Cloud-Computing Strategies for Sustainable ICT Utilization: A Decision-Making Framework for Non-Expert Smart Building Managers

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Abstract

Virtualization of processing power, storage, and networking applications via cloud-computing allows Smart Buildings to operate heavy demand computing resources off-premises. While this approach reduces in-house costs and energy use, recent case-studies have highlighted complexities in decision-making processes associated with implementing the concept of cloud-computing. This complexity is due to the rapid evolution of these technologies without standardization of approach by those organizations offering cloud-computing provision as a commercial concern.

This study defines the term *Smart Building* as an ICT environment where a degree of system integration is accomplished. Non-expert managers are highlighted as key users of the outcomes from this project given the diverse nature of Smart Buildings' operational objectives.

This research evaluates different ICT management methods to effectively support decisions made by non-expert clients to deploy different models of cloud-computing services in their Smart Buildings ICT environments. The objective of this study is to reduce the need for costly 3rd party ICT consultancy providers, so non-experts can focus more on their Smart Buildings' core competencies rather than the complex, expensive, and energy consuming processes of ICT management.

The gap identified by this research represents vulnerability for non-expert managers to make effective decisions regarding cloud-computing cost estimation, deployment assessment, associated power consumption, and management flexibility in their Smart Buildings ICT environments.

The project analyses cloud-computing decision-making concepts with reference to different Smart Building ICT attributes. In particular, it focuses on a structured programme of data collection which is achieved through semi-structured interviews, cost simulations and risk-analysis surveys. The main output is a theoretical management framework for non-expert decision-makers across variously-operated Smart Buildings. Furthermore, a decision-support tool is designed to enable non-expert managers to identify the extent of virtualization potential by evaluating different implementation options. This is presented to correlate with contract limitations, security challenges,

system integration levels, sustainability, and long-term costs. These requirements are explored in contrast to cloud demand changes observed across specified periods. Dependencies were identified to greatly vary depending on numerous organizational aspects such as performance, size, and workload.

The study argues that constructing long-term, sustainable, and cost-efficient strategies for any cloud deployment, depends on the thorough identification of required services off and on-premises. It points out that most of today's heavy-burdened Smart Buildings are outsourcing these services to costly independent suppliers, which causes unnecessary management complexities, additional cost, and system incompatibility. The main conclusions argue that cloud-computing cost can differ depending on the Smart Building attributes and ICT requirements, and although in most cases cloud services are more convenient and cost effective at the early stages of the deployment and migration process, it can become costly in the future if not planned carefully using cost estimation service patterns. The results of the study can be exploited to enhance core competencies within Smart Buildings in order to maximize growth and attract new business opportunities.

Dedication

This research began, and finished, while my home country Syria has been at war. This project is dedicated to Syria.

It is safe to say that if it was not for my family I would have not been able to reach this stage in my academic and professional career. Therefore, I would like to show gratitude and appreciation to all their efforts.

I would like to sincerely thank Professor Gareth Pender for believing in me and granting me this opportunity to complete a Doctorate degree under his supervision. I would also like to thank Dr David Jenkins for his supervision and assistance in completing this project.

This PhD carried out a considerable amount of data collection, which involved the participation of various enterprise-level personnel, CEOs, and Smart Building ICT decision-makers. On that note, I would like to thank Mr. Oliver Peuschel from Rackspace London, Mr. Mike Roch from Heriot-Watt University Edinburgh, and Mr. Salem Cheikh Najib from GBM Dubai. Moreover, a special thanks to the fifty-four management users from different industries who generously took the time to participate in this project's risk-analysis survey.

The project introduced an original web-based decision support system named *Smart Building Cloud Evaluator* (*SBCE)*, which involved various types of ICT work such as programming, web development, database, hosting and deployment. On that account, I would like to thank Engr. Fadi Al-Nawakil from MobileArts-Lebanon, for his worthy technical insights and hosting services.

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GLOSSARY OF TERMS

ICT: Information and Communication Technologies.

DSS: Decision Support System.

STM: Smart Technology Management.

Smart Buildings: ICT environments where a certain degree of system integration is accomplished.

Non-Expert Managers: Decision-makers who do not acquire a significant ICT educational or operational background, but who are obligated to make ICT related decisions, which affect their Smart Buildings' budget and lifecycle.

ICT Sustainability: Information and Communication Technologies which aim to achieve cost efficiency, management simplicity, and power consumption reduction.

Green ICT: Information and Communication Technologies that are designed to consume less electricity than the conventional ones, and that can be managed, controlled and provisioned using simplified and more cost effective processes compared to the traditional technology management techniques.

Green Buildings: Buildings that include Information and Communication Technologies that are designed to consume less electricity than the conventional ones, and that can be managed, controlled and provisioned using simplified and more cost effective processes compared to the traditional technology management techniques.

1.0- Chapter 1: Introduction

1.1- Overview

ICT technologies have radically transferred the way people, companies, economies, and governments operate on a daily basis, and have also had a massive impact on how we manage and control the built environment. Accordingly, numerous ICT management concerns on economic and environmental levels have been raised by different organizations which occupy Smart Buildings and are facing a growing ICT demand. The concerns arise as a result of the long disappointing history of managing various ICT applications within Smart Building ICT environments as will be discussed in the literature review in Chapter 2. In addition, another ICT implementation gap was identified by non-expert managers in terms of acquiring the ability to assess the long-term benefits and predict changes in the economic value of ICT assets, which can occur due to unnecessary purchase, or alternatively, underutilization of costly ICT infrastructure. On that account, the focus of this research project is to explore effective ways for non-expert managers to adopt different types of cloud-computing services in their Smart Buildings. This discussion will examine benefits, risks and challenges from performing either a full or a partial cloud migration process of ICT resources in different Smart Building cases. The overall objective is to achieve better long-term cost efficiency, sustainability, and ease-of-management of the combination of in-house and off-premises ICT systems, hardware, and outsources services.

Research attention has shifted towards identifying the best methods to make sense of large volumes of captured data from various Smart Building systems. The current adoption of ICT services in almost every aspect in the ICT management process have led to the development of more flexible deployment approaches such as cloud-computing for networking, storage, and processing tasks. Although this began to surface more across large organizations, these technologies are still not standardized properly in the information industry, and in most cases are being standardized differently by top ICT suppliers depending on what best suits their marketing objectives and competitive advantage. As a result, many potential benefits from the adoption of these technologies are being under exploited. This makes the utilization of these ICTs more challenging for

end-users in terms of being able to measure effectively the internal requirements against ICT costs, administration efforts, and associated power consumption.

This research will address this issue and develop a decision-making framework for cloud-computing management with the support of demonstrational web-application software referred to as SBCE: *Smart Building Cloud Evaluator.* This tool will support non-expert managers in Smart Buildings to make effective decisions on cloud-computing adoption techniques with the support of scalable cost features for managing resources, changes in demand across time, and other recommendations to avoid potential risks and limitations in the long-run. Furthermore, the aim is to allow end-users to identify unnecessary ICT requirements, estimate future expenses regarding contracts and the required resources, and assess potential environmental advantages from cloud-computing outsourcing solutions such as power reductions and sustainability in hardware use.

This research defines the term *Smart Buildings* as any ICT environment where a degree of system integration is accomplished. On this note, non-expert managers are highlighted as key users of the outcomes from this project given the diverse nature of Smart Buildings' operational objectives. In particular, the term *Smart Buildings* in this study highlights a generic portfolio within a building environment, where to some extent this environment includes a set of integrated ICT platforms and systems that share multiple management attributes such as hosting, networking infrastructure, 3rd party services, and control portals.

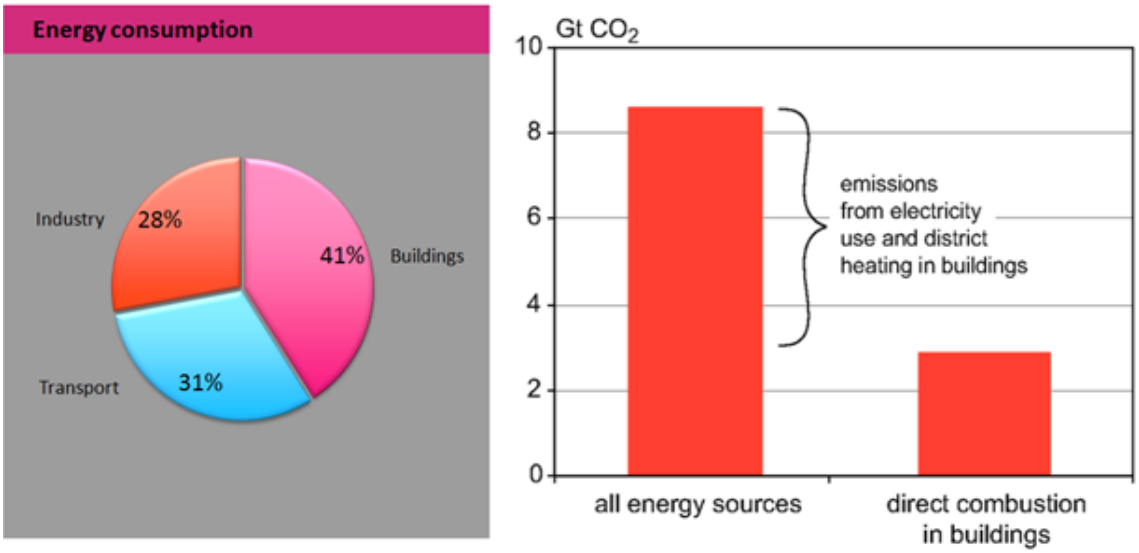
In addition to the two main objectives of this research of minimizing ICT management processes and costs in Smart Buildings, there is a secondary goal which aims to reduce the amount of power and energy used on ICT resources. In theory, this can be achieved by outsourcing all ICT components to external datacentres which are already managed by ICT providers. However, the decision-making of this migration procedure requires a thorough identification of requirements, and a clear evaluation of future circumstances in the Smart Building as will be discussed in the following chapters.

On that note, one of the major issues facing this planet today is pollution due to greenhouse gases. ICT-related pollution came to attention given the swift development of new technologies which led to the dumping of large amounts of unused and outdated hardware without proper recycling strategies or waste management. As will be

discussed in later chapters, the relevance of that to this thesis is explained in what cloud-computing services can potentially benefit the environment if utilized properly in terms of eliminating outdated hardware through virtual methods. These fast advancements in both the industrial and digital fields have raised many concerns regarding different environmental aspects such as greenhouse gas emissions, waste management, the output of raw material, and the availability and consumption of energy which is especially witnessed in 3rd world countries.

Moreover, carbon dioxide's high rates were observed by experts to reach unprecedented levels, especially in developed urban cities where almost half of the world's population resides (Parsons IBM Smarter Planet, 2012). These highly developed cities can be currently portrayed as the battlefield ground between different organizations which include the environmental side on one hand that strives for sustainability, and the winning side which only seeks economic prosperity (McKinsey & Company, 2008). With respect to the disappointing history of achieving ICT sustainability despite the massive amount of literature published on this subject, not much was offered in terms of how to effectively balance both economic growth and sustainability in an ICT infrastructure strategy.

Turning this planet into a smarter one was discussed through a wide range of literature in connection to numerous industries and disciplines. These areas were mostly related to transportation, medical services, crime prevention, banking, education, buildings and others. In response to the heavy dependence on ICT in almost all of the above areas, several associated environmental concerns surfaced in relation to, energy consumption, waste and output management, and other burdens such as how to handle previous ICTs and hardware which turn obsolete each time a newer technology appears. For example, according to the UN Habitat, highly-populated and developed cities like London, New York, and Beijing, are accountable for nearly 85% of this planet's greenhouse gas emissions (UNEP, 2011). This renders these cities -in carbon terms- as extremely polluting and inefficient places to live for the short forecast period. Furthermore, according to the Intergovernmental Panel on Climate Change one third of global energy consumption is caused by buildings, as the rest is divided almost equally between General Industry with 28%, and Transport with 31% (Figure 1.1). Moreover, greenhouse gas emissions from buildings in developed cities will reach over 12 billion tonnes by 2025.



(Figure 1.1) The Intergovernmental Panel on Climate Change: Buildings' Energy Consumption (McKinsey & Company, 2008).

Large cities in developed countries like the US and China are constantly attempting to come up with better solutions through ICT services to maximize sustainability and mitigating greenhouse gas emissions without compromising the quality of both the living and working environments. The following sections will discuss a background on Smart Buildings and explains its relevance to this research. Furthermore, this chapter will present: an introduction on the evolving ICT age, a cloud-computing background, principles of smart technology management, and the main research objectives.

From a high-level perspective, the following explains briefly the main research statement, gap, objective, methodology, and thesis roadmap.

The Research Statement:

This research evaluates different ICT management methods to effectively support decisions made by non-expert clients to deploy different models of cloud-computing services in their Smart Buildings ICT environments.

The Research Gap:

The research identified a gap which represents vulnerability for non-expert managers to make effective decisions regarding cloud computing adoption in their Smart Buildings ICT environments.

The Research Objective:

- To evaluate from a Smart Buildings ICT Management Perspective Cloud-Computing Management concepts, costs, associated sustainability, and Risks.
- To develop a theoretical cloud-computing management framework for non-expert Smart Building decision-makers, with an online decision-support System called SBCE: Smart Building Cloud Evaluator.

The Research Methodology and Thesis Roadmap:

- Chapter 1 provides an introduction and a background on:
    - Smart Buildings ICT and Management: Section 1.2
    - The Evolving ICT Age: Section 1.3
    - Drivers for Change: Section 1.3.1
    - Cloud-Computing: Section 1.4
    - Smart Technology Management: Section 1.5
    - And the Research Objectives: Section 1.6

- Chapter 2 identifies the multidisciplinary areas of focus in the literature that are relevant to this research, and discusses the state of the art literature on:
    - Sustainability Approaches for Smart Buildings: Section 2.2.1
    - Market Solutions for Cloud-based Energy Management: Section 2.2.2
    - ICT Costs in Buildings and Power Consumption Overview: Section 2.2.3
    - Business Perspectives of Cloud-Computing to Support Smart Buildings: Section 2.2.4
    - Decision-Making Methods in Smart Buildings: Section 2.2.5
    - Decision-Making Models in Cloud-Computing: Section 2.2.6
    - Cloud Adoption Risks and Trade-offs: Section 2.2.7

- Chapter 3 carries out an in-depth cloud-computing theoretical analysis with reference to the following management aspects:
    - Definition and Standardization: Section 3.2.1
    - Procedural Characteristics: Section 3.2.2
    - Architectural Models: Section 3.2.3
    - Deployment Methods: Sections 3.2.4

  - Energy Saving Aspects: Sections 3.2.5
  - Cloud Costs, with accordance to Smart Buildings' ICT Spending: Section 3.3

- Chapter 4 discusses the data collection methodology. This covers the main methodology of each section adopted by this research. Accordingly, each stage was explained separately through the identified selected field works and data collection approaches.

- Chapter 5 carries out a structured list of practical and field work. The methodologies adopted of the practical investigation is illustrated as follows:
  - A semi-structured interview with a global cloud service provider (Rackspace): Section 5.1.1
  - A second semi-structured interview with a global cloud service provider (GBM): Section 5.1.2
  - A third semi-structured interview with a major higher education organization as a potential cloud service requester (Heriot-Watt University): Section 5.1.3
  - Cost simulation using the PlanforCloud tool of a cloud deployment case study across a 3-year utilization period: Section 5.2
  - Risk-analysis survey of the relevant cloud-computing management trade-offs and potential barriers scored by non-expert managers using the Likert-scale method: Section 5.3
  - Constructing a theoretical cloud-computing Management Framework for non-expert Smart Building decision-makers. Section: 5.4

- Chapter 6 develops a demonstration online decision-support system called *SBCE*: *Smart Building Cloud Evaluator*. The objective of this tool is to enable non-expert managers to estimate and measure remotely the levels of cost efficiency, management feasibility, and sustainability in their Smart Buildings concerning the different types of cloud-computing adoption. The chapter discusses the following:
  - Introduction of the tool's main features and specification: Section 6.1
  - Syntax and Development Diagrams: Section 6.2
  - Description of Requirements: Section 6.2.1

- Workflow Diagram: Section 6.2.2
- Testing and Case Study Execution: Section 6.3
- Conclusion: Section 6.4

- Chapter 7 summarises the main research conclusions and discusses the following:
  - Overview and Critical Analysis: Section 7.1
  - Decision-Making Tool Key Outputs: Section 7.2
  - Research Limitations: Section 7.3
  - Recommendations and Future Work: Section 7.4
  - Summary of Conclusions: Section 7.5
  - Concluding Statement: Section 7.6

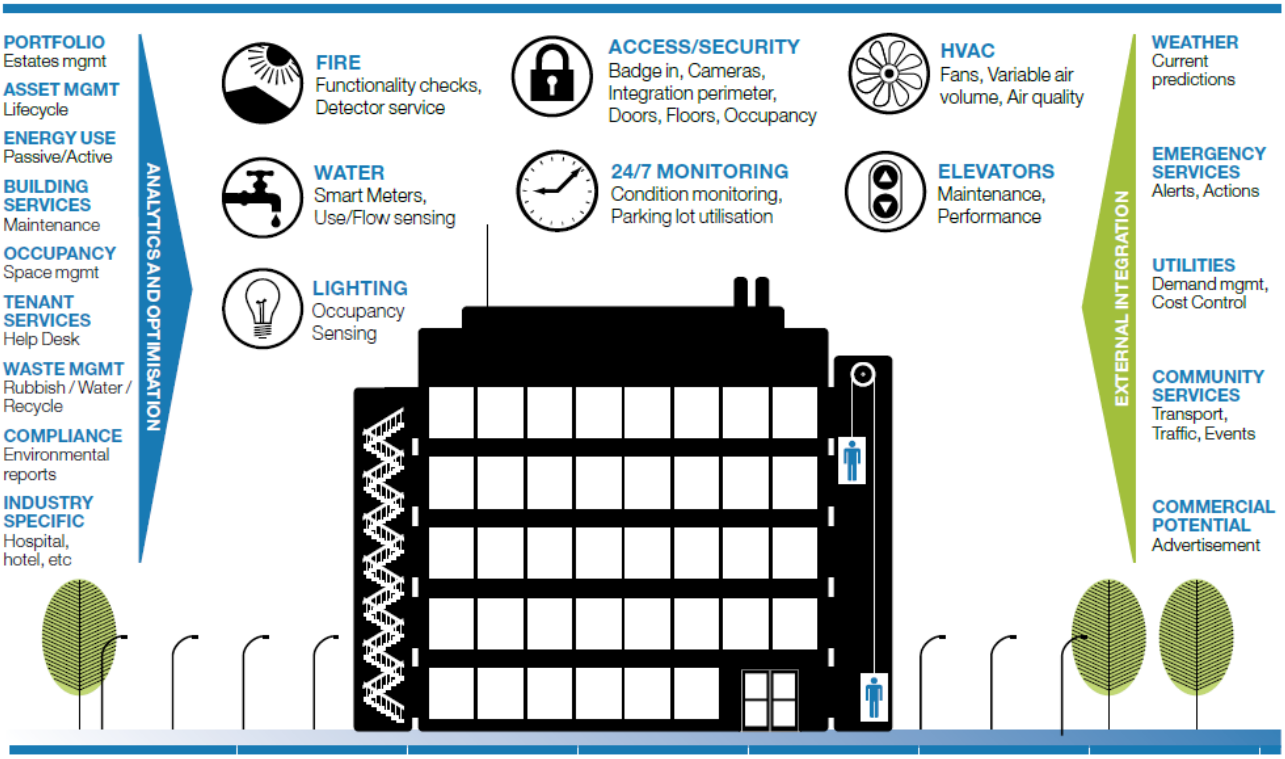
1.2- Smart Buildings Background

IBM indicated that by 2025 more than 65% of the earth's population will reside in developed cities (Simon, 2012). These urban areas are widely occupied by large groups of energy consuming buildings, which in the UK alone, are generating around 18% of the country's total carbon emissions. Furthermore, it was noted that buildings are the largest energy-consuming asset on this planet using close to 42% of the total electricity generated worldwide. As a result, attention began to shift towards balancing economic performance on one hand, with energy efficiency and environmental sustainability on the other. With regard to ICT performance and cost, the general topic of transforming building ICT management into a smarter process is not considered novel, however, other associated aspects which can greatly affect the decision-making process regarding cost, performance, and power usage in the long-run attracted further attention as new ICTs began to emerge. These aspects are mostly related to cost strategies, contract management issues with external providers, identifying the level of in-house control over ICT resources, maintenance planning, identifying service demand patterns, and measuring associated energy usage.

According to IBM, the Smart Building concept is not only concerned with being *Greener* in general performance terms. However, it also includes insights on how to effectively understand buildings behaviour towards the outer environment with reference to administration, decision-making, and operational objectives. This

awareness represents capturing and analysing vast volumes of data which are generated from sizable buildings such as hospitals, universities, airports, and businesses. In real life, this can be achieved by utilizing various forms of devices such as sensors, meters and other measurement tools. Thus, a much more effective, reliable and real-time reporting of events can be achieved, to a certain extent, in different types of Smart Buildings. This research will only focus on managing the ICT environment within the Smart Building, while taking into account that a certain level of integration is already accomplished between the Smart Building's ICT systems and implemented hardware. As a result, various solutions will be investigated to outsource different layers of the Smart Building's ICT infrastructure into online platforms. This will be responsible for handling the data output from those internal systems in terms of processing capacity, networking bandwidth, storage, and administration.

As will be discussed in sub-section 1.6, the main objective behind the above statements is to conclude a decision-making framework to assist non-expert managers in simplifying the ICT management process, obtain power reductions, and plan future cost-effective strategies in their ICT deployments. The following Figure (1.2) shows some of the main functions and systems which are typically included in a Smart Building environment, whereby data output from each system is potentially captured and integrated onto a single ICT platform. This research will investigate outsourcing this platform into a cloud-computing one in order to reduce costs, energy, and simplify the ICT management process.



(Figure 1.2) IBM's General Smart Building Internal Functions (Simon, 2012).

The purpose behind obtaining insights from the raw data generated from systems such as the above is the ability to support the decision-making process in the Smart Building by incrementally connecting numerous systems from different buildings while ensuring an integrated management base. After capturing this data, several assessment tools will then be employed through data-mining and analytical techniques, which will compare results with pre-specified algorithms, events, and previous incidents to ultimately generate reports for non-expert managers to take appropriate actions and decisions. While the purpose here is to ensure the delivery of optimal management recommendations and accurate predictions, other objectives are also highlighted to obtain sustainable multi-dimensional interactions between various building systems (Hornsby & Allan, 2012).

Previous approaches have classified these buildings as *Smart,* whereas this research defines the term *Smart Buildings* as any ICT environment where a degree of system integration is accomplished. In addition, non-expert managers are highlighted as key users of the outcomes from this project given the diverse nature of Smart Buildings' operational objectives. As will be discussed in the next chapter, several arguments suggest that applying advanced ICTs comes with a hidden price. Not only is it considered highly expensive to purchase these technologies in the first place to achieve

a Smart Building ICT environment, but what most managers currently suffer from as a significant economical challenge is the difficulty in handling constant and sudden changes in their organization's ICT requirements, support, and control over resources. This difficulty is displayed mainly as managers attempt to avoid various long-term management issues, such as costs related to systems upgrade, infrastructure maintenance, and other costly and not easily managed procedures.

The heavy utilization of today's ICTs in Smart Buildings is demanding higher performance, and faster, scalable running of services. As a result, the attention of managers has increased towards adopting off-premises platforms such as cloud-computing, which to some degree comes with outsourced control features, on-demand, and scalable services. This also makes it easier for non-expert managers to support, manage, and update systems in a network of several Smart Buildings which follows a single higher management. On this account, these virtualized processing techniques which are mostly implemented through the internet with a pay-as-you-go, remote administration and on-demand approaches, forms the main concentration of this project to achieve an optimal technology management framework in different Smart Building ICT environments.

In terms of the ICT energy-saving objective in Smart Buildings, various platforms were explored for solving interoperability problems while taking into account the implementation of different heterogeneous subsystems (Ramli, Leong, Samsudin & Mansor, 2010). For example, several web services were introduced such as SOAP (Simple Object Access Protocol), WSDL (Web Services Description Language), UDDI (Universal Description, Discovery and Integration), XML (Extensible Markup Language) or other building automation standards for information exchange across buildings' systems. These include standards like OBIX, or open communication protocols for intelligent automation, as well as the widely applied protocols *BACnet* and *LonWorks.* All of the above were introduced to offer different capabilities to support both the Local and Wide Control Networks for building ICT administrators. These technical components are not entirely related to this study's area of research, however, given the multidisciplinary ICT management framework in which this study will ultimately conclude, these standards are considered significant to understand how to best assist non-expert managers in deciding whether to integrate certain Smart Building tasks or not. This will be discussed through the several migration stages regarding the

adoption of multiple types of cost-effective, sustainable, and user-friendly cloud-computing solutions (Berl, Gelenbe, Girolamo, & Pentikousis, 2009).

This study will construct a theoretical framework and an online decision-making tool to support non-expert managers to control Smart Building ICT environments through certain cloud-computing services. In essence, these buildings can be based in different locations, and can have different operational objectives, which make measuring the degree of associated risks such as service reliability and readiness towards migrating core systems to 3rd party providers a major management concern. Furthermore, this research will focus on cloud-computing software and hardware optimization solutions, which have a significant impact on Smart Buildings' energy-aware applications. In addition, different architectural and deployment models will be investigated in terms of the associated risks, long-term cost advantages and trade-offs. The study will conclude by developing a bespoke decision-support system in order to achieve both management simplicity and sustainability within Smart Buildings that have different attributes such as sizes, workload, locations, and management policies. The next section will discuss a brief background on the evolving ICT age which led to today's current cloud-computing advancements.

1.3- The Evolving Information Age

It can be observed that as a result of today's evolving technologies novel ICT releases will constantly classify the existing market as obsolete. These ICTs are currently adopted rapidly by new markets given the constant emergence of new demands and work specification. What began in the 1740s as early mechanization has led to the sudden burst of today's information and communication technologies (Dicken, 1998). This process went through several stages of ICT evolution. One of the major turning points of this process was steam power and railways in the 1840s. In addition, basic electrical advancements and other heavy engineering works appeared in the late 1890s, which eventually led to the rise of the *Fordism* period. As a result of the 1940s' rising economies, the next stage was named *The Reorganization of Production* period, which is still observed until today to be advancing swiftly across many markets and industries.

New ICTs are being developed and rapidly introduced into today's demanding markets regardless of the industry's specifications and requirements. The previous patterns and stages of development reflect the history of economic growth followed by economic decline throughout a relatively short period of time. This phenomenon goes by the name of *Kondratieff waves*, whereby each stage is terminated instantly when another modern ICT appears to develop shortcomings and reach unfulfilled demands (Freeman & Soete, 1987).

Information and communication technologies are actively part of a nonstop advancement process. While constantly seeking to adapt and support the demand for digital services, it can be argued that the previous patterns have excessively become in control of people's daily activities, economies, and governments. For example, implementing any service in a Smart Building will most likely depend on a certain type of ICT which is already being used by end-users, such as the integration with other system outputs and remote control over a network. Accordingly, several impacts with respect to social, economic, environmental, and other areas of influence on the working environment must be pointed out as a result of allowing technologies to take more control over procedural aspects on the majority of end-user services. This can be argued currently when applying different types of ICT solutions such as cloud-computing or other virtualized techniques to an existing ICT environment as will be discussed in this research. However, although various influences on end-users behaviour towards these services is highlighted such as adapting to novel smart solutions and others, this social and behavioural aspect which accompanies new ICTs will not be particularly addressed by this study as part of the concluded decision-making framework.

In addition to the ICT demands by Smart Buildings and organizations, other sustainability factors have received similar attention in response to crucial environmental trends. These ranged from electricity consumption on ICTs, availability of natural resources, pollution, and other aspects which are considered significant to this study's main subject concerning sustainable cloud-computing management in Smart Buildings. In parallel, non-expert managers in these organizations were observed in most cases to be struggling to identify the best methods to purchase, implement, and manage these ICTs while taking into account the previous environmental concerns.

It was estimated by different scientists that buildings in highly developed cities are consuming nearly 40% of this planet's current production of raw materials, which is close to three billion tons of raw materials on an annual basis (Parsons-IBM Smarter Planet, 2012). In addition, by 2025 buildings will be considered the largest consumer of energy in comparison to any other category. As a result of this alarming fact, this research chose Smart Buildings as an ICT category for potential cloud-computing deployment to mitigate this gap through addressing effective ways of management, sustainability and economic evaluation of these ICTs.

While a large amount of literature was published on identifying the best ways to implement different types of ICTs in Smart Buildings, the economic and management values of these technologies was observed to form the biggest interest among non-expert managers across various industries. Moreover, understanding these technologies in terms of what is necessary to a specific organization, cost effective, reliably delivered, power effective and available in the long-run, is the predominant objective in which this research will discuss in relation to different cloud-computing models and services.

As will be discussed in the next chapter, the majority of literature has agreed on the large domain of potential benefits which can be obtained from constantly adopting the recently developed ICTs as they appear. This was the target of research from several multidisciplinary industries as will be explored in the next chapter. It all began to take place when the rapid development process of digital communications and information innovations appeared to spread across almost all markets as previously mentioned. However, other sciences demonstrated a different kind of interest in the general concept of transforming conventional deployments into a smarter one, as each was following different objectives from adopting these ICTs. These disciplines have varied from applied sciences, environmental, social, economic, and behavioural studies.

It can be observed that Smart Buildings which used to operate conventional ICTs for a long period of time have faced several challenges when adopting different new forms of online-based technologies (Read, 2011). This transformation has forced its way into almost all industries and end-user services. Some examples of these industries are Banks, where complex payments services are handled. Other examples are security and surveillance organizations, transportation control agencies, and other businesses. On

this note, previous forms of smart applications can jointly be integrated into a single, virtual ICT management cycle which is easily maintained, power effective, and has the potential to add economic value in the long-run (McKinsey & Company, 2008). This was referred to as *Technology and the Connected Community* (Figure 1.3).

(Figure 1.3) Technology and the Connected Community Model (McKinsey & Company, 2008).

Delivering ICT services in a real-time basis in response to the current growing demand was observed as the main concern for non-expert managers across Smart Buildings. However, the processes of delivering these services through online-hosted technologies can greatly vary from technical and management perspectives depending on the operational objectives of each Smart Building, and in relation to various administrative aspects such as the number of employees involved, physical size, location, policies, and budget.

One of the main reasons for Smart Buildings to acquire a complex ICT management process is the unstable nature of ICT development, costs, support, and deployment approaches which are usually related to dissimilar applications and embedded in multiple digital solutions that are supported by various external suppliers in a single Smart Building. In theory, these environments such as hospitals, airports, shopping

malls, police stations and so on, require an integrated ICT platform in order to achieve real-time ICT delivery of services which is referred to as the *Process Centric Objective* (Arup website, 2012). Some examples of these deliveries can vary from multimedia services, presence awareness, and monitoring. On the other hand, management attention must be then carried out to improve the infrastructure level, which is referred to as the *Device Centric Objective*. However, this research will only focus on the management side of operations, in order to conclude a cloud-computing decision-making framework for non-expert Smart Building managers.

The following sub-section will discuss the main drivers of change in which this study will adopt in terms of the main hypothesis and the research data collection methodology.

1.3.1- Drivers for Change

According to Arup (Arup website, 2012) the main drivers for change are:

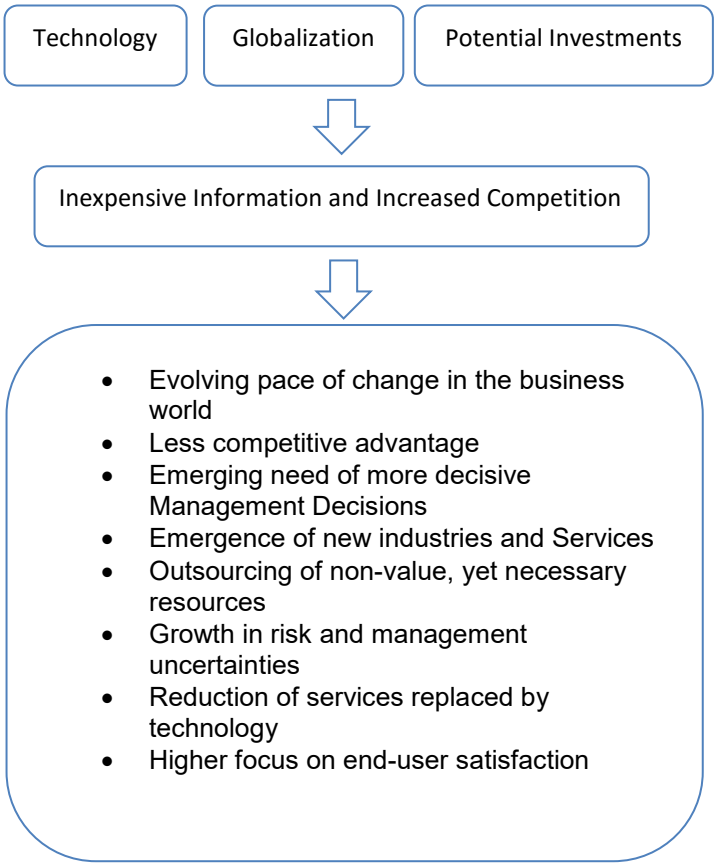
- Economy, covering issues such as, gaining commercial advantage, improving value for money, and transforming government services;
- Technology, improvements in both business and construction process from the deployment of advances in digital technology, and most importantly;
- Environment, the requirement for business to adopt a corporate socially responsible approach to major societal issues, such as, global warming and social justice.

The latter is a result of recognition that global warming caused by CO2 emissions has resulted in a seismic shift in the relationship between the economy and the exploitation of the environment. The environment driver is therefore the most significant, as if this is not addressed quickly there is a strong possibility of irreversible damage to the earth's ecological systems (Dawson, Chobotova, Rounsevell, Anastasopoulou & Oravska, 2007).

However, putting the major issue of the environment aside, growth in the use of digital technology is significantly changing the way we live, the manner in which we do business and how we interact with buildings and other infrastructure.

Figure 1.4 shows the various drivers for change to the business environment, covering, technology, globalization and investment potential, which illustrates advantages in the business environment in contrast to the associated development risks. This links to the main topic to be covered in the thesis, that through outsourcing of non-value added, yet necessary services, technology management and ICT automation via cloud-computing it is possible to:

- Enhance business efficiency providing efficient low cost access to ICT needs for a range of functions, and to,
- Reduce building power demands, reducing energy consumption and, thereby, support an organization's corporate obligations to reduce CO2 emissions.



(Figure 1.4) Drivers of Change Advantages in the Business Environment in contrast to Development Risks

1.4- Cloud-Computing Background

Internet-based ICTs were observed in many sectors to offer better leverages than the conventional ones with regard to different management, costs and sustainability aspects as will be discussed later. In many cases, these benefits were agreed to return economic and environmental values in industries such as Transportation, Smart Buildings, private housing, education and medical care organizations. Such technologies require heavy computing capabilities which are not always available on-site due to costly system requirements and staffing demand. Nevertheless, in order for those sectors to grow, these ICTs have become almost a prerequisite given the unpredictable workload peak periods and unsteady nature of requirements.

According to IBM, by 2020 there will be close to 1.5 billion transistors per human (Parsons-IBM Smarter Planet, 2012). This equals almost 35 billion RFID chips manufactured around the world against around 3 billion internet users. As a result, a large amount of data is constantly generated and improperly collected, which is the case for Smart Buildings as previously argued. On this note, cloud-computing technologies were argued to offer processing, networking, and storage capabilities which assist Smart Buildings and different industries in capturing, analysing and computing these large volumes of information, whereas in-house approaches were observed as not sufficient enough to complete these tasks in a cost-effective, administratively adequate, and sustainable manner.

The different models and techniques of cloud-computing deployments and services have a significant impact on the decision-making process in any Smart Building ICT environment. As will be discussed in the literature review chapter, this impact can positively affect multiple areas of the Smart Buildings applications such as:

- Faster identification of service-requirement patterns
- Faster analysis of large data via cloud-based data warehousing and mining services
- Faster processing of insights from the collected data
- Improved resources consumption and minimize energy use

- Minimizing additional future costs by identifying service demand patterns in advance
- Reduction of management efforts through faster and flexible ICT control services

As each of these implementations are evolving rapidly in almost all industries, several management case studies and technical examples throughout the following chapters will examine different operational aspects, risks and other decision-making considerations in relation to cloud-computing management in Smart Buildings. Moreover, end-user readiness factors towards a cloud ICT migration will be discussed through sustainable and cost-efficient strategies while taking into account changes and adjustments in the future Smart Building ICT lifecycle.

Novel information technologies were introduced for the purpose of ensuring a secure, easily deployed, and long-term maintainable hosting, computing and communication solution. For example, the adoption of wireless sensors in Smart Buildings was increased through different new digital devices which require heavy ICT capacity to function properly. On this account, many efforts were put forth to convert the physical processing power and all of its associated resources and support into a non-physical one, which is privately managed, and to some extent, utilized through an online and off-site infrastructure. Some of the Smart Building components which can benefit from these ICTs range from electrical IP-based devices, cooling, heating, ventilation, lighting, and other energy consuming systems. Therefore, given the immense deployment of today's widely-spread networking platforms such as the Internet, Virtual Private Networks (VPNs), and others, various alternative solutions started to appear as a result of the increasing number of end-users currently on the internet. This led to the introduction of a wider networking, storage, and processing platforms via virtualized, scalable and on-demand computing services, which are currently referred to as *The Cloud*. The cloud includes multiple models and service delivery approaches which will be discussed in-detail in relation to Smart Buildings ICT strategies for non-expert managers. These virtual ICT techniques are mostly utilized in developed cities where the performance of the internet is more reliable and standardized in terms of contracts, billing, support, and security.

The literature review chapter will argue that although a considerable amount of research work was published on cloud-computing potential benefits for management processes in organizations, there is still a noticeable gap for identifying a high-level decision-making framework for non-expert managers to measure the effective levels required for their organizations before adopting any types of cloud services. All the same, this study will particularly shed focus on Smart Buildings ICT management principles in order to ensure:

- The optimization of ICT-associated power consumption
- The elimination of upfront and unnecessary costs regarding cloud and conventional ICTs
- The minimization of ICT management efforts by outsourcing complex procedures

In general terms, cloud-computing is a ubiquitous platform which provides on-demand ICT services through either the public worldwide web, or other privately-managed and secure tunnelling networks (Mell & Grance, 2011). The cloud-computing model consists of key characteristics, service-delivery models, architectural types, and legal aspects, which will be discussed in the theoretical data analysis in Chapter 3 with reference to Smart Buildings ICT management.

It is essential to distinguish between different types of virtual ICT services and cloud-computing in general. Although both derive from the same root, however, virtual ICT services is a term that refers to business standards and ICT consumer solutions that are placed available on the internet with real-time access. On the other hand, cloud-computing over the internet points out to the wide range of information and communication services which can include either a software level or a hardware level of the ICT infrastructure. In addition to the real-time delivery manner of cloud services, other service provider and service requester considerations are raised in this context, which as will be proved, can affect costs, security and performance. Nevertheless, cloud-commuting solutions are embedded through virtual means, which enable end-users with a wide range of benefits regarding sustainability, management scalability, support flexibility, and mobile hosting via various levels of virtualization as opposed to the conventional in-house ICT approaches (Nguyen, 2009).

The evolution process of cloud-computing has gone through a number of development stages. What firstly began as a grid of large parallel computers solving heavy distributed problems has evolved in the late nineties into a metered computing solution referred to as *Utility Computing* (Buyya, Yeo, & Brandic, 2009). Furthermore, an *Autonomic Computing* model was consequently created in the late 2001, which solved software tasks as simple subscriptions via networked-based applications. While that model was considered, to some extent, capable of effective self-management, the latest generation of internet storage and applications, referred to as *The Cloud*, was mainly developed afterwards in 2009 for the purpose of achieving easier management and cheaper on-demand services.

The *Cloud* model came to life due to the growing requirements which were not being fulfilled through previous models due to costly ICT services and complex management procedures. However, in sequence with the cloud-computing approach, multiple trade-offs and challenges have risen, while others have remained from previous models. These will be further addressed throughout this research with respect to Smart Buildings ICT decision-making from the perspective of non-expert managers' objectives.

Whether managers realize it or not, cloud-computing services have been used on a daily basis and for a long period of time. For instance, internet email accounts, social networks, GPS locations, and numerous other forms of online data storage and sharing, are constantly being accessed by millions of users worldwide. These services are supplied by ICT providers that utilize virtualized datacentres for end-users to access online. This process forms one angle of the cloud-computing service delivery model referred to as SaaS (Software as a Service), whereas others such as PaaS and IaaS will also be investigated later in this study. Although the service delivery models, characteristics, and deployment methods will all be examined separately in Chapter 3, it is essential to point out here some of the main differences between the cloud-computing approach and the previous ICT solutions mentioned above. It is also worth mentioning that these earlier ICT approaches are still being employed widely by many organizations around the world.

In essence, three key models must be identified concerning Smart Buildings technology management. These are *Colocation, Managed*, and *Cloud Hosting* (Cummings, 2012). These models will be discussed with respect to implementation time, degree of

scalability, cost, and environmental state in order to provide insights and assist non-expert managers to select the most appropriate solution for their Smart Building's ICT environment. Table 1.1 presents the contrast between these ICT hosting approaches. However, a further examination will take place in the theoretical data analysis in Chapter 3 which follows the literature review.

(Table 1.1) Comparison between the main three ICT Hosting Models

Cloud Hosting Model / Management aspects	**Colocation**	**Managed**	**Cloud**
Physical Machine	Dedicated to the customer	Dedicated to the customer	Virtualized (Shared by one or more customers, easy to scale on-demand)
Hardware Costs	*Bring-your-own* Hardware approach (e.g. Customer buys servers and handles all Hosting expenses)	Renting the Hardware and Hosting from the provider whether used or not	Renting the Hardware and Hosting expenses from the provider depending only on usage, performance and other features' desire
Capital Expenditures	High: Best for mature budgets	No CapEx: mainly considered costly and usually used following annual contracts	Usually no upfront expenses or any contracts required for software services: Costs are instant, and usage- based only
Management Flexibility & Scalability	Rigid: This requires acquiring the infrastructure and professionals to manage and support, which makes its operational process the slowest of all	More flexible than Colocation: The administration procedure is not the responsibility of the customer, but slower than Cloud hosting	Highly virtualized and flexible. This follows a pay-per-usage approach, which makes its administration instant according to customers' desire
Implementation Time	This process could take months of planning, buying, staffing and deploying	This process could take days to weeks depending on requirements	This process would take only minutes following an online sign-up process

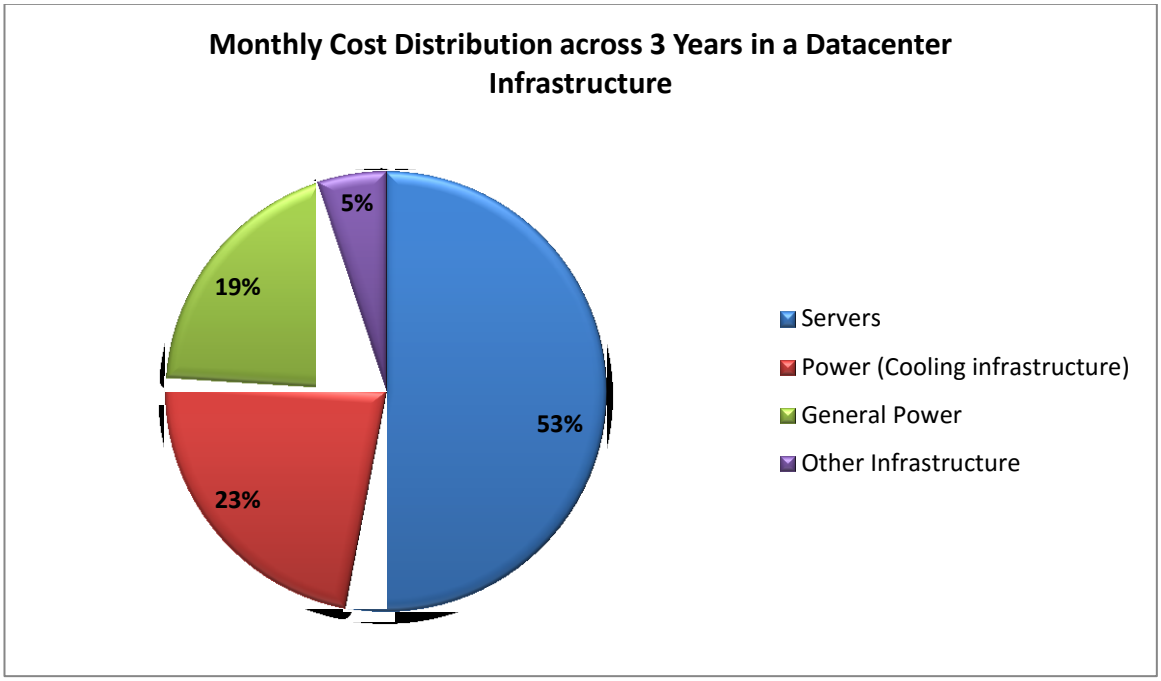
With regard to cost and sustainability of cloud-computing, this approach was considered by many organizations as *Green* in its utilization. This came to light not only due to the

fact that cloud services are highly virtualized in their hosting and delivered through online means, but because of the flexible control nature of these services also allows end-users to instantly modify different types of usage capacities, as well as being able to specify the exact level of performance required at a given time via different on-demand features. For example, a Smart Building might require only 50 servers to operate on a normal workday. However, twice a week only during night times, one hundred servers are required to perform certain heavy tasks such as the crunching and backup of large volumes of data. On this note, cloud-computing can benefit non-expert managers by avoiding purchasing costly hardware and licenses for software that is not needed at all times in their organizations. In addition to the cost factor, this advantage was classified as being environmentally-friendly given that Smart buildings will end-up owning less hardware in-house, which consumes less energy and requires less personnel for support and upgrade tasks. Accordingly, this was argued to complicate the decision-making process in managing all ICT components within the Smart Building, whereas cloud-computing can enable managers to outsource many of those decisions to the service provider. This however requires several cost and risk-analysis considerations, which will be explored by this research and demonstrated via an online decision-support tool.

Cloud-computing services can offer virtual ICT deployment solutions for Smart Buildings with minimum initial capital investments. Moreover, a key energy-saving factor will be pointed out in terms of attaining a higher ICT utilization process through ICT virtualization. Accordingly, several associated enablers from deploying cloud services will be discussed in the following chapters which are believed to be crucial in providing energy advantages for Smart Buildings. For instance, one of the main energy-consuming ICT elements in Smart Buildings is the networking infrastructure. This came as a result of the long history of complex cabling, wiring, and the upgrade tasks of older systems, it was recently observed that the majority of academic research was focusing on minimizing the general average of power employed in networking infrastructure (Berl, Gelenbe, Dang & Pentikousis, 2009). For example, as a result of this concern, the IEEE organization has developed the *IEEE 802.3az*, which is a built-in Ethernet protocol designed to meet energy-efficient requirements in ICT environments.

In order to support the previous statements regarding the potential benefits of cloud-computing for the environment, a 2008 study by the Accenture has argued that energy consumption from networked-based servers alone can be reduced by 20% from using

cloud services (Accenture, 2008). In addition, HP stated that savings from cloud-computing deployments can reach up to 30% with regard to the energy spent on cooling for heavy-duty hardware. Furthermore, it was estimated by the same study that the carbon exhaust of these equipment is currently reaching around 70% of the datacentre's total power exhaust. Figure 1.5 shows a monthly cost distribution across 3 years in the ICT infrastructure of a large-size datacentre in the US. This was divided between cost of cooling, servers, general power, and other unspecified infrastructure costs.



(Figure 1.5) Monthly Cost Distribution across 3 Years in a Datacentre Infrastructure (Berl, Gelenbe, Dang & Pentikousis , 2009).

This research will argue that there are numerous environmental and economic advantages which can be acquired from optimizing the general use of information and networking technologies through cloud services. This optimization can result in preferable types of ICT solutions without sacrificing the service level agreements, energy budgets, and other operational aspects. However, these advantages will depend on multiple management attributes which can vary across different Smart Buildings ICT environments.

This project will conduct a thorough examination of different cloud-computing management aspects to achieve a sustainable and cost-effective decision-support framework for Smart Buildings. Ultimately, a decision-making system will be introduced for demonstrational purposes which will assist non-expert managers in

measuring and selecting long-term expenses of different cloud models. The tool will also introduce the use of scalability paradigms and system patterns which reflect the service capacity growth or decline within a Smart Building ICT lifecycle with accordance to changes in costs from the service providers, and other service-feature aspects as will be discussed in Chapter 6.

1.5- Smart Technology Management

During the Second World War era, a new project management methodology was adopted by decision-makers to insure high quality deliveries of projects without affecting the common working environment and the management process (Cullen, 2010). This was called *Value Engineering* and it was used mostly in the construction and manufacturing industry. The goal was to identify the end-users' functional goals, long-term economic values, and any potential power reduction benefits. The main objective of *Value Engineering* was to guarantee effective investments in the initial project stages by following a distinctive set of procedures in a disciplinary and pre-structured manner. Moreover, highlighting the necessary actions to achieve the project's fundamental services was considered essential at all stages in addition to ensuring low-cost results in relation to energy use, staffing, salaries, maintenance, and other administrative aspects.

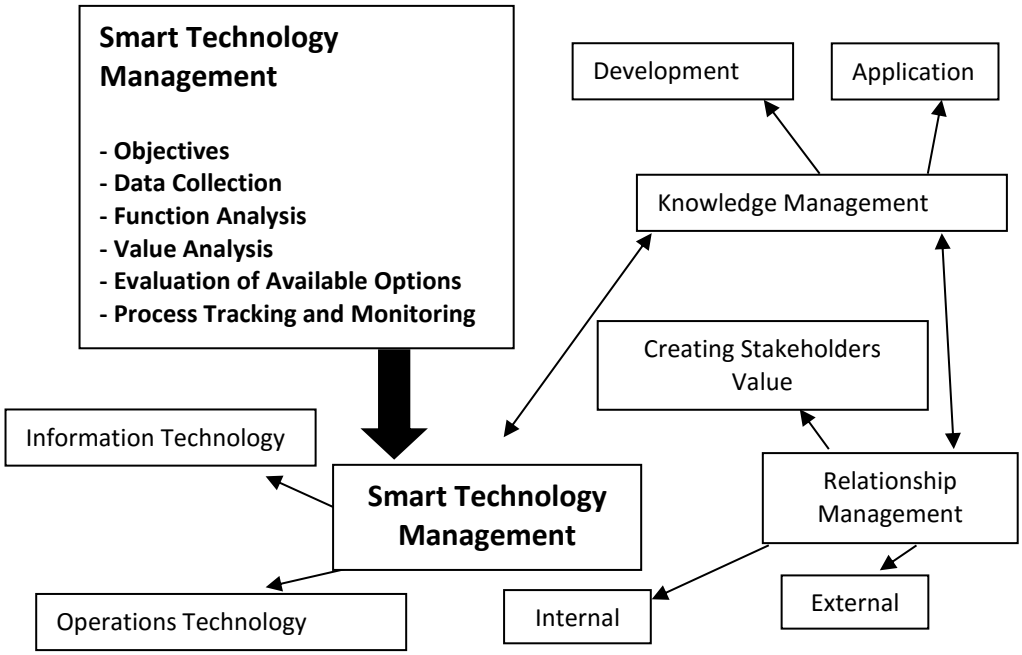
As a result of the increasing demand of ICT services given the growing requirements in almost every industry, internet-based technologies were considered a suitable approach to add value in terms of hardware acquisition, flexible capacity and bandwidth. In addition, this was deemed to provide a certain degree of business intelligence without the need of costly in-house computing infrastructure and other support services.

As will be discussed in later chapters, managing technologies in different types of organisations is considered a challenging task in terms of deploying new environments, contract management, and other aspects. As a result of this, *Smart Technology Management* was introduced given the heavy interference of ICT in almost every industry. The aim was to construct a better and more precise ICT management process. To achieve this, a generic strategy is primitively drafted by managers in order to answer key questions such as:

- ✓ Which technologies should be used?
- ✓ To what extent can these technologies be prioritized above others already in practice, which might be cheaper or more available in the future?
- ✓ How should the development process be managed in terms of highlighting the grey area between the technical and nontechnical requirements?
- ✓ To what degree is it secure, reliable, financially adequate, and power effective to implement these technologies in the long-run?

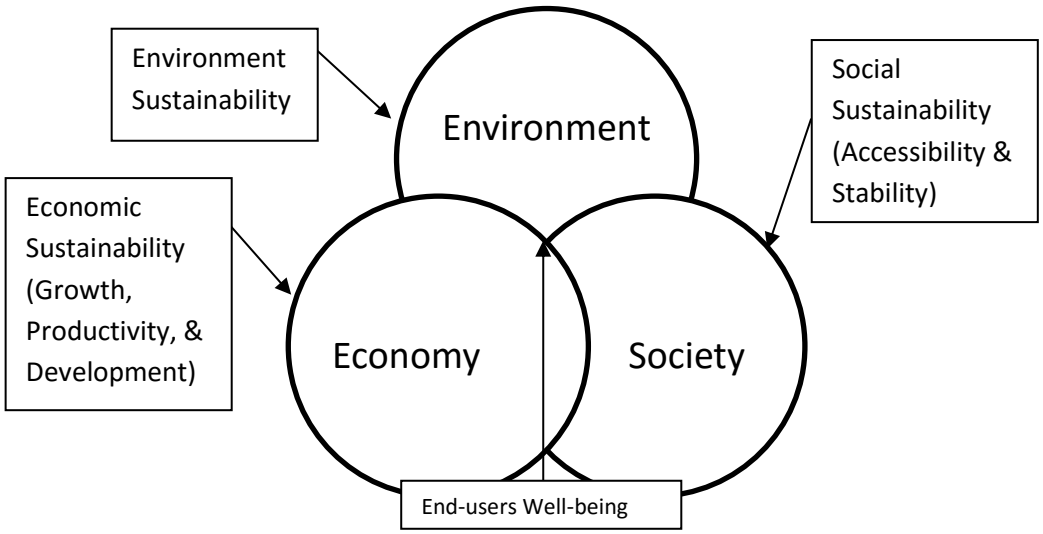
Given that this research is aimed to construct a cloud-computing management framework for non-expert managers in Smart Buildings ICT environments, it is important for these decision-makers to understand the concept of *Smart Technology Management* thoroughly. On this account, the following figure was introduced to explain the relationship between different ICT management stages which together form the overall *Smart Technology Management* process (Figure 1.6). Chapters 3 to 5 will undergo a theoretical and a practical management analysis which will connect this concept to the cloud-computing decision-making one in accordance with different Smart Building ICT requirements, cost, and power-saving factors.

According to the International journal of Project Management, the *Value Engineering* paradigm focuses mainly on the hardware thinking of systems and building projects (Green, 1994). While this model concentrates essentially on reducing costs, *Smart Technology Management* covers a slightly different concept as the software thinking of the actual operation dominates the common understanding of the problem in hand (Walters, 2000). In addition, management efforts are put forth to identify accurately the ICT deployment disciplines, agreed objectives, and requirements. This approach makes the management process more flexible in handling any changes at early periods in the development process of any ICT deployment.



(Figure: 1.6) The Concept of Smart Technology Management (Walters, 2000)

Multiple studies have defined the term *Smart* in different ways. The majority associated this to the latest advancements in ICT in terms of automation, intelligence and other aspects. In accordance with this study's focus, the term *Smart* reflects the ability to determine the most cost effective, sustainable, and user-friendly approaches to deploy a set of thoroughly selected technologies, which are suitable to a specific building environment. In connection with the previous drivers of change discussed in sub-section 1.4, the ultimate goal is to accomplish sustainability on several environmental, economic, and social levels, while consequently achieving end-users well-being in accordance with the modern life standards (Figure 1.7).



(Figure: 1.7) Sustainability Pillars in response to End-users Well-Being

The following discusses a brief background behind this figure's main concept. In essence, the society requirements formulate the concept of *Needs*, which discusses maintaining the basic living criteria in any environment while ensuring a constant future abidance to the notion of *Limits* (El-Alfy, 2010). In particular, the notion of limits points out the capacity and resources available in the built environment. Even though various sciences share the primary objective of reaching a sustainable environment, the cardinal focus was to fulfil end-users' needs while confining associated risks and limitations. The discipline of *Smart Technology Management* is considered significant to this study's main methodology, which is concerned with managing processes related to ICT cost estimation, scalable deployment of resources, ensure management simplicity, and gaining advantages from associated sustainability factors.

Smart Technology Management (STM) was proven to be effective in achieving cost benefits, even when applied at a late stage in the ICT project's lifecycle (Cullen, 2010). At first, the process of STM suggests assigning a multi-specialized team before any official ICT deployment takes place. The *Planning* stage comes next, where a full analysis is carried out regarding the project's functional aspects such as systems, facilities, programs, owners, users, alternative solutions, budget, utilities, and objectives. This stage is considered essential given that in the case of any sudden changes; only a limited cost and sub-deadlines might be affected as a result. Following the *Planning* phase comes both the *Design* and *Methodology* stages. These are considered significant given multiple mutual aspects which will assist in constructing the decision-making framework this study will conclude in Chapter 7 for cloud-computing management in Smart Building ICT environments.

1.6- Research Objectives

This project addresses the problem arising from the noticeable increase in costs and energy consumption on the ICT infrastructures across Smart Buildings. The study defines the term *Smart Buildings* as any ICT environment where a degree of system integration is accomplished. The scope of this research addresses non-expert managers as key users of the outcomes from this analysis given the diverse nature of Smart Buildings' operational objectives. On this account, the research is structured to explore

cloud-computing solutions for sustainable and cost-efficient ICT management in Smart Buildings for non-expert managers.

The management aspect of cloud-computing is classified as a virtualized, on-demand, scalable, and energy-efficient solution which is capable of enhancing long-term decision-making processes. This approach is examined to simplify the ICT purchase process and deployment strategies in contrast with today's swiftly evolving economies. In particular, the scalable concept of cloud-computing will be discussed consistently in accordance to various management attributes and decision-making challenges which were identified across different Smart Buildings ICT environments. The aim is to determine how, when, where, and to what extent are any of the different models of cloud-computing considered more valuable than the conventional approaches in terms of the economic, the environmental, and the in-house management perspectives.

As a consequence of today's unstable economies, managers strive for budget cuts and constant reductions in both upfront and capital expenses. Moreover, as ICT has currently infiltrated in almost all industries and businesses, ensuring ICT availability and reliability in organizations with dissimilar requirements is not an easy task. As will be discussed at a later stage, the process of formalizing optimal decisions in terms of being able to determine the specific types of ICT resources required, as well as debating whether these are cost-effective or not in the long run, is yet again a challenging task for any management. This evaluation is concerned with multiple aspects such as deployment cost, management of contracts, support, and hosting. On this note, this study's problem definition was constructed on the basis of allowing non-expert managers to build future service patterns which reflect a 5-year cost estimation, associated power consumption and management flexibility of required ICT resources according to their specific Smart Building ICT environment.

Supporting the overall decision-making process in order to effectively measure long-term ICT costs is examined by this study with accordance to Smart Buildings unsteady service capacity growth and decline aspects which are measured in relation to time. These patterns are affected by other aspects such as contract issues with the service providers, performance and reliability in the service delivery process, in-house ICT policies, and others. This study will argue the above points from the perspectives of

both the cloud-computing provider and the service requester. On these grounds, the main research statement of this study can be presented as follows:

> *With regard to cost, management flexibility, and associated energy consumption, this research evaluates different management methods to effectively support decisions made by non-expert clients to deploy different models of cloud-computing services in their Smart Buildings ICT environments.*

As will be discussed in the literature review, the spread of ICT in almost all domains is causing management concerns among non-expert managers. This came as a result of the difficult task of managing these technologies given how in most cases each service is provided by a different vendor and managed in-house separately. This causes multiple challenges and costly trade-offs in the administration process which is discussed in Chapters 2 to 4 through a theoretical data analysis and practical field work.

Those ICT services are mostly related to different Smart Building functions such as elevators, lighting sensors, cooling, heating, water meters, monitoring devices, ventilation systems, and other IP-based components. As mentioned earlier, this research is only focused on the integration output of such services which can be migrated onto a cloud platform and managed through different resources which would allow non-expert managers to control the Smart Building ICT infrastructure.

The above context is considered part of an interdisciplinary domain which is located in the ICT management grey area between the *Macro* and *Micro* levels of analysis. This study will attempt to bridge the gap between the technical and nontechnical concepts obtained from the three domains of Computer Science, Management Information Systems, and the Built Environment.

This research will focus on specific cloud-computing technologies, which as will be discussed in Chapter 3, still lack proper standardization from leading providers and ICT organizations. In order to achieve optimal Smart Building management strategies with regard to different scenarios of cloud-computing deployments, this study will adopt a consultancy approach which will examine different online-based ICT features. This analysis will address those features and distinguish between their different architectural forms, virtualized processing power, hosting models, scalable growth patterns, and on-demand administrative techniques. This project will ultimately construct a cloud cost forecast and management consultancy tool, which will be derived in the form of both a

theoretical technology management framework, and a web-based practical decision-support system.

Prior to any cloud deployment in a Smart Building ICT environment, this framework will assist non-expert managers to address management feasibility levels, associated sustainability considerations, long-term risks, changes in cost, and other trade-offs relevant to their organizations. The main focus is to determine which of the cloud service delivery models, hosting approaches, and resource characteristics, are most suitable for dissimilar types of Smart Buildings with accordance to the end-users' business objectives, budget, management tendencies, and work nature.

Table 1.2 lists this study's high-level objectives according to the relevant areas of focus and problem definition which is discussed above.

(Table 1.2) Research Key Objectives and Problem Definition

Research Objectives
- Evaluate cloud-computing concepts for Smart Buildings ICT environments from a Technology Management Perspective.
- Examine cloud-computing deployment approaches, management principles and main services as a potential hosting platform for Smart Buildings.
- Explore cloud-computing current costs, demand patterns and service scalability, control over resources, and associated power reduction factors.
- Address performance reliability issues and security considerations of cloud-computing services for non-expert managers in Smart Buildings.
- Identify a theoretical cloud-computing management framework for non-expert Smart Building decision-makers, which aim to support these users in estimating costs, identify management effort involved in the ICT lifecycle, and measure the power reduction associated with cloud-computing utilization.

- Develop a demonstrational online decision-support system called *SBCE*: *Smart Building Cloud Evaluator*. The objective of this tool is to enable non-expert managers to estimate and measure remotely the levels of cost efficiency, management feasibility, and sustainability in their Smart Buildings concerning the different types of cloud-computing adoption.

The roadmap of this research, which consist of multiple technical and nontechnical stages, will be discussed in-detail in the data collection methodology in Chapter 4. The following chapter will review the state-of-the-art literature on the above areas, and in reference to Smart Buildings ICT environments, cloud-computing management, and associated sustainability approaches.

2.0- Chapter 2: Literature Review

2.1- Introduction

Given the multidisciplinary nature of this study, multiple areas of review must be highlighted. In order to address the diverse topic of cloud-computing decision-making for non-expert Smart Building managers, this chapter covers concepts from Computer Science, Networking Systems, Management Information Systems, and the Built Environment. The chapter is structured to introduce readers on three main points:

- Cloud Computing Concepts
- ICT Decision-Making
- Energy Efficient ICTs

The review of these main areas is covered in a discussion of relevant subjects as illustrated in table (2.1). However, an in-depth cloud management breakdown is examined separately in the next chapter in relation to different Smart Building applications and case study scenarios for non-expert managers.

(Table 2.1) Smart Buildings' Scope of Interdependent Topics in relation to this Study's main Objectives

Smart Buildings	Cloud Computing Concepts	ICT Decision-making	Energy-efficient ICTs
Sustainability Approaches for Smart Buildings			√
Market Solutions for Cloud-based Energy Management	√		√
ICT Costs in Buildings and Power Consumption Overview		√	√
Cloud- Computing Business Perspectives	√	√	
Decision-making Methods in Smart Buildings	√	√	
Decision-Making Models for Cloud-Computing	√	√	
Cloud Adoption Risks and Trade-offs	√		

It has been argued that topics related to cloud-computing sustainable management and utilization for Smart Buildings have not been properly reviewed previously (Klems, Nimis & Tai, 2009). On that note, this literature review will explore selected academic publications and commercial reports in reference to each area from the previous table. Overall, conclusions will identify gaps in the literature, assess appropriate methods to fill these gaps, and ensure a cost-effective Cloud management framework for sustainable and flexible long-term utilization. Findings will clarify the main methodology this project will adopt, and act as a platform to construct this study's overall decision-making framework for non-expert managers.

With regard to the general subject of Smart Buildings, it is safe to say that not only has an immense volume of literature been published, but it has also been the particular target of management and environmental academics for the past few years. While the majority of attempts were focused on reaching an integrated control solution for Smart Buildings Green technologies and energy-efficient management techniques were also attracting a lot of attention.

According to the areas of focus presented in table (2.1), it can be clarified that the main discussion throughout this chapter will evolve around acquiring an ICT management framework to support non-expert managers to measure the optimal extent of cloud-computing utilization for their buildings. This however is not limited to a specific type of Smart Buildings, on the contrary, various types of organizations can adopt this methodology, such as healthcare facilities, higher education organizations, businesses of different work-load and sizes, and government agencies.

Up to the present time, the quest for substantial advancements in the information and communication industries to enhance sustainable ICT solutions in Smart Buildings has been considered one of the most widely spread areas of interest across major ICT providers (Parsons-IBM Smarter Planet, 2012). However, with each step forward towards cloud adoption several administrative concerns are frequently raised. These are mainly related to buildings' legacy control systems and conflicts caused by purchasing new subsystems from external suppliers. Whether these are related to cloud-computing or not, each time a new technology is introduced; prior ones are rapidly classified obsolete given market demands on one hand, and monopoly by ICT giants on the other. However, acquiring a state-of-the-art structure with most recent and sophisticated

technologies is currently not necessarily the key objective for managers. This is argued as a result of rising ICT costs, management complexities, and energy availability. So far, the priority for Smart Building decision-makers to improve these aspects is emphasized particularly in the developed cities where buildings consume about 45% of all electricity.

2.2- Literature Analysis

2.2.1- Sustainability Approaches for Smart Buildings

The majority of literature on Smart Buildings concentrates on how the traditional form of buildings, throughout the past century, was handling systems related to heating, ventilation, and air-conditioning. Several academics described this process as a reflection to the human respiratory system given the resemblance in the way all components operate in harmony (Wentz, 2009). Yet, the structural building design was pictured to resemble a skeletal form. Nonetheless, Wentz's study was mainly focused on transforming randomly generated data into knowledge in order for a structure to acquire a shifting ability in relation to performing internal functions automatically, similar to the actions operated by the human body. The paper discussed possibilities for a few enabling ICTs, such as MEMS (Micro Electro-Mechanical Systems), which to some degree, are cost effective and reliable HVAC (heating, ventilation, and air conditioning) sensors for embedded intelligence in a building's control system.

This study was included in this review to highlight few existing networked-based applications, which are interconnected with any cloud-computing process. For instance, wireless solutions, which support popular building automation protocols, such as *BACNet*, have proven application efficiency in control systems implementation in commercial buildings application for the past few years. However, it is acknowledged in this study that similar wireless enabling technologies were only utilized in simple-scale retrofitting solutions. Whereas until this day heavy demand firms in large commercial buildings still prefer fully-wired systems. Nevertheless, wireless networked-based support is deployed in a few, yet, not particularly crucial services, these can potentially be integrated into a cloud-based platform.

Furthermore, the study examines incentives for further smart control solutions. For example, the utilization of other widely recognized open communication building protocols, *LonWork* and *BACNet*. These technologies can add further top-level monitoring for an interconnected mesh of building systems, which ultimately simplifies management processes by adding layers of automation and ICT integration.

In conclusion, because of the increasing spread of smart devices purchased by consumers, and consequently implemented in buildings to support stakeholders' desire for cost effective solutions, the demand for intelligent control systems has greatly increased. As aims were not only concerned with speeding up the development process to improve building functionality, but also improving the comparatively slow pace of adopting specific new ICTs for an energy efficient, sustainable, and reliable management strategies, within a well-structured generic framework.

The previous paper also addressed several management solutions regarding the missing link between incentives and promoting enabling ICTs for Smart Buildings. For instance, point-to-point ICT schemes were identified, along with various compatibility aspects with previously mentioned building automation protocols, like *LonWork* and *BACNet*. However, it is without a doubt that several shortcomings can be demonstrated with respect to this paper's overall analysis. As even though only a limited demonstration was carried out with reference to recently developed technologies, which identified challenges and trade-offs in relation to long term maintenance, economic efficiency and environmental sustainability issues were not fully considered (Deborah, 2003). Furthermore, with regard to the contrast across building sizes, functionalities, and operational aims, workload averages were not investigated at a fundamental level.

One of the major potential benefits from implementing fully, or partially on-demand cloud-computing solutions in Smart Buildings, is the ability to acquire an easily maintainable energy saving, and self-healing cable-free infrastructure (Weldon, 2012). Whilst the logic behind this statement arises due to the properties of virtualized techniques achieved through online dependent cloud-computing concepts, the general statement assumes that accessing and controlling the entire Smart Building internal systems requires nothing more than a simple, reliable, and secure internet connection. These tasks outsource using such an approach corresponding with internal functions,

including IT systems, HVAC equipment, sensors, elevators, lighting control, CCTV, fire alarms, and other implemented building devices.

Following this through easily attainable online access by a secure Wi-Fi network as an example, a large-scale of permission management, administration, and heavy daily support can to a certain degree be outsourced to external datacentres owned and operated by cloud providers (Graybar Service Enterprise, 2013). In consequence, a high number of connected Smart Buildings can be managed simultaneously using the same ICT infrastructure. As a result, several sustainability objectives can be considered to be achieved from such migration procedures, as earlier attempts to acquire a cable-free virtualized building solution were unsuccessful due to complex networking hardware and wiring infrastructure.

Multiple reliability issues arise from dumping private data, resource intelligence, and built-in knowledge onto a relatively unknown destination owned by an external service provider. This will be examined further in the cloud challenges sub-section. The point gained from this is the necessity to use a secure wired connection to datacentres. In that context, another key report to this study, issued in 2005 and sponsored by the United States Department of Energy, addressed the topic of commercial buildings' control with regard to performance enhancing opportunities and potential energy saving strategies (W.Roth, Westphalen & Y.Feng, 2005). The discussion was mainly focused on the employment of various ICTs and control systems in Smart Buildings. The report is very broad in its range of contents. In essence, the investigation has been carried out on the basis of exploring energy saving approaches in respect of the following points:

- Faults in existing energy saving methods
- Barriers and drivers for the use of building control systems
- Diagnosis of future possibilities and key solutions for building management systems
- Hardware and Software control, employment, and faults' assessment in relation to buildings' various internal functionalities and impacts on energy consumption
- ICT performance inquiries on an optimal building control system.

The study explained why centralized solutions for Energy Management Control Systems like (EMCS) have greatly increased due to numerous energy concerns, which began to spread in the early 1970s. In addition, according to the same study, (EMCS)

strategies have only been utilized by less than 10% of commercial buildings in the US, where the building management market is estimated to reach 3 billion US dollars on an annual basis. Likewise, even though several energy saving attempts were executed throughout the past 25 years, in order to reduce costs as a consequence to the increasing domain of ICT functionalities within buildings, only basic *on-and-off* tasks are till this very day being implemented. For example, Direct Digital Controls (DDC), via either Networking hardware or Software solutions, are barely penetrating the building management market, which in the US alone, is responsible for nearly 67 billion feet-square of ground space.

The report explored numerous next-step technologies to minimize installed expenses of buildings' diagnostics and controls. For the purpose of enhancing these ICTs economic attractiveness, several conclusions were summarized as follows.

- Despite the fact that today's Smart Building owners only employ networked-based technologies for simple Wi-Fi and mobile services, it has been observed that virtual solutions have started to take over the buildings management market.
- Numerous Radio frequencies, and wireless communication protocols are currently being developed due to owners' demands regarding various buildings' applications. This however, came as a consequence to the low cost, self-healing, self-enabling, long-term maintenance, reliability, and Green nature of such applications. For example, as illustrated by several case studies as will be further discussed in the following chapter, this approach would provide comparatively sustainable management processes.
- Communication and virtual IT solutions will most likely benefit indoor environments, as well as substitute unnecessary IT personnel with self-healing point-to-point networks.
- Benefits from cost-efficient integrated wireless sensors and controllers are, even today, not fully comprehended by building decision makers. In addition, the future cost from this realization process will most likely narrow in comparison to current rates, and keep on decreasing as more favourable virtual technologies enter the market (e.g. Cloud-Computing, VPNs, etc.).
- It must be acknowledged that in a smart building control system, cloud-integrated wireless devices are not easily operated individually. On the other hand, a fully based IT platform must be installed to support the main structure's network. These

could be either related to HVAC measurement sensors, data transmitters/receivers, or even routers for forwarding function-calls.

- Challenges and trade-offs can occur in several aspects in relation to Smart Building networked-based implementations (Tung, Tsang & Lai, 2011). For example:
    - Starting cost
    - Networking security concerns with reference to intruders, hackers, and data access permissions.
    - Remote Administration availability and reliability, especially in response to corporate mandate management for a network of intelligent buildings

The previous Energy Impact study has to some degree examined market drivers for existing paradigms in a building management process. The approximate conclusion suggests a tendency for non-expert owners to invest in energy efficient or cost saving measures, regardless of the actual ICT solutions proposed internally or by service providers. This will depend on one of four ownership models. These will most likely range from Large heavily-operated companies, through Medium sized smaller firms, and Fee-Managed properties that optimize maintenance and power expenses reductions, to the Owner-Users model, which mainly lacks structured information and is concerned with core businesses (Reed, 2000).

In relation to energy efficient ICTs for smart applications, whether related to buildings, transportation, agriculture or any other smart principle; it can be acknowledged from previous published work that cloud-computing techniques have not been standardized and applied as a fully operating IT platform. The reasons behind this are due to performance, administration, and security vulnerabilities. Although similar topics have been the target of numerous computer science studies concerning virtual information benefits for companies' IT solutions, only a few papers have discussed the energy efficient advantages from cloud-computing utilization as will be listed next. In addition, it can be concluded from previous literature that cloud-computing benefits with regard to sustainable management and decision-making approaches are, in most cases, presented as a secondary topic in a broader energy consumption study.

According to a 2009 study by the British Computer Society and Oxford University Press, energy efficient cloud-computing has examined several *Low carbon footprint* approaches for IT datacentres and communication services (Berl, Gelenbe & Girolamo,

2009). For the primary aim of reducing Green House Gas Emissions (GHG) from computation and the physical space occupied by associated hardware, the paper significantly portrays the cloud approach as an inherently power saving technology that has recently attracted the large-scale of attention of building managers. However, it has been pointed out that despite the fact that most literature has focused on hardware aspects in relation to usage, optimization, and energy efficient performance, the information and communication services for potential *Green* solutions has not been fully implemented as an ICT infrastructure. In particular, cloud-computing solutions were mainly deemed at that time inapplicable for potential power consumption reduction.

Moreover, the study discussed various benefits to be gained from implementing an IT solution based on cloud concepts. These services, which to a considerable extent, are categorized *Green* in different operational tasks, performance, and energy-aware aspects, are fundamentally concerned with dumping heavy computational workload on an online virtually-managed system. In theory, this workload is only required either infrequently, or on a scheduled basis. For example, a certain datacentre processing function might be needed for only 30 minutes on a Sunday night, such as crunching a large number of data as part of a weekly backup. Although this particular task requires a hundred parallel servers, the normal building operation only requires 50 servers to operate on a normal workday basis.

The previous example is considered essential for non-expert building decision-makers on multiple levels. For instance, power consumption resulting from technology usage, whether related to electricity, cooling, hardware acquisition, or simply salaries disbursed for IT staff, plays a crucial role in this research progress with reference to obtaining economical and environmentally sustainable strategies for cloud-computing management within a building environment.

The paper has also analysed Amazon's cloud-computing monthly costs regarding a datacentre's energy distribution over a 3-year period (Figure 1.5) (Amazon WS, 2013). Furthermore, the study argued that an estimation of 30% savings can be obtained from unnecessary cooling power. In addition, 20% of energy emitted from networking infrastructure in a sizable building could also be dispensed with (Data Centre Energy Forecast Report, 2008).

Using building data simulations, historical trends, and case studies, this research project will identify a diverse range of variously-operated Smart Buildings. This contrast will range from sizes, workload bandwidth, and other administrative aspects. Nevertheless, IT requisites in accordance to available infrastructure and ICT specified budget will be further taken into consideration and streamed via cost analysis simulations.

To sum up, following the examination of a limited amount of literature with respect to general ICT employment, the cloud-computing approach was not this report's chief focus. However, in reference to power optimization issues, a detailed discussion has taken place in relation to energy aware smart grid systems, multiprocessors, cluster servers, software engineering of wired and wireless protocols. Of relevance to this thesis' management objective, the paper argues that businesses based on cloud-computing mechanisms would most likely face a central energy measurement issue across almost each system layer. Each employed service can be prioritized relative to the degree of reliability, response time, Quality of Service (QoS), and other factors concerning long-term costs and energy efficiency. In addition, a manager might take into account several trade-offs among other services in relation to previous aspects as will be discussed further in sub-section (2.2.7).

The main conclusions were centred on achieving virtualized, energy efficient solutions while providing insights on how to best manage the approach in large-scale infrastructures. These environments have a high demand for information and communication services as well as various other nontechnical requirements, which can also be integrated onto a single virtualized platform. The following points highlight the main conclusions, which play a significant role in this research progress.

- Benefits from employing cloud solutions are not only concerned with enhancing QoS and cost reduction aspects for Smart Buildings and ICT solutions. But also, related energy costs can be greatly optimized with respect to hardware and software applications.
- The attainment of a conservative computing power and networking infrastructure via cloud concepts is considered both environmentally green, and economically sustainable in relation to long-term management of federated establishments.

- With regard to cloud-based technologies, examples were introduced of different smart environments such as e-learning, smart transportation, and buildings' climate control. In this case, a positive energy reduction impact on business strategies and decision-makers would most likely occur.
- Several management trade-offs are generated from applying a virtualized ICT solution. As a result, reliability difficulties and availability challenges from functions such as online server migration, cloning of host-to-host data servers, or a virtual live administration from a remote site via the cloud, must be thoroughly clarified. This particularly focuses on workload throttle rates of different ICT environments.

As previously discussed, a large amount of literature from various areas of expertise has been published on interrelated topics associated to cloud-computing, energy efficient solutions for Smart Building management. This project faces a challenge against concluding a literature review framework, which is based in the grey area between the technical *micro* and non-technical *macro* levels of operation. In addition to covering previous publications on sustainable approaches for managers in general, and Smart Building non-expert decision-makers in particular, the following illustrates a crucial analytical intersection of these subjects.

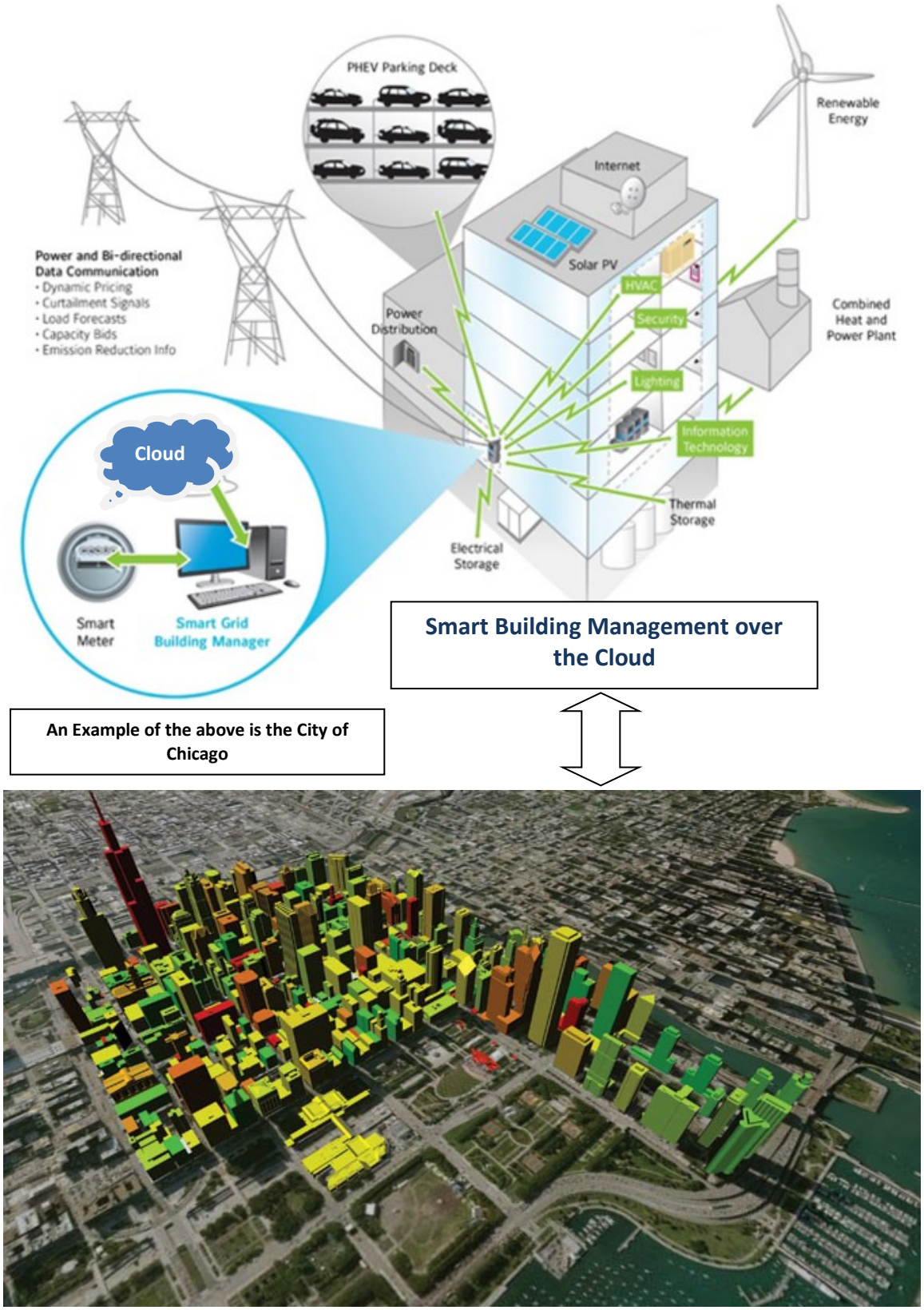
Dominating names in the IT industry such as Microsoft, Oracle, and Cisco undertake and published a considerable amount of private research. These publications address on-demand, cloud features with disparate prices and variable rates. These features and cost of these technologies depend on different building sizes, workload, along with enterprise-dependent investment strategies for optimal long-term decision-making (Grajek, 2012).

With regard to this study's management purposes for Smart Buildings, Microsoft published a report on cloud-computing smart applications, which discussed potential possibilities for cloud approaches to achieve power efficient resource management (Willson, Mitchel & Gimenez, 2011). According to a 2011 Microsoft Corporation report on making cities energy smart, building control over the cloud has recently been one of the centrally debated topics. Further, smart transportation, and a new generation of grid systems were both considered essential platforms for achieving sustainability.

The paper suggests that the long-term cost-efficient building management procedures are considered the number one driver of change. Technologies from Building Information Modelling (BIM) as well as centralized strategies provided from employing Building Management Systems (BMS) will result in an increasing ability for managers, not only to optimize the business, but the entire building performance. Various building tasks have been administered in an isolated manner. Moreover, case studies concluded that accurate decisions to enhance energy performance and management in Smart Buildings could not be effectively executed in real-time circumstances, as it was simply impossible to make sense of events, reports, and data analytics captured from IP systems. This was argued as one of the problems cloud-computing can solve via the Infrastructure as a Service layer (IaaS), which will be explained later on.

The study argued that these recently innovated cloud approaches are transforming the way energy consumption, in both buildings, and cities will occur in the long-term. Although full IT transparency is being offered for networking and processing infrastructure, contributions from several Microsoft partners like Hitachi, Stanford and California University, are comprehensively examining methods to enhance current models on Smart Building energy management.

For instance, the previous model suggests connecting a network of buildings into a Smart Grid, which to some extent can potentially be deployed across the world. By applying this approach, an interconnected administration process between disparate building systems, global environments, smart grids, and bottom-line infrastructure such as gas lines and so on, can all be linked across different enterprise locations (Figure 2.1).



(Figure 2.1) Example of Smart Building Management for disparate Systems over the Cloud, Rebuilt from (Willson, Mitchel & Gimenez, 2011).

