INTRODUCTION

1.1 INTRODUCTION

Currently, globe is facing major three kinds of crisis known as Energy crisis, Environmental crisis and Economic crisis and it is predicted if these crisis are not controlled then the economy will become worst in future. In this regard Government of India has approved the National Mission on Enhanced Energy Efficiency (NMEEE) [1] which is one of the eight missions planned under the National Action Plan for Climate Change (NAPCC). Explosive growth in the technological sector is also one of the major reasons behind these crises. The information and communications technologies are one of them as in this sector various technological breakthroughs have been taken place and more are yet to come. The rate at which information and communication technology (ICT) devices are being produced is proportional to the increase in the energy consumed and heat dissipated by these devices, which poses the problem of an energy crisis and the exacerbation of the greenhouse gas problem and global warming. We cannot escape the fact that the world is becoming more and more dependent upon the use of ICT. All over the world, personal computers are being increasingly used right from kids to professionals in the course of their everyday lives. In the late 1990s, power, energy consumption, and power density had become the limiting factors not only for the system design of portable and mobile devices, but also for high-end systems [2, 3]. The design of computer systems has been changed from the performance-centric stage to power-aware stage [4]. The predicted worldwide growth rate [5] of sales of Servers, Desktops, and Mobile computers up to year 2015, is shown in Fig.1.1, which reveals that the demand of PCs from 1990s onwards have been driven by the evolution of PC from command line-driven machines with floppy disk drives and capable of limited tasks, to user friendly, powerful PCs with Pentium processors and add-ons capable of doing anything. The decreasing cost of personal computers also allowed more people access to personal computers and added to their increasing
popularity. During the 1990s, personal computers continued to increase in popularity and this was the time when internet users had started increasing. Romm et al. [6] have estimated that the number of Internet users in the United States soared from 5 million in 1993 to 62 million in 1997, to over 100 million by mid-1999. Kawamoto et al. [7] have estimated that annual shipments of the computers increased by a factor of five in the 1990s. Matthews et al. [8, 9] estimated that in 1998 about one in four personal computers sold were laptops. There could be basically two major reasons behind this growth, first the technology is becoming cheaper with each passing day, and secondly people are getting more and more addicted to these ICT products and use of Internet is one of them. However, the offshoot in getting used to these technologies are the innumerable other adverse effects caused to our environment, health and economy [4]. Explosive growth rate of the sales of personal computer is proportional to the energy consumption, which can be observed from Fig 1.2 that personal computers occupy the largest share among the several available ICT products in the market and making them also responsible for the high quantum of power consumption [10].

![Figure 1.1: Worldwide market segments of Server, Desktop and Mobile PC.](image-url)

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This emerging issue of power dissipation has imposed a very significant question on the system and software design and it is believed that in the future there will be a great demand for the energy-sustainable software. Therefore, the vision of a sustainable planet and the minimization of the energy consumed by computer systems motivated us to examine energy-sustainable computing methods [11].

There are vast majority of the users, which leaves the computer systems running on all the time. There are various myths among the users related to powering off personal computer. These myths are listed as follows [4, 12]:

- One of the main myths is that turning off the computer system and then back on consumes more energy than leaving it on. Whereas, the reality is the power used by a computer to boot up is far less than the energy your computer uses when left on for more than three minutes.

- The second major myth is that computer system is designed to handle 40,000 on/off cycles. If you are an average user, significantly more cycles than you will
initiate in the computer’s five to seven year life. Whereas, the reality is when you turn your computer off, you not only reduce energy use, also lower the heat stress as well as wear on the system.

c) Screen savers save energy. This is a common misconception among the users of the personal computer whereas, the reality is totally different as the screen savers were originally designed to help prolong the life of monochrome monitors and nowadays these kinds of monitors are technologically obsolete. This is one of feature of the Windows operating system, which exists till now from its initial version-3.1. These Screen savers save energy only if they actually turn off the monitor’s screen.

d) LCD monitors use less energy than CRTs, so we can leave it on all the time is another common myth. Whereas, in reality these LCD monitors are considered to be “vampire energy users,” meaning the display will still be drawing power, even in Standby mode. Moreover, if we consider the case of business organization where hundreds to thousands of LCDs are in use simultaneously, this adds up in cost.

e) Network connections are lost when computers go into low-power or Standby mode. Whereas in reality this was true with the older computer system. Newer computer systems are designed to Standby on networks without loss of data or connection. Central Processing Units (CPUs) of these computer systems are designed with Wake on LAN technology and can be left in Standby mode.

