business. This study helps the manufacturer to design such a model which is low power consumption.

In case of Screen, observation is that Screen usually consumes same power both on screen savers designed by operating systems as well as on normal screen. But if we use Screen brightness setting on low then it will be helpful in power consumption mechanism. Different Screen consumes the different value of power consumption.

Chapter 7

Conclusion and Future Work

7.1 Conclusion

This study gives an introduction of green computing and also explains the concept of Power/Energy consumption. The current study also helps to establish emerging trends and future directions in Green computing research. This study has identified the established and emerging areas in the Green Computing field and identifies gaps in the literature for future research to take place. To address research question 1 (Q1: Which component consumes more Power/Energy in personal computer CPU, HDD, Memory or Screen?), according to my little domain knowledge CPU consumes more power/energy from these components. In this thesis, it is also proven true from the experiments and results in most cases that CPU consumes more power/energy than all of these components. But in case of 500GB SSD which is equipped in test system 4, it consumes nearly same power of CPUs used in this thesis and in some cases it consumes more power from some CPUs.

Moreover, the study also exposed the reason of power consumption of the CPU, which is research question 2 (Which processor architecture consume more power and what is the reason?), the answer is according to this thesis, CPU power consumption is depended on how parallel a CPU can execute the program, CPU which

execute program more parallel way it will also consume more power.
Research question 3 (How would you adapt your architecture to run with more energy efficiency?), according to this thesis, architecture should be able to execute the program according to program's parallelism. The more the CPU performs the program in more parallel ways, the more energy efficient it will be.
Additionally, in case of main memory it is better to use one chip of main memory rather than two of same size. Because two chips consume more power than one.
In case of Screen we should use it on low brightness to consume less power/energy, screen savers which are designed by operating system are not useful to save powe, just blank the screen.

7.2 Future Work

This thesis can be further enhanced in term of proposing an approach regarding temperature of test systems that which CPU or test system release more heat and what is reason. Furthermore, also examine test system with different numbers of main memory of same size would be check the power consumption.

Bibliography

[1] A. K. Soni and M. Dixit, "Study of energy efficient images with just noticeable difference threshold based on feature transform," *International Journal of Trend in Scientific Research and Development (IJTSRD)*, vol. 1, no. 3, pp. 924–927, 2019.

[2] M. S. Kayathri, M. S. Girija, and M. S. Meena, "Green computing to reduce the harmful impact of technology on the earth," vol. 13, pp. 9965–9968, 2018.

[3] R. Mata-Toledo and P. Gupta, "Green data center: how green can we perform," vol. 2, pp. 1–8, 2010.

[4] J. Baliga, R. W. Ayre, K. Hinton, and R. S. Tucker, "Green cloud computing: Balancing energy in processing, storage, and transport," *Proceedings of the IEEE*, vol. 99, no. 1, pp. 149–167, 2010.

[5] L. A. Barroso and U. Hölzle, "The datacenter as a computer: An introduction to the design of warehouse-scale machines," *Synthesis lectures on computer architecture*, vol. 4, no. 1, pp. 1–108, 2009.

[6] G. Zhou, J. Li, and Z. Jia, "Power-saving exploration for high-end ultra-slim laptop computers with miniature loop heat pipe cooling module," *Applied Energy*, vol. 239, pp. 859–875, 2019.

[7] S. Wiriyasart, C. Hommalee, and P. Naphon, "Thermal cooling enhancement of dual processors computer with thermoelectric air cooler module," *Case Studies in Thermal Engineering*, vol. 14, p. 100445, 2019.

[8] H. Koziolek, "Performance evaluation of component-based software systems: A survey," *Performance evaluation*, vol. 67, no. 8, pp. 634–658, 2010.

[9] M. Rashti, G. Sabin, D. Vansickle, and B. Norris, "Wattprof: A flexible platform for fine-grained hpc power profiling," in *2015 IEEE International Conference on Cluster Computing*, pp. 698–705, IEEE, 2015.

[10] P. Gupta *et al.*, "Minimizing power consumption by personal computers: A technical survey," *IJ Information Technology and Computer Science*, vol. 1, no. 2, pp. 225–225, 2012.

[11] S. De and W. Golab, "Energy-efficient energy analytics using a general purpose graphics processing unit," in *2020 IEEE International Conference on Big Data (Big Data)*, pp. 2482–2491, IEEE, 2020.