The main conclusion was emphasizing on various ICT leverages gained from applying cloud solutions. In particular, these solutions will influence the entire management system whether related to buildings, or other smart city aspects. Therefore, making that system operate in a smarter manner, on multiple sustainability levels, enables effective benchmarking for overall energy supply and demand and thus improves the decision-making process. Previous points were deemed significant to this research given similar virtual leverage which can be applied on a Smart Building concepts as will be further investigated.

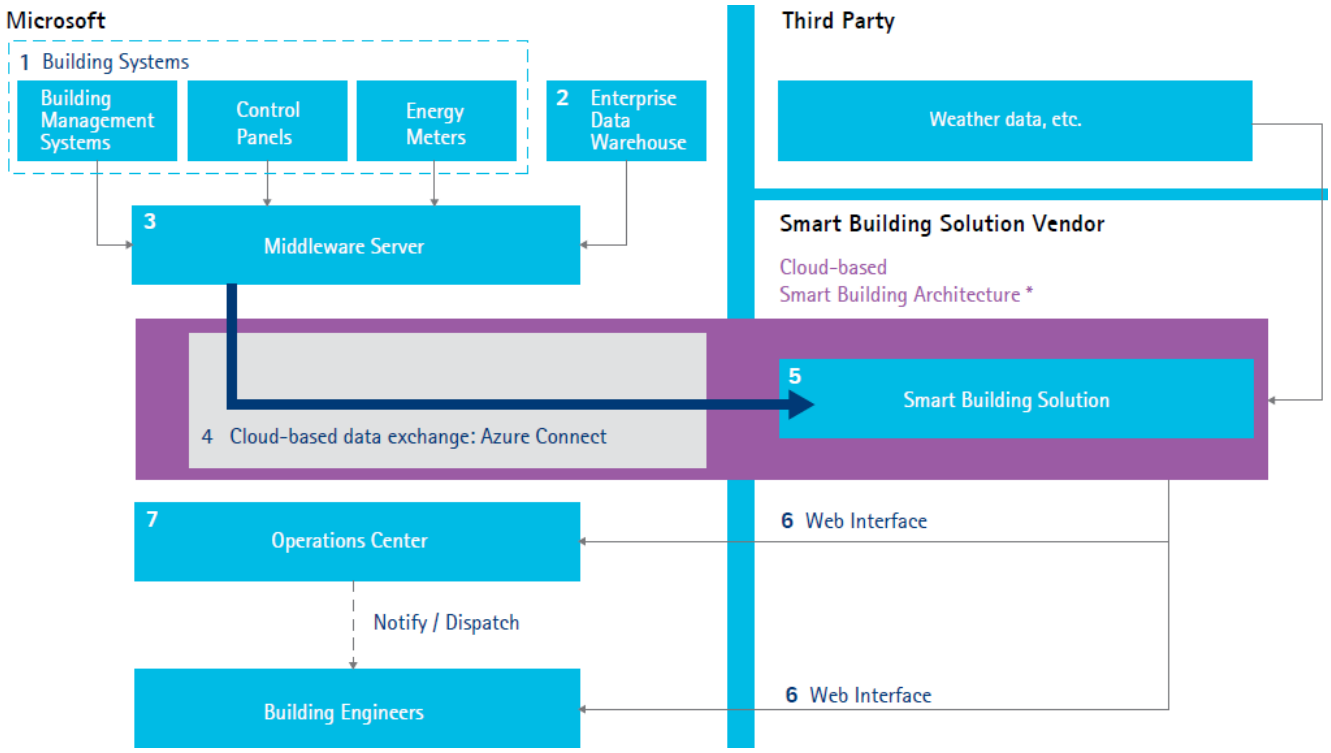
The current discussion is concerned with publications by ICT service leaders on Smart Building solutions for energy efficiency.

Another report, issued by Accenture Corporation explored interesting cloud-computing future opportunities (Kofmehl, Levine & Falco, 2011). Accordingly, the content of this paper mainly pertains to how to make optimal use of mass data generated from hundreds of sensors and IT devices installed in a building environment. In addition, an interesting explanation of limitations from the traditional building management model, it highlights the powerful advantages for managers and engineers gained from applying Smart building management systems (BMS) toolsets. These advantages are attained from applying an additional analytical layer to the ICT delivery and management process. This layer covers data output results of the entire building energy performance solution from an economic standpoint as a crucial factor in capital investment decisions for long-term opportunities.

It has been acknowledged by this study that the additional analytical layer will provide significant strategic return-benefits for building ICT decision-makers. Analysing this data, results in a sustainable and integrated platform for energy management in Smart Building applications. The resulting power management process for both supply and demand can dynamically provide additional energy-saving services such as detecting faults, and prioritizing resources for long-term buildings' base-load optimization.

The report explores numerous leverages from adopting Smart Building management scenarios. Even though supplements from employing the analytical layer were highlighted throughout the paper, potential challenges resulting from such approaches were not specifically identified. However, the reason this study is considered relevant to this research is that multiple conclusions resulted from investigating cloud-computing

utilization in building energy management. One of the crucial conclusions argued is that in order to sustain significant, reliable, and long-term methods of capturing, virtually storing, and processing mass amounts of generated data; an aggregated integration must be implemented between cloud-computing solutions on one hand, and on-site ICT building management systems on the other. From a service supplier point of view, in order to fully comprehend how previous Building Management Systems (BMS) are effectively deployed in smart structures, the following figure has been assembled to illustrate the order of the steps, where a separate number has been assigned to each stage in the following Cloud-Based architecture (Figure 2.2).



(Figure 2.2) Order of Steps in a Cloud-based Smart Building Management Systems (BMS) (Kofmehl & Levine, 2011).

The entire building's control system provides a starting point of the cloud management process. Secondly, the integration of the data storage enterprise and the entire on-site building control system is by either single, or multiple middleware servers, taking into account observations of how the data warehousing organization would operate, this reflects the transformation of raw data into contextual knowledge for various Smart Building tasks. Hence, the final stage *'the Operations Centre'* is a virtual implementation over the cloud. The previous implementation is primarily concerned

with dynamically-controlled data exchange servers via a simple web user interface (GUI), which can either be remotely monitored or simply administered via in-house solutions.

Main conclusions pointed out the fact that cloud-computing approaches are currently the core focus of any Smart Building management framework. Therefore, benefits from deploying information technology solutions through a virtual third party, can range from:

- Long-term ease of administration: By making sense of contextual information for building equipment and users, as well as offering a secure and facile connection between on-site building devices, off-site processing power, and storage servers. On the other hand, previous approaches were merely concerned with installing complicated Virtual Private Networks (VPN) to each single Building Management System.
- Large-scale of accessibility: In relation to a global management platform, which is implemented over the internet and connects disparate nodes of Smart Buildings.
- Affordable cost and scalability: Regarding on-demand services, whether hosted on a public cloud, the stakeholder's premises with external administrative controller systems, or the provider's privately managed cloud environment.

It has been pointed out by Green-Biz, which targeted the topic of Smart Building future design towards a cloud infrastructure, that over the past few years the *Green* ratings for Smart Building ICT management have been limited to an obsolete analysis of information and theoretical models (Herrera, 2011). Accordingly, cloud solutions have been strictly utilized in theoretical building simulations for forecasting aspects such as behavioural predictions as well as other energy performance scenarios. As a consequence, a crucial gap in achieving a linked process between disparate building energy control systems was identified. This was considered one of the potential advantages from adopting cloud hosting techniques.

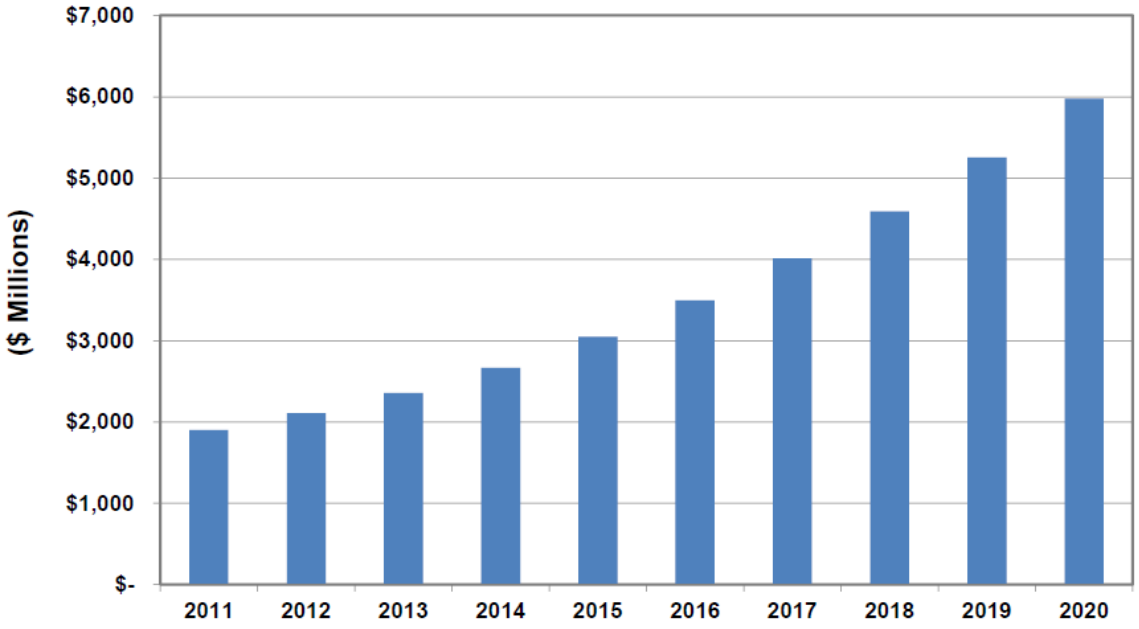
Another interesting report by the Pike research group, which emphasized recent advanced trends for Smart Building cloud migration, has addressed Smart Building ICT management from a commercial point of view (Bloom & Gohn, 2012). The study argued that a network connecting different Smart Buildings has a high potential of

optimizing energy consumption and reducing multiple expenses spent on building information modelling and energy management systems. The reason behind this mitigation ability is due to a wide range of digital information systems and networking devices already employed in a structure's ICT environment.

It was argued that the past few years in particular have witnessed a drastic transformation in the way ICT captures and analyses data generated from buildings. To a large extent, services offered from (SaaS) -Software as a Service delivery model- have effectively influenced the management process for hosting and managing these volumes as intelligence. The report mentioned several examples in that respect; one of these is a unique cloud-based service called *Intelli-Command*. This solution provides technical building operators with a statistical energy data feed service through a cloud-hosted platform. This is then merged with other data generated from other building functions, which eventually formalizes a decision reinforcement tool (Jones Lang LaSalle Website, 2013). The goal is to detect areas of incompetency, low-level actions, and unexploited real-time performance leverages.

Another example of a similar cloud-based service is *Panoptix*. This provides a virtual networking infrastructure which enables building managers or on-site users to upload, download, and stream data from different building sources into a single connected IT platform. This offers an intelligent, scalable, and real-time availability data capturing and hosting service which ensures ease-of management and optimized energy reactions to various economic and environmental changing circumstances.

Empowering non-expert building managers with these virtually-operated and ease-of-access tools, has without a doubt simplified the overall administration process. According to a revenue chart created by the Pike study (Figure 2.3), the market of energy systems for Smart building management has had a growing and almost consistent rate of revenues since the introduction of cloud-based services. For example, while revenues have gone as far as $ 2 billion in 2011, it has been estimated that by 2020 a return profit of $ 6 billion will occur from using the *Panoptix* service by Smart Buildings in the US alone.



(Figure 2.3) Estimated Profits from Cloud Energy Management services in Smart Buildings (Bloom & Gohn, 2012).

Another project called ICE-WISH began in 2011 and was estimated to finish by 2014 across 10 European countries. This has targeted the social housing sector for the purpose of implementing cloud-computing across different control systems (ICE-WISH Project, 2011). This can be similarly applied to Smart Buildings. The main objective of the ICE-WISH project was to provide highly reliable, virtual ICT solutions to decrease energy and water wastages, while maintaining the welfare of residential living environments.

The outcome has reduced both water and power usages by nearly 15 %. However, the *Green* ease-of-access and user-friendly potential targets were considered a major challenge for ICT managers to make real-time decisions. In spite of this, the employment of cloud-computing solutions has been acknowledged to positively influence numerous aspects of the project's requirements from a stakeholders' point of view. These have included benefits such as integrating all communication infrastructures on each site into a single service platform administered over the cloud, on-demand analysis of data depending on the required computing capacity, and offering ease-of-integration with various associated parties (other ICT providers, legacy systems, etc.).

2.2.2- Market Solutions for Cloud-based Energy Management

As part of the decision-making framework this research will conclude that sustainable cloud computing management in Smart Buildings, energy management solutions via cloud applications are considered significant on several levels. After outsourcing the ICT infrastructure into a third-party online service provider, cloud concepts have been argued to positively assist non-expert building managers beyond IT requisites and platforms. As energy management solutions are considered a relatively wide subject, hence, only selected decision-making advantages will be explored in connection to this study's primary focus.

The purpose of this section is to analyse selected commercial cloud services, which were observed currently as being demanded from different types of Smart Buildings to assist non-expert managers in enhancing the energy management process. These solutions are demonstrated next from the point of view of several top ICT providers in today's market.

According to Fujitsu, a smart energy management service referred to as Enetune was set to be launched in June 2013 as part of an energy optimization process for businesses and buildings located over multiple locations (Enetune-Fujitsu, 2012). This service will employ the online *Cloud* as a data capturing, storing, and processing platform from different energy consuming sources. In particular, Fujitsu argued that conventional Buildings' energy management systems, which mainly operate individual analysis nodes for power and knowledge measurement, were proven unable to provide building managers with accurate countermeasures, misuse alerts, enhanced decisions, and on-demand external computing power for long-term energy planning. As a result, major demands from non-expert managers were raised given the spread of virtualized energy management online features.

This cloud service will empower building managers with forecasting abilities to plan performance actions, predict quantified measures, estimate consumption rates, and remotely control a precise scope of utility standards. These features are operated in parallel to Smart Buildings' power peak schedules and increased rates of energy bills. For example, according to the same organization, recently in Japan, energy prices have shown increased rates in response to heavily burdened energy consumption landscapes

along with strict power-awareness laws. Thus, techniques for flexible streamlining and heavy data-analysis abilities have been acknowledged as a high priority across the nation.

The Enetune service is entirely based on Fujitsu's *Green-IT* award winning FGCP/S5 secure cloud infrastructure (Fareastgizmos.com, 2012). Nonetheless, reliability concerns was highlighted as centralized energy management for multiple building locations were estimated to operate in a real-time and on-demand basis, which can cause technical conflict between different control systems. Yet, major benefits were discussed such as integrating timely automatic actions by building managers to control power devices and so on. These features are offered remotely, on-demand, and in response to production volumes unstable levels. However, in contrast to traditional approaches, where each building is separately managed based on in-house energy consumption, bills, and ICT usage, the Enetune cloud-based software provides insights on business intelligence, and knowledge transfer between different or relatively similar Smart Building sizes.

Direct benefits acquired from such services are:

- Strengthening power demand forecasting and abilities
- Conserve power via real-time, hands-on decisions
- Provide on-site virtualized energy diagnostics, as this process generates detailed reports from collected data, which notifies building managers of any pre-triggered actions via an automated event-log alert system.

Similar features on cloud analytics and business intelligence will be discussed in the next section.

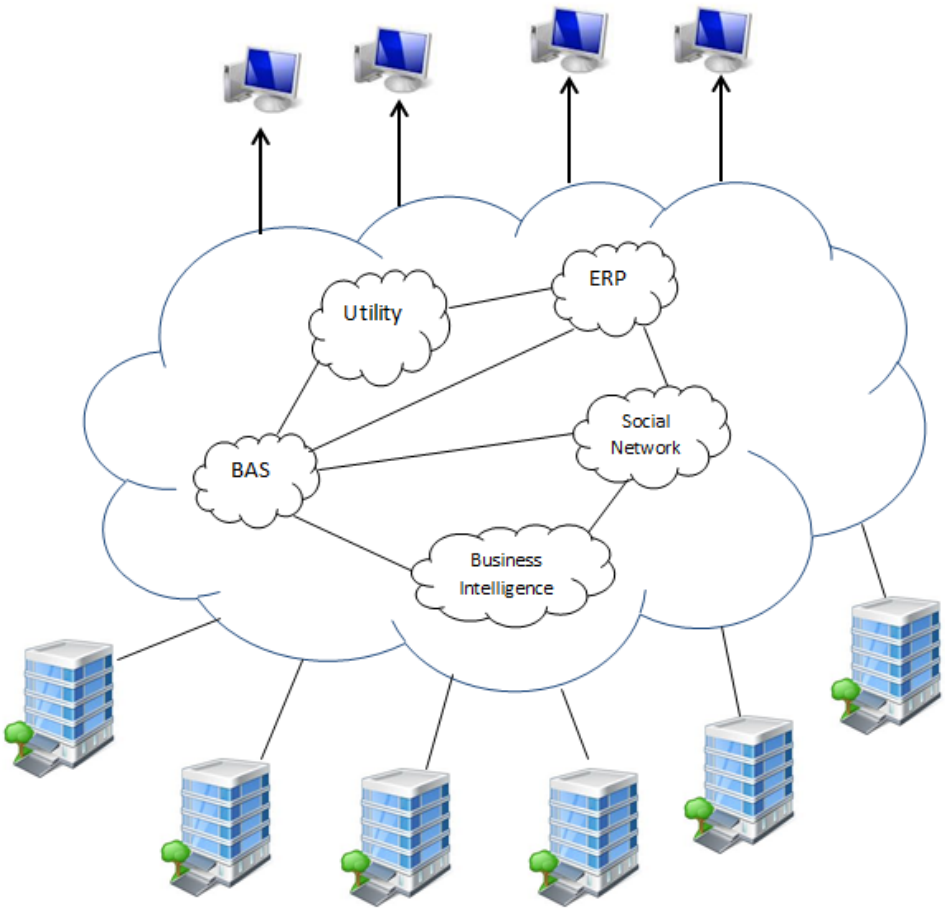
Cloud-based services arrive with a bill at the end of each month. For example, the Enetune EMS service costs about 400 US dollars per project (location) on a monthly basis. This is excluding support, upgrades or any other bespoke features. These expenses are added to the Smart Building ICT expenditure budget; therefore, it is important to analyse these costs to correspond with actual benefits attained from this and similar deliveries.

Decision-makers need to be able to streamline existing on-site prices and simulate a dynamic cost-based paradigm for cloud alternatives. This is achieved via cost

simulations which demonstrate long-term scalability patterns depending on the Smart Building service demand growth or decline across a specified period of time. Chapter 3 and 5 will explore these aspects and identify this gap for constructing the online decision support tool *SBCE*, which fulfils this demand and simulates a 5 year cost of any cloud utilization.

Several academics and IT professionals have also addressed this topic from multiple perspectives. It was pointed out by the development manager at Open General that the migration process from conventional web-enabled technologies in a building energy management system, into a transparent cloud-based solution, is considered essential to data integration methods within a Smart Building (Munasinghe, 2010). In particular, with the employment of open communication protocols such as *BACnet, Zig-Bee,* and *Mod-Bus,* two levels within the system architecture has been identified with regard to data integration: *Software* level and the *Controller* level.

The *Software* approach was considered comparatively inefficient in a way that causes a heavy networking bottleneck given the direct data-write methods, which is adopted between two vendors. For example, measuring outside air temperature in a Smart Building would simply dump all collected data into the primary IP-layer on-site server. On the other hand, the *Controller* integration will not encounter such workload issues, given a multi-protocol integration approach, which shares information at the communication protocol end, without intensifying workload at the main building workstation. However, both approaches are becoming obsolete as a result of emergent off-site-managed cloud-based integration services. For a connected set of cloud-hosted Smart Buildings, non-expert managers would only access a simple Graphical User Interface, which is installed as a single software instance at each location. This might also include a distributed database over the control network (Figure 2.4). Likewise, these are argued to reduce implementation costs, and introduce new opportunities for better performance and decision-making.



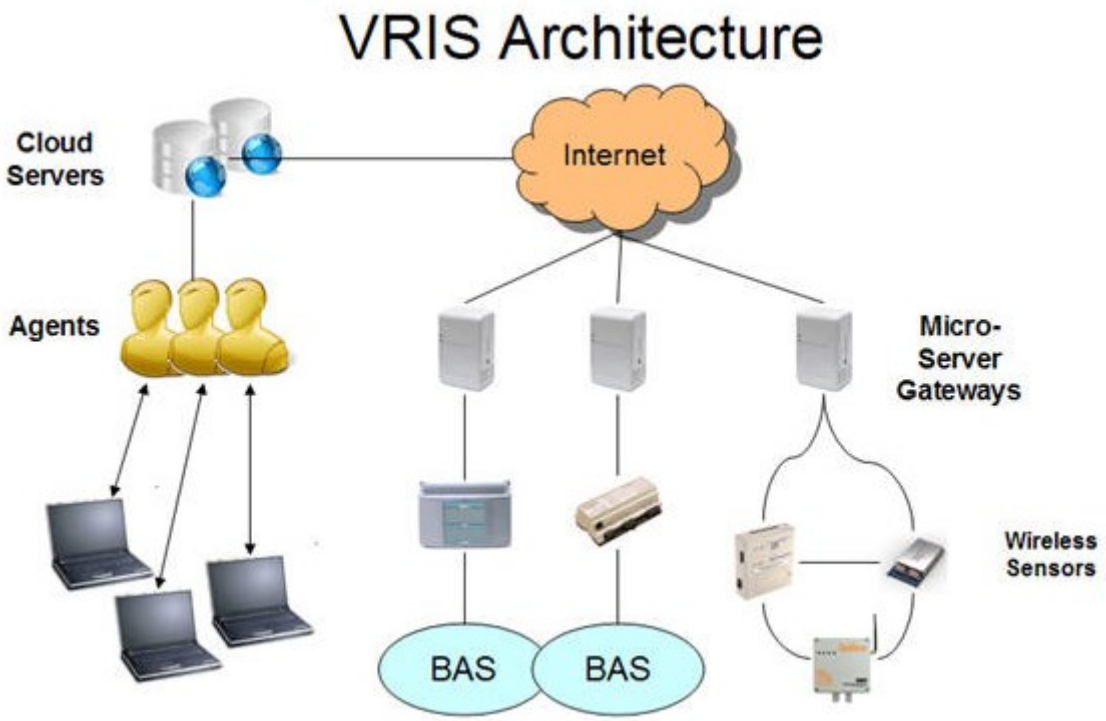
(Figure 2.4) Cloud-Computing Integration Service for Multiple Buildings: Single ICT Instance with a Distributed Database at Each Location (Munasinghe, 2010).

According to an article by *Automated Buildings Enterprise*, the current market of Building Automation Systems (BAS) for cloud energy management is leaning strongly towards a *Hybrid* interconnected approach (R. Lavelle & Onuma, 2010). This connection is expected to take place with several related industries such as Smart Grids and others. Regardless of the cloud service model and deployment method at hand, in order to achieve a sustainable cloud Energy Management the in Smart Buildings, the BAS study has investigated the use of Virtual Real-time Information Systems (VRIS) (Figure 2.5).

In essence, the cloud provider manages heavy-duty shared servers while simultaneously ensuring scalable connections with on-site micro Smart Building workstations. Benefits such as multiple integration abilities with various in-practice building solutions have been introduced to non-expert managers from adopting this service.

Examples of multi-disciplined processes identified for achieving web-based Building Information Modelling tools, are BIM-Storm by Onuma, and Lavelle's Virtual Real-

time Operating Centre (VROC). These are mostly performed via open-source protocols to capture real-time building data from different nodes such as sensors, devices, CCTVs and others.



(Figure 2.5) Virtual Real-time Information Systems (VRIS) for a Sustainable Cloud-hosted Building Energy Management (R. Lavelle & Onuma, 2010).

VRIS was argued by (R. Lavelle & Onuma, 2010) as the number one enabler to attain an interconnected set of hundreds of Smart Buildings in relation to energy and performance management. This ensures a single remote administration access via an online interface from any constant, physical, or mobile location. Features from the VRIS energy management approach have been specified to offer different types of Smart Buildings with:

- Integration abilities with multiple online, cloud-based applications (e.g. Google-Earth).
- Dynamic control in relation to data capturing and collaboration functions between in-building HVAC devices and other energy consuming equipment, for optimized and simplified measurement solutions (e.g. sub-metering, green-leases, etc.).

- 3D virtualized designs of physical data-objects regarding energy performance characteristics, on the contrary of simple BIM design solutions and Pseudo 2D images.

It can be stated from a generic standpoint that previous features from VRIS are to some extent, non-conclusive in response to each building system requirement (Zucker, Judex & Hettfleisch, 2012). In particular, several aspects in relation to security, backup, Smart Grid integration, connection with other open-source protocols, and documentation, are all observed as non-consistent factors for a long-term ICT lifecycle (Younis, Youssef & Arisha, 2003).

This research at Microsoft has carried out a cloud-computing energy performance study with respect to selected applications from the ICT organization such as Word, Excel and Outlook exchange (William & Tang, 2013). Whereby the deployment of these tools is considered almost a given in each Smart Building ICT environment, the main objective of the study was to highlight greenhouse gas emissions from utilizing a Microsoft cloud-based alternative. The study focused specifically on office environments, which is not directly related to this research. However, an important role can be recognized, which assists this project's ultimate decision-making tool, given the energy measuring framework created by this study in terms of in-house and datacentres end-user devices consumption, online communication, and data transfer.

Other studies have identified the cloud-computing energy optimization factor via mobile platforms. This was particularly discussed in a study by Purdue University where the main objective was focused on enhancing computing capabilities and applications across mobile devices (Kumar & Lu, 2010). The ultimate solution was to ensure maximum battery life for ad-hoc ICT systems. Although cloud utilization was debated as a potential solution for a low-power ICT lifecycle, multiple challenges were addressed. These are argued to prevent any cloud dependence given various considerations such as enabling unauthorized access, and data encryption.

One of the key elements to reduce in reducing energy consumption from computation in mobile platforms is to eliminate all processing actions from the mobile side of the duties. This can be achieved by outsourcing computation efforts to a third online party, thereby, extending the lifetime of batteries across lightweight mobile devices.

Moreover, this was reasoned to enhance other workload aspects affecting additional mobile functions, such as network connections, GUI quality, and so on.

The paper argues that offloading processing power to minimize energy usage is not a novel concept. Whilst currently mobile platforms allow users to freely access the internet and web services worldwide, cloud-computing differs from the conventional client-server model, by operating arbitrary software across virtual machines (VMs) that are acquired from other numerous end-users. This concept is termed *Virtualization*. The previous cycle is provided predominantly by cloud-computing suppliers, whereby end-users have the ability to minimize energy usage by decreasing the amount of processing power required on mobile devices.

In conclusion, the paper suggests that not all mobile applications are energy efficient when cloud-computing is involved. Yet, unlike cloud migration for desktop systems, mobile platforms must further scrutinize power overheads -resulted from virtualization- before any computation offloading takes place. This is primarily debated in accordance to data networks and communication, reliability, access security, and data integrity.

The previous paper forms a key significance to this research as the concept of *Computation Offloading* was argued from a mobile end-user viewpoint. In addition, the study attempted to establish the extent of cost effectiveness of computation offloading via a decision-driven energy analysis. This has a crucial influence on this study's main focus for constructing a cost-efficient cloud management framework for non-expert managers who do not necessarily comprehend the technical description of ICT offloading and specific advantages gained from potential mobile alternatives in Smart Buildings.

In reference to power consolidation via cloud approaches, another study was deemed significant to this research given multiple Smart Buildings' ICT services (Srikantaiah, Kansal & Zhao, 2008). The paper addressed the mutual liaisons between ICT utilization on one hand, and associated energy consumption on the other while taking into account execution performance obtained from strengthened workloads. The main focus was highlighting complexities in achieving energy consideration by identifying both performance barriers and benefits gained from energy consolidation across different smart environments where a certain degree of system integration is accomplished.

The study ultimately derived a power consolidation algorithm, which minimizes energy allocation of resource usage across servers. The ICT allocations regarding cloud migration of specific workloads is aimed to meet power consolidation efficiency standards within a generic building. However, several challenges have been recognized to limit the employment scope of this algorithm. These disadvantages are especially related to technical aspects such as:

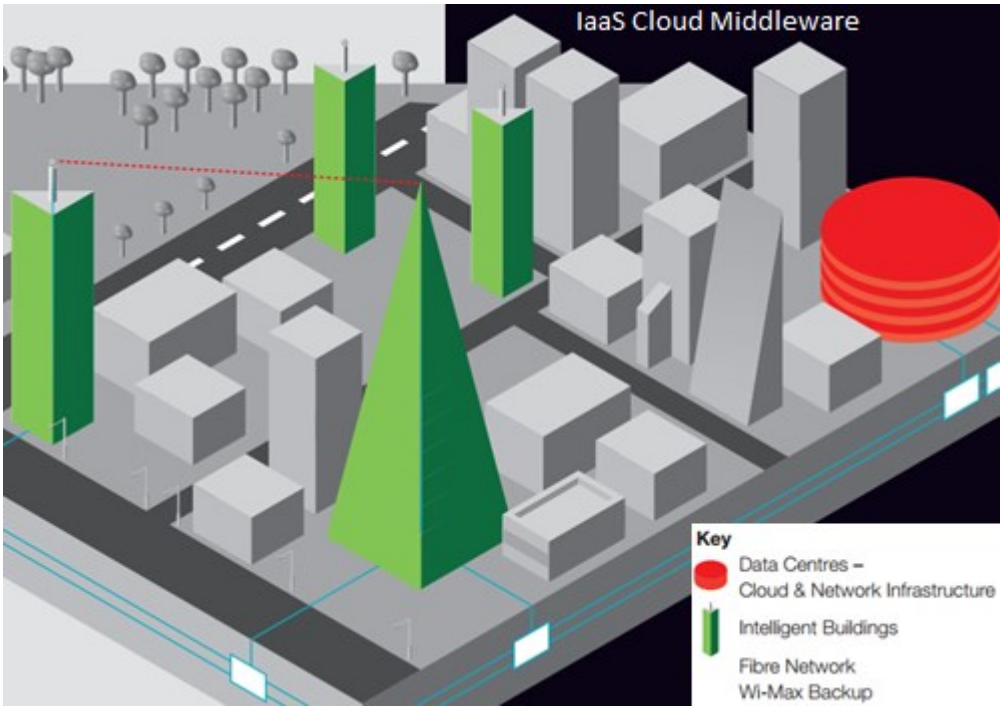
- Migration
- Resume costs
- Multi-tiered applications
- Composability profiles
- Server heterogeneity
- Application affinities

The study experimented on how ICT workloads, performance, and power consumption differ, as numerous ICT functions with diverse resource utilizations are allocated across mutual servers. This paper is considered substantial to this project given that when workloads in an ICT environment are integrated, both performance and power usage attributes alter in a nontrivial form.

Carrenza Group, another highly recognized UK-based cloud provider, has offered distinct Smart Buildings with networking solutions in general, and virtually-managed wireless applications in particular (Carrenza & HP Service Manual, 2015). The cloud-computing enterprise predominantly offer IaaS services (Infrastructure as a Service), which will be explored in the following chapter. According to Carrenza experts, while IaaS is the best fit nowadays for Smart Building internal systems, PaaS (Platform as a Service) must also be included in the company's long-term ICT strategy. In particular, several benefits have been discussed from employing such services, ranging from:

- Dynamic pay-per-go networking accessibilities
- Drastic capital expenditure savings
- Internal advantages such as space saving
- Flexible IT maintenance
- Upgrades
- Environment-friendly aims for ICT energy reductions.

Cloud deliveries were identified by Carrenza to reach Smart Buildings on a scalable basis via cohesively installed Fiber Optics. As a result, internal networking infrastructure will ensure high hardware compatibility with an entire cable-free building solution. However, previous requisites will be limited to a direct connection between various Smart Buildings' hardware on one hand like HVAC sensors, routers, etc. and the cloud-based servers on the other. Furthermore, Carrenza Cloud providers have presented an interesting diagram with respect to a connected set of Smart Buildings (Figure 2.6). This figure illustrates additional benefits obtained from cloud-computing utilization concerning the transformation from internally installed Datacentres, to the virtual model of cloud networking concepts, which are mainly achieved by Fiber Optics, and reliably backed-up via Wi-Max technologies.



(Figure 2.6) Carrenza IaaS utilization Model for a connected set of Smart Buildings (Carrenza & HP Service manual, 2015)

This section demonstrated several cloud-computing energy management solutions by top service providers. The discussion also examined academic papers and case studies, which aims to empower non-expert managers in Smart Buildings with tools to enhance the ICT energy management process. Although it can be observed that the previous models mostly market a specific cloud-computing service as has been illustrated earlier regarding similar analytical solutions by IBM, Microsoft, Siemens, and others, applying

IaaS services for Smart Buildings is considered significant to this research as will be examined in the next chapter.

2.2.3- ICT Costs in Buildings and Power Consumption Overview

Smart Buildings can be predominantly defined by an interrelated management process between cost-effective, environment-friendly, and end-user responsive aspects. This interaction is continuously supplied using intelligent automation controlled via ICTs (Love, Tse & Edwards, 2005). Recent surveys have indicated that salaries for employees in Smart Buildings are currently exceeding those of the annual maintenance power and construction industry by almost 25%. It was argued by the same study that a 2% increase in productivity has occurred as a result of added capital investments on processes to reinforce Smart Building services, which reduced the need for personnel, hence, salaries. Furthermore, capital investments in the UK building industry have reached 200 GBP /m² on an annual basis. Similarly, energy and running costs per year have been measured to reach 10 GBP /m², while staffing is estimated to cost around 15,000 euros per year, which merely demonstrate a 1% of productivity. However, for example, Sydney Opera House has resulted in 120 million US dollars in general expenses, a 1700% in overrun costs, and 120 million US dollars in replacement expenditures. With regard to internal functions in a medium-sized Smart Building, heating is responsible for 45% of total energy consumption and 5% of energy was used to construct the same structure on annual basis.

In relation to different ICT attributes which cause energy consumption, the following discusses different data collected of general costs, carbon emissions, power reduction approaches in accordance to different reports and case studies on Smart Building technology management.

According to a study on ICT energy consumption across different environments, in 2010, ICT global emissions were responsible for 2% of worldwide carbon dioxide emissions, whereas 5.3% of global electricity consumes over 9% of overall US power demand (ITA Official Blog, 2010). By 2020, ICT manufacturing, support, and disposal will be responsible for almost 4% of worldwide carbon dioxide emissions. Further, by 2025 emissions from buildings in developed cities will reach over 12 billion tonnes

(The Intergovernmental Panel on Climate Change, 2007).On that note, buildings were deemed as the largest energy-consuming asset on earth with close to 42% of all globally generated electricity (Parsons IBM Smarter Planet, 2012).

Global ICT energy consumption growth has reached 246 billion kWh in 2010, which equals 2% of worldwide CO2 emissions. In terms of Carbon Trust; PCs across UK offices, which reaches about 10 million computers, are consuming 15% of each facility's total energy, following an increasing rate of 30% by 2020. Moreover, 10% of the overall ICT energy consumption in the UK equals 3 nuclear reactors (Crooks & Ross, 2010). In parallel, CPU power and Storage capacity are doubling every 18 months across general ICT markets (Fettweis & Zimmermann, 2008). Even though buildings alone are responsible for 40% of global energy consumption, it was argued that 15% reduction can be attained in the near forecast period from adopting emerging ICTs as a major energy efficient contributor for building control systems (Neves, Krajewski & Jung, 2008).

According to a recent report by The Climate Group, in 2025 energy demands from buildings will reach 33% in commercial buildings and 67% in residential buildings. Buildings alone are responsible for 40% usage of the global energy consumption. The same study acknowledges that a 15% reduction can be attained in the near forecast period from adopting emerging ICTs as a major energy efficient contributor for building control systems (Neves & Krajewski & Jung, 2008). As a result, multiple technical and nontechnical aspects were noted as playing a fundamental role in creating energy efficient Smart Buildings in the future. These usually require a heavy hosting ICT platform which might not be affordable to purchase, install and support on each building location, hence comes the cloud. Some of these aspects are:

a. Embedded smart objects (e.g. electronic chips) for data sharing and protocol interaction
b. Standardized communication protocols for sensors and metering devices
c. Building management distributed software systems (BMS) for dynamic control, configuration, and monitoring in relation to prior embedded systems
d. Simplified internal networked interfaces, which support interoperable and multimodal services (e.g. man/machine interactions, and augmented reality), some of which will be discussed more in the next section.

Conventional legacy solutions already practised in most buildings must be firstly comprehended as a solid platform for prior contributions. These systems include conventional wired devices such as meters, sensors, lighting, HVAC and so on, or remotely administered equipment via Wi-Fi technologies. However, in order to ensure a best-practice lifecycle and energy efficient criteria for Smart Buildings, several indications have been stated in that respect. These include energy reduction opportunities for effective ICT management between various providers which offer different services to variously located buildings.

A general building environment would include the following ICT devices: networking servers (e.g. back-ups, load balancers, web-hosting, etc.), routers, switches, personal PCs, printers, copy machines, voice-over-IP telephones, faxes, Wi-Fi access-points, and cabling infrastructure. Each internally embedded device, which has the integration ability to act as an IP-assigned entity, is added to the previous list and will be referred to as an *IP-object*. In fact, each building will require a certain amount of computing ability, storage capacity, support, as well as CPU power and networking hardware. This is argued in contrast to workload, size and other performance factors as previously explained.

The following is an example by Amazon's Web Services and Microsoft's Exchange Datacentre Futures (Hamilton, 2010). The example discusses a heavy burden, large-scale Smart Building Datacentre, which demonstrates:

- ICT costs and associated power consumption
- ICT amortizations for specified elements in a datacentre environment
- Other general infrastructure requirements and expenses

The purpose of presenting both monthly and annually assumptions of the above is to conduct a technical comparison between the traditional approach and the virtualized cloud-computing one. In addition, this particular facility represents a heavy-duty and large-scale datacentre, as will be discussed later in relation to cloud-computing providers. The overall cost and requirement amortizations have been altered to reasonably fit a generic Smart Building ICT environment and necessarily a datacentre. However, it must be noted that in the case of other specific Smart Building examples, values of the following estimations can vary depending on several factors such as region, currency, critical load, energy availability and charges. Other cost aspects such

as networking charges, software licensing, operating systems, and administrative expenses, have all been excluded due to their variation from one site to the next. The following Table 2.2 illustrates ICT input assumptions and the following chart demonstrates a generic model executed using Microsoft Excel's PMT function for cost calculations.

(Table 2.2) Smart Building ICT Costs and Energy Usage: Assumptions for a Large Datacentre Example

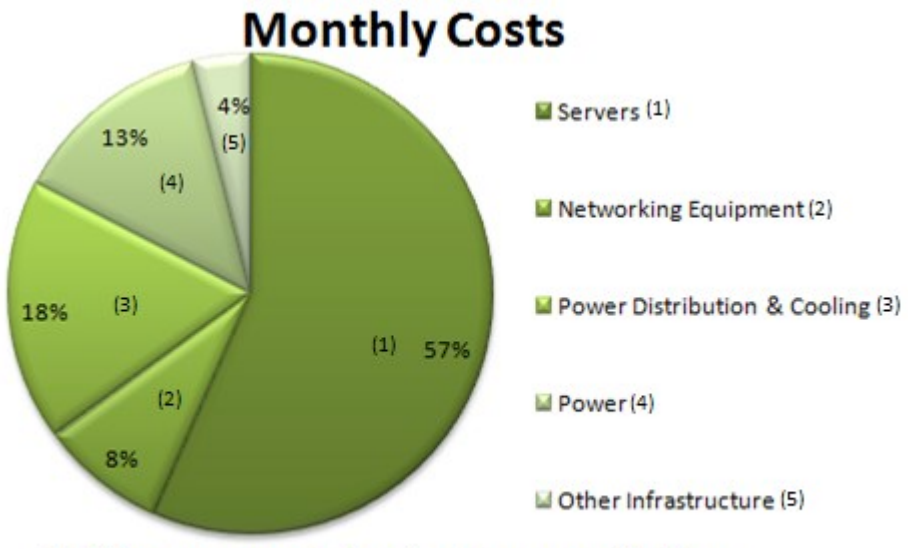
Attribute	Value	Description
Building Size	8,000,000 (Critical Load in Watts)	Estimated for 50k servers
Power Costs $/kWh	$ 0.07	Might vary between (0.03-0.15) in terms of location, regulations and region
Critical watt Cost $/W	$ 10	According to the Uptime Institute (Turner & Seader, 2006)
Building Amortization	12*10 = 120	Chosen for 10 years
Watts per Server	165	None
Abstract Cost for each Server	$ 1,500	None
Monthly Server Amortization	12*3 = 36	Chosen for 3 years
Monthly Network Amortization	12*5 = 60	Chosen for 5 years
Percentage of Money Cost	5 %	On an annual basis
Percentage of Critical Load Consumption	80 %	Provisioned power average for actual use
PUE (Power Usage Effectiveness)	1.2	According to Google Datacentre
Total Average on Cooling and Related Power Resources	82 %	Estimated from (Belady, 2007)

Using previously discussed assumptions, the total load was derived by multiplying Critical Load with Power Usage Effectiveness (PUE). In particular, the number of servers in a heavy-burden datacentre example has been calculated to approximately reach 45,978, while the total building cost, which represents the Critical Load multiplied by Cost per Critical Watt, has been estimated to reach almost $ 72,000,000.

The study calculated the total power delivered to the IT gear, including efficiency losses and cooling overhead, where the megawatt cost of power has been multiplied by the PUE value. Further, the result was multiplied by the total amount of power consumed

on average -which is less than the fully provisioned power of the datacentre- times the number of hours in a year. In conclusion, monthly cost calculations were demonstrated in the following figure in addition to the overall infrastructure cost of power. This has been executed via Microsoft Excel charts in terms of three years of server lifecycle (Figure 2.7).

Nevertheless, it is important to keep in mind that the scope of this research is limited to generic technology management and decision-making concepts for Smart Building ICT environments. Therefore, technical prospects concerning energy rates and additional infrastructure measurements, shown in the previous datacentre example, are not the core focus of this study. Nevertheless, the purpose of the illustration is to provide theoretical insights on ICT cost and power breakdown for a heavy-burdened IT environment in contrast to a smaller one.



(Figure 2.7) Percentages of 3 Years of Server Lifecycle

The previous example covered a mega-scale datacentre, which has been estimated to be equal in nearly 12 times the size of a regular football field. The datacentre was approximated to consist of almost 50K of server units. However, a medium-sized datacentre would solely include over 1000 servers (Gagliardi, 2009). On the other hand, a regular form of a non-datacentre Smart Building would require far less depending on system requirements. These facts would greatly rely on workload capacities, lifecycle performance factors, size, and networking topology attributes.

According to a 2011 *Green-Peace report*, the ICT sector's carbon footprint around the world has been estimated to represent 2% of total Green House Gas (GHG) emissions (Cook, Van Horn, 2011). Although these emissions include buildings' general IT components, 116 Million Tons of Carbon Dioxide (MtCO2e) is accounted for main PCs and internal computing devices. In addition, telecom hardware is responsible for 407 (MtCO2e), while 307 (MtCO2e) was assigned to datacentres units (Greenpeace International: Cool IT, 2012).

In relation to the prior heavy-burden datacentre example, a technical comparison can be derived with similar cost findings from a medium-sized datacentre in relation to networking, storage, and administrative expenses, as shown in the following table (Table 2.3).

(Table 2.3) ICT Costs of a Heavy-burden vs. Medium-sized Datacentre

ICT	Heavy burden Datacentre > 5000 Servers	Medium sized Datacentre > 1000 Servers	Ratio
Storage	$ 0.40 per month (Gigabytes)	$ 2.20 per month (Gigabytes)	5.7
Administration	Less than 1,000 Servers per Admin required	About 140 Servers per Admin required	7.1
Networking	$ 13 per month (Mbps)	$ 95 per month (Mbps)	7.1

Cloud service providers can be classified as the best example for the previous ICT estimation approach. These companies occupy massive buildings, which require heavy power-consuming tasks such as cooling, networking and CPU processing functions. Yet, cloud providers have been facing serious carbon emission issues. These have been exhibited by several environmental research organizations such as *Green-Peace*, who has published particularly throughout the past decade several environment assessment reports (Cook, 2012). These have assessed promising cloud solutions towards a greener ICT lifecycle and low carbon economies, and other contributions for a cleaner information industry.

Green-Peace has had multiple collaborations with giant datacentre-dependent organizations such as Facebook. Currently speaking, Facebook globally accounts for almost 800 million users, and has established the first renewable energy-based datacentre facility in Sweden (Cook, 2012). These studies were purposed for acquiring

clean and renewable ICT energy for virtualized smart servicing solutions. On that account, multiple global warming aggravation factors have been proposed in response to datacentres' increasing demand for processing, storage, and networking resources. Although these facilities have been focusing on a *Greener* operation, the drastic ICT evolution, observed by *Green-Peace,* has indicated that CO2 emissions will continue to grow, as mitigation solutions can be acquired from building more power efficient datacentres.

Another example is Google's datacentres' power usage effectiveness, which has been estimated by the *Green-Peace* to reach an average of 1.21, consisting of 50% Coal, and 38% Nuclear as dirty energy emanations (Kumar Garg & Buyya, 2012). This resulted in 3.8% of renewable electricity usage. On the other hand, Apple and Microsoft's datacentres, which are located in heavily developed cities like New York and Chicago, have both been similarly utilizing about 2% of renewable electricity. Furthermore, Yahoo has achieved the biggest percentage of 7% in reference to significant cloud datacentres renewable electricity consumption. Yet, Microsoft's New York datacentre has been estimated to cover around 473,000 servers, while Yahoo includes roughly 100,000 servers across different locations.

The thousands of networking devices and PCs within a cloud datacentre are associated with power distribution sub-systems which are directly responsible for cooling, heating, and other power demanding tasks for the infrastructure. On that note, it has been observed that almost 42% of each datacentre's power consumption is assigned to cooling equipment (Ranganathan, 2010). While ICT devices are responsible for nearly 30% in that respect, only 28% were approximated for further electrical hardware such as PDUs (Power Distribution Units), UPSs (Uninterruptible Power Supply), and others related to lighting.

The main tendency from the previous example was to attain an in-depth conception on general costs required for such mega-scale, server-dependent facility. However, cloud-computing cost calculations for end-user Smart Buildings are further analysed in the following chapter. The goal is to assess cost implications and potential energy reduction opportunities from utilizing certain cloud services. The next chapter will explore into the primary management principles of cloud-computing. These are examined in relation to market standards, architectural models, hosting solutions, and service characteristics.

Further investigation will take place according to different ICT criteria of Smart Building environments and control systems as discussed in the previous sections and the Introduction chapter.

2.2.4- Business Perspectives of Cloud-Computing to Support Smart Buildings

Combining the two domains of cloud-computing and Smart Buildings in one ICT management solution has so far not been attempted in great detail in a single implementation. Nevertheless, multiple technical and non-technical business aspects, benefits, and challenges, have been widely discussed on each separately.

In relation to the energy efficiencies benefits of using the cloud, companies such as Microsoft have recently identified that with over a hundred buildings worldwide, nearly 500 million data records are being generated daily from over two million processing nodes (Willson, Mitchel & Gimenez, 2011). This is expected to decrease drastically from the adoption of cloud hosting services, which relies on off-site processing nodes. Moreover, sophisticated computer modelling such as wind assessment, HVAC instant correlation, and analysis of complex external environmental patterns, requires massive processing power. Arguably, this would benefit from adopting cloud services for cost reduction and ease-of-management (Kofmehl & Levine & Falco & Schmidt, 2011). This approach would also be a sustainable one from an energy management point of view. In the US alone, different techniques of ICT utilization is Smart Buildings are expected to reduce CO2 Emissions by 130 to 190 million tons annually, with cost reductions in building electricity consumption on these ICTs estimated to reach 20 to 25 billion US dollars.

Other top cloud-computing providers are currently contributing positively towards reaching cloud-based Smart Buildings. For instance, IBM has published numerous executive reports, which are significant to this research on several levels (Verdelli-Mason, 2013). IBM argued that in order for businesses, or individual users, to remove unnecessary costs spent on baseless computing solutions, cloud-computing is the answer. For example, most companies are already paying for similar ICT services without taking real advantage of added capabilities of cloud-computing. This includes

long-term costly aspects such as support fees for administration, upgrades and maintenance. This cost-saving factor offers a significant added value in reducing ICT management workload, thus, less intensive administrative efforts required for installing procedures, maintenance, and ensuring system compatibility.

One example for Smart Buildings is security. Non-expert managers constantly struggle with security system updates and ensuring 24/7 uptime hosting, which requires costly hardware if implemented and managed on the premises. Another is data backup operations which are most likely to be executed on a monthly or weekly basis and require heavy-duty systems for a limited amount of time, these can be performed on-demand by renting the appropriate cloud services. This will help eliminate management burdens from IT personnel, salaries and other expenses.

Another study at IBM discussed cloud analytics from understanding the business value of employing different cloud models in disparate smart environments. One report relevant to this research has pointed out several business value indicators resulted from adopting cloud-based solutions (IBM Smart Analytics Cloud, 2010).The report covers multiple business value solutions for functional, operational, and management cloud-based architectures. The main purpose was to provide insights and implementation issues for non-expert business managers on how and when to apply this specific approach. Another motive was to introduce a specific cloud service which provides organizations with multiple locations with fully virtualized ICT delivery for business intelligence and administration. Moreover, multiple sustainability aspects such as long-term costs, energy efficiency approaches, real-time response features, and the acquisition of new business opportunities, were also discussed as opportunities arising from deploying this service. However, several re-shaping challenges such as adjusting and initializing existing environments are recognized to ensure a substantive competitive advantage.

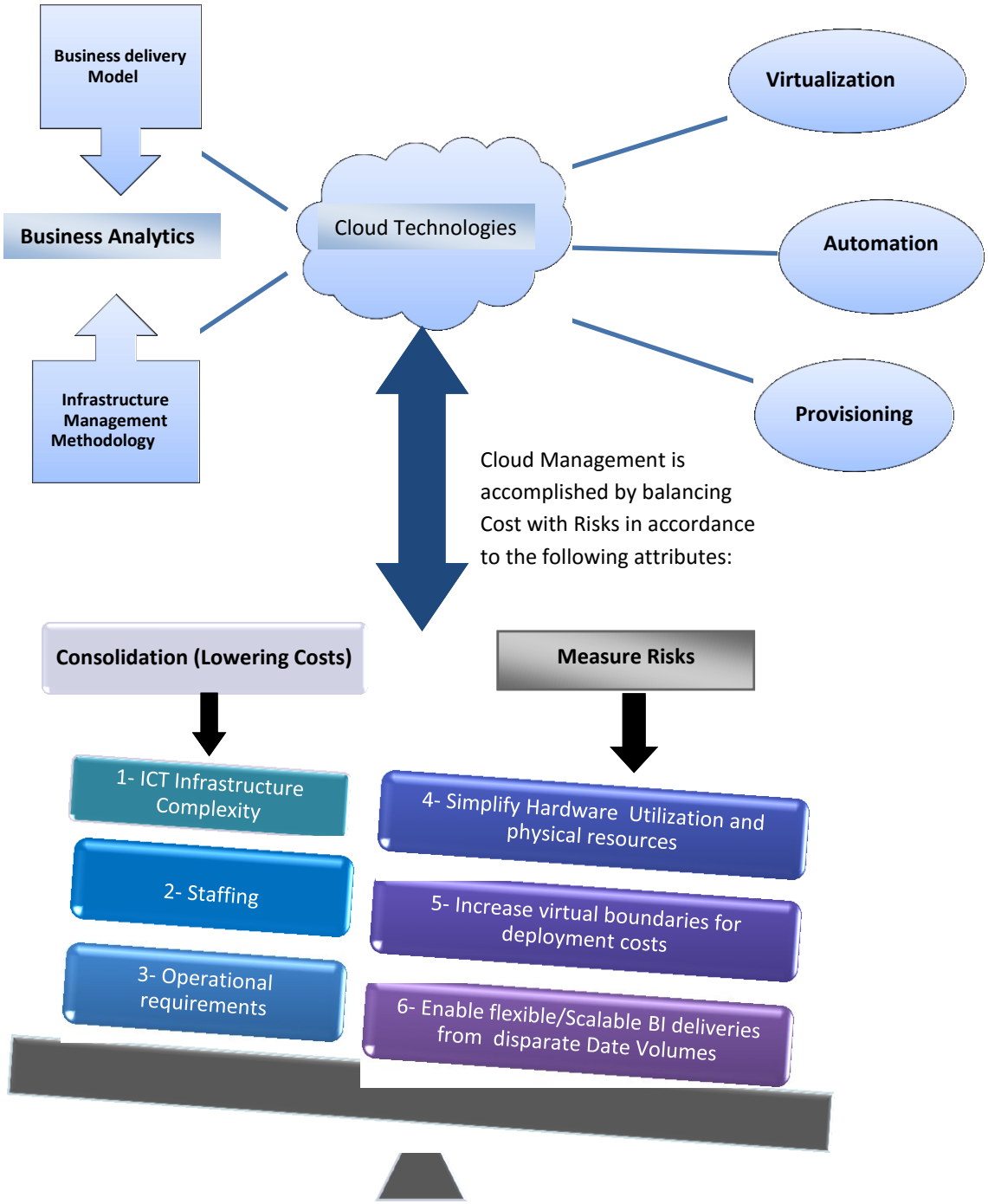
The report argued that in order to achieve this transformation from conventional data manipulation methods to a cloud-based approach, several considerations must be addressed. These aspects include current ICT system architectures and the data management process in the Smart Building. It was also observed by the study that similar ICT developments such as Virtualization, Automation, and Data-Provisioning will continue to mature and cloud-computing services will evolve and become

consistently employed by decision-makers. The outline debated that with each cloud service, less control over resources is offered in the Smart Building infrastructure.

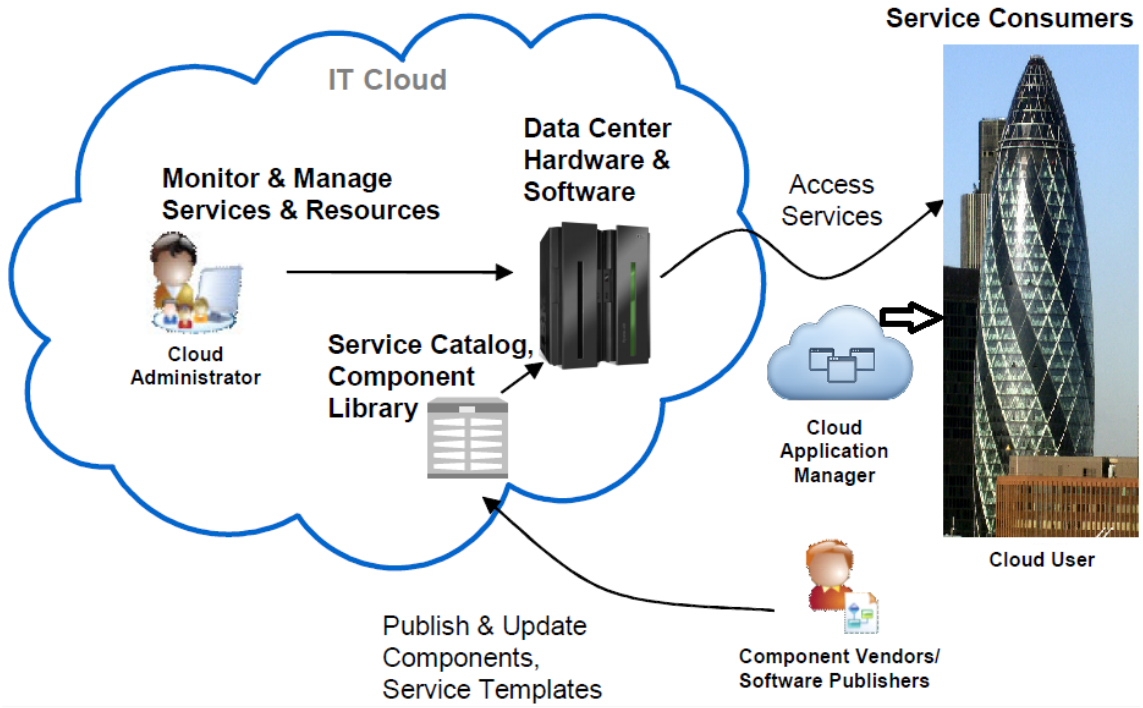
It is essential that a balanced approach is adopted when assessing an effective ICT optimization strategy prior to any virtual deployment action. While the general business aim is to investigate which types of cloud hosting attributes are suitable for a specific Smart Building environment, the inquiry about how to best balance these attributes is an essential task that is required to be performed by non-expert managers. These aspects involve balancing reliability risks, long-term sustainable rewards, and other administrative trade-offs as illustrated in Figure 2.8.

The figure was constructed to illustrate the decision-making steps with regard to ICT optimization strategies, including general cloud-computing dependencies for a large-scale utilization in a Smart Building.

Business financial returns related to services such as Enterprise Resource Planning (ERP) and supply chain aspects from the cloud analytics services are not the focus of this research, yet, numerous points concerning cloud management frameworks and functionalities will play an important role of this thesis. For instance, a significant error-reduction factor can be gained by Smart Buildings from deploying certain functions over the cloud. These functionalities will depend on key cloud components as illustrated in Figure 2.9.



(Figure 2.8) IT Optimization Strategy (Order of Steps), and Cloud Development Dependencies for Future Large-scale Utilization (IBM Smart Analytics Cloud, 2010)



(Figure 2.9) IBM Cloud Automated Deployment from a Smart Building Service Consumer Perspective. Rebuilt from (IBM Smart Analytics Cloud, 2010)

According to Siemens, the drive for energy-efficient Smart Building management has never been greater. The statement arises from several recent world-changing circumstances such as global warming, urbanization, resource storage, and population growth (Rubner, 2011).

Siemens has explored developing ICT and cloud trends, which have been assessed in relation to virtualized software, processing power memory capacity, data handling, and storage. They argued that by implementing fully operating cloud-based platform in the near future, ICT services will be available and accessed by users in a similar manner in which water, electricity and other life dependent requisites are currently utilized.

Furthermore, Smart Buildings with virtualized and on-demand computing power will be capable of automatically controlling connected systems to manipulate electricity usage, water consumption, ventilation power, and other energy-dependent tasks. These will be practised with various environmental and economic aspects as previously discussed. This will allow an increased dynamic harmonization between numerous energy-consuming tasks, taking account of external variables such as changing costs in bills and taxes, bottle-neck workload periods, and sudden changes to the external

environment (Schroder, 2011). It was also argued that when it comes to Smart Buildings' general functions, there is still potential for large scale of improvements to be executed with respect to energy-efficient ICT solutions, and cloud-computing in particular.

Other big names such as Google, Amazon, and Microsoft have been offering various cloud-based online services such as webmail, online programs, storage of files, and other types of dynamic delivery of information. These cloud providers are still discovering the best ways to operate these forms of internet services in a dynamic, distributed, and virtualized manner.

According to a study by the Experton Group, the entire concept of renting ICT capacity according to pre-scheduled demand, is without a doubt heading towards a great deal of cost effective opportunities in almost all fields of science and business (Velten, Janata & Hille, 2013). For instance, it was confirmed that in 2011 Germany alone has gained almost $1.4 billion of revenue from the utilization of disparate forms of cloud-based solutions across different smart structures. Furthermore, the same number is considered to reach $10 billion by 2015 (Rubner, 2011).

2.2.5- Decision-Making Methods in Smart Buildings

Decision-making techniques have been introduced from different perspectives through various systematic models. Many science-based firms, ICT suppliers, and scale-intensive corporations have adopted these approaches based on a wide-range of publications (Pavitt, 1994). Decision-making types in relation to different information system (IS) management standpoints have been defined as follows (Teale, Dispenz, Flynn & Currie, 2003).

- Structured
- Unstructured
- Programmed
- Non-Programmed
- Strategic
- Operational

Further, IS decision-making models have ranged from:

- Qualitative
- Normative

- Quantitative
- Descriptive

On the other hand, various decision-making perspectives were identified as:

- Rational
- Bounded Rationality
- Political

According to the previous Information System decision-making models, aspects from structured, programmed and normative decision-making methods will be adopted, to a large extent, by this study. The reason being is that these support established and pre-planned situations with sound-basis knowledge of different management circumstances (Mintzberg & Westley, 2001). However, other selected points from several unstructured approaches regarding emergent, un-planned ICT situations in Smart Buildings will be referenced as part of this research main cloud management framework.

This review will conclude that in order to form a generic decision-making tool for the implementation of rapidly evolving cloud-computing services, a hybrid framework that consists of multiple in-practice models is the appropriate approach. Findings will be assessed in response to different building case studies in terms of size, operational objectives, employees, branches, and workload. These are argued to shift the direction of decisions in relation to actual value estimations, cost of withdrawal or persistence, ambiguity, and long-term admissibility rates from utilizing cloud techniques.

Classical views on IS decision-making for planning and design have been mainly introduced with respect to benefits from upfront costs and capital expenditure. However, techniques of administration and long-term ease-of-management were not particularly highlighted in a company's everyday heavy-duty lifecycle. This classic view had focused on expanding advantages to gain additional value, while sequentially measuring costs against related factors such as change, implementation and maintenance (Cordoba, 2010). Furthermore, in reference to the return value, management estimations had ranged from: (De-Bono, 1999)

- Strategic Assumption Surface Testing (SAST)
- Soft Systems Methodology (SSM)
- Power-based Critical Systems Heuristics (CSH)
- Idealist interactive planning

- Competitive advantage
- Information analysis
- Available IS architectures

This study will prove that the conventional view of IS decision-making is inefficient, and obsolete with regard to cloud-computing utilization and services in Smart Buildings. It can be argued that the classic model addresses the identification, analysis, and evaluation of the problem on a general basis (Figure 2.10). However, only a minimum focus on follow-up actions is considered, which is a disadvantage as these subsequent processes are significant for ensuring a reliable, long-term cloud administration.

(Figure 2.10) Conventional View of Information Systems (IS) Decision-making (Cordoba, 2010)

Another popular evaluation model for IS strategies is the Escalation and de-Escalation approach. The model mainly focuses on IS commitment processes for avoiding conflicts while weighing positives with negatives along each development stage. The aim was to enable managers to diagnose changing implementation conditions throughout both sudden social analysis, and rapidly evolving revolutionary levels (Pan, L.Pan, Newman & Flynn 2006**).** On that note, this model is considered essential to the outsourcing process for Smart Building ICT infrastructure into a cloud platform, as multiple aspects can be analysed while purchasing costly, on-demand cloud services.

Several academics have published on Decision Support Systems (DSS) for Smart Buildings ICT systems (Bui & Lee, 1999) (Turskis, Kazimieras & Peldschus, 2009). Whilst some have leaned towards general agent-based systems for assessing potential benefits concerning data filtering, mining and capturing, others have explored multi-criteria DSS schemes. Throughout the past two decades, various methods were examined by different fields of science from various perspectives. These acquired a strong connection to several analytical processes, such as the Analytic Hierarchy

Process (AHP) for a generic specification of different Smart Building components (K.W. Wong & Li, 2008). Furthermore, others were suggested in terms of energy assessment DSS models, which were mainly concerned with buildings' lifespan measurements for optimal performance decisions (Chen, Clements-Croome & Derek, 2006). These models were mostly implemented with the support of certain networked-based methodologies such as ANP (Analytical Network Process) and ETI (Energy-time Consumption Index) (Wong & Li, 2005).

Numerous reports measured performance levels of service as part of an assessment process for different integration techniques for Smart Buildings (Arkin & Paciuk, 1997). The identification of novel on-going Smart Building advances, and deriving supplementary DS systems along the way was addressed by specialties from both economic and technical perspectives (Yang & Peng, 2001). A large amount of literature focused on the customer-value of a smart structure. This has highlighted the energy-saving factor as a time-bounded and uncertain hypothesis, which interrelates with progressive and ongoing artificial decision-making systems (Boman, Davidsson & L. Younes, 2001).

Several other studies have inquired into DSS frameworks in reference to Smart Buildings' multi-agent control systems. Although specific communication methods between these agents have been explored on multiple asynchronous levels, online-based Smart Building algorithms were developed in that regard as a result of large volumes of captured, yet improperly handled data (Rutishauser, Joller & Douglas, 2005). Various DSS papers emphasized selectively on one particular Smart Building task, for example lighting control systems via wireless sensor networks (S. Sandhu, M. Agogino & K. Agogino, 2005).

In terms of cloud-hosted system designs from different computational capacity standpoints, conclusions argued this approach as being strongly dependent on multiple non-human, software agent characteristics. These were identified in accordance with various DSS construction processes as:

- Independence
- Learning
- Cooperation
- Reasoning

- Intelligence.

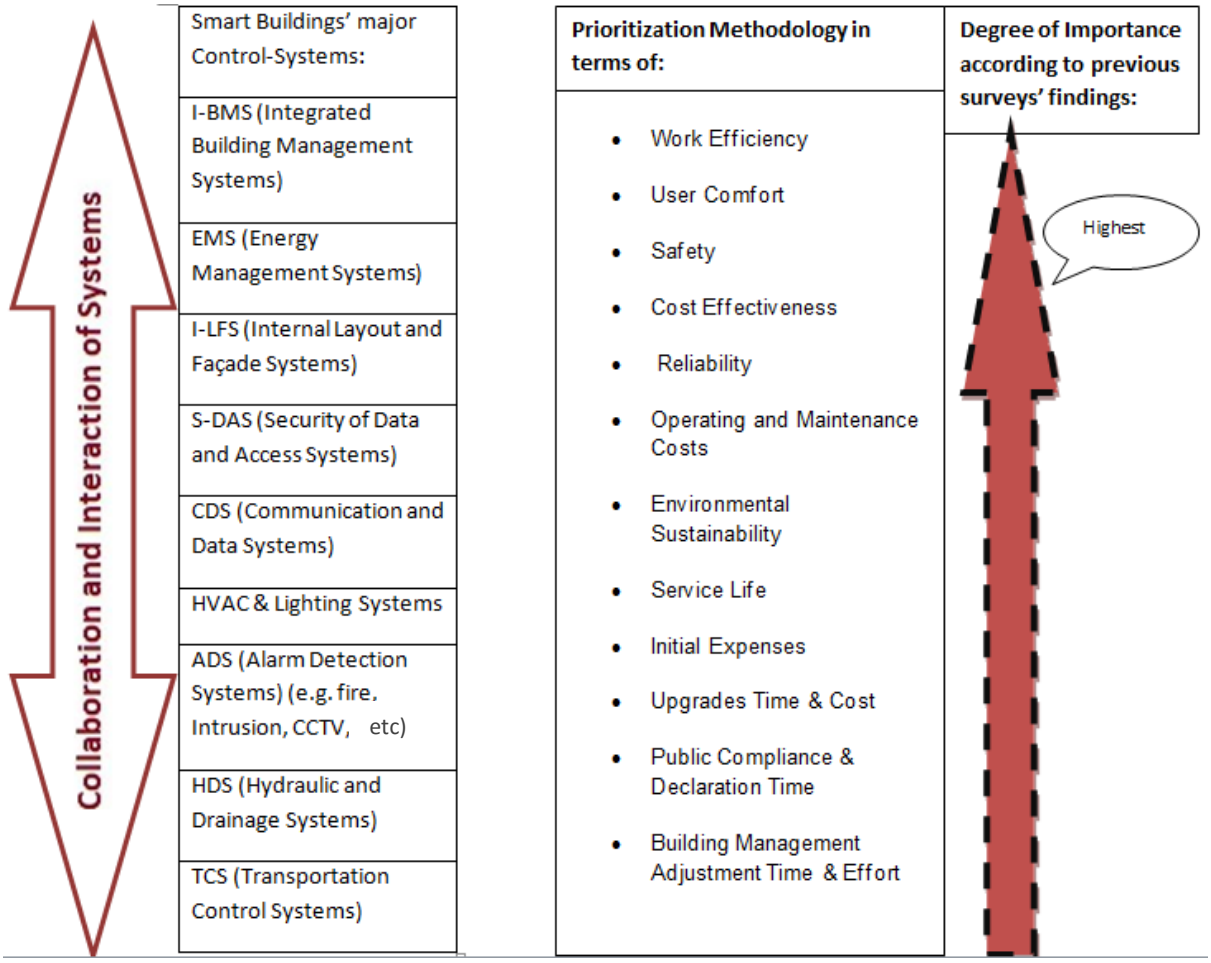
However, constructing a DSS framework to correspond with multiple complex and distributed task-determined patterns of Cooperative Information Systems (CIS) (Bui & Lee, 1999). Even though this was carried out to solve numerous end-user issues, agent-based DSS approaches have mainly distinguished between *Micro* and *Macro* levels of the development process.

The previous paper has largely followed a generic point of view for building decision-support systems. With regard to internet-hosted approaches which have been viewed to rely on taxonomy of software-based non-human factors, a strong connection to third-party cloud services can be identified in terms of case-by-case decision-making tools for Smart Buildings. On this note, key identification criteria concerning prioritizing Smart Buildings' primary systems have up till now been frequently undertaken.

A particular DSS selection survey that took place in 2008 has followed an AHP (Analytic Hierarchy Process) approach, and was aimed to evaluate and prioritize collected knowledge, which was perceived from Smart Buildings' non-expert managers and practitioners (K.W. Wong & Li, 2008). Conclusions were inspected in a detailed manner which was comparatively approached with reference to quantified Smart Building end-systems. In addition, it was essentially argued that in the case of each sub-system in a building environment, disproportionate sets of identification methods are the actual conclusive factor that evaluates the degree of importance of that particular solution.

Given the broad and comprehensive exploratory investigation, which targeted almost every Smart Building functional aspect, this research will only address interrelated points which correspond with cloud-computing management in particular. On that ground, major points from the AHP multi-selection criteria can be outlined in the following diagram for achieving management weighting, implied value, and degree of prominent status within a Smart Building ICT environment (Table 2.4).

(Table 2.4) Prioritization Status of Collected Management Attributes within a Smart Building



It can be noted from the previous table that major survey conclusions have strongly classified *work efficiency* as the number one priority in almost every Smart Building management situation. However, *cost effectiveness* has dropped behind both *safety* and *user comfort.* Further, *operational & maintenance costs*, *environmental sustainability*, as well as *reliability* were all observed as significant to building managers. As a result, a strong indication can be acknowledged which reflects a critical management concern towards long-term costs and potential chances of failure. This can be effectively practised to enhance decision-makers' evaluation and selection methods with respect to novel technologies such as cloud-computing, and similar virtualized techniques essentially concerned with acquiring a sustainable ICT lifecycle and ease-of-administration.

Various limitations of Smart Building rating procedures were similarly argued. These assessment techniques were respectively categorized and analysed according to

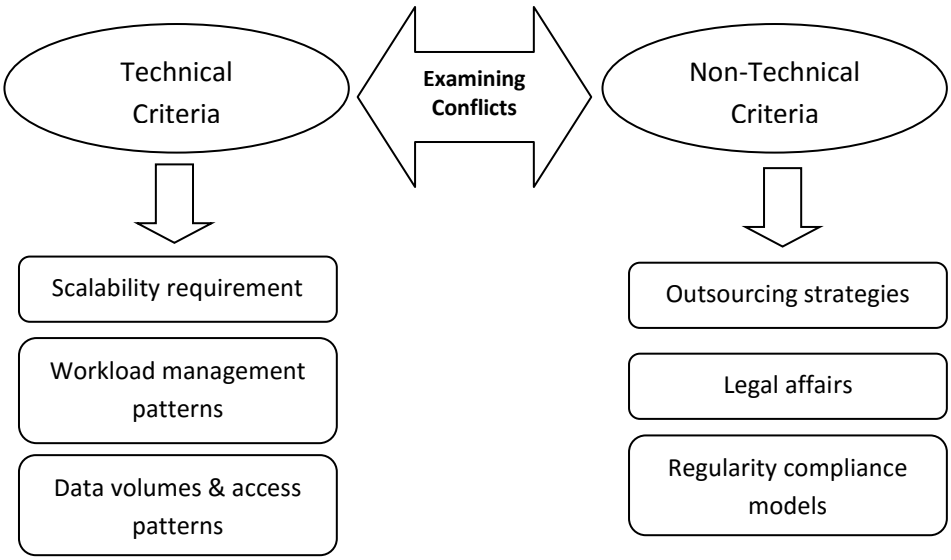
different rating modules for building systems. For instance, these modules have ranged from the AIIB (Asian Institute of Intelligent Buildings), which was adopted in Hong Kong, going through the CABA (Continental Automated Building Association) method that was applied in Canada, all the way to the UK's BRE (Building Research Establishment) method.

In principle, this research will exclusively highlight a specific internet-hosted, virtually-administered, and on-demand cloud-computing alternative for Smart Buildings, for the aim of reaching a decision-making framework with sustainable, long-term ICT management.

Conclusions on quantitative selection indicators, tactical, and strategic evaluation models are believed to play a significant role in the time and energy consumption in a Smart Building ICT environment. In essence, this research will not adopt a certain selection method given the global aspects and aims, and different themes of cloud-computing concepts, which follows a transparent and remotely-administered approach as a major management objective. Nevertheless, a balanced approach between ICT technical and non-technical management in Smart Buildings will be investigated in order to ensure cost-effective, reliable, and long-term sustainable cloud strategies.

2.2.6- Decision-making Models in Cloud Computing

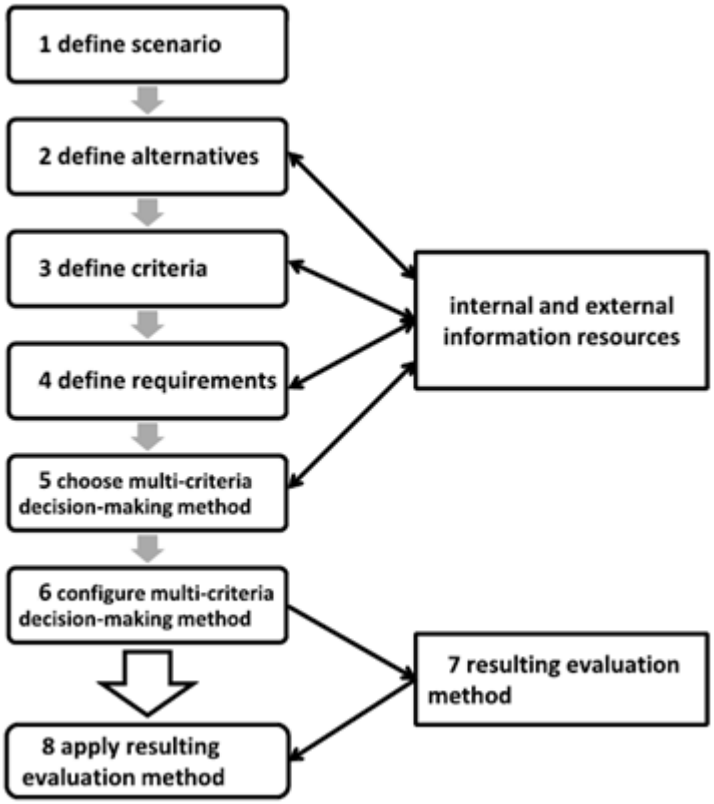
In reference to cloud-computing decision-making tools, a generic study on cloud systematic evaluation was undertaken in 2010 as part of multi-criteria decision-making system for various information technology applications (Menzel, Schonherr & Nimis, 2010). The main objective was to offer a wide scope of cost effective platforms with specific decision-enhancing methods. In addition, a broader comparison with traditional non-cloud services was examining other opportunities for sustainability and managing risks with respect to ICT adoption for unrelated domains of operation. One of the challenges presented was concerned with different Smart Building conflicts from applying cost-efficient cloud solutions. These were evaluated to assess potential conflicts between either technical applications or nontechnical standards as illustrated in the following diagram (Figure 2.11).



(Figure 2.11) Cloud-Computing Conflicts between Technical and Nontechnical Standards of ICT Management (Menzel, Schonherr & Nimis, 2010)

The study explored previous decision-making methods from employing cloud solutions for sustainable customization of nontrivial ICT alternatives. However, it has been claimed that although most decision-making formulas were constantly analysing issues in contrast to potential cost reductions obtained from purchasing on-demand cloud-hosted services, not much has been offered with respect to value propositions. In particular, the gap in previous decision-making frameworks was identified as not fully approaching technical advantages, whereas a confined scope of research has merely addressed ICT infrastructure expenses and nontechnical organization's requisites. Nevertheless, the paper reviewed different business scenarios in relation to alternative goals, value characteristics, framework attributes and requirements, and other evaluation methods.

The final discussion proposed a demonstration on how to select, define, and implement the framework for a Smart Building's ICT environment (Figure 2.12). For instance, the outlined step-by-step process for evaluating cloud employment possibilities as an ICT supporting infrastructure were presented as an abstract procedure with an explicit consideration to internal and external aspects of the structure's knowledge-based systems (i.e. database, business intelligence management, analysis software, and so on).



(Figure 2.12) Example Decision-making Framework for selecting, defining, and implementing Cloud projects for Smart Building ICT environments (Menzel, Schonherr & Nimis, 2010)

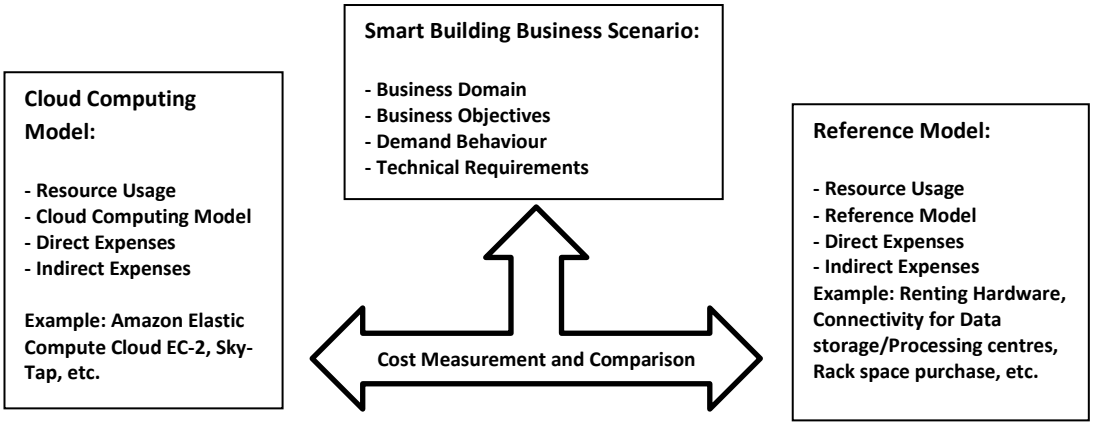
It can be noted that the previous paper did not support the above framework with any real-life examples. However, a strong argument can be established, which measures the possibility of applying the ultimate ICT assessment tool in a generic business environment. In addition, a management connection to different functions in a Smart Building can be observed from overall conclusions. In essence, it was suggested that employing cloud-computing services could potentially form a management dilemma as decision-makers must comply with a systematic, step-by-step evaluation of various alternatives. This is discussed in relation to detailed comparisons with resource usefulness rates, and ratio-scale identification of proposed criteria.

Several unstated assumptions were put forth concerning the examination of quantitative and qualitative frameworks, wherein the former cannot be accurately measured (Armbrust & Fox, 2009). It can be argued that an itemized data analysis and collection for specified tasks in different environments would empower cloud decision-making tools with a concrete group evaluation, qualitative measurements, and resource data collection.

Various technical issues have been investigated to a systematic degree, by the FZI informatics institute (Klems, Nimis & Tai, 2009). The topic mainly covered cloud-computing benefits gained from cost estimation techniques, and a comparison tool between virtualized returns and traditional ICT services. This was approached from an economic point of view, with the environmental sustainability aspect not addressed in any context.

The paper has structured a fixed framework for obtaining business valuation scenarios via cloud-based services (Figure 2.13). While the stages were mainly focusing on business demands and behaviour, the technical advantage has been added as an end-point requirement which included aspects from availability, scalability, and ease- of-deployment. This demonstrates consistency with Smart Buildings both business, and technical aspects following a generic value estimation framework.

According to the US-DISA, a successful long-term utilization of IT cloud services depends on a detailed cost comparison between two ICT infrastructure schemes: the *Conventional*, and the *Cloud* (Gartner, 2013). The *Conventional* is an arbitrary sophisticated reference model that includes resource usage analysis such as processing power, data transfer and storage. Further, the model analyses both direct, and indirect associated costs as will be examined in this study's demonstrational decision-making tool. In particular, two examples in that respect are the SME and TCO pricing evaluation models for purchasing or renting hardware for either in-house or migrated cloud solutions. The *Cloud* service pricing model also estimates ICT resource consumption, and is usually provided by the cloud service provider such as Amazon Elastic Computer Cloud (EC2). Associated costs with the cloud-based scheme are identified as a metric comparison to IT alternatives in any Smart Building (Chiu & Subrahmonia, 2008).



(Figure 2.13) Primary Phases of the FZI Cloud-Computing Value Estimation Framework (Chiu & Subrahmonia, 2008)

After reviewing several similar cost estimation reports, it can be concluded that the entire process of outsourcing computing power, data storage, and numerous other energy consuming ICT features into the cloud, is till this day unclearly and neither standardized nor defined with reference to multiple business requirements (Stamoulis, Courcoubetis & Thanos, 2007).

It can be identified from the previous report that a significant assumption with regard to non-expert decision makers' evaluation was vacuously stated and can be logically challenged. Moreover, it was mentioned that a precise estimate needs to be carried out by decision-makers to pass judgment on selecting the best time and place for a cloud utilization. These examples were put forth on a general basis with no specific examination for a single scheme. Additionally, a logical argument was noted to be missing from the cost comparison framework. This research will attempt to establish a disciplined connection between various cloud advantages for different ICT areas of implementation, thus, apply this methodology to Smart Buildings.

Another paper published on cloud-computing decision-making in relation to cost planning and ICT component provisioning, is the cloud adoption toolkit: *PlanForCloud* (Khajeh-Hosseini & Greenwood & Sommerville, 2013). The report describes the challenges, end-user concerns, and elastic features associated with cloud-computing decisions, and develops a framework to assist end-users in this process. The paper examined this by utilizing a case study, and models the expenses of that organisation through illustrating the variations in requirements, thus, changes in cloud costs across the organisation's ICT lifecycle. This paper is considered significant to this research, given that the *PlanForCloud* tool is adopted in Chapter 5 in a cloud cost simulation for

this study's main case study. Furthermore, this research develops in Chapter 6 *SBCE,* which is an in-depth decision-support system for non-expert managers in Smart Buildings, and this system is built on top of the *PlanForCloud* tool, only with reference to the cost estimation aspect.

This tool was developed at first for experimental purposes by researchers at the University of St Andrews in the United Kingdom, which eventually led to the successful launch of the well-known company called *PlanForCloud*. This research developed the first part of the system: SBCE upon the *PlanForCloud* tool with differences in the usage patterns and reporting as will be discussed in Chapter 6. Furthermore, SBCE shifts from the cost estimation objective, to a management consultancy one called the In-Depth Analysis, which focuses on decision-making attributes for non-experts in different Smart Building categories.

2.2.7- Cloud Adoption Risks and Trade-offs

According to Carrenza and HP, upgrading an existing ICT system for three consecutive years is more costly than the system itself. This was argued in connection to potential cloud solutions for Smart Buildings in the UK (Carrenza & HP Service Manual, 2015). Given the vital security aspect and apprehension of virtualization within companies' datacentres, knowledge, and intelligence, a great deal of constraining reliability concerns have been raised. It can be acknowledged that risks concerning these two topics have not been adequately addressed. However, a wide range of previous literature has been published on each matter. The focus of the following analysis will be to intersect key points from both areas and acquire a central connection between Smart Building management and cloud adoption concerns and challenges.