1.2 FACTS RELATED TO USE OF ELECTRICITY BY PERSONAL COMPUTERS

In this section, we have listed some interesting facts about the electricity used by personal computers that focuses on the need of proper use of these systems [12]. As proper management of these systems not only save energy but also good for environment [4].

- An average desktop computer system requires 85 Watts just to idle, even with the monitor off. If that system were in use or idling for only 40 hours a week instead of a full 168, over $50 in energy costs would be saved annually.
• One computer system left on 24 hours a day costs you between $120 and $175 in electricity costs annually while dumping 1,500 pounds of CO₂ into the atmosphere.

• A tree absorbs between 3 and 15 pounds of CO₂ each year that means up to 500 trees are needed to offset the annual emissions of one computer left on all the time.

• If each household in a metro city turned off its computer for just one additional hour per day, it would save $3.2 million in electricity costs and prevent 19,000 tons of CO₂ from heating the atmosphere.

• The added heat from inefficient computers can increase the demand on air conditioners and cooling systems, making your computing equipment even more expensive to run.

• Even though, presently most of the today’s desktop computers are capable of automatically transitioning to a Standby or Hibernate mode when inactive, but about 90% of the systems have this function disabled.

• Some 25% of the electricity used to power home electronics like computers, DVD players, stereos, and televisions is consumed while the products are turned off because anything that uses a remote continues to consume power even when they are turned off. This phenomenon is called “vampire energy use” or “phantom energy use” where a device draws Standby power in home.

• This vampire energy loss represents between 5 to 8% of a single-family home’s total electricity use per year. This is on average equals one month’s electricity bill and adds up to at least 68 billion kilowatt-hours of electricity annually.

• On a global scale, standby energy accounts for 1% of the world’s carbon emissions.

• Electricity production is the largest source of greenhouse gas emissions in most of the countries like United States, India and China, ahead of transportation.

1.3 POWER CONSUMPTION BY PERSONAL COMPUTERS

Very early, the computers were extremely inefficient with low computing power and high energy consumption. The energy efficiency of computers increased from the mid-1980s until the mid-1990s, as demonstrated in [13-16] and also depicted in Fig. 1.3. In early 1990s, personal computer's energy consumption first entered the literature of the
energy conservation communities [17, 18]. The power requirements of computer systems have changed considerably since the 1980s and are indicated in two modes, active mode is when the device is in operation and Standby mode refers to a mode which attempts to conserve power with instant recovery. In 1988, Norford and Dundridge [17] have reported that newer models of computers with equivalent performance were often more energy efficient. In newer systems, the average power requirements is decreased by almost 50%, from nearly 100 watts (W) in the mid-1980s to 50 W in the mid-to late 1990s, and standby power consumption stayed relatively constant at approximately 25 W. The computer power consumption is on the increase, however, while standby power consumption is decreasing. The Pentium 4 computer systems consume more power than its predecessors at 67 W in active mode, while consuming only 3 W in Standby mode [19, 20]. There is much more variation in the power requirements of the modern computer systems, due to the addition of consumer-specified features, such as increase in speed of Hard disk drives (HDDs) capacity and add-on cards, which vary power requirements of similar models [21-24]. In Fig. 1.3, the power consumption of average computer system was compared [4]. We can also find that the modern HDDs require significantly less power than earlier models (10W compared with 35W), as does the motherboard (25W compared with 52W in 1988) [4]. The modern CPU is one of the few computer components that use more energy than earlier models. The CPU was not recorded in the study because it consumed minimum power – compared with an average of 34W in 2001 [17, 18].

![Graph showing power consumption of various devices during the year 1988 to 2001.](image)

**Figure 1.3:** Power consumption of various devices during the year 1988 to 2001.
The power required by the CPU can be expressed as "the product of the processing speed, the number of transistors being switched, and the energy required to switch each transistor, which in turn varies with the capacitance and the square of the voltage" [17]. The number of transistor in a CPU has increased faster than the transistor size has decreased, as indicated by the growing overall dimensions of CPUs [17]. Power consumption of an electronic chip depends mainly on the type of transistor used like NMOS and CMOS. Both types of transistors drew similar amounts of power when switched, but CMOS requires almost no power when in a quiescent state. Use of CMOS transistors has reduced power consumption by around 30 to 40% [17, 18].