[12] K. O'brien, I. Pietri, R. Reddy, A. Lastovetsky, and R. Sakellariou, "A survey of power and energy predictive models in hpc systems and applications," *ACM Computing Surveys (CSUR)*, vol. 50, no. 3, pp. 1–38, 2017.

[13] N. M. N. Pham and V. S. Le, "Applying ant colony system algorithm in multi-objective resource allocation for virtual services," *Journal of Information and Telecommunication*, vol. 1, no. 4, pp. 319–333, 2017.

[14] S. Murugesan, "Harnessing green it: Principles and practices," *IT professional*, vol. 10, no. 1, pp. 24–33, 2008.

[15] R. W. Ahmad, A. Gani, S. H. A. Hamid, F. Xia, and M. Shiraz, "A review on mobile application energy profiling: Taxonomy, state-of-the-art, and open research issues," *Journal of Network and Computer Applications*, vol. 58, pp. 42–59, 2015.

[16] R. W. Ahmad, A. Gani, S. H. A. Hamid, F. Xia, and M. Shiraz, "A review on mobile application energy profiling: Taxonomy, state-of-the-art, and open research issues," *Journal of Network and Computer Applications*, vol. 58, pp. 42–59, 2015.

[17] Y. He, Y. Chen, Z. Yang, H. He, and L. Liu, "A review on the influence of intelligent power consumption technologies on the utilization rate of distribution network equipment," *Protection and Control of Modern Power Systems*, vol. 3, no. 1, pp. 1–11, 2018.

[18] S. Sarkar and S. Misra, "Theoretical modelling of fog computing: a green computing paradigm to support iot applications," *Iet Networks*, vol. 5, no. 2, pp. 23–29, 2016.

[19] K. Amasyali and N. M. El-Gohary, "A review of data-driven building energy consumption prediction studies," *Renewable and Sustainable Energy Reviews*, vol. 81, pp. 1192–1205, 2018.

[20] R. Panwar and B. Mallick, "Load balancing in cloud computing using dynamic load management algorithm," in *2015 International Conference on Green Computing and Internet of Things (ICGCIoT)*, pp. 773–778, IEEE, 2015.

[21] S. Murugesan, "Harnessing green it: Principles and practices," *IT professional*, vol. 10, no. 1, pp. 24–33, 2008.

[22] M. Domínguez, J. J. Fuertes, S. Alonso, M. A. Prada, A. Morán, and P. Barrientos, "Power monitoring system for university buildings: Architecture and advanced analysis tools," *Energy and Buildings*, vol. 59, pp. 152–160, 2013.

[23] S. Murugesan, "Harnessing green it: Principles and practices," *IT professional*, vol. 10, no. 1, pp. 24–33, 2008.

[24] K. Krosman and J. Sosnowski, "Exploring disk performance benchmarks," in *Photonics Applications in Astronomy, Communications, Industry, and High Energy Physics Experiments 2017*, vol. 10445, p. 104455N, International Society for Optics and Photonics, 2017.

[25] H. Styles and W. Luk, "Compilation and management of phase-optimized reconfigurable systems," in *International Conference on Field Programmable Logic and Applications, 2005.*, pp. 311–316, IEEE, 2005.

[26] S. Deore, A. N. Patil, and R. Bhargava, "Energy-efficient scheduling scheme for virtual machines in cloud computing," *International journal of computer application*, vol. 56, no. 10, pp. 79–86, 2012.

[27] B. R. Bruce, J. Petke, and M. Harman, "Reducing energy consumption using genetic improvement," in *Proceedings of the 2015 Annual Conference on Genetic and Evolutionary Computation*, pp. 1327–1334, 2015.

[28] A. Marowka, "On performance analysis of a multithreaded application parallelized by different programming models using intel vtune," in *International Conference on Parallel Computing Technologies*, pp. 317–331, Springer, 2011.

[29] J. C. Phillips, D. J. Hardy, J. D. Maia, J. E. Stone, J. V. Ribeiro, R. C. Bernardi, R. Buch, G. Fiorin, J. Hénin, W. Jiang, *et al.*, "Scalable molecular dynamics on cpu and gpu architectures with namd," *The Journal of chemical physics*, vol. 153, no. 4, p. 044130, 2020.

[30] C.-J. Su and S.-F. Huang, "Real-time big data analytics for hard disk drive predictive maintenance," *Computers & Electrical Engineering*, vol. 71, pp. 93–101, 2018.