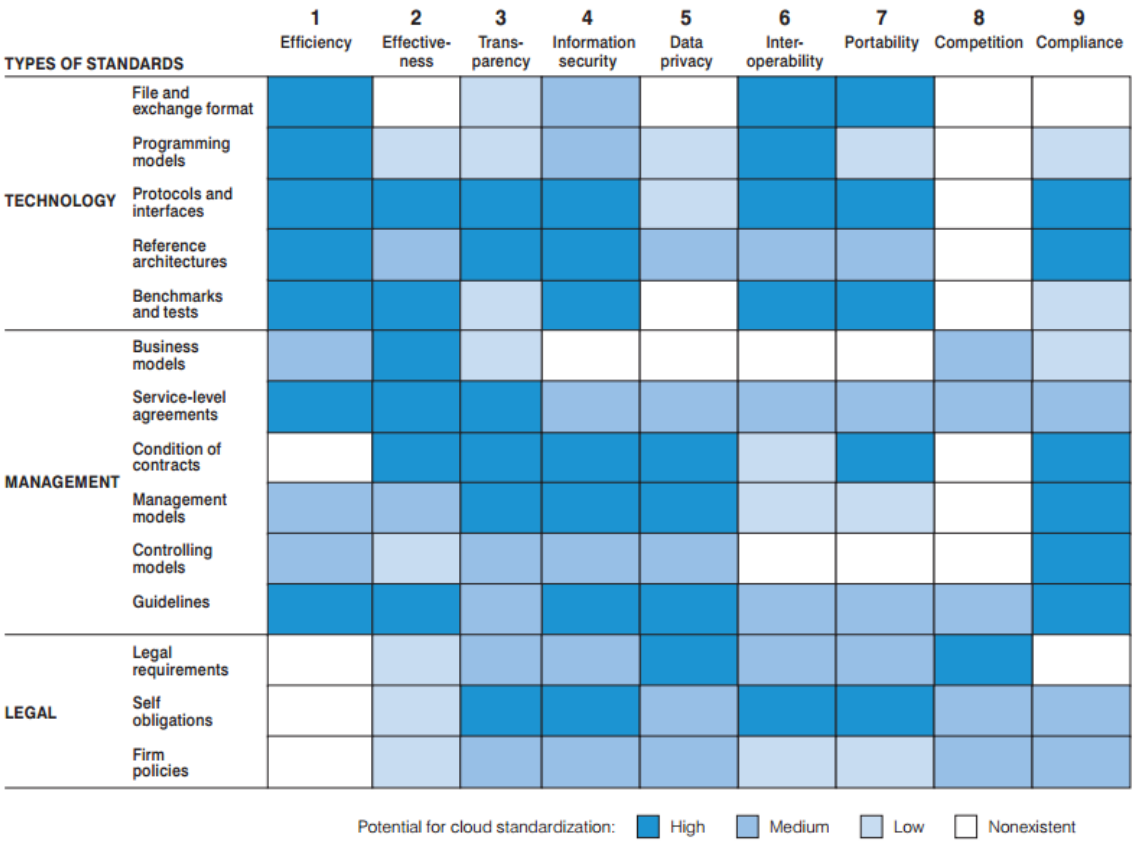
While a new level of versatility was offered to any Smart Building cloud management process, several key inconsistencies were identified as a potential barrier to the rapid evolution of cloud-computing. For example, a risk analysis study by Booz and Company investigated this particular issue and suggested that in spite of the business value of cloud-computing, concerns regarding various security limitations must be

reviewed carefully by any manger before any cloud migration takes place (Bernnat, Zink, Bieber & Strach, 2012).

The report argued that a slower pace of virtual ICT adoption is currently spreading across large organizations simultaneously with the rapid evolution of cloud techniques. These risks were argued to range from technical, management, all the way to legal aspects of employment. Further, industry core standards for cloud purchase and implementation have been argued to be missing for different governmental, business users, and cloud service providers. This standardization is to a large extent related to optimizing the manner in which cloud services are disparately purchased, supported, and governed. However, numerous other administrative, technical, and legal gaps to reach an accurate cloud definition were identified to help attain a *Cross-Industry* enterprise standard.

After inquiring into existing cloud-computing standards, the previous study reported a large number of definitions by ICT providers such as Cisco and IBM. These cloud standards were believed to be inaccurately developed, and estimated to reach about 160 different definitions (LaManna, 2012). These however have ranged from *EuroCloud*, to (*The US National Institute of Standards and Technology) NIST*, all the way to others like *CSA (The Cloud Security Alliance)*, and the *ETSI (The EU institute of Telecommunication Standards)*.

Specific conclusions regarding cloud utilization gaps resulting from the previously mentioned standards were considered significant to this project's decision-making objective for Smart Buildings' non-expert managers. These gaps are clarified in the following chart and cross-referenced from a technical, administrative, and legal standpoint (Figure 2.14).



(Figure 2.14) Utilization Gaps resulted from numerous Cloud-Computing Definitions (Bernnat, Zink, Bieber & Strach, 2012)

This research will adopt the NIST definition of cloud-computing in both the theoretical cloud management framework, and the online demonstration decision-making tool, which will be developed and discussed in Chapter 6.

According to the previous report, cloud adoption risks have ranged between technical and nontechnical points from different levels of:

- Efficiency
- Control
- Transparency
- Interoperability
- And other legal compliance issues
- Security
- Information confidentiality
- Mobility
- Unguaranteed competitive advantage

Other vital data privacy concerns were put forward in terms of access verification, management roles, threat detection, prevention, and integrity of information transfer. These security risks are considered the main reason behind the current unsuccessful attainment of standardized definitions for cloud concepts. Due to the fact that all models are fully implemented over the internet, cloud-computing concepts might never be fully implemented until an agreed definition is established. In addition, a cloud standard

would enable users to access cloud services remotely from any physical location with a full data-handling control along with various editing permissions. Therefore, a large scale of separate nontechnical aspects with reference to transparency of monitoring, quality assurance control, inquiry into liability mechanisms, and compliance with underdeveloped laws, are all considered valuable to this section's security analysis.

Several logical assumptions were considered hypothetical from the previous paper. For example, the suggestion that obtaining a singular and prototypical cloud classification would act as a panacea to all integrity risks and management challenges, is unstated and can be considered overrated. However, this study has a positive influence on this research decision-making framework, given its several consistent recommendations for Smart Buildings' administrators. For instance, it identifies that managers should:

- Not strictly measure the integration process concerning existing ICT systems in their structures, however, a contribution to standardize the cloud is required from each cloud consumer.
- Carefully define the organization goals, position and strategies in relation to specific cloud advantages.
- Acquire a full comprehension of current cloud definitions and industry standards, which corresponds with optimizing corporate actions via a fair, individual contribution in promoting cloud services.

Other general assumptions were arguing for outsourcing of non-core ICT capacity into a third-party provider that owns the infrastructure. However, numerous growth-limiting barriers have been explored concerning data breach and knowledge sharing risks (Kuyor, Ibikunle & Awodele, 2011). Adopting a fully outsourced cloud-computing solution is currently considered an unfavourable decision by most non-expert managers given the uncertainty of private data whereabouts and many other considerations related to less control over owned resources. As a result, an efficient business model has been offered for utilizing cloud services, which has proven to dismiss upfront expenditures as previously discussed.

The previous study focused particularly on challenges related to cloud deployment models and security risks resulting from various system delivery methods. Further, the detailed analysis established a risk measurement comparison between Private, Public

and Hybrid cloud delivery methods, consistently with the three distinct forms of cloud service models:

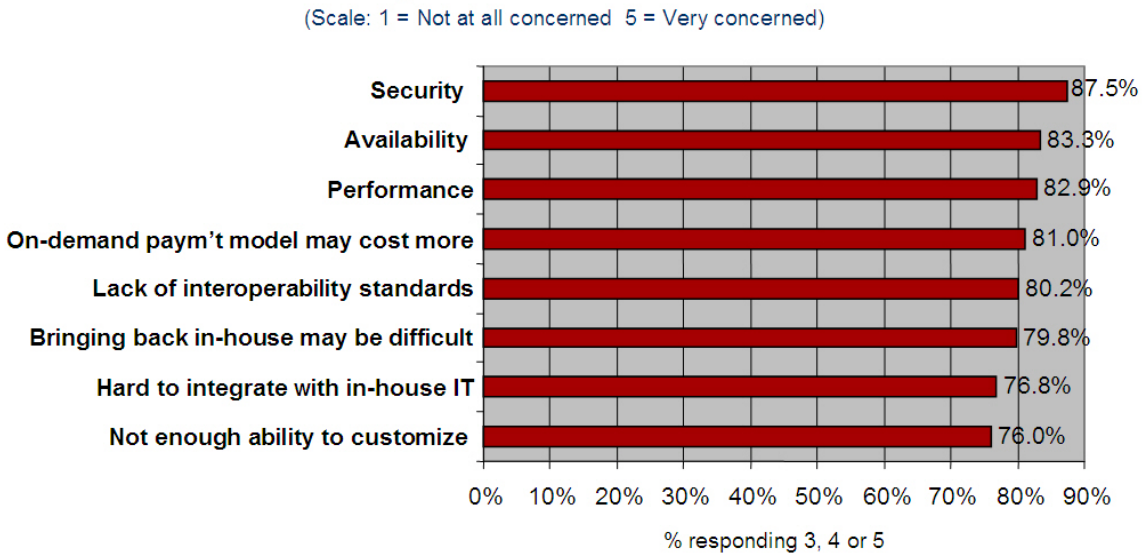
- Software as a Service (SaaS)
- Infrastructure as a Service (IaaS)
- Platform as a Service (PaaS).

These primary types of cloud service solutions are illustrated in the following table against associated security and reliability challenges and potential beneficiaries in relation to relevant Smart Building ICT management case studies (Table 2.5).

Cloud Service Models	Brief Description	General Example	Smart Building Case Study	Reliability & Security Challenges for Smart Buildings
SaaS **(Software as a Service)**	Users can access applications via networked hosted infrastructure (i.e. Internet, VPN, etc).	Gmail, Blogger, Cisco WebEx, Flicker, Windows Live Meeting, Windows Office Live.	HVAC technicians (on-site) using only a tablet smart device to access a Cloud-based service- via the internet- to view, update and administer maintenance data, event status, and reports for different buildings, all at once.	Given that SaaS is mostly offered free of charge, or accompanied as an additional service with larger paid solution, Software is not installed on users' servers or personal PCs. Therefore, access can occur strictly on an on-demand manner. As a result, only confined functionalities, selected configuration, service availability issues, and limited control of programs -to underlying ICT developments- are provided by the SaaS approach.
PaaS **(Platform as a Service)**	Users develop software via a fully networked-hosted platform, including a Cloud-based utilization of Hardware and operating systems.	Force.com (development platform), GoGrid, Facebook Developers.	PaaS services offered by Force.com, has provided commercial buildings in the hospitality industry, across Asia and Australia in particular, with a scheduled migration process to dispense the use of legacy IT systems (like label printing, license key generation, case management) with an integrated Cloud-based software, developed by users to fulfil specific, centralized IT requirements.	Underlying cloud solutions (in addition to several dependencies like storage, network, servers and operating systems) are not administered by the service-requester. However, more control is available than the SaaS model, as the main IT environment in the PaaS approach is considered *'Closed'* or *'Contained'*. Nevertheless, availability restrictions are still considered a tradeoff for building managers, from the traditional physically installed ICT infrastructure.
IaaS **(Infrastructure as a Service)**	The Cloud provider rents out Hardware, Software, data Storage or networking bandwidth via virtual, on-demand accessing policies.	Amazon Web Services, IBM Cloud-works, Windows Azure.	Implement, or directly replicate a flexible IT solution for an entire Smart Building ICT system (replacing physical computing and networking infrastructure/capacity with a fully virtualized IaaS approach, for an interconnected set of disparately located buildings).	Even though buildings' IT managers have, to some degree, the ability to control, deploy, and run user-created programs (operating systems, privately developed software, networking components such as Firewalls, hosting folders, etc.), nonetheless, the underlying cloud solution, is again, primarily administered by the Cloud provider. Thus, security access of information, user-group permissions and other administrative dependencies are all considered for reliability management.

(Table 2.5) Three Primary Types of Cloud Service-Delivery Solutions

In relation to various Smart Buildings' operational tasks and objectives, sceptical concerns regarding credibility and authenticity have been observed and increased among managers with the spread of cloud services. According to a survey by the IDC Enterprise Panel in 2009, the following barriers have been identified and rated on the degree of worrying in contrast to the acceptance percentages attained from purchasing on-demand cloud benefits (Figure 2.15) (Gens, 2009).



(Figure 2.15) Management Survey on Cloud-Computing Worrying Degree (Gens, 2009)

It can be noticed from the previous diagram that private data sharing and migrating to an off-site storage is constantly the highest concern of managers. Thus, a crucial limiting factor towards cloud acceptance is raised in that respect. However, other concerns were also acknowledged as critical in relation to ensuring availability of ICT resources, performance, and integration difficulties with on-site systems. Additionally, regularity issues for certain enterprises that operate on critical user data-records such as banks, government agencies and others, have also been identified to cause concern among decision-makers.

In connection to Smart Buildings' ICT requirements, these virtualized techniques might cost more than the entire implemented ICT solution within a Smart Building (Kuyoro, Ibikunle & Awodele, 2011). As a consequence, included installation procedures, management efforts, support, and administration expenses are expected to accumulate.

Other technical studies examined cloud implementation risks in relation to performance measurement and modelling (Lim, Babu, Chase & Parekh, 2009). It was argued that outsourcing IT services via a *Lease* between one or multiple providers such as Smart Buildings are only considered *Temporary Guests*, which are utilizing from an off-site, virtually managed IT infrastructure on a strictly pay-as-you-go basis. However, a dynamic set of clients can share owned software by using the same *Lease* in relation to already purchased utility clouds.

The paper addressed several cloud performance concerns, and recommended acquiring an on-site control system that operates a web-service via leased cloud resources. Even though this can still cause reductions in overall operational expenses, it simultaneously enables managers with significant feedback features on *Elastic* cloud provisioning and automation as will be discussed in the next chapter.

Several papers and risk assessment studies have discussed offering privacy as a service, availability, and data integrity in Smart Buildings. For instance, it was acknowledged by many academics that cloud-computing technologies can enable non-expert building managers to focus on appropriate energy reduction strategies in substantial areas of operation (Yarwood, 2012). Further, meeting customers' demands requires the handling of neglected functions such as erasing large amounts of unneeded data, off-grid operational tendencies and privacy automation services (Considine, 2009). These aspects distinguish a Smart Building from other conventional types of ICT structures.

It can be observed that previous points were addressed from a risk assessment standpoint of state-of-the-art literature on Smart Buildings and cloud-computing. However, this research will conduct a risk analysis survey, which will target management-level personnel and identify the worrying level of utilizing different architectural forms of cloud-computing services within different ICT environments.

2.3. Conclusion

This chapter has reviewed interdisciplinary aspects of Smart Building's ICT management techniques in relation to on-demand cloud-computing solutions. Multiple technical and non-technical gaps were identified which suggests that future implementations of ICT management techniques would benefit from a bespoke value assessment decision-making tool. The system will enable non-expert Smart Building managers to measure the extent of cost-efficiency, management feasibility, risk acceptance, and energy saving estimations before purchasing or deploying any sorts of cloud-computing services.

A major conclusion is that various technical and nontechnical issues must be addressed by non-expert managers to ensure cost-efficient and *Green* utilization of such cloud technologies. In essence, the literature review has attempted to connect different areas of discussion related to the main goal of this research: achieving ease-of management, cost minimization, and energy-efficient ICT utilization in Smart Buildings via cloud services. These topics have covered:

- Sustainability Approaches for Smart Buildings
- Market Solutions for Cloud-based Energy Management
- ICT Costs in Buildings and Power Consumption Overview
- Cloud- Computing Business Perspectives
- Decision-making Methods in Smart Buildings
- Decision-Making Intelligence for Cloud-Computing
- Cloud Adoption Risks and Trade-offs

It can be concluded from the review that although a large volume of literature has been published on Smart Buildings' energy-efficient and cost optimization ICT solutions; little has been offered to non-expert management users in terms of effectively analysing needs and taking implementations decisions for rapidly evolving cloud-based technologies. This is essential to assist decision-makers in developing a long-term reliable ICT lifecycle and vision of sustainable management strategies, across different ICT portfolios, where various services are deployed, and delivered by multiple vendors.

The following chapter will examine cloud-computing standards, architectural models, on-demand hosting solutions, and virtual administrative techniques. These will be investigated by adopting a data collection exploratory approach in accordance to selected Smart Building management scenarios and case studies. More, the assessment will conduct a secondary systematic data-analysis which will compare collected data from conventional buildings' ICT requirements and existing control solutions. This theoretical framework will further analyse literature findings with up-to-date price rates of key cloud services supplied by top providers.

The application of cloud-computing affects numerous types of decision-makers where information and data must be appropriately translated and effectively communicated. This research is structured to explore cloud solutions for sustainable ICT management in Smart Buildings for non-expert managers in Smart Buildings.

3.0- Chapter 3: Theoretical Data Analysis

3.1- Introduction

It can be argued that the generic topic of technology management is relevant to all internal ICT requirements within a Smart Building environment. Therefore, proposing a cloud-based solution to manage the entire building's ICT platform must be addressed from multiple technical and non-technical angles. Due to the decision-making standpoint of this research, integrating these structures into the cloud requires a thorough investigation of numerous cloud-computing management concepts. This chapter will explore:

- Non-technical standards and definitions of cloud-computing for non-expert managers: Section (3.2.1)
- Technical analysis of cloud service characteristics: Section (3.2.2)
- Cloud Architectural Models for different Smart Building requirements: Section (3.2.3)
- Hosting and deployment approaches of cloud solutions: Section (3.2.4)
- Energy-efficient aspects of different cloud service characteristics: Section (3.2.5)
- General overview of cloud costs and division of key ICT components involved in any utilization Section: (3.3)

These areas are analysed to determine the degree of long-term management suitability, cost-efficiency and sustainability benefits gained from employing a structured list of cloud services. In addition, the previous points are discussed with reference to different case studies concerning either a single or a network of Smart Buildings. The findings will form a platform for constructing the data collection and experimental work methodology, which is discussed in the next two chapters.

This chapter will adopt several cloud-computing management principles concerning Smart Buildings various applications. This is highlighted in relation to ICT infrastructure to ensure management adequacy, in-house system compatibility, and acceptable budget expediency are achieved. In addition, the inquiry will rely on findings obtained from the

previous literature review, as conclusions will outline examples from different ongoing cloud projects and Smart Building practices.

It is pointed out that the theoretical evaluation will play a significant role in assessing cloud decision-making requisites and performing an in-depth comparison between different presently-identified cloud efficiency measures. While these are being currently researched, designed, and implemented in Smart Buildings, multiple hosting approaches with respect to hybrid, public or private cloud techniques, have not yet been properly standardized as argued in the literature analysis.

The purpose of the above is to assemble a solid platform for designing this study's overall decision-support tool, *SBCE.* This is necessary to ensure that multiple energy-efficiency advantages, budget strategies, and management simplicity attributes are subsequently obtained. This chapter is considered significant for analysing scalable aspects of cloud-associated power and expenses. This eventually allows non-expert managers to identify their organizations' growth and counteraction patterns for ICT hardware and software demands across different time periods, which can be easily adjusted by using the flexibility offered by contracts with cloud providers.

3.2- Cloud-Computing Management Analysis

It was argued by the EU Information Society and Media Commission that current ICTs were observed to cause several management inefficiencies as discussed earlier in Chapter 2, and will be explored further in Chapter 5 through a decision-making risk-analysis survey (Schubert, Jeffery & Neidecker-Lutz, 2010). These are constantly causing non-expert managers difficulties when following pre-defined strategies for the implementation of ICT components in Smart Buildings. While buildings are responsible for nearly 45% of energy capacity in Europe alone, decision-makers were spotted to follow non-standardized management approaches for these components. Although integrating each system into a mutual hosting platform was noted to decrease costs and power usage, readiness factors and precautionary measures were identified across decision-makers as being inadequately

assessed. Yet, facilitating emerging ICTs were debated to ensure valuable benefits towards reaching *Green* management approaches for general organizations.

Cloud-computing services were acknowledged to remove reliance on in-house computing capacity to some extent. This in turn reduces the need for management to plan future ICT strategy, as future needs can be accommodated by altering the contract with cloud-computing providers. Potentially migrated ICT components range from storage servers, networking hardware infrastructure, and other types of integrated systems. However, adopting the previous solution was observed to produce various ICT management trade-offs and service reliability concerns such as unstable service scaling abilities and access control difficulties as will be discussed in Chapter 5. Therefore, prior to any cloud versus traditional model comparison which compares the costs, nature of services, and technical implications of in-house versus cloud services, a conceptual cloud overview must be established within each Smart Building management scenario.

The following will address these points from a Smart Building ICT management perspective. Starting with a cloud-computing critical assessment, secondly, the analysis will carry out an in-depth comparison between different cloud-computing characteristics, architectural types, and deployment models from a Smart Building management perspective. It will also include a systematic investigation of cost in relation to purchase charges, support contracts, Green applications, and administrative attributes. These points will be explored using information from leading cloud-computing providers such as Rackspace, Amazon and others, taking into account market share ratings, level of experience, scope of service dominance, and popularity.

3.2.1 Definition and Standardization

One of the major issues in standardizing cloud-computing is the large range of different purchase standards and technical definitions. Most of these standards are relatively similar in their overall operational context. However, the use of ICT in almost every industry means that cloud-computing has evolved with a variety of standards and principles depending on which field of deployment one is considering (Bernnat, Zink, Bieber &

Strach, 2012). These standards and principles began to be developed in 1999 when Salesforce introduced the first online application (Mohamed, 2010). Consequently, this study has identified a requirement for consistent and universal standardization to aid the implementation of cloud-computing.

A basic definition of cloud-computing for non-expert clients is the use of the Internet for the tasks performed on computers. The Cloud here represents the Internet. The main benefit of cloud-computing to Smart Buildings is that it allows their managers to focus in-house operational efforts on improving internal business procedures and core competencies related to their specific industry, without worrying about purchasing, management, and long-term maintenance of conventional ICTs. This approach follows a flexible and dynamic pay-as-required model, which fits into different Smart Building technical categories where ICT requirements and peak loads are constantly adapting to meet unpredictable demands (Bloom & Gohn, 2012).

Cloud concepts also provide environmental benefits in comparison to traditional ICT implementations as the later require large-scale staff resources, physical space, and energy consumption, whereas adopting a cloud solution provides savings in each of these areas. Furthermore, cloud-computing provides additional benefits as the ICT resources can be altered dynamically to optimize not only cost but also energy usage.

This is particularly true in the case of small-sized buildings, where investments in ICT infrastructure can be a disproportionately large cost. In such circumstances, cloud platforms are deemed to be the optimal solution to avoid costly systems. For example, an ecommerce organization requires large ICT capacity in terms of hosting and networking performance, this is mostly needed during business hours. In addition, another two hours at night are crucial when large amounts of data are being backed-up and archived. If a standard in-house ICT system was adopted, the resources would be idle during most of the work business hours, whereas the use of cloud-computing allows purchasing of resource to match demand. Alternatively, a health care Smart Building will own a relatively small volume of data compared to an ecommerce agency, however a significant privacy concern exist in terms of data security, storage location and other factors. This can be solved by employing either a hybrid or private cloud solution which follows an on-site, virtually managed

hosting method as will be examined in the cloud-computing deployment methods in sub-section 3.2.4.

The discussion above explored various standards of cloud-computing which were offered by different organizations and academics, such as The National Institute of Standards and Technology (NIST) and other leading service providers. The following will now discuss various market-oriented and end-user utility characteristics of cloud-computing. These will be fully illustrated in the next section; however one particular aspect is highlighted at this stage which is considered significant for Smart Buildings ICT decision-making. This feature is called *'Economy of Scale'*, which indicates a distributed manner of computing access and sharing of resources. This cloud characteristic is virtually obtained between independently structured and operated end-user policies. Here, a cost per use model is implemented in that regard in terms of storage administration, server utilization, performance workload deliveries, processing power, networking capacity, and scheduling and designation of policies (Mell & Grance, 2011).

The *Economy of Scale* concept offers a great deal of management flexibility and minimal administration effort in reference to Smart Buildings, as highly integrated and heavily provisioned systems are implemented at the service provider's level of operation. This approach deploys sophisticated algorithms for scheduling, which play a significant role in configuring a distributed loop of end-user resource-sharing policies. These include various utility computing aspects such as virtualization, minimal management effort, elasticity, real-time delivery and on-demand as-you-go purchase. In essence, using the *Economy of Scale* concept of cloud-computing for Smart Building applications was argued to remove capital investments (Buyya, Shin Yeo & Venugopal, 2009).

The following will discuss cloud-computing procedural characteristics, end-user architectural models, and deployment methods respectively. Further, intersected green features concerning decision-making potentials through the utilization of cloud-computing will be explored on a theoretical basis. In particular, each aspect will be examined in contrast to Smart Buildings ICT management pros and cons, case studies on actual spending, performance and additional operational attributes.

3.2.2 Cloud-Computing Procedural Characteristics

Several cloud-computing scientists and organizations have identified different characteristics of a system necessary to support cloud-computing. For instance, according to the NIST definition of cloud-computing concepts, five essential characteristics were necessary: *On-Demand Self Service, Broad Network Access, Resource Pooling, Rapid Elasticity,* and *Measured Services* (Mell & Grance, 2011). In addition, experts from The Cloud Security Alliance have identified a sixth cloud characteristic called *Multi Tenacity* (Brunette & Mogull, 2009), with academics from Melbourne University adding two sub-features, *Autonomic,* and *Economy of Scale* (Broberg, Buyya, & Goscinski, 2011). However, IT specialists have divided the scope of cloud-computing characteristics based on reciprocal aspects of Grid, Cluster, and Cloud platforms (Gong, Liu, Zhang, Chen & Gong, 2010). These were assigned into specialized sub-sections by distinguishing between technical, conceptual, economical, user experience, and other administrative types of virtualized resources, as illustrated in the following table (Table 3.1).

(Table 3.1) Cluster and Grid Model Contrast in relation to Technical, Conceptual, and Economical Domain of Application

Cloud-Computing Characteristic	Grid Interrelation	Domain of Application
User-Service Oriented	Offered	Conceptual
Ease of Use	Limited offering	User Experience
TCP/IP Networked-based	Limited offering	Technical
Business Model	None	Economical
Loose Coupling	Limited offering	Technical
Fault Tolerant	Limited offering	Technical
Virtual Application	Limited offering	Other
Security-Enabled Delivery	Limited offering	Other

Nevertheless, it must be noted that the cloud-computing concept combines aspects from both Cluster and Grid models. While resources in the Cluster platform are available in a singular entity via one scope of administrative procedures, the Grid solution offers distributed resources which can be utilized through several entities, and attained by multiple management specification rules.

From this point forward this research will adopt the standardization specified by NIST. This consists of five essential cloud characteristics listed previously, which can vary depending on different options available for the type of cloud services that a client might choose. This definition was chosen given the complex and various viewpoints relevant to Smart Building applications on cloud service-model features. In addition, ongoing relevant evaluations are expected to play a significant role in supplementing this study's overall cloud decision-making framework in terms of cost efficiency, sustainability, and user service-friendliness.

- **Self-Service**

Non-expert managers of Smart Buildings must acquire a minimum amount of knowledge and basic technical understanding of cloud service-model principles before any decisions are made on purchase or implementation. These can be costly and might require an entire internal system migration of ICT capacity and infrastructure to cloud facilities. On that account, one of the major cloud-computing characteristics is self-service which follows an on-demand**,** pay-as-you-go model.

Cloud-computing services are all available on a network as part of a resource pooling shared platform where users have permission to access and request facilities directly from the network through personal logins. In particular, while cloud ICT resources such as processing capacity, networking bandwidth, or data storage are assigned to the service-requester, several levels of virtualization techniques are utilized to deliver services to end-users (Olive, 2011).

For example, with reference to Smart Buildings' potential service-model methods, VMs (Virtual Machines) are one of the primary solutions for achieving cloud services. VMs provide the user with the ability to run applications and operating systems have the computing ability to run simultaneously via a single device. In addition, VMs offer a hybrid built-in security hosting solution, which relies on a role-assigned access management approach as will be clarified in the later section on cloud deployment (Vmware Website: Private Clouds, 2013). Another potential benefit of virtualization is achieved by adopting a *Platform Pillar* methodology, which is mostly used when an organization is purchasing

cloud services from multiple providers. The *Platform Pillar* technique offers a smooth, coherent and consistent mapping of various needs onto an additional single or multiple cloud components. End-users' access features are offered on-demand and following either a scheduled timetable depending on peak hours and specific large tasks, or by adopting a monthly or annual service-package, whereby each ICT unit is rented exclusively according to constant demands. Each component from the entire scope of cloud services is delivered as a service, which reflects the core definition behind the service-oriented mode of cloud delivery.

In order for this primary characteristic to operate successfully in a Smart Building ICT environment, it is essential to ensure an automated manipulation of any cloud ICT service without the necessity of directly contacting the service provider. This must be accompanied with a 24/7 availability rate, except in the case of agreed schedules of operation. As a result, several technical considerations in relation to hardware support and server uptime levels must be carefully identified before transferring any existing ICT capability to cloud-computing.

The needs of any Smart Building that is wishing to adopt the *Self-Service* characteristic will vary depending on several readiness factors such as size, system workload, and other regulative aspects. For instance, a heavily IT-dependent structure will not initially fully utilize the self-service mode of operation, as the computing, networking, storage capacity, and critical system configuration must be carefully determined by IT administrators depending on changing requirements of large applications (Baker, Gillam & Antonopoulos**,** 2010). Once the required cloud capacity is identified and agreed, the cloud resource can then be applied on-demand with a dynamic changeable capacity in contrast to earlier factors such as organization size and workload.

In terms of energy management, Smart Buildings' non-expert decision-makers can significantly benefit from the *self-service* cloud characteristic by accessing -upon-desire- large energy automation web-based applications. This can provide power usage insights and analytics on equipment control systems, thus allowing users to manipulate the entire building operation depending on data results, which are mainly affiliated with relatively expensive applications. Therefore, renting a cloud-based energy management tool that is

delivered entirely via on-demand services is considered fairly cost-effective regardless of the Smart Building size and operational objectives (Talon, 2013). Additionally, given the ad-hoc virtual accessibility manner that accompanies any cloud-based server, the *self-service* feature is considered more appealing to non-expert managers, especially when the organization consists of an interconnected set of buildings located in various locations.

- **Broad Network Access**

Almost three decades ago, computing services were implemented by connecting terminals in an entire building into a core, singular, and considerably large mainframe device. This process has shifted with time as users began to migrate into a lighter solution by adopting desktop PCs. These two approaches were classified as *Thick* or *Fat Clients* given the solution-oriented package that was supported and run by each device. The *Broad Network Access* characteristic indicates that cloud services empower users with a light, mobile, dynamic, and distributed ability to access requested applications via *Thin Client* appliances (McKenna, 2002). While these range from mobile phones, laptops, to smart PDA screens and I-Pads, the mutual method in accessing cloud-based services is typically carried out through simple internet browsers. Moreover, various manners were introduced in that respect such as virtual desktops, roaming data profiles, and follow-me accounts, (Whittaker, 2011).

It can be argued that *Thick Clients* are comparatively more powerful than *Thin Clients* in terms of end-user friendliness and other aspects given the heterogeneous attributes associated with the latter which greatly depend on the service provider. On the other hand, although cloud-computing has brought back the paradigm of core mainframes, virtualizing the entire operation has resulted in tremendous potentials for scalable high-performance, cost and energy cuts, as well as administration simplicity for Smart Building systems.

In conclusion, the *Broad Network Access* characteristic reflects the method in which services are deployed, accessed, and hosted whether these are software solutions, servers or database engines. In particular, it can be debated that in order for the diverse majority of Smart Buildings to benefit from the broad access feature, a steady, persistent and reliable online connectivity must be guaranteed. Even though these services are mostly attained by

standardized internet mechanisms, reducing the total cost of in-house ICT ownership in the first instance might not always result in cost efficiency in the long-run, with the multiple follow-up aspects investigated in the following chapter.

- **Resource Pooling**

This characteristic of cloud-computing raises a major security concern for Smart Buildings given the shared-resource manner in which both virtual and hardware services are accessed, managed, and hosted by the cloud provider. These services might include memory, server racks, routing capacity, and storage. Cloud providers dynamically employ and assign the same datacentres and ICT capabilities to users by following a *multi-tenant* approach. This means that cloud users do not possess any knowledge or direct control as to where assigned machines and data are deployed and with whom it is being shared (Zhang, Cheng & Boutaba, 2010). Nevertheless, by following different hosting models including private, public and hybrid, there are a few cases where the cloud service requester can acquire a certain amount of information regarding resource location. This is mostly carried out on a higher abstraction domain where the Smart Building operation needs to comply with regulative laws and off-shore data policies towards end-clients.

The *multi-tenant* criterion adopts an *Economy of Scale* method. This means that shared resources include the cost-per-user and other ICT services (Kumar Garg & Buyya, 2012). In parallel, the security threat behind the *Resource Pooling* characteristic is due to service users' doubts and readiness to share the organization's critical data with other unknown cloud users. These other users are potentially direct rivals given the virtual manner in which cloud providers usually organize datacentres. This is mostly carried out by assigning server-groups to companies with similar ICT needs such as Healthcare facilities, Banks, Government buildings, and Stock market firms (Kuyoro**,** Ibikunle & Awodele, 2011). Therefore, several information security professionals have inquired into both novel and old-fashioned measures to minimize threats resulting from adopting cloud-based *Resource Pooling.*

Given the insufficient *Auditability* that is currently observed by datacentre operators (hypervisors) to isolate Virtual Machines (VMs), possible mitigation steps were illustrated in Table (3.2) in relation to different Smart Building ICT functions and data sharing

concerns (Shinder, 2012). These categories will be further examined and assigned to each cloud-computing deployment model in the following section.

(Table 3.2) Mitigation steps for ICT resource pooling in Smart Buildings

Resource Pooling **Associated Implications**	**Smart Building Mitigation Approaches**	**Management Example**
Smart Building's underlying infrastructure (e.g. VMs) is shared with unknown users.	Adopting a Multi-layered hosting approach for further VMs isolation.	vCloud service by VMware: ensuring a trusted, auditable, and hybrid layer 2 isolation, along with RBAC (Role Based Access Control). (VMware vCloud, 2013).
Minimum control over ICT servers, data and core networks.	Service levels agreements (SLA), which increases client involvement (e.g. requesting deployment location specifications at higher levels of abstraction).	Cluster as a Service Technology (Goscinski & Brock, 2010).
VMs do not typically run and communicate via traditional networking/server protocols, thus, traffic listening and data capturing is at stake.	Smart Buildings' system administrators can, to a certain extent, prevent this by employing monitoring tools or cloud-based anti-viruses and IDS (Intrusion Detection Systems), which would sniff traffic and listen to networking ports between different VMs.	Sourcefire, RSA, SNORT, SANS, EMIST, NSRP, and others open-source and commercial IDS
While each purchased end-user application is hosted on a virtual machine by the cloud provider, this particular VM is most likely hosting other dissimilar applications, which could result in security conflicts (e.g. authentication, different capabilities, framework compatibilities, authorization, etc.).	Adding various external Plug-Ins to assist cloud providers with the overall security conflict identification and management. Ergo, cloud hypervisors would reassign service consumers to different VMs depending on resource usage, applications' mutual technical aspects, and optimization objectives.	Hyper-V Pro by Microsoft and DRS by VMware.

Numerous security concerns were observed regarding rented servers and networking bandwidth of cloud tenants' applications.	Enhance automated processes that are mainly in-charge of altering allocation procedures for multi-tenant Cloud services.	These security concerns include unhandled resource re-use and unauthorized services' co-locating, which might occur by tenants sharing the same VM.

The *Resource Pooling* cloud characteristic is not the core focus of this research. However, Smart Building non-expert decision-makers must acquire an overview of potential associated threats, which can further generate issues ranging from privilege escalation to virtualized network abstraction. The latter can result in both unmonitored and unreachable networking bandwidth given hypervisors' data separation between logical and physical layers. Yet, this can be mitigated by preventing VM-to-VM direct traffic, and ensuring a physical device middleware (e.g. switches, routers, etc) (Shinder, 2012). Even though most of these mitigation techniques are practised at the cloud provider's end, managers still must obtain a general comprehension regarding these risks before making decisions to reduce in-house ICT personnel depending on the structure's critical operation, outsourcing feasibility, and sharing admissibility.

- **Elasticity**

This characteristic was considered by many academics as an essential feature for almost all ICT scenarios and sizes of organizations (Voss & Barker & Sommerville, 2013). In essence, *Elasticity* is defined as a rapid, flexible and user-provisioned ability to achieve dynamic scaling and automated alteration concerning purchased cloud services in accordance to in-house resource utilization. After examining the *Resource Pooling* feature allows cloud users to request ICT resources from an automatically managed and virtually hosted shared pool, these resources are procured, employed, and finally released to the same pool of services for other users to access. This pre-defined and automated policy forms the core concept of the *Elasticity* characteristic, which allows users to begin the service acquisition process. Further, users can scale cloud services –up or down- depending on QoS demands and budget, while disbanding no-more-needed resources into the shared-pool for others to access (Orzel & Becker, 2012).

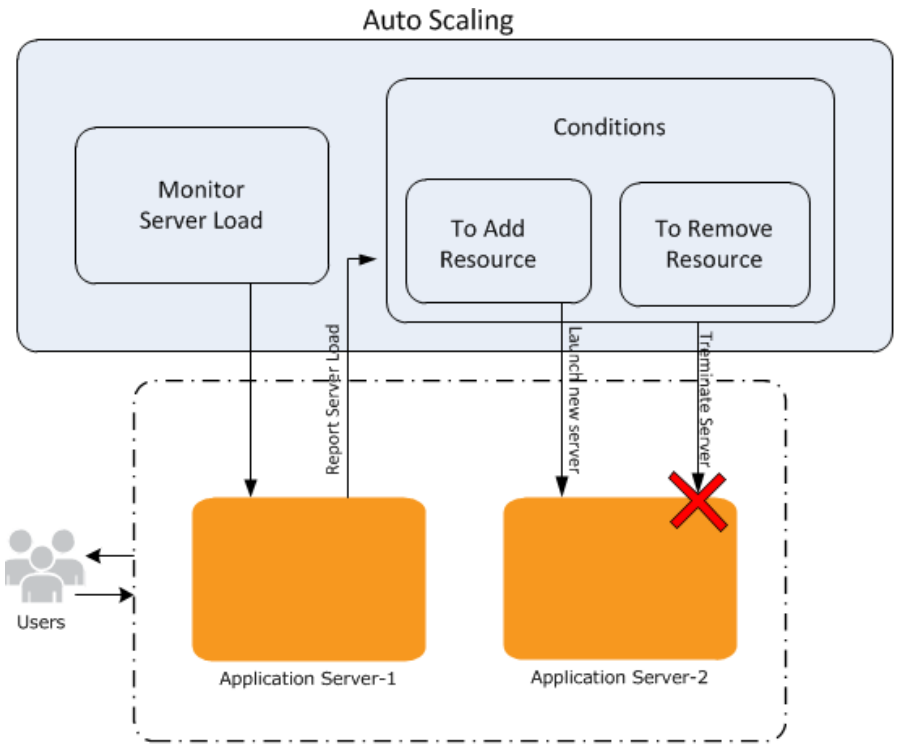
Hosted ICT services within a Smart Building might require instant scaling in accordance with peak hours, network spikes, and other sudden or planned changes of requirements. As mentioned in the introduction chapter, a Smart Building that includes approximately one thousand IT-dependent users would generally require unsteady computing capacity, access to applications, designated memory, and networking bandwidth. In addition to standard uses, other unsteady demands will depend on tasks which are usually performed on a pre-scheduled basis such as:

- Data backup operations
- Threat detection
- Virus scanning
- Policy monitoring
- Centralized heavy back-ups
- Crunching large volumes of data
- Disaster recovery upgrades
- Regulation compliance
- System migration

Similar ICT-burdened procedures require a bigger processing capacity than what most in-house platforms can offer. Most cloud providers offer services that can be scaled either automatically or manually without the need to directly contact the cloud provider. This widely reflects the *Rapid Response* key attribute of the *Elasticity* characteristic as will be analysed further in contrast to costs, sustainability, and performance of different Smart Building case studies.

The automatic scaling aspect is significant to this study's overall decision-making tool on several ICT management levels. In simple words, this characteristic indicates that even non-expert managers can perform cloud scaling depending on unanticipated peak loads or on a pre-planned basis with the cloud provider (Fronckowiak, 2008). For instance, deciding when to scale, and to what extent, ensures maintaining the cost-efficient and sustainable benefits gained from cloud-computing. While this is considered the heart of any cloud management process, these decisions range from determining whether to increase, decrease, update or delete levels of computing capacity, number of servers, availability periods, and bandwidth rates. In addition, providing application access at selected times for users in a particular organization are also an important part in the previous process. For

example, one of the state-of-the-art automatic scaling services, which offer both scriptable and GUI scaling administration features, is the *Cloud-Watch*, provided by Amazon's *EC2* and *Scalr* services (Figure 3.1).



(Figure 3.1) Amazon Auto Scaling Example. **Source:** Amazon Web Services. (2015). "What is Auto Scaling?". Auto Scaling Docs: Developer Guide

Although cloud scaling is a relatively large topic from a technical perspective, the purpose of this section is only to explore management principles of cloud-computing utilization from a Smart Building ICT decision-making viewpoint. On that note, new scaling features are constantly being offered by top cloud providers. These offer dynamic services and allow end-users to automatically launch configurations regarding any specific cloud instance in the organization. Examples of such scaling services include:

- Grouping ICT components
- Suspending and resuming processes
- Updating previous actions
- Executing and terminating policies

- Adding notifications for further support and maintenance

Various potential concerns that could accompany the *Elasticity* characteristic were researched from a cloud provider point of view. These are mostly associated with impacts from repeated requests sent by end-users to acquire or scale already captured cloud services from the provider's shared-pool. Other security threats were pointed out which are related to authentication processes with other Smart Building users, as this could be linked to any of the service requesters involved, and especially in the case of multiple branches of the same organization. Moreover, while monitoring procedures are considered significant, any cloud provider needs to guarantee that resources are scanned, cleaned-up, and reviewed each time a Smart Building consumer dumps a used component back to the shared-pool (Shinder, 2012).

It was argued by several cloud providers that if a single cloud user does not perform consistent and appropriate in-house management of ICT resources, this can potentially put cloud resources for other users at risk (Zhang, Cheng & Boutaba, 2010). In particular, in addition to the lack of in-house resource management, this can also occur as a result of the insufficient identification of in-house requirements, and improper configuration of cloud resources which is usually configured by end-users through web control panels. Another reason for this to occur is when a specific user with a large bandwidth, requests a large amount of cloud resources at a short amount of time. This can cause reliability and confidentiality issues in the service delivery process if the cloud provider's ICT infrastructure was not designed or tested properly to handle such requests.

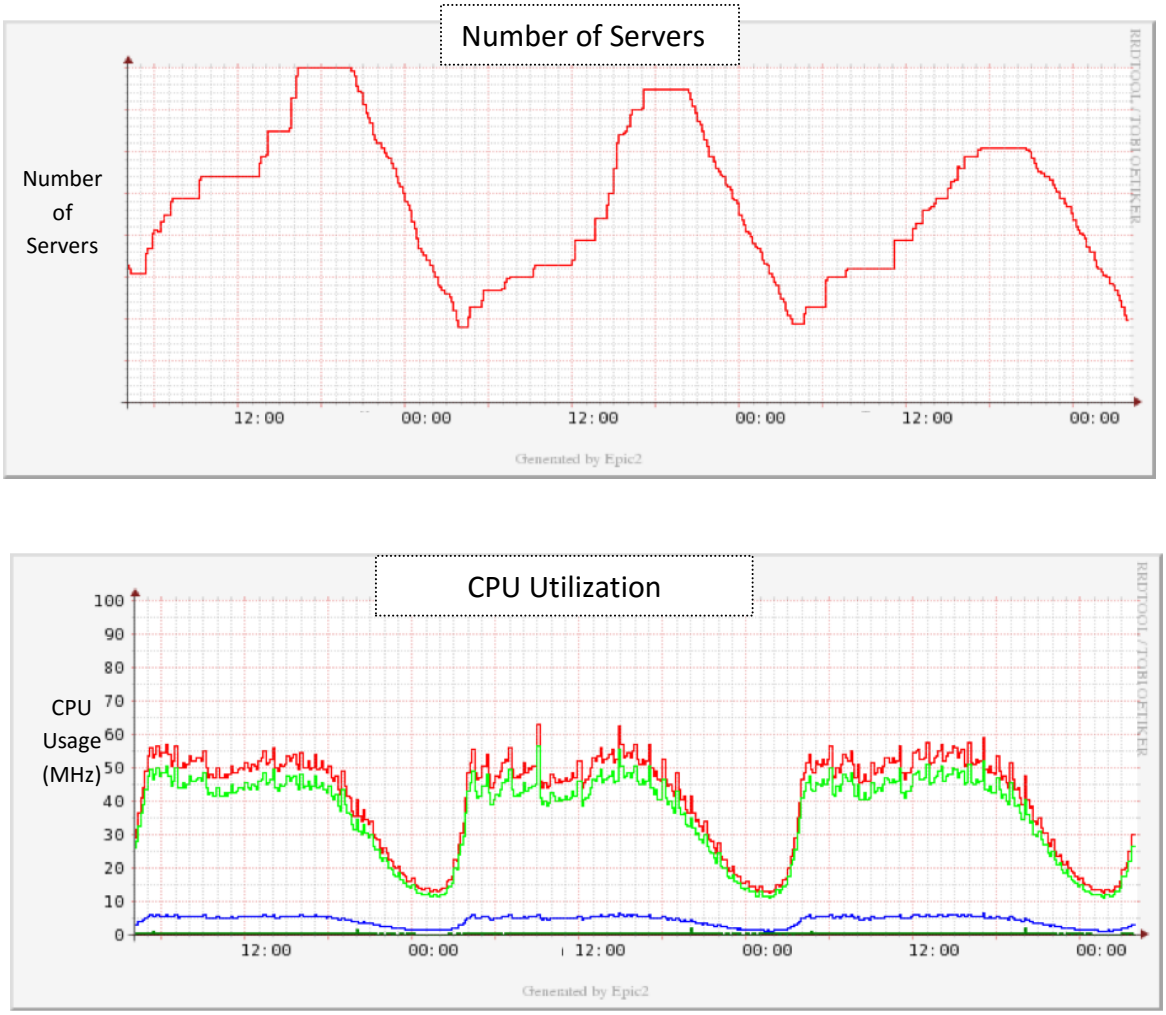
The following will discuss an auto scaling example to illustrate the various potential benefits. System administrators at Netflix were outsourcing the entire ICT infrastructure into Amazon's EC2 cloud for the past two years (Orzel & Becker, 2012). This project was considered a complex one given several preliminary detailed tasks, which included the following:

- Identification of potentially migrated components such as CPU, storage, bandwidth, etc.

- Policy configuration and definition in order to track down profile changes in relation to all shared resources, thus, configure subsequent actions (e.g. CPU capacity utilization).
- Other general migration analysis and decision-making work related to in-house support and tracking of cloud resources, which was administered by Netflix via Amazon. This was achieved through Amazon's *Cloud-Watch* tool, which offers monitoring and tracking of cloud resources by tracking the associated system metrics responsible for any changes in cost, system health, running of applications, and log files.

Overall, according to the aforementioned reference, ICT costs at Netflix have decreased ever since auto scaling was initially practised in 2010. This was measured by applying two basic scripting tools: a *Cloud-Watch* automated monitoring library for resource export metrics; and a Netflix built-in tool, which controls the entire migrated infrastructure. The following figure demonstrates two-day scaled Netflix traffic via *EPIC2* graphics in contrast to cloud servers and the total-sum CPU capacity employed to support aggregate traffic (Figure 3.2)

The reason behind presenting the Netflix example is to illustrate the significant management value attained from monitoring and testing the running behaviour of auto-scaled cloud resources in Smart Buildings. In particular, non-expert decision-makers can save money by scaling resources -up or down- in the right time given the crowded shared-pool of cloud resources.



(Figure 3.2) Two-Day Netflix Traffic: Illustrating the Demand for Auto Scaling (Orzel & Becker, 2012).

Several recommendations were acknowledged from the previous Netflix example that would help managers to reach cost-efficient cloud utilization. Firstly, it was suggested that non-expert managers should scale down at a slower pace in contrast to scaling up, which would minimize the possibility of unintentionally eliminating much needed resources. However, scaling up was implied to be more effective when performed in an early manner. This can be achieved by configuring the *Cloud-Watch* Alarm to scale-up at 75% of targeted threshold, with a 25% room for unpredictable peak for requests, in addition to CPU start-up loss due to failed instances.

- **Measured Services**

In order for a Smart Building ICT management to operate efficiently, a certain level of transparency must be attained between the service provider and the requester. In theory, cloud-computing services are offered simultaneously to a large number of users, which makes the reporting, logging, monitoring, and tracking of use, a complex management task in terms of resources' types and usage (Brunette & Mogull, 2009). Accordingly, cloud-hosted services are typically run through a metering solution, which provides a dynamic, variable, and automatic process for accurate service measuring.

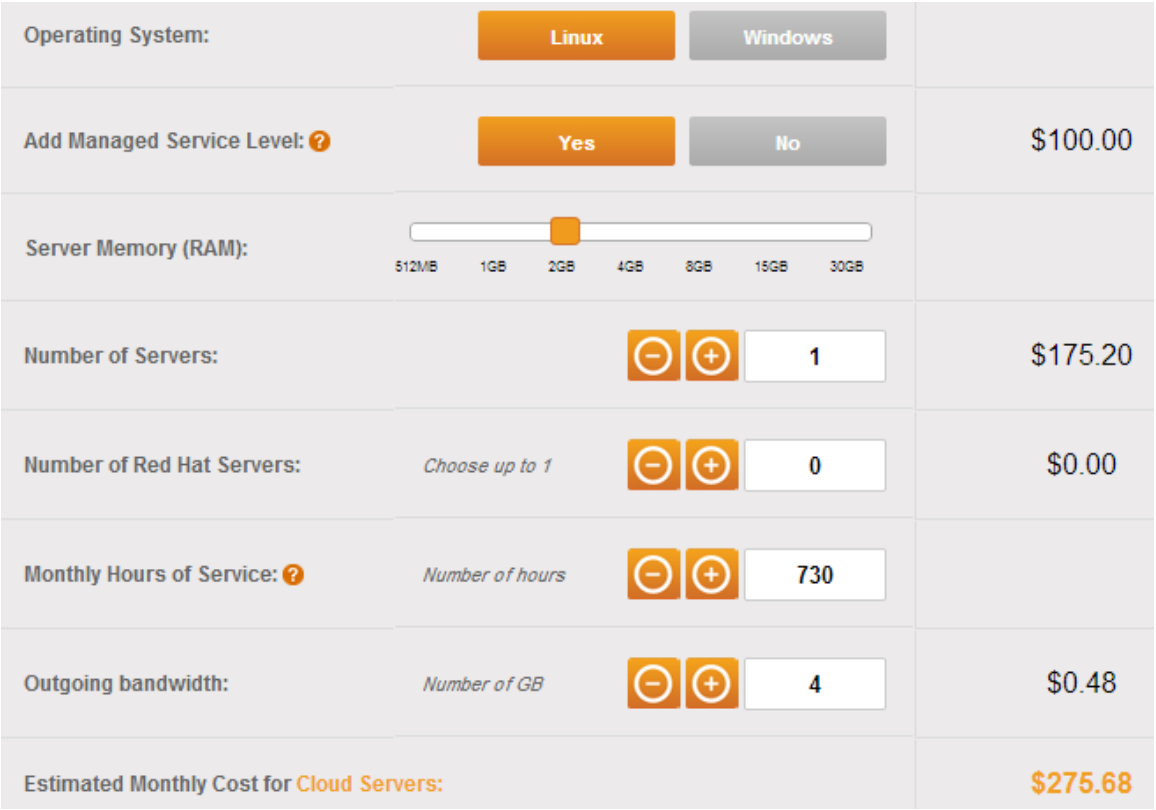
There are however instances where metering is inappropriate, for example, a Smart Building may require constant access to a specific energy analytics application. Although this software is virtually-hosted due to its high purchase cost and other requirements like maintenance and support, metered-based charges are in this case considered inefficient for long-term utilization.

As an example of the cloud-computing Measured Service characteristic, several tools were introduced by the top providers, which provide an online user-friendly solution that calculates cloud instances cost and measure the associated requirements. Some of the top tools currently in the ICT market are:

- Google Cloud Platform Pricing Calculator
- Amazon EC2 Simple Monthly Calculator
- Rackspace Cloud Cost Calculator
- IBM Silverpop Revenue Pipeline Calculator

The Rackspace Cloud Cost Calculator will be demonstrated below as an example of an online price estimation tool. This study calculated the cost of a cloud server with a Linux platform, RAM memory of 2 GB, a Red Hat operating system, outgoing bandwidth of 5 GB, and a 24/7 monitoring with a managed level of infrastructure layered support. All the above was estimated to incur a monthly charge of $275.68 (Figure 3.3). This cost was estimated with the exclusion of any additional cloud instances which might be required in a real life environment depending on the work nature of the Smart Building. These instances can range from cloud files, load balancers or bandwidth connection. While the previous estimation is only attempting to highlight the cost efficiency factor of cloud computing, other technical and sustainability leverages can potentially be gained from deploying the

previous range of cloud instances. Accordingly, non-expert decision-makers must analyse all cloud requirements in terms of performance, energy savings, and long-term costs prior to any implementation as will be further demonstrated.



(Figure 3.3) Cloud Calculator Measured Service Example Generated from: Rackspace Cloud Cost Calculator, 2015.

Various web-pricing tools and theoretical frameworks were designed and introduced into the cloud industry as previously listed, such as Amazon's Elastic Compute Cloud (EC2) which operates via a monthly measurement tool: *On-Demand Instant Price Calculator.* In addition, other cost-estimation tools such as the *Evolutionary Bioinformatics* generic framework have targeted comparative roundup methods to guarantee maximum cloud utilization at minimal expenditure (Kudtarkar, DeLuca, & Wall, 2010).

As discussed in the literature review chapter and as will be explored further in Chapter 5, it can be argued that in many cases, running some of the essential applications of a Smart Building ICT environment on a cloud-hosted platform is more cost-efficient than following a conventional ICT approach. However, as will be discussed later in sub-section (3.3), in

few unique cases a cloud deployment can be more costly than the conventional approach. Typically, the cloud Measured Service characteristic pricing approach requires managers to pay either a monthly or an annual fee to the provider, in return for hosting services, an agreed level of control over resources, and support.

Cloud-computing pricing tools and business value methods will be further investigated following an analysis of Smart Building general ICT spending and management compatibilities. Non-expert decision-makers must comprehend the *Metered Service* characteristic by thoroughly analysing internal ICT requirements. It is also suggested that managers should request a detailed billing report from the cloud provider to identify how resource consumption is measured, charged, and delivered.

While the pay-as-you-go model usually follows pay-per-hour, per-server, per-GB or other sorts of resource acquisition, Smart Building managers should internally determine the most appropriate types of purchase and payment methods to be applied with the provider before entering into a contract (Gong, Liu, Zhang, Chen & Gong, 2010). If the billing method was not selected carefully, cloud utilization might end up being more costly and energy-inefficient in the long run. Moreover, this would negatively influence the portfolio's administrative attributes, spending policies, integration with other systems, and end-user accessibility times and spikes.

Potential cloud-resource billing problems can be thought of as similar to leaving the lighting switched on in a Smart Building after no one is around, or the water running without being used. In particular, metered facilities will still be charged for even when they are not being utilized. Therefore, it can be noted that a considerable amount of administrative attention must be paid to properly analysing the buildings needs in relation to metered facilities. If this is neglected, managing the entire cloud solution might become a complex management task which greatly contradicts the ease-of-management leverage to be gained from ICT virtualization. Nevertheless, this can be enhanced and mitigated by using a cloud decision-support system which can transparently identify users' critical requirements, by establishing a resource measurement comparison between Smart Buildings' assumed ICT needs on one hand, and actual optimized demands on the other.

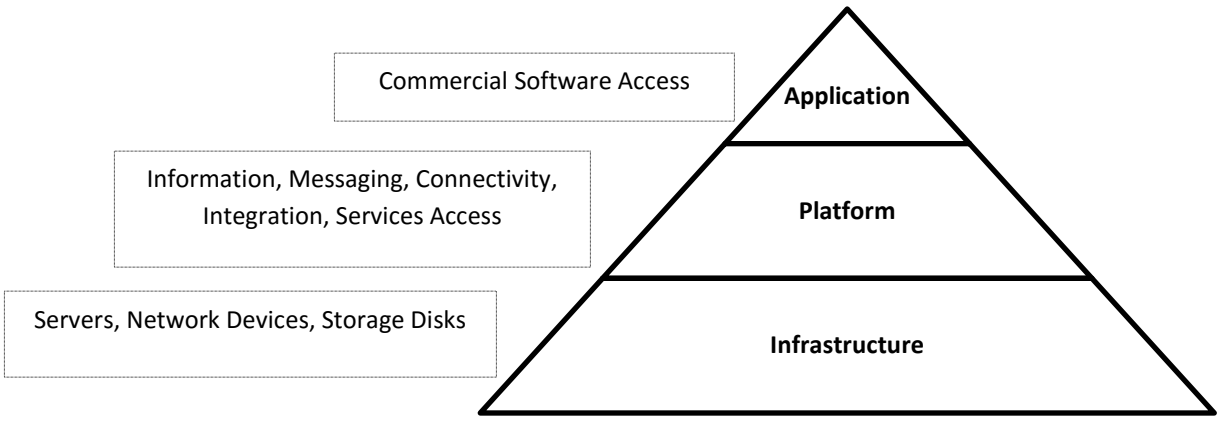
This gap was highlighted by this research and put forth as one of the objectives for building this study's cloud decision-making tool: SBCE (Smart Building Cloud Evaluator).

Cloud-computing scaling tools are constantly emerging as a result of the high demands recently displayed by managers who seek more control over cloud resources in addition to obtaining cost efficient solutions. As a result, ICT providers are constantly exploring new areas of cloud scaling abilities in order to reduce management efforts by the end-users, and maintain a convenient cost measuring structure at the same time (Vaquero, Rodero-Merino, Caceres & Lindner, 2008).

3.2.3 End-user Architectural Models

This study approached the subject of cloud service models in Table (2.6) in the Literature Review chapter by highlighting different Smart Building management techniques and associated concerns. The discussion was briefly introduced in terms of previous publications on technical descriptions, top providers examples, security concerns, and brief case studies for ICT-dependent environments. The following will further elaborate on cloud end-user architectural models in relation to the pros and cons of each, implementation and purchase methods, additional expenses, and management readiness.

The overall cloud-computing stack consists of three main interdependent layers (Figure 3.4). These include: the application, the development platform, and the heterogeneous infrastructure which forms a solid base for customizing all the above.



(Figure 3.4) Cloud-Computing three Interdependent Architectural Layers

The main cloud service approach was divided respectively into Infrastructure as a Service IaaS, Platform as a Service PaaS, and Software as a Service SaaS. However, numerous separate models have also been introduced such as Database as a service (DaaS), Cluster as a Service (CaaS), Network as a Service (NaaS), and Policy Management as a Service (PMaaS). As previously established, the three main models represent the primary focus of this research in order to acquire a scalable, sustainable, and cost-efficient solution for Smart Building ICT management.

- **Infrastructure as a Service IaaS**

The IaaS model provides end-users with the backbone computing infrastructure that is essential for internal application hosting, operating systems, software component management, and deployment. These resources include hardware machines, virtual PCs, or a combination of both. In addition, the IaaS scope covers on-demand processing units for specified capacity and networking bandwidth for switching, routing, and other data sharing functions, clusters, and physical storage (Brunette & Mogull, 2009). For example, Smart Buildings that represent health care facilities, airports, or shopping malls, are recommended by cloud engineers to adopt the IaaS solution given many up-front cost and technical abilities, which allow in-house IT administrators to select the appropriate number of virtual machines and install privately owned applications. Although controlling these tools is carried out to a limited extent by in-house personnel, only a minimum amount of administration is allowed in reference to the underlying cloud platform. This usually includes networking software units like deployed firewalls and other routing tools (Goscinski & Brock, 2010).

The Infrastructure as a Service model follows a raw delivery concept which is used in services from top providers such as Amazon's EC2, and GoGrid. This is considered the lowest abstraction level in the cloud hierarchy structure. In addition, the virtualized management of ICT components provides non-expert Smart Building managers with a high degree of implementation simplicity, as there is no need to perform full and complicated system installation procedures, which involve complex administrative decisions and in-house maintenance. Furthermore, the money spent on purchasing such systems is greatly reduced as computing resources are virtually rented, managed and supported according to

actual needs (The Cloud Scaling Group, 2011). Charges are delivered either monthly, annually, or depending on actual service consumption, definition, and agreed terms of measurement.

It can be stated that the majority of today's Smart Buildings require complex and costly ICT resources that burden the overall technology management process. While this is by default added to the entire building control framework, it includes systems such as HVAC, CCTVs, energy sensors, and various measuring devices regardless of the organizational nature and operational objectives. Therefore, the IaaS model is generally considered an efficient way to implement cloud-computing services. Yet, this is argued whilst maintaining a certain level of in-house control over virtually utilized resources. This efficiency factor not only covers purchase expenses as the IaaS also alleviates additional management efforts along with energy consumed on cooling and other ICT associated tasks. In particular, several cloud providers like *Commensus,* offer a hybrid console solution called *vCloud*, which enables IT managers to integrate existing systems with newly added virtual ones via an agile, user-friendly desktop interface (Commensus Website, 2013).

From a Smart Building perspective, it can be noted that the IaaS approach is the key element behind ICT migration and efficient management, especially when end-users utilize a relatively large-scale portfolio. While good performance in terms of speed and maintenance was acknowledged as a major aspect of IaaS, it was observed by various cloud users that incompatible availability and unstable performance lifecycle had occurred on frequent occasions from utilizing IaaS features. In addition, numerous studies have taken on performance benchmarking, challenges, and value analysis in relation to IaaS purchase and implementation. For example, some publications have highlighted several system procurement aspects of the IaaS general performance concerning cloud middleware benchmarking and evaluation (Iosup, Prodan & Epema, 2012). Particularly, a non-functional analysis was carried out in accordance to multiple industry-based principles, which reflect essential decision-making considerations for Smart Building non-expert managers.

IaaS challenges concerning benchmarking and performance standards can be identified in reference to Smart Buildings' workload, system metrics, and management properties on various levels. These considerations include:

- Legal jurisdiction and level-of-trust issues regarding identifying shared stakeholders
- Cloud resource infiltration between different rival organizations
- Insufficient governance
- Re-requisition of purchased features (Hay, Nance & Bishop, 2011).

Potential solutions were recommended by top cloud providers like Rackspace and Google to add data encryption, malware detection, and other vulnerability assessment tools. These were introduced through communication channels between end-users' in-house ICT infrastructure and providers' virtual machines. In particular, similar solutions were highlighted for a set of interconnected and differently-located Smart Buildings where large volumes of data are shared, accessed, integrated, and altered on a daily basis.

Recommendations suggested that if Smart Buildings were to apply IaaS features, a major consideration must be established for specifying employees' permissions to forbid access, manipulate user details, and setup new cloud accounts (McKendrick, 2012). These situations were expected to occur due to fragile policy identification between cloud providers and consumers.

Nevertheless, given that IaaS resources are located at the bottom of all cloud service models (Figure 3.4), these features form a fundamental platform for both PaaS and SaaS multi-tenant services. Therefore, examples of IaaS users cover almost all types of industries in relation to size, workload, nature of business, and international branches. For example, relatively large Smart Buildings often tend to maintain as much *on-premises* control as possible over ICT infrastructures, while simultaneously lever from virtualized services that essentially eliminate ICT purchase costs and personnel staffing.

It can be concluded that decision-makers only employ the IaaS model when the intention is to acquire a virtual, billing-oriented and as-needed infrastructure. While this covers networking, computational, and storage components, it consequently allows managers to integrate with existing applications and legacy platforms. It must be noted that IaaS users

are typically divided into *Private* and *Public* service requesters, as will be elaborated next in the deployment sub-section. Overall, gaining more administrative and technical control over both cloud-based and in-house ICT components will result in a wider range of flexibility within Smart Building ICT environments. These are usually associated to database engines, networked operating systems (NOS), and VMs (Massimo, 2010). While this was observed to increase management overheads, a higher transparent transformation is attained from adopting the IaaS model, which was agreed as cost-efficient in sizable organizations.

- **Platform as a Service PaaS**

The PaaS model comes directly above the IaaS layer. While it includes both technical aspects from the latter, the main goal from PaaS is to virtually provide a larger scope of ICT features, which is essentially utilized as a development environment for specialized software. In particular, the PaaS model is designed for end-users to develop, compile, and run applications via IaaS virtual machines. Moreover, in reference to potential PaaS users from Smart Buildings, this group would involve to a considerable degree specialized ICT and business organizations requirements.

These were observed to cover ecommerce database providers and software development companies who already possess a high knowledge of code and programming languages, yet, neither have the ability nor the proper budget to purchase these development platforms and install them in-house. On the other hand, other non-technical firms such as business knowledge experts, project management, eStrategy and eMarketing providers who also seek to develop consumer-created applications, are included in the PaaS scope of potential users. These however do not necessarily acquire coding expertise as well as other technical deployment aspects. In this account, IaaS services have the ability to provide a suitable environment for developing software via higher levels of abstraction while following pure business logics (Subramanian, 2010).

One of the main challenges in adopting PaaS services is information integrity and encryption. Each data record is recommended to undergo repeated encryptions through digital signature functions before being sent to the cloud provider. This would largely result

in CPU bottle-neck and speed reduction in relation to in-house servers and networking infrastructure. Nevertheless, this can be solved by applying certain sorting functions that encrypt important pieces of data such as users' critical information, healthcare records, and banking details (McKendrick, 2012).

The decision-making task of assessing whether to employ virtual platform services over the cloud, or not, is usually performed by ICT managers in the Smart Building, and not by non-expert managers alone. However, decision-support systems can to some extent empower non-experts to measure the degree of cost and power efficiency obtained from applying PaaS, which is one of the goals of *SBCE* as will be discussed in Chapter 6.

It must be noted that PaaS features only ensure a minimum amount of underlying flexibility in addition to medium management savings. However, end-users are enabled with restricted control abilities, which merely cover in-house developed applications and associated data (Kuyoro**,** Ibikunle & Awodele, 2011). Accordingly, potential options for the PaaS migration process can be summed up through the following scenarios:

- Migrating to the cloud: to ensure compatibilities with in-house development platforms
- Migrating in the cloud: for additional hosting procedures or ad-hoc deployments within the PaaS infrastructure
- Migrating from the cloud: for system backtracking for internal software deployment, which is often subsequent to cloud-based development
- Migrating out of the cloud: such as relying on in-house development platforms after unsuccessful PaaS migration

PaaS providers range from medium-sized software companies which operate on pure coding and programming environments, to well-known ICT giants such as Microsoft Azure, VMforce and Google App-Engine. This model was argued by these providers as the future of information systems (Hölzle, 2014). Nevertheless, protecting the Smart Building private information in a way that erases all potential audit trails, protects API keys, and maintains both confidentiality and integrity throughout various development processes, is still an ongoing research matter.

Platform cloud services are mostly used by companies that develop ICT software which require unstable ICT requirements in terms of the programming platforms, bandwidth capacity, and processing power. These organizations also adopt PaaS solutions to ensure that their business objectives are met in terms of cutting down ICT costs, reducing management processes, and reducing ICT-related power consumption.

PaaS cloud providers allow users to control development platforms on a middleware level. This is accomplished through a higher abstraction level, which essentially distinguishes PaaS from IaaS services. In addition, it determines the general performance employed in compiling the programming code in terms of QoS levels, runtime, and APIs' scalability agreements between PaaS users and providers (Rymer, 2010). Similarly, this was tested to reduce costs, time spent, and risks in relation to frequent upgrade purchase and availability check-ups, while subsequently concentrating internal efforts on concrete application development. Although the PaaS approach does not occupy a major part of this research, several principles will be examined in the next chapter across different academic interviews and other data collection.

- **Software as a Service SaaS**

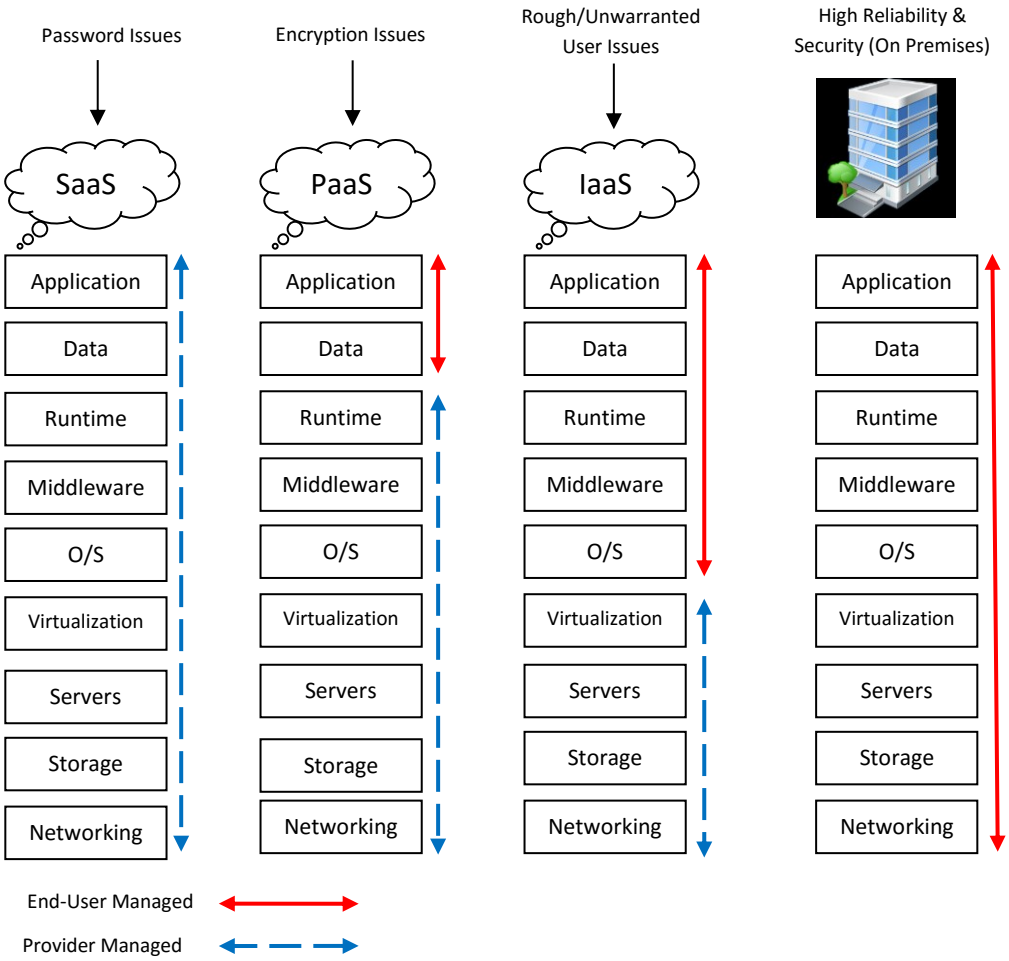
The Software as a Service model is located at the top of the cloud hierarchy layers. In principle, end-users rent out access to certain cloud-hosted applications according to:

- On-demand availability periods,
- Number of users,
- QoS attributes,
- Mobile vs. fixed profiling,
- Other administrative aspects.

In order to ensure cost-efficiency and long-term management simplicity, these points must be clearly defined by both Smart Building managers on one hand and cloud providers on the other. While the SaaS model is entirely controlled by the cloud provider, service consumers do not possess any management flexibility with built-in, virtually managed, and fully integrated cloud applications. Nevertheless, only limited abilities in terms of basic configuration manipulation is within reach by cloud end-users.

SaaS solutions such as Google Apps, DropBox, Yahoo mails, and Sales-Force, are mainly utilized by business companies for optimization purposes in relation to Enterprise resource planning (ERP), Customer relationship management (CRM), and Stock management. This approach is considered the most common cloud solution in terms of simplicity, speed of implementation, usage regulations, capacity alteration, upfront expenses, upgrades and maintenance. In addition, SaaS features offer a key sustainable factor as it limits users' access to cloud applications to a simple interface of thin-client middleware. Whereas these range from either internet browsers or other remote desktop tools, overall management overheads and power consumption averages are significantly decreased in this context.

In relation to cloud utilization decision-making, the following figure was assembled to demonstrate different levels of control that end-users can acquire across the previous three cloud service models. This is illustrated in accordance with key cloud components, which are either managed by the service provider or requester (Figure 3.5). The diagram shows the separation of responsibilities, security appropriate methods and other outsourcing readiness aspects which can vary depending on various ICT objectives of different Smart Buildings.



(Figure 3.5) ICT Components: Division of Management Responsibilities between on-premises (Smart Buildings) vs. cloud providers. Reconstructed from: (Bort, 2013).

- **Conclusion**

According to the Cloud Security Alliance, IaaS was considered the core platform of all cloud-computing services (Brunette & Mogull, 2009). Each cloud provider was following both a unique in-house technical agenda and a layering methodology when it comes to the actual delivery and definition of cloud service models. This has resulted in issues regarding standardizing the cloud as highlighted earlier in the Literature Review chapter. Therefore, non-expert managers have a critical quantifying task of validating the entire scope of available selections, alternative options, potential risks accompanied with each, and growth/decline lifecycle scenarios.

Certain cloud providers have offered few other architectural forms regarding certain bespoke user objectives such as Data as a Service (DaaS), Identity and Police Management as a Service (IPMaaS), and Network as a Service (NaaS). It can be concluded from previous publications that until now Smart Building ICT management have not had a consensus on identifying the most favourable cloud service model. This is mainly because of the dissimilar operational types of portfolios and existing contracts with many external ICT providers.

The previous three core types of cloud service models were analysed according to the definition by *The US National Institute of Standards and Technology 'NIST'.* Further, the technical extent of in-house Smart Building participation in managing cloud-based resources internally, can be concluded as the key factor towards minimizing long-term expenditure, energy consumption, improving user experience (UX), and service-friendliness (Bates, 2010). In addition, multiple compliance and regulation issues form another key consideration for Smart Building non-expert managers to ensure effective cloud purchase. While several features might appear attractive and cost-efficient at first sight, the built-in operational nature of the highlighted Smart Building could prove otherwise after deployment. This can be in response to rooted government considerations, real-life correspondence with end-users' needs, ICT laws' concurrence, and compatibility with conventional methods of computing and networking systems.

3.2.4 Cloud-Computing Deployment Methods

Cloud hosting preferences are essential to this study's core objective of identifying cost-efficient, sustainable, and scalable cloud utilization for different Smart Buildings. This predominantly addresses either a single structure or a networked set of distinctly located Smart Buildings. The following will elaborate on each deployment criterion by taking into account various Smart Building ICT management viewpoints.

In reference to NIST, three different hosting models were highlighted: *Public*, *Private*, and *Hybrid*. However, this section will argue for an additional deployment method called *Community*, which is a sub-set of the Private model as clarified next.

The exclusive range of risks, benefits and administrative efforts associated with each category, which impact Smart Buildings' ICT environments on multiple decision-making standards, are discussed below.

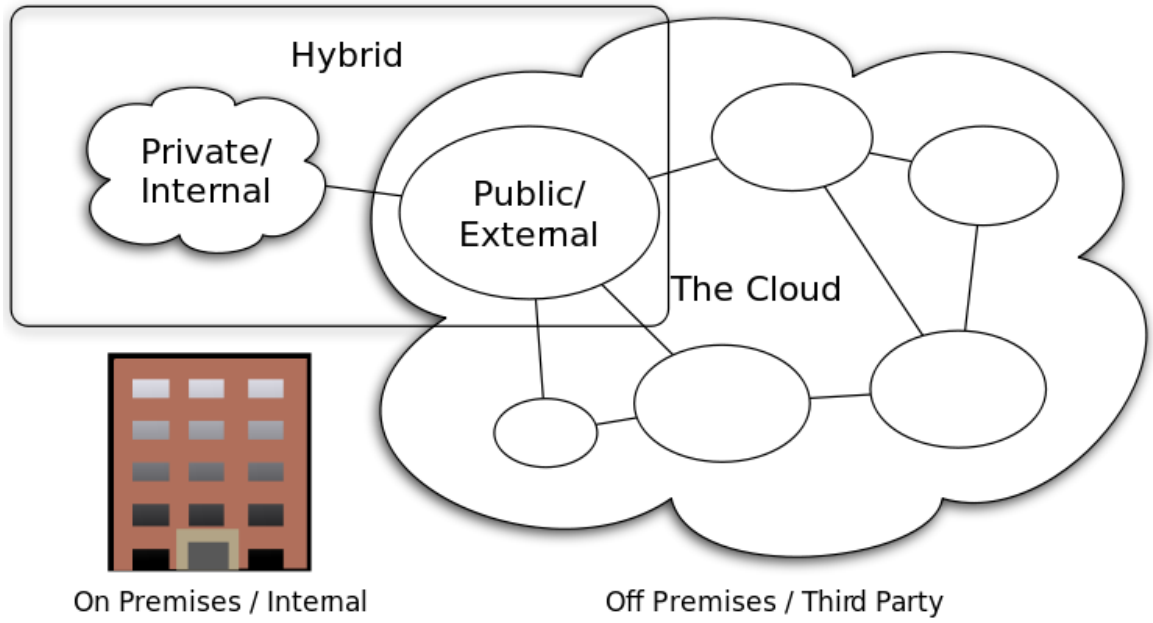
- **Public**

Public clouds are infrastructures made available for general users to purchase, access, utilize, and log-off. While this is mostly performed via simple internet means, the on-demand pool of shared ICT resources is offered by cloud providers which host computing, networking, and physical data storage services through large, high-speed datacentres. Moreover, deploying public clouds is to some extent considered the easiest method, as Smart Buildings can minimize almost the entire on-premises ICT infrastructure. However, relying massively on virtual solutions has several pros and cons in terms of access mobility, flexibility in upgrades, system migration, and other technology management aspects (Figure 3.6).

Public cloud services such as Amazon EC2, Microsoft Azure and others are made 24/7 available and delivered to thousands of online users. Whether these are individuals, middle-sized organizations or other types of buildings, public cloud-computing components include all types of service models (*IaaS*, *PaaS*, and *SaaS)* given the provider large-scale, sophisticated, and heavy duty servers and networking bandwidth. Yet, adopting this hosting approach causes a key issue in relation to resource monitoring, portioning, users' allocation, and usage benchmarking. This was highlighted as a key challenge for public cloud providers for providing accurate billing, support, and an automated history of log-ins and other reporting requests (Ragan, 2012). On that note, Smart Building non-expert decision-makers must carefully consider all associated privacy and shared access trade-offs, particularly the ones discussed in the *Multi tenancy* cloud characteristic, given the underlying significant connection established through the employment of public clouds.

The public deployment model was noted to be most effective for relatively small-sized Smart Buildings. This was argued given that associated features of pay-as-you-use, multi-tenancy, and peak period management would reduce ICT purchase and maintenance expenses that constantly form a major growth challenge to this range of users. On the other

hand, medium-sized and largely staffed organizations might prefer much more reliable and security dependent hosting solutions.



(Figure 3.6) Cloud-computing Deployment Models. (BizCloud, 2010).

- **Private**

Deploying privately owned cloud services does not indicate that the highlighted Smart Building will solely install virtual machines on-premises. However, the ICT infrastructure in this model can either be internally hosted through different methods, or externally, using the cloud provider's datacentre. Nevertheless, all rented components are strictly utilized to a specific end-user, and via previously agreed contracts. These are defined mutually by following a structured step-by-step process to determine how usage is measured, delivered, and supported (Foxwell, Born & Venkataraman, 2012). Furthermore, the management of cloud resources in this approach can either be handed to end-users, or to a third party regardless of the hosting end-destination.

In the case of in-house cloud control, the provider is only in-charge of implementing virtual machines on-site, in addition to support and upgrade agreements. While these might be performed monthly or annually according to the consumer's desire, providing additional itemized and on-demand PaaS or SaaS deliveries, is always specified depending on users'

requirements and via service-oriented packages. Moreover, private clouds have often been named *Enterprise Clouds* given the individual ownership and management by a single organization, where multiple locations and branches are also supported. However, overall risks associated with this model were debated as quite similar to those in public clouds. In particular, several barriers were noted in comparison to the seamlessly utilized public cloud solution (Adler, 2012), such as:

- Elastic scaling inabilities: as in some cases users will find it difficult to automate and perform scaling of resources (up or down) in real time.
- Lower dynamic abilities with respect to on-demand adjustments
- Rapid response limitations when purchasing additional virtual machines for user expanding purposes (e.g. In private clouds, installing new VMs would be carried out at a slower pace in contrast to public clouds where this can be configured almost instantly).

Multiple scenarios of Smart Building ICT management have recommended the employment of private in-house clouds by adopting top providers' solutions such as VMware, Net-App or Cisco devices. These are widely related to critical cases of Smart Buildings such as healthcare centres where a major privacy concern is raised towards medical records whereabouts, supervision and data storage.

- **Community**

Smart Buildings that represent a multi-branched organization are considered the most expensive category in relation to ICT infrastructure purchase, deployment, and non-resilient support. On that account, virtual hosting technologies via cloud services were proved to massively cut down general expenses regarding initial installations. However, applying a private cloud solution on each site have resulted in complex integration levels with respect to either on-premises or outsourced management. In addition, access policies between globally operating, yet, networked companies, are considered a debatable procedure given complex policy considerations. Particularly, both cloud providers and clients have a responsibility in keeping an accurate track of level of user permissions and separation of roles.

The community cloud hosting model was introduced on the basis of turning both the cloud administration and implementation task into a simpler one in terms of costs, ICT associated power consumption, and personnel. The virtual community paradigm includes almost all technical aspects in the private model. However, it combines Smart Building internal VMs, operating systems, and attained ICT capabilities from the provider's infrastructure. As a result, a solid, secure and standardized connection is established between a fixed circle of cloud consumers who submit to a single higher management through a virtual private network (VPN) (Metha, 2012). For example, these can range from different bank branches in multiple countries, all the way to food restaurant chains that occupy physical space in various shopping malls, yet require a core computing and networking platform.

It must be pointed out that the community cloud hosting model can potentially be applied to different organizations who had previously agreed to be part of a virtual, shared, and resource-oriented ICT circle. However, multiple risks and operational barriers were observed to accompany the community approach. These were mostly identified in relation to policy compliance and cost distribution regularities between different corporations under one community solution (Rubinow, 2012). In conclusion, Smart Building non-expert managers who are presumably responsible for a portfolio of buildings within a company, usually find the community deployment approach to be more appealing given several added security and privacy features, in comparison to public cloud hosting as previously evaluated.

- **Hybrid**

The Hybrid model is considered the preferable cloud deployment method for the majority of organizations (Mell & Grance, 2011). This was observed to be implemented by the majority of enterprises utilizing cloud services for the purpose of ensuring additional management flexibilities in terms of security, risk elimination, information systems portability, entity uniqueness, and standardization. Predominantly, the hybrid cloud platform is a mixture of various sub-components from previously discussed deployment approaches. While this approach combines both technical and nontechnical aspects of private, public and community models, unparalleled infrastructure is uniquely established

for a single enterprise management in reference to applications, data, and networking deliveries.

With Hybrid deployments, Smart Buildings have a strong potential for embracing the cost reductions and economy of scale attributes of public clouds, and data security and ICT infrastructure isolation of private clouds.

The typical hybrid structure indicates that crucial ICT operations are performed within the building's physical location via internal systems, while only second-hand ICT infrastructure is rented, auto-scaled, and then released into the provider's shared pool of services. Software services are usually not included in the hybrid domain of cloud resources, as this domain essentially covers networking, processing, and storage capabilities provided by public clouds. These are mostly rented to assist users in peak-load periods and heavy access (Goscinski & Brock, 2010).

Hybrid core systems that combine in-house virtual ICT infrastructure with outsourced cloud components, were tested to result in numerous management, technical, and cost limitations. Non-expert decision-makers must thoroughly weigh-in different pros and cons of each added feature in order to guarantee optimal ICT optimization practices, while maintaining a wider range of control over critical ICT assets. In addition, it was recommended by several cloud specialists that managers, who had already invested in private cloud hosting and virtualization, are the best audience to benefit from hybrid cloud solutions (Goodwin, 2011). Although this group of end-users is commonly seeking to adopt certain information security (IS) and integrity compliances, other low-cost, performance, scalability, and capacity expansion attributes forms another driver behind switching into a semi-public deployment.

The hybrid networking platform of delivery was identified as the most challenging aspect to maintain. This was argued given crucial roles played by each Smart Building internal communication environment. In particular, hybrid setups rely essentially on load distribution and elastic connection between multiple datacentres (Cruz, 2013). Therefore, deploying a hybrid cloud platform on a poorly-implemented and relatively inconsistent

networking infrastructure was found to potentially cause numerous performance drawbacks. These are briefly illustrated as follows:

- ✓ Data Authentication and Protection: This can occur as a result of administrative complexity in the hybrid configuration parameters, which mainly covers data transfer malpractices, and can be reinforced by guaranteeing smooth integration and compliance between both public and private providers.

- ✓ Distribution of Workload between Public and Private Infrastructure: Smart Buildings that include government agencies or other ICT dependent companies have a critical technology management task in defining solid Service Level Agreements SLAs. These would provide a detailed approach which can eliminate needs for a third-party management layer.