1.4ECO-LABELING

Eco-labels are a primary tool available to inform consumers about the environmental characteristics of the products [4]. They appear as a label or logo that gives consumers actual data on the product and lets them know that it meets a fixed set of environmental criteria. Eco-labels are often characterized in three categories: type-I, type-II and type-III. Type-I, Eco-label is essentially a "certificate of approval" for the product and given by the third party organization like government agency. Type-II Eco label, a company declares that its product meets independent standards such as for recyclability or energy-efficiency [4]. A type-III, Eco-label is designed to provide a set of quantitative environmental data to consumers so that the consumers can use this information themselves to evaluate the product. Eco-labeling of personal computers poses a number of difficulties, however, one major difficulty is that personal computers are complex and rapidly changing products and in many cases new models are introduced every six months means that the environmental issues associated with personal computers can change more rapidly. The criteria for an Eco-label for a personal computer should address the major environmental issues like energy consumption, effect of heat dissipation, the impacts of hazardous substances, and possible exposure to chemicals during production processes. A great variety of eco-labels for computer systems have been introduced over the years and most existing labels are of type-I. On this way, the Energy Star program [25-27] launched by the United States Environmental Protection Agency (EPA) in June 1992 is one of them, which is designed to promote energy efficiency via a voluntary, EPA-certified, Eco-label on a wide variety of equipment. This label has been widely adopted by number of
organizations and computers and monitors were addressed from the program’s inception. Swedish Confederation of Professional Employees introduced the certification and labeling system developed and managed by the TCO which focuses on the workplace environment issues, such as limiting the electromagnetic radiation from cathode ray tube (CRT) monitors, sound emitted by devices, ergonomics, and electrical safety. Currently, there are two types of TCO labels: TCO’ 95 and TCO’ 99 [4, 28, 29]. The Japan Electronics and Information Technology Industries Association (JEITA) developed the PC Green label [4, 30]. Its criteria cover energy use (must satisfy Energy Star), content of hazardous material (similar to TCO’ 99), and ease of recycling issue. Nordic Council of Ministers have introduced Nordic Swan certification label which is used in Finland, Iceland, Norway, and Sweden [4, 31]. At last, India’s ecomark is an earthen pot [32], which is chosen as the logo for the Ecomark scheme in India. Government of India also set up Bureau of Energy Efficiency (BEE), a statutory body under Ministry of Power, on 1st March 2002, under the provisions of the Energy Conservation Act 2001 [33]. One of the regulatory functions of BEE, under this Act, is to develop minimum energy performance standards & labeling, for equipment/appliances and buildings, starting from one star for the least energy-efficient, and going up to five stars, for the most energy efficient. These star labels have been created to standardize the energy efficiency ratings of different electrical appliances and indicate energy consumption under standard test conditions. BEE star label is now mandatory for equipments from January 7, 2010 onwards. Similarly, there are various others eco-labels exist like Blue Angel from Germany [34], E.U. Flower from European Union [35], and Eco Mark from Japan [36] are roughly similar in the issues they cover.

1.5 POWER MANAGEMENT IN PERSONAL COMPUTERS

Power management technology has been developed for personal computer to reduce the energy consumption when they are not in active use. This not only provides the environmental benefits of reduced energy consumption, power management but also can improve the equipment reliability by reducing the waste heat. The heat produced by these devices has the adverse effect on the environment as well as on human health [37, 38]. First developed for laptop computers, power management is now common in desktop computers. As of early 1996, the EPA estimates that upwards of 70% of all new personal computers and nearly 100% of all personal computer monitors sold have
power management capability [39]. Computer systems are supposed to use a variable amount of power when they are switched on and this depends on their configuration, add-on devices, and the various software processes running on them [11, 12, 40]. Though power management interact with every part of computer system but still there is the potential for unexpected interactions between power management and computing environment. Computer manufacturers have addressed this problem by making power management more flexible and more compatible with current personal computer networks. As the technology has matured, power management has emerged as an effective tool for saving energy. Early power management systems had long recovery times, awkward configuration methods, and low energy savings. However, the power management has improved rapidly, becoming more powerful, reliable, and easier to use. It also now delivers considerably more energy savings. In 1992, U.S EPA has introduced the Energy Star [25, 26] program which is among the one of Eco-label that provides guideline for power saving by the computer system. In 1993, Intel and Microsoft introduced Advanced Power Management (APM) [41, 42], which is becoming an industry standard. The APM protocol supports power management by defining how power management commands are communicated within the personal computer system. Power-management does not reduce the performance of a computer, but simply adds features to reduce their power consumption when not in use. These energy-efficient machines save money on electricity bills and reduce pollution from power plants. Most power management savings come from reducing power when the machine is not fully active by adding low-power or "sleep" modes that kick in when idle.

