A FRAMEWORK FOR BENCHMARKING ENERGY RETROFIT SYSTEMS

THROUGH BUILDING INFORMATION MODELING (BIM)

by

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Dedication

I dedicated this Thesis to my beloved parents, I hope this achievement will make you proud of me and may GOD bless both of you...

Abstract

The rapid increase in worldwide energy consumption has raised a global concern about the future of energy use and its impact on the surrounding environment. Such impact is causing resource degradation, increased carbon emissions, depletion of the ozone layer, and global warming. As the building sector is considered one of the main energy-consuming sectors, the trend of sustainable designs, green projects, energy optimization and reduction policies are many countries' recent focus. This focus is typically on new buildings, and it constantly overlooks the vast impact of existing buildings. Efficient energy retrofitting of existing buildings, therefore, is highly needed to mitigate the impact on the surrounding environment, due to the excess use of energy. This research presents a framework for benchmarking energy retrofit systems of office buildings in climate zone 1 (very hot humid regions), by integrating building information modeling (BIM) and laser scanning. The reason for considering existing office buildings is related to the great benefits of retrofitting and the ability to efficiently analyze the main energy consuming systems, which are office equipment, lighting, and heating ventilation and air conditioning (HVAC) systems. The proposed non-destructive methodology will assist in providing an estimate of the amount of possible energy use reduction, and the likelihood of achieving standard and sustainable conditions. The analysis of separate and overall energy consumptions for each of the systems will be investigated through a developed benchmarking tool. The tool will analyze each of the systems' existing performance and benchmark this performance to an enhanced condition. The integration of laser scanning and BIM will provide an accurate measure of the building's existing condition and will provide the required data input for analysis in the developed tool. In addition, the benchmarking tool analysis for an office building energy system in the UAE will illustrate the proposed procedure and analytical process. The results of the investigative framework show that the examined office floor can reduce its total energy consumption according to standard and sustainable conditions by almost 14% and 29%, respectively. Also, the energy end use breakdown was found to be 55% for the HVAC system, 23% for lighting, and 17% for office equipment.

Search Terms: Energy retrofit; Existing buildings; BIM; Benchmarking tool; Retrofitting management; Office buildings, Laser scanning, Retrofitting framework.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AEC	Architecture, Engineering and Construction
AEDG	Advanced Engineering Design Guide
ASHRAE	American Society of Heating, Refrigerating, & Air Conditioning Engineers
AUPC	Abu Dhabi Urban Planning Council
BIM	Building Information Modeling
BOP	Building Performance Optimization
BPIE	Buildings Performance Institute Europe
BPS	Building Performance Simulation
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Methodology
CBECS	Commercial Building Energy Consumption
COP	Coefficient of Performance
DGNB	German Sustainable Building Council
DSF	Double-Skin Façade
ECG	Energy Consumption Guide
EEM	Energy Efficiency Measures
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EPBD	Energy Performance of Buildings Directive
HVAC	Heating, Ventilation, and Air Conditioning
IEA	International Energy Agency
IES	Integrated Environmental Solution
IR	Infrared
STA	Stabilization Strategy
FM	Facility Management
SUB	Substitution Strategy
VE	Virtual Environment
LC	Life Cycle
LEED	Leadership in Energy and Environmental Design
LPD	Lighting Power Density
LSD	Line Segment Detector
NREL	National Renewable Energy Laboratory
NZEB	Nearly Zero Energy Buildings
U-Value	Coefficient of Thermal Conductivity

Chapter 1: Introduction

1.1 Background

Green project designs and implementation of sustainable theories fall under the ability of the individual, company or society to deliver projects according to an efficient set of standards. Those standards are established based on research, studies, experimental results, codes, and regulations of a specific climate region and country's desired outcomes. Examples of such standards are ASHRAE, Part L, EIA, ESTIDAMA, ACE, EEM, IECC, AEDG, and LEED. Unfortunately, the acceptance of green and sustainable concepts into construction projects was implemented late and introduced as a law for delivering projects in some countries. While countries have reached huge developments in the area of construction, only a small percentage of construction projects either under construction or constructed in the past 8 years are considered as green projects [1]. Existing buildings (residential, commercial, and industrial) constructed before the implementation of green sustainable designs are in the majority of countries conditions.