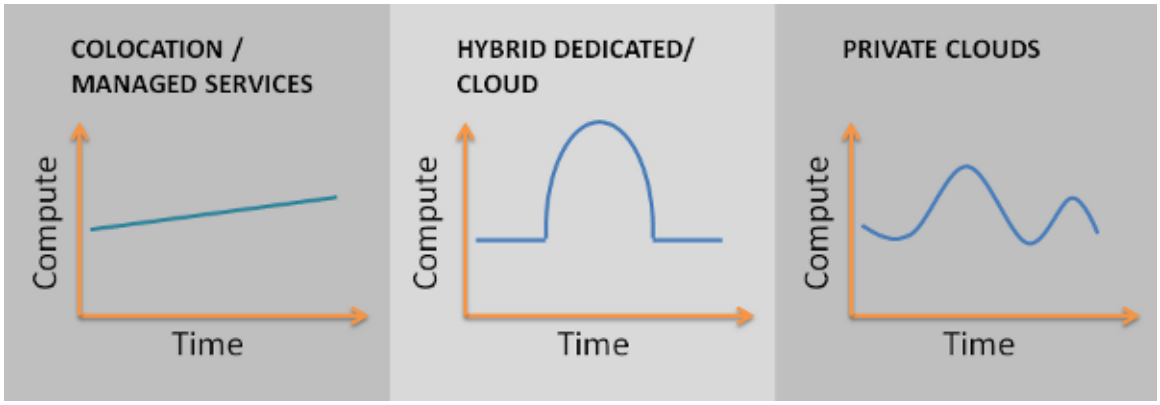
- ✓ Datacentre's Outages: Distributing ICT resources across public clouds and in-house virtual machines was observed to generate many internal inconsistencies in relation to service delivery and access. This is occasionally termed as *Infrastructural Dependency* (Jones, 2013).

Hybrid cloud hosting raises a wide security scope which triggers numerous fields of research in terms of information, internet and communication security. These have ranged from complex data encryption vulnerabilities, to long-term risks for potential intrusion caused by partial outsourcing of scalable ICT components. Moreover, other disadvantages of the hybrid model are related to storage latency, disaster recovery failures, and supplier availability. These would negatively impact the privately hosted domain of the cloud infrastructure given multiple system dependencies and service exchange procedures. This study's overall decision-making framework will only analyse costs, ease-of-management and associated sustainability aspects in accordance to these limitations.

Public, private, community, and hybrid cloud models represent a unique implementation methodology in which non-expert Smart Building managers must comprehend before executing any kind of cloud deployment or purchase. In addition, small-sized structures have a much simpler task in that respect, as these do not possess any legacy systems or rooted networking infrastructure. Therefore, migrating into the cloud is considered

comparatively efficient for such portfolios, even without performing an in-depth management and risk analysis beforehand. However, a sizable Smart Building would require an accurate migration analysis concerning costly legacy systems which are already in use and support crucial systems such as HVAC, water sensors, CCTVs, elevators, and other ICT systems. In conclusion, a detailed investigation in that regard is recommended to take place concerning initial and long-term expenses, power usage, salaries, workload, potential returns, infrastructure integration and management complexity.

The following figure illustrates performed processing capacity across time for each cloud deployment model (Figure 3.7).



(Figure 3.7) Cloud Hosting Methods: Compute in contrast to Time. (United Layer, 2014).

The following table demonstrates a management comparison and summarizes the three key models of private, public and hybrid clouds (Table 3.3).

(Table 3.3) Private, Public and Hybrid Administrative Comparison (Foxwell & Born, 2012).

Private Cloud		Public Cloud	
Implement Shared Services	Increase the speed and agility of IT services, bring application to market faster	Implement SaaS	Lease model eliminates acquisition cost restraints / barriers
Optimize IT Resource	Increase utilization of server, network, storage resources	React to Business Requirements	Elastic services environment addresses peak workload, high volume periods
Streamline IT Operations	Improve efficiency of IT operation staff, increase competency, standardization	Pay as-you-go Services	Add or contract service on demand allows for right-size services at all times
Improve Service Levels	Provide a single support model across large number of applications	Focus on Core Competencies	Increase attention to differentiating business services decrease non-core functions
Focus on Business	Shift costs from infrastructure build-out to business applications	Change the Color of Money	Shifts cost from capital expense to operation expense, eliminates depreciating assets
Hybrid Cloud	The combination of the two environments allows customers to minimize expenditures of non-mission critical environments and maximize security and performance of mission critical ones.		

3.2.5 Cloud Energy Saving Aspects

The dynamic scaling ability offered by on-demand cloud services provides the opportunity for energy saving in Smart Buildings, this is now discussed. It was argued that ICT investments are the most influential factor for attaining *'Green',* low carbon Smart Buildings (Peltomaki, 2009), also, numerous projects have recently been carried out on adopting emerging ICT solutions for contributions to energy saving (Pérez Ortega, María, 2012) (Project Earth, 2013). For instance, EU Commission standards, initiated in 2009, investigated the significance of in-depth relationships between ICTs' technical administration, and energy-intensive industries such as Smart Buildings and Transportation.

According to the Accenture Group and in response to intensive virtualization and economy of scale techniques applied by cloud datacentres, cloud-computing solutions have the ability to reduce a company's carbon emissions by approximately 30% per IT user (Kofmehl & Levine, 2011). This was argued as being a result of outsourcing applications, networking bandwidth, and processing units into cloud-hosted datacentres. This indicated

that some ICT components deployed in a non-virtual manner are responsible for energy consumption in terms of different portfolio sizes and workload. The following will present cloud-computing's contribution to power usage minimization with reference to the previous literature analysis. This is argued in accordance with key cloud management attributes discussed earlier.

In a normal Smart Building environment, users (e.g. people or IP devices) access the internet through either a local area network (LAN) cable (e.g. RJ 45), or via a direct wireless connection. Then, a cloud service request, which follows IaaS, PaaS, or SaaS, is sent as IP packets from the internal on-premises router to the internet provider's main router, to eventually reach the cloud service provider's gateway router. These requests are then subsequently dispatched to a shared pool of distributed virtual machines (VMs), which host a diverse scope of ICT resources, covering software applications, development platforms, processors, and networking bandwidth. Each step of the previous process consumes a certain amount of energy. Other tasks/services that are not directly involved in the cloud service delivery process (e.g. cooling, lighting, and electrical equipment needed to support the ICT lifecycle in Smart Buildings) were argued to consume the largest part of energy (Berl, Gelenbe & Girolamo, 2009).

Research found during the Literature Review chapter has particularly highlighted five key areas of cloud characteristics by the Accenture group, which demonstrated positive impacts on reducing greenhouse gas emissions and refining ICT energy usage in Smart Buildings. These aspects have covered:

- Dynamic provisioning
- Multi-tenancy
- Virtualization
- Server capacity utilization
- Cloud provider's large-scale datacentres

Other sub-factors listed in the following table, were identified in the overall Smart Building ICT energy consumption process, in which cloud-computing has a strong potential to optimize (Table 3.4).

(Table 3.4) Energy consuming Elements against Cloud-Computing Contribution for Smart Buildings

Energy consuming ICT Elements	Cloud-Computing Contribution	Smart Building Example
Core Applications	Eliminating extensive CPU power	Internally installed, long-running software consume a considerable amount of CPU power (e.g. CRM tools for banks, security monitoring tools for shopping malls, etc.). Although this is not usually a concern during the development of these applications, electricity consumption can be reduced through outsourcing core applications through utilizing SaaS resources, which are virtually run over distributed machines at the cloud provider's infrastructure.
PCs & Servers' response time	Reducing end-user response time by relying on distributed VMs instead of high performance on-premises servers	Smart Buildings' non-expert managers have a tricky task of weighing cloud-computing QoS and energy saving features on one hand, with branching limitations on the other. For example, it is well known that any physical server would perform, to a large extent, better than a virtual substitute (Cherkasova & Gardner, 2005). However, enhancing response time is nonetheless a major energy saving attribute, as cloud providers mostly employ a large number of VMs assigned over globally located datacenters, hence, ensuring reliability via data replication, rapid provisioning, and availability rates.
Networking Hierarchy Systems	Minimizing capacity bandwidth from no-more-necessary internal networking devices (e.g. topology design, wired networking awareness)	Utilizing cloud solutions could relatively increase networking processes regarding number of hops between source and destination. However, employing a dynamically scalable infrastructure as a service IaaS, will only consume energy on the basis of delivering packets to the in-house router according to peak workloads. This is done in Smart Building networking systems, which are mostly structured to deal with worst case scenario such as throttle-neck periods. As a result, this can eliminate internal connection complexities as opposed to implementing conventional on-premises datacenters that require power-burdened networking devices (e.g. switches, cables, signal power points, hubs, conditioning equipment, etc.).

To date, cloud experts claim that there is not a clear consensus towards classifying cloud-computing as a Green ICT (Younge & Laszewski, 2010). Generally, management awareness was considered arguably misperceived towards cost minimization on one hand, and reducing ICT electricity usage on the other. While many Smart Building features aim to automate as many end-user tasks as possible, in-house ICT infrastructure is mostly over-implemented as deliveries and capacity exceed what is actually needed, through the use of costly systems. This was termed in the conservative and traditional service methodology as *Over Provisioning.* This approach would result in minimizing energy consumption and maximizing carbon savings, as this indicates that multiple versions of each system or networking process, is replicated, installed, and supported separately on each site.

In most cases when unpredictable heavy user access occurs, it is very difficult to predict the amount of bandwidth required to install a specific system. Non-expert decision-makers might adopt several frameworks for *Green* ICT operation; however, another crucial aspect must be taken into consideration. This highlights analysing resource minimization of internally hosted alternatives. Accordingly, cloud providers' energy efficient datacentres are mostly run next to massive renewable energy sites in order to maximize energy usage in the best way possible (Kumar, Garg & Buyya, 2012). Smart Buildings can rely on these heavily-burdened structures for obtaining resource-efficient ICT systems with minimum on-site equipment installed. However, this should be performed prior to taking into consideration all energy consuming attributes within the ICT environment. These attributes were defined by several academics throughout different frameworks via ICT power-usage parameters as (Mines, 2011):

- COP (Coefficient of Performance) average
- The Carbon intensity of the electricity being used by each ICT component (kgCO2e/kWh)
- Electricity prices per ICT component
- Networking (next-hop) cost per GB, for data transfer (up/download)
- CPU uptime, downtime, quantity, frequency ratio, and power required

Cloud-computing has a significant potential for eliminating plugged-in equipment, thus, minimizing associated electricity consumption, space, and management effort. More, this

was assumed to reinforce Green utilization for Smart Building ICT applications. In addition, the fact that in most cloud hosting cases energy is being displaced from onsite to offsite, this displacement only saves energy if these processes can be run more efficiently due to economy of scale (e.g. large datacentres) (Costello & Rathi, 2012). These datacentres could be situated in geographically favourable locations such as cooler climates, which will have lower cooling loads than buildings located elsewhere which are using those off site servers.

In concern, multiple energy efficient aspects were concluded in response to previously discussed cloud characteristics as clarified next.

- **Enabling Resource Virtualization**

Regardless of the deployment method, the core concept behind cloud-computing is the ability to run several operating systems on one machine. Therefore, adopting virtual machines with relatively similar capabilities can be acquired either on, or off-premises within a single or multi-branched ICT environments. With that in mind, the e-waste footprint of each ICT element such as servers with high CPU power can be substituted by VMs, thus, reducing electricity spending and energy of physical plugged-in units.

- **Strengthening Consolidation**

Although virtualization is considered the primary cloud energy-efficient aspect, a crucial reliance on software automation for scaling up/down as workload demands, forms a key benefit behind virtual ICT implementation. This criterion allows non-expert Smart Building decision-makers to fully utilize rented cloud resources in contrast to resource ratios via conservative physical ICT methods. The conventional approach was noted as more costly and power consuming in reference to unhandled high rates of server utilization, which can be minimized through virtualization and a solid backup of software automation.

- **Enabling Energy-Efficient Behaviour**

The pay-as-needed billing concept of cloud-computing has a significant impact on energy end-user behavior for enhancing lifecycle administration and service oriented expenditures. More, while Smart Buildings' heavy ICT dependence mostly includes the utilization of

plugged-in, off-site, and third party managed infrastructure, this is accomplished - in cloud terms – following an as-needed approach. Each unwanted ICT element will simultaneously be switched off, and these resources are then pushed back into the shared pool as previously explained in the cloud characteristics section.

- **Applying Multi-branched Demand Patterns**

In relation to a multi-branched set of Smart Buildings such as Banks, Hotels, or Hospitals, operating on a single networking platform, the multi-tenancy attribute of cloud-computing is considered a major energy saving aspect for several reasons in accordance with each cloud deployment model as follows:

- Public clouds mobility standards allow differently located users to access ICT services and applications from anywhere via the Internet, while taking into account several security, reliability, and data integrity considerations. This saves energy in Smart Buildings because these users are relying more on privately owned end-systems from off-premises locations, which takes the load off the organization's ICT infrastructure.

- Private clouds, which are installed on one site such as the main headquarters of the organization, can act as a cloud provider datacentre for other Smart Building branches. These are able to access, utilize, and release ICT resources by following similar public cloud techniques.

- Hybrid clouds, whether deployed on or off-premises, have a significant role in reinforcing both the security and performance of previous approaches as discussed earlier in the deployment models analysis.

Previous points indicate that each location with a certain workload peak rate, have a strong potential for saving energy. For instance, peak rates for networking, processing, or application access are widely reduced when distributed between multiple end-users via shared demand patterns. Although less physical infrastructure is required as a result, the economy-of-scale aspect of cloud-computing plays a considerable role in maximizing energy efficiency and resource troughs. This will be further demonstrated in Chapter 5 by

highlighting specific Smart Building case studies through semi-structured academic interviews and risk-analysis surveys.

3.3 Cloud Costs, in accordance with Smart Buildings' ICT Spending

Economic considerations on cloud-computing purchases can vary extensively according to different Smart Buildings. Examples of these were researched in concern with geographical locations, regularities, cost of electricity, salaries for staffing and so on. Whilst cloud-computing was introduced on the basis of providing economically-efficient ICT solutions, Smart Buildings with ICT applications that do not represent a key lifecycle requisite, suffer from costly support and maintenance. Therefore, outsourcing either a partial or the entire ICT infrastructure into the cloud was identified as a major cost reduction factor in reference to initial installation costs, implementation, operation, support, and other external dependencies such as purchasing licenses and ensuring frequent, costly upgrades.

After identifying various types of cloud-computing with associated security limitations and lifecycle concerns, cloud costs are investigated in relation to each deployment, architectural, and service delivery model. On that note, it was argued that in-house private clouds are more expensive to attain than the internet-hosted public clouds (Pantić & Ali Babar, 2012). However, private approaches are still considered cheaper than the conventional full hardware purchase and on-premises deployment. Nevertheless, private hosting techniques are more favourable when it comes to large buildings, given various reliability and availability advantages.

The core requisite to any non-expert manger before adopting any cloud solution, is to guarantee a 24/7 -or during working hours- internet availability with reliable and acceptable connection performance. Private clouds can provide Smart Buildings, to some extent, with an offline contingency operation in case of unpredictable internet outages, which can be obtained via the same physical machines which host multiple VMs simultaneously. However, decision-makers must first analyse the overall cost of ownership (TCO) in contrast to system migration processes for already installed in-house systems.

In some cases, purchasing a certain cloud solution would cost more than physically owning the hardware and application. With that in mind, long-term ICT expenditures can still be reduced given both pay-as-you-go and economy-of-scale characteristics. Smart Buildings with automated functions require a rapid processing power, as offered by major cloud providers like Amazon's EC2 and others. For example, it was found that renting 2,000 VMs from Amazon for only 2 hours, would have a similar cost to renting 2 VMs for 2,000 hours (Armbrust & Fox, 2009).

The following will analyse real-life costs of cloud services and key components in accordance with Smart Buildings' ICT spending, which was illustrated in the literature review chapter in sub-section 2.2.3. While these are estimated according to current billing and charges across different organizations, the investigation is performed with the support of two internet-based tools on cloud cost measurement:

a) *Simple Monthly Calculator*: by Amazon Elastic Computing EC2, the world's leading cloud-computing provider
b) *Cloud Cost Calculator*: from Rackspace, the second globally largest cloud hosting company

The following example was conducted by the *Uptime Software Company* in 2010. It demonstrates the cost of outsourcing into the cloud a non-complex ICT infrastructure of a small-sized Smart Building's data storage. This was carried out throughout a two-week period under simulated storage and networking bandwidth of 1,000 cloud systems via Amazon's *EC2-S3 web-storage* service. This service is designed to simplify internet scaling through on-demand instant billing. However, it is important to note that during the ICT requirement identification stage, pricing of cloud services will vary, to some degree, depending on each system. This is mostly determined at the stage where Smart Building managers would analyse compatibility issues in relation to operating systems, database engines, networking OS and so on. These instances range from Linux OS to Microsoft NOS server, in addition to associated database engines like MySQL, SQl Express, and Oracle.

The main conclusion has indicated that overall costs, including input/output, processing, and storage rents, were estimated to reach $ 789,000 US dollars for 300 *EC2* components per year, which can be rounded to 744 hours per month (Bewley, 2010). These expenses were distributed and calculated as follows (Table 3.5):

(Table 3.5) *Uptime Software* case study: Annual cost for selected Amazon's EC2 instances (Bewley, 2010)

ICT EC2 Component	Number	Cost / Component Hour	Monthly Cost
Compute			
Microsoft Windows	100	$ 0.125	$ 9.300
Microsoft Windows + SQL Express Server	50	$ 1.100	$ 40.920
Linux	150	$ 0.100	$ 11.160
Windows (SQL/xLarge)	2	$ 2.400	$ 3,571.20
		Total Monthly Cost =	***$ 64,951.20***
Storage			
5.6T (usable)		$ 0.10 Gb/month	$ 573.44
I/O	30 B	0.10 per 1MM I/Os	$ 300.00
Network			
I/O	20 Gb	$ 0.10 Gb/month	$ 2.00
Total Monthly Cost for EC2			$ 64,826.64
Total Annual Cost for EC2			$ 789,919.68

On the other hand, the cost of adopting a conventional deployment environment by fully purchasing the necessary hardware, excluding any management and administrative overheads, was estimated to reach $ 298,000 US Dollars on an annual basis (Table 3.6).

(Table 3.6) *Uptime Software* case study: annual cost for Conventional Approach instances (Bewley, 2010)

ICT Hardware Component	Number	Monthly Cost
Infrastructure		
Dell 1950	28	
Dell 2950	2	
HP-DL 585	2	
10-TB iSCS-I	1	$ 10.000
Dell-HP-Equallogic Support		$ 300
HVAC & Electricity		$ 1,000
Floor Space	500 sq/ft $ 24sq/ft per year	$ 1,000
VMware ESX	9	$ 1,250
VMware Support (Annually)		$ 1,250
Internet Contracts		$ 1,200
Networking Infrastructure		$ 556
	Total Monthly Cost =	***$ 16,556***

Software		
SQL Server 2008		$ 2,083
Oracle 10g/11g		$ 2,083
	Operational Monthly Cost:	$ 4.166
Total In-House Monthly Cost:		$ 24,888.89
Total In-House Annual Cost:		$ 298,666.67

A clear conclusion can be observed at first instance from the previous tables. This suggests that owning the actual infrastructure is more cost-efficient than utilizing cloud resources from Amazon according to this particular case study. However, the non-cloud ICT lifecycle was observed to result in a much more costly solution in the long-term. This is widely influenced by many in-house management factors mostly related to:

- Salaries for IT administrators
- Software licensing
- Performing system upgrades
- Monitoring and maintenance
- Energy bills
- Discarding old hardware, and purchasing new ones with up-to-date systems (e.g. Networking OS, CPUs, etc.)

The previous example shows that in some cases the initial implementation cost of the traditional ICT approach can be more cost-effective than the cloud-computing one. The future cost of many associated management aspects within the organization will prove that utilizing cloud resources will result in a better economic value as will be discussed in Chapters 5 and 6. On this account, in relation to Rackspace cloud services, and Amazon's *EC2* resources, the following tables illustrate up-to-date prices of some of the high-level cloud-computing components offered by these providers. These also include a brief description of each and associated key ICT attributes (Tables 3.7 to 3.13). Particularly, these are highlighted in response to the significant role each category plays in almost any Smart Building ICT infrastructure. In essence, the domain of cloud service deliveries includes

- Managed Clouds
- Block Storage

- Cloud Servers
- Cloud Files
- Cloud Databases
- Back-up services
- Load Balancers
- DNS
- Monitoring

Other lower-level cloud models include critical data and require further special security considerations, such as private hosting in Banks or Health care Smart Buildings (Cisco Systems Inc, 2010).

(Table 3.7) 2014-2015 Rackspace & Amazon Prices of Cloud Servers

Cloud Servers Instance	Feature Quantity Description	Monthly Cost in £ (GBP)
Operating Systems	Windows or Linux	Depending on each feature
Managed Levels of Service	Yes / No	Yes = £ 65.5
RAM Capacity	From 512MB to 30GB	Depending on number of Windows or Linux Servers
Utilized Servers	2 GB Windows / Linux (1 Server)	£ 75.92 / £ 58.40
SQL Servers (Windows)	2 GB Web Edition / Standard Edition (1 Server)	£ 29.20 / £ 328.50
R2 / 2012, SQL Server 2008 (Windows)	Web Edition / Standard Edition	Associated with number of SQL Servers
Red Hat Servers (Linux)	1 Red Hat server	£ 12.50
Service hours required per month	730 hours	Added to each service price
Output (Bandwidth)	For 10 GB	£ 0.80
Virtual Router (Linux)	Yes / No, for 2 GB Linux (1 Server)	£ 105.12

(Table 3.8) 2014-2015 Rackspace & Amazon Prices of Cloud Files

Cloud Files Instance	Feature Quantity Description	Monthly Cost in £ (GBP)
Storage Capacity	1 GB	£ 0.07
Output (Bandwidth)	1 GB	£ 0.08

(Table 3.9) 2014-2015 Rackspace & Amazon Prices of Cloud Load Balancers

Cloud Load Balancers Instance	Feature Quantity Description	Monthly Cost in £ (GBP)
Cloud-based Load Balancers	10 Load Balancers	73.00

SSL Load Balancers	10 Load Balancers with SSL	109.50
Service hours per month	730 hours	Added to each service price
Concurrent Connections (average number)	100 connections	7.30

(Table 3.10) 2014-2015 Rackspace & Amazon Prices of Managed Cloud

Managed Cloud Instance	Feature Quantity Description	Monthly Cost in £ (GBP)
Server Capacity / Disk Storage	1.024 MB / 40 GB	£ 102.20 (Linux) / £ 110.96 (Windows)

(Table 3.11) 2014-2015 Rackspace & Amazon Prices of Databases Cloud

Databases Cloud Instance	Feature Quantity Description	Monthly Cost in £ (GBP)
Database Instance Size / with Managed Level of Service	1 GB	£ 69.35 / £ 98.55

(Table 3.12) 2014-2015 Rackspace & Amazon Prices of Back-up Cloud

Back-up Cloud Instance	Feature Quantity Description	Monthly Cost in £ (GBP)
Cloud Server	1 Server	£ 8.00
Storage	1 GB	£ 0.7 p

(Table 3.13) 2014-2015 Rackspace & Amazon Prices of Monitoring Cloud

Monitoring Cloud Instance	Feature Quantity Description	Monthly Cost in £ (GBP)
Monitoring Zones	3 Zones	£ 1.20

Top cloud providers offer on-demand training with different hosting options, in addition to other bespoke features. Few examples are *Open-stack* software for maintenance, *New-Relic* for developers, *Send-Grid* for simplified emails, *Zeus* for extra load balancing, *Kaltura* for open source video encoding, and *Scalr* for website smart auto scaling (Rackspace Cloud Products, 2014).

Analysing the variable cost nature of cloud services is a key objective throughout the next chapter in comparison to conservative methods of Smart Building internal ICT hosting. The primary value analysis will specify the scope of ICT expenses for the selected Smart Building case studies. This will eventually derive a framework for cloud utilization

strategies to measure the degree of budget efficiency, sustainability, and ease-of-management.

3.4 Conclusion

The primary objective of this chapter was to critically analyse major literature review findings in relation to up-to-date Smart Building ICT statistics, case studies on cloud expenses, energy consumption estimations, and business observations of market contribution. Key cloud-computing management aspects were outlined along with an up-to-date pricing overview. This forms a platform for developing this project's overall theoretical and practical decision-support framework for non-expert managers to highlight actual efficiency from adopting cloud services in Smart Buildings.

This chapter examined key management aspects of cloud-computing techniques, which included:

- Assessing different concepts and standardizations of cloud-computing, as the NIST definition was adopted given previously argued administrative reasons, which were highlighted to best fit Smart Buildings control environments.
- A critical analysis of the cloud procedural characteristics with security overview of each, and management limitations.
- An investigation of each cloud service model, in addition to a cost-efficiency and sustainability evaluation for various Smart Building lifecycle scenarios.
- Exploring different methods of cloud deployment options, which as observed, play a significant role in Smart Building technology management with regard to on/off-premises hosting, system migration, and in-house integration with multiple locations.
- Examining various cloud energy saving potentials and propositions in reference to long-term implementation, operation, monitoring, and upgrade alternatives in response to traditional approaches of in-house full ICT ownership and staffing.

Ultimately this chapter presented, in accordance with buildings' general ICT spending, a medium-sized portfolio example of up-to-date cloud prices in relation to key components,

application services, and networking features. These were presented with the support of both Amazon's *EC2* and Rackspace *Cloud Calculator tool*. This chapter selected Rackspace for the cloud price review given that Chapter 5 will include a semi-structured interview with a senior specialist from the same service provider. Therefore, it was more appropriate to conduct this analysis using the same organization's standards, as private data was gathered and handed from Rackspace to assist this research in the experimental data collection field work.

In order for any non-expert manager to validate organizational abilities aiming to measure actual efficiency rates before any cloud adoption, each of the previous cloud management aspects must be thoroughly examined in contrast to variable lifecycle features of that specific structure. Furthermore, decision-makers have a crucial task of weighing in these management attributes, which mostly revolve around costs, security limitations, availability patterns, long-term maintenance savings, and integration compatibility with in-house legacy systems. It can be asserted that this assessment needs extra attention when Smart Buildings are employing a hybrid cloud hosting solution given the numerous considerations evaluated earlier.

The following chapter will demonstrate different types of data collection methods, introducing the core methodology this project will adopt for the experimental work and field research.

4.0- Chapter 4: Data Collection Methodology

4.1- Introduction

This research eventually aims to formulate a decision-making tool for assigning different models of cloud-computing services to Smart Buildings to improve their sustainability. The previous chapter has explored cloud service characteristics, delivery and hosting approaches, costs, and associated energy efficient aspects. Taking this knowledge into account, the following carries out several stages of experimental work consisting of:

a. Two in-depth semi-structured interviews with cloud service providers
b. Primary semi-structured interview of a cloud service requester case study
c. Real-life cloud deployment cost simulation across a 3-year period
d. Risk-analysis survey following the Likert-scale approach
e. Development and analysis of *SBCE*: the online decision-support software

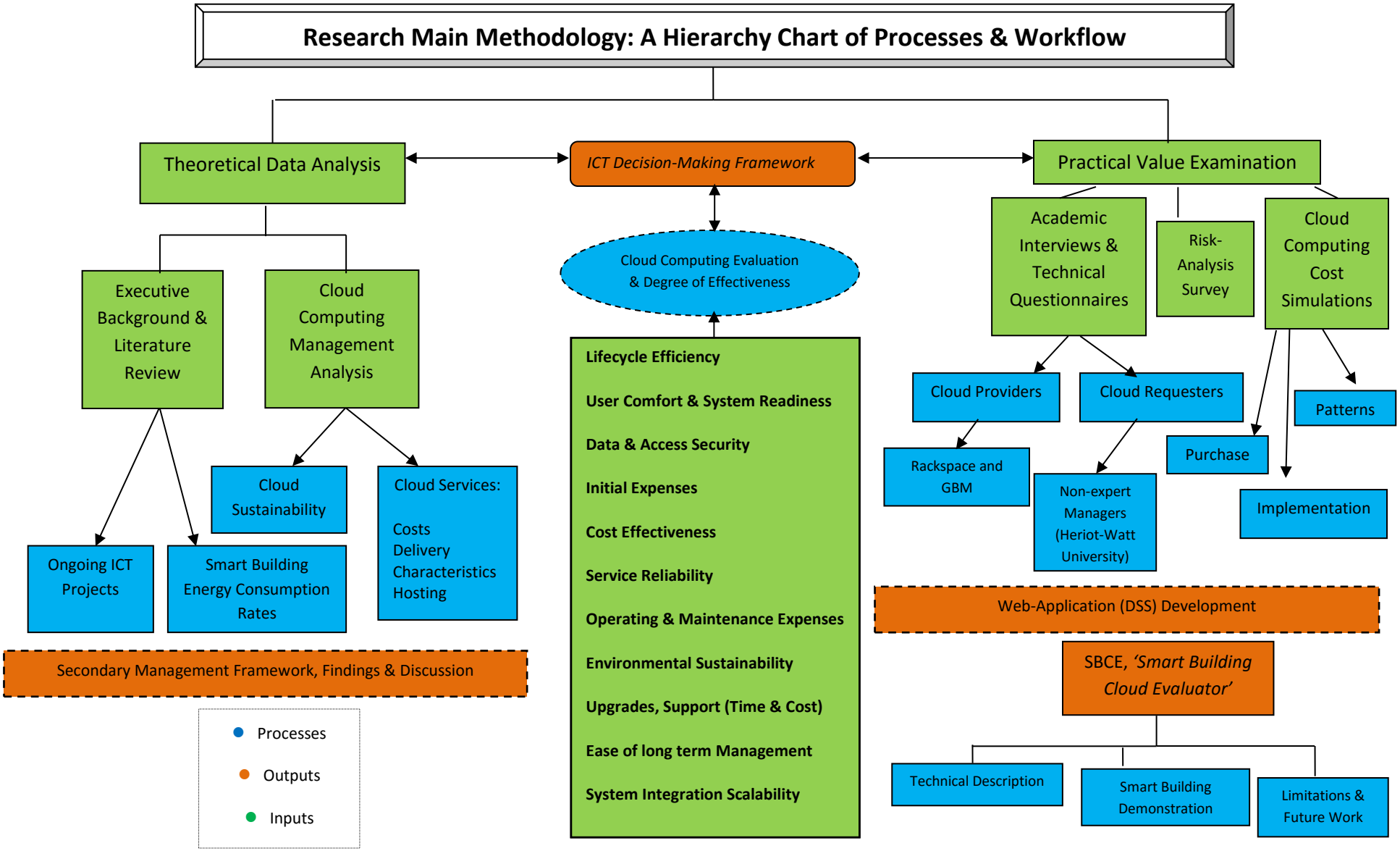
The methodology of each stage is described briefly in the following sub-sections.

The reason this study undergoes a primary value estimation is to analyse purchase, ownership, implementation, and integration with on-site end-systems of Smart Buildings. This examination is related to selected ICT tasks, internal data-collection requisites, and current green approaches to improve economic and environmental sustainability. It was identified by this study that the best way to tackle these areas is by conducting in-depth interviews with cloud providers on one hand, whilst intersecting points from interviews with cloud end-users on the other. Furthermore, a real-life cloud deployment scenario was considered essential in order to simulate and reflect long-term changeable costs depending on the growth or decline of that organization. Moreover, measuring readiness and reliability aspects as well as potential trade-offs from adopting cloud-computing services is highlighted by performing a bespoke risk analysis questionnaire against a number of non-expert decision makers from various domains and specialties.

Findings from earlier practical work will be employed to conclude a theoretical ICT management framework for non-expert managers in Smart Buildings. This is highlighted in terms of cloud acceptance, unstable expenditures, and appropriate sustainable approaches.

Ultimately**,** this study will develop an explanatory web-based application with a simplified online graphical user-interface. The software is called *SBCE*: Smart Building Cloud Evaluator. The goal is to offer a wide range of non-expert managers with dynamic services for analysing detailed cloud-computing costs depending on user-defined growth and decline paradigms as will be explained later. In addition, the tool provides non-expert managers with administrative consultancy reporting features, which are uniquely built for different types of Smart Buildings. According to the users' inputs, the system highlights the optimal deployment scenario, appropriate service delivery models, and management related insights for each including associated contract and security considerations.

This project has been divided into multiple stages as previously pointed out, starting with the executive background, all the way to the technical development of *SBCE*. The following diagram illustrates the workflow of these processes in a flow chart, which represents the main methodology adopted by this project (Figure 4.1). The following boxes are colour coded in terms of outputs, inputs and processes.



(Figure 4.1) Research Methodology Hierarchy Scheme of Action

4.2- Experimental Work Methodology

According to the National Defence Research Institute (RAND), the different types of data collection methods are (Harrell & Bradley, 2009):

a. Survey: This is a structured and fixed group of questions that can be collected through paper sheets or online interfaces.
b. Interviews: This is a discussion between the interviewer and the interviewee following a pre-structured and prepared set of questions on a single or multiple topics, which can be conducted through different means (e.g. one-on-one, over a conference meeting, etc.).
c. Focus groups: This is a dynamic method of collecting data by conducting group discussions.
d. Observation: This method allows the interviewer to collect information without physical interaction with the interviewee.
e. Data extraction: This data collection method is carried out though the analysis of documents and organizational data records.
f. Secondary data sources: With this method researchers can gather information from existing data sets such as census data, and other similar types of data variables that are already in existence.

Throughout the experimental work chapter, this research will conduct a risk-analysis survey and three interviews. This project has considered adopting different methods for data collection. However, after examining the above techniques in accordance to this study's workflow, the semi-structured method was selected as being the most suitable for conducting all of the interviews. The following discusses the reasons behind this selection, and the chosen methodology for each stage of the experimental work process.

4.2.1- Semi-structured Interviews

A semi-structured interview is a data collection method used for qualitative research, which is usually adopted when the researcher seeks to thoroughly understand a specific area of interrelated topics (Newton, 2010). This type of interview is mostly used when the research

aim is to gather expert opinions and attitudes on a standardized set of topics. This research identified the semi-structured interview approach as a suitable one for this project given that it is applicable to various scenarios and types of questions which will be discussed in Chapter 4.

Academic interviews are Highly-structured, Structured, Semi-structured, or Unstructured. This range demonstrates the control in which the interviewer has over the interaction with the interviewee in terms of the questions provided, arguments of answers, and the continuum of each discussion. Arguably speaking, the interviews conducted in this research are most suitable with the semi-structured method given the following

- This project is fundamentally concerned with policy research, management opinions, work experience, and attitudes towards decision-making procedures, which is argued as being suitable for the semi-structured interviewing method (Harrell & Bradley, 2009).
- A guide is pre-structured to clarify topics and questions that must be covered.
- Certain discretion is identified regarding the order of questions.
- All questions and material are standardized and highlighted for the interviewee, which offer a certain degree of control by the interviewer over the interaction.
- Some information is collected through a conversational manner, which is one of the main aspects of the semi-structured interviewing method.

This study will conduct a number of technical and non-technical academic interviews. This comes as a result of the theoretical analysis in the previous chapter, which argued literature review findings and cloud-computing management attributes in relation to different ICT energy and decision-making case studies. These in-depth interviews are designed to address management abilities for adopting virtually hosted and on-demand cloud-computing solutions in various Smart Building ICT environments.

Given the interdisciplinary context of cloud services, numerous aspects must be identified and thoroughly intersected prior to these interviews. To reflect the different deployment models, implementation designs, and architectural types of cloud-computing clarified in previous chapters, these interviews will follow a semi-structured approach which allows this study to gather data more efficiently and expand on specific topics offered by the

interviewees via various documents. While disparate aspects of administrative and decision-making impacts on Smart Building ICT applications will be examined, these interviews will include experts that were carefully selected from multiple industries and specialties. In particular, managers from ICT networking companies, who offer virtual services for portfolios and non-expert business firms, will play a significant role throughout the primary assessment chapter. The second part will perform an additional semi-structured interview following the viewpoint of cloud service-requesters. While this focuses particularly on Smart Building non-expert managers, an analysis will be carried out on decision-making performance, which is fundamentally concerned with energy, cost, simplifying time-consuming tasks, and long-term ICT lifecycle.

Case studies will be presented in reference to Smart Buildings' different objectives and operations. For instance, one of the examples will explore a large university with a comprehensive ICT environment. This case study was chosen given the large number of interconnected facilities included, in addition to numerous departments located in different portfolios with remotely-based users including students, staff, and external users. The domain involved is considered largely divergent given the inner management context, in contrast to other Smart Building practices such as airports, shopping malls, hospitals, and other heavily staffed businesses. In essence, this research will attempt to differentiate between selected case studies which will be further explored with the employment of cost simulation tools.

The following will illustrate the technical and non-technical workflow of these interviews, which identifies the scope of questions addressed. Furthermore, a brief technical overview will be carried out concerning each interviewee's background of expertise to explain relevance associated with this research. Timeframes and dates for planning and approaching interviewees will be also discussed.

The initial stage selects ICT companies with relevant operational objectives to this project. The first expert this research approached was Mr Salem Cheikh Najib, whose previous experience in delivering ICT virtualization projects to different organizations was considered significant to this study. With a wide domain of previous experience in Information Systems and ICT Management, Salem was approached to take part in this

research in May of 2013. Furthermore, Salem was involved in a wide range of employment, entrepreneurship, and consultancies positions, which took places across London, Qatar, Dubai and other rapidly developing Middle Eastern countries. Currently speaking, Salem is a Senior Integrated Networks Specialist at a heavily IT-business solutions company, GBM, which is IBM's sole distributor across the Arab Gulf region (GBM website, 2013).

Given the end-system virtualization services offered by *GBM*, and in reference to the cloud-computing focus of this research, this interview was considered beneficial to understanding Smart Buildings' cloud decision-making. In agreement with Salem, this interview was divided into three main stages:

- One-on-one semi-structured interview
- Provide professional suggestions and structured technical consultancy in accordance with the theoretical analysis from the previous chapter.
- Provide real-life case studies, previous project examples, and business analysis reports, in which Salem has personally participated in. These projects will include issues of ICT cost and energy-efficient contributions, hardware optimization, and management standards for employing cloud techniques in smart portfolios.

Secondly, this research approached Rackspace, which is currently one of the largest cloud providers in the UK and around the world. This interview was structured to shed light on the following interconnected areas of concern from a cloud provider perspective which directly influence end-users.

a. Actual benefits from dissimilar cloud deployments
b. Degree of clients' readiness
c. Contracts' barriers
d. Purchase requisites
e. Cost rates and patterns
f. End-users' trainings and configuration
g. Comparison of global case studies' ICT cost, and impacts on management
h. Energy-efficient ICT management
i. Service reliability and breakdown response time

j. System compatibility decision-making.

Rackspace has agreed to take part in a one-on-one semi-structured interview as part of this study's experimental research. The interview was set to take place with Mr Oliver Peuschel, who is currently the senior Solution Specialist, and Enterprise Hosting and Channel Consultant at Rackspace. The interview was carried out via multiple Skype conference calls between both London and Edinburgh Rackspace offices. The main discussion was structured to cover similar management points and technical aspects from the previous interview with (GBM). Yet, other in-depth case studies were presented by Peuschel, which has positively influenced the progress of this research. These real-life examples such as Domino's Pizza, Antler Luggage Corporation, and Axios Systems, have included disparate companies that currently occupy Smart buildings with integrated virtual technologies.

Following the previous two cloud-provider interviews, this chapter will use Heriot-Watt University as a primary case study for cloud-computing service-requester and deployment. This university was chosen by this study because of the different locations involved, which are systematically operated as an interconnected set of buildings. In addition, this portfolio is globally distributed with a large-scale ICT nature consisting of transparently-managed objects included in a singly-managed domain. This environment includes different types of end-users (e.g. academic employees, administrative staff, and on-site or remotely active students). This represents a significant example for this study which is purposed to enhance decision-making processes regarding cost and energy efficient ICTs and ease-of-management levels of cloud utilization.

This interview was scheduled to take place on the 2nd of August, 2013 in the Heriot-Watt University Edinburgh campus with Mr Mike Roch, who is the current Information Director and lead IT specialist at the university. The Heriot-Watt University semi-structure interview questions can be viewed in Appendix D. The semi-structured interview was set to cover a specified range of technology management aspects as follows.

a. Cloud-computing adoption Readiness degrees
b. Security limitations and considerations

c. Availability requisites
d. Migration processes and efforts involved
e. Long-term cost comparisons and noticeable patterns
f. Scalability paradigms of service uptime, downtime, and bottleneck
g. Support and maintenance
h. Licensing expenses
i. ICT staff salaries
j. Management simplicity
k. Compatibility with other Smart Building control systems and levels of integration
l. Energy efficient ICTs and legacy systems

Ultimately, collected data from the previous interview concerning Heriot-Watt University ICT dependencies, bills, sustainability, and other instances, will have a significant role in conducting the cost analysis cloud simulation example, clarified next.

4.2.2- Cloud Simulation Overview

The practical value assessment chapter will include a cloud-computing simulation, which is aimed to estimate 3-year energy and cost efficiency of different cloud services regarding selected ICT examples. Various tools and GUI simulators were offered for general ICT and cloud-computing modelling, provisioning, and deployment. Some of these tools are briefly reviewed next.

Net-Suite is currently ranked the number one cloud ERP tool across the United Kingdom by end-users' reviews, as it offers a wide range of packages regarding cloud-based business solutions, which include ecommerce, inventory, and accounting. While these management areas are not the focus of this research, *Net-Suite* is considered comparatively significant in terms of providing potential solutions to eliminate unnecessary on-site hardware and software usage. It was mentioned by *Net-Suite* product reviews that more than 16 thousand organizations have shown noticeable cost-savings on ICT maintenance, upgrades, real-time access, and scalable productivity aspects after applying its applications (Net-Suite Free Product Tour, 2013).

In 2011, *Cloud-Sim* was officially introduced as a modelling toolkit for cloud-computing resource provisioning simulation. Features such as behaviour modelling of cloud systems, datacentres workload measurement, VMware (Virtual Machines) solutions, and other extensible QoS components, were all added to the *Cloud-Sim* scope of supported items. These were considered part of a generic wide-scale range of pay-per-usage functions in terms of system requirements, configuration, and deployment. As the general purpose of this tool was to minimize management efforts and enhance the ICT decision-making process, ICT giants such as HP and others are currently developing *Cloud-Sim* for further energy-efficient investigation in reference to either a single, or federated cloud-computing utilization across interconnected portfolios and business environments (Buyya, Ranjan & Calheiros, 2011). It can be argued that *Cloud-Sim* evaluates data following data-mining experimental processes from a cloud service provider viewpoint and through reproducing results from real-life examples.

Other project tools were introduced in that regard, which offer in-depth cloud simulations. These adopt a relatively similar paradigm for demonstrating cloud implementation costs and administrative efforts over a specified period of time. All of these solutions provide users with graphical interfaces, distributed networks, and virtual environments to simulate deployments, some of which are outlined as follows:

- Plan for Cloud Simulator (Khajeh-Hosseini & Greenwood & Sommerville, 2013).
- Real-Cloud-Sim (Agostinho, 2012).
- Cloud-Reports (Sa, 2012).
- Cloud-Auction (Teimoury & Samimi, 2013).
- Cloud-MIG Xpress (Frey & Fittkau, 2012).
- Cloud-Analyst (Wickremasinghe, NCalheiros & Buyya, 2009).
- Green-Cloud (Kliazovich, Bouvry & Audzevich, 2010).

This sub-section will examine selected hypotheses to simulate a cloud utilization case study, which will undertake Heriot-Watt University as a key case study from the previously explored semi-structured interview. The areas involved are ICT infrastructure cost; selection of cloud applications; cloud expenses and associated patterns; sustainability benefits; and management limitations.

In order to carry out this simulation, this project used the *PlanForCloud* modeling tool by *RightScale* which was discussed earlier in the literature review chapter (Khajeh-Hosseini & Greenwood & Sommerville, 2013).

A further overview on the *PlanForCloud* toolkit will be presented as part of the practical value examination by introducing a layered decision-making approach for various cloud-computing architectural types. Furthermore, relevant cloud-computing deployment aspects will undergo a management analysis in accordance with the overall case study findings. These will include cloud-hosted user standards, internetworking concepts, *VMware* allocation modelling, networked behaviour, and federated power consumption measurement.

Prior to this simulation, in order to attain accurate numbers and collect real-life data on different types of cloud deployments, this research has approached an Edinburgh-London based ecommerce agency: *Digital Boutique*, for the purpose of assessing this research. The scope of work had involved investigating different enterprise-level, online hosting techniques, whereas the main objective was to attain a pure technical perspective on the following central decision-making aspects:

- Server deployment methods.
- Liaising with server providers for Managed, Cloud, or Collocation hosting
- Industry pricing.
- Managing real-life structured contracts for a wide domain of UK-based enterprise clients depending on in-house requirements, employees, and bandwidth capacity.
- Managing various situations of cloud-ICT support and client ticketing-system handling.

The study approached Digital Boutique in June of 2013, and established a collaborative effort for technical assistance in data collection, management insights, and other tasks. This was agreed to be executed across an unspecified period of time in return of sharing key research conclusions with the agency's higher management and technical teams. Moreover, as this research will ultimately develop a decision support tool, Digital Boutique offered to send requests to existing clients to test this tool and potentially improve the agency's users' decisions on cloud ecommerce hosting in the future (Digital Boutique Internship, 2013).

The detailed results of the simulation can be viewed in Appendix A. Digital Boutique also offered to assist this research by sending this study's risk-analysis survey to existing clients from managers and non-expert decision-makers, as clarified next.

4.2.3- Risk-Analysis Survey Methodology

This study will carry out a risk-analysis survey based on findings from both the theoretical evaluation chapter, and the cloud security sub-section 2.2.7 of the literature review. The goal is to collect data on cloud-computing trade-offs and management risks following the viewpoint of decision makers across different types of Smart Buildings. This survey will include a single rating-scale question, which will target a specified number of managers from different organizations that were highlighted as relevant to this project. Particularly, potential recipients will involve a generic domain of non-expert decision-makers who occupy management positions in a number of ICT-dependent organizations that practice a minimum amount of system integration.

The Likert approach was specifically selected for this survey given the nature of opposing opinions between different non-expert managers. This has been observed by this study from observing different aspects, such as the degree of concern towards utilizing cloud solutions. The questionnaire will attempt to reflect the diverse attitude of these managers towards ICT budgets and sustainability acceptance, readiness to change, and other management aspects on the feasibility towards cloud migration within these organizations (Johns, 2010).

This rating-scale survey was conducted via the popular online Survey provider: *SurveyMonkey,* as will be illustrated in the following practical assessment chapter. The risk-analysis survey form can be viewed in Appendix B.

4.3- Decision-Making Tool Methodology

In reference to energy-aware, virtualized, and customizable computing resources in Smart Buildings, this project will ultimately conduct a real-time cloud-computing representation of essential decision-making processes, concluded from the previous assessment. These processes will be selected from ICT areas of focus within a Smart Building control environment as will be clarified in Chapter 6.

This research will introduce *SBCE: Smart Building Cloud Evaluator*, which is a cloud-computing web-based decision-making tool, designed to assist non-expert managers to achieve a sustainable, scalable, and cost-efficient Smart Building ICT management. This decision support system is designed as an outcome from both the theoretical and practical data analysis, which will ultimately empower managers with dynamic cloud cost estimation, deployment consultancy, and report generation services.

The theoretical platform in which this software was built takes into account the previously explored cloud service models, architectural types, challenges, and degree of intangible and tangible efficiencies associated with different management standards. In general, *SBCE* is designed to enable building managers, who are not particularly experienced in information systems, to determine whether a virtualized solution -based on cloud concepts- is considered beneficial or not, and to what extent this solution can be applicable within a particular Smart Building. While this process involves various economical, technical, and sustainability considerations, the outcome report will specify the optimal degree and recommendations of utilizing either a partially-virtualized implementation, or a complete outsourcing and replacement of traditional on-site ICT systems. Yet, in some Smart Building cases, the report could suggest a specified combination of both migrations under one hybrid solution.

This study selected the programming language of C#/ASP.NET, given its web-layered and object- oriented features, which were identified as being appropriate for this type of tool. Furthermore, Microsoft SQL Express was chosen as a Database platform.

A demonstrational virtual simulator will be developed, which will compare business, technical, and operational values of cloud services in accordance with required networking

and computational capacity in a Smart Building ICT environment. In essence, this software will be concentrating on Smart Buildings' key inputs from non-expert end-users concerning ICT instances, associated energy consumption figures, and management scalability aspects. The technical specification and primary evaluation templates of SBCE can be viewed in Appendix C.

This tool will customize a UML *(Unified Modelling Language)* diagram, which will be designed via *Enterprise Architecture* software prior to the development stage. According to the methodology workflow chart (Figure 4.1); the primary algorithm will be composed using a systematic comparison analysis, which is set to contrast findings from the literature review, theoretical cloud management analysis, and the practical field work conclusions from semi-structured interviews, surveys, and simulations. In conclusion, an in-depth case study of a Smart Building environment will be executed via *SBCE,* which will generate management reports illustrating recommendations on the extent of cloud costs, estimated energy efficiency, and other deployment considerations.

5.0- Chapter 5: Practical Value Examination

The main objective of this chapter is to construct a knowledge platform to develop a practical tool and a theoretical decision-making framework for cloud-computing utilization in different Smart Building ICT environments. This is discussed following a structured set of management and technical concepts, as explored in Chapter 3. As explained in Chapter 4, this research will carry on a primary field work which will follow a hierarchy workflow of unique stages as shown in Figure 4.1. This will first conduct semi-structured interviews with each side of the cloud-computing service delivery partnership (cloud service providers, and service requesters).

The first part covers viewpoints from *Rackspace-UK* and *GBM-Dubai* as major cloud service providers. Secondly, this study has selected Heriot-Watt University to represent a cloud service requester case study. Heriot-Watt University was chosen given its multiple branches which are located across three different countries, and each campus has numerous buildings. It was identified after investigation work that Heriot-Watt University can potentially form an ideal example for exploring ICT virtualization applicability, allowing this research to conduct a thorough assessment of cloud utilization in order to measure cost efficiency, sustainability, and future ICT ease-of-management.

This chapter will eventually conduct different scenarios for cloud adoption processes, which will employ certain technologies in relation to user access, hosting, and purchase. These will range from end-user general cloud instances, all the way to a certain extent of hardware and software outsourcing via cloud providers datacentres and networking infrastructures. The examination will then carry out –based on previous findings- a cost-forecast cloud simulation for a relatively similar environment to Heriot-Watt University, with altered ICT figures to enable a real-life demonstration of costs and sustainability benefits gained from cloud approaches to ICT provisioning. Furthermore, this project will perform a risk-analysis survey concerning multiple cloud-computing security aspects in order to address concerns and viewpoints of different non-expert decision-makers.

5.1- Semi-Structured Interviews

5.1.1- Cloud Service Providers Part (1)

This study first approached Oliver Pueschel, who is a senior Solution Specialist and Enterprise Hosting and Channel Consultant at Rackspace. The semi-structured interview was set to cover aspects of cloud-computing management from the service provider perspective. In essence, the structure of the semi-structured interviews was divided into three main categories: Business and Administration, Technical, and Sustainability. The interviews were structured to follow this project's main methodology discussed in Chapter 4. The full list of questions discussed with the cloud provider interviewees are explained and listed in Appendix D. In summary, the key areas of discussion have covered the following:

- Evaluating current cloud-computing market acceptance
- Up-to-date user-demanded cloud models
- Previous client experience and the provider's readiness to offering IaaS services and a complete infrastructure outsourcing onto the cloud
- Potential Smart Building ICT components for achieving an IaaS cloud migration
- Identifying virtualization and integration levels from clients' ICT system history
- Key challenges identified regarding support and implementation
- Pricing flexibility and time estimations regarding different cloud deployment approaches
- End-user motivation towards achieving sustainability in ICT, and associated economic influence on business and management.

At first, this project requested a personal industry brief from the interviewee in relation to Rackspace's general evaluation on today's top cloud market trends. This was approached with reference to market acceptance and progress of emerging cloud services in comparison with the traditional on-site-managed ICT industry. In that context, the interviewee portrayed the current status of any virtual ICT implementation as the future of how

businesses, governments, or even individuals request, access, utilize, and pay for technology appliances. According to Rackspace private records, today's client readiness towards cloud adoption is notably and rapidly increasing with each new development introduced to the ICT commercial market. While this was observed since 1998 to form a key factor in almost all internet-dependent service providers, it was particularly identified by Rackspace as a result of delivering cloud solutions to about 206,000 clients. The clients varied in terms of workload, sizes, and bespoke organizational requirements. They are being serviced through approximate 5,000 information system units across the world (Rackspace Int. Website, 2014).

The interviewee proceeded by discussing how cloud-computing services are the core of what Rackspace predicts to be the optimal solution to all sorts of ICT demands. These reflect virtualization, democratization, which are delivering top ICT services to small sized portfolios, and commoditization on several infrastructure levels. However, with regard to different Smart Building sizes and technical types, the interviewee termed this diversity as being "a *ubiquitous information and communication delivery"*. This statement was based on the fact that almost all existing ICT users adopt legacy systems via costly in-house infrastructure. For example, it was referenced by the interviewee that the CEO of Oracle Larry Ellison argued that cloud-computing is simply a newer version of previous innovations, and assigning a new polished name to existing internet-based services does not indicate the creation of a new virtual ICT era. For instance, from 2009 till today, the increase in the number of users and businesses currently hosted on cloud servers, classifies this period as a cloud-computing one; similarly to when mainframe computing was headlining the 60s (Kepes, 2012).

The interview carried on with investigating today's most popular cloud models in terms of cost-efficiency, reliability, and other administrative aspects as follows:

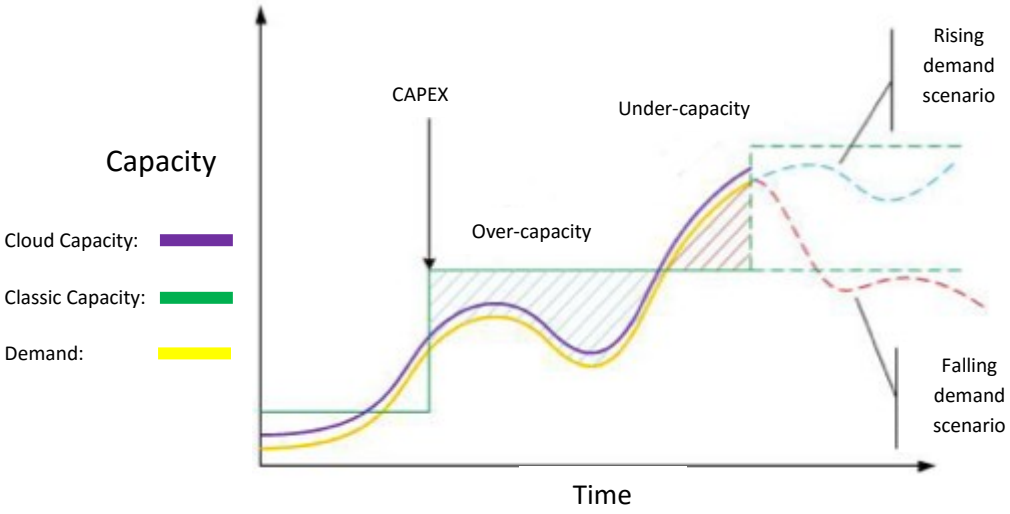
- Service Models: (SaaS, PaaS, IaaS)
- Architectural types: (Off-premise Public, On-premise Private, Hybrid, and Community)
- Hosting techniques: (Colocation purchase, Managed renting, or a fully Cloud-based virtualization).

We asked the interviewee to provide an estimated percentage of each approach in relation to Rackspace heavy-load operations and accumulated professional experience. While these were collected without taking into account end-users' project sizes, budgets, or specific business aims, it was first confirmed that SaaS services are the most popular among the majority of Rackspace clients, given the following facts:

- The core service domain of Rackspace is currently industry-focused on Managed Hosting, Cloud Hosting, and Email Applications: This indicates that today's ICT market is more focused on increasing revenues from purchasing online pay-as-you-go features by preferring the easily accessed, purchased, and managed SaaS dynamic characteristics as explored in Chapter 3.
- High readiness factors in terms of security and simplicity: This was argued in response to the manner in which resources are entirely hosted online and can be accessed easily following isolated connections from on-premises, and in some cases offline-managed systems, which provided additional security.

Hybrid Hosting was identified by the interviewee as the most popular deployment model to be across existing Rackspace clients. In particular, the interviewee emphasized on *Rack-Connect*, which is a VPN access service between Rackspace datacentres and end-users who wish to combine both scalability and fast provisioning features of cloud services with high levels of security and in-house management of internal systems. The following figure shows how cloud services have almost achieved the ICT demand level of end-users, while the classic capacity line is fixed and does not always correspond with the ICT demand of end-users (Figure 5.1). As a result, end-users will end-up with either:

- *Over Capacity*: This will occur when organizations use owned conventional ICTs that have more capacity than required in real-life. As a result, these users will be forced to continue managing and paying for system runtime and maintenance of unneeded ICT infrastructure.
- *Under Capacity*: This will occur when organizations use their owned conventional ICTs that have less capacity than required in real-life. As a result, these users will be forced to fully purchase new systems to meet this demand, and provide support for this new infrastructure, which is only needed for a short period of time.



(Figure 5.1) *Rack-Connect Service*: Capacity comparison of Cloud vs. Classic Demand (Rackspace Interview, 2014)

According to Rackspace's client records which were provided exclusively to this research, consumers with unstable ICT demands are complaining from the rising cost of their existing in-house systems. The *Over Capacity* is observed more in big organizations where unexploited resources are purchased, which leads to additional expenses on support and upgrade. However, the *Under Capacity* aspect is observed more in small organizations where less ICT demand is usually required in most applications.

Following an IaaS approach with the exclusion of numerous current cloud-hosting services, this study inquired about the actual technical feasibility of outsourcing and hosting an entire Smart Building ICT infrastructure onto a cloud platform. This covers networking servers (e.g. employees' personal profiles, permissions, group policies, mail services, and databases). Simultaneously, this process was argued by the interviewee to rely only on Graphical User Interfaces (GUIs) as an on-site ICT platform (e.g. screens with Ethernet access, ad-hoc ports with minimum buffering power like Chrome Box from Google, IBM pure-systems, which act as an optimized private cloud and self-service user interfaces).

The interviewee showed interest in the previous question, and stated that to date, a 100% cloud-migrated infrastructure was never accomplished. However, multiple case studies that are currently using Rackspace technologies have been investigating this possibility, while already being implemented through major virtualization approaches with respect to hosting, networking, and storage. The interviewee provided this research with several case studies

from Rackspace clients who are utilizing either a Managed Hosting approach, or Cloud Hosting services. For instance, Rackspace users are empowered with a Cisco powered networking infrastructure. This is implemented through an open source cloud platform called *OpenStack.* While this mainly includes routers, firewalls, and other networking devices, it was pointed out that ensuring performance reliability of such services currently forms one of the major cloud-computing limitations as discussed previously in Chapter 2, sub-section (2.2.7).

On that note, six different case studies were presented from Rackspace's private client records. Rackspace allowed this research access to these records in order to support the overall decision-making system in which this project will ultimately construct for demonstrational purposes. The examples included are

1- London Olympics 2012: VisitBritain
2- The UK's leading luggage company: Antler
3- The world's largest and most popular pizza chain: Domino's Pizza
4- One of the world's top plastic manufacturers: Moss
5- The global SaaS provider: Axios
6- The online ecommerce giant: Groupon

These organizations were selected given that their ICT environments cover about 500 markets across 40 countries combined. The following table was constructed in response to the interviewee's semi-structured answers and available client records (Table 5.1). The table illustrates each case study's domain of cloud utilization, type of hosting, degree of virtual migration, and clients' feedback.

(Table 5.1) Rackspace Case studies' Analysis

Name of Rackspace Client	ICT Dependence	Location	Type of cloud-computing Utilization	Case Study Technical Description
Antler Luggage	Online distribution covering over 15 countries	Manchester, UK (Physical Building) with multiple UK and global online-connected distribution centers	Annually renewed contract for Managed Hosting only, with a fully managed Cisco ASA firewall. (£ 783.55 Setup + £ 1,080.56 monthly payments)	Dell PowerEdge website hosting server, single processor with Raid5 managed MySQL agent backup and a Red Hat Linux Enterprise operating system with 100 Mbps network, 1000 GB bandwidth per account.
Domino's Pizza	Radically evolving online demand with 770 online-connected stores	Milton Keynes, UK (Physical Building)	*RackConnect* Hybrid Cloud Hosting. While aiming for 1200 UK stores in 2021, Dominos had outsourced the entire hosting infrastructure for economical and scalability leverages.	With 1/3 of orders are purchased online), Dominos internal team was able to focus more on improving core competency innovations, and less on IT upgrade, business apps, hosting and support.
Moss Plastics	ecommerce industrial Point-of-Sale units, with 7 UK & 11 EU-based online-connected distribution centres	Clapham Junction, UK (Physical Building)	Annually renewed contract for Managed Hosting only, with a fully managed Cisco ASA firewall. (£ 783.55 Setup + £ 1,080.56 monthly payments)	Dell PowerEdge website hosting server, single processor with Raid5 managed MySQL agent backup and a Red Hat Linux Enterprise operating system with 100 Mbps network, 1000 GB bandwidth per account.

GroupOn ecommerce	ecommerce/business shopping and distribution giant, covering 500 markets across 48 countries	Chicago, USA (Physical Building) Dublin, Ireland (Physical Building)	Rackspace SaaS Software as a Service solutions (e.g. Zendesk ticketing system)	The demand was to radically increase customer service through a cloud-based ticketing system.
VisitBritain – 2012 London Olympics Project	Marketing Britain worldwide for tourism and travel via digital engagement and online-channel commerce	London, UK (Virtual Buildings & multiple physical distributed offices)	Design, built, front & back-end development of VisitBritain web-application, in addition to shared online hosting with SapientNitro brand communication and cloud hosting company.	Main demands were concentrating on acquiring a server ability to manage about 500,000 users per hour during the 2012 London Olympics, in addition to ensuring ICT hardware sustainability after all games are concluded (e.g. dumping large amounts of unneeded hardware).
Axios - SaaS Provider	World's leading best practice-based IT solution management (ITSM) across 6 continents.	Headquarters in the UK with global offices & virtual middleware services across USA, Canada, Middle East, Africa, and the Asian Pacific.	Rackspace cloud hosting primary partner (servers, software licensing, restore functions, upgrades, monitoring, backup, and IT management)	Clients require 100% network uptime and worldwide fanatical support. Therefore, Axios was able to greatly reduce in-house IT staff, merely, through a complete hosting migration.

The previous information relates to Smart Buildings given that those organizations include ICT environments where a degree of system integration is accomplished as confirmed by Rackspace. Furthermore, the *Location* column in Table 5.1 above shows that most of these organizations have multiple physical branches in various locations which occupy numerous buildings that include different types of ICT applications.

Other examples were also mentioned throughout the Rackspace interview, such as the Australian hardware and software hospitality industry: Monument, which utilized PaaS services for ICT migration from business legacy systems. In addition, the global dieting company Live Smart, relied on Rackspace IaaS services for massive scaling processes in order to manage large server spikes and increasing traffic that reached around one million viewers in 2008.

With regard to cloud-computing limitations which were observed from Rackspace client profiles, a two-part question was asked to the interviewee as follows:

Which cloud products have been observed as the most challenging to implement, administer, and support? Furthermore, from a clients' perspective, what key barriers have been observed as a result of adopting cloud-computing solutions in Smart Buildings?

The interviewee approached this question by referring to various Rackspace executive studies and internal surveys, which were published on a regular basis as part of the company's process for enhancing core competencies. These reports were aimed to address cloud-computing challenges, security issues, system suitability and readiness, and other potential trade-offs. The interviewee did not answer this question directly. Instead, the discussion leaned towards Rackspace's research on this matter and the observed outcomes regarding potential hosting threats and other reliability issues.

> *"We recently added a considerable budget, along with an entire domain of internal research and development tools, all with respect to cloud security threat-recovery and maintainability. This was carried out as a result from an accumulated experience obtained from clients, whereas different hosting techniques have raised various threats concerning reliability, integrity of service access, confidentiality, and authenticity"*

Mitigating cloud-computing risks have been observed to cost organizations millions of pounds across the UK with reference to both contingency and recovery, the range of these risks have mainly included online terror attacks, Denial of Service DoS, in-house misuse of

information that leads to major losses in data and core knowledge, internal hardware failure, web worms, and other sorts of man-made server viruses. Furthermore, from a cloud provider viewpoint, Rackspace has argued that SaaS services are the most challenging to support in terms of maintenance, billing and utilization strategies. While these services are online hosted, accessed, and shared between multiple end-users, managing the methods that are implemented to achieve this access to the shared-pool of cloud resources, forms the biggest challenge to ICT providers.

Moreover, the interviewee was asked to specifically address the same cloud management limitations in accordance to different Smart Building ICT environments. The answer covered multiple ICT infrastructural aspects, which were divided into users who are either employing on-site private cloud hosting, or others who are utilizing a fully-online public solution. According to Rackspace, each of these includes numerous angles which have proved to be vulnerable in several areas for end-users, as will be explained next.

In order to best assess and minimize these vulnerabilities, Rackspace recommended that decision-makers thoroughly examine different cloud features before any virtual deployment takes place particularly regarding the various ICT attributes of the Smart Building involved. These mostly include in-house components which influence workload, peak averages, number of users, and internal integrated systems (e.g. sensors, CCTV, etc.). The following table discusses potential areas of threat regarding each ICT component in response to public and private deployments (Table 5.2). Furthermore, this table was constructed based on Rackspace reports provided by the interviewee as part of the interview. However, the table does not take into consideration the mutual aspects of both deployment techniques (Public and Private), as these result in the Hybrid hosting method, which is addressed as a separate case study.

(Table 5.2) Recommendations of In-house vs. Off-Premise Cloud Risks - Source: Rackspace Reports provided by the Interviewee.

Cloud-computing Areas of Vulnerabilities for Smart Buildings	**In-house Deployment**	**Off-Premises Deployment**	**Mitigation Approaches Recommended by Rackspace for Smart Buildings**
Personnel		√	Only specialist engineers with detailed background checks, are allowed to access clients' data records, networking devices and hosted servers
Datacentre Infrastructure		√	The provider applies 24/7 surveillance on server rooms, HVAC, UPS for contingency power generators, on-site security guards with forbidden public access, and ad-hoc (instant swappable) servers and router devices in case of unpredictable outages
Networking Infrastructure	√	√	Rackspace employs a 100% Cisco powered infrastructure to ensure a maximum networking security by offering Smart Buildings several in-house developed product solutions (e.g. ALTM *'Alert Logic Threat Manager'* as an IDS '*Intrusion detection System*', DoS *'Denial of Service'* for attacks mitigation techniques, and Firewalls)
Operating Systems & associated Hardware	√	√	Disabling non-essential operating system features, as this could prevent DoS attacks and guarantee hardware availability through acquiring close relationships with mutual vendors
ICT Conventional Virus Infections	√	√	Adding a fully-managed anti-virus solution to each cloud component, whether operating a Linux or Windows NOS
Internet Security Patching		√	Rapid processing of web-emerged risks and applying constant upgrades to all online security systems for regular effective monitoring

Cloud-computing Areas of Vulnerabilities for Smart Buildings	In-house Deployment	Off-Premises Deployment	Mitigation Approaches Recommended by Rackspace for Smart Buildings
Online-Oriented Apps		√	Identifying vulnerabilities in critical areas such as Databases, Linux Apatchi or Windows IIS platforms, different core servers including DNS, FTP, Mail Exchange, and so on
End-User Training	√	√	Adequate management, business processes safeguarding, and address Intelligent Buildings in-house policies and internet security (IS) potential threats, which would arise as a result from hosting critical customer data
Business Consultation	√	√	Apply a 3rd party consultancy (Web Security corporations)
Risk Admin Analysis	√	√	Apply a scheduled monitoring via state-of-the-art automated scanning technologies for all firewalls, SSL engines, load-balancer servers, networked routers/switches, and externally utilized systems, applications
ICT Virtual Forensics		√	Customizing a post-incident strategy for any unpredictable errors, by allowing a safe period of contingency time to analyse, handle, and eliminate occurring threats in real time
Testing Simulations	√	√	Implementing a full testing environment before any virtual deployment on either the web as public clouds, or on-site following a private or hybrid hosting
Customer service logs	√	√	Providing detailed reports on end-user cloud utilization in terms of access statistics, data rates, and billing, by designing a momentarily feedback portal for each service requester (e.g. vendor messages, potential threats)

In relation to the energy-efficient cloud-computing factor, the Rackspace interview did not include this as a key subject given that technical decision-making aspects took of the time available for discussion. However, this topic will be highlighted throughout the next semi-structured interview with GBM.

It can be concluded from the interview that Rackspace is focused on service delivery in terms of support, availability, and customer satisfaction, rather than empowering Smart Buildings with energy-efficient features of cloud applications. This conclusion came primarily as a result of service requesters' demands towards eliminating in-house ICT maintenance, upgrades concerns, and staff salaries. It was observed by this research that the majority of Rackspace Smart Building clients over the past 5 years are not particularly interested in the energy-efficient benefits gained from cloud services. Their main interest is obtaining cost reductions and decreasing time-consuming management efforts. This was explained by the interviewee due to the fact that obtaining considerable energy cuts from cloud-computing is still a debatable argument depending on multiple ICT attributes related to the specific Smart Building ICT environment involved. This research will particularly examine this argument in the cloud simulation case study in sub-section (5.2).

Nevertheless, it was stated by Rackspace that the topic of sustainability via cloud solutions has been recently emerging across different clients. For example, power optimization techniques have been addressed by Rackspace sizable clients from a wider perspective, which was mainly addressing electricity reduction impacts on various heavy-duty Smart Building functions such as elevators, HVAC smart solutions, and water meters.

In reference to previous Rackspace case studies presented in Table 5.1, one of the key examples was the VisitBritain agency, where the cloud sustainability factor has played a significant role in forming the client's ICT strategy. In this example, a large amount of hardware, and networking infrastructure was required to support a heavy communication processes and ICT capacity peaks. This demand was only required for the 2012 London Olympic games, which only cover one month of uptime ICT utilization. Therefore, cloud-computing features were a great solution for this scenario, avoiding having both *over capacity* and *under capacity* at the same time. Furthermore, cloud-computing sustainable techniques played a significant role in that respect, where ICT virtualization, migration, and

support, provided large scale virtual machines, server components, networking bandwidth, and 24/7 contingency maintenance of an entirely outsourced infrastructure, as presented in Table 5.1. On the other hand, stable ICT demands with minimum change patterns in capacity or service upgrade were also identified such as Domino's Pizza, and the luggage company, Antler.

The interviewee indicated that the topic of cloud sustainability is evolving drastically as clients' energy awareness in terms of ICT usage minimization, is gaining more attention every day in response to the costly ICT bills and associated management complexities.

5.1.2- Cloud Service Providers Part 2

The second part of the cloud providers' decision-making examination has been obtained from another semi-structured interview with Mr. Salem Cheikh Najib, who is a Senior Integrated Networks Specialist from the IBM subsidiary company, GBM. This interview has relatively inquired into similar areas from the last discussion with Rackspace. However, the intention of this examination is to cover a different domain of clients, which is considered significant to this research given several dissimilarities in ICT aspects. These are connected with geographical locations, ICT migration readiness, regulations, impacts on business processes, and special security considerations. In essence, the main area of discussion was addressing ongoing case studies, outsourcing limitations, ICT power consumption client awareness, and potential cloud sustainability solutions for GBM's Smart Building customers.

To some extent, it can be noted that the interviewee's answers were mostly following a technical and management nature, similarly to the data collected from the Rackspace interview. Accordingly, the main theme of the interview was discussing energy consumption via cloud solutions in Smart Buildings.

At first, this study requested a professional evaluation of market acceptance and progress of today's cloud-computing emerging services. This was discussed in comparison with the

traditional on-site-managed ICT industry. A summary of the interviewee's words are quoted as follows:

> "*I would say the technology in general is not at the acceptance level at all, but we have passed this stage a long time ago. There is a major shift from legacy physical server environments to virtual environments and we see this on a daily basis from both customers and vendors. The private cloud solutions have reached the expected maturity but there might be some reluctance about adopting public clouds due to many reasons such as security, bandwidth and latency issues"*

The interviewee was then asked to select and discuss -from a personal observation- the most demanded cloud service model, architecture type, and hosting technique. This was addressed in terms of client's tolerance to virtual ICT migration, reliability, and economic viability. The interviewee stated that all the above aspects are currently taken into account by clients and are being used in parallel with cloud processes. Furthermore, from the company's records point of view, the on premise private cloud is viewed as the preferred solution to GBM clients as it gives customers all the benefits of server and service consolidation without stripping the end-users' sense of control. In terms of on-site versus off-site hosting, customers in the Middle East region still prefer the on-site option due to lack of high-end datacentres and the partial absence of the co-location culture. As the number of datacentre facilities grows, private clouds will start moving from the local sites to the co-location facilities as long as the offerings make commercial sense. As for the subscription-based approaches, the interviewee argued that these are to this day extremely limited in general, except for some well-known IaaS platforms such as SalesForce, which are popular with many enterprise customers.

In terms of the feasibility to outsource and host an entire building's networking infrastructure on a cloud platform, end-users will only be required to use thin-client Graphical User Interfaces (GUIs) as an on-site ICT infrastructure. Examples of these GUIs are screens with ad-hoc ports Ethernet access and minimum buffering power such as IBM pure-systems, Google ChromeBox Cloud-based PCs, which are an optimized private cloud with a self-service user interface.

In general, the migrated domain of instances can include servers, employees' personal profiles, permissions, group policies, mail services, and database engines. In this context, some of the interviewee's key words were as follows:

> *"Fully managed hosted environments are being adopted by many businesses. Many IT managers would prefer a simple GUI that allows them to control the entire environment from a single screen. The larger enterprises such as Oil & Gas and financial services in addition to the public sector are still hesitant about moving their equipment off their site but wouldn't mind the concept of simplifying their environments as long as it stays in-house. IBM pure systems combined with VMWare vSphere, VMWare View and other cloud-based applications are on most ICT RFPs these days; and taking into consideration the support on the hardware and infrastructure levels from vendors like Cisco, Juniper and Fortinet is allowing end-to-end virtualizing of the modern data centre. On the other hand, IT staff themselves would probably resist such models as they see it as a threat to their employment"*

With reference to Smart Building IP-based internal functions (e.g. sensors, HVAC devices, CCTVs, and other server-integrated equipment), the interviewee estimated the percentage of ICT outsourcing via cloud services in overall building control systems, as being very low. In particular, this was concluded based on GBM's previous client experience obtained from different Middle Eastern and Asian case studies, and given that the migration of Smart Buildings' internal functions is viewed as a new trend. Moreover, systems like HVAC, BMS, intrusion detection, access control, and fire detection/suppression are still being hosted on-site. This came as a result of these systems being usually managed by external specialized companies rather than by ICT providers. The interviewee argued that this occurred when the telephony and surveillance services shifted to IP-based applications, and it will eventually happen with these services as well. Vendors like Cisco are already pushing for other areas such as Smart Connected Homes and others, as it is seen as an inevitable development of the available technology, which will be developed by many vendors over the next few years.

Nevertheless, in relation to the most challenging cloud products to implement, administer, and support, Mr. Salem acknowledged that Desktop Virtualization is one of the most difficult to accomplish due to different requirements of each client portfolio. From the client's point of view, when it comes specifically to public clouds, one of the main barriers is security, as clients still feel uncomfortable storing all of their data off-site. In addition,

other issues related to performance were observed by GBM in that context. In particular, high speed network connectivity being not always available, especially for GBM clients in the Middle East region, made clients more reluctant to move core applications onto the cloud. Moreover, even when the network is made available, the cost of obtaining this connectivity is very high in this part of the world as argued by the interviewee.

In the next question, we divided Smart Buildings into three hypothetical sub-categories:

- Small-sized start-ups (businesses, , small hotels, etc)
- Mid-sized users (schools, hospitals, government facilities, etc)
- Heavily-operated, IT-dependent organizations (banks, airports, stock markets, universities, etc)

We asked the interviewee to classify cloud customers using these categories from an economic value standpoint. Some of the interviewee's Key words were as follows:

> *"At the moment I would say the split is between the first two categories. Cloud-computing makes a lot of commercial and business sense for the first category as adopting such technologies simplifies their IT requirements, eliminates the need for expensive human resources, and turns the IT into a simple utility that they can factor into their OpEx easily. As for the second category, the benefits would centralize around simplifying IT management, reducing rack space and associated bills, and reducing IT team size"*

The interviewee confirmed the earlier statement concluded by this research in Chapter 3, that the long debate over whether acquiring a full cloud-computing ICT solution is more cost-effective than the conventional on-site one, has not yet been fully clarified. On that note, this research asked the interviewee to present GBM's business take on this dilemma. Recent examples presented in Chapter 3 proved that in some cases cloud migration was not economically efficient for a bespoke medium-scale deployment (Tables 3.5 & 3.6). This was shown to be a result of the numerous changeable technical and nontechnical variables in a Smart Building ICT environment.

According to the interviewee, for a Green installation in an heavily ICT dependent organization, adopting cloud-computing was in most of GBM's client cases more cost

efficient in terms of hardware, datacentre costs, and management. It was additionally specified that GBM has provided many customers with comparison matrixes, which showed annual savings, and in most cases customers were able to demonstrate up to 30% on both CapEx and OpEx. The savings got lower when a client moves from a legacy environment into a cloud one due to extra costs such as professional service support expenses, and non-planned hardware upgrades.

In relation to one of this study's aims of examining potential energy consumption reductions attained from cloud utilization, the interviewee has conclusively evaluated the energy-efficient cloud concept in contrast to traditional ICT approaches, and whether that would differ in relation to each Smart Building category or not. In brief, the interviewee's points were:

> *"We managed to demonstrate 30% savings on the OpEx and a major part of this saving was related to energy and rack space, which in turn means savings on cooling. For example, consolidating 10 racks into 5 would be an obvious saving even if the new racks required more power since power increase per rack costs is not linear"*

Several conclusions can be made after conducting the previous semi-structured interviews with the two cloud providers, Rackspace and GBM. This analysis will play a significant role in constructing this study's decision-making tool and theoretical cloud management framework for non-expert Smart Building managers. These areas of assessment have an impact on evaluating:

- Real-life cloud service costs attributes
- End-user acceptance and cloud migration readiness levels
- Integration feasibility with different Smart Building internal functions and systems
- Energy impacts
- Ease-of-management to reduce efforts and time, thus, enhance core competencies.

Both interviews have a particular significance to this research, whereby points from each discussion will play a critical part in programming this study's online decision-support system *SBCE*. The following sub-section discusses the second part of cloud service delivery equation, which is the cloud service requester. This will use Heriot-Watt

University as a primary case study for cloud-computing management and potential deployment assessment.

5.1.3- Cloud Service Requesters

The main objective of this research is to construct a decision-making tool for non-expert Smart Building managers to assess the extent of both sustainability and cost efficiency in outsourcing either a partial, or the entire ICT infrastructure onto the cloud. Heriot-Watt University was selected as a key case study to analyse the service requester point of view towards cloud-computing decision-making. The example was chosen given the nature of the university's business which includes:

- Three different campuses across three countries, Malaysia, Dubai and Edinburgh
- A considerable number of ICT-active users from students, staff and others
- Heavy ICT support and maintenance work required across numerous buildings located across the three locations
- Several Smart Building functionalities, which to some extent, have the ability to be integrated into different types of information and communication systems

As clarified in the Methodology chapter, this research involved an interview with the Director of Information Services at Heriot-Watt University, Mr. Roch. It was first highlighted that the ICT installation nature of the Edinburgh university campus was divided into separate schools. Each one acquired independent Local Area Networks (LANs), and this was due to regulative, political, and legacy system dependencies. This ICT adoption which is run by each school separately forms a challenge against which this semi-structured interview aimed to collect accurate data. However, all schools' ICT resources operate, to some degree, under a high-level platform which is managed by a primary ICT department in the main Edinburgh campus of Heriot-Watt University. The main aim of this interview is to measure costs, management effort, and sustainability aspects of existing ICT components, and analyse benefits or drawbacks from adopting a potential cloud alternative.

Firstly, I asked the interviewee to score the following ICT Management attributes for an interconnected set of Smart Buildings such as the campuses of Heriot-Watt University. This was answered depending on the degree of priority as illustrated in the following table (Table 5.3).

(Table 5.3) Heriot-Watt University ICT Management Attributes: Degree of Priority

ICT Management Attribute	**Degree of Priority** (1: lowest score, 12: Highest score)
• User Comfort	**7**
• Safety & ICT Security	**8**
• Public Compliance & Declaration Time	**5**
• Cost Effectiveness	**5**
• Building Management Adjustment Time & Effort	**4**
• Reliability	**6**
• Operating and Maintenance Costs	**6**
• Initial Expenses	**5**
• Service Life	**8**
• Work Efficiency	**9**
• Environmental Sustainability	**3**
• Upgrades Time & Cost	**6**

The discussion then asked the interviewee to evaluate the current Heriot-Watt University Smart Building management situation. This was requested in relation to existing building components, integration feasibility, levels of data collected by ICT systems and so on. On that note, the Information Services director argued that most of the components within the existing building infrastructure are neither integrated, nor compatible in any sense to be integrated to any sort of single jointly-administered solution. Examples of these components are HAVC systems, water sensors, power measuring devices, and CCTV

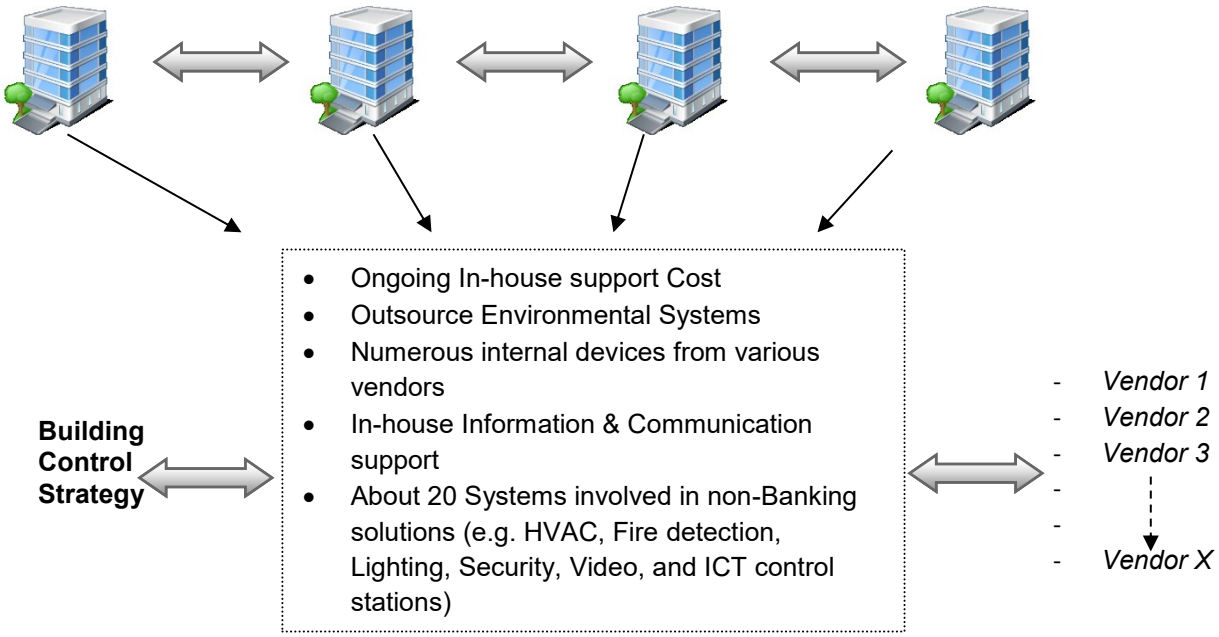
systems. This came predominantly as a result of acquiring legacy contracts with over a hundred different vendors as will be clarified in the following case study analysis.

The interviewee mentioned that being bounded by legacy contracts with external providers is a central existing principle, not only for Heriot-Watt University, but also across most large organizations in the UK that include various political and internal legacy factors. For instance, these vendors such as the CCTV monitoring provider have built the best of breed in-house security systems, which is intentionally made not to be compatible with other IP-based system in order to ensure providers monopoly. In addition, the generated output from such equipment is hosted on what is most likely to be a dedicated server. Therefore, the Heriot-Watt University security vendor, which is currently *Group 4 Security*, has specified certain system attributes that Heriot-Watt University systems must attain, such as 200 of a specific type of camera devices for the university's security system. In particular, *Group 4 Security* has demanded a pair of two additional servers, which are also residing in-house at Heriot-Watt University datacentres, but with a *Group 4* logo on them. Thus, these are administered by *Group 4* external personnel. Likewise, *Group 4* is nonetheless obligated to install an environmental air conditioning system as well as any other associated task to support each monitoring server, whereas this is by default plumbed-in into the building wiring systems of Heriot-Watt University connected campuses.