1.5.1 ADVANCED POWER MANAGEMENT
APM saves energy by putting the computer and monitor into a low power mode during periods of inactivity by temporarily reducing their speed or functionality. In response to Energy Star program in 1993, Intel and Microsoft first introduced APM [41, 42], which defines how power management commands are communicated within the personal computer system and established an industry standard in power management. Before the release of Microsoft Windows 95 operating system software was only minimally involved in desktop personal computer power management. At that time application software was only used to monitor power management not for controlling the personal computer itself. Thus the basic Input/output system (BIOS) was, and remains, a critical
component. Later, in 1998, Microsoft and Intel have developed the Advanced Configuration and Power Interface (ACPI) [43-45] and primary control of power management shifted from BIOS to the operating system [4] in the form of power schemes. ACPI has allowed manufacturers to produce computers that automatically power up as soon as the keyboard is touched [23, 24]. In computer systems, the operating system acts like a manager and controls a computer's hardware and software, therefore, it is considered as a major source of power consumption. Advanced power management interacts with every part of the computer - the operating system, software CPU, and various other peripheral devices. To manage the power consumption, there are several predefined power schemes at one's disposal. These power-saving options are responsible for switching a computer system to different states, such as standby mode, sleep mode, and, monitor and Hard Disk Drive (HDD) shutdown, depending on the inactivity period defined by the power scheme of the operating system. As shown in Fig. 1.4, computers are logically organized as a hierarchy of layers [4, 46]. Those at the top are the software that the user directly interacts with, those closer to the bottom direct the physical control of electrical signals. Power management can involve the application software and the operating system, and always requires an action by the firmware (BIOS), processor and peripheral hardware. However, the control signals must still pass through each intermediate layer for action to occur. The working of these power management schemes is also shown in Fig. 1.4, which accomplishes four different levels. First is to monitor activity levels of the processors, input devices like keyboard, mouse and other devices. Second, component is to utilize timers to decide when to switch the computer system to low power mode. Third component, changes in the power management status need to be communicated to the correct device and must occur actually. Finally, power management must find out when the activity gets resume and return to a full power mode. In Fig. 1.4, The BIOS monitors the keyboard, mouse and other input devices activity (as per number 1) and sends periodic signals to the operating system to begin power management (as per number 2). Here the operating system will only pass the signal through if it detects an activity from the user application software (as per number 3) and triggers the start of the power management timers in the BIOS. In case, no activity is detected, the operating system passes the signal back to the BIOS (as per number 4) and once the time-out occurs the BIOS will initiate power management by sending a message to various connected devices like CPU, HDD etc. (as per number 5). After initiating a change in mode, the BIOS begins
another timer which indicates when to initiate the next lower power management mode. The BIOS continues to monitor keyboard, mouse, and network activity. If activity is detected, the BIOS will send the appropriate messages to return the personal computer to an active state. The timing of the power management modes is determined by the settings (usually in BIOS or in Power Scheme), specifying the delay between each power management mode and the next. Each successive power management mode represents a decrease in energy consumption and CPU function, and therefore more time is required to bring the computer back to active mode [4, 46].

In addition to the direct electricity savings, power-managed computers generate less heat, and since most offices have to cool the air more than they heat it, for every four kWh of energy saved by the computer, an additional kWh is saved in the cooling and ventilation system [47, 48]. Power management in personal computer relies on the fact that for most of the time a typical personal computers is on, it is not doing anything productive. As long as the computer is idle, energy use can be reduced without interfering with work.

![Diagram of computer power management and communication paths.](Figure 1.4: Personal computer power management and communication paths.)

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Common methods used to reduce the energy use are slowing down or stopping the processor clock, spinning down the hard disk, and turning off entire system components such as video or sound cards or disk controllers.

1.6 POWER SAVING MODES AND PROBLEMS WITH POWER MANAGEMENT

In computer systems, for minimizing the energy consumption various power saving modes are defined by the power scheme of operating system [2, 4]. The following section lists about the various power saving modes implemented either by APM or by operating systems in personal computer to save the energy.