Existing buildings with their existing conditions have vast environmental, financial, and social impacts on the society, building owners, and surrounding environment. According to the U.S. Energy Information Administration, existing buildings that are 18 years and older make up more than 70% of the built environment by square footage [2]. The need to assess existing buildings' performance is one of the indicators of the as-built condition of the building. Existing buildings' energy consumption is almost 1.5 to 2 times the amount of energy consumption of new buildings with similar characteristics [2]. The frightening increase in energy consumption of existing buildings has raised concerns for the need to efficiently investigate the best applicable interventions. As a result, energy retrofitting through as-built condition enhancement is the current field of research and the industry focus.

Retrofitting existing buildings is the process of upgrading the building components and performance to be more efficient, cost-saving, and environmentally friendly. The process aims are to prevent demolishing the building because of its impacts and to extend the building's life span. Although there are different types of existing buildings, refurbishment of the building's equipment, lighting systems, and building envelope achieves the desired performance and reduction outcomes [3].

Specifically, existing office buildings are considered one of the major types of commercial buildings, where the consumption of equipment, lighting, and HVAC is estimated to be 85% - 90% of the total energy demands [4].

There are no set standards or procedures for retrofitting existing buildings, as each building has its unique properties that differentiate its condition and systems from one building to another. In addition, the availability of as-built information 15 or more years old, if found, does not reflect the existing condition of the building. The amount of uncertainties and challenges that face the retrofitting operations make it difficult to generalize a method that addresses all types of buildings. Instead, by defining the major building characteristics, utilizing advanced technology, using normative assumptions and current building standards in refurbishment analysis and documentation, the ability to benchmark buildings' energy performance can help in supporting intervention decision making. The use of energy benchmarking tools is considered a great asset that overcomes common uncertainties and challenges.

The great benefits achieved in implementing advanced technologies in the construction of new and complex projects have illustrated the need to investigate such technologies in the area of retrofitting existing buildings. The introduction of Building Information Modeling (BIM) in areas of design, management, supervision and coordination has driven the force to integrate such development in existing buildings. Building information modeling consists of a smart 3D virtual model in which all project information, materials, specifications, standards and requirements are included in a virtual-to-reality clash-free model. In addition, BIM is an open data platform which enables integration between multiple software packages for different analysis reasons. BIM models are dependent on the information added through modeling from 2D blueprints and existing information. In the case of missing or inaccurate information of existing buildings, the introduction of laser scanning has filled this gap by accurately capturing the existing geometry information and the as-built condition of the building. Thus, through the integration of BIM and laser scanning, great benefits can result in order to facilitate the process of energy retrofitting of existing buildings.

Energy benchmarking is defined as the process of associating existing energy performance to an enhanced condition based on achievable standards and outcomes [5]. Benchmark results are a significant source of information that provides support to decision making and uncertainties provision. The benchmark analysis results are the

main preliminary information that defines the best intervention procedure, expected outcomes, and required retrofitting elements [5].

1. 2 Problem Definition

The energy consumption of existing buildings has been increasing rapidly in the past few years, causing a global alert of the impact of this increase. As existing buildings are in the majority, buildings that are 15 years and older are causing almost twice the consumption of energy and are having an adverse impact. These issues have raised concerns for energy retrofitting of existing buildings in order to enhance the as-built condition and reduce the consumed energy. Energy retrofitting of existing buildings consists of a multi-analysis approach to determine the best intervention to be applied, yet there are no standard frameworks of implementing the refurbishment process. The procedure of retrofitting existing buildings is done based on the common practices followed for rehabilitating building components; however, the performance of existing buildings does not only depend on components, but also on the overall condition and performance of the systems. In office buildings, 98% of the energy consumption is caused by office equipment, lighting, and HVAC systems, where in climate zone 1, office buildings' cooling energy accounts for more than two thirds of the total consumption [3]. The unavailable information of the as-built and current condition of the building diminishes the ability to determine whether the energy consumption is efficient or not, as the only available information is the building's utility bills. Moreover, the difficulty of making accurate decisions and estimating potential outcomes is due to the lack of advanced benchmarking tools that consider the existing condition and analyze the effect of the systems' performance on the overall consumption.

In summary, energy retrofitting of existing buildings promises huge benefits if applied successfully by following an organized approach and efficient energy analysis. Moreover, due to the lack of benchmarked data on retrofitting projects' performance and results, the ability to make accurate decisions and estimate potential outcomes for similar projects are limiting the adaption of energy intervention.