[31] J. Xu, L. Zhang, A. Memaripour, A. Gangadharaiah, A. Borase, T. B. Da Silva, S. Swanson, and A. Rudoff, "Nova-fortis: A fault-tolerant non-volatile main memory file system," in *Proceedings of the 26th Symposium on Operating Systems Principles*, pp. 478–496, 2017.

[32] G.-L. Zhang, A.-S. Li, C.-G. Miao, X. He, M. Zhang, and Y. Zhang, "A consumer-grade lcd monitor for precise visual stimulation," *Behavior research methods*, vol. 50, no. 4, pp. 1496–1502, 2018.

[33] A. O. Ojo, M. Raman, and A. G. Downe, "Toward green computing practices: A malaysian study of green belief and attitude among information technology professionals," *Journal of Cleaner Production*, vol. 224, pp. 246–255, 2019.

[34] S. Trimi and S.-H. Park, "Green it: practices of leading firms and ngos," *Service Business*, vol. 7, no. 3, pp. 363–379, 2013.

[35] J. Grand, "Practical secure hardware design for embedded systems," in *Proceedings of the 2004 Embedded Systems Conference, San Francisco, California*, 2004.

[36] A. Noureddine, S. Islam, and R. Bashroush, "Jolinar: analysing the energy footprint of software applications," in *Proceedings of the 25th International Symposium on Software Testing and Analysis*, pp. 445–448, 2016.

[37] A. Marowka, "On performance analysis of a multithreaded application parallelized by different programming models using intel vtune," in *International Conference on Parallel Computing Technologies*, pp. 317–331, Springer, 2011.

[38] M. Hähnel, B. Döbel, M. Völp, and H. Härtig, "Measuring energy consumption for short code paths using rapl," *ACM SIGMETRICS Performance Evaluation Review*, vol. 40, no. 3, pp. 13–17, 2012.

[39] T. Ilsche, R. Schöne, J. Schuchart, D. Hackenberg, M. Simon, Y. Georgiou, and W. E. Nagel, "Power measurement techniques for energy-efficient computing: reconciling scalability, resolution, and accuracy," *SICS Software-Intensive Cyber-Physical Systems*, vol. 34, no. 1, pp. 45–52, 2019.

[40] D. Beyer and P. Wendler, "Cpu energy meter: A tool for energy-aware algorithms engineering," in *International Conference on Tools and Algorithms for the Construction and Analysis of Systems*, pp. 126–133, Springer, 2020.

[41] T.-D. B. Le, D. Lo, C. Le Goues, and L. Grunske, "A learning-to-rank based fault localization approach using likely invariants," in *Proceedings of the 25th International Symposium on Software Testing and Analysis*, pp. 177–188, 2016.

[42] R. Trobec, M. Depolli, K. Skala, and T. Lipić, "Energy efficiency in large-scale distributed computing systems," in *2013 36th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*, pp. 253–257, IEEE, 2013.

[43] A. Noureddine, R. Rouvoy, and L. Seinturier, "A review of energy measurement approaches," *ACM SIGOPS Operating Systems Review*, vol. 47, no. 3, pp. 42–49, 2013.

[44] A. Noureddine, S. Islam, and R. Bashroush, "Jolinar: analysing the energy footprint of software applications," in *Proceedings of the 25th International Symposium on Software Testing and Analysis*, pp. 445–448, 2016.

[45] J. von Kistowski, H. Block, J. Beckett, C. Spradling, K.-D. Lange, and S. Kounev, "Variations in cpu power consumption," in *Proceedings of the 7th ACM/SPEC on International Conference on Performance Engineering*, pp. 147–158, 2016.

[46] K. Jalbert and A. J. Kinchy, "Sense and influence: environmental monitoring tools and the power of citizen science," *Journal of Environmental Policy & Planning*, vol. 18, no. 3, pp. 379–397, 2016.

[47] S. Ibrahim, T.-D. Phan, A. Carpen-Amarie, H.-E. Chihoub, D. Moise, and G. Antoniu, "Governing energy consumption in hadoop through cpu frequency scaling: An analysis," *Future Generation Computer Systems*, vol. 54, pp. 219–232, 2016.

[48] E. Sheme and N. Frasheri, "Software tools and techniques for energy efficiency in data centres," *International Journal on Information Technologies and Security*, vol. 3, no. 7, pp. 13–22, 2015.

[49] P. Mittal and N. Kaur, "Green computing–need and implementation," *International Journal of Advanced Research in Computer Engineering & Technology (IJARCET)*, vol. 2, no. 3, 2013.