**Full-Power-on:** In this mode all the connected devices and components with the computer systems are fully powered with no power management activated. This mode supports no energy savings.

**APM-Enabled:** In this mode, power management features are activated and based on the BIOS settings CPU is slowed or stopped whereas other connected devices and components draw the power similar to full-power-on mode. This mode supports up to 25% of energy savings.

**Standby mode:** In this mode, power management features works actively and CPU may stopped its operations depending upon the activity detected on the personal computer as well as connected devices and components also gets switches to low power saving mode. This mode claims up to 30% of energy savings. In case of any activity is detected may trigger the personal computer back to enabled or full-power-on mode.

**Suspend mode:** In this mode, CPU is stopped and most power managed devices or components are not powered except network card and provides the maximum power savings under APM. This mode claims up to 45% of energy savings. In this mode, any activity can trigger the change of state of computer system from suspend to standby, enabled or full-power-on mode.

**HDD off mode** this mode is not a part of APM; hence it is not a system mode and normally managed by the operating system. In this mode, HDD spin is stopped to save energy used by HDDs. This mode is independent of other power saving modes and hence other connected devices or components may remain at full-power-on mode or in
enabled, standby and suspend mode. This mode claims up to 10% of energy savings only and any activity on the personal computer can facilitate quick reactivation of HDD to operational mode.

**Hibernate mode**: This mode is also not a part of APM mode and normally managed by the operating systems. In this mode, all available memory contents and current state of the PC saved to the HDD and further PC gets switch off. When user wants to work again on hibernated PC, then he/she has to power on the PC and system takes 15 to 60 seconds to recover the user’s state. This mode claims 90 to 100% of energy savings. This mode must be properly configured to take its advantage.

**Shutdown mode (Off mode)**: In this mode, the computer system, various connected devices and components gets switch off. As compared to previous hibernate mode no operational parameters are saved to the HDD. This mode supports 96 to 100% of energy savings and whenever user wants to perform some operations on the computer system then he/she has to switch the system to full-power-on mode.

Though, with the change of time, the power management feature has been shifted from BIOS to Operating system and more power saving modes are being designed to save power but a small amount of power ranges from 3W to 15W is consumed in these modes [4]. However, most of the time, these power saving modes are not properly configured or most of time users rely on the default settings of power saving modes, which allow for only up to 20% in energy savings [4, 12]. The difficulties in properly configuring power management in computers and monitors are the largest barrier for achieving energy savings from automatic energy management. Further, many power management systems for both monitors and computers had long recovery time, awkward configuration methods, and low energy savings [46, 47]. In [49], Webster et al. estimated that 80 percent of monitors and 50 percent of computers are Energy Star-activated. A study of power management features and configuration of Energy Star-compliant machines found only 11 percent of CPUs fully enabled and about two-thirds of monitor’s power managed [23, 24] whereas Kawamoto et al. [7] have obtained in their study that only 25 percent are correctly power-managed to achieve maximum power savings [7]. It is very difficult to determine whether power management is properly operating in machines. The only indication to the user that power management is occurring in their computer is when the HDD audibly spins down or delays in the
appearance of keystrokes when spinning up. Other than this, it is difficult to know whether the computer is accomplishing any further power management [23, 24]. There is an illusion among the users of personal computer that their system is power-managed because the Energy Star logo appears during start up. Many users do not realise that they must first activate the power management features to save energy [15, 50].

Once enabled, the power management may present some further challenges. Power management interacts with every part of the computer, and therefore there is potential for unexpected interactions, which may cause problems [51, 52]. In most cases, however, automatic power management is not a substitute for switching the machine off when not in use for extended periods of time. However, substantial energy savings can also be made by switching the personal computer off since it has been found that more than 50 percent of computers are left on at night [4, 12, 17, 18].