The interviewee has acknowledged about 30 different ICT vendors that Heriot-Watt University is currently in contract with. However, the area of discussion at this point covers any building components that are already integrated with ICT systems. These systems are mostly located off-premises, and managed externally through server hosting, upgrade processes, license purchasing, allocation of on-demand bandwidth and virtual machines. This allocation is structured by end-users through usage patterns according to peak times and other service attributes.

The interviewee presented an example to demonstrate the difficulty of assessing the feasibility for outsourcing the entire Heriot-Watt University building infrastructure into the cloud. This example discussed [a major UK bank] which has multiple Smart Buildings in different locations, and includes many ICT systems. The bank employed a considerable number of external providers on several management and technical levels which affected

almost all ICT attributes of the bank's plumbed-in systems such as its datacentres' sizes, storage, security, control panels, and power supplies. Moreover, other types of ICTs for environmental control purposes were also adopted by the bank, and provided by external and independent vendors such as *Fujitsu* and others (Figure 5.2).



(Figure 5.2) Example of Plumbed-in Systems of Major UK Bank

It was observed that the Heriot-Watt University director of Information Services (DIS) was emphasizing the complexity of any ICT management as a result of being bounded with contracts between external providers and a multi-vendor organization such as a large university, a global bank or others. It was pointed out that it is extremely challenging to combine a large number of services from existing suppliers into one hosting solution, as this forms the first stage of any type of cloud migration.

With reference to the Heriot-Watt University ICT management strategy, the main areas currently covered are hosting characteristics, hardware purchase requisites, installation effort and costs, networking suppliers, end-user access, administration, and maintenance. This study investigated these areas by relying on the direct assistance of some of the university's ICT personnel. The Heriot-Watt University Edinburgh campus alone consists of eight schools, whereby each run a small number of PC labs and acquires in-house servers and sub networking domains. Above all, the head ICT department is responsible for several

external labs in addition to the university's central datacentre that covers the entire buildings' ICT infrastructure, which is including the main library where a considerable number of PCs are also installed.

The following illustrates estimated numbers on the Heriot-Watt University core ICT infrastructure of the Edinburgh campus. These statistics only represent completed figures and all labs in each school will be jointly calculated in relation to servers, PCs and other networking devices. Furthermore, measured numbers have been slightly modified to best fit the case study's cloud simulation, which will take place in the next sub section in terms of approximated cost and environmental benefits gained from applying ICT virtualization.

It was clarified that there are currently 25 ICT personnel employed for the entire Edinburgh campus. Nevertheless, the interviewee argued that only one technician out of the 25 is enough to manage the entire server infrastructure, as administrators rarely ever intervene with any switched-on servers after a proper configuration, planning, installation, and initial monitoring had taken place. In addition, Heriot-Watt University has around £0.5 million a year assigned to the ICT infrastructure and divided as follows:

- £ 100,000 for Information Systems upgrade
- £ 250,000 for Networking and Communication Systems upgrade
- £ 100,000 for Hardware Maintenance (e.g. core networks, remote monitoring, etc.) (20% of the total budget each year)
- £ 50,000 for Software support from various vendors (excluding fixed contract costs)

As previously mentioned, a large number of information and networking suppliers are currently in contract with Heriot-Watt University on either an annual or a five-year contracts. These service providers are employing, to some extent, a redundant system strategy with the Heriot-Watt University in-house datacentre. Some of these key providers are as follows:

- *Extreme*: a five year deal with fixed price for Data Switching and Networking solutions (e.g. VTNs: Virtual Tenants Networks, Datacentres connectivity, enterprise LANs)
- *NetApp*: a five year deal with fixed price for Raid Technology File Servers, with a 4-hour response support in case of high level urgent issues

- *Blackboard*: a five-year deal with fixed price for student/teachers Virtual Learning Environment. This is mainly a Hosted Application located in Amsterdam-Holland, and accessed via a 1 GB Internet bandwidth (e.g. Student exams, e-learning storage and editing system, similarly to Moodle Open Source).
- *Microsoft Office 365*: a five year implementation, support, and upgrade deal, with fixed price for Student Emails, whereby a hosted application located in Dublin is accessed via a 1 GB Internet bandwidth.
- *Protocol Hobsons*: a five year deal with fixed price for a Hosted Application located in the US for Student recruitment, CRM, etc, and accessed via a 1 GB internet bandwidth.
- *Oracle*: For a Hosted Application concerning student financial records. This is on-premises and accessed / monitored through local area switches.

It was argued by the interviewee that given the strong dependence on external vendors, along with the unstandardized separate schemes concerning each school's ICT distribution and administration, major decisions regarding technology are adopted through a collective participation between each school's head of IT, and the university's information system director. Ultimately, the principle of the university will sign-off any final decisions related to ICT purchase, and new strategy adoption. This process forms another complexity towards migrating into a cloud solution, given the bureaucracy behind each decision.

With reference to the current status of cloud-computing at Heriot-Watt University, this interview investigated any existing types of virtualization in relation to ICT deployment, application access, or infrastructure utilization. According to the interviewee, about 250 (VMs) virtual machines are currently installed and operating on the Heriot-Watt University main datacentre servers. The overall server infrastructure includes around 28 racks of servers, and these were divided into 20 racks on-premises, and 8 hosted in a rented datacentre which is located in Edinburgh city centre. On that account, the following key points can be identified from the virtual deployment which Heriot-Watt University is currently running and privately managing:

- The current ICT cloud situation is similar to a private cloud solution, yet, the management, support and purchase are all privately attained, and without any external

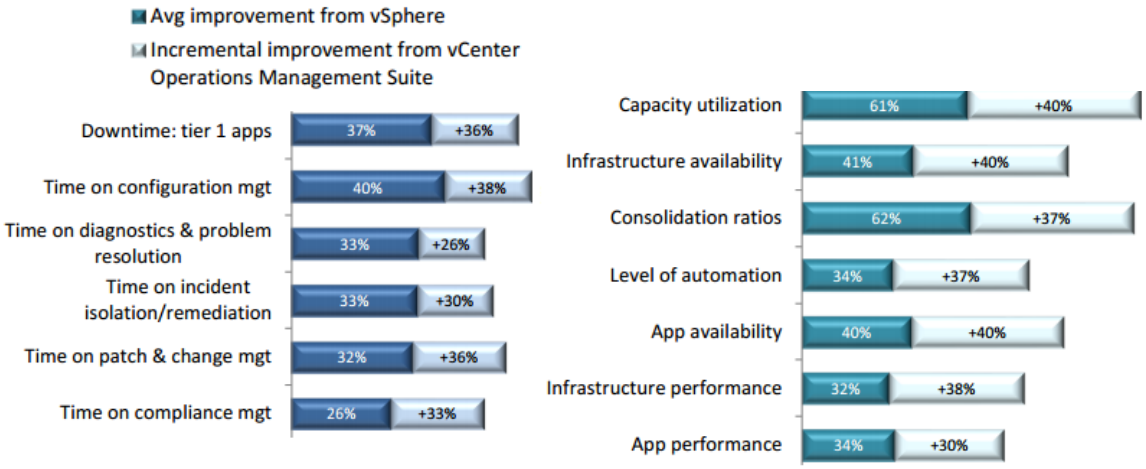
cloud provider involvement (application and networking vendors are not included in the server-racks administration).

- The 250 VMs are running on privately owned hardware, thus, there is no ability to scale up/down instantly to suit peak demands and the overall servers' performance might be compromised when changing the capacity (e.g. student exams, an annual staff records backup, and online registrations).
- While private clouds assist in critical aspects such as load balancing, provisioning a number of concurrent processes, reclaiming access to service, and monitoring deployed applications, the existing in-house VMs are solely operating on a load-balancing basis.
- Even though the private cloud deployed by Heriot-Watt University uses similar fundamental components to eventually deliver a parallel virtual environment, the main difference in both the financial and operational aspects of the ICT lifecycle, which are likely to be more expensive and less flexible than the current Heriot-Watt University approach.
- IT personnel do not receive access to a GUI vCentre such as VMware's *vSphere*, as is the case in an in-house private cloud solution. Accordingly, essential service characteristics will have a restricted reach by in-house administrators at Heriot-Watt University, which decreases the potential for performance metrics improvement.

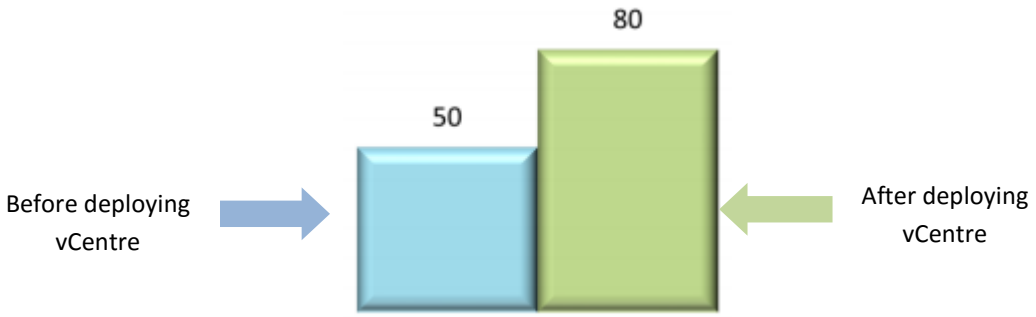
The following figures clarify this by displaying an average improvement rate and operational benefits from applying *vSphere* private vCentre cloud for ICT management instead of a partial in-house virtual datacentre (Figures, 5.3 and 5.4).

With reference to the previously discussed cloud-computing deployment models (Hybrid, Private, Public and Community), this study asked the DIS to determine which hosting method would best suit the portfolio nature of Heriot-Watt University campuses. The answer suggests the Hybrid hosting approach (as identified in the literature review Chapter 3) as the ideal choice and a middle ground to meet most requirements of the different types of non-expert cloud users. These groups of users are mostly looking to adopt the securest approach without investing money, time, and management effort in a detailed ICT options appraisal process, which often needs to be outsourced to a costly 3rd party consultancy provider called a cloud broker. As will be discussed in Chapter 6, this gap can be mitigated by this study's online decision making tool *SBCE*, which follows an automated process to

enhance decision procedures required for various types of cloud adoption depending on the unique aspects of different Smart Buildings and organizations.



(Figure 5.3) A VMware customer survey: Reported Benefits from Applying *vSphere* Private Cloud-computing , instead of a Virtual in-house Datacentre. Source: VMware: Management Insight Technologies.



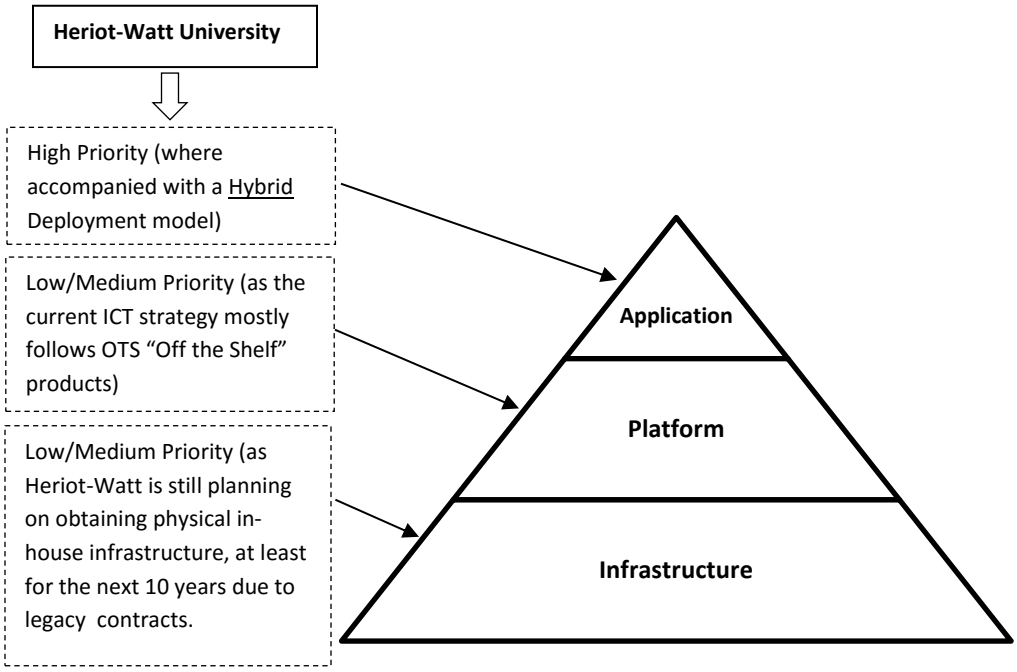
(Figure 5.4) Support Requirements: Number of VMs per 1 Administrator after and before applying vCentre. Source: VMware: Management Insight Technologies.

This research raised a similar question with reference to the three -NIST defined- service oriented techniques (IaaS, PaaS, and SaaS). This was discussed with respect to the various types of applications employed, users, building requirements, networking bandwidth and hardware infrastructure, which would best fit the end-user utilization criteria of Heriot-Watt University. The interviewee argued this as being an administratively challenging side of cloud-computing, which affects key ICT variables currently practised at Heriot-Watt University. In essence, it was pointed out that Software as a Service SaaS comes at number one, as Heriot-Watt University already employs numerous applications across each sector of the university, such as systems for human resources, sports club membership, students' union, examination administration, and many others. While each of these applications is

billed individually in terms of both copy/licence and hosting, the latter is mostly performed in-house using privately owned and managed Heriot-Watt University servers. Some of the interviewee's views on this topic are captured by the following statement:

> *"SaaS is where we are starting; If Heriot-Watt was to pay somebody else to solve its ICT problems, we do not really care if they are doing it with a string and a wooden box. Although, we are not interested of the means, we strongly examine the price, the quality, and the risk. Therefore, because we do not internally develop, and because Heriot-Watt University always uses packages which are taken off the bag, I am currently less interested in anything below the SaaS"*

With reference to the Platform as a Service PaaS and Infrastructure as a Service IaaS deployments and ranking depending on the ICT migration priority for Heriot-Watt University, the interviewee showed no current interest towards both models given several risks and uncertainties. While the emphasis was strictly on acquiring SaaS applications as a starting point, various barriers were noted to limit management readiness and decisions, especially as a result of the large number of external vendors and systems in which Heriot-Watt University is currently in contract with. Nevertheless, according to the earlier discussion on the three deployment models (Public, Private and Hybrid), the ICT director connected both answers and argued that a Hybrid model consisting of SaaS applications is by far the most suitable hosting technique for the three campuses across Malaysia, Dubai and Edinburgh (Figure 5.5). This figure was constructed from applying the interviewee's response to the standard cloud-computing architectural model, which was discussed previously in Chapter 3. It was discussed by the interviewee that realistically, in the foreseeable 10 years future, Heriot-Watt University will still have in-house servers regardless of any cloud outsourcing procedures in terms of information systems, networking infrastructure, or other Smart Building equipment with integrated output.



(Figure 5.5) Cloud Service Models: Heriot-Watt's Degree of Priority in relation to each Model

Subsequently, this interview addressed the management priority selection for Heriot-Watt University in relation to the cloud-computing characteristics, which are explained in Chapter 3. On these grounds, the interviewee re-ordered the following cloud characteristics, depending on the level of importance and according the university's ICT peak reliance and service demands (Table 5.4).

(Table 5.4) Cloud-computing Characteristics: Degree of Priority (1: being the lowest, 5: being the Highest)

Cloud-computing Characteristic	Description, and the Interviewee's Argument	Degree of Priority
On-demand self-service	Automotive provisioning of service without the need for a direct contact between Heriot-Watt University and the service provider each time an adjustment is required (e.g. scaling up/down, turning off particular servers during weekends, and so on).	3
Broad network access	Heriot-Watt University end-users can access each service, virtual machines, networking devices, or development platforms via an online-based network, which supports both thin and thick clients.	5
Resource pooling	Applying a multi-tenant architectural model by the service provider, where numerous consumers are sharing the same services from an unknown shared pool of dynamically accessed, released, assigned	2

	and reassigned resources.	
Rapid elasticity	Enabling rapid service scalability (up/down), depending on Heriot-Watt University periods of peak workload, number of users, and bandwidth demands.	1
Measured service	Applying a metering approach of billing relatively similar to water and electricity bills for any Smart Building. This optimizes resource utilization, thus, providing an additional transparent layer of controlling suitable types of ICT components specifically required for Heriot-Watt University buildings across different locations.	4

It was suggested by the DIS that while money is not a key decision-making factor for the ICT infrastructure, the on-demand self-service characteristic was therefore identified as a low concern. Moreover, it was stated that being charged a fixed price for a yearlong reliable service is more important to this organization, even during the summer low-demand period, than acquiring a self-service-oriented delivery model where the price certainty is worth a limited amount of associated risk. Therefore, Rapid Elasticity was classified as an essential prerequisite, only if cloud-computing services were to be purchased. Nevertheless, with respect to Resource Pooling, the DIS argued that Heriot-Watt University must operate in a way that would ensure an exclusive use of all shared resources. In parallel, with regard to all virtual machines located at the provider's datacentre, although all end-user resources are hosted and run alongside each other, both the finance and registry records must not have any sort of shared access. As a result, this would cause a slight concern for guaranteeing optimal deployment from the provider's end of operations.

In relation to the previous question, several security and management limitations were mentioned by the interviewee from partially outsourcing ICT services, similarly to what was discussed in Chapter 2, sub-section (2.2.7). However, from an end-user risk-analysis perspective, we asked the interviewee to score the following limitations and potential threats towards employing any virtual techniques of cloud-computing. This was presented with reference to outsourcing either a partial or an entire scope of the Heriot-Watt University ICT platform, which includes ICT support, personnel salaries, and external contracts with numerous vendors. Essentially, each of these limitations was argued from a technology management perspective, and taking into consideration acquiring a long-term

ICT utilization. The following table demonstrates the level of priority of each limitation in accordance to the ICT lifecycle nature of Heriot Watt University (Table 5.5).

(Table 5.5) Scoring of Potential Cloud-computing Threats in relation to Heriot-Watt University current ICT Management (1: being the lowest, 10: being the Highest)

Potential Risks	Degree of Priority
General Security for critical data records	2
Replacing on-site ICT personnel with a third party management provider	3
Data storage confidentiality, authentication and integrity	6
Unpredictable performance with respect to online connectivity and various networking factors	8
Availability rates	1
Concerns about an unstandardized access of information	6
Difficulties in integrating with costly in-house legacy systems	8
The self-service, pay-as-you-go model will cost Heriot-Watt University more than conventional in-house deployment and support.	7
The unsteady billing nature of cloud services is in some cases unreliable	7
Other limitations related to system rollback difficulties and lack of system customization,	5

The previous table presented each risk category in relation to Heriot-Watt University, and the score identified by the interviewee next to each. Furthermore, this research discussed with the interviewee in more detail each aspect of the above and highlighted the relation to Heriot-Watt University current ICT environment in terms of requirements, case studies, and current infrastructure setup.

With regard to the first point: *General Security for critical Data records,* this can involve student records, staff employment information, exam questions, and budgets. According to the interviewee, the 3 Heriot-Watt University campuses across 3 countries must comply with each regional regulation in terms of users' data records. Therefore, this must be specified accurately in any cloud contract with an external provider that employs shared

pooling and other integrity alarming features. In relation to the second risk category: *Replacing on-site ICT personnel with a third party management provider*, according to the interviewee, this can be challenging for the university in terms of response time, rapid delivery, scalability of deliveries, and so on. The DIS argued that the only way to appoint a cloud supplier to replace the management of the ICT infrastructure is by obtaining more confidence, and Smart Building control readiness, as opposed to what in-house staff can offer.

With regard to the third point: *Data storage confidentiality, authentication and integrity*, the interviewee argued that adopting cloud services is risky at this stage for Heriot-Watt University given several privacy concerns such as the unspecified hosting whereabouts, shared systems with unknown number of users, and number of virtual machines employed for delivering a single service. While every data record at Heriot-Watt University is subject to the Data Protection Act, there are laws controlling where the data is stored, who is it shared with, and who has access to it. This was raised as a key management barrier towards a full cloud migration given that UK laws for instance are dissimilar to Asian ones in respect of deploying private user records off-premises. With reference to the fourth risk category: *Unpredictable Performance with respect to online connectivity and various networking factors*, the interviewee related this directly to online connectivity and various other networking factors. Furthermore, it was pointed out that by examining the example of *Blackboard* SaaS utilization, a major concern occurs at this point in the case of any disruptive problems in terms of a connectivity collapse, electricity breakdown, and so on. For example, these unpredictable incidents might occur in Holland, where this Software as a Service SaaS is hosted, which causes a complete paralysis in all sorts of access.

In relation to *Availability rates*, which is the fifth risk category scored in the previous table, the interviewee connected this to urgent support, contingency actions in case of an offline situation, and change of permissions.

> *"While networking outages were the main concern in the previous point, no specific risk was identified in availability rates, as subconsciously, a manager is always assured that a 24/7 support is within reach if needed according to the cloud contract with the supplier"*

With regard to the sixth risk category: *Concerns of Unstandardized Access of Information*, the interviewee argued that this can occur as a result of adopting multiple offsite parties due to lack of interoperability standards. It was proposed by the interviewee that there will always be a need to link-up the Amsterdam's *Blackboard* software specifications (e.g. Students' calendars), to Microsoft's email hosting solutions in Dublin via Microsoft 365 accounts. This forms a real concern in relation to applying this integration between each supplier's ICT systems, whether hosted on the cloud or not. On the other hand, this is known to be easily performed in the situation of a full in-house hosting, administration, and support.

In relation to the seventh risk category: *Difficulties in Integrating with Costly In-house Legacy Systems*, the interviewee presented challenges related to system compatibility as an example of this.

> *"These systems are currently working fine and there is no actual need for cloud migration at this point in my opinion. In order for Heriot-Watt University staff and students to adapt to novel cloud applications after an old habit of constantly utilizing in-house conventional platforms, it is a major concern not only to comply with the technical side of compatibilities, but also with regard to users' comfort, knowledge, training cost and time, and long term readiness"*

It was also argued by the Heriot-Watt University DIS that the cost of change in contrast to the process of installing, configuring, and adapting to a new system, would take the university at least 3 years of heavy work and training.

With reference to the eighth risk category from the table above: *The self-service, pay-as-you-go model might cost more,* the interviewee discussed his previous work experience with [a major UK university], where various points on a cloud-computing migration processes were evaluated and put into practice after proper risk investigation. The project employed Amazon EC2 services as an alternative to a two million pound in-house infrastructure solution. However, it was concluded that an Amazon contract, which will be charging per each GB of lifetime service upload and download, will be more expensive than purchasing the required hardware, excluding long-term upgrade costs.

With respect to the ninth risk category: *The Unsteady Billing Nature of Cloud Services is in some cases Unreliable*, the interviewee argued that regardless of whether this is connected to IaaS, SaaS, or PaaS employment, there is a risk of unreliable contract handling to occur from the provider due to the lack of detailed measurements and solid contract specifications before any virtual deployment or purchase. While the university currently adopts a fixed price contract with *Blackboard* in return of cloud hosted SaaS student learning services, a key concern is raised in case Heriot-Watt University expanded its ICT capacity, and hence, a faster ICT service delivery will be required. This is mainly due to the current fixed deal, which includes a specified amount of ICT attributes such as bandwidth and storage.

With regard to the tenth and final risk category presented in Table (5.5): *Other limitations related to System Rollback Difficulties and Lack of System Customization,* the interviewee argued that it is essential to possess an alternative in case of a full system breakdown caused by a cloud failure. Given that this solution will integrate the entire Heriot-Watt University portfolios into a single virtual system regardless of multiple back-ups also installed on virtual machines, this would result in a complete halt of the system, which is a key risk for the university. It was acknowledged that a complete halt of the connected ICT platform is without a doubt a possibility and a potential risk, which must be prepared for in response to a full Smart Building cloud migration. While companies such as Google, Vodafone, and Yahoo have had a complete shutdown of service, it is a massive management misconception not to equip a Smart Building for such a potential occurrence, especially while cloud-computing is still an evolving technology on numerous management and standardization levels.

In conclusion, the interviewee argued the main change that occurs when a Smart Building or any organization utilizes cloud services, is the fact that instead of dealing with personnel management issues, managers in this case are forced to deal with contract management issues. It was also emphasized by the ICT director that as a decision-maker, it is to a large extent less favourable for a university to pay revenue costs and service charges on ICT components, than spending capital on actually buying the required systems. Particularly, the more Heriot-Watt University can own actual infrastructure, the more confidence it acquires in terms of having control over already paid-for services. In other words, the

university would rather spend a million pounds on systems, than spend the same million for a three year deal in relation to the same service but with a virtual deployment solution.

In relation to the energy consumption standpoint of Heriot-Watt University regarding existing information and communication technologies, this was classified by the interviewee as being insignificant at the moment. In essence, it was recognized by the interviewee that the general ICT power consumption factor does not form a concern on any level for the IT department, or any other department for that matter. In principel, the ICT physical and software infrastructure only occupies a small portion of a wider domain of heavily power consuming systems such as building equipment and HVAC. This also includes associated salaries of staff and external personnel involved in these systems.

Nevertheless, while each PC consumes almost 250 Watt of the CPU/power supply, according to statistics provided by the interviewee, Heriot-Watt University campuses across three countries currently acquire around 5,000 PCs implemented. This is distributed across nearly 30 labs for the Edinburgh campus alone. While 21 labs are assigned to Schools, 8 were designated for external utilization, and one for the main library. The ICT director pointed out that so far the university is only focused on virtualizing servers, and not thin client devices such as PCs and other Smart Building ICT units. This results in around 1.25MW from ICT components alone, and not including any other power generated end-user devices.

The following in-depth discussion will analyse cloud deliveries, requirements, and management attributes in accordance to aspects from the existing Heriot-Watt University ICT environment. This forms one of the main pillars for Smart Building ICT decision-making for measuring the extent of cloud cost efficiency and sustainability towards a specified level of migration, and according to ongoing legacy systems and rooted contracts with various external vendors.

5.1.4- Summary of Interview Responses

This study carried out two semi-structured interviews, which addressed the cloud-computing supplier perspective with regard to feasibility levels of outsourcing a Smart Building ICT infrastructure via different types of cloud techniques. Although this was argued in terms of cost efficiency, management readiness and sustainability, other barriers and ongoing solutions were analysed to achieve optimal decision-making and risk mitigation processes. Furthermore, this study used Heriot-Watt University as a key case study for assessing the management and technical readiness for cloud adoption from the service requester point of view. The following table shows data estimates from selected areas and ICT aspects of the university, which were pointed out and provided by the Heriot-Watt University DIS. These estimates were investigated and sorted in order to highlight the relevant aspects to this study's objectives (Table 5.6).

(Table 5.6) ICT Completed Annual Costs, Sustainability and Infrastructure Budget Estimates (Academic term of September 2012-August 2013)

Completed Estimates on Cloud-computing Dependencies:	**Values & Description**
ICT Establishment Costs (Electricity VAR to per/year actual)	£ 49,863.00 out of £ 175,000 of full annual establishment costs (Cooling, HVAC and other associated power consuming attributes)
Power Usage Effectiveness (PUE):	For PCs alone: around 5,000 PCs and 250 Watts per PC = 1.25MW for the entire Thick-Client / PC infrastructure.
Number of Heriot-Watt University ICT Users (Staff / Student)	17,000 Student + 1,500 Edinburgh Staff + 100 Dubai Staff + 20 Malaysia Staff = around 20,000 Total
Number of IT personnel (networking administrators, system specialists, in-house developers, etc.)	25 Edinburgh Campus (Main IT Department) + about 25 personnel assigned for Heriot-Watt University schools.
Average Salary of a Heriot-Watt University IT personnel	UK 7 Grade Salary = around 36K per year

Number of Physical Server Racks (Owned)	28 Racks = (8 Racks located in City Centre private facility) + 20 Racks in-house
Number of existing Virtual Machines	250 VMs installed
Connection Bandwidth/Cost	Privately owned 10 GB/s Fibre = £ 40,000 a year
Watts per Server Rack	8K Watts per Rack
Abstract Cost for each Server	Around £ 50,000 a year
Networking Bandwidth (Traffic) average	250 Mb/s for 1 GB Internet Link
Networking and end-user operating systems employed (Linux / Windows)	A full Microsoft OS / NOS Solution
Type of licensing purchase and renewability (OS & applications)	An annual fee of £ 0.5 million
Costs of Hardware Maintenance	An annual expenditure of £ 25,000 a year
Average budget for complete ICT maintenance (PCs, Networking equipment, Servers, etc.)	An annual expenditure of £ 110,000 a year
An Overview Cost of key –externally assigned- ICT suppliers	*Microsoft*: £ 75,000 a year *Blackboard*: £ 120,000 a year *Oracle*: £ 100,000 a year And numerous others such as *NetApps, Extreme, Protocol Hobsons,* etc.*).*
Cost of Internet (Annually/Monthly/Contract)	BT provider: £ 50K a year for 1GB via Janet UK (The Joint Academic Network)
Heriot-Watt University overall floor space (*Google Planimeter tool*)	9.136e+5 m^2 / 91.36 hectares / 0.9136 km^2 / 9.834e+6 ft^2 / 225.8 acres / 0.3528 $mile^2$
Average number of occurrences in relation to ICT alarming/contingency issues (per year)	A ratio of once every 2 months
Types of ICT alarming issues	Logging issues, authentication, emails gateways, etc.

Average Time/Cost of resources for resolving alarming/contingency ICT issues	An average of 15 minutes in a working day An average of 2-3 hours out of hours

The estimated floor area of Heriot-Watt University Edinburgh campus was measured via *Google Planimeter* tool, by enclosing the campus map with 16 checkpoints as shown below (Figure 5.6).

(Figure 5.6) An Estimated Measurement of Heriot-Watt University Edinburgh Campus Floor Space

According to the interviewee, beginning of the 2014 academic term, Heriot-Watt University initiated a few fundamental steps towards a cloud migration. This covered all user emails via the Edinburgh Datacentre, and was hosted by Microsoft through their 365 account services. However, other alternative services such as Google and Oracle have had multiple difficulties and unguaranteed assurances to meet this university's specific requirements. This was mostly demonstrated in areas related to integration with Legacy systems and other procedures for reducing ICT reliance on conventional systems. In fact, Google was considered as a strong candidate at first given a wide scope of integration offerings with Microsoft applications that were already utilized by the university. These cloud services were mainly in the SaaS domain such as such as Google Docs. However, other IaaS alternatives were also assessed like Chrome Box thin client devices and MAC books.

In principle, one of the examples discussed by university's ICT director was the existing SaaS solution offered by *Blackboard*, which is being charged as a hosted service deployed in *Blackboard's* datacentre in Amsterdam. Accordingly, while Heriot-Watt University operates on a 24-by-7 basis around 3 countries, in addition to a large number of distance learners and resources, there is no possibility of staffing 24-by-7 ICT personnel. Therefore, the decision was made to purchase the *Blackboard* SaaS application, even though this was limited to the virtual learning platform only. In essence, the *Blackboard* hosted application runs on managed servers, and is costing the university around £ 85,000 a year. On this note, the interviewee argued that with this cost, the university has the ability to staff about 1 and a half ICT administrators; yet, this resource will not be able to cover any required server works given the *Blackboard* 3rd party built structure. In addition, two system personnel with weekday shifts of 9 to 5 are without a doubt no match against a fully supported -24 hour-operation, which most SaaS cloud providers can reliably offer to an expectable extent.

The interviewee mentioned an alarming incident which occurred around the end of the 2013 academic semester. In brief, students were not able to perform exams via *Blackboard* systems, which are accessed through a 2 GB internet connection. The problem took the university and the cloud supplier about 3 weeks to investigate. The issue was eventually identified as a result of a server cloning incompatibility. While 3 servers were implemented at the *Blackboard* supplier to ensure CPU capacity for a large domain of concurrent users, one server contained software that resulted in conflicts with the other 2 servers already integrated in the cloning process. Around the same time, emails were drastically slowed down as a result of having one out of three mail gateways halting, which was almost instantly resolved by restarting the gateway and testing it internally by Heriot-Watt University ICT personnel.

The interviewee argued from the previous example that although acquiring a 24/7 support supplier instead of in-house personnel is likely to cost more in terms of higher salaries against less availability rates, real life technical issues are most likely to obligate in-house personnel to take initiative alongside the cloud-computing provider.

After examining Table 5.6, it can be argued that as a result of the vast variety of ICT suppliers, with external long-term contracts, a difficult task is formed to migrate the entire

scope of ICT infrastructure into a cloud alternative. Each migration stage must be uniquely analysed in terms of management readiness, future costs, and integration compatibility between associated external suppliers and existing in-house systems. In particular, as discussed earlier, the NIST definition of cloud-computing pointed out three layers for cloud delivery: Application, Platform and Infrastructure. According to the interviewee, this derives the actual process from the software level of operation, all the way to the physical platform. While this procedure reaches the IaaS level, nonetheless, non-expert decision-makers mostly find the technology management of any Smart Building more challenging given the organization's minimized control over owned infrastructure. On these grounds, the next section will perform a 3-year cloud-computing cost simulation which will evaluate data estimates presented in table 5.6. The purpose of this is to highlight the level of management efficiency and identify whether a cloud solution would benefit Heriot-Watt University or not concerning future ICT costs, associated sustainability aspects, and various management attributes as clarified in Chapter 3.

In Chapter 7 this research will conclude a decision-making framework for cloud computing management by taking into account the previous key points discussed in the three interviews. This assessment is intended to allow Smart Buildings' non-expert managers to assess cloud computing requirements and conduct effective decisions according to their organizations' needs and demand patterns before adopting any models of cloud computing.

In conclusion, with reference to the Heriot-Watt University semi-structured interview, the following key aspects of cloud computing decision-making were discussed as follows:

- Prioritizing selected ICT management attributes for Heriot Watt University campuses across three different countries, which represents a network of ICT-connected Smart Buildings (Table 5.3).

- Evaluating the current Heriot Watt University ICT management strategy, in terms of hosting, owned hardware, networking suppliers, end-user access methods, and support contracts.

- Evaluating Heriot-Watt University current ICT virtualization status in relation to the service delivery layers of Infrastructure, Platform, and Software.

- Evaluating which of the four cloud deployment models (Hybrid, Private, Public, Community) and the three cloud service techniques (IaaS, PaaS, SaaS) would best suit the ICT infrastructure of the three Heriot-Watt University campuses.

- Prioritizing the main cloud computing characteristics discussed in Chapter 3 with regard to the Heriot-Watt University ICT peak loads and ICT demands.

- Evaluating the feasibility level of outsourcing the entire Smart Buildings ICT-integrated equipment of Heriot-Watt University campuses onto the cloud.

- Evaluating the risk acceptance and potential limitations and threats from adopting cloud computing services in the Heriot Watt's ICT infrastructure.

- Evaluating the energy saving factor of cloud computing utilization and the degree of importance and impacts on the Heriot-Watt University DIS decisions on ICT deployments.

5.2- Cloud-computing Cost Simulation

This section will perform a technical cost simulation by analysing Heriot-Watt University ICT data estimates which were collected previously and illustrated in table 5.6. In addition, this examination will create, to a certain extent, a cloud-computing virtual environment in order to simulate a real-life measurement of benefits, limitations, and decision-making processes. This is carried out through a selected period of time and in contrast to ongoing ICT methods. Although this simulation is performed in accordance to estimated costs, management flexibilities, sustainability aspects, and integration readiness factors concerning different suppliers and existing systems, the overall case study breakdown will follow the following decision-making objectives:

- Measure the extent of management feasibility to integrate existing Smart Building systems provided by various vendors into a singular hosting solution. At the moment, each supplier offers an isolated deployment criterion, which forms a major obstacle against any cloud migration.

- Examine existing SaaS applications and determine potential upgrades to cover a complete end-user utilization of needed tools.
- Simulate a limited cloud IaaS and PaaS combination of deliveries, which takes into account a measurable range of associated energy consumption estimates.
- Explore into alternative hosting techniques by simulating a Private, Hybrid and Public deployment models in addition to already in-practice ICT hosting methods.
- Analyse results in contrast to conventional approaches, which determine the appropriate degree of expenditures, sustainability, and management strengths as opposed to potential weaknesses.

5.2.1- Case Study Technical Description

This simulation will take into account specific hypotheses in relation to the utilization scope of cloud-computing characteristics. It was observed from the previous interview that with each external vendor an integrated solution is recommended for Heriot-Watt University with full output control, support and integration. However, it was identified from the earlier investigation that only the existing physical infrastructure will take part of this simulation in contrast to a virtualized solution. In particular, the following comparison will perform a technical examination for measuring the extent of attaining cost-efficiency from cloud-computing. Furthermore, this examination will also assess associated sustainability and ease-of-management potential benefits from outsourcing either a partial substance of the currently-owned hardware infrastructure, or an entire cloud migration via on-demand access.

Measured expenses will rely on the Cloud Calculator tool by Rackspace. Nevertheless, this research explored in Chapter 3 a general cost breakdown of different cloud-computing service models. As a result, each physically-owned cloud component will be identified according to the ICT hosting investigation, which was carried out at the Edinburgh and London based ecommerce agency, *Digital-Boutique*, as discussed in Chapter 4. Each server acquires features illustrated in Table 5.7 below. Accordingly, current aggregated hosting costs, excluding additional bills for monitoring and other additional services, were approximated to reach £ 400 a month for each server following a fixed Total-Transfer

billing model by the employed hosting supplier, Peer 1 (Peer1 Website - Bandwidth Billing, 2014).

(Table 5.7) Example of each Server Details involved in the Cloud-computing Simulation

Server Details	Value Range
Server Manufacturer	Dell R620 PowerEdge Server
Average Price per Server	(for a fixed Bandwidth): £ 400 per month
Fixed Bandwidth	2 TB per month (aggregated bandwidth)
Networking Operating System	Windows NOS 2008
DDR 3	32 GB
RAM	1333 Mhz
SATA Drives	1 TB for two drives with RAID 1 Hardware
Total processors	24 Processors
Each Processor	• Vendor: Genuine-Intel • Name: Intel(R) Xeon(R) CPU E5-2640 0 @ 2.50GHz • Speed: 2500.012 MHz • Cache: 15360 KB

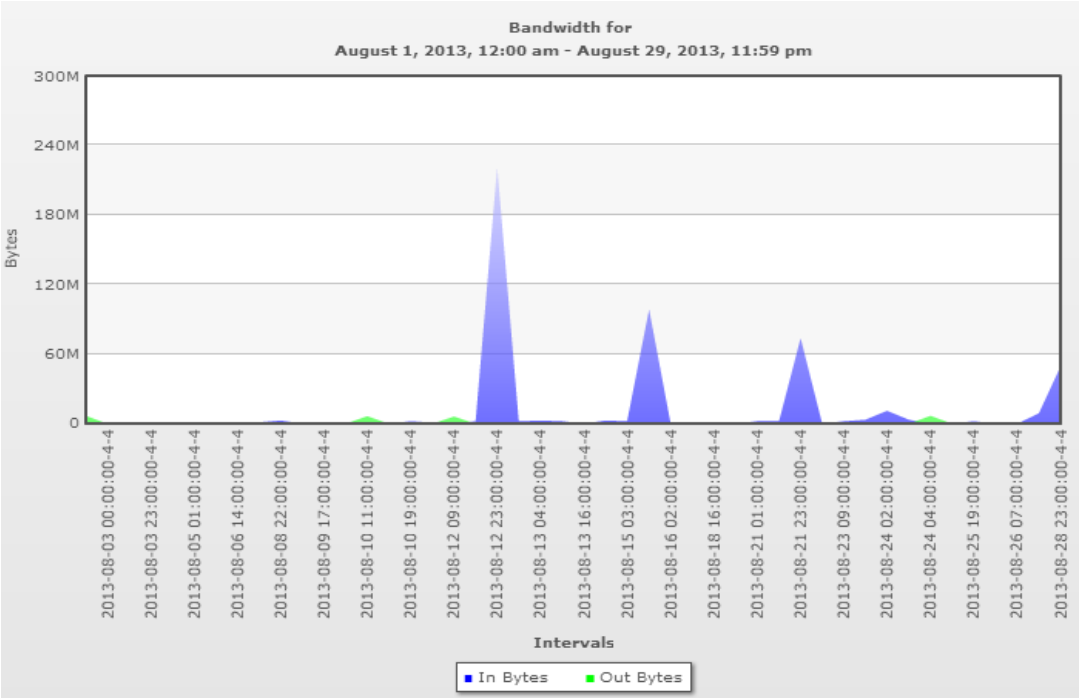
The previous collected data concerning the Heriot-Watt University owned ICT infrastructure is specifically highlighting estimated costs against the servers employed. While this was calculated for the 28 racks involved in the overall capacity process as presented earlier, each rack would have an estimated number of 25 servers. However, it must be noted that previous facts are introduced on a general basis and regardless of the specific domain of applications involved. This is because each rack would have room for additional networking devices such as firewalls, switches, and so on. Accordingly, the following will rely on results attained from the *Digital-Boutique* internship as explained in the Methodology chapter earlier.

In order to follow a similar lifecycle to the Heriot-Watt University collected datacentre data, and even though a real-life hosting environment was created, only a minimized model was employed in this simulation, which attempts to measure the overall cloud migration process of the Heriot-Watt University.

With respect to the available hosting services from *Peer1*, Smart Buildings can choose between:

- Public Cloud – Entry Level Unmanaged
- Public Cloud – Enterprise Managed, which include additional support services
- Private Cloud – Enterprise Managed

In essence, the bandwidth billing system operates in a way which ensures simple monitoring of resources via automated, instantly generated usage, and error sampling graphs (Figure 5.7). Furthermore, the public cloud is purchased via a pay-as-you-go approach. Also, the private cloud was obtained as an enterprise level solution which according to *Peer1* would cost from a minimum of £ 1,500 per month. This price includes the licensing, installing and monitoring of multiple VMs for one in-house managed physical server.



(Figure 5.7) The core Server's Usage and Error Sampling Graph from Peer1 Control Panel

After acknowledging a 25 server per rack from 28 racks as the overall Heriot-Watt University infrastructure, *Peer1* quoted a £ 400 per month for the previous simulated server. While this server was already purchased by *Digital-Boutique* for supporting

numerous clients, previous interview findings indicated that the university is currently paying £ 500,000 per year to support the entire server infrastructure. In that context, with the employment of the simulation tool *PlanForCloud* as explained in Chapter 4 (Khajeh-Hosseini & Greenwood & Sommerville, 2013), the following will create selected patterns for a new virtual deployment model. In parallel, these will be presented by specifying cloud requirements for a minimized ICT environment, based on Heriot-Watt University ICT findings illustrated in Table 5.6.

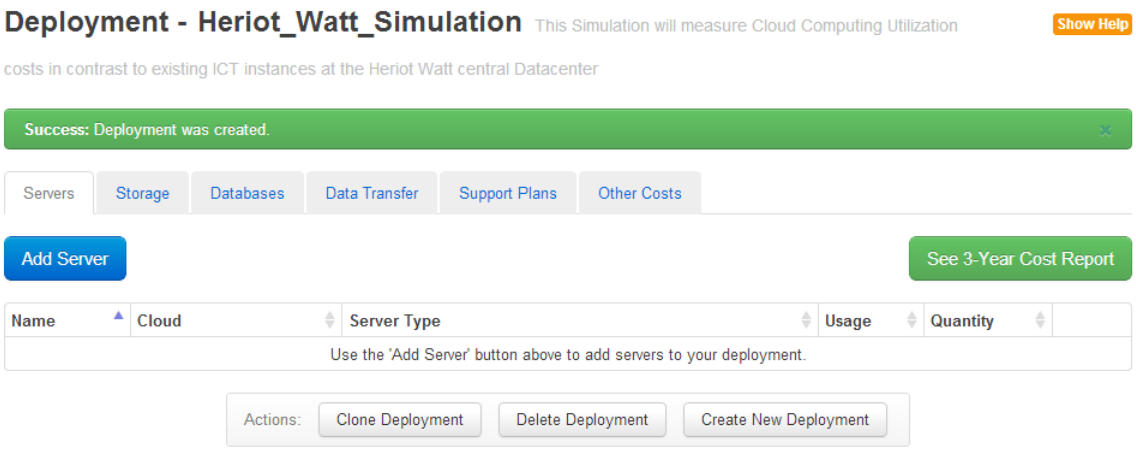
Prior to any cloud requirements' identification, it must be noted that in a real-life cloud deployment it is essential to point out the bottleneck status thoroughly of the targeted Smart Building. This is purposed to select the optimal solution that meets end-users' peak standards. Nevertheless, with regard to the Heriot-Watt University cloud-computing simulation via the *PlanForCloud* cost modelling tool, three main sections were recognized. Firstly, the Deployment instance was highlighted to represent the ICT domain of servers, storage capacity, and database engines. Whereas each deployment reflects a unique cloud scenario, the cost prediction simulation will distinguish each respectively.

As previously examined, one of the key characteristics of cloud-computing is Rapid Elasticity. While this indicates that users can scale-up or down instantly depending on peak times and other workload factors, Heriot-Watt University heavy workload is dependent by term time, which shows an obvious peak in server capacity during academic semesters, and specifically during online-exam periods. As a result, this simulation will create various custom programmed patterns in response to scaling expenses for cloud utilization. In addition, each ICT aspect, currently in direct association with an external vendor whether already applying cloud solutions or not, will be excluded from the previous analysis. However, previous cost estimations of each supplier will be added as a fixed price to the subtotal cloud cost report.

In reference to the *Peer1* scope of server specifications illustrated in table 5.7, this study will employ Rackspace enterprise servers for the simulated cloud deployment. This is because *PlanForCloud* supported features does not support *Peer1* as a cloud provider, which had to be used for the dedicated server case study earlier given *Digital-boutique*'s

involvement. However, corresponding attributes represent, to a large extent, an equal price as utilized previously from the *Peer1* server.

On that note, the first stage of this simulation was to create a new virtual deployment, named *Heriot_Watt_Simulation* as follows (Figure 5.8). Furthermore, in accordance to Heriot-Watt University ICT statistics presented in Table 5.6, stage 2 will cover adding estimated virtual servers to substitute the lifecycle capacity currently provided by Heriot-Watt University main servers located in the in-house datacentre. This is set to include various networking and processing attributes in relation to servers, storage, database engines, data transfer, support strategies, and other related costs from external suppliers. These additional expenses were observed to be indispensable at this stage according to the previous semi-structured interview findings.

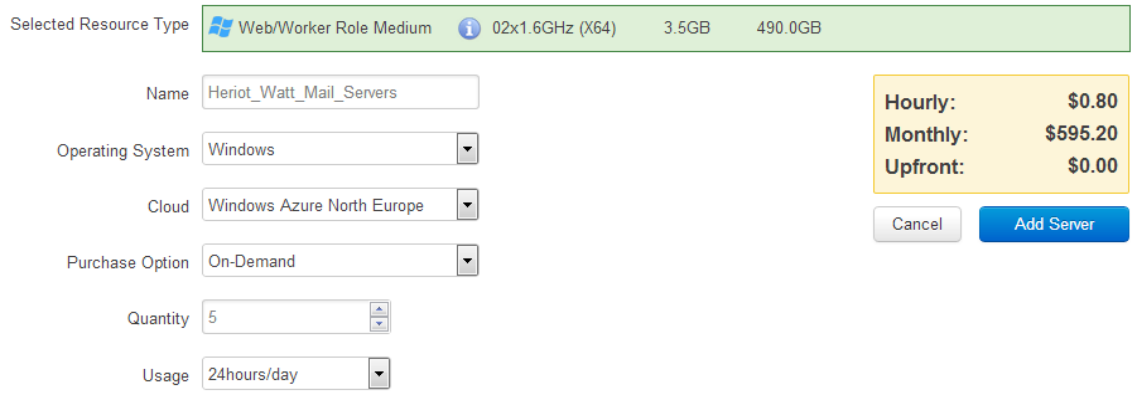


(Figure 5.8) Stage 1 of the Heriot-Watt University Case-study Simulation: Creating Deployment. Source: Right-Scale Inc. (2013). "Plan for Cloud Simulator".

As mentioned earlier, all added servers from Rackspace will acquire almost identical features to the *Peer1* server, which was studied during the *Digital-boutique* server environment representation. Therefore, in order to contrast 28 racks in the overall Heriot-Watt University ICT infrastructure, the following servers were added accordingly (Figure 5.9).

(Figure 5.9) Stage 2: Adding Main Servers (Rackspace, UK)

In addition, given that Heriot-Watt University currently employs Microsoft servers in-house for both students and staff emails, this simulation proposed Windows Azure as a cloud substitute for the email servers, which is also provided by Microsoft, hence, simplifying the transformation and integration process from conventional legacy systems to the cloud alternative (Figure 5.10).

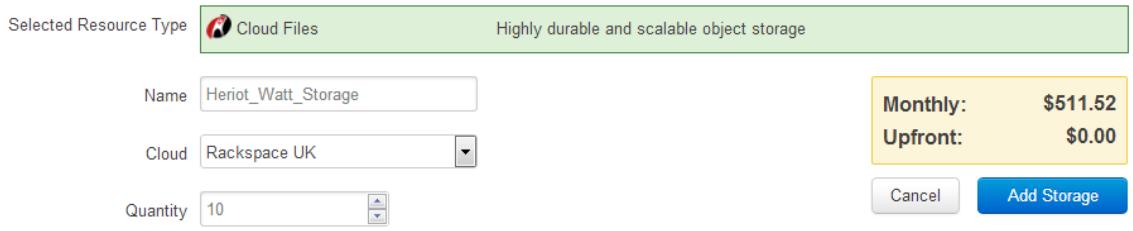


(Figure 5.10) Stage 3: Adding Email Servers (Microsoft, North Europe)

It must be noted at this point that this simulation is addressing the Infrastructure as a Service IaaS resources. However, both Platform and Application layers are also involved on a minimum basis as discussed earlier in relation to applications such as students' e-learning solution by *Blackboard,* finance records management by Oracle, and other systems by external providers. The impact of not addressing Platform and Application layers as

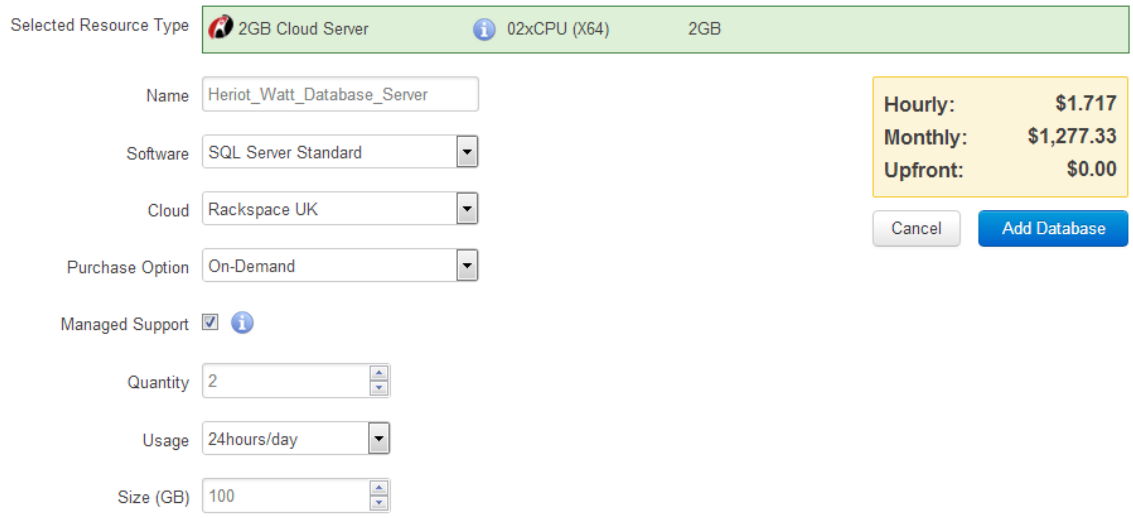
separate entities is because of the hybrid nature of the majority of cloud services, which are currently adopted by organizations as previously discussed.

The fourth stage involves adding storage capacity on the cloud with reference to the number of read and write requests, which forms a crucial cost factor when the payment contract follows a fully pay-as-you-use model (Figure 5.11). Nevertheless, Rackspace was selected in that context given one of the main objectives of this framework, which is to ensure ease-of-management, yet, take into account integration difficulties with numerous suppliers which are already in-contracts with the university for a considerable number of years.



(Figure 5.11) Stage 4: Adding Storage Capacity (Rackspace, UK)

Furthermore, stage 5 demonstrates the required database servers, which were presumed to replace current conventional database engines installed and were estimated for the SQL engine installation in order to back-up the main Rackspace servers (Figure 5.12). In addition, stage 6 covers bandwidth expenses, which is reserved for data transfer between each one of the previous instances back and forth (Figure 5.13). Accordingly, another critical stage is added to specify different types of evaluated support required for the Heriot-Watt University ICT infrastructure (Figure 5.14). Moreover, two monitoring services were added to this simulation, which covers a 90-day log management history, and a cloud standard application performance management.



(Figure 5.12) Stage 5: Adding Database Servers (Rackspace, UK)

Source	Destination	Source to destination data/month (GB)	Destination to source data/month (GB)	
Server: Heriot_Watt_Central_Servers on Rackspace UK	Storage: Heriot_Watt_Storage on Rackspace UK	100 0 Patterns	100 0 Patterns	Delete
Remote Node: Users	Server: Heriot_Watt_Central_Servers on Rackspace UK	1024 0 Patterns	1024 0 Patterns	Delete
Remote Node: Users	Database: Heriot_Watt_Database_Server on Rackspace UK	100 0 Patterns	100 0 Patterns	Delete
Remote Node: Users	Server: Heriot_Watt_Mail_Servers on Windows Azure North Europe	100 0 Patterns	100 0 Patterns	Delete

(Figure 5.13) Stage 6: Specifying Required Bandwidth Strategy between previous Instances

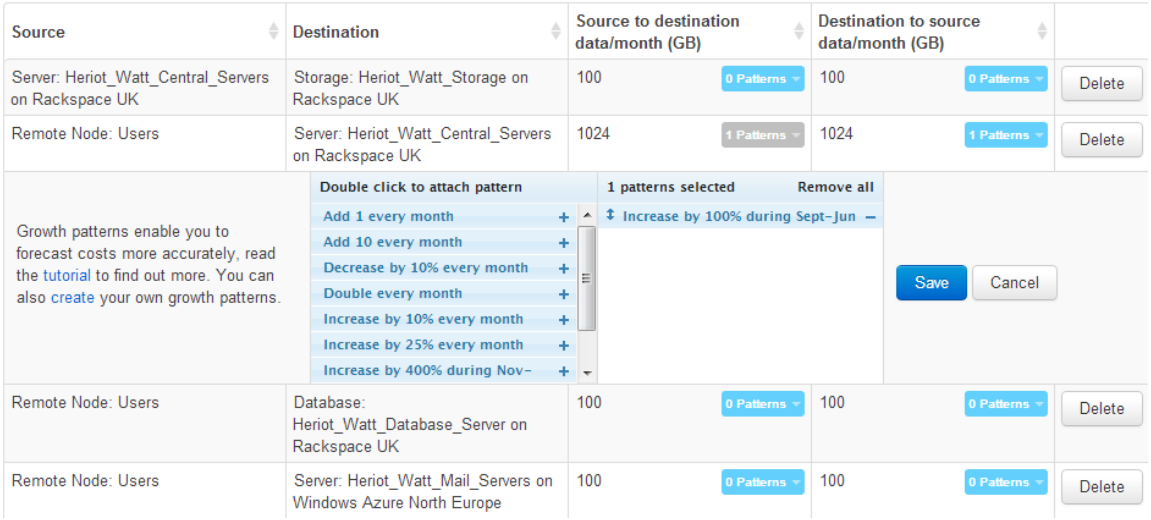
	Ticket System	Email	Phone Support	Response Time	Cost
Rackspace plan details					
Included	✔	✔	✔	20 minutes	Free
Managed Cloud	✔	✔	✔	1 hour	$100 base monthly + between $0.04 to $0.12 per server hour
Windows Azure plan details					
Included	✔	✘	✘	Unspecified	Free
Developer	✔	✘	✘	8 hours	$29
Standard	✔	✘	✔	2 hours	$300
Professional Direct	✔	✘	✔	1 hour	$1000
Premier	✔	✔	✔	15 minutes	Please contact the cloud provider for the cost of this plan

Name	Description	Cost (USD)	Include in Deployment?
Loggly	Log Management Service in the Cloud. 1GB/Day, 90 Day History.	149.0	Include / Do not include
New Relic	Application Performance Management & Monitoring. Standard Plan.	49.0	Include / Do not include

(Figure 5.14) Stage 7: Specifying Support Plans (Rackspace & Microsoft)

Prior to generating the final cost forecast report, two detailed patterns will be created in relation to Heriot-Watt University ICT peak periods. While one of the main advantages behind a cloud utilization is to make use of the Dynamic Elasticity characteristic as discussed earlier, these patterns will be employed to scale-up and down a selected scope of previous cloud components. Although Heriot-Watt University busiest term time is relatively between September and June, other ICT units will be left with a permanent performance cycle, given the 24/7 demand and capacity needed across the entire 12 months per year. On that ground, the first pattern was specified against the bandwidth between end-users and main servers, which is accessed remotely (Figure 5.15).

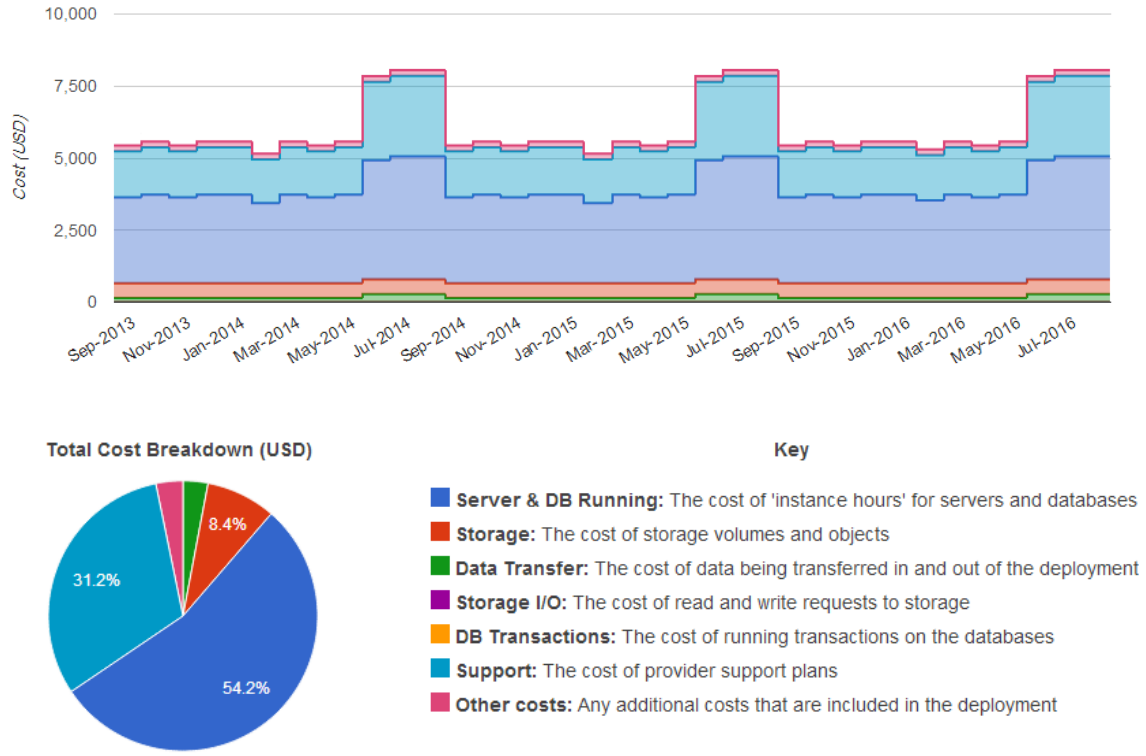
In particular, this automatic scaling customization was set to double the main servers' capacity bandwidth, only during term time. Moreover, the second pattern was structured to adjust the CPU capacity of the same cloud servers, also by 100%, and during the same period where peak loads are expected. However, it must be noted that these patterns can be adjusted manually, at any given time, from the end-user cloud control panel in case of any unexpected demand for extra or less storage, CPU capacity, or networking bandwidth for any cloud component.



(Figure 5.15) Stage 8: Specifying Peak Load Patterns (an automatic increase by 100% during term time)

5.2.2- Summary of Simulation Results

After analysing the existing Heriot-Watt University ICT infrastructure, this section estimates cloud substitute components required to run a similar environment, instead of the physically owned datacentre. This process has covered 8 stages starting with adding estimated cloud servers, storage, files' transfer bandwidth, database engines, and additional support strategies and performance management processes. Furthermore, two automated scaling patterns were programmed to handle unpredictable peak loads in response to the Elasticity cloud characteristic. At this point, a complete execution was performed using this tool, which covered a 3-year cost forecast report, and a detailed pricing of each cloud-based ICT component following a monthly billing basis (Figures 5.16 and 5.17).



(Figure 5.16) Stage 9: Generating a 3-years Cost Report Forecast

Yearly Deployment Costs (USD)

Year	Server & DB	Storage	Data Transfer	Storage I/O	DB Transactions	Support	Other Costs	Total
Year 1	39,722.19	6,138.24	2,196.75	0.00	0.00	22,889.22	2,376.00	73,322.40
Year 2	39,722.19	6,138.24	2,196.75	0.00	0.00	22,889.22	2,376.00	73,322.40
Year 3	39,821.27	6,138.24	2,196.75	0.00	0.00	22,929.38	2,376.00	73,461.64
Totals	119,265.65	18,414.72	6,590.25	0.00	0.00	68,707.82	7,128.00	**220,106.44**

Yearly Deployment Support Costs (USD)

Year	Rackspace	Windows Azure	Total
Year 1	19,289.22	3,600.00	22,889.22
Year 2	19,289.22	3,600.00	22,889.22
Year 3	19,329.38	3,600.00	22,929.38
Totals	57,907.82	10,800.00	68,707.82

(Figure 5.17) Stage 10: Detailed Report of a 3-year Deployment & Support Cost per year (see Appendix A for the monthly billing report)

The objective of the previous simulation was to compare conventional vs. cloud advantages and limitations in terms of costs, sustainability, and ease-of management. From a cost perspective, the previous chart illustrates pricing details attained from utilizing the cloud environment of Heriot-Watt University Smart Building main datacentre. In essence, it can be concluded that applying a cloud solution seems cheaper than the ongoing multi-vendor, in-house solution. This was demonstrated from the £0.5 million pounds spent by Heriot-Watt University on the ICT infrastructure per year, in contrast to the £ 96,211.62 required for the first year from applying the cloud alternative as follows:

Estimated Total Cost for the first year cloud-computing simulation: Deployment costs (£ 73,322.40) + Support costs (£ 22,889.22) = £ 96,211.62

In relation to a 3-year deployment, the total estimated cost is calculated as follows:

Estimated Total Cost for the three years cloud-computing simulation: Deployment costs (£ 220,106.44) + Support costs (£ 68,707.82) = £ 288,814.26

These numbers are excluding any additional elasticity service demand patters, or any fixed service contracts with specific vendors such as Blackboard, and others, which costs Heriot-Watt University around £ 50,000 per year as explained earlier. Although the previous simulation ensured, to some extent, similar performance features, several other monitoring,

scaling, and support services were added to simulate a real-life operation. Although these have the potential to save money from ICT personnel salaries, a crucial ease-of-management and support factor requirement are added at this stage, these guarantee a 24 by 7 response rate, while in-house ICT staff is merely covering regular working hours. However, the *UpTime Software* example previously examined in Chapter 3 (Table 3.5), outlined that in some heavy-scaling demand cases, cloud-computing can be more costly than the conventional approach. Nevertheless, a considerable management challenge is raised in relation to integrating legacy systems from multiple Smart Building vendors into a single contract with the cloud provider. This must be thoroughly planned by decision-makers by following a strategic framework depending on system priority and critical utilization, which will be discussed in Chapter 7.

Combining each ICT supplier into a single cloud hosting platform will cause a high preliminary cost as previously argued. While these suppliers are delivering numerous Smart Building functions, acquiring a single deployment of outputs for various systems needs to be carried out following a step-by-step process. Each phase towards of the cloud migration process is individually explored in the final decision-making framework in Chapter 7 from the point of view of non-expert managers. The previous simulation created a virtual cloud deployment for the Heriot-Watt University case study. This was executed in terms of costs related to the in-house main datacentre concerning networking devices, end-user PCs, and other ICT-integrated building hardware.

As examined earlier, Heriot-Watt University, Edinburgh campus, acquires about 5,000 computers covering school labs and staff offices. These in addition to the main library are administered privately by the in-house ICT support team. In that context, this study previously proposed the purchase and utilization of light-weight thin-clients, instead of the currently utilized thick-client devices. The former will soon become obsolete resulting in thick-client hardware being dumped and replaced on a regular basis. Therefore, expenses related to purchasing, upgrading, managing, and licensing, are enormous as the Heriot-Watt University DIS has acknowledged in the interview earlier. In addition, with regard to hardware acquisition and associated power consumption for the entire infrastructure, the Green aspect of operating in an environmentally friendly manner can be drastically improved from employing thin-client equipment.

For instance, Google and Samsung offer *ChromBox,* a light weight PC that only consumes 8-15 watts instead of the 250 watts per each regular thick-client device (Chrome website, 2013). As a result, end-user device costs can reach around £ 269 instead of a £ 600 average for an HP desktop computer. With accordance to the Heriot-Watt University case study, the number of watts approximately consumed by end-user PCs only can be measured approximately as follows (Table 5.8).

(Table 5.8) Watts approximately consumed by end-user PCs: Thick-client vs. Thin-client

Following the existing thick-client approach:	*5,000 PCs: each PC consumes 250 watts ↔ 250 x 5,000* = 1.25MW *(Total Consumption)* *5,000 PCs: each PC costs £ 600 ↔ 600 x 5,000 = £ 3,000,000 (Total PC Infrastructure Cost)*
Following the potential thin-client approach:	*5,000 thin PCs: each PC consumes 12 watts ↔ 12 x 5,000 = 60,000 watts (Total Consumption)* *5,000 PCs: each thin PC costs £ 269 ↔ 269 x 5,000 = £ 1,345,000 (Total PC Infrastructure Cost)*

By default, any thick-client device will exclude costs related to any operating system licenses, anti-virus protection, and other required software, given that devices like *ChromeBox* are online-based, self-healing with automatic built-in system upgrade. Moreover, other desktop computers were also classified under the thin-client category. These have also been argued to optimize energy usage, minimize hardware possession, and ensure efficient remote utilization of resources given that the operating system is already hosted on the manufacturer's cloud environment (Andr´es, Tolia, Balan, de Lara & O'Hallaron, 2006). Some examples of today's ICT market, these light-weight hardware can range from the HP MultiSeat PC, to the Wyse computer by Dell, in addition to other networking storage systems such as Sun MicroSystems, KronosSystem, and ReadyNAS by NetGear.

In essence, the overall decision-making framework will illustrate an essential prerequisite of reconciling each architectural cloud-computing layer in a Smart Building environment to reach a cost-effective, sustainable, and a manageable cloud migration.

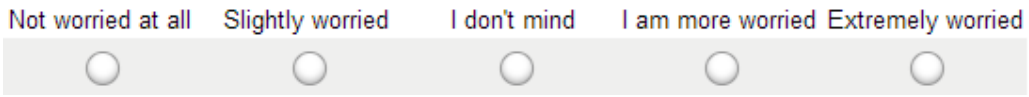
5.3- Risk Analysis Questionnaire

As discussed in the Methodology chapter, this research conducted a risk-analysis survey which followed a Likert-scale approach from the point of view of different types of Smart Building decision-makers. This range of recipients covered different types of administrative employees, non-expert business owners, ICT consultancies, engineers, and other academics involved in the domain of cloud-computing. However, this study only approached interviewees who are at a management level position, or were in a place to perform ICT decisions in their organizations. Moreover, this questionnaire followed a similar approach to the 2009 risk-analysis survey, which was examined previously in the literature review chapter. The survey collected a general overview of cloud concerns regarding purchase, utilization, and other management attributes (Figure 2.15).

This study experienced several difficulties in reaching out to a selected number of management-level employees. This was due to the fact that these have an extremely busy time schedule, which made the communication, time allocation, and approval process to take part in this survey a challenging task.

This risk analysis questionnaire was purposed to measure the concern level towards multiple structured statements that were identified as a result of this project's previous analysis in Chapters 2 and 3. Furthermore, this survey was not structured to target a specific audience from a particular industry given that each case study is located within a different ICT-dependent Smart Building, hence, is subject to dissimilar requirements. However, these categories are divided in the next chapter for developing *SBCE,* as follows: Small or Medium or Large Businesses, Government Agencies, Healthcare Facilities, or Higher Education Facilities. While all of these form a potential cloud service requester, different risks must be taken into consideration. These are related mainly to capacity loads, domains of utilization, contract-specified support, service availability and number of concurrent connections.

The following Likert-scale questionnaire was constructed on a five-point basis as shown below (Figure 5.18).



(Figure 5.18) Risk-Analysis Questionnaire: Rating-Scale Choices

In essence, it was the intention of this study to use relatively simple and non-technical expressions for the purpose of delivering this survey in a simplified and time-appealing manner to non-expert managers. While the complete form of this survey is presented in Appendix B, the template was predominantly structured across five sections as follows:

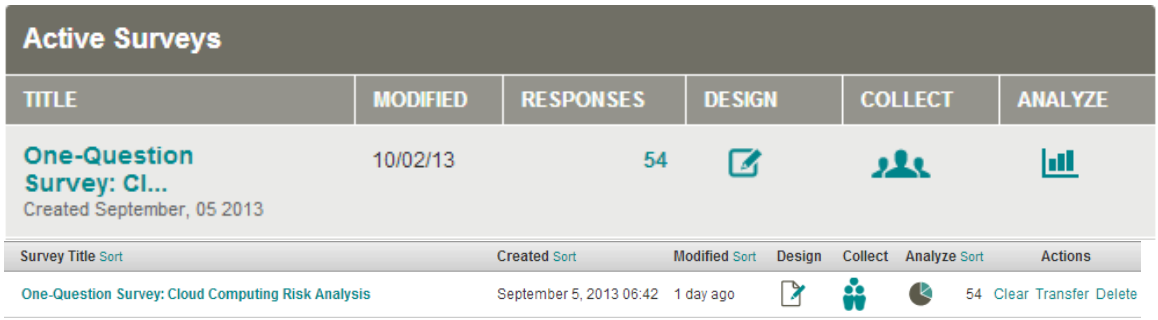
1- A brief overview on cloud-computing
2- Key Benefits
3- Extending the cloud to cover unique Smart Building functions
4- The main rating question of the Likert-scale survey
5- Potential Risk Analysis statements

5.3.1- Data Collection and Discussion

According to a survey by Forester conducted by the *BMC-Software* corporate, 78% of ICT decision-makers are willing to increase their company's expenditures on cloud-computing solutions (Forester Survey, 2013). In addition, 76% of the same group will prioritize cloud-computing administrative training as a key pillar for the next 5-year term plan. Furthermore, in the forecast period, 50% of technology managers in Smart Buildings will be classified as cloud driven. Nevertheless, while the Software as a Service layer SaaS has already been dominating most of today's ICT access by general end-users, both Platform and Infrastructure migrations, PaaS and IaaS, began to form a solid consideration for Smart Building ICT decision-makers across various organizations as highlighted in previous chapters.

This survey reached out to 54 management-level personnel from various specialties, organizations, and Smart Building environments (Figure 5.19). As mentioned in Chapter 4, the ecommerce development and hosting agency, Digital Boutique, collaborated mutually

with this research and helped providing most of these management contacts. The targeted audience was essentially a non-expert one in neither cloud-computing, nor any ICT solutions. Therefore, a simplified language was used throughout the form, which covered a brief overview on key cloud benefits, definition, and main characteristics of service delivery.



(Figure 5.19) Risk-Analysis Questionnaire: Date and Number of Responses

SurveyMonkey was the selected platform for conducting this Likert-scale survey. This was due to numerous security and reliability features in which this solution offers in contrast to other systems. The security aspect of SurveyMonkey was an important feature for the interviewees to ensure anonymity. On that ground, successful results were collected from 54 participants out of a total of 80 management contacts approached by this study. This number was considered sufficient for this particular section, as the objective initially was to achieve a total of 50 participants from ICT-dependent companies within different Smart Building environments. As a consequence, the following table demonstrates collected results, ordered by the average rating in relation to each cloud-computing risk statement (Table 5.9).

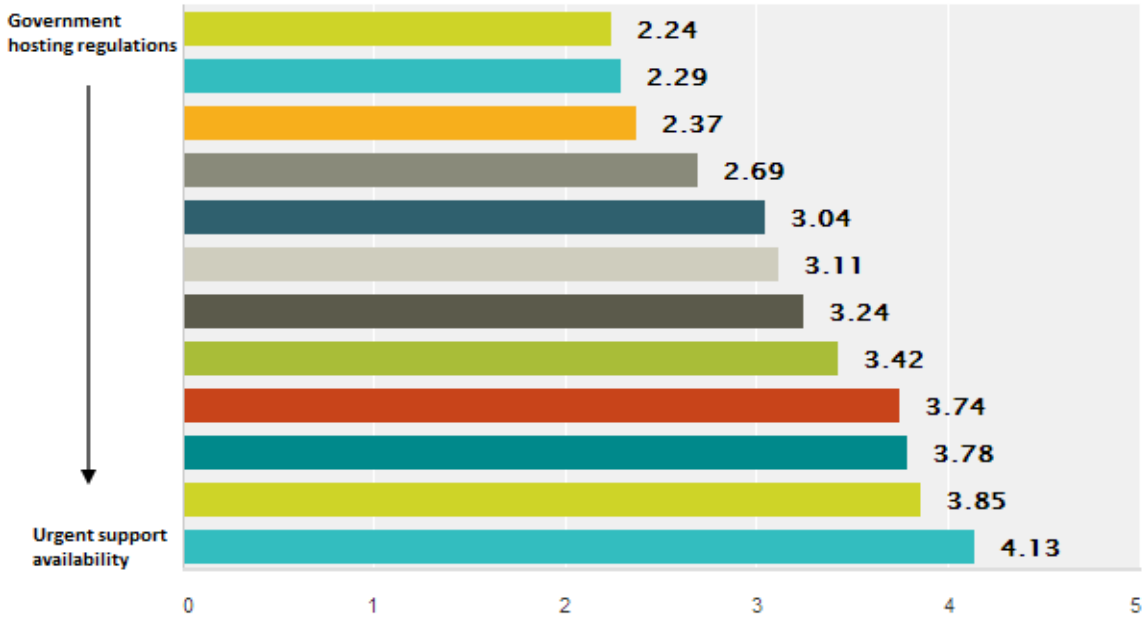
(Table 5.9) Risk-Analysis Questionnaire: Results in contrast to Statements

Level of Concern Cloud Risk Category	Not worried at all	Slightly Worried	I don't mind	I am more worried	Extremely worried	Total Number of Participants	Average Rating
Government hosting	46.30%	12.96%	18.52%	14.81	7.41%	54	2.24

regulations							
Difficulties in going back to old hosting methods	28.85%	28.85%	26.92%	15.38%	0%	52	2.29
Unknown hosting locations	35.19%	16.67%	27.78%	16.67%	3.70%	54	2.37
Integration difficulties between the cloud and existing systems supplied by different vendors	15.38%	28.85%	26.92%	28.85%	0%	52	2.69
A complete service shutdown	3.92%	43.14%	17.65%	15.69%	19.61%	51	3.04
Contract management issues	7.55%	32.08%	15.09%	32.08%	13.21%	53	3.11
Performance issues	1.85%	33.33%	9.26%	50%	5.56%	54	3.24
Control over resources	1.89%	28.30%	9.43%	47.17%	13.21%	53	3.42
The 'on-demand' payment method of cloud computing might cost more than the	5.66%	13.21%	3.77%	56.60%	20.75%	53	3.74

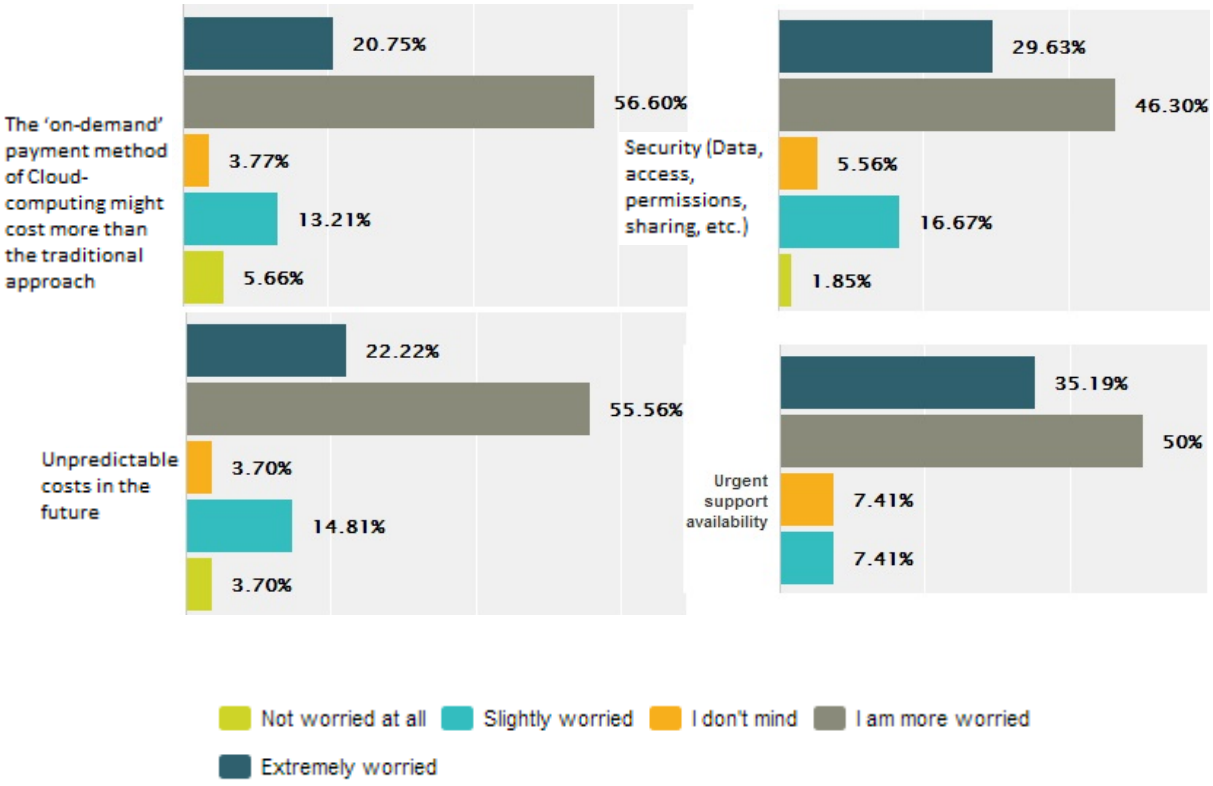
traditional approach							
Unpredictable costs in the future	3.70%	14.81%	3.70%	55.56%	22.22%	54	3.78
Security (Data, access, permissions, sharing)	1.85%	16.67%	5.56%	46.30%	29.63%	54	3.85
Urgent support availability	0%	7.41%	7.41%	50%	35.19%	54	4.13

Furthermore, statistics from the previous table were further illustrated using a metrical-value approach as follows (Figure 5.20).



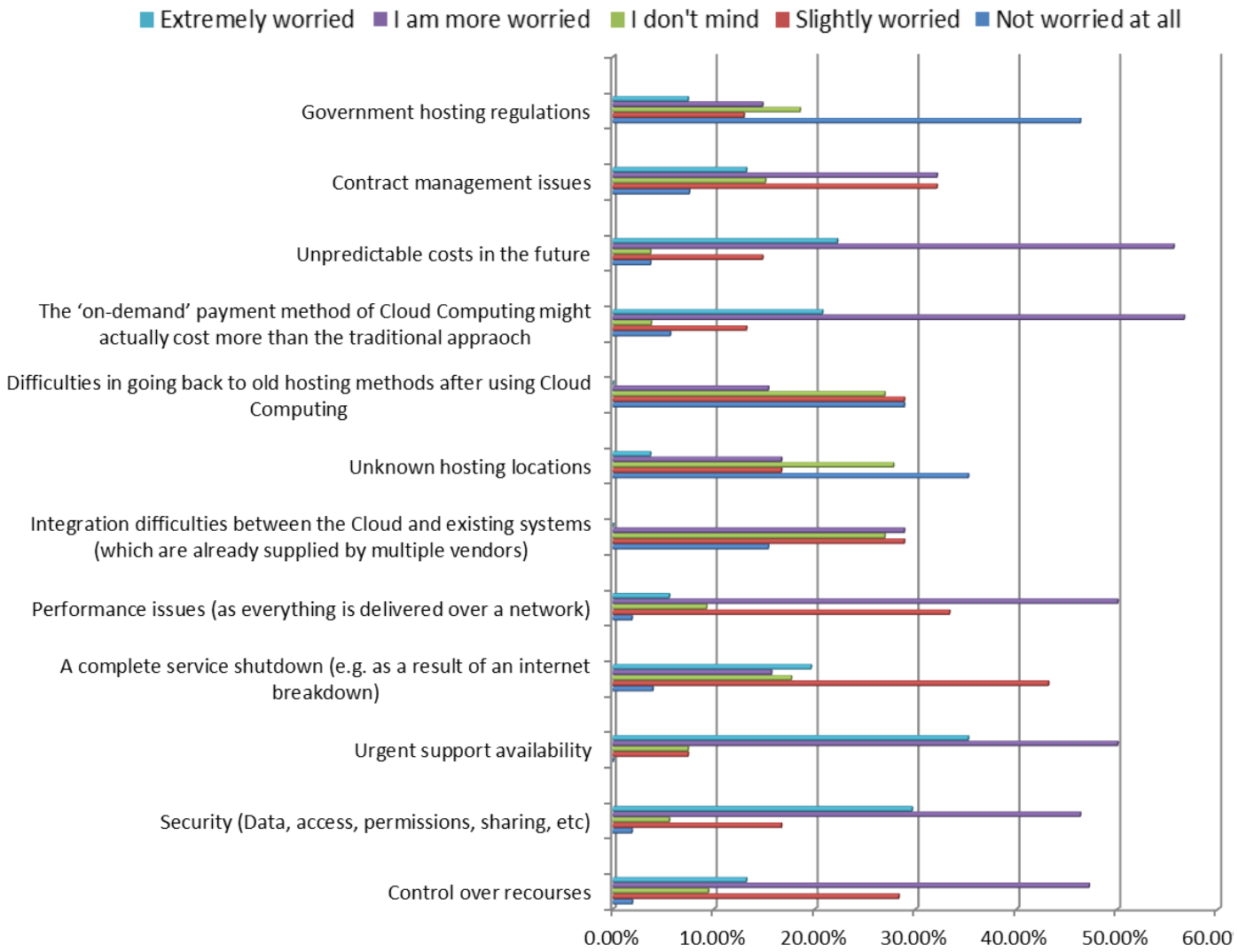
(Figure 5.20) Survey Analysis: Weighted-Value Representation

In order to attain a more detailed view of each risk statement in contrast to the five Likert-scale values, the following percentage-chart demonstrates similar results; yet, each statement was analysed from an axis-distribution viewpoint as shown below (Figure 5.21).



(Figure 5.21) Survey Analysis: Axis-Distribution Percentage Representation

It is important to note that with the Likert-Scale method, the *I Don't Mind* option means that the highlighted risk statement is irrelevant to this particular interviewee or organisation. The next figure shows the completed survey findings from Table (5.9) as a bar chart, which was re-generated through Microsoft Excel (Figure 5.22).



(Figure 5.22) Survey Analysis: Microsoft Excel Representation of Individual Inputs

The previous analysis indicated that the most worrying risk factor among the recipients of the previous survey is the '*Urgent Support Availability'*. This concern received a 4.13 average response rate out of the 54 participants in comparison to the other 11 security statements. The '*Security'* factor of cloud computing has landed at the second position with a 3.85 average response rate. At the third and fourth positions, the two price-associated factors landed respectively with a 3.78, and a 3.74 average rate. These risk statements are the '*Unpredictable Costs in the Future'* and '*The on-demand payment method of cloud-computing might actually cost more than the traditional approach'*. At the bottom of the cloud computing risk factors, the 11th and the 12th positions covered both the '*Difficulties in going back to old hosting methods'* and the '*Government Hosting Regulations'* factor, with a 2.29 and a 2.24 average rate respectively.

The information can be further analysed for Smart Building management frameworks following a security, cost, support processes, and additional ICT administrative factors. As discussed previously in the semi-structured interviews, Smart Buildings are in most cases bound with a large number of external ICT vendors that are unrelated in their service delivery. This makes the '*Urgent Support Availability'* a crucial aspect for non-expert managers. In particular, given the large domain of suppliers involved, a clear standardization of this risk factor must be thoroughly clarified with the service provider, as multiple associated aspects to the highest worrying factors can be observed as a result of an unstandardized service delivery. This is also shown in relation to cloud-computing utilization in organizations within integrated ICT systems where different platforms are mutually managed. For example, in the occurrence of an urgent system breakdown incident, the traditional in-house approach might result in administrative chaos to determine which vendor is responsible and should be contacted in order to resolve the issue. On this ground, cloud-computing unifies the support platform by following a *Blackbox* solution, which operates regardless of the type of support required.