1.3 Objectives

The main objective of this thesis is to develop a framework for benchmarking energy retrofit systems through building information modeling (BIM) for existing

office buildings in climate zone 1. The framework can be used as a non-destructive analysis that approximates the amount of possible energy use enhancement that can be achieved based on the existing condition of the building.

The detailed objectives are:

1. Utilize laser scanning for capturing building geometry and existing conditions.
2. Develop an as-built BIM model for the existing condition which can allow future building analyses and performance control studies.
3. Create a benchmarking analysis tool.
4. Develop a procedure for energy retrofitting of office buildings in zone 1.
5. Analyze an office building according to the developed framework.

Deliverables:

- Frameworks to assist in benchmarking energy retrofit systems through BIM for zone 1 office buildings.
- Energy benchmarking tool.
- UAE office building energy Benchmark results.

1.4 Literature Review

The literature review in this research provides an overall knowledge of the main aspects of the study on existing buildings, while information related to new buildings is also included to illustrate a wider base of knowledge for the main topics. The main topics are sustainability in buildings and designs, benchmarking of building performance, building information modeling and the integration of laser scanning, office buildings' energy consumption, retrofitting of office buildings, buildings' rating systems, and green construction and performance optimization. In addition, examples of the performed projects for some of the main topics are summarized in order to demonstrate their applicability in real life.

1.5 Research Significance

Energy retrofitting of existing buildings revolves mainly around the ability to successfully rehabilitate the building and upgrade its performance with minimal impact and an extended life span. Financial impacts of retrofitting include cost-savings, while environmental impacts include reduction in energy consumption, emissions, and use of resources. As for social impacts, retrofitting the building will

maintain its social value and avoid its demolishment. Over decades, the idea of retrofitting buildings was not taken into consideration, as the trend was more focused on developing and constructing new projects. Recently, the market and the construction industry are more focused towards rehabilitating existing buildings, and this is due to all of the advantages that can be achieved from implementing such a process. The main challenges faced in retrofitting are the availability of documents and information that represent the as-built current condition of the building, as well as the availability of efficient benchmarking tools to analyze the building's energy performance.

Although technological developments in the construction industry, especially on new projects, have reached a high level of detail and propose effective and accurate analyses of alternatives studies, the use of this technology on existing projects is taken into serious consideration. Such technologies are the implementation of BIM models, the integration of different software platforms, and the application of laser scanning, working in 3D environments, and point cloud sensors. The current retrofitting procedures are not based on set standards and the use of integrated technologies. Thus, the significance of proposing a framework for benchmarking energy retrofit systems through BIM lies in achieving greater benefits, overcoming regular retrofitting challenges, and allowing the use of integrated technologies for better outcomes.

1.6 Research Methodology

This research delivers a framework for benchmarking energy retrofit systems through Building Information Modeling (BIM) for existing office buildings in climate zone 1. The framework provides an organized approach with a benchmarking tool for analyzing possible energy reductions according to standard and sustainable conditions. In addition, the methodology integrates BIM and laser scanning to capture the as-built condition of the existing building and to allow analysis of alternatives and visualization of the proposed retrofitting decisions by the user. The implementation of energy retrofitting analysis by the proposed approach generates an as-built benchmarked BIM model, where all data required for performing the energy current or future retrofit can be available. In order to illustrate the workflow of the proposed framework, an analytical framework on an existing office floor in the UAE will be

examined. The following stages explain the work of developing the proposed framework.

1.6.1 Stage one: initial work.

In this stage, the main work was focused on selecting the proposed topic, setting the objectives to be done, and carrying out an extensive literature review about the chosen topic. The investigation included a review of previous work in journals, articles, research, proposed ideas, market reports, conference papers, books, and achieved projects. This was in order to ensure that the topic was new and that we made significant contributions to it. After carrying out the extended literature review, the topic was formulated in a way to ease the process of estimating the potential reductions in energy by retrofitting climate zone 1 office buildings.

1.6.2 Stage two: framework development.

This stage consisted of analyzing each part of the proposed topic: benchmarking retrofitting, energy systems, and the integration of BIM and laser scanning for existing office buildings. Each part has different elements and components that need to be set and studied separately to produce an efficient system that combines all the required aspects for retrofitting a climate zone 1 office building. The whole framework is attached in Appendix A.