1.7 ENERGY-SUSTAINABLE COMPUTING

To handle the issue of power management in efficient manner in the computer systems, the concept of ‘Sustainable Computing’ is gaining a lot of popularity presently and is being considered as one of the most promising technology by the designers of Information Technology (IT) industry. Sustainable computing is also known as ‘Green computing’ of which computing methods provide the benefits of solving the energy-consumption issue by computer systems and being environmentally friendly [11, 53]. There are basically three major aspects of sustainable computing: i) reduction of energy consumption from any running computing process on the system ii) to ensure the longer life cycle of any computing equipment, and iii) curtail the need of energy consumption within the energy available from all resources in the environment [11]. Therefore, the sustainable computing performed from energy perspective is known as energy-sustainable computing. A major issue in addressing the different aspects of sustainable computing is the need for awareness of the non-computing processes in the physical environment like dependency of the equipment life cycle on the environmental factors and the availability of energy from the available resources in the environment. On this way, energy sustainable computing can also be defined as the balance between the power required for computation and power available from sources like renewable sources, green sources etc. However, the power required and available power may vary according to the time as solar power will not be available in the night and computing
operations will become unsustainable if the required power is higher than the power available. This varied nature of energy sustainability can be defined as follows:

1.7.1 Energy Sustainability
Energy-sustainable computing needs to ensure minimum energy requirement from the grid or battery and emphasizes a lot on green sources. In case, if there is no or less energy available from green sources then energy sustainability brings down the average energy required by reducing the computing operations. There are different directions in achieving energy-sustainable computing [2] such that need for grid and battery power is minimized.

a) Energy storage
Here, energy storage devices are used to store the energy available from green sources with the help of various available techniques like ultra-capacitors, compressed air storage, batteries, fuel-cells, and flywheels [16-18 paper]. This storage of energy is constrained by the energy capacity limit of the storage device.

b) Reducing energy requirement
Another major direction for energy sustainability is to reduce the energy requirement to avoid unsustainable operations or to reduce the energy need from grid or batteries which, can be achieved in variety of ways: 1) by using spatio-temporal distribution of operations, where computing operations are distributed among multiple computing units and no machines gets overloaded. These types of spatio-temporal distributions are used in data centers [12, 24, 25, paper]. 2) by using computing power management means to reduce the power requirements. This can be achieved by switching the computing units in to different power saving modes for example, processor not performing any operation can be switched to sleep mode or hibernate mode to reduce the power requirement [paper, 27, 28, 29]. 3) by managing non-computing systems where power requirement by the computing units is followed with the requirement from some associated non computing processes like for cooling, for server longevity etc.

c) Scavenging energy from various sources: This is another complimentary option for energy-sustainable computing which focuses on need of energy
harvesting and requires identification of different energy sources to scavenge energy from them [2, 7, 30, 31 - paper].

1.8 ORGANIZATION OF THE THESIS

This thesis aims to understand the limitations of existing power schemes available in the operating systems and to investigate new ways of designing energy sustainable framework and algorithms for minimizing the power consumption by personal computers. The framework discussed in this thesis is a user centric energy sustainable framework. The remainder of the thesis is organized as follows:

Chapter 2 concerns with the various ways of the minimizing energy consumption in the computer systems. Here, we have represented various simulation based, hardware based, and software based scenarios to minimize the power consumption and focused on the software based sustainable techniques. We have also discussed the need of enhancement of the dynamic power management and dynamic voltage and frequency scaling methods to achieve this goal.

Chapter 3 presents the user centric energy sustainable framework. In this chapter, we have modelled the energy and power consumption, which is build around the CPU utilization and presented a user centric energy sustainable framework. This framework also considers the total CPU utilization and implements two different modes known as Swift mode and Exhaustive mode for the power saving. We have also discussed about the various advantages of the proposed framework over traditional power schemes available in the operating systems.

Chapter 4 focuses on the algorithmic implementation of the proposed energy sustainable framework. This framework implements two algorithms known as Swift algorithm and Energy Sustainable Snapshot algorithm (ESSA) for the proposed modes, respectively. The various results are obtained using these algorithms for the respective modes using scenario when there is no load on the machine and when there is processing going on which shows that the CPU of the machine is utilized. Here, only the proposed ESSA algorithm is designed around the percentage of total CPU usage, which is recorded for each minute whereas the proposed swift algorithm focused on its smooth functioning for the supplied login-duration time.
Chapter 5 evaluates the performance of proposed energy sustainable framework for its two different modes in the real time environment. By using profiling, we have evaluated the framework for thread monitoring, memory performance like heap analysis, thread analysis, memory leakage, and garbage collection is done. Finally, we have also analyzed the CPU performance by using three methods for finding invocations of each method during login-duration. Using profiler, various results have been obtained in real time environment and are presented in this chapter.

Finally, we conclude the thesis and recommend the future scope of the work in Chapter 6.