It was observed from the risk analysis survey that most non-expert decision-makers have similar concerns when it comes to unpredictable costs, performance difficulties, contract management challenges, and integration with on-premises platforms. This came to light after reaching out to different organizations that involve various types of ICT processes. In theory, each risk statement was selected and addressed based on current ICT limitations observed by this type of users within their organizations. On that note, a future research work is suggested to develop an automated filtering and

comparison criteria, to analyse and compare each of the previous risk factors of cloud-computing against the '*Urgent Support Availability'*, which was classified as the highest concern amongst the survey recipients. This can support previous findings by identifying the unpredictable maintenance delivery in any Smart Building as the most worrying aspect of cloud-computing applications.

The majority of survey recipients identified cost, security, and support as the top risk factors to be taken into account prior to any cloud deployment in Smart Buildings. On this ground, this survey plays a significant role for developing a cloud-computing management framework following various Smart Building technical and non-technical standpoints. In essence, the previous questionnaire forms a knowledge platform which gathers the specification required for developing *SBCE,* which is a decision-support tool for cloud-computing adoption that targets non-expert managers, as will be discussed in the next chapter.

As mentioned earlier, given that the science of cloud-computing is evolving at a faster pace than most of the other services provided by various industries, it is important to identify the patterns and changes in collecting data results when performing similar surveys over different periods of time (Mualla & Jenkins, 2015). This risk-analysis survey was intended to illustrate a relatively different viewpoint of the earlier cloud-computing surveys. For instance, as previously discussed in the literature review chapter, the IDC survey in 2009 has covered a dissimilar approach to present the risk categories of cloud-computing. The concluded results in 2009 have shown obvious differences in the recipients' answers in comparison to the earlier survey. For example, both '*Security'* and '*Availability*' aspects have received the highest ranking in terms of end-users' concerns. Meanwhile, this research identified the '*Support*' and '*Unpredictable Future Costs'* aspects as the highest worrying factors among managers. Furthermore, while most surveys address the operational and administrative issues of cloud-computing regarding the access and provision of resources, this survey has limited the range of audience to management-level users with only a medium or low technical background on cloud-computing.

The purpose of the previous risk analysis survey is to evaluate the level of concern of non-expert ICT decision-makers towards adopting and provisioning cloud-computing services in Smart Buildings. In conclusion, the previous collected data was analyzed

and summarized from a decision-making perspective in the following risk assessment categories in relation to the 12 highlighted cloud-computing challenges:

Privacy and Security: IBM argued that the '*Security'* and *'Privacy'* risk factors have consistently occupied the highest ranking in almost all recent surveys on cloud-computing (Sreekanth, 2011). On this note, cloud-computing introduces an additional level of concern given that essential services are in most cases outsourced to a third party, which complicates the management process and makes it harder to maintain integrity, compliance, support, privacy, and availability of services.

Economic Benefits: As discussed in the previous semi-structured interviews, most of today's non-expert decision-makers are not convinced of the potential benefits of cloud-computing with regard to cost reduction, sustainability, and management simplicity. As mentioned in the *Uptime Software Company* example in Chapter 3, in some cases, cloud-computing can be more costly at the initial deployment than the conventional ICT approach (Bewley, 2010). This can be determined by in-house managers through analyzing the organization's ICT requirements before following any scenarios of cloud-computing.

The main concern for non-expert decision-makers is to comprehend and make use of the investment requisites to the maximum potential (Sreekanth, 2011). This would add value by making the cloud-computing services part of the Smart Building mainstream ICT portfolio. It was argued that the return on investment (ROI) on utilizing cloud resources must be accomplished and verified by comparing the relevant management attributes of traditional ICT with cloud-computing services. As a result, this comparison will demonstrate savings on future expenses, which can lead to revenue, reduction in management effort and time, compliance, and more effective workload assessment.

Support and Quality of Service: As viewed in the previous survey, Service Quality is one of the highest factors ranked among non-expert managers. This factor was highlighted as a challenge against outsourcing ICT environments and business applications onto the cloud. On this account, if the Service Level Agreements (SLAs) provided by the cloud service providers are not sufficient to guarantee the requirements for running applications on the cloud, especially related to the availability, performance and scalability, then in most cases, those non-experts must ensure that any signed contracts would state that the provider will cover business loss for the amount of time

consumed while cloud resources or services were unavailable. This is essential to any Smart Building to consider, as most of today's cloud contracts often include limited assurances on service quality and return of business loss. Therefore, managers are reluctant to outsource any core elements and critical business infrastructure to the service providers' datacenters.

Integration: As outlined in the semi-structured interviews earlier, most Smart Buildings acquire legacy systems. And if those systems were outsourced onto the cloud, this would require special integration with certain types of cloud-computing resources. These applications often have complex integration requirements such as APIs or encrypted ports, which need special modifications to interact with other cloud platforms. Non-expert managers usually find this process more challenging with reference to effort, cost, and time to complete the integration between legacy and cloud systems. As a result, these managers in many cases would rather invest more on upgrading existing on-premises technologies. On this account, it is recommended that a proper evaluation of the cloud contract with the provider is thoroughly examined given that most Smart Buildings will face a situation where integration is required between cloud applications and in-house systems in an easily-managed, fast, and cost-efficient manner.

Performance: Chapter 3 discussed that most of today's cloud services require a high internet bandwidth and a reliable connection whether delivered via software, platform or infrastructure cloud applications. Cloud-computing providers inform clients prior to signing any contracts that the performance of delivering complex services through the cloud is expected to be unpredictable if the in-house network bandwidth was not reliable or adequate to support the clients' ICT demand. Therefore, it has been pointed out earlier that the majority of non-expert decision-makers in Smart Buildings prefer to postpone any cloud outsourcing tasks until a better internet bandwidth with lower costs is made available in their ICT infrastructure.

The following chapter will undergo further examination of the technical specification required for developing *SBCE*. Subsequently, UML diagrams (Unified Modelling Language) will be constructed as the last stage of the requirement analysis stage. Furthermore, the system will be built using the .NET framework via ASP.NET web-programming language, and Microsoft SQL Express as a database engine. Ultimately,

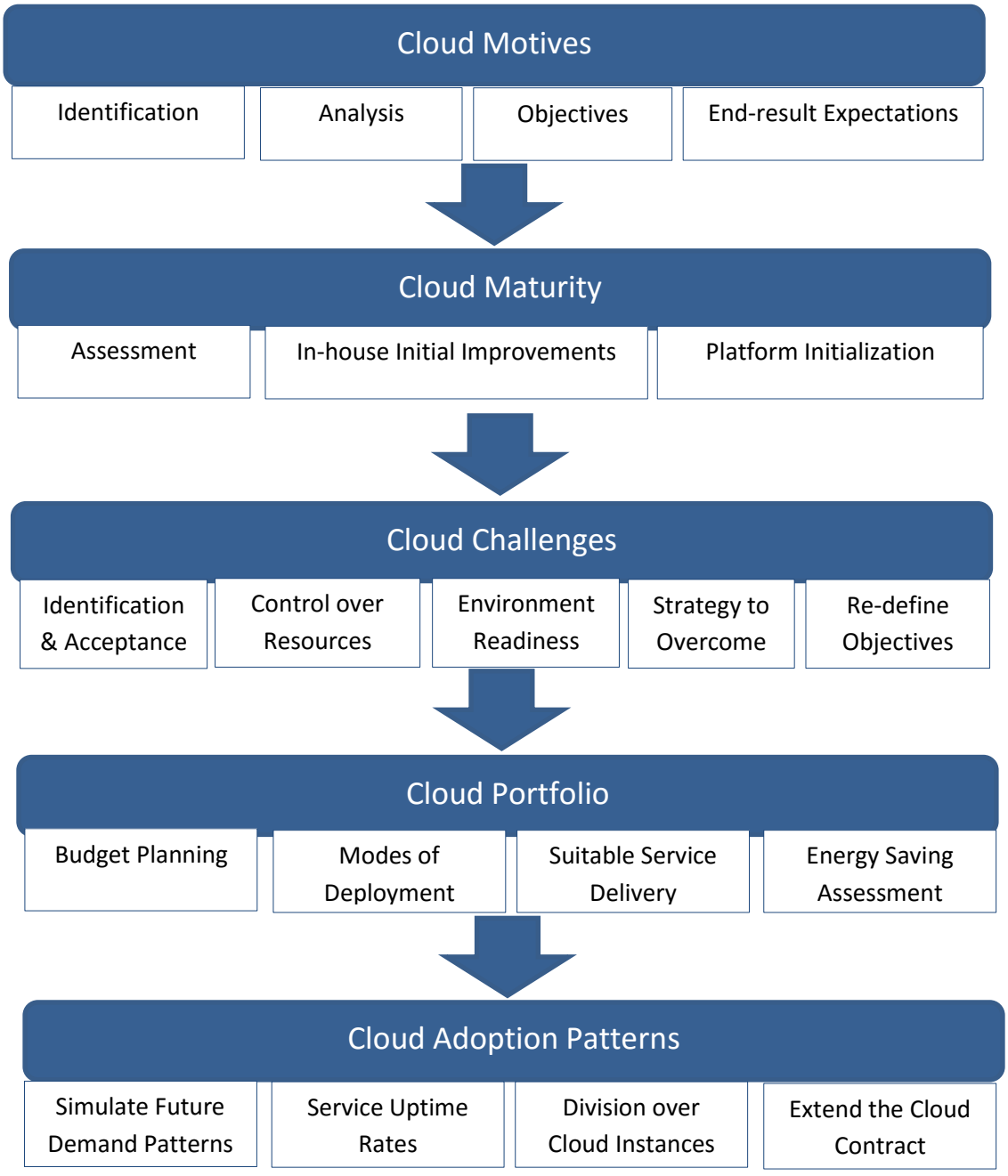
the next chapter will point out key findings from executing a full cloud-computing consultancy case study via *SBCE*, which will examine overall conclusions and construct an ICT management framework for cost-efficient and sustainable cloud utilization in Smart Buildings.

5.4- Theoretical Decision-Making Framework

Although separate outcomes were argued post each section, the purpose of this section is to summarize major conclusions in order to form a cloud-computing decision-making framework for non-expert managers in Smart Buildings. As discussed earlier, the main purpose of this framework is to achieve a sustainable and cost-efficient ICT lifecycle with minimum management effort for different types of Smart Buildings that follows dissimilar work objectives.

Achieving business success through cloud-computing technologies is a complex task from the end-user perspective that requires comprehensive management understanding of multiple technical and nontechnical aspects. In general, this research argues that constructing a cloud-computing strategy for different types of Smart Buildings is developed by adopting key correlating steps to maximize the overall value of the ICT lifecycle in terms of upfront costs, and associated power consumption. On that ground, this research has developed a theoretical decision-making framework for non-expert managers. The aim of this framework is to assist those types of users to evaluate their ICT environments before utilizing any types of cloud-computing services. This is accomplished by presenting simple decision-making steps in a fixed order for managers to adopt with accordance to their ICT requirements and budget. These steps are developed to cover the implications, objectives, and description of the major management aspects and areas of concern associated with cloud-computing deployments as discussed earlier.

The following discussion explains these steps from an ICT decision-making standpoint, and the relationship with the energy consumption factor. Each step takes into account several management sub-stages, which were identified by this research following the theoretical and the practical analysis in Chapters 3 and 5 (Figure 5.23).



(Figure 5.23) Cloud-Computing Evaluation Framework for Non-expert Managers

As illustrated in Figure 5.23, this research has identified five key stages of the overall decision-making framework as follows (Mualla & Jenkins, 2015):

Cloud Motives: It is recommended for any Smart Building to accurately examine the main drivers of change and reasons behind outsourcing certain ICT components onto the cloud prior to committing to any contracts with the service provider.

Cloud Maturity: As discussed earlier, most Smart Buildings already adopt various types of cloud computing solutions. On that note, a special management consideration is required before utilising new cloud services given that newer features might include a duplicate of existing ones in some aspects, therefore, unnecessary costs can be added as a result of duplicating the same cloud services and purchasing unneeded resources.

Cloud Challenges: Organizations adopt different work objectives and have various attributes such as size, ICT demand, and budget. As a result, particular cloud challenges can have more impact over the others as concluded in the previous survey. Therefore, it is recommended for organizations to identify the relevant areas of concern to their businesses and management processes. As a consequence, this can mitigate the level of concern by emphasizing on those aspects when signing a contract with the cloud provider. This can be achieved by requesting additional assurances and SLA guarantees from the cloud provider.

Cloud Portfolio: This stage is focused on measuring the internal smart building ICT budget against potential future changes in cloud cost. Cloud computing providers such as Google and Amazon have changed their cloud pricing calculations and associated service features on several occasions in the last two years (Hölzle, 2014). On that ground, this research suggests that non-expert clients are recommended to measure results obtained from the previous stage with their allocated ICT budget for three to five years in advance. This stage is argued to help managers in predicting price changes in their cloud services across time, which as a result would enable them to define and elaborate on these rules with the cloud provider at an earlier stage.

Cloud Adoption Patterns: As discussed earlier, one of the main cloud computing characteristics is the dynamic scalability which allows users to scale the capacity of their cloud resources up or down in a flexible, remote, and instant manner. This forms the fifth stage of this framework, which recommends non-expert managers to simulate their organizations' demand patterns across the off-peak and heavy demand periods prior to any actual cloud computing utilization.

Extend the Cloud Computing Contract: This forms the final stage of the decision-making framework after the non-expert cloud clients take into account all the previous stages. The main objective of this stage is to identify the potential threats and areas of

ambiguity in the contract with the cloud provider, which can affect the organization's future ICT spending, management effort, and support.

The previous framework was constructed as an outcome of this research's main investigation on cloud-computing management principles. In order for managers to adopt this methodology for an industry-specific ICT portfolio, the analysis of all previous stages is required, which can form a bespoke solution for different types of ICT environments. In a practical utilization, enabling cloud services and management for an ICT-dependent organization comprises three attributes of self-service, elastic management, and analytics. As previously concluded from the semi-structured interviews for cloud service requesters, adopting any type of cloud deployment (e.g. Public, Private, or Hybrid), might result in a multi cloud chaos in terms of decision-making and in relation to numerous service providers which requires a thorough re-ordering of management priorities. As an outcome, this process can be ordered according to a pre-defined spec-management, contract governance, and power optimization strategies. The main objective behind this is to minimize resources, energy, and maintain cost-efficient deployments without limiting the ICT productivity.

In order to support the framework concluded above, according to a 2014 cloud survey by Right-Scale, Smart Buildings today have reached cloud ubiquity given that 94% of all survey recipients were employing cloud services (Weins & Tolani, 2014)**.** This was divided between 29% for Public clouds, 7% for Private, and 58% using a combination of both as a hybrid solution**.** In order to support this study's main conclusion, the same survey argued that any in-house cloud utilization is currently lacking proper governance depending on key decision-making elements which can vary for different Smart Building ICT environments. As a result of taking the previous decision-making categories into account, different viewpoints concerning management tendencies on cloud strategy adoption were collected across different types of organizations.

An obvious advantage can be highlighted from the previous figure regarding defining benefits, security, and other timeframe aspects for cloud deployments. On that note, the exclusion of an adequate cloud-computing framework results in the appearance of Shadow ICT, which is a term used when unplanned efforts occur within an organization resulting in unwanted ICT works. This can be related to migration, support, or maintenance. Accordingly, a contrast must be established with reference to Smart

Building views of ICT roles in any cloud deployment process. This compares central ICT works on one hand, and business unit procedures on the other. For example, it was noted by Right-Scale, that 67% of central-ICT works, across a considerable number of enterprises participated in an internal survey, are accounted for efforts on selecting private clouds, whereby only 38% of business works were acknowledged in that respect. In addition, selection of public clouds took over 60% of central-ICT works, while only 42% were highlighted for business operations. Similarly, other aspects of ICT roles in a cloud environment were observed for a generic Smart Building such as setting-up cloud policies for efficient utilization, determining when to include business strategies to cloud applications, constructing in-house private clouds, and considering the acquisition of cloud broker services.

While identifying cloud motives is classified as the predominate stage in the five key steps of the cloud adoption framework for sustainable decision-making, several points must be assessed accordingly in response to major enterprise goals such as gaining competitive advantage, and maintaining ICT value with minimum administrative efforts. These aspects ranged from accelerating application delivery and improving ICT efficiency of both infrastructure, and personnel. This also covers business attributes such as expanding markets with novel competencies and optimizing returns by increasing flexibilities for both investments and risk reductions.

Secondly, assessing cloud maturity across the intended Smart Building ICT environment forms the next phase of this framework. For instance, cloud maturity respondents can be divided as follows: Cloud Watchers, Beginners, Explorers, Focused, and those who acquire no tangible plans that are visible for the foreseeable future. Moreover, Cloud Watchers means that users are still in the planning phase, while Beginners have already deployed virtualization as a first project. In addition, Cloud Explorers means that the organization is currently running applications on either SaaS or PaaS, while Cloud Focused consumers are heavily involved in the infrastructure and platform layers of service. For example, looking back at the previous survey by Right-Scale, the group of Cloud Beginners can be noticed to form the highest percentage amongst respondents regarding the cloud maturity assessment.

The significance behind assessing the organization's cloud maturity is essentially to offer business benefits in terms of OpEx, CapEx, ICT personnel efficiency, service

higher performance, geographical reach, power consumption optimization, faster time to market, faster access to infrastructure, and greater scalability. Alternatively, various accompanied challenges can be observed across the different types of cloud users such as security, compliance, integration with internal systems, expenses, performance, lack of maintenance, and governance control. This research argues that identifying the next steps for a cloud evaluation journey regarding a specific Smart Building ICT environment should thoroughly distinguish between different demand and involvement types of cloud users.

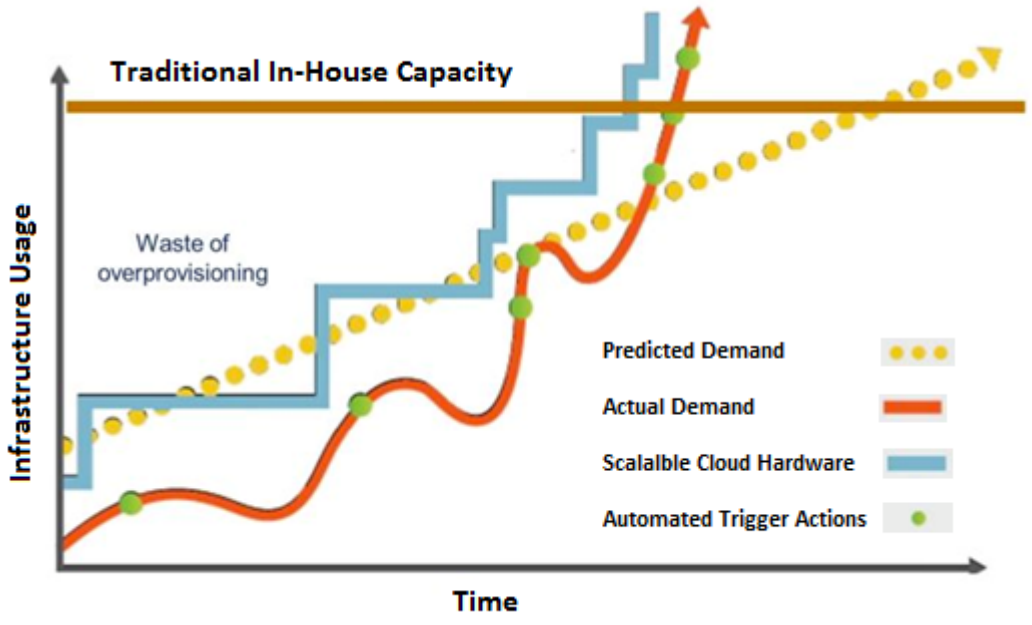
The third stage of this study's decision-making framework illustrates overcoming common technical trade-offs and management risks from cloud utilization in a Smart Building ICT deployment. The first phase is to determine to what extent this particular portfolio acknowledges the significance of the cloud-computing security impact. In particular, the structure in which each manager would follow can differ depending on multiple in-house ICT rules. However, in order to ultimately derive an appropriate cloud security strategy, this can be portrayed as a cloud security ecosystem, which connects the cloud provider and 3rd party vendors with the organization's different branches and ICT components.

This cloud security ecosystem within a Smart Building must comply with a shared responsibility roadmap, which analyses, prioritizes, and assigns numerous information security attributes to the correct destination. For instance, while the vendor is in-charge of data encryption in transit and destination points, a 3rd party cloud broker would ensure secure communications, system integration, cloud logs concerning end-user activity, privileged identity management, backups, and data replication. This also helps in delivering reliability via outage-proofed and redundant platforms, which forms one of the key objectives non-expert managers must attempt to achieve before making any decisions concerning cloud migration.

Above all, this study classified the cost optimization factor as the most crucial area for non-expert Smart Building managers to take into account. As this forms another cloud challenge, a management comparison can be highlighted between the in-house model which relies on upfront spending decisions, and the on-demand scenario which allows continuity in cost and future expenditure decisions. Accordingly, conclusions of this research argues that the in-house ICT model must cover structured steps of defining

infrastructure requirements and maximum demand, negotiate prices, attain internal approvals, and deploy services according to capacity. Nevertheless, the on-demand approach re-evaluates the previous process to offer managers more flexibility in terms of forecast abilities regarding potential utilization, budget allocation, and detailed monitoring of ICT expenditures. On that ground, this study's web-application tool, SBCE, which is developed to offer non-expert managers further decision-making abilities, will introduce an original approach in which managers can manage cloud components' changeable capacity in contrast to the in-house conventional solution.

As will be discussed in Chapter 6, this study explored this solution by taking into account specific ICT management aspects such as demand prediction, actual demand, attributes of scalable cloud components, and waste of overprovisioning. The following figure demonstrates SBCE's infrastructure usage outcome in relation to time after performing several case studies via SBCE as will be discussed in Chapter 6 (Figure 5.24). This shows the scalable capacity of utilized cloud components in contrast to the conventional in-house solution, whereas automated trigger points would generate various pre-defined actions whenever a change in the ICT demand is observed.



(Figure 5.24) SBCE: Managing Cloud Components' Capacity in contrast to the Conventional In-house Approach

As illustrated in Figure (5.23), this framework discusses the planning of a bespoke cloud-computing deployment and any associated utilization patterns. In principle, this

study suggests that segmenting the organization's cloud goals and application paradigms is a crucial task that must be thoroughly identified even by non-expert managers. This framework involves users who adopt either a cloud solution by choice whenever convenient or others who only employ specific types of cloud services depending on their organizations' unique requirements. The management evaluation between these two types of users highlights the impact on the business aspect, which measures the actual benefits from the migration of a particular application to the cloud, and also identifies the impact on the technical side of things, which measures the levels of system compatibility and other technical areas. Predominantly, this framework is constructed on the basis of identifying the management and the technical feasibility levels for implementing a specific ICT solution over a certain cloud environment. If this was deemed feasible for a certain Smart Building ICT process from a cost, environmental, and ease-of management perspectives, another value examination is required at this stage which measures the cost-efficiency status as a result of adopting and supporting the selected cloud solution in comparison to a conventional in-house deployment.

This research proposes a cloud cost methodology, which clarifies five domains including cost analysis, procurement management, and cloud finance accurate prediction. This structure starts with *Visibility*, which is a key identification step to point out what is exactly being spent on either tangible or intangible ICT components. In addition, the second stage is *Forecasting*, which obligates non-expert decision-makers to predict hidden future costs on ICT virtualization whether related to purchase requisites, upgrades, or unpredictable support. Furthermore, the third stage is *Governance*, whereby managers would regulate a policy regarding the division of responsibilities as discussed in Chapter 3, which thoroughly illustrate the extent of each user's permissions to control and alter cloud components. The fourth step is *Allocation*, which covers cost management and designation across all involved systems, cloud vendors, and 3rd party suppliers. Ultimately, the fifth stage is *Optimization*, which forms the final phase of this research cloud cost methodology. This stage is intended to minimize expenses regarding the cloud purchase process, support, and service upgrade, in addition to any energy consumption reductions which occurs as a result of an ICT infrastructure migration as discussed in earlier chapters.

In conclusion, this research explored into different approaches and available solutions of cloud-computing management for Smart Buildings' non-expert managers. This study investigated costs, associated sustainability benefits, and ease-of-management opportunities from employing various types of on-demand, scalable cloud deployment services. With that in mind, multiple technical and management trade-offs and challenges were identified at almost each stage of this decision-making framework. These were mostly related to contract limitations in response to adopting multiple ICT service suppliers and 3rd party vendors, which turns the migration process into a difficult task, as explored in the Heriot-Watt University case study in Chapter 5. On that ground, Smart Buildings have the ability to operate and manage cloud-computing services from any location with minimum upfront expenses, while preserving leverage over ongoing investments and enhancing core competencies. This research constructed this framework to assist non-expert managers maintaining a supplier influence by acquiring a detailed five-year cost strategy which empowers Smart Buildings with elastic ICT architectures that meet today's business demands.

6.0- Chapter 6: SBCE: Smart Building Cloud Evaluator

6.1- Introduction

As discussed in previous chapters, organizations operating across different Smart Buildings need to utilize multiple interactional systems within multiple interconnected ICT environments. As a result, ICT planning, budgeting, and deployment were identified as the most crucial and time consuming elements of any management process. In this thesis cloud-computing is introduced as a solution to reduce ICT hardware and software cost-of-ownership, administrative effort, and improving scalability and speed of deployment. Nevertheless, deriving long-term strategies and estimating real-time cost values according to different Smart Building circumstances, is still considered a difficult task for decision-makers using traditional approaches. On that ground, *SBCE: (Smart Building Cloud Evaluator)* was introduced as a decision-support tool to simulate ICT and cloud lifecycle costs and associated sustainability aspects in accordance with unique and changeable Smart Building ICT requirements. In addition, SBCE investigates various ICT management strategies for the purpose of evaluating effective ICT hosting alternatives in Smart Buildings through cloud computing. As discussed earlier, these services are mostly supplied by a number of external vendors with minimum standardization or integration between any of the suppliers.

SBCE was built on a core objective of simplifying cloud-computing management processes in different Smart Building ICT environments. This is accomplished through generating specific types of consultancy reports to assist non-expert decision-makers in achieving a cost-efficient and sustainable cloud lifecycle in their organizations. The following table illustrates the relationship between the tool's key benefits to decision-making, and the main technical features from an end-user perspective (Table 6.1).

(Table 6.1) SBCE Key Technical features and Decision-making Benefits

Key Non-technical Decision-making Benefits	**Technical Benefits**
Solving management complexity issues in relation to time, effort, cost, and the number of involved staff	Instant Cloud-Computing admin report generation without any direct need of external ICT consultancy involvement

Dispensing the need for external (third-party) consultancy involvement	End-user customized performance through bespoke paradigms for growth and decline service patterns.
Rapid estimation processes via online platforms, appealing to a wider audience rather than employing off-line specialized agencies via non-integrated solutions	Flexible content management in reference to Cloud-Computing instances and relevant ICT attributes
Rapid deployment via open platforms without the need of high-performance software or hardware installed	Ease-of-Access, fully responsive solution through any web interface (desktop or mobile)
Ensure a 5-year automated forecast accuracy results, depending on long-term changes in pricing and regulations	Dynamic price updates via built-in scripts and live database queries
Reduce time between analysing requirement evaluation, and generating estimation reports, as this is automatically updated upon each user change	Technical contrast between several existing evaluation systems and ongoing projects
Multi-user / multi-dimensional transition abilities for enterprise business deployments across different Smart Building ICT environments.	Scalable cloud-based architecture that supports user accounts and permissions
Time-specific scalable model design and timeframe delegation of ICT lifecycle.	Supports back-end control-panel functionalities for system administrators
Ability to manage employees and control over personal data.	Supports various user account functionalities to edit, view, alter, add, re-generate, or delete previous evaluations
Ability to generate statistical reports for cost forecast and measurement objectives.	Ability to export reports to CSV and other formats, in addition to a wide range of chart selections.

As discussed in Chapter 4, SBCE was built on a demonstration basis, and the application is not intended at this stage for any industrial use. However, as will be argued in the Future Research Recommendation section in the Chapter 7, potential commercial plans to introduce SBCE as a market-ready application are already being considered. This research included SBCE as a key demonstration conclusion to highlight the practical side of the decision-making framework this study will discuss in the next chapter. This covers cloud cost forecasting, deployment consultancy reports in

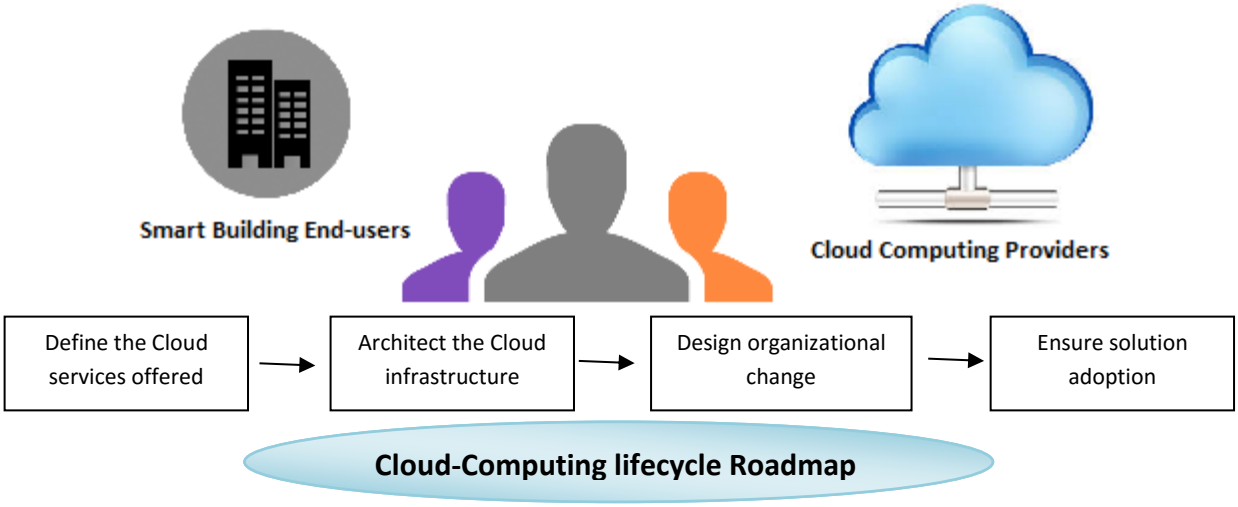
terms of growth paradigms and scalability patterns, and associated recommendations on service acquisition and purchase.

In theory, SBCE was constructed on the basis of bringing together non-expert managers in Smart Buildings with cloud computing providers, by simplifying the ICT management process as will be concluded in Chapter 7 through a decision-making framework for cloud computing employment and utilization. The primary intention is to help managers architect a cloud environment by estimating pros and cons, future costs, and interrelated management aspects in relation to a real-life practice for a specific organization. While a cloud employment strategy is evaluated by the end-user to deliver against the expectations of the business, other ease-of-management and deployment simplicity factors represent the significance behind SBCE for this research as a decision-support tool from an MIS (Management Information Systems) perspective.

The theoretical concept behind building SBCE relied on four main stages, which were introduced as part of a cloud planning workshop by BMC Software in 2014 (BMC Workshop, 2014). The first step covers defining offered cloud services, which raises the following questions: (Figure 6.1)

- Who are the users of this cloud?
- What type of services will they require?

In essence, specifying upfront answers to the previous questions results in a sizable list of end-user expectations, which will ultimately employ the intended cloud strategy as an ICT platform to support the workload of the targeted portfolio. On these grounds, the second step will adopt each specification to design the back-end of the cloud infrastructure. Accordingly, managers will be able to define the cloud infrastructure while keeping in mind each of the selected services required from step 1. The third step points out the process for designing the organizational change element. In particular, introducing a cloud solution to any Smart Building ICT environment can alter the way business objectives are handled in response to conventional in-house ICTs.



(Figure 6.1) SBCE Theoretical Concept

The majority of users in different types of organizations are not particularly accustomed to dealing with cloud-based technologies. These include ICT tasks such as adding, altering, upgrading or removing resources. Similar actions in cloud-computing can be carried out within minutes instead of days when using conventional approaches, especially for tasks such as hardware upgrades. These factors create new relationships between the service requester and provider on multiple levels. In particular, as a result of enabling this kind of automated and self-service functionality, the timeline associated with delivering ICT services was observed to vary considerably. This causes more time to be spent on planning and in-house ICT adjustments before adopting cloud services. Finally, ensuring effective adoption of the proposed solution can be classified as the fourth and last stage of the theoretical concept for developing SBCE. This adoption requires managers to guarantee that end-users will actually use the on-site cloud portal as a post planning process.

The adoption solution is referenced firstly as an educational process to business users in the intended Smart Building. This mainly requires identifying what types of resources are being received and when are they available. Secondly, the ICT provider ensures that end-users are ready to utilize this cloud at an appropriate level, which is compatible with their understanding to deal with the new services and integrate it with in-house applications. The ultimate goal behind this theoretical assessment is to efficiently deliver a bespoke and a long-term reliable cloud-computing consultancy system for Smart Buildings.

According to survey findings from the previous chapter, typically, managers in small businesses expect to complete a cloud-computing planning and deployment process within a period of 30 days. However, this study suggests that those 30 days are only an initial phase, which is not responsible for growing the business and service footprint in terms of both resources encompassed by the cloud portal, and users employing the infrastructure.

In relation to recent commercially-active cloud planning tools, which are –in technical terms- relevant to SBCE, this research referenced the following existing systems as a platform to assist in the development of SBCE, and the construction of this study's ICT management framework.

- PlanForCloud by RightScale Corporation: which solely analyses the cloud market for existing instances and generates a 3-year cost forecast, as employed in the previous cloud-computing simulation for Heriot-Watt University as a key case study (PlanForCloud, 2013).
- Anaplan, The Cloud-based Modelling and Planning for Operation and Finance: This tool offers a business-focused ICT consultancy features via on-demand modelling platforms for a strategic role in variously operated enterprises (Anaplan, 2013).
- Oracle Planning and Budgeting Cloud Service: A high-enterprise estimation application, which runs on Oracle Hyperion for companies that operate on a cloud-based hosting model (Oracle Hyperion, 2013).
- BMC Solutions and Services: This enterprise provides a cloud-computing planning workshop for in-class corporations and Smart Building ICT environments (BMC, 2013).

The following table illustrates a technical comparison between the features of each of the above tools in contrast to SBCE key features. This is also shown with accordance to the relevant cost simulation and decision-support tools which were discussed in Chapter 4, Section (4.2.2). The research gap in which SBCE addresses can be observed in the shaded rows below (Table 6.2).

(Table 6.2) SBCE Key Technical Features in comparison to Selected Relevant Tools

Tool / Feature	Rackspace Cloud Calculator	Amazon EC2 Calculator	Plan-For-Cloud	SBCE	Real Cloud-Sim	Ana-Plan	Green Cloud	Google Pricing Calculator
Basic calculation of cloud features cost according to user-selected resources	✔	✔	✔	✔	✔	✔	✔	✔
3-Years Cost estimation / reporting of resources	✘	✘	✔	✔	✘	✔	✔	✔
5-Years detailed breakdown / reporting of resources' costs and sub-instances / features	✘	✘	✘	✔	✘	✘	✘	✘
Business perspectives and decision-making insights of cloud entered platforms	✘	✘	✘	✔	✘	✔	✘	✘
Independent energy models for each type of resource	✘	✘	✘	✘	✘	✘	✔	✘
Ability to Program detailed scalability paradigms across a 5-year deployment	✘	✘	✘	✔	✘	✘	✘	✘
Dynamic reports according to user-programed paradigms	✘	✘	✘	✔	✘	✘	✘	✘
In-depth management consultancy reporting of cloud requirements and security perspectives (see Appendix C)	✘	✘	✘	✔	✘	✘	✘	✘

Pre-Programmed Services patterns	✕	✕	✔	✔	✕	✕	✕	✕
Ability to edit previous evaluations	✕	✕	✔	✔	✔	✕	✔	✔
Cloud energy consumption simulation of resources	✕	✕	✕	✔	✕	✕	✔	✕
Estimated future benefits / reductions from deployed cloud resources depending on the organization category	✕	✕	✕	✔	✕	✕	✕	✕
Modelling and simulation of large scale cloud computing data centers	✕	✕	✕	✕	✔	✕	✕	✕
Ability to enter a unique kWh cost for commercial use to generate an estimated cloud energy bill	✕	✕	✕	✔	✕	✕	✔	✕
User friendly GUI	✔	✔	✔	✔	✕	✔	✔	✔
Open Source	✕	✕	✕	✕	✔	✕	✔	✕
Complete TCP/IP implementation	✕	✕	✕	✕	✔	✕	✔	✕
User-defined policies for allocation of hosts to VMs	✕	✕	✕	✕	✔	✕	✕	✕

As acknowledged from the semi-structured interviews in Chapter 5, Smart Buildings distinctively operate a considerable number of unrelated functionalities; each is usually supplied from a different vendor through a 5-year contract on a minimum basis. These generate raw output data which are related to tasks such as hosting, processing, recovering, and backup. On that account, ICT solutions that offer the means for previous procedures within a Smart Building environment, have been noted to constantly demand heavy-duty and in most cases conflicting functionalities such as support, upgrade, licensing and scaling.

As a result, cloud-computing was introduced on various application levels in terms of architectural models, service criteria, and deployment methods as previously explored in Chapter 3. However, Smart Building non-expert managers have an additional barrier of forecasting actual advantages/disadvantages gained from virtualizing ICT resources. This was debated in terms of key cloud benefits in relation to cost, ease of management, sustainability, and future utilization challenges. To a large extent, this estimation is considered a dilemma given the uniqueness and diversity of each Smart Building environment on various operational levels. On these grounds, SBCE was created to tackle this problem, from a generic and ICT decision-making perspective with regard to disparate Smart Building cases.

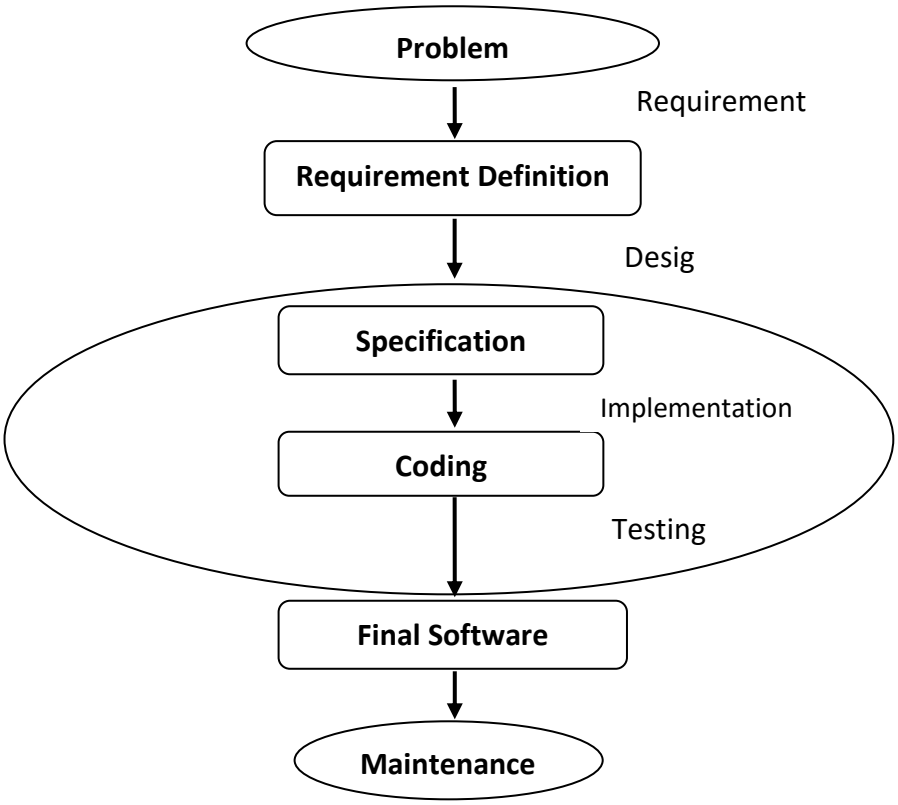
6.2- Syntax and Development Diagrams

To this point, the roadmap for this research has paved the way for this tool to be developed on a knowledge-based platform through analysing main findings from the literature review, theoretical cloud management analysis, and the primary value investigation which covered three interviews, a cost simulation and a risk analysis survey. SBCE will follow an object-oriented approach with reference to software engineering, design, and top-down algorithmic and modularity abstraction (K. Lekeas, 2011). In theory, the data-flow oriented programming method adopts a software system modelling and implementation paradigm, which is based on multiple self-contained information systems principles as follows:

- Displaying the entire project's scope through Objects.
- Specifying a template description for common object and grouped entities via Classes.
- Creating an abstract, fixed-interface to Encapsulate objects' information. This controls data hiding, invoked operations, messages, and objects' behaviour.
- Classes Generalization, which extracts grouped attributes of multiple classes into a super-class.
- Specialization, which creates descriptive information on descendant-classes, subclasses, and multiple inherited ones. This details classes' relationships within a system.

- Defining different implementation methods for classes that acquire identical signatures, yet, each follows a dissimilar operation. This is carried out through Polymorphism.

Previous points clarify a structural overview, which includes operational phases adopted by SBCE via the Unified Modelling Language (UML) (Booch, Rumbaugh & Jacobson, 1998). Tackling each problem concerning the entire development process will follow five separate stages. This starts with Requirement Analysis, then Design, Implementation and Testing. The development process of SBCE will be finalized with Maintenance, Recovery, and Support as shown in the following process (Figure 6.2).



(Figure 6.2) *SBCE* Development Steps: UML Methodology

The objectives of this tool lie in the grey area between the computer science and management principles where non-expert managers usually struggle in making decisions based on technical issues, as these issues still require a thorough analysis from a cost and administration perspectives. The main purpose is to enhance decisions on cloud utilization by simulating a real-life cost and management process across different Smart Building ICT environments. The following illustrates a brief project description from an end-user point of view, which will be referred to as an *Actor*. This symbolizes

the SBCE user journey and is clarified through a simple text to reflect the system's processes in order to convert the textual requirements into a UML workflow diagram.

6.2.1- Description of Requirements

SBCE is designed to provide user-friendly graphical interfaces, specifically intended to simplify the process for non-expert managers to estimate cloud benefits, disadvantages, and preferable options for either explicit, or generic enterprises. The domain of potential users involved can vary from Smart Building executive managers, CEOs, CFOs, entrepreneurs, project managers, ICT administrators, all the way to non-expert business owners. The main target is to assist decision-makers to determine the extent of effectiveness of employing a cloud-computing solution for cost-effective and sustainable future lifecycle. This is intended to replace the need for external ICT consultancy support. The main process is structured around three key factors: cost, sustainability, and ease-of-management. In essence, an SBCE client can access the project via either a simple web browser whether he/she is a mobile-based one or regular desktop in order to pursue a structured actor-journey flowchart, as discussed next in simple steps.

At first, the user enters the home page of SBCE, where general information is provided to explain the main requirements, technical description, and additional knowledge such as Background, Creating an Account (Sign-up or Sign-in), Tutorials, About, Contact, and References. As a next step, the user must Sign-up to create a new account where only minimum information is required such as the organization name, email domain, and other details. Similarly, SBCE administrators can Sign-in via a special control panel where all users' details and projects' information is stored and edited in relation to earlier cloud evaluations.

After the user enters the My Account page, the tool then offers to choose between two fundamental options to start a new cloud-computing evaluation. These are Quick Cost Estimation, or the In-Depth Analysis. While both represent the core features of this tool, the two options result in a cloud decision-support analysis in terms of the Smart Building's ICT value forecast and associated management considerations depending on the user's inputs. However, several selected recommendations with reference to the

most suitable cloud-computing deployment models and service criteria, will vary depending on each option's data entry as discussed next.

The Quick Dynamic Cost Estimation option requires only the user to input a small amount of key ICT variables, which are previously determined from the cloud-computing components available in today's market (e.g. Rackspace, GBM, etc). The end-result will generate a future cost report illustrating all components and elasticity models defined by the user. Furthermore, a key feature is provided at this stage allowing the user to build either a single or multiple seasonal growth/decline paradigms in association with each selected cloud-computing element. These reflect the changes in operational requirements, service capacity, and timeframes across the specified ICT environment.

Alternatively, the in-depth option offers further recommendations and elaborated data inputs regarding the intended Smart Building's ICT demands. Ultimately, the end result will generate a future cost report illustrating all user-defined instances, elasticity models, and seasonal scalability paradigms. This is carried out similarly to the Quick analysis method. However, the outcome report in the in-depth approach is generated as a result of the user's answers and data input on multiple pre-structured management questions. In other words, the Quick Dynamic Cost Estimation is intended for non-expert managers, or ICT administrators who already acquire an understanding of the organization's basic ICT requisites in order to outsource resources onto a cloud substitute. Nevertheless, this group still requires a detailed cost forecast report, which shows the ICT growth and decline patterns for different services in their organizations in relation to time. However, the in-depth analysis is meant for non-expert Smart Building decision-makers who do not necessarily obtain a sufficient cloud-computing knowledge, yet are seeking an extended benefit analysis for multiple ICT management levels. Although each step has similar client-journey inquiries, each section will adopt different methodologies as clarified in the Actor-Use Case diagram presented next.

The In-depth process includes multiple sub-steps involving straight-forward inquiries with respect to various ICT inputs for the targeted Smart Building. These are presented as simple questions, which end-users can answer online in order to generate the final in-depth report accordingly. These questions are listed in Appendix C, and each area is identified in this study's decision-support methodology as follows:

- The organization's main attributes in association to type, size, operation, and ICT dependence.
- Current ICT and Smart Building attributes in terms of existing expenses, number of locations, associated systems, number of suppliers, and relevant power consumption within the existing environment.
- ICT Risk acceptance and existing technology management challenges regarding the Smart Building's operational nature.
- The cloud-computing administrative knowledge, preferable solutions, in-house control optimization, and relevant ongoing implementations.

The In-depth option provides an elaborative approach for extended cloud utilization investigation. This is intended to generate an automatic ICT requirement forecast for a preferable management lifecycle. The following demonstrates an overview of different angles of assessment and types of management inquiries, which are included in the previous analysis process.

The main mutual aspect between both the Quick and the In-depth approaches is the cost forecast framework, which simulates expenses over a 5-year ICT lifecycle period with accordance to user-built scalability paradigms as previously explained. As a consequence, the In-depth analysis generates the cloud decision-making consultancy report by firstly adopting the following five enterprise categories shown below. These were referenced from the cloud tracking poll by the CDW (Caraher & Nott, 2011).

- Small Business
- Medium Business
- Large Business
- Government Agency
- Higher Education Institution

These categories are examined by the CDW in relation to strategic plans, development percentages, technical description, cost reductions regarding outsourced applications, and finally a 2 to 5 years ICT budget forecast estimation concerning savings and expenditures of cloud utilization. Moreover, each class was illustrated with primary considerations, which covers major ICT management pillars from Terminology, Remedies, Compliance, Security, Negotiated Service Agreement, and Changes with respect to the latter.

Following the initial portfolio cloud-overview section, the in-depth final report proceeds to analyse the primary concept of Information Security, which was identified by the user as most relevant to the Smart Building line of work. This stage discusses three points, which include Confidentiality and Integrity, Availability, and Accountability. However, in terms of the former, three different approaches are programmed by SBCE depending on the selected cloud service model, IaaS, SaaS, or PaaS. Each security concept consults on critical organizational aspects such as privacy risks, disclosure, storage location considerations, legal uncertainties, and servers' uptime. This is analysed in contrast to the organization's owned datacentres, and further recommendations concerning Mechanisms and Systems, which are specifically identified within the cloud provider's contract.

Furthermore, the report switches to identify the preferable cloud service model depending on answers entered by the user, whereas the domain of involved questions were inspired from the NIST cloud-computing standardization as previously discussed. Whether the criteria suggests for the highlighted Smart Building to utilize only a Software, a Platform, or an Infrastructural level of cloud ICT deployment, a combination of all the above can nonetheless form an ICT management recommendation in the final SBCE report. As far as each solution is dynamically suggested, the report then provides an elaborated analysis on the most-likely associated advantages, trade-offs, and additional notes in comparison to in-house conventional installations in terms of the Smart Building's policy and tolerance towards control over ICT physical components and intangible resources. This was based on findings from the theoretical cloud management analysis in Chapter 3, which arguably investigated 4 different approaches of managing in-house vs. off-site control over main ICT layers (Figure 3.5).

The remaining points of the enterprise ICT management examination -adopted by the in-depth final report- are illustrated in the table below in response to each decision-support action taken by SBCE according to the user's answers (Table 6.3).

(Table 6.3) In-depth Examination Pillars for a Generic Smart Building ICT Environment

In-Depth Examination Stage	SBCE Response Action
The necessity of obtaining a 24/7 availability of ICT resources on both a hardware and software levels of service.	If confirmed, an automatic recommendation to add an additional layer of a Managed Service Level is displayed. In addition, a Hybrid or Private approach is suggested in order to attain additional control over resources.
Identifying the most relevant line-of-work, application-demanded, usage-fee, and future ICT lifecycle scenarios, which are identified as being suitable for the intended organization from an ICT consumer point of view.	At this stage, 3 categories in relation to the previous points are displayed in reference to the NIST analysis as previously explained. Each category of the selected line-of-work, application-demanded, usage-fee, and future ICT lifecycle, reflects the preferable service model, which will be illustrated in the final report in response to an IaaS, PaaS, or SaaS approach, as will be observed in the testing and execution section next.
Identifying from a pure business perspective the suitable service-category model in relation to users' inputs on the selected Smart Building.	This inquiry provides 4 main business ICT administrative scenarios; each reflects either the Public, Private, Community, or Hybrid cloud deployment model. However, in case the user identifies either the Community or the Private hosting solution as the most preferable to the enterprise, SBCE then offers additional analysis in order to select the optimal sub-hosting option in terms of either in-house Private/Community, or outsourced Private/Community as discussed earlier with reference to NIST.
Identifying the most relevant application-workload categories.	At this stage, three workload categories are presented as follows: - Applications with unpredictable growth prospects, - Regular traffic fluctuations Apps - Easily parallelized tools. Each is accompanied with a management consideration with accordance to the work nature of the highlighted Smart Building.

Identifying the most relevant application-characteristic category in relation to the selected organization's ICT lifecycle.	At this stage, application-characteristics are illustrated across three options as follows: - Smart Building ICT environments that include proprietary databases and applications with high I/O and consistent throughput, occasionally undergoing replication and clustering operations for the ICT infrastructure - Smart Buildings without a noticeable demand for replication and clustering operations - None of the above

The following inquiries identify additional ICT management attributes in relation to the number of Smart Building physical locations. This changes the outcome of the final report depending on various cloud considerations such as minimum bandwidth required, and assessing the need for employing other suggested solutions such as Content Delivery Networks (CDNs) for speed enhancements and cloud files. Secondly, other management attributes are examined concerning the number of in-house ICT personnel, ICT storage, and Legacy systems already implemented. All of which considerably determine the final report's output, taking into account cost and associated sustainable benefits. Such features are adding additional Managed Service levels, installing Cloud Block Storage, and identifying the extent of service runtime worthiness concerning outsourcing proprietary and legacy equipment to a cloud-based platform.

The next stage of the In-depth analysis presents a similar cost measurement process to the Quick Dynamic Cost Estimation. This step enables the user to build specific scalability paradigms, which reflects the service growth and decline patterns of their Smart Buildings ICT utilization. Each pattern is constructed for a separate cloud component and in relation to changes in different service attributes against time. These attributes are:

- Service runtime
- Workload peak times
- Changes in resources' capacity depending on certain tasks and time periods
- Periods of pre-scheduled system shutdown

The scalability paradigms are discussed in terms of the following five key cloud components, which were referenced by SBCE from Rackspace regarding prices, types of features included, and other variables concerning support and administrative services.

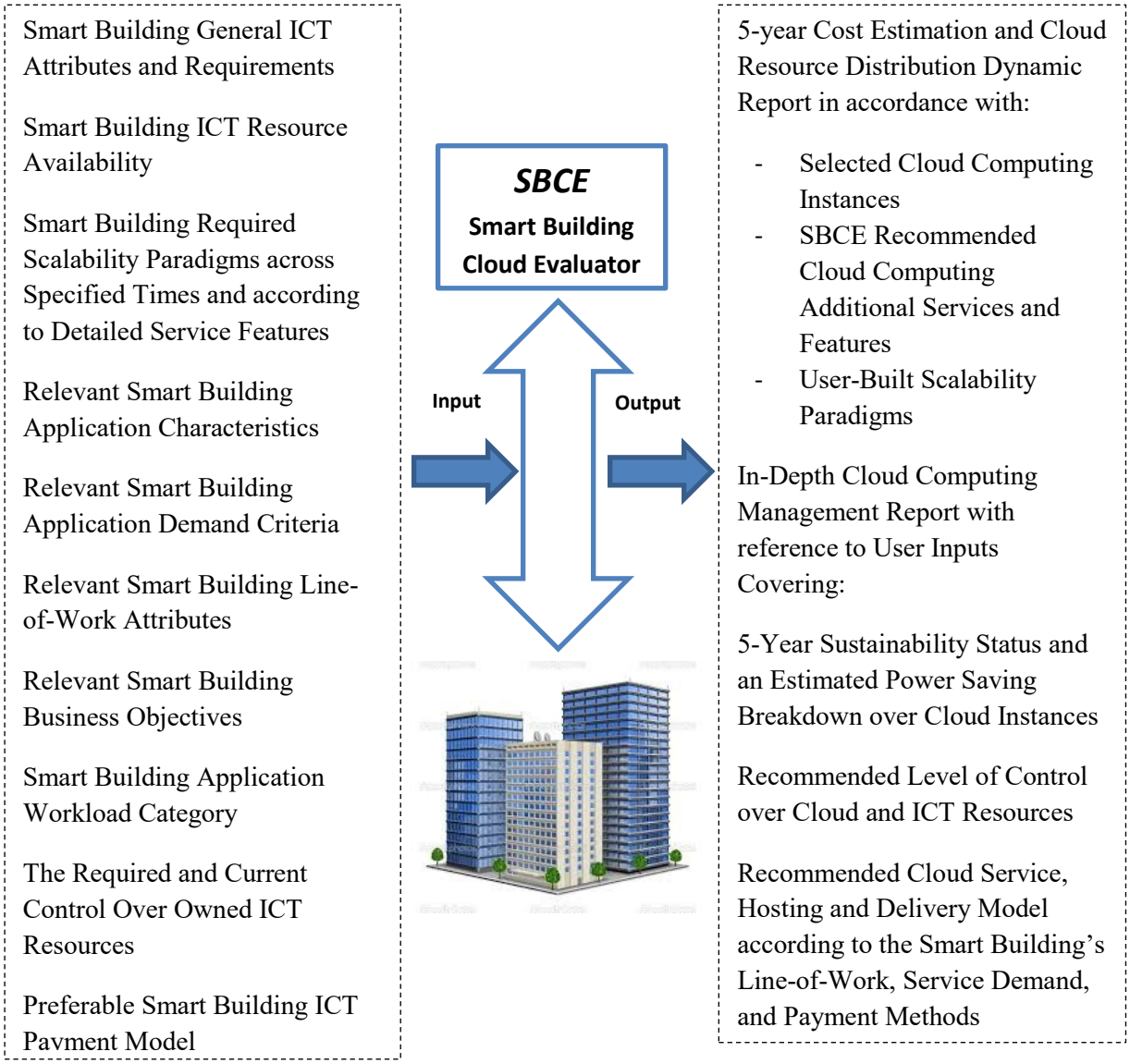
- Primary Servers
- Database Servers
- Load Balancer Servers
- Cloud-Based Storage:
    - Cloud Block Storage
    - Cloud Files
- Additional Support
    - Additional Managed Service
    - Cloud Files Back-up

The scalability paradigms are built as a major part of SBCE to allow non-expert managers to specify the exact times and capacity of service required for their organizations. and hence, obtain accurate long-term cost estimations depending on changeable ICT demands. These paradigms represent the cloud-computing service pattern across a 5-year period of the Smart Building ICT lifecycle. These are programmed in a way that allows the decision-maker to fully and dynamically edit specific cloud requirements on a detailed level which analyses service growth and decline demands. The purpose is to ultimately provide end-users with an optimal cloud deployment scenario for their specific Smart Building ICT workload, management attributes, and associated sustainability aspects. On that ground, the following cloud management investigation will discuss the technical side of the user journey of SBCE. This will cover users' inputs, which estimates the number of Servers, PCs, Racks, external networking devices, and number of ICT employees involved in the highlighted organization.

As a result, SBCE will calculate an average Watt per hour, day, and an annual estimation of electricity consumption on Desktop Computers, Servers, and associated insights for similar case studies with similar cloud deployments to the one considered. This is accompanied with a kWh cost average for commercial use regarding the intended type of organization involved in the ongoing In-depth Consultancy analysis. Finally, the report will calculate the potential average of cost savings on ICT electricity consumption alone from employing previously recommended cloud solutions, as

viewed in the testing section next. Overall, the following figure illustrates the input and output structure of SBCE, which covers both the In-depth and Quick approaches (Figure 6.3).

At this stage, SBCE will identify deployment criteria, estimate expenses, and associated utilization attributes according to the data entered by the end-user. This is accomplished through bespoke algorithms and database queries which were designed exclusively as part of this research project. While the user clicks *submit* to confirm all previous steps, SBCE offers a constant option of navigating back to edit previous data entries from earlier stages and re-generate the same reports. Finally, SBCE will generate a multi-structured consultancy report for a 5-year cloud deployment period. This recommendation framework covers predominantly spike growth and decline paradigms and cost-forecast charts through a multi-choice domain of user-specified timeframes.



(Figure 6.3) SBCE: Core Methodology for the In-Depth and Quick User Options

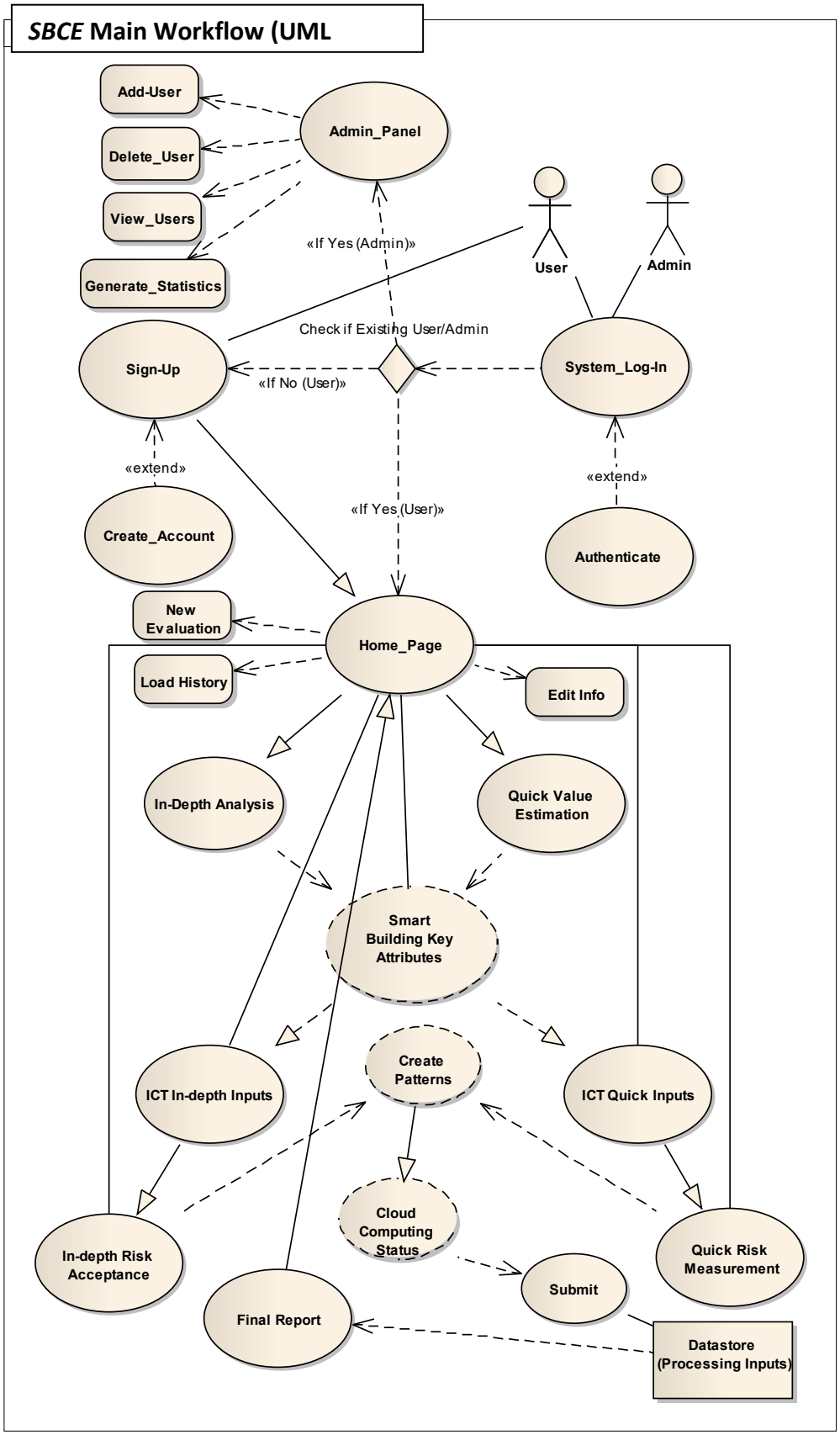
6.2.2- Workflow Diagram

The following diagram illustrates a complete user-journey roadmap for the SBCE decision-making cloud-based system from an Actor journey perspective. The following UML entities reflect the entire scope covered by the tool. However, specialized software engineers mostly follow a more elaborative course of action, which is mostly packaged separately via three different diagrams: Use case, Class, and Sequence diagrams. Given that this tool only represents a demonstrational part of this study's overall ICT management framework, a single primary UML diagram was constructed as illustrated below (Figure 6.4).

It can be concluded from Figure 6.4 that SBCE adopts a user-specified workflow in order to ultimately generate a unique cloud consultancy framework through an automated reporting functionality. This can be re-edited dynamically depending on unexpected changes in requirements which can be observed by managers at any stage of the Smart Building ICT lifecycle.

6.3- Testing and Case Study Execution

As previously argued, SBCE enables non-expert managers to simultaneously add, delete, or edit one or many pre-built scalability paradigms while constructing a unique cloud deployment as part of this tool's dynamically generated consultancy framework. This intends to identify ICT peak-dependence, growth changes, and elastic manipulation of resources within a Smart Building environment. These pre-defined patterns reflect the service requirements' growth and decline status across a specified period of time. Some examples of the main pre-defined scalability paradigms by SBCE are presented in the following list.



(Figure 6.4) SBCE UML Workflow Diagram: Generated via *Enterprise Architecture* Software

- Pre-Built and ready-to-use Scalability Paradigms recommended by SBCE for non-expert managers:
    - Double the main Servers' Performance (RAM) every 2 months (e.g. When the workload peak in a business is expected to increase accordingly).
    - Increase the Servers' Performance (RAM) by 100% on Christmas and New Year's Eve (on December and January) (e.g. when busy transactions are expected to occur heavily in an ecommerce organization).
    - Cut down the Servers' Performance (RAM) by 50% every summer across June, July, and August (e.g. when less users are active in a University).
    - Apply the Managed-Level Support feature for two months a year only (e.g. when heavy backup is required for a Bank with different branches in different locations).

End-users have the ability to customize a new or existing pattern by selecting one of the 5 categories mentioned above for each paradigm in terms of associated admin attributes (e.g. performance, capacity, quantity, and months of Service). For instance, in relation to the scalability paradigms for each cloud-computing component selected, end-users are able to create new paradigms, or customize existing ones, following a structured SBCE formula as shown below:

Do (*Pre-Specified Action*) -> In the Amount of (*The New Capacity*) -> To (*The intended Cloud Component*) -> Every (*Specified Time Period*)

An example of the above can be defined by non-expert managers as follows:

(Add) -> (5 GB of RAM) -> (To All Servers) -> ('every August and September')

After the completion of all stages, if users had adopted the Quick Dynamic Cost Estimation option, the final outcome will be an auto-generated analysis report, which will cover the following sections:

- Introduction: This explains the main structure of this report, which covers the content, definitions of terms, and references to additional information.
- Selected categories of cloud-computing components: Table of all ICT instances from the 5 main categories explained earlier, in addition to associated features and capacity, names, and cost details.

- A 5-year table of costs: A monthly-dependent grid-view for each year which covers 5 tables. This offers the ability to expand all grids to assess the overall breakdown of each month in relation to cost changes for added or altered requirements and usages with accordance to scalability paradigms.
- A 5-year detailed diagram of costs and distribution of cloud components: This illustrates multiple options of statistical charts regarding the 5-year cloud deployment, whereas a breakdown of all selected elements are analysed depending on expenses, user-defined paradigms, and time consumption across each pattern.

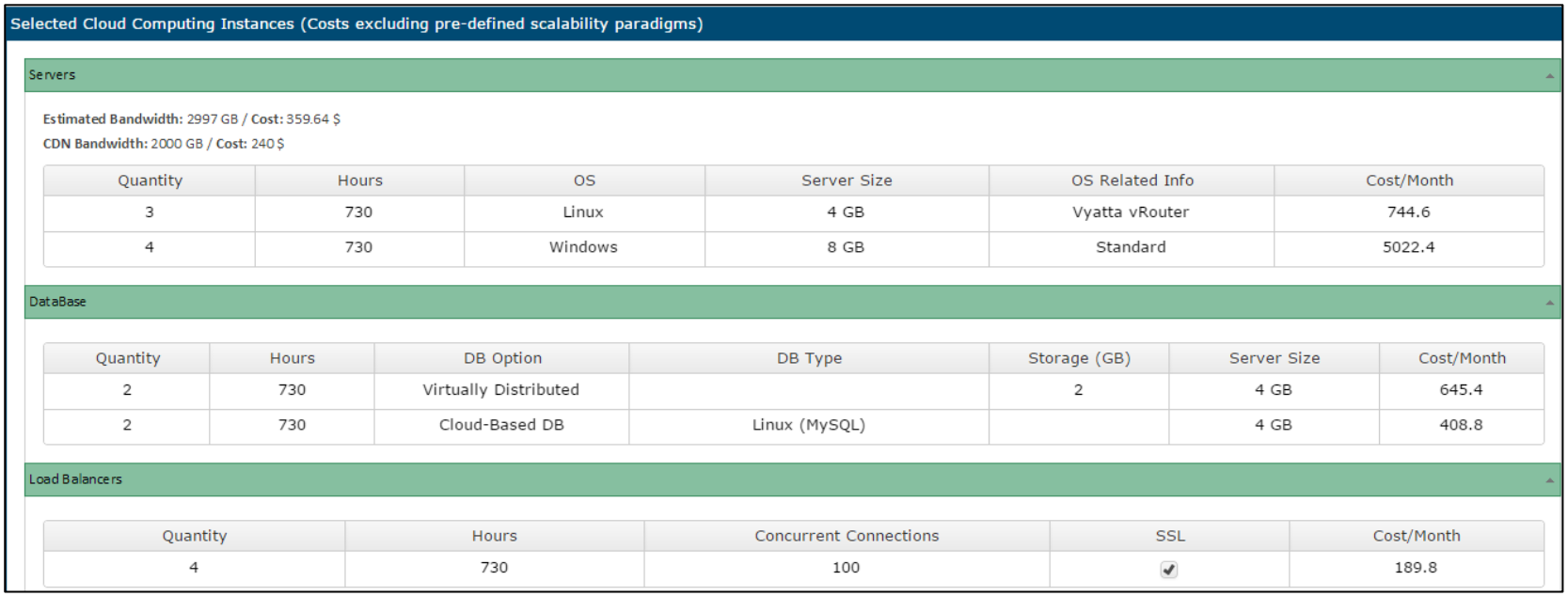
On the other hand, users who demand a more elaborative approach of cloud management and value estimation can follow the In-depth analysis process. This option is intended generally for managers who do not acquire particularly an adequate ICT knowledge to select their own cloud components for their organizations and specify appropriate attributes of each. Usually these managers would hire a third party consultancy provider, which can be costly, time consuming, and causes complexities with the in-house management process in the future. Therefore, this option is designed to allow decision-makers to further analyse and determine the suitable criteria for achieving cost-efficient and sustainable cloud utilization with minimum management difficulties. The final report of the In-depth process includes similar points to the Quick Cost Estimation one. However, this analysis provides a complete cloud management recommendation report, as will be stated in the case study example next. All reports are constructed automatically based on the user's inputs from the 5 administrative stages which were discussed earlier. According to the specific requirements of the organization inputted to SBCE, the ultimate consultancy statement is assembled as a result of the overall analysis to highlight benefits and disadvantages against the Smart Building work nature and management attributes. As a result, this identifies the most appropriate cloud-computing:

- Architectural model
- Hosting method
- And additional considerations regarding expenditures, benefits, and limitations of each aspect respectively

In theory, the next phase is left to the end-user for reviewing, and potentially conducting a further consultation by a third-party supplier, or what is referred to as a Cloud Broker. Depending on the organization's critical workload and size, this is recommended to take place prior to any cloud deployment in the highlighted Smart Building.

The following will perform a case study demonstration of the Quick Cost Estimation option for Heriot-Watt University. However, the data collected from previous practical work were adjusted slightly to represent a relatively larger Higher Education facility. Furthermore, an In-depth deployment report will be executed similarly to the Heriot-Watt University case study which was performed in Chapter 5. In addition, as this research conducted previously a cost forecast simulation on the Heriot-Watt University via the *PlanforCloud* cost estimation tool from RightScale, the following demonstration is intended to add value to the former through inputting similar attributes to the In-depth consultancy feature. This aims to compare differences in results between both systems to determine the optimal cloud implementation for the highlighted Smart Building.

The following discussion will present selected diagrams from the overall Quick, and In-depth report, which is eventually presented to the end-user. These reports were generated according to data inputs from the previous case study for estimating cloud costs and calculations in connection to pre-defined service scalability paradigms as explained before. All data inputs were collected and estimated mainly as a conclusion from the semi-structured interviews in Chapter 5 regarding the Heriot-Watt University ICT components and management attributes, these approximates were also derived and tested previously via the *PlanForCloud* cost simulation tool. Nevertheless, the following ICT assumptions were also adjusted to cover a more detailed approach, which is intended to provide a forecast report for a 5-year lifecycle. On that ground, the first discussion is concerned with the Quick Dynamic Cost Estimation for a relatively large higher education organization. This is illustrated through the following diagrams which represent screenshots taken from the final Quick Cost report generated by SBCE (Figures 6.5 to 6.14).



Selected Cloud Computing Instances (Costs excluding pre-defined scalability paradigms)

Servers

Estimated Bandwidth: 2997 GB / **Cost:** 359.64 $
CDN Bandwidth: 2000 GB / **Cost:** 240 $

Quantity	Hours	OS	Server Size	OS Related Info	Cost/Month
3	730	Linux	4 GB	Vyatta vRouter	744.6
4	730	Windows	8 GB	Standard	5022.4

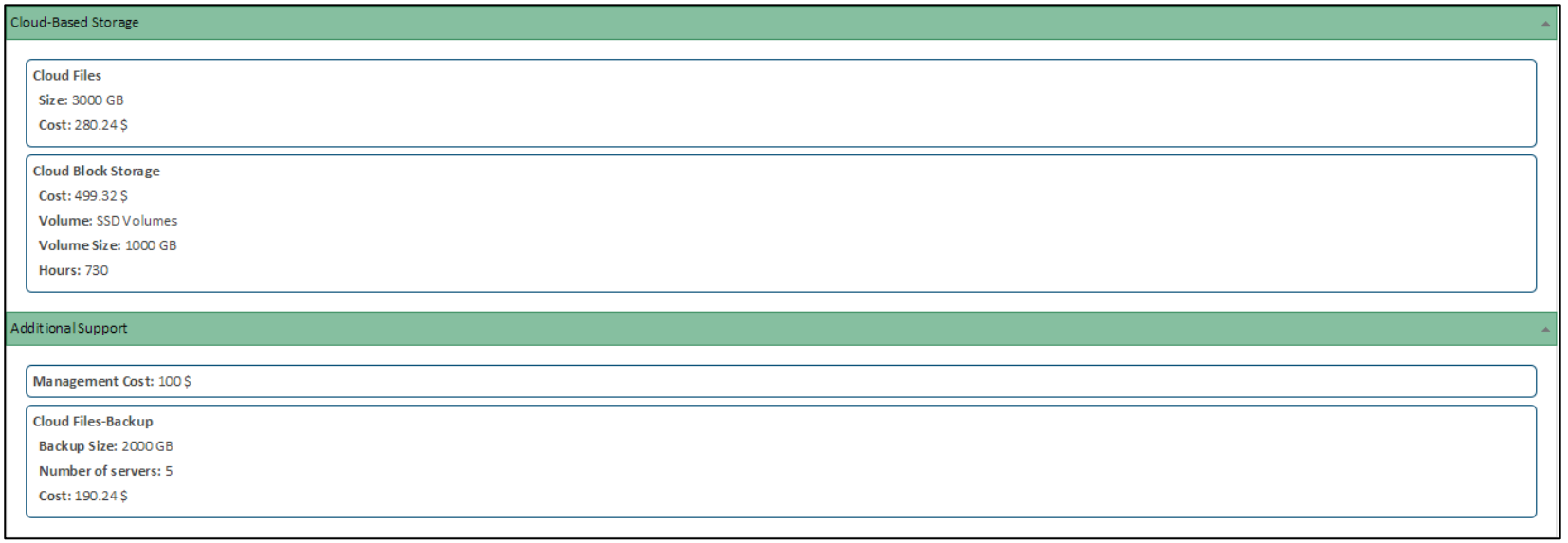
DataBase

Quantity	Hours	DB Option	DB Type	Storage (GB)	Server Size	Cost/Month
2	730	Virtually Distributed		2	4 GB	645.4
2	730	Cloud-Based DB	Linux (MySQL)		4 GB	408.8

Load Balancers

Quantity	Hours	Concurrent Connections	SSL	Cost/Month
4	730	100	☑	189.8

(Figure 6.5) Quick Dynamic Cost Estimation Report: Cloud Components' costs Excluding Scalability Paradigms



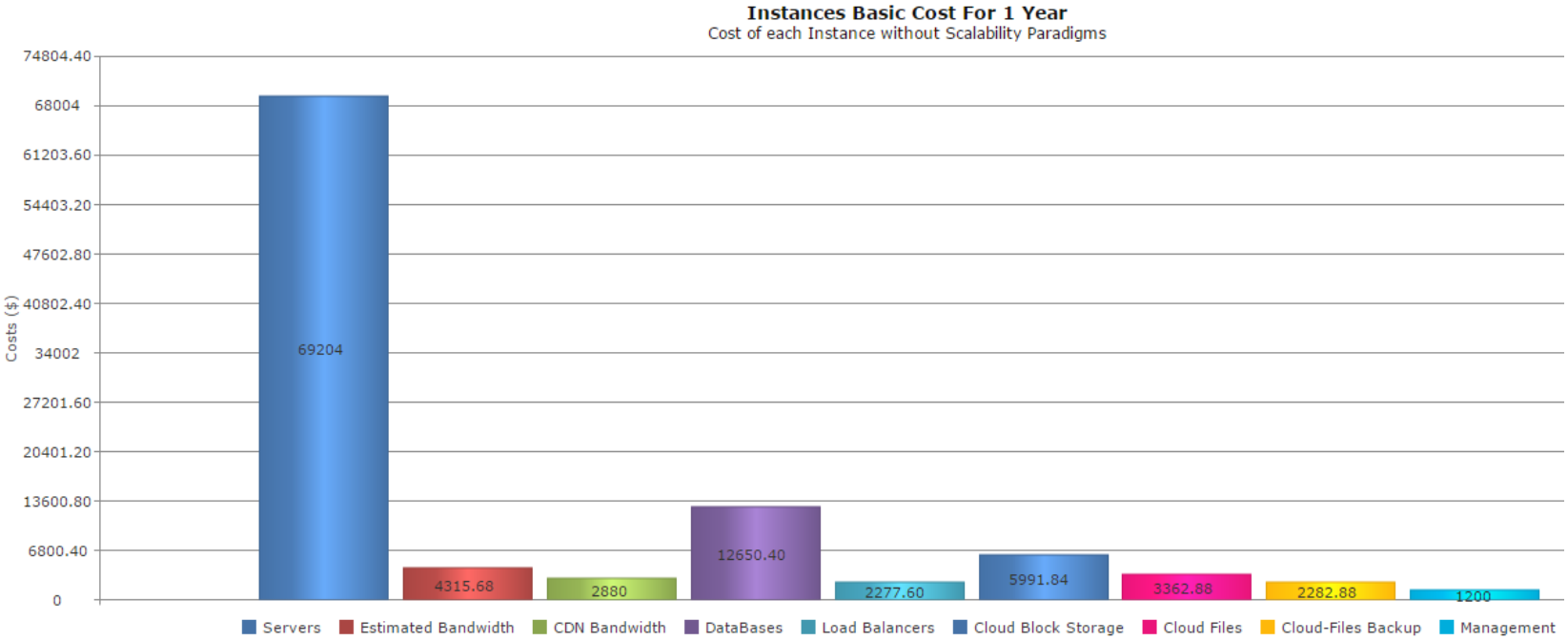
(Figure 6.5) Quick Dynamic Cost Estimation Report: Cloud Components' costs Excluding Scalability Paradigms

The previous figure shows a dynamic table of cloud components selected by the end-user. In addition, this is accompanied with associated costs, excluding any pre-defined scalability paradigms which are calculated separately in the next stage. This section also includes the previously selected five ICT categories according to this case study's requirements, which cover Core Servers, Database Servers, Load Balancers, Cloud Based Storage, and additional Support.

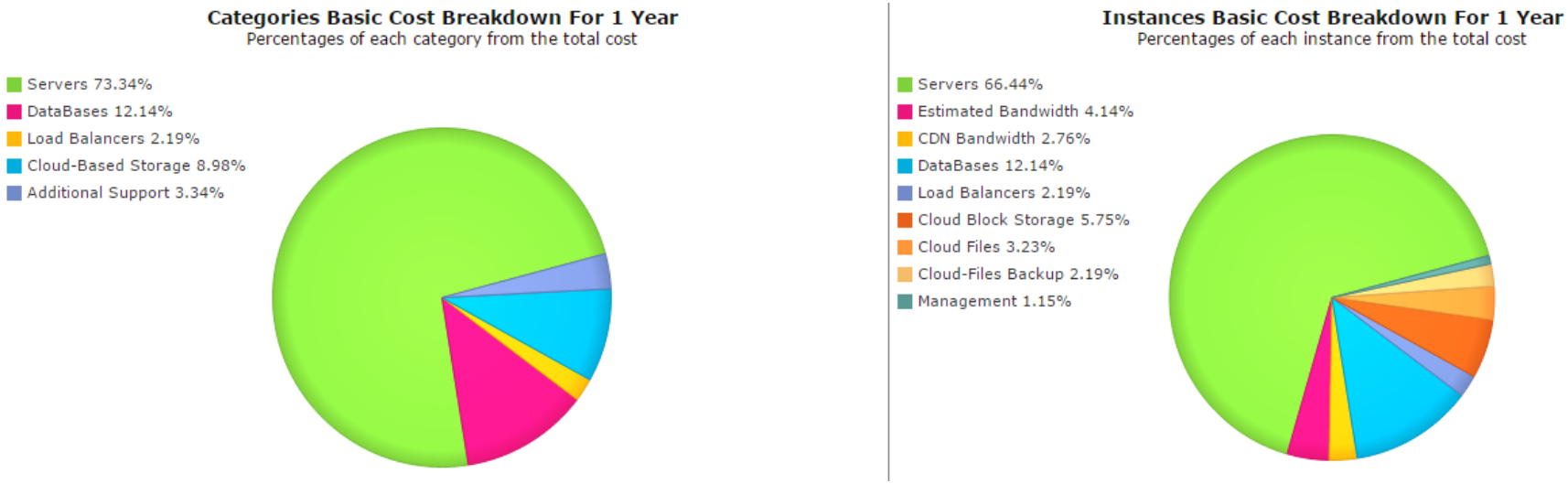
With accordance to the previous selection, the following figure shows a statistical bar chart of these cloud components in relation to associated costs for a 1-year deployment, and also excluding any scalability paradigms applied in this implementation (Figure 6.6).

In order to provide a wider overview of the highlighted cloud implementation, the third stage of the Quick Cost report demonstrates two Pie charts which cover all chosen cloud components for the 1-year cost breakdown. The first Pie chart shows the ICT categories cost for a 1-year deployment, which calculates percentages of each category from the total cost. Secondly, ICT sub-categories cost for a 1-year deployment are illustrated in the second pie chart, which calculates percentages of each ICT component from the total cost (Figure 6.7).

The fourth stage of this report presents a detailed and dynamic table of all scalability paradigms which were built uniquely by end-users. This section explains the patterns chosen by decision-makers to reflect on real life ICT growth, decline, or any adjustment in the cloud service or component capacity. As discussed earlier, these patterns are programmed by non-expert managers using the SBCE interface in a detailed process, which allows users to separately assign a different pattern to each individual ICT category as a whole, or any sub-features of this category. In particular, every attribute of a sub-service of any ICT category can also be assigned to growth or decline service pattern across multiple options. For example, the user can adjust hours of service across each month of the 5-year period calculated by SBCE. This includes aspects such as raise/reduce unit quantity, capacity, bandwidth, or manually manipulate volume sizes through any specific period of the pre-scheduled timeframe (Figures 6.8 to 6.11).