1.6.3 Stage three: development of benchmarking tool.

A benchmarking tool will be developed in order to allow the analysis of possible interventions and estimate the reduction in energy use. The developed tool will allow users to perform retrofitting analysis for office buildings in climate zone 1, where it integrates the data results from laser scanning, BIM integration, and the standard and sustainable requirements. The benchmarking tool is attached in Appendix B.

1.6.4 Stage four: analytical framework of an office building in the UAE.

Once stage three is finalized, an office building in the UAE (climate zone 1) will be examined according to the developed framework and benchmarking tool, which will contain detailed calculations for cooling, lighting, and office equipment energy consumptions. The analysis of the office will be based on existing conditions

inferred from utility bills and used the as-built condition, standard requirements from ASHRAE and UAE standard regulation, and sustainable conditions for best performance practices according to sustainable references in the country. The results of the case study will be validated and presented as possible percentages of energy use reduction. Also, the resulting energy end use breakdown can be used as a reference for future retrofitting projects.

1.7 Thesis Organization

Chapter 2 will consist of a literature review. Chapter 3 contains the detailed research methodology followed to develop the whole framework. Chapter 4 verifies the applicability of the proposed framework by accompanying analytical framework study. Finally, Chapter 5 will conclude the study and provide future recommendations.

Chapter 2: Literature Review

2.1 Green Buildings Design, Construction, and Optimization

Following the green trend and sustainable developments in the architecture, engineering, and construction (AEC) industries, building design is obligated to follow mandatory rules, codes, standards, and regulations to optimize building performance into net zero energy buildings (NZEBs) [6]. As the number of energy use reducing measures is increasing in development projects and research nowadays, green and sustainable building performance objectives will change the way buildings are designed and operated [6]. Although evaluating different design options will be a strenuous approach, the results of this approach will lead to achieving the best suitable solution into NZEB. In 2008, the European Union Energy Performance of Buildings Directive requires all buildings to be nearly zero energy buildings by 2020, including ongoing rehabilitation operations on existing buildings [7].

According to literature, one of the most effective methods into NZEB design is by optimizing the combination of the building and its systems, rather than optimizing each as a separate level [8]. Another suggested approach is to evaluate different design options by integrating automated mathematical building performance optimization (BOP) with building performance simulation (BPS) to achieve best design solutions [9]. Such solutions include lowest life cycle cost, greatest thermal comfort, and lowest capital cost. The purpose of automated BPO is to select the best design alternatives or control problems that lie under specific performance criteria or mathematical functions, which define the set objective of performance optimization. This objective might be either to minimize or maximize a certain performance, or it can combine both to whole-system performance. In addition, the integration of BPO with visualization techniques adds great benefits in terms of helping the extraction of information related to performance trade-offs, the understanding of uncertainties, the analysis of sensitivity, and the possibility of designer interaction in the optimization procedure [9].

The implementation of building performance optimization has better value in the early design stage. Nevertheless, optimization can be also useful in the late design stage, during which the selection of control strategies, building operation procedures, and mechanical (HVAC) system design is finalized. This selection can be through

building control based on mixed-model or predictive model control practices [10].

In 2005, the National Renewable Energy Laboratory (NREL) in the United States developed different optimization models to evaluate energy usage and the potential cost-savings for constructing efficient net zero energy homes [11]. In addition, the European Commission in 2011 issued a rule for all building design to state the minimum energy performance following EPBD framework standards. This framework was created to ensure that building design has the best cost level of energy use [12]. The main problems that lie in optimizing the building performance procedure are due to the different design variables, and the unique, constrained, and nonlinear characteristics of the building and its systems. There are different methods for optimizing building performance, and each of these methods depends on different information and analysis elements [12]. These methods are applied algorithms that depend on the characteristics of optimization operations and current and future optimization needs. Such algorithms include enumerative, deterministic, stochastic, genetic, and evolutionary algorithms.

Applying effective energy measures and optimizing the building and its components' performance during the design stage has an impact on the economic value of the building. The main objective of introducing energy policies is to ensure that all parties involved in the building are interested and benefit from having high energy efficiency. Those benefits do not specifically serve one category, as the returns of applying such a procedure benefit the owners, government, society, environment, and building occupants. According to Popescu et al., One of the most significant barriers in applying those policies is to evaluate the potential financial savings, which, on their own, do not encourage investment [13]. Thus a large number of market researchers are quantifying the added value to the energy efficient properties. As a result, the payback period of the energy efficient investment in buildings depends on two factors: the potential of financial savings and the amount of added value to the facility.