(Figure 6.6) Quick Dynamic Cost Estimation Report: 1-year deployment statistical Bar Chart Excluding Scalability Paradigms



(Figure 6.7) Quick Dynamic Cost Estimation Report: Two Pie Charts of Cloud Components' Percentages for a 1-year Deployment

Estimated Bandwidth

Paradigm	Value	Period
Raise	50 %	initial | Every 3 Month
Adjust	4000 GB	February, March, October, November, December,

CDN Bandwidth

Paradigm	Value	Period
Raise	30 %	initial | Every 6 Month
Adjust	4000 GB	February, March, October, November, December,
Adjust	500 GB	May, June, July,

(Figure 6.8) Quick Dynamic Cost Estimation Report: Description of Pre-built Scalability Paradigms for Bandwidth

Core Servers

Paradigm	Attribute	Value	Period
Instance: Server 1 (7)			
Raise	Quantity	25 %	initial | Every 3 Month
Reduce	Hours	10 %	initial | Every 6 Month
Adjust	Quantity	5	January, September, October,
Adjust	Quantity	2	May, June, July,
Adjust	ServerSize	8 GB	October, November, December,
Adjust	ServerSize	2 GB	May, June, July,
Adjust	Hours	300	May, June, July, October,
Instance: Server 2 (4)			
Shutdown	Server	0	June, July,
Adjust	Quantity	6	January, October, November, December,
Adjust	ServerSize	4 GB	May, June, July,
Adjust	Hours	300	May, June, July,

(Figure 6.9) Quick Dynamic Cost Estimation Report: Description of Pre-built Scalability Paradigms for Bandwidth for Core Servers

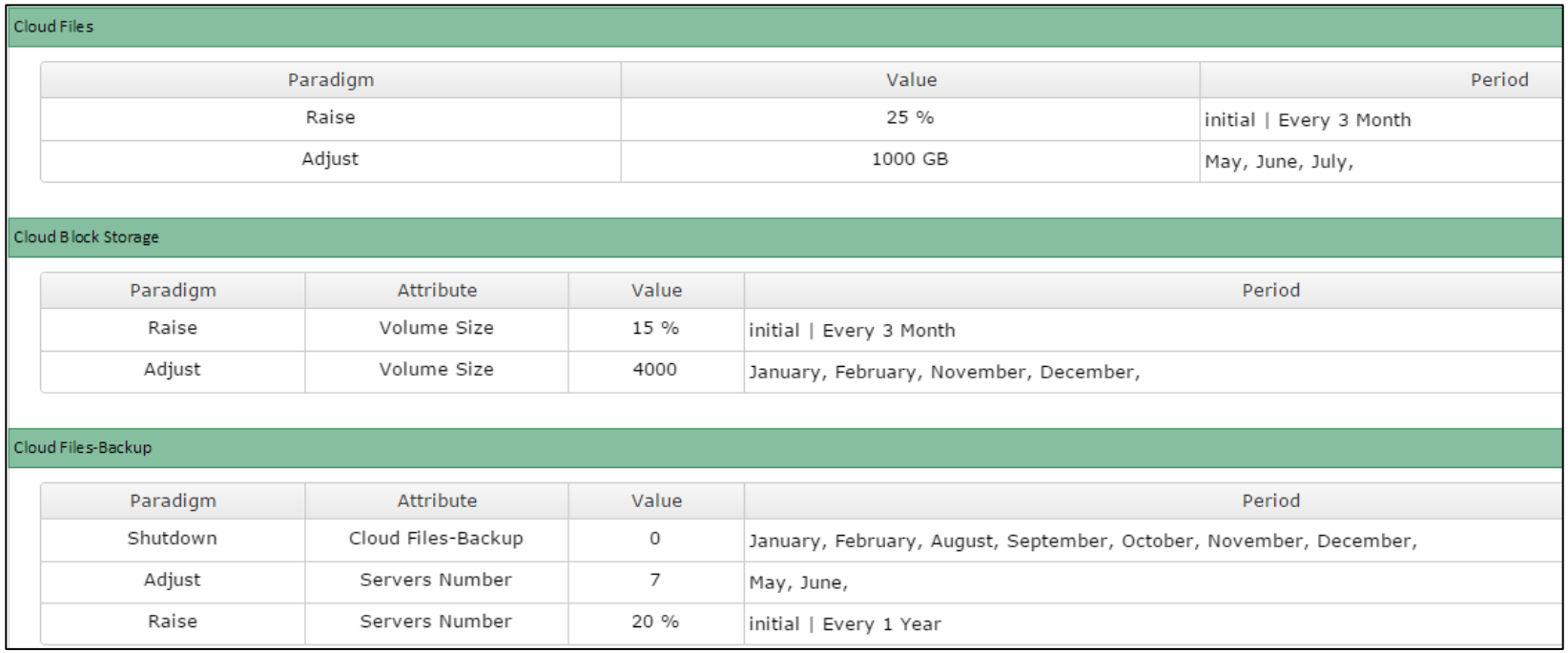
Database Engines

Paradigm	Attribute	Value	Period
Instance: Engine 1 (5)			
Raise	Quantity	10 %	initial | Every 6 Month
Raise	Storage	25 %	initial | Every 4 Month
Adjust	Quantity	4	June, July, August,
Adjust	Storage	100 GB	May, June, July,
Adjust	Hours	100	January, February, March, April, August, September, October, November, December,
Instance: Engine 2 (2)			
Adjust	Quantity	4	May, June, July,
Adjust	ServerSize	8 GB	May, June, July,

Load Balancers

Paradigm	Attribute	Value	Period
Instance: Load Balancer 1 (3)			
Shutdown	Load Balancer	0	May, June, July,
Adjust	Quantity	5	January, February, November, December,
Adjust	Concurrent Connections	250	January, February, March, October, November, December,

(Figure 6.10) Quick Dynamic Cost Estimation Report: Description of Pre-built Scalability Paradigms for Bandwidth for Database Engines and Load Balancers



Cloud Files

Paradigm	Value	Period
Raise	25 %	initial | Every 3 Month
Adjust	1000 GB	May, June, July,

Cloud Block Storage

Paradigm	Attribute	Value	Period
Raise	Volume Size	15 %	initial | Every 3 Month
Adjust	Volume Size	4000	January, February, November, December,

Cloud Files-Backup

Paradigm	Attribute	Value	Period
Shutdown	Cloud Files-Backup	0	January, February, August, September, October, November, December,
Adjust	Servers Number	7	May, June,
Raise	Servers Number	20 %	initial | Every 1 Year

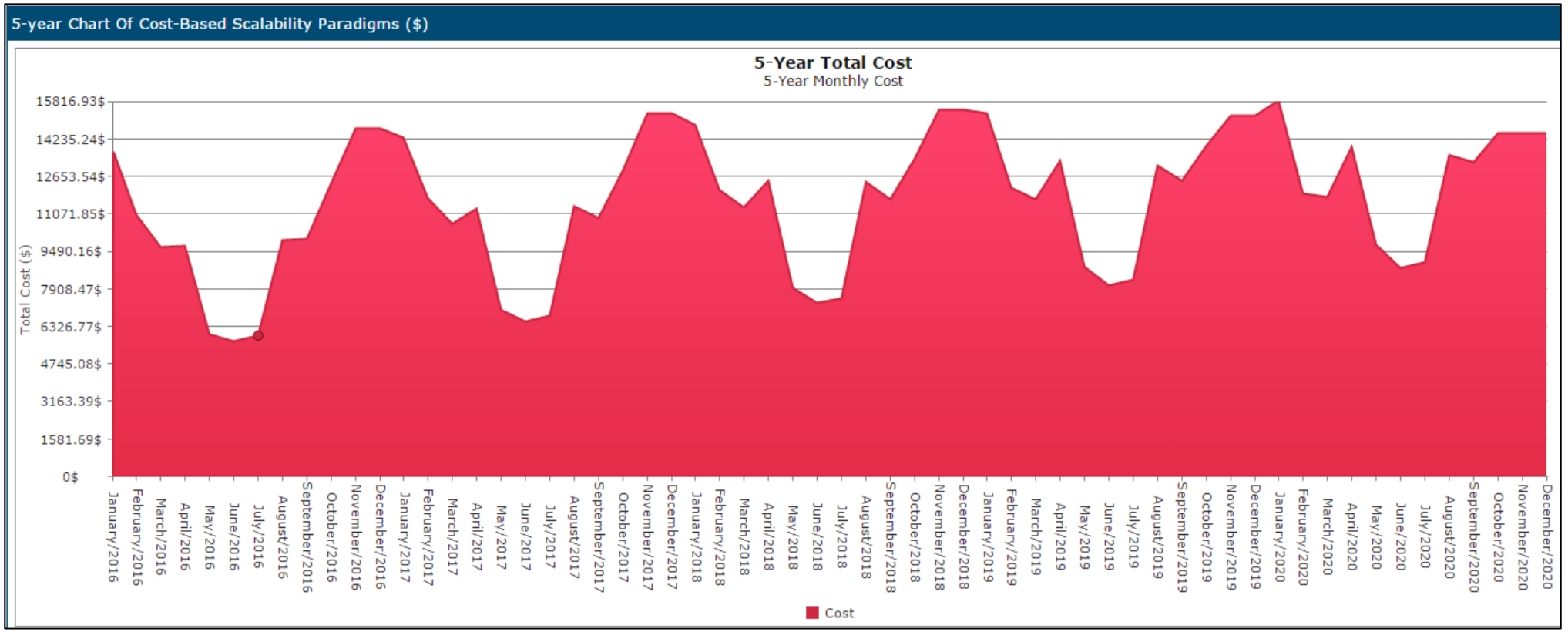
(Figure 6.11) Quick Dynamic Cost Estimation Report: Description of Pre-built Scalability Paradigms for Bandwidth for Cloud Files, Storage, and Backup

The fifth stage of this report calculates the cost of all cloud components selected by the end-user, which takes into account all pre-built scalability paradigms. This is presented via a dynamic table which covers a 5-year -monthly structured- cloud expenses (Figure 6.12). The following figure shows the 5-year cost, however, only one month was expanded as an example. Nevertheless, the full table of costs which shows all 60 months across the 5-year cloud deployment period is presented in Appendix C at the end of this thesis.

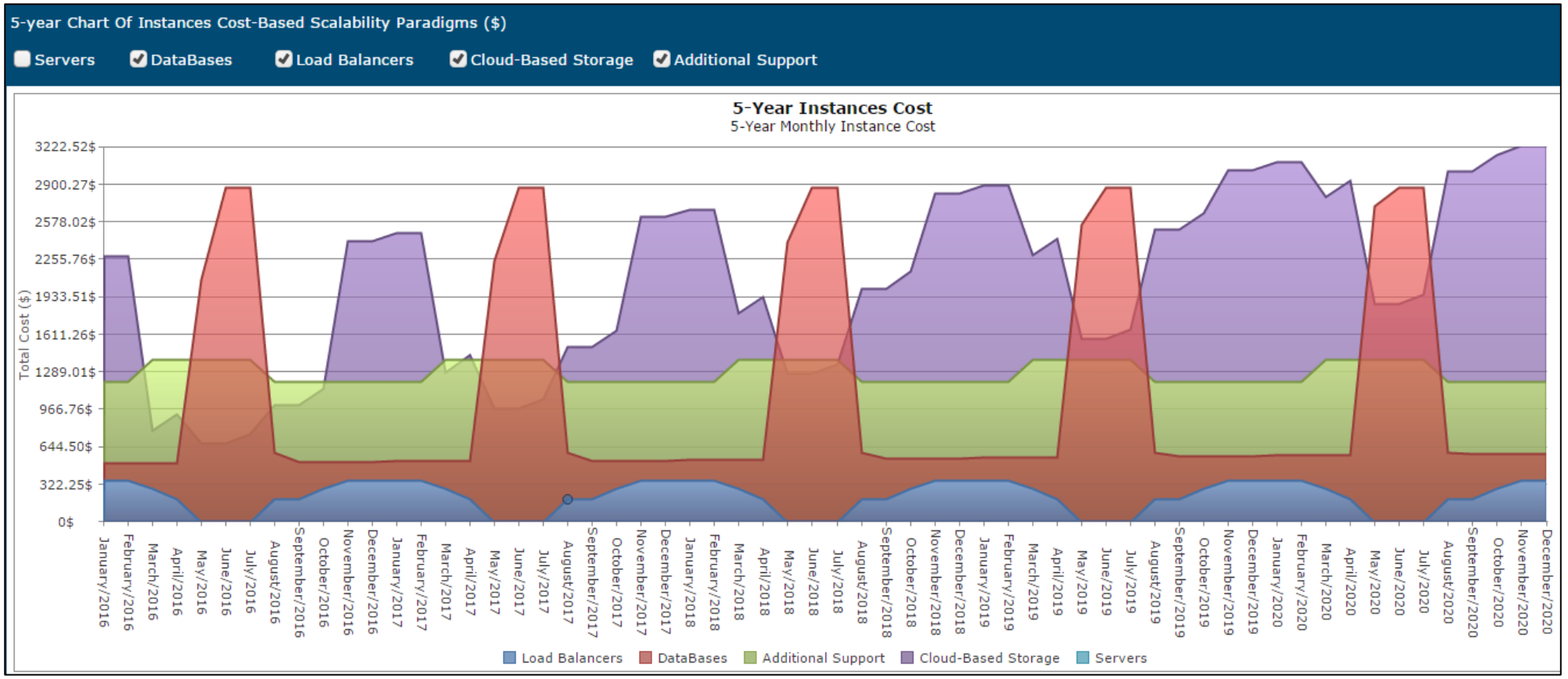
The sixth and final stage of the Quick Dynamic Cost report generates two user-interactive charts for the 5-year cloud deployment, which calculates the subtotal cost with reference to pre-built scalability paradigms. The first diagram shows the core servers as the main component, while the latter excludes core servers and only highlights the remaining 4 categories of Database Engines, Load Balancers, Cloud Storage, and Additional Services The second diagram is a user-interactive chart, which demonstrate the 5-year subtotal of the cloud deployment, and illustrate an expenditure breakdown of each individual ICT category, also in contrast to pre-built scalability paradigms (Figures 6.13 & 6.14).

Month / Year	Total Servers	DataBases	Load Balancers	Total Cloud-Based Storage	Total Additional Support	Total
Year: 1 **Total Cost:** 123466.98 $ **Servers:** 76876.56 $ **DataBases:** 12415.89 $ **Load Balancers:** 2511.2 $ **Cloud-Based Storage:** 16312.13 $ **Additional Suport:** 15351.2 $						
Year: 2 **Total Cost:** 133910.23 $ **Servers:** 82796.82 $ **DataBases:** 12719.65 $ **Load Balancers:** 2511.2 $ **Cloud-Based Storage:** 20531.36 $ **Additional Suport:** 15351.2 $						
Year: 3 **Total Cost:** 141802.61 $ **Servers:** 86165.17 $ **DataBases:** 13024.46 $ **Load Balancers:** 2511.2 $ **Cloud-Based Storage:** 24750.58 $ **Additional Suport:** 15351.2 $						
Year: 4 **Total Cost:** 147498.75 $ **Servers:** 87336.31 $ **DataBases:** 13330.23 $ **Load Balancers:** 2511.2 $ **Cloud-Based Storage:** 28969.81 $ **Additional Suport:** 15351.2 $						
Year: 5 **Total Cost:** 151128.46 $ **Servers:** 86440.05 $ **DataBases:** 13636.95 $ **Load Balancers:** 2511.2 $ **Cloud-Based Storage:** 33189.06 $ **Additional Suport:** 15351.2 $						
January/2020	10612.5	570.16	346.75	3087.52	1200	15816.93
February/2020	6727	570.16	346.75	3087.52	1200	11931.43
March/2020	6727	570.16	277.4	2787.93	1390.24	11752.73
April/2020	8784.78	570.16	189.8	2930.33	1390.24	13865.31
May/2020	3772.55	2711.02	0	1872.59	1390.24	9746.4
June/2020	2668.55	2869.48	0	1872.59	1390.24	8800.86
July/2020	2818.4	2869.48	0	1947.48	1390.24	9025.6
August/2020	8562.33	588.29	189.8	3005.22	1200	13545.64
September/2020	8276.9	579.51	189.8	3005.22	1200	13251.43
October/2020	9243.6	579.51	277.4	3147.62	1200	14448.13
November/2020	9123.22	579.51	346.75	3222.52	1200	14472
December/2020	9123.22	579.51	346.75	3222.52	1200	14472

(Figure 6.12) Quick Dynamic Cost Estimation Report: 5-year Dynamic Table of Full Costs of Selected Cloud Components



(Figure 6.13) Quick Dynamic Cost Estimation Report: User-interactive chart for the previous 5-year Cloud Deployment

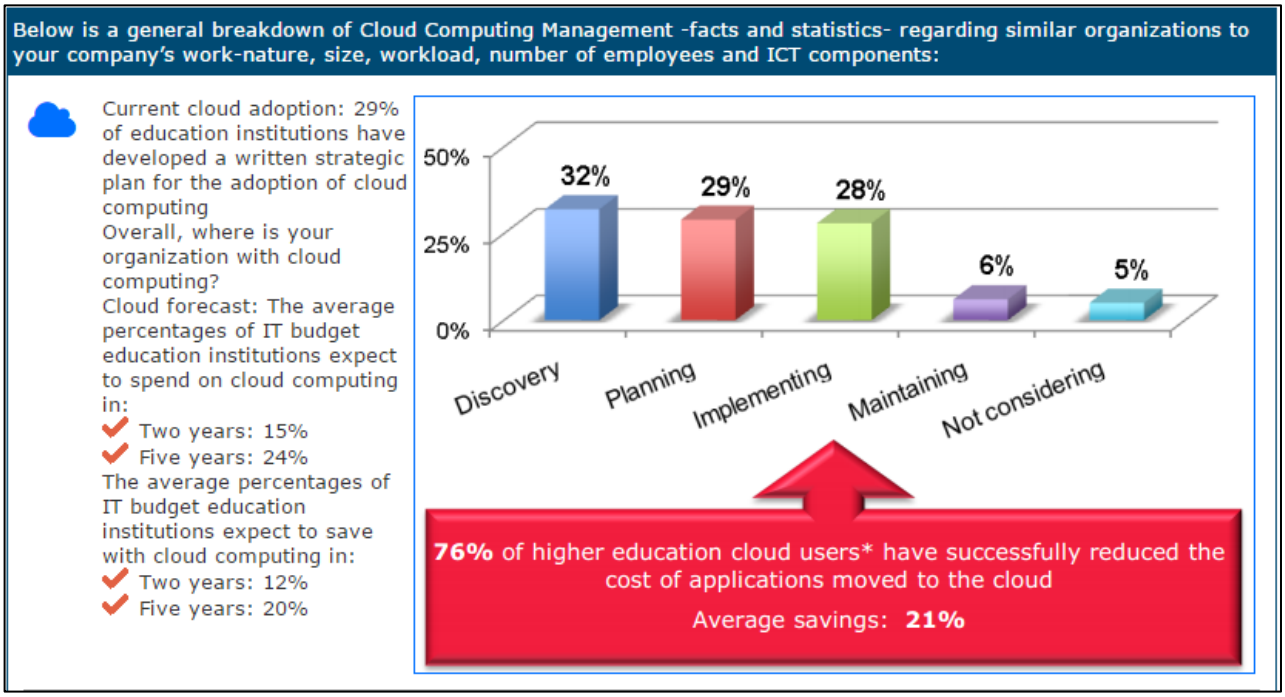


(Figure 6.14) Quick Dynamic Cost Estimation Report: Two User-interactive charts for the 5-year Cloud Deployment

The previous figures explain all stages of SBCE's Quick Cost Estimation report, which was generated for a relatively large Higher Education facility. Given that the In-depth consultancy option also includes the Quick Cost Estimation one as previously discussed, the same case study was extended and inputted in order to generate the In-depth final report. This dynamic consultancy report is generated automatically by the tool after non-expert managers answer a structured-list of 21 administrative questions which are programmed by SBCE following a semi-data mining approach. The goal is to examine specific decision-making inquiries and investigate the organization's technical ICT attributes and requirements. The In-depth list of 21 questions is explained and listed in Appendix C in relation to the same Higher Education example. The following discusses some of the main stages of the final report for a relatively large Higher Education organization. This is illustrated through diagrams which represent screenshots taken from the final In-depth consultancy report after the user submits successfully all 21 questions (Figures 6.15 to 6.19). Moreover, the full template of the final In-depth consultancy report, in addition to the 21 management questions requested from non-expert managers by this tool, are presented in Appendix C.

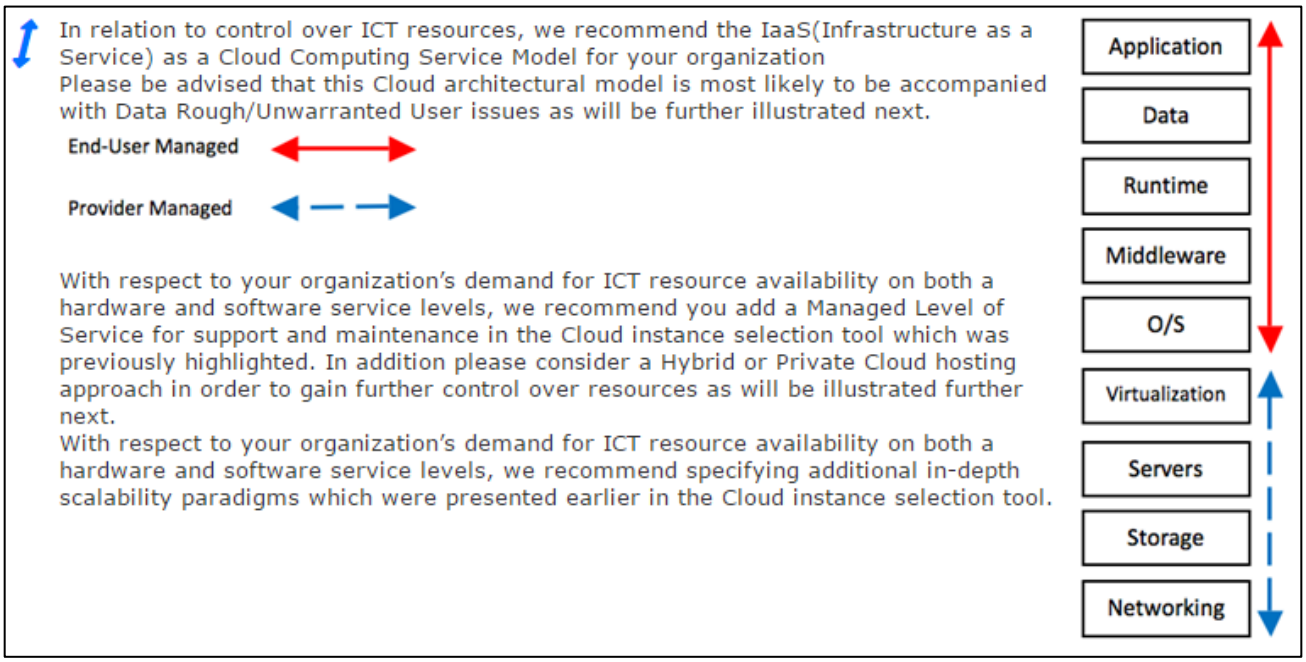
Firstly, the final In-depth Management Consultancy report displays a list of general key recommendations on cloud-computing utilization as previously discussed in sub-section (6.2.1). Furthermore, the report generates cost-saving facts from previous studies on cloud deployment statistics according to the answers inputted by end-users in relation to their Smart Building's work nature. For instance, Figure 6.16 shows one report which includes statistics on cloud-computing cost savings and management in a higher education facility, which was referenced by SBCE from the CDW Tracking Poll report in 2011 (Caraher & Nott, 2011). In essence, the tool automatically generates one of six similar reports to Figure 6.16 when the end-users submit one of the following six options with accordance to their Smart Buildings' type of operation: (Figure 6.15)

(Figure 6.15) In-Depth Management Consultancy Report: Six Options regarding the End-user Smart Building Category



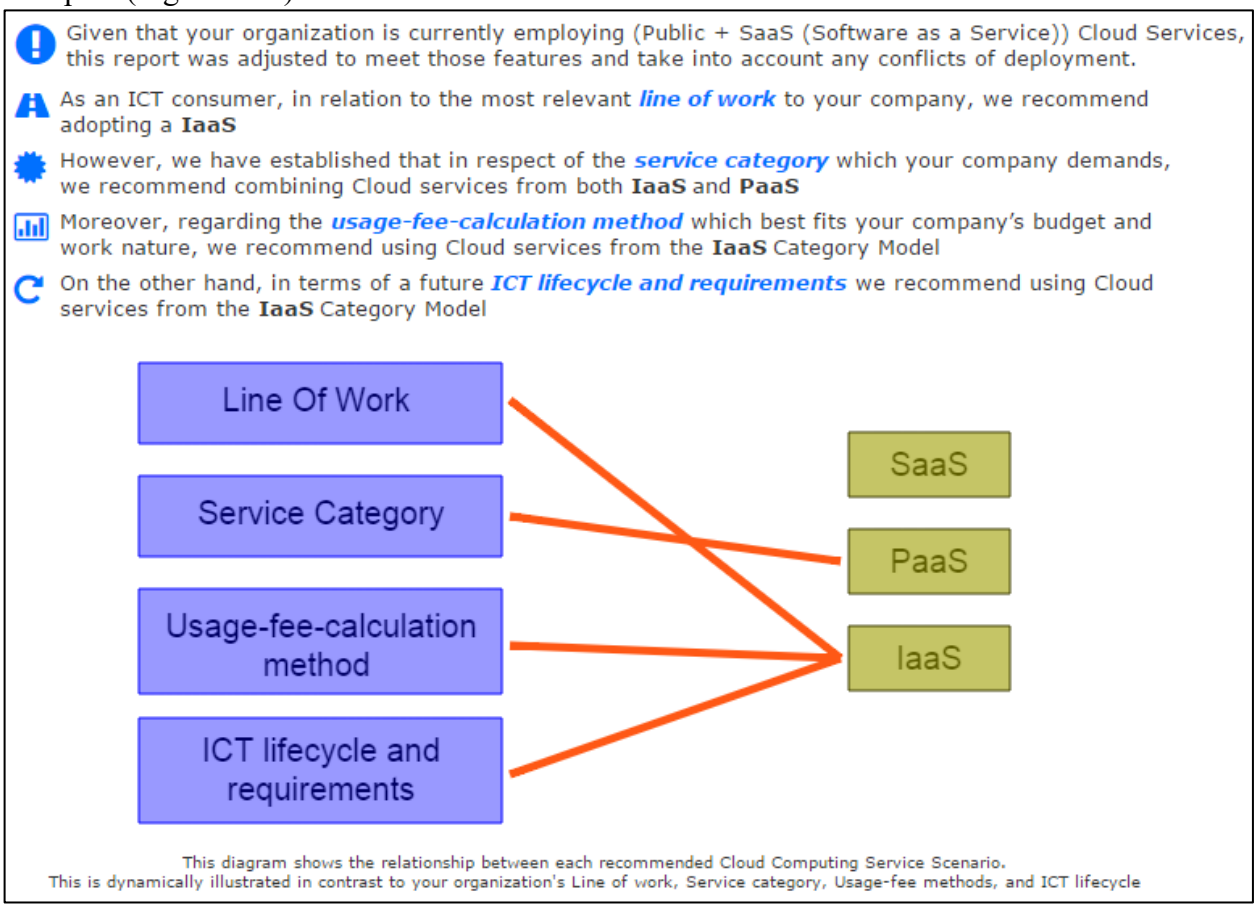
(Figure 6.16) In-Depth Management Consultancy Report: General Cloud Statistics Related to the Inputted Smart Building Category. Source: (Caraher & Nott, 2011)

The third stage of this report elaborates further with specific recommendations on each cloud delivery model in relation to the inputted Smart Building category. Subsequently, the fourth stage discusses the potential resource acquisition status according to the user's data entries, which identities the appropriate level of in-house vs cloud control over ICT resources with reference to the highlighted Smart Building case study (Figure 6.17).



(Figure 6.17) In-Depth Management Consultancy Report: Recommendations on Control over ICT Resources in relation to the Inputted Smart Building

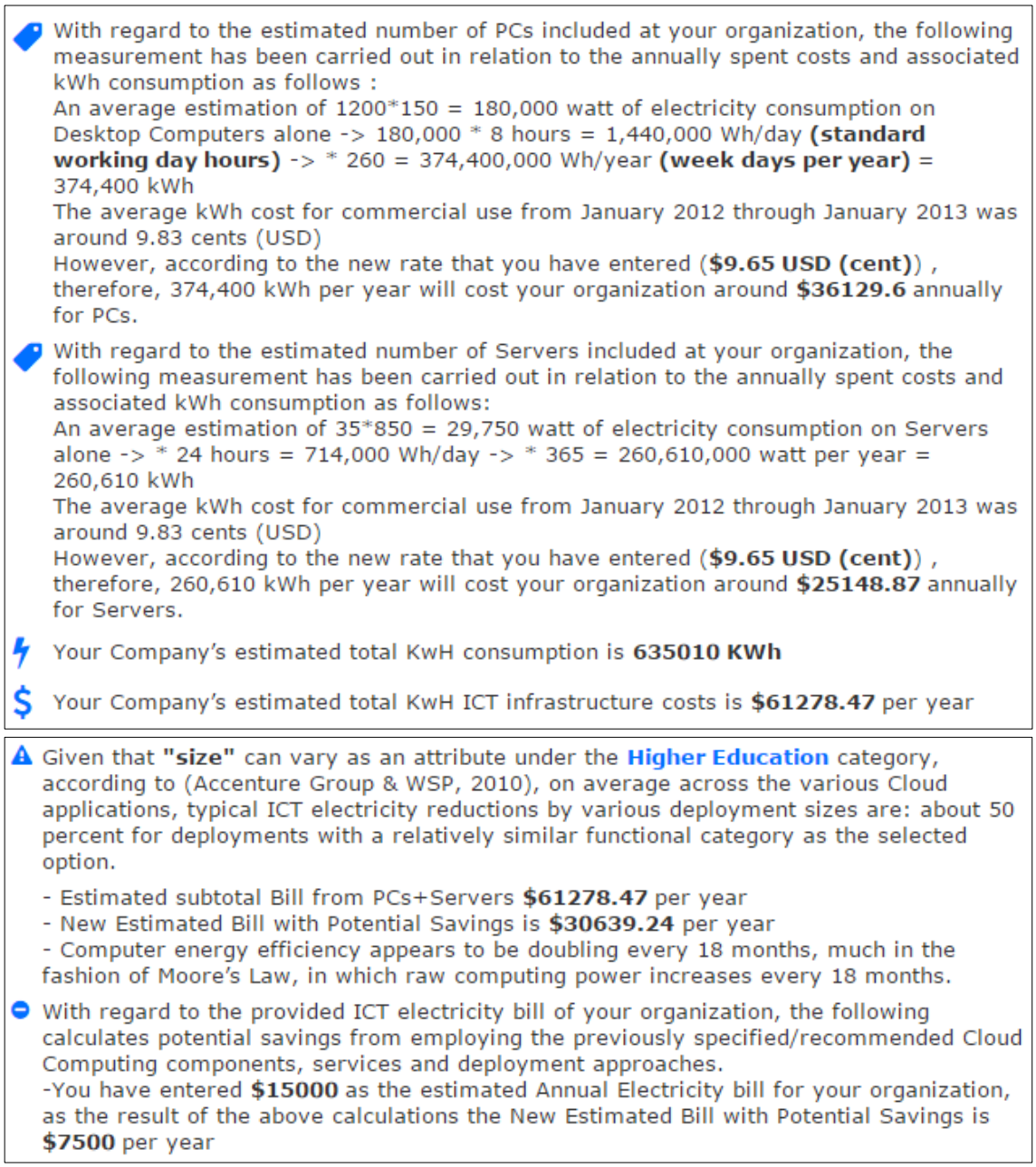
The fifth stage is concerned with analysing the unique relationship status between the different recommended cloud service delivery approaches according to end-users' data inputs (Figure 6.18).



(Figure 6.18) In-Depth Management Consultancy Report: Recommended Relationship between each Suggested Cloud-computing Service Scenario in relation to the Inputted Smart Building

The sixth stage of the In-depth report provides detailed suggestions regarding the most appropriate cloud hosting model for this case study, which SBCE identified as being the most applicable from a management and administrative point of view, sustainable, and cost-efficient for the long-term ICT lifecycle. Furthermore, the seventh stage includes an overview of the organization's cloud application workload, which suggests the optimal deployment criteria to follow in terms of the cloud infrastructure set-up and actual capacity needed (e.g. storage, bandwidth, etc), preferable service characteristics, and cost-effective ways to integrate with legacy systems.

This report reaches ultimately the eighth and final stage of this In-depth consultancy process. This stage calculates -depending on the inputted ICT attributes for the highlighted organization- estimations on ICT related electricity consumption reductions, which can be potentially obtained as a result of adopting the above consultancy points (Figure 6.19).



(Figure 6.19) In-Depth Management Consultancy Report: Estimations on Electricity Consumption and Potential Reductions in relation to the Inputted Smart Building

Following the previous case study execution using SBCE's Quick Cost Estimation and In-depth options, this research approached three independent management-level users to test this tool externally using different ICT inputs concerning various requirement, sustainability objectives, and administrative concentrations. The following table discusses the general feedback obtained from each tester as a result of their data entries, work nature usage and tendencies, and cloud employment requirements (Table 6.4).

(Table 6.4) SBCE: Three Eternal Management-Level Testers

Tester Management Position	**ICT Requirements and Operational Aims**	**Tester Comments and Feedback**
Tester 1: CEO of Digital Boutique: The ecommerce Software Agency (UK)	Attain a complete cloud migration of in-house servers and apply hosting virtualization for global clients, and measure the ability for adopting (PaaS) solutions for off-premise ecommerce developers.	"The application offers a detailed cost-analysis report, which follows sophisticated patterns and live cloud service prices. I found the In-depth option to be unique in its representation for several potential advantages, and warnings from possible limitations that are associated to my bespoke cloud deployment. In my opinion, I found the detailed ability to program the growth and decline patterns –especially by non-expert users such as myself-, to be very useful. Mainly because this feature allows industry managers to cut back on upfront expenses on external consultancy suppliers that could easily be avoided, or used for more helpful services"
Tester 2: Head of School of Built Environment (SBE) at Heriot-Watt University (UK)	Identifies energy efficient solutions for potential ICT migration regarding thin/thick end-users and SaaS storage features.	"The final generated results and reports have given me an understanding of how cloud-computing services are deployed and managed with accordance to my –relatively- specific department needs. I was more interested in the final admin questions, which allow managers to measure cost savings from electricity bills on ICTs if migrated to different recommended types of cloud platforms"

Tester 3: Deputy Minister of Communications and Technology (SYR)	In-depth cloud-computing deployment and cost consultancy in relation to long-term budget strategies with unpredictable growth scalable patterns.	"I have carried out 2 different examples on this tool. The first one was for a large-scale organization, and the second one was for mega-scale (city-scope) ICT utilization. This software was able to generate accurate cost estimations with reference to a heavy-burden deployment, which included numerous cloud components and pre-built service patterns. However, when the second mega-size deployment was performed, it can be observed that the In-depth consultancy process is not designed to fulfill relevant ICT requirements for such a major deployment. Having said that, I found the simplicity of each process to be appealing by decision-makers who are mostly busy, and will prefer a quick, yet, accurate reporting application, with minimum time and effort involved"

6.4- Conclusion

This tool attempts to fill a management and technical gap which reduces the need for managers to employ costly 3rd party consultancy providers. The goal is to offer non-expert decision-makers a scalable, dynamic, easy to use, and comprehensive recommendation report which identifies –after analysing end-users' inputs- the preferable cloud-computing options for their specific Smart Building ICT environment. The system is implemented through user-friendly methods which can be accessed via online means from different locations, and using different desktop or mobile platforms.

This research highlighted in Chapters 3 and 5 the end-user demand and values behind constructing this decision-support system. This was discussed through a theoretical management analysis of different cloud-computing models and definitions, academic interviews, risk-analysis surveys, cost simulations, and external testers. The conclusion identified and measured the actual need for adopting a decision-support system such as SBCE in order to meet the daily demands of non-expert managers in Smart Buildings. These users are normally more involved in non-ICT aspects in relation to their specific industry, which increases the need for a cost-effective, scalable, and user-friendly cloud management tool. While the main objective is to empower non-expert managers with

various insights on cloud utilization and hosting approaches according to their organization's particular requirements, other associated sustainable management techniques are also recommended and uniquely generated as a result of end-users' inputs for different types of organization.

As argued in Chapter 3, one of the main cloud-computing procedural characteristics is the ability to offer Smart Buildings with an ICT elastic lifecycle. This means that decision-makers can easily adjust cost and budgeting plans, associated sustainability estimates, and technical deployment strategies as a result, all via user-programmable patterns. These patterns –which in SBCE are called scalability paradigms- demonstrate any dynamic changes in the services' attributes to reflect the unstable growth or decline in requirements, such as adjusting capacity attributes across a specified period of time, editing runtime or shutdown periods, and other administrative aspects as discussed earlier.

With regard to both the Quick Cost estimation option and the In-Depth analysis provided by SBCE, it can be observed from the previous case study execution that each scalability paradigm was constructed following a specific theme, which shows the Smart Building's workload for a particular cloud service category. For example, given the university's work nature, it can be noticed in Figures 6.8 to 6.11, that almost all the elastic paradigms were constructed on the basis that core servers, database engines, cloud bandwidth, and support hours, are limited to only 9 months throughout two academic terms. In addition, specific months (e.g. May, June, and July) were identified as not being heavy-duty periods in relation to usage and capacity of involved cloud components. Nevertheless, the opposite of the above was set in terms of load balancers, cloud back-ups, and cloud block storage, given that non-working hours are considered a preferable time to conduct heavy data crunching and back-ups.

The Quick Cost Estimation report demonstrates in more detail the concept behind each scalability paradigm depending on the steady (initial or incremental) growth or decline in each cloud service. This is carried out through percentage fields which are defined by end-users directly after adding each cloud component or service to measure the final cost. For instance, the previous case study execution illustrated a specific paradigm which calculates cost in relation to a 30% initial increment for all cloud content delivery networks (CDN). The term "*Initial*" here indicates that the first value will be raised or

reduced depending on the primary value, while the new percentage will be added in response to the selected period. For example:

January (servers = 3, raise each 1 month by 100%) => February (servers = 6), March (servers = 9), April (servers = 12), May (servers = 15)

Furthermore, SBCE offers the option to select an *"Overall Incremental"* feature regarding any pre-built scalability paradigm. This means that the overall value will be raised or reduced depending on the original value, and the new percentage will be added in response to the selected period. For example:

January (servers = 3, raise each 1 month by 100%) => February (servers = 6), March (servers = 12), April (servers = 24), May (servers = 48)

In addition to the above, two configuration options are offered by SBCE for easier measurement on the scalability paradigm, which allow users to specify periods of a complete shutdown or Switch-on of services for certain months across the five-year period. This allows non-expert managers to alter any service values (e.g. capacity) for any selected cloud component. For example, decision-makers can manually change the RAM memory and CPU power of all Linux servers from 16 GB to 4 GB in December only, whereby the number of staff is expected to decrease by 50%. Vice versa, the previous case study shows a specific paradigm set on the Cloud Files category, which deploys a 25% increment following the *"Initial"* value every 3 months.

As pointed out earlier, with reference to the In-depth cloud consultancy option (Figures 6.14 to 6.17), the final report was generated after a series of twenty-one administrative inquiries were submitted into SBCE as shown in-detail in Appendix C. The outcome was calculated through several data-mining connections between both the Quick Cost Estimation, and the In-depth Analysis. Depending on each answer inputted by the end-user, the tool displays additional labels throughout the Quick Cost Estimation stages in order to allow non-expert managers to submit additional data, which were invisible in the first instance before certain questions were answered, according to their unique requirements. This illustrates various management insights for measuring the feasibility level for the Smart Building ICT work nature, which ultimately assist managers in making the decision on whether to add, cancel, or adjust different values of each cloud component. This procedure is intended to enhance the cloud decision-making process, which affects future costs and associated sustainability aspects, and evaluates the in-house level of acceptance for control over resources.

In relation to the potential sustainability benefit from adopting cloud-computing, another objective of this tool is to enable Smart building decision-makers to estimate energy savings attained from adopting the recommended cloud components and services. An initial estimation of the Smart Building's overall energy bill is firstly calculated after users' submit answers regarding inquiries on:

- The number of end-user PCs
- The number of racks/servers, including virtual VMs, outsourced datacentres, etc.
- The number of involved in-house or external ICT personnel (salaries or other fees for freelance personnel)
- The number of in-house or external employees (not particularly related to ICT)
- The number of physical locations/branches of the highlighted organization
- The average service uptime for running the selected ICT components
- Existing types of cloud-computing solutions employed in the organization in contrast to legacy systems, and other ICT solutions in place.

Furthermore, the tool offers managers with an optional feature to input an estimation of the annual electricity bill in relation to the company's current ICT consumption. Consequently, the system will calculate potential savings in response to completed figures and conclusions from previous studies, as shown in figure (6.17). The energy consumption is estimated via a fixed percentage of 9.65 cents (USD), which reflects the average kWh cost for commercial use in the United States from January 2012 through January 2014. However, if known, users are able to enter any bespoke rate, which would then change the calculations accordingly. This option is provided due to the fact that most corporations acquire special power usage deals with energy providers, which causes this rate to change constantly. In conclusion, the final energy calculation generated by the In-depth Analysis report covers the following key estimates for a generic Smart Building (Figure 6.17):

- KWh consumption of total end-user Desktop PCs during weekly working hours
- KWh consumption of total racks/servers with uptime service rates
- Average kWh cost regarding commercial use for both units above
- Subtotal of the company's ICT kWh consumption
- Subtotal bill (cost) of the company's ICT infrastructure

- New electricity bill with potential savings in case users submit a bespoke static rate

SBCE was built to mirror both cloud-computing business intelligence on one hand, and Smart Building technology management on the other. Moreover, while virtual ICTs have been utilized to deliver lightweight, hassle-free, and agile computing services to enterprises, a robust connection between business intelligence and cloud deployment decision-making methodologies was established with this tool on the basis of circumventing around conventional ICT barriers. This was particularly shown in terms of in-house requirements, available hosting applications, on-site deliverables, and access procedures. On that note, this tool represents a demonstrational aspect of this research that resembles the ability to provide business intelligence to non-expert managers concerning identifying industry-tailored cloud services. As this was argued predominantly in relation to cost, sustainability and ease-of-management, this web-application explains essential advantages gained from identifying the correct cloud deployment process of any ICT environment.

In conclusion, this tool's objectives have covered end-users' flexible manipulation of cloud components over in-house resources, thus, reducing personnel involvement and associated expenses. In addition, providing elasticity in resources, simplified accessibility means, and increase in the speed of ICT management, have also been acknowledged as a major advantage from using a cloud-based consultancy solution. As a consequence, these aspects were specifically recognized by non-expert managers given that complex hardware installation and other dependencies on maintenance, licensing, support and so on, are regularly rendered obsolete when using cloud-computing as explained earlier. Additionally, delivering business intelligence via cloud platforms was proven by this research as being largely misleading on various power estimation and cost-forecasting levels. On that ground, SBCE adopts a primary objective of bringing decision-makers closer to ubiquitous business intelligence strategies regardless of their organization's work nature or ICT attributes. This system was developed for research purposes only in order to prove the unsteady pattern of cloud-computing costs in response to a diverse range of both business, and technical Smart Building requirements. While taking into consideration deployment risks, future information security barriers, and contract limitation issues with external suppliers, this study sheds light particularly on the unstandardized growth and elastic impact of cloud services on a Smart Building ICT lifecycle.

7.0- Chapter 7: Conclusion

7.1- Overview and Critical Analysis

This research was structured to explore cloud-computing solutions for sustainable ICT management in Smart Buildings for non-expert managers. This application of cloud-computing was concluded to greatly affect numerous types of decision-makers where information and data must be appropriately translated and effectively communicated.

The objectives this research adopted are as follows:

- Evaluate cloud-computing concepts for Smart Buildings ICT environments from a Technology Management Perspective.
- Examine cloud-computing deployment approaches, management principles and main services as a potential hosting platform for Smart Buildings.
- Explore cloud-computing current costs, demand patterns, service scalability, control over resources, and associated power reduction factors.
- Address performance reliability issues and security considerations of cloud-computing services for non-expert managers in Smart Buildings.
- Identify a theoretical cloud-computing management framework for non-expert Smart Building decision-makers, which aims to support these users in estimating costs, identify management effort involved in the ICT lifecycle, and measure the power reduction associated with cloud-computing utilization.
- Develop a demonstrational online decision-support system called *SBCE*: *Smart Building Cloud Evaluator*. The objective of this tool was to enable non-expert managers to estimate and measure remotely the levels of cost efficiency, management feasibility, and sustainability in their Smart Buildings concerning the different types of cloud-computing adoption.

As previously discussed in Chapter 1, studies such as the UN Habitat indicated that developed cities with high population such as London and Beijing, are accountable for nearly 85% of greenhouse gas emissions (Zhao, 2011). According to other previously reviewed studies, this number classified these cities, in carbon terms, as unsuitable places to live in the future. It was also stated that buildings are responsible for around 45% of energy consumption in Europe alone. In particular, ICT in a normal Smart

Building with medium-capacity datacentres is currently responsible for over 10% of the total cost of this structure. Furthermore, the overall global CPU power and storage capacity was observed to double every 18 months, and the global ICT consumption growth was noticed to rise from 123 billion kWh in 2005, to 246 billion kWh in 2010. This reflected a 2% increase of the worldwide CO2 emissions. As a result, it was estimated that a set of server racks, which include around a thousand servers, would currently cost around $ 4.5 million of annual running cost, mainly due to its power consumption in a normal capacity datacentre.

Cloud-computing was introduced to help mitigate this issue, not only from ease-of-management and economic perspectives, but also in relation to various associated environmental factors. This was argued to have a strong potential to minimize software and hardware physical acquisition and usage in different types of Smart Buildings.

Moreover, cloud-computing can be defined as a deployment paradigm, where today's Smart Buildings can focus operational efforts on improving core competencies of internal facilities without worrying about purchase, management, and long-term maintenance of indispensable information and communication infrastructure. This approach follows a flexible and dynamic pay-as-you-go model, which fits into various Smart Building work categories. To a large extent, ICT requirements and peak loads amongst current organizations are considered dissimilar and sporadically changeable in relation to demand and the technical nature.

On that ground, numerous environmental, economic, and management advantages were attained from optimizing and migrating the general use of both information and networking technologies into cloud platforms. In theory, this optimization will result in a favourable administration lifecycle of the Smart Building's ICT process without sacrificing service level agreements (SLAs) and other management aspects. This was argued to positively participate in energy savings on one hand, and help non-expert managers to construct scalable ICT strategies on the other. With reference to different Smart Buildings ICT environments, cloud-computing services were acknowledged to remove unnecessary reliance on specific computing capacity, management efforts, and strategy design processes. Although the ICT components which can be migrated potentially onto the cloud can range from data storage, processing servers, and networking infrastructure, other several other scaling, power distribution, and risk-

cutting aspects were also recognized in this context. In relation to cost, service features and technical issues, and prior to any cloud vs. traditional ICT model comparison, a conceptual cloud overview must be established according to each Smart Building management specification as previously explored.

Cloud-computing was classified as a ubiquitous platform, which offers an on-demand network access via either the public worldwide web, or a privately managed and secure tunnelling service. The former solution can also be embedded through the Internet's infrastructure. However, this would require privately encrypted resources such as Virtual Private Networks (VPN). In addition, the cloud-computing model consists of several key characteristics, hosting solutions, architectural types, and legal issues. Similarly, these virtual concepts are consistent with being environmentally friendly in terms of ICT usage, whereas traditional ICT systems require greater onsite power consumption, staffing resources, physical space, and post-setup expenses.

This research project focused on examining sustainable techniques of cloud-computing solutions, along with virtually-based aspects of relevant, service-delivery approaches for Smart Buildings. As a demonstration of this approach, a decision-support system, named SBCE: *Smart Building Cloud Evaluator*, was introduced for the purpose of offering non-expert managers a scalable decision-making platform to determine the level of cost efficiency, sustainability and appropriate management practices in order to achieve business growth and adapt to the changes in ICT demand. This solution is constructed through the utilization of specific models of cloud-computing according to unique requirements, budget, and service availability. SBCE was designed to enable managers to highlight the Smart Building's most suitable domain of cloud architectural types, service characteristics and deployment models, in addition to offering both technical and non-technical insights depending on the unique data input of each organization.

This research adopted a hierarchy conceptual analysis of cloud-computing management for Smart Building ICT environments. The process began with a detailed background on the relevant concept of Smart Buildings, which was re-defined to fit the objectives and analysis of this research. The argument characterized Smart Buildings as a modern ICT environment, which consists of an interconnected set of information systems, and to a certain extent, offers integrated solutions in terms of data output, adherent services and

networked platforms. The introduction argued next the evolving information age, which explored the concept of *Technology and the Connected Community*. In addition, this discussion highlighted the three key drivers of change relevant to this research: Economy, Technology and Sustainability, which forms the main motives behind this project's primary analysis. Moreover, the overview examined a virtual organization based on cloud-computing concepts, which was intended to demonstrate the significance of ICT virtualization towards a cost efficient and environmentally sustainable lifecycle.

This research addressed the grey area between the micro and macro levels of ICT management principles on one hand, and the technical operation on the other. Accordingly, the background discussion explored the interrelationship between value engineering and smart technology management (STM), whereas potential savings can be attained after adopting STM approaches in Smart Building applications. This was derived in correlation with ICT smart decision-making and project management principles when STM is performed. The argument took into account previous drivers of change and associated factors of certain management information systems principles such as the *Technology and the Connected Community*. Furthermore, this investigation conducted a literature review, which was divided into multiple interdisciplinary topics in correlation with specific decision-making aspects of cloud management in Smart Building ICT environments.

In order to obtain a preliminary framework to assess cloud-computing service requisites, the literature analysis inquired into the following subjects. This was argued in terms of the sustainable approaches, deployment cost, purchase motivations, and other management aspects.

- Sustainability Approaches for Smart Buildings
- Market Solutions for Cloud-based Energy Management
- ICT Costs in Buildings and Power Consumption Overview
- Cloud Analytics and Business Perspectives
- Decision-making Methods in Smart Buildings
- Decision-Making Intelligence for Cloud-Computing
- Cloud Adoption Risks and Trade-offs

As discussed in Chapter 3, conclusions argued that although a large-volume of literature was published on Smart Building ICT related topics, it is safe to acknowledge that publications on cloud-based technologies for non-expert managers in Smart Buildings were mostly from the cloud provider's perspective. This was mainly illustrated through the investigation of services to assist Smart Buildings in ICT outsourcing, cloud management, and Green applications.

Reviewing these multidisciplinary topics was significant to this study given the complex process of ICT decision-making, whereas recent reports indicated a strong connection between numerous aspects within a single ICT building environment. In particular, the impact on management was essentially discussed regarding the relationship between the administrative processes, and cloud-hosted platforms. To a certain degree, the latter can be involved in almost all functional areas of a Smart Building control system, such as HVAC, security, and other integrated systems that require ICT hosting, support, and upgrade. Consequently, this thesis presented a full methodology roadmap, which explored the relationship between the technical and management aspects of this research.

This methodology identified a bespoke framework, which highlighted the selected decision-making stages and methods of investigation adopted by this study. The framework identified and discussed the relevant decision-making categories which included a general Smart Building ICT environment, statistical analysis for data collection, primary value assessment, and a simulation overview for cloud-computing end-user costs. In addition, this process clarified the approaches adopted by this study, which conducted three semi-structured interviews, one risk-analysis management questionnaire, a 3-year cloud cost simulation, and a demonstrational decision-support system. Furthermore, a full online deployment was executed via this tool, and tested by external management-level users from several organizations. This work covered an in-depth technical description, end-user specification report, and a complete case study execution.

In relation to this study's theoretical cloud-computing management analysis, the primary objective was to establish an in-depth comprehension of unrelated aspects and disciplines of cloud-computing management processes. In addition, another objective was adopted to measure the ability of estimating actual costs of a Smart Building ICT

infrastructure while providing a state-of-the-art power consumption analysis. This discussion took into account ICT-associated power consumption figures which were concluded from the previous literature analysis. Accordingly, the administrative analysis also assessed the state-of-the-art cloud-computing definitions, procedural characteristics, deployment approaches, and architectural models. While this was discussed from both market and academic perspectives, further investigation was carried out on energy saving aspects of cloud information hosting and virtual computing. Finally, the theoretical management data analysis underlined present expenditures of cloud components in relation to major providers, as opposed to a normal-size Smart Building ICT spending.

Conclusions identified that in order for any portfolio manager to validate abilities to measure actual efficiency rates before any cloud deployment or adoption, each of the argued cloud-computing principles must be thoroughly examined in contrast to variable lifecycle features of that specific structure. On that ground, non-expert decision-makers will firstly have a crucial task of assessing the current and future costs, security limitations, service reliability and availability. Secondly, another requirement is to balance results from the former assessment with the Smart Building's risk acceptance, long-term maintenance requirements, and potential integration compatibility with in-house legacy systems.

Furthermore, during the primary practical investigation, this study adopted the previous cloud management assessment for generic Smart Buildings, and conducted a semi-structured interview with a senior specialist from Rackspace; one of the world's largest cloud-computing providers as discussed in Chapter 4. In addition, a second one-on-one interview was carried out with a senior manager from GBM, which is a virtual ICT subsidiary company from IBM in the Middle-East and the Gulf region. Similarly, this interview was aimed to evaluate the cloud providers' side of the service delivery equation. In addition, this research selected Heriot-Watt University as a primary case study for an in-depth semi-structured interview. This took place with the university's ICT director, and inquired into end-users' ICT demands, cloud vs. in-house conventional costs, and factors related to readiness and control acceptance. Key conclusions from previous interviews and cost simulations argued that acquiring an external support supplier instead of in-house personnel is often observed to cost more at first instance given the unstandardized contracts involved and due to the fact that the

support service might not be instant or available at all times. However, as a result of the occurrence of complex technical issues, in-house personnel will anyway be obligated to ask for the service provider's assistance in solving those problems which would result in a costly solution. Therefore, outsourcing a certain level of the ICT management task to the cloud provider is recommended by this study for non-expert managers, only after a thorough identification of requirements, contract specifications, and identification of long-term changes in their ICT demand.

As a result of involving numerous ICT suppliers with long-term contracts in any organization, this was concluded to turn the task of migrating the ICT infrastructure onto a cloud alternative an extremely difficult one. Instead, this research suggests that each migration stage should be individually analysed in terms of management readiness, added future cost, and integration compatibility between associated external suppliers and existing in-house systems. As discussed in Chapter 3, according to the NIST cloud-computing definition which divided the cloud into 3 different layers (Application, Platform and Infrastructure), the analysis of each migration stage reflects the real-life management process between the software level of operations, and the physical platform. While this procedure could in fact reach the Infrastructure (IaaS) level as examined in Chapter 5, this study concluded that non-expert decision-makers will mostly find this technology management process of any Smart Building more challenging given the organization's minimized control over owned infrastructure.

This research conducted a cost-measurement simulation, which performed a real-life cloud deployment component evaluation in contrast to current market costs and service-feature requirements. While this was identified correspondingly at an earlier stage, the aim was to visualize and estimate whether a cloud solution would benefit the highlighted case study of Heriot-Watt University in terms of long-term potential expenses, sustainability, and in-house management feasibility. The key conclusion outlined that with regard to general expenditures, not every Smart Building ICT deployment will gain a cost advantage from employing cloud services. This was argued in terms of general ICT savings, and regardless of the adopted cloud hosting model, service characteristic, or delivery method. This simulation concluded that the Heriot-Watt University case study would attain a considerable cost-benefit from adopting a cloud migration process against in-house traditional approaches. However, according to the *Uptime Software* case study which was discussed in Chapter 3, adopting cloud-

computing was observed at the initial stages to be more costly in some heavy-scaling circumstances, than maintaining the current conventional ICT environment.

7.2- Decision-Making Tool Key Outputs

SBCE: (Smart Building Cloud Evaluator) is an online-based cloud-computing decision-making tool that was built on a core objective of simplifying cloud-computing management processes in different Smart Building ICT environments. This is accomplished through generating dynamic and user-oriented consultancy reports to assist non-expert decision-makers in achieving a cost-efficient and sustainable cloud lifecycle in their organizations.

As discussed in Chapter 6, this tool offers two primary features: the Quick Cost Estimation, and the In-depth Value Analysis, and both estimate a 5-year cost breakdown of any cloud-computing deployment selected by the end-users, taking into account the growth and decline service patterns also defined by the end-users. This research tested both features through the execution of technical and management case studies. The examples used were similar to the Heriot-Watt University case study which was earlier discussed in the semi-structured interview in Chapter 5.

Several conclusion points from the results of those case studies are listed as follows:

- Depending on the Smart Building category, work nature, management attributes and ICT requirements, cloud-computing costs can differ greatly between those categories when estimating a 5-year breakdown of actual expenses against the foreseeable changes in the service patterns by non-expert managers.
- Given that SBCE was built to allow non-expert managers to dispense with the need for a 3rd party cloud consultancy (e.g. cloud broker), this research observed that when it comes to setting up the support services associated with the purchased cloud components, these services might become very costly after two or three years from the initial deployment if not adjusted in the service patterns depending on the Smart Building's priority and actual demand.
- The study argued in Chapter 6 after analysing the testers' case study results that there is not a concrete proof that cloud-computing is always more cost efficient

and sustainable than traditional solutions for small and medium-sized organisations in the future. Although the chapter demonstrated examples where this was the case, the objective was to develop an approach that helps managers estimate if cloud-computing is more effective according to their different requirements and work circumstances, and what decisions to make when designing strategies for cloud utilisation. Although large organisations such as Heriot-Watt University were identified to save cost and energy when using cloud-computing components and services, in some heavy-demand cases like the Amazon EC2 example discussed in Section 3.3, cloud-computing was observed as more costly than owning the hardware and supporting it in-house. This additional cost was identified in the long-run when bounded by detailed support contracts with the cloud provider. Therefore, as discussed in the concluded decision-making framework earlier, this research suggests that after non-expert managers complete the two stages of cloud requirement analysis and the development of all needed scalability patterns, a contract restructuring stage must be thoroughly carried out with accordance to the contract specifications with the cloud provider in terms of support and long-term service delivery methods.

- Providing elasticity in ICT resources, simplified accessibility means, and an increase in the speed of ICT management, have been acknowledged by this research as major advantages from using a cloud-based consultancy solution (Voss & Barker & Sommerville, 2013).
- This tool has highlighted the unstandardized nature of the current ways non-expert managers develop their organisations' ICT growth and decline patterns, and the elastic future impact of cloud services on their ICT lifecycle.

This tool attempts to fill a management and technical gap which reduces the need for managers to employ costly 3rd party consultancy providers. The goal is to offer non-expert decision-makers a scalable, dynamic, and simplified recommendation report which identifies –after analysing end-users' inputs- the preferable cloud-computing options for their specific Smart Building ICT environment. As explained in detail in Chapter 6, this system is implemented through user-friendly methods which can be accessed via online means and using different desktop or mobile platforms.

7.3- Research Limitations

Multiple barriers were identified throughout the various stages of this research. To a small extent, these challenges delayed the progress of this study and resulted in a few minor adjustments across this project's main methodology. This section will clarify these limitations by arguing the actions taken to redefine, overcome, and re-evaluate specific research processes.

This study initially faced a challenge concerning data collection in both the literature review and the introduction chapters. The main reason behind this was due to the large scope of research, which required a thorough identification in order to assess the relevance to this study's main areas of analysis. In particular, the challenge here was due to the multidisciplinary nature of this project, which involved both technical and nontechnical aspects from dissimilar fields of science. This included Management Information Systems, Computer Engineering, and the Built Environment. It was essential to overcome this difficulty by highlighting the exact fields of analysis in which this project will follow.

This research derailed from its intended course on a few occasions, however, after the regular re-assessment work was carried out, this was successfully restored according to the main methodology as discussed in the methodology chapter earlier. Furthermore, another challenge to attain and measure accurate numbers of Smart Buildings' current ICT costs and associated power consumption rates was noted. This limitation was identified during the theoretical data analysis in Chapter 3, which analysed the state of the art literature findings and carried out an in-depth cloud-computing management assessment. The former limitation was observed in relation to both the conventional ICT approach and cloud-computing solutions. This challenge mainly occurred given the unstable current cost structure of cloud-computing services, which is observed not to comply with Moore's Law as argued in the next section.

As discussed in Chapter 3, given the unstandardized definition of cloud-computing with reference to management principles, service characteristics, deployment models, and components' attributes, this formed another limitation for this research in order to develop a common ground to adopt as a platform for constructing the cloud decision-making framework. Moreover, the practical data analysis in Chapter 5 included three

key semi-structured interviews with management interviewees from enterprise-level originations. The main challenge faced by this research at that stage was obtaining the contacts of these managers, scheduling the timeframes for the interviews, and adjusting the progress of the study depending on each interview's outcome. Furthermore, the data privacy aspect was a major consideration, especially concerning the first interview with Rackspace, which took place with an in-house senior solution expert. Accordingly, private client data concerning contracts, prices, and so on, was confidentially handed to this project for investigation purposes.

This project also faced a time-consuming challenge with respect to the cloud risk-analysis survey, which was answered by 54 management-level personnel as discussed in Chapter 5. Similarly, this difficulty was manifested in contacting this number of management-level decision-makers, which was necessary for this type of risk-assessment questionnaires.

One of the objectives of this project was to evaluate the energy efficiency factors and power saving aspects resulting from adopting cloud-computing services in Smart Building ICT applications. On that ground, another challenge was observed consistently throughout the progress of this study due to the confusion between the hardware and the software employment of certain cloud delivery models. In particular, this was shown when organizations adopt a combination of services from the IaaS and SaaS delivery models, as components from both can be involved in any cloud deployment as discussed in Chapter 3. As a result, measuring a real-life energy usage of cloud-computing was considered a difficult task when attempting to isolate the nature of services of a cloud hosting environment given the mixture between the physical and non-physical delivery of ICT. Because of this inaccuracy, generated energy bills have included other power consuming resources within the Smart Building such as HVAC systems, water, and other ICT-dependent equipment. However, this study attempted to isolate this measurement, to a certain degree, from external sources that are indirectly related to ICT virtualization. This was clarified in Chapter 5 and 6 with reference to the Heriot-Watt University case study.

Overall, this study maintained a thoroughly structured methodology and research roadmap, which preserved the efficiency of both the time tracking, and the progress documentation of each stage. The primary progress was subject to a project

management Gantt chart, which was adopted at an early stage of this research. Nevertheless, managing change has played a crucial role throughout this project given several unexpected challenges as discussed earlier. Change management was taken into account on numerous occasions in order to ensure effective compliance with the initial hierarchy process shown in Figure 4.1 in Chapter 4, progression of each stage, and the assigned timeframe of each.

7.4- Recommendations and Future Work

The primary objective of this project was to evaluate cloud-computing strategies for Smart Buildings in order to obtain further management flexibility, sustainability, and long-term cost efficiency regarding different types of deployments and according to various decision-making attributes. Although a specific methodology was structured to exclude any irrelevant areas to this study, the main analysis followed a relatively generic discussion that was not related to a single industry. In order to mitigate generalization in this research, the In-depth value estimation option provided by the SBCE tool distinguished and categorized 6 different cloud management deployments, which included Small Businesses, Medium Businesses, Large Businesses, Government Agencies, Healthcare Facilities, or Higher Education Organizations.

On that note, this project recommends that future work should focus on specific industries in order to cover multiple unrelated domains of ICT environments, as each would adopt cloud requirements specific to their needs, and their own unique dependencies. For example, the suggested future research will highlight specific cloud-computing management case studies such as Airports, Banks, ICT Providers Organizations, Education, and Government Agencies.

It can be argued that the recommended work will rely on this research, by adopting it as a development platform, in order to construct an industry-specific cloud-computing management standard and hypothesis for unique Smart Buildings from specific industries.

Given the Management Information Systems standpoint which is adopted throughout this thesis, the study proposes analysing the Cloud Cultural Shift aspect with reference to dissimilar industries. It is suggested by this research that this shift takes into account associated bespoke requirements of each domain separately, and forms multiple sub-

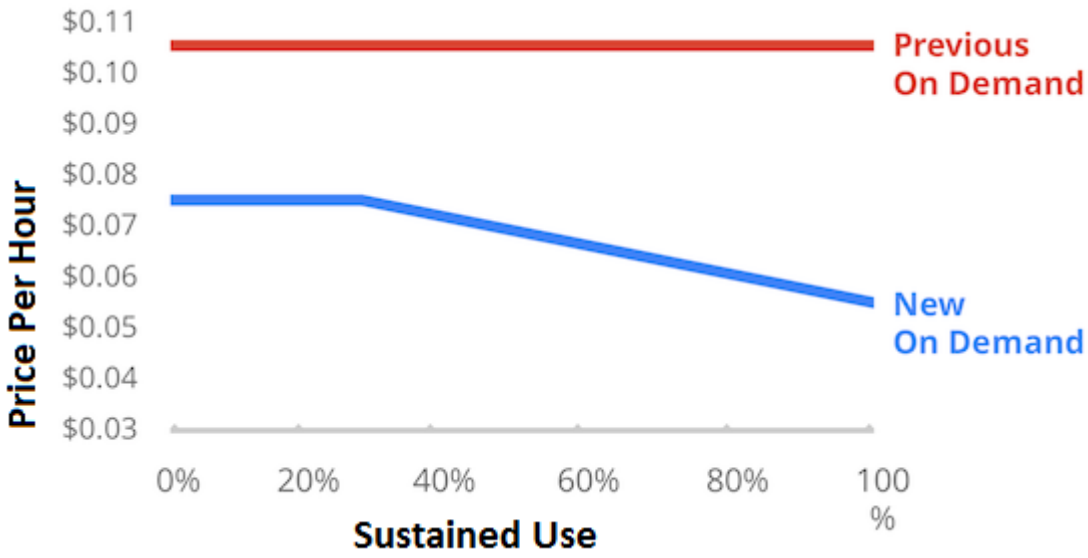
decision-making frameworks ultimately for non-expert managers in each industry. In particular, it was argued by the ICT director at Heriot-Watt University -interviewed in Chapter 5- that to migrate the Smart Building's ICT onto a hybrid, public, or a private cloud, may have more cultural impacts on the organization's work atmosphere than the technical aspects. The reason behind this argument was mainly due to the numerous cloud quality offerings, which were recognized as uneasily managed from a cultural perspective in terms of in-house personnel, contracts with service providers, ICT infrastructure, and end-user management within the organization.

In essence, a future work is identified to examine and identify the reasons behind classifying a cloud migration career path as a natural threat to in-house employees and existing systems, without a full comprehension of potential future cost benefits, security challenges, ease-of-management, and energy optimization advantages. On that ground, the research question would be: Why are some organizations culturally averse to cloud-computing solutions?

This research has subjectively focused on cloud-computing price prediction through the final decision-support system, SBCE, which was developed in Chapter 6. In that tool, the in-depth management consultancy assessment was built via dynamic scripts with reference to prices provided by Rackspace in particular. On that note, this research suggests some future development to be carried out on this tool, in order to empower non-expert managers with an open-standard enterprise price selection to cover a bigger market of cloud-computing providers such as Google App Engine, Amazon EC2, and others.

The reason behind the previous suggestion is the changeable cost management nature in which each provider standardizes differently for competitive reasons. This makes the cost estimation of SBCE challenging to keep up with these changes. For example, in April 2014 and following a drastic shift in the cloud-computing cost handling and service distribution, Google announced massive discounts for users who are utilizing cloud resources in a predictable manner. In particular, this feature covers organizations which have been running cloud services steadily in terms of workload and capacity for a persistent time period. This included several competitive cost reductions to organizations that are adopting a sustained use of various cloud services. The following figure shows one of the aspects of this feature, which illustrates how if a cloud resource

is being utilized for over 25% in a given month, then the sustained-use discount would apply. Moreover, if organizations utilize a cloud resource for a whole month, then these will be awarded with an additional 30% discount on the new on-demand costs (Figure 7.1).



(Figure 7.1) Sustained-Use Discount Example by Google regarding a Predictable Cloud Utilization

This move from Google was intended to increase revenues by expanding the range of potential consumers. Furthermore, Google classified this step as a logical approach to meet the current market standards given that the cloud-computing pricing process was observed not to comply with Moore's Law (Hölzle, 2014). In particular, this argument was clarified due to the observed annual decrease of ICT hardware costs, which was measured to reach 30% across the last 6 years. However, cloud-computing prices have only shown a maximum of 8% cost reduction throughout the past year alone in terms of public clouds as a major service consumer. This rapidly changeable and unstable nature of pricing, standardization, contract management, and other administrative factors of cloud services which were discussed previously throughout this project, classifies the efficiency degree of SBCE as outdated in certain circumstances.

On that note, this research recommends regular adjustment work to be carried out on this decision-making system in order to adapt with both key cloud providers' policies, and associated changes regarding deployments and long-term service growth and decline management. This is highlighted to eliminate weak points such as a drastic shift in commercial prices, or any major contract alterations with consumers, which turns any

dynamic web consultancy system obsolete as a result of the unpredictable cloud-computing evolution that is currently being witnessed across the majority of industries.

7.5- Summary of Conclusions

This research was structured to explore cloud-computing solutions to achieve cost effective and sustainable ICT management for non-expert managers of Smart Buildings. This application of cloud-computing greatly affects numerous types of decision-makers where information and data must be appropriately translated and effectively communicated. The thesis began with an introduction chapter which discussed the following areas:

- Understanding of the relationship between Smart Buildings and ICT management
- The evaluation of Smart Buildings main applications, ICT economic value, and current environmental status
- Identifying the three drivers of change behind this research (Economy, Technology, and Environment)
- Introducing cloud-computing and evaluating in practice general techniques
- Highlighting the principles of smart technology management and describing the relation to this project
- Formalizing the main research objectives, statement, and course of assessment

The main outcome of the work presented in this research is listed as follows against each chapter:

- **Chapter 2: Literature Review**

- The first section focused on identifying the multidisciplinary areas of research included in the literature analysis. This evaluation concluded that the key areas are highlighted in the management information systems mutual aspects of cloud-computing technical and non-technical administrative concepts, ICT decision-making models, and energy-efficient ICTs.

- The second section evaluated the recent literature on Smart Buildings' sustainable technologies and environmental approaches. A gap was identified arguing that the

majority of literature is mostly focused on the general scope of ICTs without exploring into each area separately. Therefore, it was challenging to highlight the contrast in benefits, trade-offs, and the effects on the sustainability objectives of Smart Building from employing technologies such as cloud-computing.

- The third stage evaluated various market solutions for energy management through the application of cloud-computing. The conclusion suggested that several current energy cloud-based services by top providers are lacking proper standardization in definition and deployment. This non-standardization has caused several security, reliability and integration challenges, especially in Smart Buildings that are supported by numerous ICT vendors.

- The fourth section focused on analysing the ICT costs in buildings and evaluating the associated energy consumption as a result of adopting those technologies. The main conclusion argued that Servers occupy the biggest percentage in cost and energy consumption as opposed to all other ICT components and associated attributes across almost all heavy-burdened ICT environments. Moreover, it was concluded that almost 42% of the power consumption of each ICT-burdened Smart Building is designated to the cooling infrastructure.

- The fifth section examined the business perspectives of cloud-computing and investigated the relation to Smart Buildings ICT environments. The key conclusion argued that non-expert managers struggle with security system updates and ensuring a 24/7 uptime hosting of services. In addition, it was observed that the entire concept of renting ICT capacity according to a pre-scheduled demand is heading towards a great deal of cost effective opportunities and multiple sustainability benefits such as reductions in long-term costs, energy efficiency, and real-time response features. Furthermore, the acquisition of new business opportunities is still a major concern regarding the deployment of ICT services such as cloud-computing. Moreover, other re-shaping challenges such as adjusting and initializing the existing environments were identified as crucial to ensure an economic advantage.

- The sixth section reviewed recent literature on the decision-making models in Smart Buildings and the relation to cloud-computing management. The key outcomes argued that work efficiency is the number one priority in almost every

Smart Building management scenario. However, cost effectiveness has dropped behind both data safety and user comfort. Furthermore, operational & maintenance costs, environmental sustainability, as well as reliability were all observed as significant to buildings' managers. After reviewing various decision-making models, this research concluded that for these criteria this study will not adopt a certain selection method given the global aspects, aims, and different themes of cloud-computing concepts. Alternatively, a balanced approach between the ICT technical and non-technical management in Smart Buildings was investigated in order to ensure cost-effective, reliable, and long-term sustainable strategies for cloud-computing. In addition, a significant assumption with regard to non-expert decision makers' evaluation was stated and was logically challenged against previous literature. Moreover, this study concluded that a precise estimate needs to be carried out by decision-makers to pass judgment on selecting the best time and place to adopt cloud services.

- The seventh stage evaluated previous work on cloud-computing risks and limitations. The main conclusion argued that adopting a fully outsourced cloud-computing solution is currently considered an unfavourable option by most non-expert managers given the uncertainty of private data whereabouts and other reliability, support, and upgrade concerns, which result in less control over owned resources.

- **Chapter 3: Theoretical Data Analysis**

This chapter carried out the following theoretical analysis and discussed the following areas:

- Evaluating market-ready cloud services currently offered by ICT providers and utilized by Smart Buildings' operators
- Investigating non-technical standards and definitions of cloud-computing for non-expert managers
- The technical analysis of the current in practice cloud-computing service characteristics, hosting models, and deployment approaches
- Evaluating the current and available cloud architectural models for different Smart Building requirements
- Identifying energy-efficient aspects of the cloud-computing characteristics

- Identifying the current cloud-computing pricing methods and standard costs for non-expert users
- The discussion of the major theoretical analysis conclusions and decision-making outlines

The main conclusion has argued that one of the biggest challenges of developing a decision-making framework for cloud-computing utilization in terms of cost, sustainability and management assessment is the current improper service standardization and the large number of different purchase and technical definitions by top providers. In addition, another observation was made that cloud experts currently claim that there is not a clear consensus towards classifying cloud-computing as a Green ICT. The investigation concluded that in order for non-expert managers to evaluate their organizational abilities aiming to measure actual efficiency rates before any cloud adoption, each of the cloud management aspects explored in Chapter 3 must be thoroughly examined in contrast to the variable lifecycle features of that structure. Furthermore, this research argues that decision-makers have a crucial task of weighing in these management attributes, which are mostly associated with the cost, security limitations, availability patterns, long-term maintenance savings, and the integration compatibility with in-house legacy systems. It was also concluded by this chapter that this assessment needs special attention when Smart Buildings are employing a hybrid cloud hosting solution given the numerous technical and non-technical considerations which were evaluated earlier.

- **Chapter 4: Data Collection Methodology**

This chapter described the main methodology of each section adopted by this research. Accordingly, each stage was explained separately through the identified selected field works and data collection approaches.

The main conclusion was a multi-step project roadmap which illustrates the full research workflow, and distinguishes between the theoretical and practical phases of the primary field work (Figure 4.1).

- **Chapter 5: Practical Value Examination**

This chapter has carried out a structured list of practical work as discussed in the methodology chapter. The main outcome of the work presented in this chapter is listed as follows:

- **Performing a semi-structured interview with a global cloud service provider (Rackspace):** It was concluded that Rackspace is focused on service delivery in terms of support, availability, and customer satisfaction, rather than empowering Smart Buildings with energy-efficient features of cloud applications. This conclusion came primarily as a result of the service requesters' demands towards eliminating in-house ICT maintenance, upgrade concerns, and staff salaries. It was observed by this research that the majority of Rackspace Smart Building clients over the past five years are not particularly interested in the energy-efficient benefits gained from cloud services. Their main interest is obtaining cost reductions and decreasing time-consuming management efforts. This was explained by the interviewee due to the fact that obtaining considerable energy cuts from cloud-computing is still a debatable argument depending on multiple ICT attributes related to the specific Smart Building ICT environment involved. Moreover, Rackspace indicated that the topic of cloud sustainability is evolving drastically as clients' energy awareness in terms of ICT usage minimization, is gaining more attention every day in response to the costly ICT bills and associated management complexities.

- **Performing a second semi-structured interview with a global cloud service provider (GBM):** The main conclusion argued that for a Green installation in a heavily ICT dependent organization, adopting cloud-computing was in most of GBM's client cases more cost efficient in terms of hardware, datacentre costs, and management. In some cases, the savings get lower in the long-term when a client moves from a legacy environment into a cloud one due to extra costs such as support expenses, and non-planned hardware upgrade.

- **Conducting a semi-structured interview of a major higher education organization as a potential cloud service requester:** One of the main conclusions argued that the complexity of any ICT management comes as a result of being bound with contracts with many external providers. It was pointed out that it is extremely challenging for a multi-vendor organisation to combine a large number of services from existing suppliers into one hosting solution as this forms

the first stage of any type of cloud migration. It was concluded that while money is not a key decision-making factor for the Heriot-Watt University ICT infrastructure, the on-demand self-service characteristic was therefore identified as a low concern. Moreover, it was stated that being charged a fixed price for a yearlong reliable service is more important to this organization, even during the summer low-demand period, than acquiring a self-service-oriented delivery model where the price certainty is worth a limited amount of associated risk. Therefore, Rapid Elasticity was classified as an essential prerequisite if cloud-computing services were purchased.

- **Performing a cost simulation of a cloud deployment across a 3-year utilization period:** It was concluded that although in some heavy-scaling demand cases cloud-computing can be more costly than the conventional approach, a considerable management challenge is raised in relation to integrating legacy systems from multiple Smart Building vendors into a single contract with the cloud provider. This must be thoroughly planned by decision-makers by following a strategic framework depending on system priority and critical utilization. Nevertheless, with regard to the Heriot-Watt University cost simulation, cloud-computing was observed to be cheaper than the cost of the conventional existing approach. Furthermore, the thick-client approach was calculated to consume 1.25 MW and cost around £ 3,000,000 for 5,000 PCs, whereas the thin-client approach was estimated to consume 60,000 Watts and cost around £ 1,345,000 for the same infrastructure. Moreover, while Heriot-Watt University spends around 0.5 million British pounds on ICT infrastructure per year, the simulation estimated that this number can be reduced to around £73,461 per year excluding any external contracts for special software such as Blackboard and others.
- **Performing a risk-analysis survey of the relevant cloud-computing management trade-offs and barriers selected by non-expert managers:** The main conclusion argued that the *Urgent Support Availability* aspect was classified as the most worrying factor amongst managers. The lowest concern was the *Government Hosting Regulations*, and the two price-associated factors: *Unpredictable Costs in the Future* and *The 'on-demand' payment method of cloud-computing might actually cost more than the traditional approach,* came at positions three and four. In addition, the *security* risk aspect was the second most

worrying in the cloud management process following the delivery of *unpredictable maintenance*.

- **Chapter 6: SBCE: Smart Building Cloud Evaluator**

The main conclusions of this chapter were discussed earlier in section 7.2.2. The following summarizes the steps taken in developing the online decision-making tool and the stages included in the testing and result analysis.

- The analysis of the tool's specifications and the adopted development platforms, and identifying the methods of data and requirements' collection
- Explaining the tool's development process and the input/output workflow
- Case study specification, execution, and result analysis
- The discussion of the major conclusions after calculating data results generated by SBCE
- External testing of the tool's two main features (Quick Cost Estimation and the In-Depth Value Analysis)

7.6- Concluding Statement

The overall aim of this work is to contribute to the evaluation and realization of cloud-computing management in practice by non-expert clients in Smart Buildings ICT environments. Various limitations were identified in the current decision-making processes. As a result, several management solutions were discussed to potentially mitigate the highlighted gaps and barriers, and these methods were tested and simulated via selected types of practical and field work. The conclusion outlined a decision-making framework, with an accompanying tool designed for non-expert managers, which are aimed to reduce costs generated after cloud-computing is adopted, simplify management procedures, and minimize the associated energy use of the overall ICT infrastructure.

This research suggests that the future direction of cloud computing to make buildings smarter is subject to understanding the ICT demand patterns and the thorough identification of the security and service-delivery trade-offs from the perspective of non-expert managers in Smart Buildings. Furthermore, making buildings smarter is also subject to the revaluation of the current cloud-computing market standards and pricing methodologies which are set by the service providers.

References

Adler, Brian. (2012). 'Designing Private and Hybrid Clouds'. Architectural Best Practices, Right Scale.

Agostinho, Lucio Rocha. (2012). 'RealCloudSim'. Software developed by State University of Campinas, Brazil. Web Link: http://sourceforge.net/projects/realcloudsim/files/latest/download

Albrecht, Steve. Sack, Robert J. (2000). 'Accounting Education: Charting the course through a perilous future'.

Accenture Group & WSP Report. (2010). 'Cloud Computing and Sustainability: The Environmental Benefits of Moving to the Cloud'. Web Link: http://www.accenture.com/SiteCollectionDocuments/PDF/Accenture_Sustainability_Cloud_Computing_TheEnvironmentalBenefitsofMovingtotheCloud.pdf

Accenture Report: Silicon Valley Leadership Group. (2008). 'Data Centre Energy Forecast Report'.

Amazon Web Services. (2013). 'Auto Scaling Getting Started Guide'. API Version: Quick Reference Card.

Amazon Web Services. (2013). 'Auto What is Auto Scaling?'. AWS Documentation, Auto Scaling Docs: Developer Guide.

Amazon: Elastic Compute Cloud (EC2). (2013). 'Monthly On-Demand Instance Price Calculator'. Web Link: http://calculator.s3.amazonaws.com/calc5.html

Amazon AWS. (2013). Amazon Web Services. Web Link: http://aws.amazon.com

Anaplan Inc. (2013) 'Cloud-based Modeling and Planning for Operations and Finance'. WebLink: www.anaplan.com/uk/discover?gclid=CPmF4qb36LkCFZShtAodHXwAiw

Arkin, H. Paciuk, M. (1997). 'Evaluating intelligent buildings according to level of service systems integration'. National Building Research Institute (NBRI).

Armbrust, Michael. Fox, Armando. Griffith, Rean. D. Joseph, Anthony. H. Katz, Randy. Konwinski, Andrew. Lee, Gunho. A. Patterson, David. Rabkin, Ariel. Stoica, Ion. Zaharia, Matei. (2009). 'Above the Clouds: A Berkeley View of Cloud Computing'. Electrical Engineering and Computer Sciences, University of California at Berkeley.

Arup, Web link: http://www.arup.com/About_us.aspx

Metz, B. Davidson, O.R. (2007). 'Climate Change 2007: Working Group III: Mitigation of Climate Change'

Baker, Mark. Gillam, Lee. Antonopoulos, Nick. (2010). 'Cloud Computing: Principles, Systems and Applications'. Springer: Communication Networks.

Baraga, Roger. Lu, Wei. Gannon, Dennis. «Microsoft Cloud Computing Platform«. External Research, MSR : Cloud Computing Futures MSR.

Bates, Shayne. (2010). 'Understanding Risk Management Approaches in the Cloud Computing Service Model'. International Security Buyers Guide.

Belady, Christian. (2007). 'In the Data Center, Power and Cooling Costs More than the IT Equipment It Supports'. Electronics Cooling. Web Link: http://www.electronics-cooling.com/2007/02/in-the-data-center-power-and-cooling-costs-more-than-the-it-equipment-it-supports/

Berl ,Andreas. Gelenbe, Erol. Di Girolamo, Marco. Giuliani, Giovanni. De Meer, Hermann. Dang, Minh Quan. Pentikousis, Kostas. (2009). 'Energy-Efficient Cloud Computing'. Oxford University Press on behalf of The British Computer Society.

Bernnat, Rainer. Zink, Wolfgang. Bieber, Nicolai. Strach, Joachim. (2012). 'Standardizing the Cloud: A Call to Action'. Booz and Company Inc.

Bewley, Alex. (2010). 'Cost of cloud computing, expensive!'. The Uptime IT Systems Management Blog, Web Link: http://www.uptimesoftware.com/uptimeblog/cloud-virtualization/cost-of-cloud-computing-expensive/

BizCloud. (2010). 'Defining Cloud Deployment Models'. Web Link: http://bizcloudnetwork.com/defining-cloud-deployment-models

Bloom, Eric. Gohn, Bob. (2012). 'Smart Buildings: Ten Trends to Watch in 2012 and Beyond'. Pike Research: CleanTech Market Intelligence.

BMC-Software Inc. (2014). 'Cloud Strategy, Planning & Design: A 3-week Workshop'. Web Link: http://www.bmc.com/solutions/cloud-computing/cloud-computing-management/cloud-planning-design.html

Boman, Magnus. Davidsson, Paul. L. Younes, Haka. (2001). 'Artificial Decision Making Under Uncertainty in Intelligent Buildings'. Stockholm University & University of Karlskrona & Royal Institute of Technology Electrum.

Booch, Grady. Rumbaugh, James. Jacobson, Ivar. (1998). 'The Uni-Fied Modeling Language: User Guide'. Addison Wesley Publishing.

Bort, Julia. (2013). ‘The 10 Most Important Companies in Cloud Computing’. Business Insider: SAI Enterprise. Web Link: http://www.businessinsider.com/10-most-important-in-cloud-computing-2013-4?op=1

Brajesh, Verma. (2012). ‘What Is Cloud Computing? What are Its Advantages and Disadvantages?’. Tech in Mind, Web Link: http://www.techinmind.com/what-is-cloud-computing-what-are-its-advantages-and-disadvantages/#

Bristow, Rob. (2013). ’Greening ICT programme’. JISC programme on the Green ICT Blog. Web Link: http://www.jisc.ac.uk/whatwedo/programmes/greeningict.aspx

Brunette, Glenn. Mogull, Rich. (2009). ‘Security Guidance for Critical Areas of Focus in Cloud Computing V2.1’. CSA, Cloud Security Alliance.

Bucklay, S. (2004). ‘Wireless: The Enterprises New Utility’. Telecommunication Online.

Bui, Tung. Lee, Jintae. (1999). ‘An agent-based framework for building decision support systems’. University of Hawaii.

Buyya, Rajkumar. Broberg, James. Goscinski, Anderzej. (2011). ‘Cloud Commuting: Principles and Paradigms’. Wiley Press, New York, USA.

Buyya, Rajkumar. Ranjan, Rajiv. N. Calheiros, Rodrigo. (2011). ‘Modeling and Simulation of Scalable Cloud Computing Environments and the CloudSim Toolkit: Challenges and Opportunities’. University of Melbourne, Australia. The University of New South Wales & Sydney, Australia. Pontifical Catholic University of Rio Grande do Sul Porto Alegre, Brazil.

Buyya, Rajkumar. Shin Yeo, Chee. Venugopal, Srikumar. (2009). ‘Market-Oriented Cloud Computing: Vision, Hype, and Reality for Delivering IT Services as Computing Utilities’. The Australian Department of Innovation, Industry, Science and Research (DIISR).

Buyya, Rajkumar. Yeo, Chee Shin. Srikumar Venugopal. Brober, James. Brandic, Ivona (2009). ‘Cloud computing and emerging IT platforms: Vision, hype, and reality for delivering computing as the 5th utility’

Caraher, Kelly. Nott, Martin. (2011). ‘From Tactic To Strategy: The Cloud Computing Tracking Poll’. CDW.

Carrenza. Eu-Networks. HP Cloud Agile Select Partner. VM-Ware Partner: V-Cloud Powered. (2015). ‘Enterprise Cloud Computing for Intelligent Buildings: Service Overview for Tenants’.

Cheikh Najib, Salem. (2013). ‘Exclusive interview with Karim J Mualla: Cloud Computing Business, Sustainability and Technical Matters’. GBM-Qatar, Senior Integrated Networks Specialist.

Chen, Zhen. Clements-Croome, Derek. Hong, Ju. Li, Heng. Xu, Qian. (2006). ‘A multicriteria lifespan energy efficiency approach to intelligent building assessment’. University of Reading & Hong Kong Polytechnic University.

Cherkasova, Ludmila. Gardner, Rob. (2005). ‘Measuring CPU overhead for I/O processing in the Xen virtual machine monitor’. ATEC '05 Proceedings of the annual conference on USENIX Annual Technical Conference.

Chiu, Willy. Subrahmonia, Jayashree. (2008). ‘From Cloud Computing to the New Enterprise Data Center’. IBM Corporation.

Chrome Website. (2013). ‘Introducing Chrome Box’. Web link: http://www.google.co.uk/intl/en_uk/chrome/devices/features.html

Cisco Systems Inc. (2010). ‘Independent Review Organization Builds Private Cloud’. Customer case study. Web Link: http://www.cisco.com/en/US/solutions/collateral/ns340/ns517/ns224/case_study_c36-580410.pdf

Clements-Croome, Derek. (2009). ‘Challenges and Opportunities for Green Intelligent Buildings in the 21st Century’. De Montfort University, Leicester.

Commensus Cloud Computing Website. (2013). ‘Infrastructure as a Service: Next Generation Cloud Hosting’ Web Link: http://www.commensus.com/Cloud-Hosting/Infrastructure-as-a-Service?gclid=CJK-0ruAsbcCFRMQtAod1FYAoQ

Considine, Toby. (2009). ‘Privacy: The Essential Service for Smart Buildings’. University of North Carolina, Chapel Hill.

Cook, Gary. (2012). ‘How Clean is your Cloud’. Green Peace International.

Cook, Gary. Van Horn, Jodie. (2011). ‘How Dirty is your Data’. Green Peace.

Cope, Jane. (2011). ‘How Cloud Computing Will Transform Information Management’. Presentation for the Information Management Summit – Wellington, NZ. Knowledge Cue: Microsoft SharePoint.

Córdoba, Jose-Rodrigo. (2010). ‘Systems Practice in the Information Society’. Routledge Series in Information Systems.

Costello, Patrick. Rathi, Roshni. (2012). ‘Data Center Energy Efficiency, Renewbale Energy and Carbon Offset Investment Best Practices’. Real Energy Writers.

Crooks, Bob. (2012). ‘Can we achieve Sustainable ICT?’. Royal Academy of Engineers.

Crooks, Bob. Ross, Margaret. (2011). ‘Greening your IT Work Space’. BCS, GreenIT SG.

Cruz, Xath. (2013). ‘Analyzing Security Challenges in the Hybrid Cloud’. Cloud Times, web link: http://cloudtimes.org/2013/02/21/analyzing-security-challenges-in-the-hybrid-cloud/

Cullen, Scott. (2010). ‘Value Engineering’. WBDC: A Program of the National Institute of Building Sciences.

Cummings, David. (2012). ‘10,000 Startup Hours’ Web link: http://davidcummings.org/2012/02/19/cloud-vs-colocation-vs-managed-hosting-for-startups/

Curtin, Richard. Prellezo, Raúl. (2010). ‘Understanding Marine Ecosystem Based Management: A literature review’.

Green, Stuart. (1994). ‘Beyond Value Engineering: Smart Value Management for Building Projects’. International Journal of Project Management. Vol 6, Page Numbers: 123-135.

David Walters, (2000) ‘Virtual organisations: new lamps for old’, Management Decision

De-Bono, Edward. (1999). ‘Six Thinking Hats’. Gran ica Editions.

Deborah, Snoonian. (2003). ‘Smart Buildings Control Systems’. IEEE Spectrum.

Dicken, P. (1998). ‘Global Shift: Transforming the World Economy’. London, Chapman.

Digital Boutique: The Creative E-Commerce Agency. (2013). ‘Internship for Hosting Solution Analysis’. Edinburgh - London, United Kingdom. Website: http://www.digitalboutique.co.uk/

El-Alfy, Alaa El Dean . (2010). ‘Design of Sustainable Buildings through Value Engineering’

Enetune-Fujitsu. (2012). ‘Fujitsu Launches New Enetune Cloud-based Energy Management System’. Public and Investor Relations Division, Fujitsu Limited. Web Link: http://www.fujitsu.com/global/news/pr/archives/month/2012/20120515-04.html

Envido, Energy Ltd London. (2013). ‘Save Energy, Save Money, Save Carbon’. Case Study ICT & Data Centre Energy Reduction.

Fareastgizmos. (2012). ‘Fujitsu Enetune Cloud-based Energy Management System helps to optimize energy usage’. Web Link: http://www.fareastgizmos.com/other_stuff/fujitsu-enetune-cloud-based-energy-management-system-helps-to-optimize-energy-usage.php

Fettweis , Gerhard. Zimmermann, Ernesto. (2008). ‘Ict Energy Consumption – Trends and Challenges’. The 11th International Symposium on Wireless Personal Multimedia Communications.

Fisk, David. (2012). ‘Cyber Security, Building Automation, and the Intelligent Building’. Intelligent Buildings International, Taylor & Francis.

Foxwell, Harry. Born, Geri. Venkataraman, Girish. Andres, Paul. Brunette, Glenn. (2012). ‘Oracle Cloud Solutions for Public Sector’. Oracle Corporation.

Freeman, C. Soete, L. (1987). ‘The Economics of Industrial Innovation’. London Pinter.

Frey, Soren. Fittkau, Florian , (2012). ‘CloudMIG Xpress’. Software developed by Software Engineering Group, Kiel University, Kiel, Germany. Web Link: http://sourceforge.net/projects/cloudmigxpress/files/latest/download

Fronckowiak, John. (2008). ‘Auto-Scaling Web Sites Using Amazon EC2 and Scalr”. Amazon EC2. Web Link: http://aws.amazon.com/articles/1603

Koomey, Jonathan G. (2007). “Estimating Total Power Consumption by Servers in the U.S. and the World”.

Gagliardi, Fabrizio. (2009). ‘Cloud Computing for Scientific Research’. Microsoft Research, Karlsruhe.

Gartner. (2013). ‘Key Challenges in Cloud Computing’ Web Link: http://www.gartner.com/technology/topics/cloud-computing.jsp

GBM ‘Gulf Business Machines’. (2013). ‘Background Overview’. Official Web Link: http://www.gbm4ibm.com/inside_aboutus.php

Gellman, Robert. (2009). ‘Privacy in the Clouds: Risks to Privacy and Confidentiality from Cloud Computing’. Privacy and Information Policy Consultant, World Privacy Forum.

Gens, Frank. (2009). ‘New IDC Cloud Services Survey: Top Benefits and Challenges’. IDC Exchange. Web Link: http://blogs.idc.com/ie/?p=730

Gong, Chunye. Liu, Jie. Zhang, Qiang. Chen, Haitao. Gong, Zhenghu. (2010). 'The Characteristics of Cloud Computing'. Department of Computer Sciences, National University of Defense Technology, Changsha, China.

Goodwin, Phil. (2011). 'Weighing the pros and cons of a hybrid cloud model'. Search Cloud Storage, web link: http://searchcloudstorage.techtarget.com/tip/Weighing-the-pros-and-cons-of-a-hybrid-cloud-model

Google Planimeter tool. (2013). Web Link: http://acme.com/planimeter/

Goscinski, Andrzej. Brock, Michael. (2010). 'Toward a Higher Level Abstraction of Cloud Computing'. Web Link: http://www.deakin.edu.au/sebe/it/research/trc10-1.pdf

Grajek, Michal. (2012). 'ICT approach: A Targeted Approach'. Bruegel Policy Contribution.

Graybar Service Enterprise. (2013). 'In-Building Wireless Solutions'. Web Link: http://www.graybar.com/applications/intelligent-buildings/mobility/in-building-wireless.

Greenpeace International. (2010). 'Make IT Green: Cloud computing and its contribution to climate change'. Web Link: http://www.greenpeace.org/international/Global/international/planet-2/report/2010/3/make-it-green-cloud-computing.pdf

Greenpeace International. (2012). 'Cool IT: LeaderBoard Version 5'. Web Link: http://www.greenpeace.org/international/Global/international/publications/climate/2012/CoolIT/Leaderboard5/Cool%20IT%20v-5.full%20report.pdf

Greggo, Andrea. Hagen, Christian. Lin, Douglas. Machung, James. Roik, Nicole. Parziale, Lydia. Avramenko, Andrey. Chan, Simon. de Valence, Foulques. Dziekan, Christopher. Dziekan, Michael. (2010). 'IBM Smart Analytics Cloud'. International Technical Support Organization: Redbooks.

Griffith, Martin. (2008). 'ICT and CO2 Emissions'. Parliamentary Office of Science and Technology.

Hamilton, James. (2010). 'Perspectives on Overall Datacentre Costs'. Web Link: http://perspectives.mvdirona.com/2010/09/18/OverallDatacentreCosts.aspx

Hannus, Matti. Kazi, Abdul Samad Sami. Zarli, Alain. (2010). 'ICT Supported Energy Efficiency in Construction: Strategic Research Roadmap and Implementation Recommendations'. REEB: European Strategic Research.

Harrell, Margaret C. Bradley, Melissa A. (2009). 'Data Collection Methods: Semi-Structured Interviews and Focus Groups'. RAND: National Defense Research Institute.

Hay, Brian. Nance, Kara. Bishop, Matt. (2011). ‘Storm Clouds Rising: Security Challenges for IaaS Cloud Computing’. Proceedings of the 44th Hawaii International Conference on System Sciences.

Herrera, Tilde. (2011). ‘Looking to the Cloud toward the Future of Building Design’. GreenBiz Web Link: http://www.greenbiz.com/blog/2011/10/31/looking-cloud-toward-future-building-design?page=0%2C1

Hölzle, Urs. (2014). ‘Google Cloud Platform Live: Blending IaaS and PaaS, Moore’s Law for the cloud’. Google Developers Blog: Senior Vice President.

Hornsby, Steve. Allan, Jason. (2012). IBM Corporation.

ICE-WISH Project. (2011). ‘Demonstrating through Intelligent Control Energy and Water wastage reductions In European Social Housing’. ICT-PSP & EU Community Programme. Web Link: http://www.ice-wish.eu/uk/about-icewish/about-icewish.asp

Iosup, Alexandru. Prodan, Radu. Epema, Dick. (2012). ‘IaaS Cloud Benchmarking: Approaches, Challenges, and Experience’. Parallel and Distributed Systems, Delft University of Technology, Delft, the Netherlands & University of Innsbruck, Innsbruck, Austria.

ITA Official Blog. (2010). ‘Energy and Cost Savings through Green ICT’. International Trade Administration. Web Link: http://blog.trade.gov/2010/06/16/energy-and-cost-savings-through-green-ict/

Johns, Rob. (2010). ‘Likert Items and Scales’. University of Strathclyde.

Johnson Control. (2004). ‘Metasys Systems Extended Architecture Wireless Networks’

Jones Lang LaSalle Website. (2013). ‘Integrated Facilities Management’. Worldwide: United States Edition. Web Link: http://www.us.am.joneslanglasalle.com/UnitedStates/EN-US/Pages/FacilityManagement.aspx

Jun Li. (2008). ‘Towards a low-carbon future in China's building sector—A review of energy and climate models forecast’

Khajeh-Hosseini, Ali. Greenwood, David. W. Smith, James. Sommerville, Ian. (2013)."The Cloud Adoption Toolkit: Supporting Cloud Adoption Decisions in the Enterprise". Cloud Computing Co-laboratory, School of Computer Science: University of St Andrews, UK.

K. Lekeas, George. (2011). ‘Object-Oriented Design’. Presentation on Information System Design, Development and Management, Royal Holloway, University of London.

Wong, Johnny K.W. Li, Heng. (2008). ‘Application of the analytic hierarchy process (AHP) in multi-criteria analysis of the selection of intelligent building systems’. Department of Building and Real Estate, Hong Kong Polytechnic University.

Kepes, Ben. (2012). ‘Revolution Not Evolution: How Cloud Computing Differs from Traditional IT and Why it Matters’. Rack-Space Support Publications.

Klems, Markus. Nimis, Jens. Tai, Stefan. (2009). ‘Do Clouds Compute? A Framework for Estimating the Value of Cloud Computing’. FZI Forschungszentrum Informatik Karlsruhe, Germany.

Kliazovich, Dzmitry. Bouvry, Pascal. Audzevich, Yury. Khan, Samee Ullah. (2010). ‘GreenCloud: A Packet-level Simulator of Energy-aware Cloud Computing Data Centers’. IEEE Communications Society, publication in the IEEE Globecom proceedings.

Kofmehl, Andri. Levine, Abigail. Falco, Gregory. Schmidt, Kreg. (2011). ‘Energy-Smart Buildings: Demonstrating how information technology can cut energy use and costs of real estate portfolios’. Accenture Corporation.

Kudtarkar, Parul. DeLuca, Todd F. Fusaro, Vincent A. Tonellato, Peter J. Wall, Dennis P. (2010). ‘Cost-Effective Cloud Computing: A Case Study Using the Comparative Genomics Tool, Roundup’. Evolutionary Bioinformatics: Libertas Academia.

Kumar Garg, Saurabh. Buyya, Rajkumar. (2012). ‘Green Cloud computing and Environmental Sustainability’. Cloud computing and Distributed Systems (CLOUDS) Laboratory, Dept. of Computer Science and Software Engineering, University of Melbourne, Australia.

Kumar, Karthik. Lu, Yung-Hsiang. (2010). ‘Cloud Computing for Mobile Users: Can Offloading Computation Save Energy?’. Purdue University, Published by the IEEE Computer Society.

Kuyoro, S.O. Ibikunle, F. Awodele, O. (2011). ‘Cloud Computing Security Issues and Challenges’. International Journal of Computer Networks (IJCN), Volume (3), Issue (5).

Lagar-Cavilla, Andr´es. Tolia, Niraj. Balan, Rajesh. de Lara, Eyal. O’Hallaron, David. (2006). ‘Dimorphic Computing’. School of Computer Science - Carnegie Mellon University, Pittsburgh.

LaManna, Lindsey. (2012). 'Top 9 Challenges in Cloud Computing'. SAP - Business innovation. Web Link: http://blogs.sap.com/innovation/cloud-computing/top-9-challenges-in-cloud-computing-that-are-slowing-its-adoption-011918

Likert-scale Exclusive Survey. (2013). 'One-Question Survey: Cloud Computing Risk Analysis'. Web Link: www.SurveyMonkey.com

Lim, Harold C. Babu, Shivnath. S. Chase, Jeffrey. S. Parekh, Sujay. (2009). 'Automated Control in Cloud Computing: Challenges and Opportunities'. ACDC, Barcelona, Spain.

Love, Peter. Tse, Raymond. Edwards, David. (2005). 'Time–Cost Relationships In Australian Building Construction Projects'. Journal of Construction Engineering And Management.

Luna Cloud Website. (2013). 'Cloud Computing Pricing models'. Web Link: http://www.lunacloud.co.uk/en/cloud-server-pricing?gclid=CJ7A_JS56rUCFW_KtAod9C8ASg

Massimo, Elano. (2010). 'Random Thoughts and Blasphemies around IaaS, PaaS, SaaS and the Cloud Contract'. IT 2.0: Next Generation IT Infrastructures. Web Link: http://it20.info/2010/11/random-thoughts-and-blasphemies-around-iaas-paas-saas-and-the-cloud-contract/

McGraw-Hill Professional. (2013). 'Fundamental Security Concepts'. Educational E-Books. Web Link: http://cryptome.org/2013/09/infosecurity-cert.pdf

McKendrick, Joe. (2012). 'SaaS, PaaS and IaaS: three cloud models; three very different risks'. ZDNET, WebLink: http://www.zdnet.com/blog/service-oriented/saas-paas-and-iaas-three-cloud-models-three-very-different-risks/8815

McKenna, Frank. (2002). 'Thin-Client vs Fat-Client Computing'. CEO Knowledge-one Corporation, White Paper.

McKinsey & Company. 'Siemens'. (2008). Sustainable Urban Infrastructure London Edition – a view to 2025: A research project sponsored by Siemens

Mell, Peter. Grance, Temothy. (2011). 'The NIST Definition of Cloud Computing: Recommendations of the National Institute of Standards and Technology'

Menzel, Michael. Schonherr, Marten. Nimis, Jens. Tai, Stefan. (2010). '$(MC^2)^2$, A Generic Decision-Making Framework and its Application to Cloud Computing'. International Conference on Cloud Computing and Virtualization, GSTF.

Metha, Neeraj. (2012). 'The 4 Primary Cloud Deployment Models'. Cloud Tweaks, Web Link: http://www.cloudtweaks.com/2012/07/the-4-primary-cloud-deployment-models/

Mines, Christopher. (2011). '4 Reasons Why Cloud Computing is Also a Green Solution'. GreenBiz, Web Link: http://www.greenbiz.com/blog/2011/07/27/4-reasons-why-cloud-computing-also-green-solution?page=0%2C1

Mintzberg, Henry. Westley, Frances. (2001). 'Decision Making: It's not what you think'. MIT, Sloane Management Review.

Mohamed, Arif. (2010). 'A History of Cloud Computing'. Web Link: http://www.computerweekly.com

Mualla, Karim. Jenkins, David. (2015). 'Evaluating Cloud Computing Management Challenges for Non-Expert Clients'. Proceedings of the Second International Conference on Data Mining, Internet Computing, and Big Data, Reduit, Mauritius 2015.

Mualla, Karim. Jenkins, David. (2015). 'Evaluating Cloud Computing Challenges for Non-Expert Decision-Makers'. International Journal of Digital Information and Wireless Communications (IJDIWC): Vol 5, Issue 4. Page Numbers: 285-296

Munasinghe, Nirosha. (2010). 'The Future of Cloud Connectiviity for BAS'. Open General.

Net-Suite, Product Overview. (2013). 'Free Product Tour'. Web Link: http://www.netsuite.co.uk/portal/uk/platform/main.shtml

Neves, Luis. Krajewski, Joan. Jung, Philipp (2008). 'Smart 2020: Enabling the Low Carbon Economy in the Information Age'. Global E-sustainability Initiative.

Newton, Nigel. (2010). 'The use of semi-structured interviews in qualitative research: strengths and weaknesses'. Exploring Qualitative Methods: Academia.Edu.

Nguyen, Nhan. (2009) 'Cloud Computing Introduction'. Presentation by BEHR: Stains Varnishes Paints.

Olive, Christopher. (2011). 'Cloud Computing Characteristics Are Key'. General Physics Corporation.

Oracle Hyperion. (2013). 'Oracle Planning and Budgeting Cloud service'. Oracle Datasheet, Web Link: http://www.oracle.com/us/solutions/cloud/planning-budgeting-cloud-service-1851924.pdf

Orzell, Greg. Becker, Justin. (2012). 'Auto Scaling in the Amazon Cloud'. Netflix Inc, the Netflix Tech Blog.

Pan, Shang Ling. L.Pan, Gary. Newman, Michael. Flynn, Donal. (2006). 'Escalation and De-Escalation of Commitment to Information Systems Projects: Insights from an

Avoidance Process Model'. European Journal of Operational Research. Vol 3, Issue 4. Page Numbers: 242-253.

Pantić, Zoran. Ali Babar, Muhammad. (2012). 'Guidelines for Building a Private Cloud Infrastructure'. University of Copenhagen.

Pavitt, K. (1994). 'Sectoral Patterns of Technological Change'. Research Policy Publication.

Pearson, Siani. (2011). 'Toward Accountability in the Cloud', View from the Cloud, IEEE Internet Computing, IEEE Computer Society.

Peer1 Hosting Publications. (2014). 'Managed Dedicated Server Hosting'. Web Link: http://www.peer1.com/whitepaper/managed-dedicated-servers http://www.peer1.com/hosting/bandwidth-billing

Peer1 Website. (2014). 'Bandwidth Billing Assessment'. Web Link: http://www.peer1.com/hosting/bandwidth-billing

Peltomäki, Antti. (2009). 'ICT for a Low Carbon Economy: Smart Buildings'. Findings by the High-Level Advisory Group and the REEB Consortium on the Building and Construction sector, EU Commission.

Pérez Ortega, María. (2012). 'FIT4Green ICT Project', Website: http://events.networks.imdea.org/content/e-energy-2012/e2dc-workshop.

Peuschel, Oliver. (2013). 'Exclusive interview with Karim J Mualla: Cloud Computing Business, Sustainability and Technical Matters'. Rack-Space Solution Specialist, Enterprise Hosting and Channel Consultant.

Project Earth: Energy Aware Radio and neTwork tecHnologies. (2013). 'Driving the Energy Efficiency of Wireless Infrastructure to its Limits'. Website: www.ict-earth.eu.

R. Lavelle, Michael. Onuma, Kimon. (2010). 'Virtual Building Energy Management: Moving to Cloud-based Building Energy Management'. Open General.

Rack-Space International Corporation. (2013). 'Rackspace Security Products: Supported Security Components and Technologies'. Experienced Fanatical Support Publications.

Rack-Space International Website. (2013). 'About Us'. Web link: http://www.rackspace.co.uk/about-us/

Rack-Space: The Open Cloud Company. (2013). 'Cloud Cost Calculator'. Rack Space Cloud Servers, powered by Open-Stack. Web Link: http://www.rackspace.co.uk/cloud-hosting/learn-more/calculator/

Ragan, Steve. (2012). ‘Cloud Deployments Carry Security, Regulatory Risks’. Slashdot, web link: http://slashdot.org/topic/cloud/cloud-deployments-carry-risks/

Ramli, Abd Rahman. Leong, Chui Yew. Samsudin, Khairulmizam. Mansor, Shattri. (2010). ‘Automation in Construction: Middleware for heterogeneous subsystems interoperability in intelligent buildings’. Intelligent Systems and Robotics Laboratory, Institute of Advanced Technology, University Putra Malaysia.

Ranganathan, Parthasarathy. (2010). ‘Recipe for Efficiency: Principles of Power-Aware Computing’. Communications of the ACM, Vol. 53 No. 4.

Rating-Scale, Risk Analysis Questionnaire. (2013). ‘Likert Survey for multi-enterprise-oriented Smart Building Managers’.Web Link: www.SurveyMonkey.com

Read, Jim. (2011). ‘The interaction between People, Technology & Business’. Arup.

Reed, J.H. (2000). ‘The Structure and Operation of the Commercial Building Market’. ACEEE Study on Energy Efficiency in Buildings.

Right-Scale Inc. (2013). ‘Plan for Cloud Simulator’. Web Link: https://planforcloud.rightscale.com/deployments

Roch, Michael. (2013). ‘Exclusive interview with Karim J Mualla: Cloud Computing Business, Sustainability and Technical Matters’. Heriot Watt, Information Systems Director.

Rubinow, Steve. (2012). ‘Accelerate IT Innovate with Your Cloud’. VMware Corporation.

Rubner, Jeanne. (2011). ‘When the Sky’s the limit’. Collective Intelligence: Cloud Computing. Web Link: http://www.siemens.com/innovation/apps/pof_microsite/_pof-spring-2011/_html_en/cloud-computing.html

Rutishauser, Ueli. Joller, Josef. Douglas, Rodney. (2005). ‘Control and Learning of Ambience by an Intelligent Building’. IEEE Transactions On Systems, Man, And Cybernetics—Part A: Systems And Humans.

Rymer, John. (2010). ‘The Future of Application Delivery’. Webinar: PaaS, Chapter 2. Web Link: http://appistry.com/news-and-events/press/05172010-webinar-paas-chapter-2-future-application-delivery

Anastasopoulou, S. Chobotova, V. Dawson, T. Kluvankova-Oravska, T and Rounsevell, M. (2007). ‘Identifying and assessing socio-economic and environmental drivers that affect ecosystems and their services’

Sandhu, S. Jaspal, M. Agogino, M. Alice, K. Agogino, Adrian. (2005). 'Wireless Sensor Networks for Commercial Lighting Control:Decision Making with Multi-agent Systems'. Department of Mechanical Engineering, University of California & NASA Ames Research Center.

Sreekanth, S. 'Top 5 Challenges to Cloud Computing', IBM, Web: https://www.ibm.com/developerworks/community/blogs/c2028fdc-41fe-4493-8257-33a59069fa04/entry/top_5_challenges_to_cloud_computing4?lang=en, 2011.

Sa, Thiago. (2012). 'CloudReports'. Software developed by Federal University of Ceara, Brazil. Web Link: https://github.com/thiagotts/CloudReports

Sabahi, Farzad. (2011). 'Cloud Computing Reliability, Availability and Serviceability (RAS): Issues and Challenges'. International Journal on Advances in ICT for Emerging Regions. Vol 5, Page Numbers: 74-86

Sanou, Brahima. (2012). 'Cloud computing in Africa: Situation and Perspectives'. ITU, Telecommunication Development Sector.

Schroder, Tim. (2011). 'Siemens Smart Buildings: The Future of Building Technology'. Siemens Corporation. Web Link: http://www.siemens.com/innovation/apps/pof_microsite/_pof-spring-2011/_html_en/smart-buildings.html

Schubert, Lutz. Jeffery, Keith. Neidecker-Lutz, Burkhard. (2010) 'The Future of Cloud Computing: Opportunities for European Cloud Computing beyond 2010'. EU Information Society and Media Commission.

Sheffield, Sonia. Mandelbaum, Jack. (2012). 'The Benefits of VMware's vCenter Operations Management Suite: Quantifying the Incremental Value of the vCenter Operations Management Suite for vSphere Customers'. VMware: Management Insight Technologies.

Shinder, Deb. (2012). 'Security Considerations for Cloud Computing (Part 4) - Resource Pooling'. Window Security, Web Link: http://www.windowsecurity.com/articles-tutorials/Cloud_computing/Security-Considerations-Cloud-Computing-Part4.html

Siemens history spotlight. Web link: http://www.siemens.com/history/en/

Simon, Parsons. (2012). 'IBM, Smarter Buildings: A Smarter Planet'. Web Link: http://www.ibm.com/smarterplanet/uk/en/green_buildings/ideas/index.html

Srikantaiah, Shekhar. Kansal, Aman. Zhao, Feng. (2008). 'Energy Aware Consolidation for Cloud Computing'. Pennsylvania State University and a Microsoft Research.

Subramanian, Krishnan. (2010). 'PaaS Is The Future Of Cloud Services: Orangescape Helps Business Users Design Applications On Cloud'. Cloud Ave, Web Link: http://www.cloudave.com/8939/paas-is-the-future-of-cloud-services-orangescape-helps-business-users-design-applications-on-cloud/

Swain, Becky. Pohlman, Marlin. Posey, Laura. (2011). 'Cloud Security Alliance GRC Stack Training'. CSA Web Link: www.cloudsecurityalliance.org

Talk Cloud Computing. (2013). 'Cloud Service Providers Compete to Capture the Cloud Market'. Web Link: http://talkcloudcomputing.com/cloud-service-providers-compete-to-capture-the-cloud-market/

Talon, Casey. (2013). 'The Impact of Cloud Computing on the Development of Intelligent Buildings'. CABA's Intelligent & Integrated Buildings, Council (IIBC) White Paper Sub-Committee.

Tantow, Martin. (2011). 'Cloud Computing: Current Market Trends and Future Opportunities' WEBLINK: http://cloudtimes.org/2011/06/22/cloud-computing-its-current-market-trends-and-future-opportunities/

Teale, Mark. Dispenza, Vincenzo. Flynn, John. Currie, David. (2003). 'Management Decision Making: Towards an Integrated Approach'. Prentice Hall, Financial Times.

Teimoury, Youness. Samimi, Parnia (2013). 'CloudAuction'. Software developed by QIAU & UKM. Web Link: http://www.cloudbus.org/cloudsim/CloudAuctionV2.0.zip

Thanos, George A. Courcoubetis, Costas. Stamoulis, George D. (2007). 'Adopting the Grid for Business Purposes: The Main Objectives and the Associated Economic Issues'. Grid Economics and Business Models

The Cloud Scaling Group. (2011). 'Infrastructure as a Service Building's Guide Network Edition: the Case of Network Virtualization'. NEC Ltd.

Thiry, Michel. Sylva. (1997). 'Value Management Practice'. NC: Project Management Institute.

Tsarchopoulos , Panagiotis. (2011). 'Intelligent Cities: Innovation Echo Systems'. Urenio, Intel Space. Web Link : http://www.urenio.org/2011/01/31/chicago-smart-grid-city/

Tung, H. Tsang, K. Lai, L. Lam, K. Tung, H. (2011). 'Hybrid Energy Management Solution for Smart Building'. IEEE International Conference on Consumer Electronics (ICCE).

Turner, Pitt W. Seader, John H. (2006). ‘Dollars per kW plus Dollars per Square Foot Are a Better Data Center Cost Model than Dollars per Square Foot Alone’. The Uptime Institute.

Turskis, Zenonas. Kazimieras Zavadskas, Edmundas. Peldschus, Friedel. (2009). ‘Multi-criteria Optimization System for Decision Making in Construction Design and Management’. Economics Of Engineering Decisions. Vol 9, Page Numbers: 222-232

UNEP. (2011). ‘Building for the Future: A United Nations showcase in Nairobi’. Division of Communications and Public Information.

United Layer. (2013). ‘Cloud Services: Secure Managed Cloud from UnitedLayer’. Web Link: http://www.unitedlayer.com/cloud-services.htm

Vaquero, Luis M. Rodero-Merino, Luis. Caceres, Juan. Lindner, Maik. (2008). ‘A Break in the Clouds: Towards a Cloud Definition’. Telefonica Investigacion y Desarrollo, Madrid, Spain (EU) & SAP, Belfast, UK (EU).

Velten, Carlo. Janata, Steve. Hille, Max. (2013). ‘Cloud Vendor Benchmark’. Experton Group.

Verdelli-Mason, Christopher. (2013). ‘IBM Smart Cloud: IBM cloud computing: Rethink IT’. Reinvent business. Web Link: http://www.ibm.com/cloud-computing/uk/en/?csr=emuk_aoagspcc-20100526&cm=k&cr=google&ct=101AE02W&S_TACT=101AE02W&ck=ibm_efficient_performance&cmp=101AE&mkwid=s5MFNOKI9_16150750003_4328nk2971

Vmware Website. (2013). ‘Private Cloud Computing: Amplify Your Datacentre for Business Agility’. VMware, Inc. Web link: http://www.vmware.com/uk/cloud-computing/private-cloud/private-cloud-solutions.html

Vmware Website. (2013). ‘VMware vCloud Datacentre Services’. VMware, Inc. Web link: http://www.vmware.com/solutions/cloud-computing/public-cloud/vcloud-datacentre-services.html

Vodafone Corporate. (2007). Social Responsibility Reports.

Voss, Alex. Barker,Adam. Asgari-Targhi,Mahboubeh. van Ballegooijen, Adriaan. Sommerville, Ian. (2013). "An elastic virtual infrastructure for research applications (ELVIRA)". Journal of Cloud Computing: Advances, Systems and Applications. Vol 6, Page Numbers: 153-165

W.Roth, Kurt. Westphalen, Detlef. Y.Feng, Michael. LIana, Patricia. Quartararo, Louis. (2005). ‘Energy Impacts of Commercial Building Controls and Performance Diagnostics: Market Characterization, Energy Impact of Building Faults and Energy Savings Potential’. TIAX LLC for U.S. Department of Energy.

Weins, Kim. Tolani, Vijay. (2014). ‘State of the Cloud Report’. RightScale Inc.

Weldon, Kathryn. (2012). ‘M2M Evolution: What are the Enablers of Future Growth?’. M2M Evolution, Advisory Report.

Wentz, Josh. (2009). ‘Literature Review: Green Intelligent Buildings’. Web Link: http://www.scribd.com/doc/22398440/Green-Intelligent-Buildings-Literature-Review-EnGL202C

Whittaker, Zack. (2011). ‘Updating Screenshots of Upcoming Windows 8 Features’. Tech Republic, Web Link: http://www.techrepublic.com/photos/updating-screenshots-of-upcoming-windows-8-features/6219892?seq=15

Wickremasinghe, Bhathiya. NCalheiros, Rodrigo. Buyya, Rajkumar (2009). ‘CloudAnalyst’. Software developed by University of Melbourne, Australia. Web Link: http://www.cloudbus.org/cloudsim/CloudAnalyst.zip

Williams, Daniel. Tang, Yinshan. (2013). ‘Impact of Office Productivity: Cloud Computing on Energy Consumption and Greenhouse Gas Emissions’. University of Reading, United Kingdom.

Willson, Kathryn. Mitchel, Bill. Gimenez, Joseph. (2011). ‘The Central Role in Cloud Computing in Making Cities Energy Smart’. Microsoft Corporation.

Wong, J.K.W. Li, H. Wang, S.W. (2005). ‘Intelligent building research: a review’. The Hong Kong Polytechnic University.

Yang, J. Peng, H. (2001). ‘Decision support to the application of intelligent building technologies’. School of Construction Management and Property, Queensland University of Technology.

Yarwood, Simon. (2012). ‘Intelligent Buildings: Understanding and managing the security risks’. IET: The Institution of Engineering and Technology.

Younge, A.J. Laszewski, von. Wang, Lizhe. Lopez-Alarcon, S. Carithers, W. (2010). ‘Efficient resource management for Cloud computing environments’. Green Computing Conference, 2010 International

Younis, Mohamed. Youssef, Moustafa. Arisha, Khaled. (2003). ‘Energy-aware management for cluster-based sensor networks’. Department of Computer Science and Electrical Engineering, University of Maryland.

Zhang, Qi. Cheng, Lu. Boutaba, Raouf. (2010). ‘Cloud Computing: state-of-the-art and Research Challenges’. Journal of Internet Services and Applications. Vol 4, Page Numbers: 192-204

Zhao, Jimin. (2012). ‘Climate Change Mitigation in Beijing, China’. Case study prepared for Cities and Climate Change: Global Report on Human Settlements 2011.

Zucker, Gerhard. Judex, Florian. Hettfleisch, Christian. Schmidt, Ralf-Roman. Palensky, Peter. Basciotti, Daniele. (2012). ‘Energy aware building automation enables Smart Grid-friendly buildings’. Elektrotechnik & Informationstechnik, Springer-Verlag.

Appendix A – 3-Year Cloud Cost Simulation: A Detailed Data Interpretation

The following demonstrates elaborated results, along with an extended view of Chapter 5, which conducted a cloud-computing simulation on this study's key case study, Heriot-Watt University. The table below explores the Heriot-Watt University example cost-estimation report as a result of the previously determined cloud-computing instances, support domains, managed service levels, and customized patters depending on peak time periods. The data scope of the monthly-assigned expenses shown below is presented as an extended version of Figure (5.17), which recognizes a 3-year cost report without specifying the in-depth cost spent on cloud-computing per month.

Deployment Summary: Heriot_Watt_Simulation								
15 x Servers								
	10 x Heriot_Watt_Central_Servers - Managed 2GB RAM (2GB server) on Rackspace UK							
	5 x Heriot_Watt_Mail_Servers - Web/Worker Role Medium (Web/Worker Role Medium) on Windows Azure North Europe							
10 x Storage								
	10 x Heriot_Watt_Storage (500.0GB) - Cloud Files on Rackspace UK							
2 x Databases								
	2 x Heriot_Watt_Database_Server - Managed Cloud Server 2GB RAM (2GB Cloud Server) on Rackspace UK							
4 x Data Links								
	100.0GB from Heriot_Watt_Central_Servers (Server) to Heriot_Watt_Storage (Storage)							
	100.0GB from Heriot_Watt_Storage (Storage) to Heriot_Watt_Central_Servers (Server)							
	1024.0GB from Users (Remote Node) to Heriot_Watt_Central_Servers (Server)							
	1024.0GB from Heriot_Watt_Central_Servers (Server) to Users (Remote Node)							
	100.0GB from Users (Remote Node) to Heriot_Watt_Database_Server (Database)							
	100.0GB from Heriot_Watt_Database_Server (Database) to Users (Remote Node)							
	100.0GB from Users (Remote Node) to Heriot_Watt_Mail_Servers (Server)							
	100.0GB from Heriot_Watt_Mail_Servers (Server) to Users (Remote Node)							
2 x Other Costs								
	Loggly							
	New Relic							
Yearly Cost Summary								
Date	Server & DB Running Costs (USD)	Storage (USD)	Data Transfer (USD)	Storage I/O (USD)	DB Transactions (USD)	Support (USD)	Other Costs (USD)	Total (USD)
Year 1: Sep-2013 to Aug-2014	39722.19	6138.24	2196.75	0	0	22889.22	2376	73322.4

Year 2: Sep-2014 to Aug-2015	39722.19	6138.24	2196.75	0	0	22889.22	2376	73322.4
Year 3: Sep-2015 to Aug-2016	39821.27	6138.24	2196.75	0	0	22929.38	2376	73461.64
Total	119265.7	18414.72	6590.25	0	0	68707.82	7128	220106.4

Support Plans - Yearly Cost Summary

Date	Rackspace	Windows Azure	Total
Year 1: Sep-2013 to Aug-2014	19289.22	3600	22889.22
Year 2: Sep-2014 to Aug-2015	19289.22	3600	22889.22
Year 3: Sep-2015 to Aug-2016	19329.38	3600	22929.38
Total	57907.82	10800	68707.82

Monthly Cost Summary

Date	Server & DB Running Costs (USD)	Storage (USD)	Data Transfer (USD)	Storage I/O (USD)	DB Transactions (USD)	Support (USD)	Other Costs (USD)	Total (USD)
13-Sep	2972.38	511.52	151.33	0	0	1605.6	198	5438.83
13-Oct	3071.47	511.52	151.33	0	0	1645.75	198	5578.07
13-Nov	2972.38	511.52	151.33	0	0	1605.6	198	5438.83
13-Dec	3071.47	511.52	151.33	0	0	1645.75	198	5578.07
14-Jan	3071.47	511.52	151.33	0	0	1645.75	198	5578.07
14-Feb	2774.23	511.52	151.33	0	0	1525.27	198	5160.35
14-Mar	3071.47	511.52	151.33	0	0	1645.75	198	5578.07
14-Apr	2972.38	511.52	151.33	0	0	1605.6	198	5438.83
14-May	3071.47	511.52	151.33	0	0	1645.75	198	5578.07
14-Jun	4132.65	511.52	278.26	0	0	2721.24	198	7841.67
14-Jul	4270.41	511.52	278.26	0	0	2798.58	198	8056.77
14-Aug	4270.41	511.52	278.26	0	0	2798.58	198	8056.77
14-Sep	2972.38	511.52	151.33	0	0	1605.6	198	5438.83
14-Oct	3071.47	511.52	151.33	0	0	1645.75	198	5578.07
14-Nov	2972.38	511.52	151.33	0	0	1605.6	198	5438.83
14-Dec	3071.47	511.52	151.33	0	0	1645.75	198	5578.07
15-Jan	3071.47	511.52	151.33	0	0	1645.75	198	5578.07
15-Feb	2774.23	511.52	151.33	0	0	1525.27	198	5160.35

15-Mar	3071.47	511.52	151.33	0	0	1645.75	198	5578.07
15-Apr	2972.38	511.52	151.33	0	0	1605.6	198	5438.83
15-May	3071.47	511.52	151.33	0	0	1645.75	198	5578.07
15-Jun	4132.65	511.52	278.26	0	0	2721.24	198	7841.67
15-Jul	4270.41	511.52	278.26	0	0	2798.58	198	8056.77
15-Aug	4270.41	511.52	278.26	0	0	2798.58	198	8056.77
15-Sep	2972.38	511.52	151.33	0	0	1605.6	198	5438.83
15-Oct	3071.47	511.52	151.33	0	0	1645.75	198	5578.07
15-Nov	2972.38	511.52	151.33	0	0	1605.6	198	5438.83
15-Dec	3071.47	511.52	151.33	0	0	1645.75	198	5578.07
16-Jan	3071.47	511.52	151.33	0	0	1645.75	198	5578.07
16-Feb	2873.31	511.52	151.33	0	0	1565.43	198	5299.59
16-Mar	3071.47	511.52	151.33	0	0	1645.75	198	5578.07
16-Apr	2972.38	511.52	151.33	0	0	1605.6	198	5438.83
16-May	3071.47	511.52	151.33	0	0	1645.75	198	5578.07
16-Jun	4132.65	511.52	278.26	0	0	2721.24	198	7841.67
16-Jul	4270.41	511.52	278.26	0	0	2798.58	198	8056.77
16-Aug	4270.41	511.52	278.26	0	0	2798.58	198	8056.77
Total	119265.7	18414.72	6590.25	0	0	68707.82	7128	220106.4

Support Plans - Monthly Cost Summary

Date	Rackspace	Windows Azure	Total
13-Sep	1305.6	300	1605.6
13-Oct	1345.75	300	1645.75
13-Nov	1305.6	300	1605.6
13-Dec	1345.75	300	1645.75
14-Jan	1345.75	300	1645.75
14-Feb	1225.27	300	1525.27
14-Mar	1345.75	300	1645.75
14-Apr	1305.6	300	1605.6
14-May	1345.75	300	1645.75
14-Jun	2421.24	300	2721.24
14-Jul	2498.58	300	2798.58
14-Aug	2498.58	300	2798.58
14-Sep	1305.6	300	1605.6
14-Oct	1345.75	300	1645.75
14-Nov	1305.6	300	1605.6
14-Dec	1345.75	300	1645.75
15-Jan	1345.75	300	1645.75
15-Feb	1225.27	300	1525.27
15-Mar	1345.75	300	1645.75
15-Apr	1305.6	300	1605.6
15-May	1345.75	300	1645.75
15-Jun	2421.24	300	2721.24
15-Jul	2498.58	300	2798.58
15-Aug	2498.58	300	2798.58

15-Sep	1305.6	300	1605.6
15-Oct	1345.75	300	1645.75
15-Nov	1305.6	300	1605.6
15-Dec	1345.75	300	1645.75
16-Jan	1345.75	300	1645.75
16-Feb	1265.43	300	1565.43
16-Mar	1345.75	300	1645.75
16-Apr	1305.6	300	1605.6
16-May	1345.75	300	1645.75
16-Jun	2421.24	300	2721.24
16-Jul	2498.58	300	2798.58
16-Aug	2498.58	300	2798.58
Total	57907.82	10800	68707.82

Appendix B - Risk Analysis Survey Form

With regard to this study's risk analysis survey which was explained in sub-section 5.3, the following shows the complete rating-scale user-form divided into five stages as explained in Chapter 5 (SurveyMonkey.com, 2013).

- *With Cloud-Computing, companies can get rid of IT Hardware and simply use virtual recourses instead. This is done through various ways such as the Internet or private networks, which can be hosted either within the same company, or at the provider's datacentre. Organizations can use Cloud-Computing by renting from the Cloud-provider required devices, applications, data storage and platforms, while only paying for what they use, and when they use it.*
- *Key Benefits:*
  - *Minimize costs from buying, upgrading, licensing and supporting the Hardware.*
  - *Minimize electricity and associated power bills.*
  - *Scaling the performance, up or down, at any time, depending on what companies need and when they need it.*
  - *24/7 Support: no need to staff fulltime IT personnel.*
  - *Environmentally friendly 'Green': as companies never have to worry about regularly dumping old devices and buying new ones.*

- *However, extending Cloud-Computing services to cover hosting the entire Buildings' servers, and internal systems (e.g. Heating, Cooling, Ventilation, CCTV, water, sensing devices/applications, lighting, elevator control, etc), can raise some concerns.*
- *To what extent do you think the following statements are a concern to your organization or field of work?*
- *Please choose one of the following answers:*
  1- *Not worried at all*
  2- *Slightly worried*
  3- *I don't mind*
  4- *I am more worried*
  5- *Extremely worried*

Concerns	***Please write down a number from (1 to 5)***
Control over recourses	
Security (Data, access, permissions, sharing, etc)	
Urgent support availability	
A complete service shutdown (e.g. as a result of an internet breakdown)	
Slower performance (as everything is delivered over a network)	
Integration difficulties with existing systems, delivered by multiple suppliers	
Unknown hosting locations	
Difficulties in going back to old hosting methods after using Cloud-Computing	

The 'on-demand' payment method of Cloud-Computing might actually cost more than the traditional approach	
Unpredictable costs in the future	
Contract management issues	
Government hosting regulations	

Appendix C - SBCE, Technical Specification and Primary Evaluation Templates (The tool *SBCE* is hosted temporarily at: http://198.38.93.229/SBCE)

- **Cloud-computing Component Breakdown in relation to a generic Smart Building ICT Environment:**

In reference to Chapter 5, this study interviewed a Rackspace Solution Specialist: Mr. Oliver Peuschel for the purpose of analysing the management perspective of cloud-computing service providers for Smart Buildings' utilization. On that account, this study has taken Rackspace as a primary reference regarding this project's decision-support tool *SBCE* . This was referenced in terms of cloud service prices, instances' description, and distribution of costs across cloud features and the different types of implementation.

Below are the key cloud instances used by this research. Each presented with the associated and pre-specified attributes, along with the appropriate prices, which were referenced from Rackspace online cloud prices in 2015. However, as these prices are constantly changing, this research suggests a future work to be carried out which would enable those prices to be dynamically adjusted via setup scripts in case of any changes from the provider's end. In particular, those scripts can be directly connected via an API with Rackspace's Cloud Calculator tool.

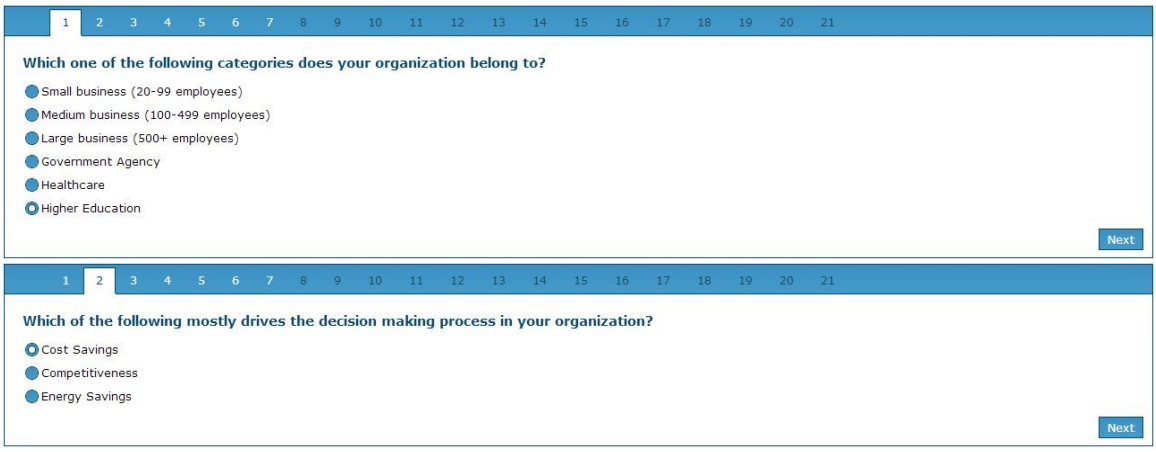
Cloud Instance	**Associated Attributes**
Servers	(Number) & (RAM Size) & (Windows OS or Linux) & (Amount of service-hours per month) & If OS = Linux: (Add Vrouter or not) & (RedHat Enterprise or not)
Database Servers	(Number) & (RAM Size) & (Amount of service-hours per month) & Choose from: - Cloud Servers for a Database Implementation (Linux-MYSQL or Windows MS-SQL-Web or Windows MS-SQL-Standard) - Virtually Distributed Cloud-Based Databases
Load Balancer Servers	(Number) & (Concurrent Connections) & (amount of service hours per month) & (With SSL or not)
Cloud-Based Storage	Choose from: 1- Cloud Block Storage: Attributes: (Size in GB) & (amount of service hours per month)

	Also Choose from: - Standard Volume (Consistent performance) - SSD volumes (Faster performance for I/O intensive databases and file systems) Users can specify the amount of hours per month for this service to be active, Default is 730 hours (This can be added to each end0user patter to reflect growth or reduction changes at specified periods). 2- Cloud Files
Additional Support	Choose from: 1- Additional Managed Service 2- Cloud Files Back-up

All Prices have been dynamically programmed into *SBCE* via pre-built scripts, measured from RackSpace Cloud Calculator tool as a primary reference (RackSpace-Cloud Cost Calculator, 2013).

- **SBCE In-Depth Consultancy Option: 21 Management Questions**

The following demonstrates the In-Depth process by this study's decision-support web-application, *SBCE.* The evaluation covers twenty one administrative questions, which provides a bespoke deployment report for the recommended cloud-computing hosting solution in terms of management and purchase insights. The generated report is presented in Chapter 5 in Figures (5.16 to 5.19).



1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21

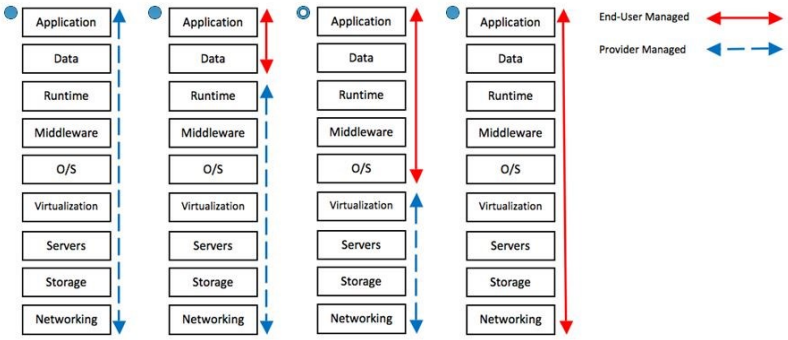
If known, please select the appropriate Primary Concept of Information Security that is most relevant to your organization

- Confidentiality & Integrity
- Availability
- Accountability and Logs
- All the above on an equal respect

Next

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21

With regard to control over ICT resources, which of the following three models would you consider to be most appropriate to your company's operational nature?



Next

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21

Does your organization require a 24/7 ICT resource availability on both a hardware and software levels of service?

- Yes, main ICT resources must be always up and running
- No, it is possible at certain selected periods to have a system shutdown

Next

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21

Does your organization already employ any sorts of ICT virtualization or Cloud Computing?

- No
- Yes

Please choose one of the following deployment approaches	Please choose one of the following associated service delivery models
Private	SaaS (Software as a Service)
Public	PaaS (Platform as a Service)
Hybrid	IaaS (Infrastructure as a Service)
Community	Combination of all service models

Next

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21

As an ICT consumer, in relation to the most relevant line of work to your company, which one of the following three categories would you include your organization in?

- Category 1:
  - You provide your employees with access to typical software applications such as office productivity or email.
  - Your employees directly use software applications, whether on their own behalf or that of your organization.
  - Your company employs Software application administrators who configure an application for other end users.
- Category 2:
  - Your company employs Application developers, who design and implement an application's software.
  - Your company includes Application testers, who run applications in various (possibly cloud-based) testing environments.
  - Your company works with Application implementers, who publish completed or updated applications into the Cloud, and manage possible conflicts arising from multiple versions of an application.
  - Your company manages Application administrators, who configure, tune, and monitor application performance on a platform.
- Category 3:
  - Your company employs full-time or part-time System administrators who manage independent datacenter(s).

Next

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21

As an ICT consumer, which of the following 3 service-categories does your company demands?

- Category 1: Using specific applications on demand, and application data management, such as backup and data sharing between consumers.
- Category 2: Using of the ICT provider's tools and execution resources to develop, test, deploy and administer applications.
- Category 3: Access to virtual computers, network-accessible storage, and network infrastructure components such as firewalls, and configuration services.

Next

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21

As an ICT consumer, which of the following 3 usage-fee-calculation methods do you believe would best fit your company's budget and work nature?

- Method 1: Typically, based on the number of users, the time in use, per-execution, per-record-processed, network bandwidth consumed, and quantity/duration of data stored.
- Method 2: Typically, based on the number of consumers, the kind of consumers (e.g., developers vs. application end users), storage, processing, or network resources consumed by an outsourced application development platform, requests serviced, and the time the platform is in use.
- Method 3: Typically, per CPU hour, data GB stored per hour, network bandwidth consumed, network infrastructure used (e.g., IP addresses) per hour, value-added services used (e.g., monitoring, automatic scaling).

Next

1 2 3 4 5 6 7 8 9 **10** 11 12 13 14 15 16 17 18 19 20 21

In terms of a future ICT lifecycle and requirements, which of the following ICT scenarios would you consider to be most appropriate to your organization?

- Accessing applications via networked hosted infrastructure (i.e. Internet, VPN, etc).
- Developing software via a fully networked-hosted platform, including virtual utilization of Hardware and operating systems.
- (•) Your ICT provider rents you the required Hardware, Software, networking bandwidth, or all the above, via on-demand accessing policies (i.e. data Storage, computing power, arbitrary networks solutions, etc).

Next

1 2 3 4 5 6 7 8 9 10 **11** 12 13 14 15 16 17 18 19 20 21

From a pure business perspective, please select one of the following 4 service-categories in relation to what you believe is more suitable to your company

- Category 1:
  - ✓ Increasing the speed and agility of ICT resources
  - ✓ Bringing applications to market faster
  - ✓ Increase utilization of servers, network, and storage resources
  - ✓ Improve efficiency of IT operations staff, increase competency, and standardization
  - ✓ Provide a single support model across a large number of applications
  - ✓ Shift costs from infrastructure build-out to business applications
- Category 2:
  - ✓ Eliminating acquisition costs (constraints and barriers)
  - ✓ Elastic and rapid reaction to business requirements in relation to peak workload and high volume periods
  - ✓ Pay-as-you-go for services to allow only the right-size of resources at any given time
  - ✓ Focus on core competencies rather than non-core ICT functions
  - ✓ Shift costs from capital expense to operation expense
- (•) Category 3:
  - ✓ Combination of both categories 1 and 2 to allow a higher level of security and performance reliability, yet at the same time, offer a cost-efficient solution regarding non-mission critical Smart Buildings' environments.
- Category 4:
  - ✓ The ICT infrastructure is shared by several other organizations with the same -or similar- policy and compliance considerations.
  - ✓ My company is part of a various state-level government departments, or information related portfolios, which requires access to the same data or ICT infrastructure, such as hospitals, sub-branches to a root company, roads, electrical stations, etc.
  - ✓ My organization requires a higher level of privacy, security and/or policy compliance

Next

1 2 3 4 5 6 7 8 9 10 11 **12** 13 14 15 16 17 18 19 20 21

According to your previous selection this step will be skipped

Next

1 2 3 4 5 6 7 8 9 10 11 12 **13** 14 15 16 17 18 19 20 21

Please select one -or more- from the following application workload categories that you believe are most relevant to your organization's line of work

- (•) Applications that have unpredictable growth prospects, such as social software, web mails, and marketing campaigns
- Applications with regular traffic fluctuations, such as daily financial market activity or seasonal e-commerce, benefit from auto-scaling to keep utilization high
- Easily parallelized Applications, such as media encoding, batch processing, and big data analytics

Next

1 2 3 4 5 6 7 8 9 10 11 12 13 **14** 15 16 17 18 19 20 21

Relatively speaking, please select one -or more- of the following application-characteristics which most applies to your organization's ICT lifecycle

- Your company has proprietary databases and applications that require high I/O and consistent throughput, occasionally undergo replication and clustering operations for the ICT infrastructure
- (•) Your company's ICT environment has proprietary databases and applications that require high I/O and consistent throughput.
- None

Next

1 2 3 4 5 6 7 8 9 10 11 12 13 14 **15** 16 17 18 19 20 21

Please select the number of locations (connected branches, offices, buildings, etc) that your organization facilitate:

- Only one physical location
- Less than 5 locations
- (•) 5 – 10 locations
- 10 – 30 locations
- 30 – 50 locations
- More than 50 Branches

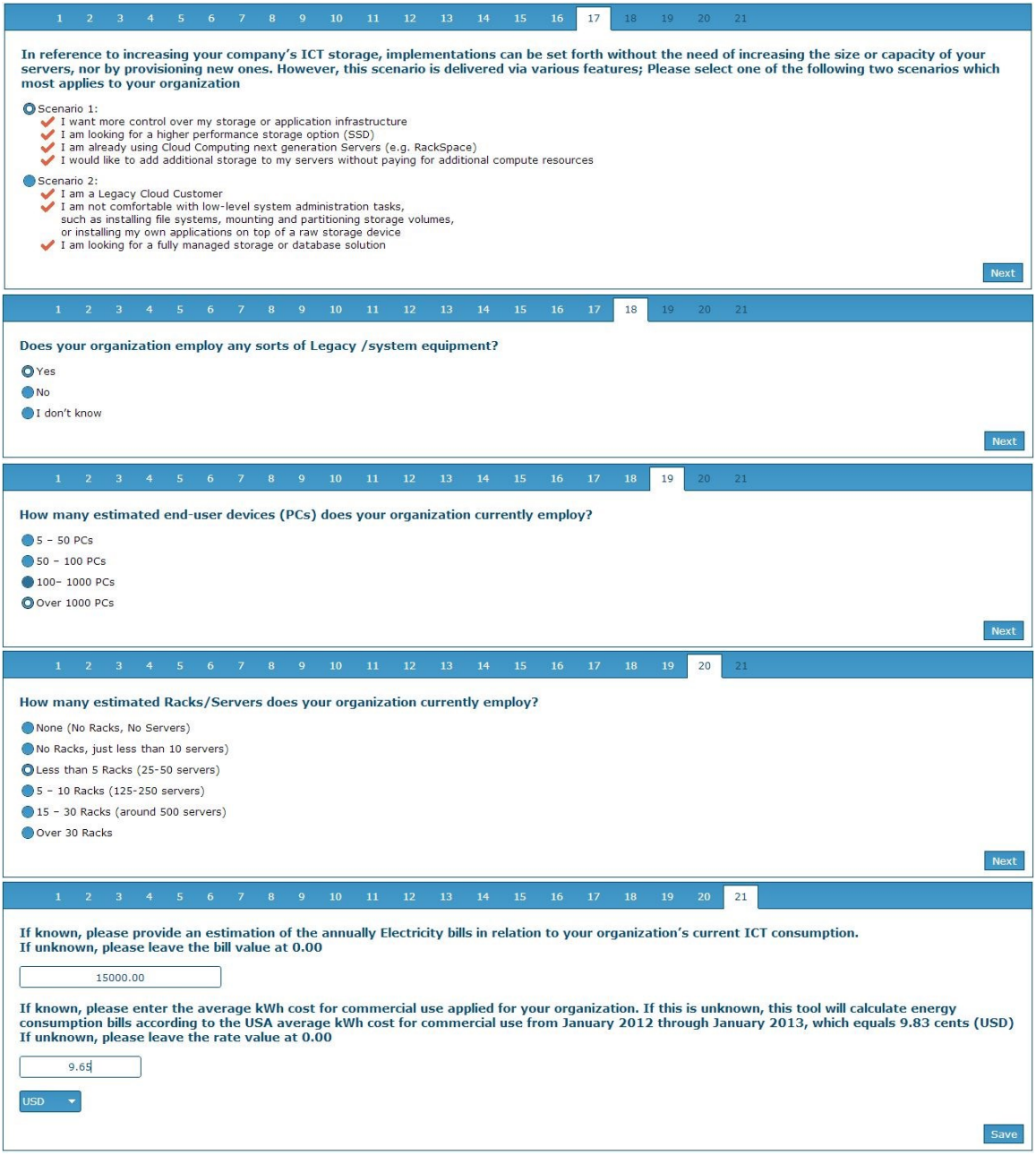
Next

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 **16** 17 18 19 20 21

Does your organization currently employ in-house ICT personnel? Please select one of the following.

- (•) In-house IT personnel (full time department)
- In-house IT personnel (part time minimum staff)
- External support and implementation
- No In-house IT personnel

Next



- **SBCE In-Depth Consultancy Option: Final Report Template**

HERIOT WATT UNIVERSITY **SBCE** Smart Building Cloud Evaluator

Home | Quick Value Estimation | In-Depth Analysis | Sign-in / My Account / My Evaluations | About SBCE

Cloud Computing Value Estimation Report for "Test Company" Page 1/2 Next: Quick Estimation Report

Report Date: 07-April-2015
User: Karim Mualla
Selected Evaluation Approach: 'In-Depth Analysis"
Powered by SBCE: Smart Building Cloud Evaluator

Introduction:

The following report is dynamically structured to assist your organization in simplifying the ICT decision-making process and providing insights on multiple management levels in terms of cost, sustainability aspects, and other management considerations.
In particular, as a result of selecting the In-Depth Analysis approach, a 5-year expenditure forecast report is generated below, in addition to associated scalability paradigms as been pre-selected earlier in reference to your organization's line of business. Moreover, this report weighs-in both advantages and limitations, while providing automated insights on Cloud Computing recommended deployment methods, architectural models and service criteria.
Depending on your previous answers, the following report was dynamically structured based on what SBCE has concluded to be the most appropriate Cloud Computing approaches, management recommendations, architectural and hosting methods, sustainability, as well other general considerations concerning risks, service expenses, and performance advantages. We recommend the following report to be acknowledged by your organization before any virtual deployment or a third party consultation is carried out.

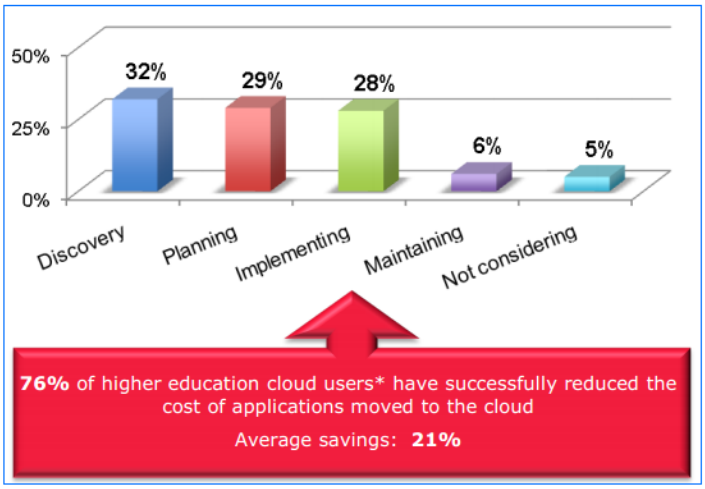
General Key Recommendations:

- **Terminology:** Your organization should pay close attention to the terms that are used in service agreements. Common terms may be redefined by a cloud provider in ways that are specific to that provider's offerings.
- **Remedies:** Unless you have negotiated a specific service agreement with the provider, remedies for any failures are likely to be extremely limited; your organization may wish to formulate and negotiate remedies that are commensurate with damage that might be sustained.
- **Compliance:** Your organization should carefully assess whether the service agreement specifies compliance with appropriate laws and regulations governing consumer data.
- **Security, Criticality, and Backup:** Your organization should carefully examine the service agreement for any disclaimers relating to security or critical processing, and should also search for any comment on whether the provider recommends independent backup of data stored in their cloud.
- **Negotiated Service Agreement:** If the terms of the default service agreement do not address your company's needs, you should discuss modifications of the service agreement with the provider prior to use.
- **Service Agreement Changes:** Be aware that, depending on the details of the service agreement, a provider may change the terms of service with a specified level of advance notice. Changes may affect both price and quality of service. It is prudent to develop a plan to migrate workloads to alternate cloud providers, or back on-premise, in the event that a change in service terms is unacceptable.

Below is a general breakdown of Cloud Computing Management -facts and statistics- regarding similar organizations to your company's work-nature, size, workload, number of employees and ICT components:

Current cloud adoption: 29% of education institutions have developed a written strategic plan for the adoption of cloud computing
Overall, where is your organization with cloud computing?
Cloud forecast: The average percentages of IT budget education institutions expect to spend on cloud computing in:
- Two years: 15%
- Five years: 24%

The average percentages of IT budget education institutions expect to save with cloud computing in:
- Two years: 12%
- Five years: 20%



If you are to use Software as a Service delivery model, please acknowledge the following:
In respect of Logs and Intrusion Detection within you company's ICT environment: The reality is that in SaaS, you will have no choice except to trust your Cloud provider to perform Intrusion Detection properly. Some providers give their users the option of getting some system logs and users can use custom application for monitoring those data, but in reality, most Intrusion Detection activities must be done by the provider and your organization can only report suspicious behavior for analysis.

If you are to use Platform as a Service delivery model, please acknowledge the following:
In respect of Logs and Intrusion Detection within you company's ICT environment: In PaaS, most of the Intrusion Detection activities must be done by the Cloud provider as the case in SaaS. However, if Intrusion Detection systems are outside your organization's application, you have no choice and must rely on the provider to implement IDS. But PaaS configuration is more flexible than SaaS, therefore, we recommend that you specifically request from the provider to be given the choice to configure the security parameters of platforms that log on to a centralized place. Thus, your users can incorporate Intrusion Detection performance accordingly.

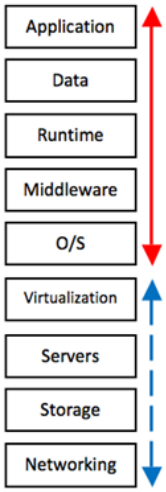
If you are to use Infrastructure as a Service delivery model, please acknowledge the following:
In respect of Logs and Intrusion Detection within you company's ICT environment: IaaS is the most flexible service for Intrusion Detection implementation. But the most important challenge in constructing a secure cloud-computing infrastructure is Transparency. Without it, your organization cannot know if the cloud provider meets significant security requirements or not. Moreover, you will not be able to properly design application architecture to mitigate any risks that may exist.

In relation to control over ICT resources, we recommend the IaaS(Infrastructure as a Service) as a Cloud Computing Service Model for your organization
Please be advised that this Cloud architectural model is most likely to be accompanied with Data Rough/Unwarranted User issues as will be further illustrated next.

End-User Managed ⟷

Provider Managed ⟷

With respect to your organization's demand for ICT resource availability on both a hardware and software service levels, we recommend you add a Managed Level of Service for support and maintenance in the Cloud instance selection tool which was previously highlighted. In addition please consider a Hybrid or Private Cloud hosting approach in order to gain further control over resources as will be illustrated further next.
With respect to your organization's demand for ICT resource availability on both a hardware and software service levels, we recommend specifying additional in-depth scalability paradigms which were presented earlier in the Cloud instance selection tool.



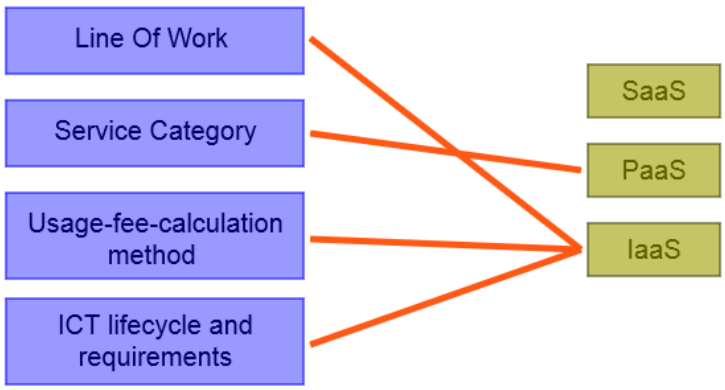
Given that your organization is currently employing (Public + SaaS (Software as a Service)) Cloud Services, this report was adjusted to meet those features and take into account any conflicts of deployment.

As an ICT consumer, in relation to the most relevant ***line of work*** to your company, we recommend adopting a **IaaS**

However, we have established that in respect of the ***service category*** which your company demands, we recommend combining Cloud services from both **IaaS** and **PaaS**

Moreover, regarding the ***usage-fee-calculation method*** which best fits your company's budget and work nature, we recommend using Cloud services from the **IaaS** Category Model

On the other hand, in terms of a future ***ICT lifecycle and requirements*** we recommend using Cloud services from the **IaaS** Category Model



This diagram shows the relationship between each recommended Cloud Computing Service Scenario.
This is dynamically illustrated in contrast to your organization's Line of work, Service category, Usage-fee methods, and ICT lifecycle

From a pure business perspective, we recommend following a **Hybrid Cloud Computing hosting solution**. Please note that The Hybrid model is a combination of Private and Public Clouds. Therefore, depending on the specification acquired with your Cloud provider, the following considerations must be taken into account from a Hybrid Cloud perspective:

- **Network dependency:** In the public scenario, your organization will connect to the provider via the public Internet. The dependability of connections thus depends on the Internet's infrastructure of Domain Name System (DNS) servers, the router infrastructure, and the inter-router links. The reliability of connections can thus be affected by misconfiguration or failure of these components as well as network congestion or attack. Additionally, your ICT infrastructure will require a connection via an Internet Service Provider, often designated the "last mile." This connection must also be functional for the Cloud to be accessible.

- **Workload locations are hidden from your company's users, and administrators and managers:** data centers (and hence workloads) can be located where costs are low. Generally, workloads in a public cloud may be relocated anywhere at any time unless the provider has offered (optional) location restriction policies and the consumer has configured their account to request specific location restrictions. The confidence that restrictions are actually enforced rests upon protection of your company's credentials (e.g., that the account has not been hijacked and had its location preferences changed).

- **Risks from multi-tenancy:** In a public cloud, a single machine may be shared by the workloads of any combination of consumers, which your company will take part off. In practice, this means that your organization's workload may be co-resident with the workloads of competitors or adversaries. This introduces both reliability and security risk. A failure could occur or an attack could be perpetrated by any consumer. Although this solution achieves low costs and elasticity;large scalings implies to a large collection of potential attackers.

- **Limited visibility and control over data regarding security:** With this approach, your organization do not have a guaranteed way to monitor or authorize access to the purchased/rented resources in the cloud. Although providers may make strong efforts to carry out the requests of consumers and some may provide monitoring services, as a manager, you must either trust that the provider is performing operations with fidelity or, if the provider has contracted with a third party auditing organization, trust that the auditing is accurate and timely. As an example of this limitation, a consumer cannot currently verify that data was completely deleted from a provider's systems.

- **Low up-front costs to migrate into the cloud**

- **Elasticity: illusion of unlimited resource availability:** With this approach, a solid multi-tenancy solution is provided without having your company limited by static security perimeters, which allows a potentially high degree of flexibility in the movement of your workloads to correspond with available resources. As a consequence, public clouds have unique advantages in achieving elasticity, or the illusion of unlimited resource availability.

- **Restrictive default service level agreements:** It must be taken into account that the default service level agreements of public clouds specify limited promises that providers make to subscribers, limit the remedies available to subscribers, and outline subscriber obligations in obtaining such remedies. This forms an ambiguity in terms of legal obligations of both of the provider regarding cloud system reliability, security, and so forth.

With respect to the application workload categories which are most relevant to your organization's line of work, we recommend you emphasize on the on-demand nature of cloud infrastructure. Whereas the On-demand self-service would assist your company in an Automotive provisioning of service without the need of a direct contact between your company and the service provider each time an adjustment is required (e.g. scaling up/down, turning off particular servers during weekends and so forth.

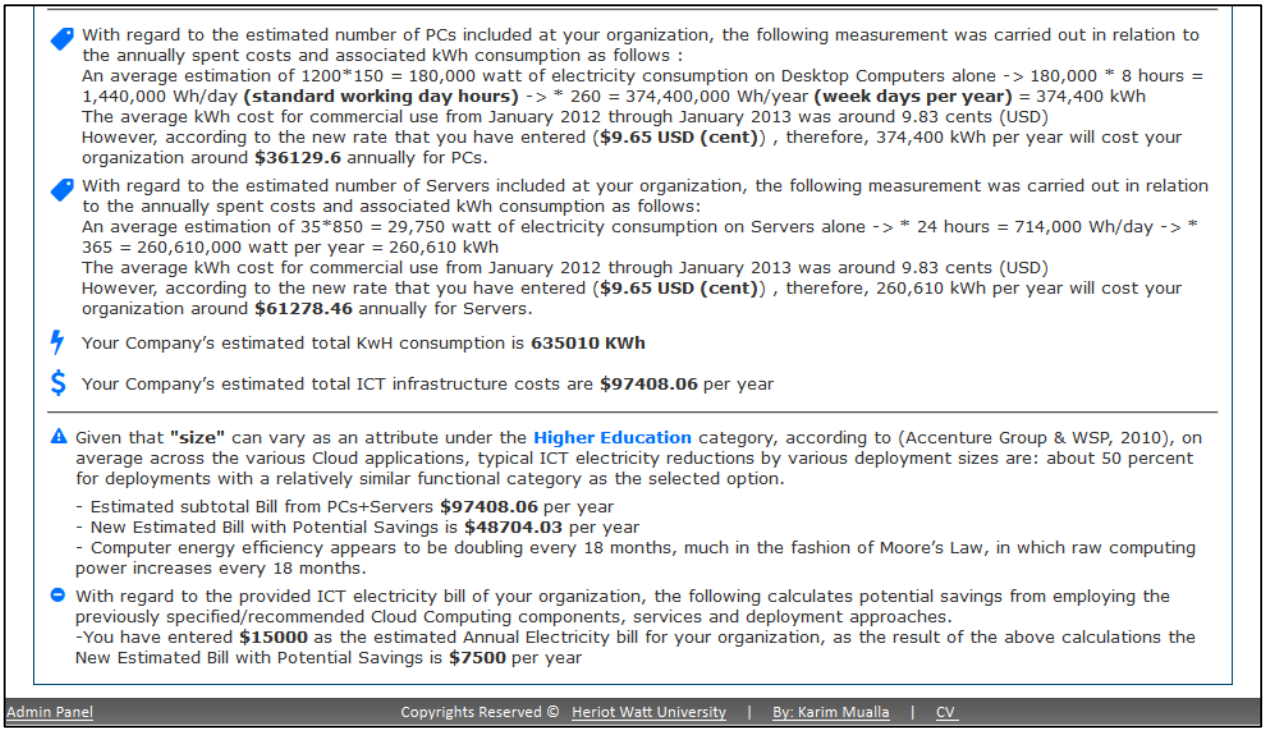
With regard to the application-characteristics which most applies to your organization's ICT lifecycle, we recommend adopting a Hybrid Cloud Solution as this requires High disk I/O and low latency, and most public clouds cannot guarantee this level of consistent low latency and performance.

In reference to your organization's number of locations , this tool has previously recommended in the Cloud instances selection that your organization employs More Bandwidth depending on the line of business and should consider CDN.
FYI: CDN is a Content Delivery Networks: Akamai's content delivery network (CDN) powers Cloud Files, delivering your data globally at blazing speeds

In reference to your organization's in-house ICT personnel status, this tool has previously recommended in the Cloud instances selection that your organization does not need to add Additional Managed Service

In reference to the ICT storage needed for your organization, it is strongly recommended to add Cloud Block Storage onto your virtual infrastructure.

With respect to potential legacy systems already in practice at your organization, please be advised that applications that require specific proprietary or legacy equipment are not likely worth moving to a cloud environment - either keep in house using virtual machines or do not integrate to any Cloud environment as this might be costly and difficult to manage in response to old system dependencies.


With regard to the estimated number of PCs included at your organization, the following measurement was carried out in relation to the annually spent costs and associated kWh consumption as follows :
An average estimation of 1200*150 = 180,000 watt of electricity consumption on Desktop Computers alone -> 180,000 * 8 hours = 1,440,000 Wh/day (standard working day hours) -> * 260 = 374,400,000 Wh/year (week days per year) = 374,400 kWh
The average kWh cost for commercial use from January 2012 through January 2013 was around 9.83 cents (USD)
However, according to the new rate that you have entered ($9.65 USD (cent)) , therefore, 374,400 kWh per year will cost your organization around $36129.6 annually for PCs.
With regard to the estimated number of Servers included at your organization, the following measurement was carried out in relation to the annually spent costs and associated kWh consumption as follows:
An average estimation of 35*850 = 29,750 watt of electricity consumption on Servers alone -> * 24 hours = 714,000 Wh/day -> * 365 = 260,610,000 watt per year = 260,610 kWh
The average kWh cost for commercial use from January 2012 through January 2013 was around 9.83 cents (USD)
However, according to the new rate that you have entered ($9.65 USD (cent)) , therefore, 260,610 kWh per year will cost your organization around $61278.46 annually for Servers.
Your Company's estimated total KwH consumption is 635010 KWh
Your Company's estimated total ICT infrastructure costs are $97408.06 per year
Given that "size" can vary as an attribute under the Higher Education category, according to (Accenture Group & WSP, 2010), on average across the various Cloud applications, typical ICT electricity reductions by various deployment sizes are: about 50 percent for deployments with a relatively similar functional category as the selected option.
- Estimated subtotal Bill from PCs+Servers $97408.06 per year
- New Estimated Bill with Potential Savings is $48704.03 per year
- Computer energy efficiency appears to be doubling every 18 months, much in the fashion of Moore's Law, in which raw computing power increases every 18 months.
With regard to the provided ICT electricity bill of your organization, the following calculates potential savings from employing the previously specified/recommended Cloud Computing components, services and deployment approaches.
-You have entered $15000 as the estimated Annual Electricity bill for your organization, as the result of the above calculations the New Estimated Bill with Potential Savings is $7500 per year
Admin Panel
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Appendix D - Heriot-Watt University Semi-Structure Interview Questions

Interview #3: Cloud Computing Service Requester: Heriot-Watt University Case Study
Interviewee: Mr. Mike Roch – Director of Information Systems (DIS), Heriot-Watt University Edinburgh, United Kingdom.

Questions:

1- Generally Speaking, how would you re-order the following ICT Management attributes for an interconnected set of facilities such as Heriot-Watt University campuses depending on degree of priority:
(Please assign a number to each 1 to 12) 1: the highest, to 12: the lowest
   - User Comfort
   - Safety & ICT Security
   - Public Compliance & Declaration Time
   - Cost Effectiveness
   - Building Management Adjustment Time & Effort
   - Reliability
   - Operating and Maintenance Costs
   - Initial Expenses
   - Service Life
   - Work Efficiency
   - Environmental Sustainability
   - Upgrades Time & Cost

2- What is the current Heriot-Watt University ICT management strategy, in terms of hosting, hardware purchasing, networking suppliers, end-user access, administration and maintenance?

3- Is Heriot-Watt University currently employing any sort of Virtualization in relation to ICT deployment, Application access, or Infrastructure utilization? In simple words,

4- In your personal opinion, which of the four deployment models (Hybrid, Private, Public and Community) would best suit the portfolio nature of Heriot-Watt University campuses?

5- In your personal opinion, which of the Three service oriented techniques (IaaS, PaaS, and SaaS) would best suit the end-user utilization of Heriot-Watt University in relation to type of applications employed, users and buildings'

requirements, networking bandwidth and hardware infrastructure (servers, integrated building equipment, switches, firewalls, etc)?

6- How would you re-order –depending on degree of importance- the following Cloud Computing characteristics, which were standardized by NIST (National Institute of Standards and Technology), in terms of Heriot-Watt University ICT peak reliance and service demands?

(Please assign a number to each 1 to 5) 1: the highest, to 5: the lowest

- On-demand self-service: Automotive provisioning of service without the need of a direct contact between Heriot-Watt University and the service provider each time an adjustment is required (e.g. scaling up/down, turning off particular servers during weekends and so forth).
- Broad network access: Heriot-Watt University end-users will access each service, virtual machine, networking device, or development platform via an online-based network which supports both thin and thick clients.
- Resource pooling: Applying a multi-tenant architectural mode by the service provider, whereby numerous consumers are sharing same services from an unknown shared pool of dynamically accessed, released, assigned and reassigned recourses.
- Rapid elasticity: Enabling rapid service scalability (up/down), depending on Heriot-Watt University periods of peak workload, number of users, and bandwidth demands.
- Measured service: Applying a metering approach of billing relatively similar to water and electricity bills for any Smart Building. This optimizes recourse utilization, thus, providing an additional transparent layer of controlling suitable types of ICT components specifically required for Heriot-Watt University buildings around different locations.

7- To what extent would you rate the feasibility degree in respect of outsourcing the entire Heriot-Watt University buildings' equipments into the Cloud -already integrated into information systems, (e.g. meters, HVAC equipments, CCTVs, etc)- for off-premises management, servers' hosting, automatic upgrades, license purchasing, on-demand bandwidth, on-demand virtual machines according to peak times, and so on?

8- From an end-user Risk-Analysis perspective, how would you rank the following limitations/threats towards employing virtual techniques of Cloud Computing, whether to outsource a partial or an entire scope of the Heriot-Watt University ICT platform? (This includes IT support personnel, external contracts and so on)

(1 to 10) 1: being a low concern, 10: extremely concerned

- General Security for critical Data records (Student records, Staff employment info, Exam questions, Budgets, etc)
- Replacing on-site IT personnel with a third party management provider, which could be challenging in terms of response time, rapid delivery, scalability of deliveries and so on.
- Data storage confidentiality and authentication integrity in reference to virtual networking and communication methods as a result of unspecified hosting whereabouts, shared systems with unknown number of users, and number of virtual machines employed for delivering a single service.
- Unpredictable Performance with respect to online connectivity and various networking factors
- Availability rates in terms of urgent support, contingency actions in case of an offline situation, and change of permissions.
- Worrying towards an unstandardized access of information from multiple of site parties due to lack of interoperability standards
- Difficulties towards integrating with costly in-house legacy systems (system compatibility challenges), which are currently working fine and no actual need for Cloud migration.
- The self-service, pay-as-you-go model will cost Heriot-Watt University more than conventional in-house deployment and support.
- The annually, monthly, or instant-utilization billing nature of Cloud Computing services, regardless of IaaS, SaaS, or PaaS employment, is still unreliable due to lack of detailed measurements, and solid contract specifications before any virtual deployment or purchase.
- Other limitations related to system roll-back difficulties, lack of system customization, and acquiring the key disadvantage of a full system breakdown in case of Cloud failure. This would result given that this solution will integrate the entire Heriot-Watt University portfolios into a single virtual system regardless of multiple back-ups also installed on virtual machines; a complete halt of systems is a subject of occurrence.

9- Does Heriot-Watt University currently acknowledge the energy saving awareness and ‘Green’ pillar in applying virtualization to ICT utilization? or is this currently not an issue given that information and communication systems are not as power consuming as other major Smart Building factors such as HVAC devices, water meters, renewable energy sites and so on?

The second part of this interview will request Data estimates from Heriot-Watt University with regard to selected ICT domains as clarified in the following table. However, this can be provided either by:
-Filling in the following table
-Or by simply sending through (provide access) to ICT university reports, charts, actual previous bills, ICT/energy studies, reports, or any publications in that respect.

Please Provide estimated Data for the following:	Values & Comments
IT Electricity Costs (monthly/ annually Bills)	
ICT Electricity Consumption (monthly/ annually Bills)	
Energy Bills for the entire Heriot-Watt University portfolio (monthly/ annually Bills)	
Total Average on Cooling and Related Power Resources	
Power Usage Effectiveness (PUE): e.g. for every 500 kW of IT System-load (If available)	
Carbon Trust (e.g. for UK office PCs 10 million Computers consuming 15% of each facility's total energy (on an increasing average of 30% by 2020) (If available)	
Number of Heriot-Watt University ICT Users (Staff / Student)	
Number of IT personnel (networking administrators, system specialists, in-house developers, etc)	
Average Salary of a Heriot-Watt University IT personnel	
Storage capacity average (per server)	
CPU power average (per server)	
Watts per Server	
Abstract Cost for each Server	
Networking Bandwidth (Traffic) average	
Networking and end-user operating systems employed (Linux / Windows)	
Type of licensing purchase and renewability (OS & applications)	
Types/Names/Number/Costs of specifically purchased software (students, project management, planning, staff, etc.) (e.g. SQL servers, Oracle, Accounting, student virtual examination)	
Overall costs of externally assigned ICT support providers (Annually/Monthly)	
Server Memory (RAM) (Range from 512MB to 30GB)	

Outgoing bandwidth (Number in GB)	
Cost of Internet (Annually/Monthly/Contract)	
Heriot-Watt University overall floor space (Sq/ft)	
Number of VMware installed (if there were any)	
Cooling, HVAC and other associated power consuming costs (Annually/Monthly)	
Costs for cabling infrastructure and support	
Average number of occurrences in relation to ICT alarming/contingency issues (per year)	
Types of ICT alarming/contingency issues (per year)	
Average Time/Cost of recourses for resolving alarming/contingency ICT issues	
Average number/Cost of a full system upgrade (networking operating systems, PCs operating systems, specifically purchased applications, firewalls, etc.)	
Average number/Cost of a full Hardware upgrade (networking devices, routers, switches, servers, PCs, CPUs, firewalls, etc.)	
Average number of networking Bottle-neck (per year or less)	
Average number of Offline incident occurrences (per year or less)	

Appendix E – Publications of the Author

- Mualla, Karim. Pender, Gareth. Jenkins, David. (2016). 'Standardizing Sustainability Benefits of Cloud Computing for Non-Expert Decision-Makers'. International Journal of Digital Information and Wireless Communications (IJDIWC): Vol 6, Issue 2. Page Numbers: 139-152

- Mualla, Karim. Jenkins, David. (2015). 'Evaluating Cloud Computing Management Challenges for Non-Expert Clients'. Proceedings of the Second International Conference on Data Mining, Internet Computing, and Big Data, Reduit, Mauritius 2015.

- Mualla, Karim. Jenkins, David. (2015). 'Evaluating Cloud Computing Challenges for Non-Expert Decision-Makers'. International Journal of Digital Information and Wireless Communications (IJDIWC): Vol 5, Issue 4. Page Numbers: 285-296