A method that incorporates the yearly increase and decrease in the value of the building according to the differences in the market transaction prices was developed to capture the financial analysis of the cost of energy savings [14]. The author's method will help in estimating the property added value of energy efficient buildings in a specific market, and the payback period inverse relationship with the properties'

prices (a decrease in the payback period when the properties' prices increase and vice versa).

According to a study conducted by Pivo and Fisher (2009) on the investment return in responsible (green) facilities in the United States, green buildings have increased residents' net income by 5.9%, decreased utility expenses by 9.8%, increased the market value of the property by 13.5%, and caused a rise of 4.8% in the rental cost of the property [15]. Also, the authors illustrates on the benefits of implementing green home designs in terms of savings, showing that greenhouses save around 10-20% of the maintenance and operation costs compared to non-green houses.

The exploration of optimizing control systems for window operations using energy plus software in mixed mode buildings has been done through different predictive control model methods [10]. The first study, done on an office building in Colorado resulted in a potential savings of 40%. This savings was from the cooling energy which was based on using night cooling techniques to reduce day cooling energy used. Depending on the weather and climate conditions in Colorado, night cooling is also controlled by a heating unit in case the temperature becomes too cold. In addition, to be able to imitate the characteristics of the resulting optimization analysis, a generalized linear model (GLM) in the form of multilogistic regression was developed and introduced in the systems to enable energy saving optimization to reach 70-90% [10]. Also, the implementation of this system will allow the integration of a decision model into any digital control system developed for mixed mode buildings and act as a predictor variable to save the work when the information reading process is lagging. The focus on mixed mode buildings is due to the effective potential controls that can result in energy and cost savings from space conditioning by integrating a mix of natural ventilation and mechanical systems without compromising occupants' comfort [16]. The purpose of controlling strategies for mixed mode buildings is to determine to what extent the replacement and reduction in mechanical systems can be achieved by natural ventilation.

Optimizing building component designs and alternative operating systems is the main procedure for delivering a green building with high cost and energy savings. The main energy systems that should be considered to be optimized are heating, ventilation, air-conditioning (HVAC); lighting; security; elevators and escalators; and fire detection and abatement systems [17]. According to the authors, the reason for

optimizing those systems is to improve energy efficiency and to decrease energy demand, as well as to demonstrate the economic values of optimization and the related issues of implementing the control methods [17]. In HVAC systems, the main energy consumed is for maintaining the indoor temperature, humidity, and the quality of air. Although the aim of optimization is to reach maximum energy and cost savings, there are many constraints in the overall process. Hence, due to those constraints the process should be developed through a bottom up procedure [17]. The authors used two control methods to optimize energy use. The first method focused on vapor-compression cycle systems which account for a huge amount of the total cost of the used energy. In this method a model-predictive control strategy was implemented to improve tracking and disturbance rejection while introducing the system constraints to capture overall performance. The second control method was developed to assess how to decrease the cost of energy used for electricity during peak-demand times. The reduction in demand was formulated as an economic model-predictive control problem [17], which was applicable for the unsteady usage rate and the dynamic change in electricity prices. Implementing the authors' proposed methodology and by using the predictive control algorithm developed, the cost of electricity usage can be minimized significantly. In addition, the minimum and maximum optimization issue was transformed into a linear program to ease the process and assume controlling variables. Both of the methods introduced to minimize the energy used and maximize cost savings were presented to show a promising way to optimize the energy efficiency of buildings through smart integration and predictive control models [17].

2.1.1 Green building standards and rating systems.

With the increased social, environmental, and financial impacts of the building sector, the number of sustainable ratings, standards, and assessment approaches has increased over the last 10 years. Although there are many standards and rating systems in the different countries, the leading sustainable metrics are: LEED, BREEAM, DGNB, and Estidama (used in Abu Dhabi, Al-Ain, and the Western Region of the UAE).

BREEAM (Building Research Establishment's Environmental Assessment Method) was developed by the U.K.'s Building Research Establishment (BRE) in 1995, and is one of the first building rating methods to be designed. BREEAM

principles are sustainable solutions for energy, materials, ecology, pollution, waste, water, and transport. BREEAM version 2008 is only applicable to office buildings, and version 2011 is for new construction. There are a variety of BREEAM versions applicable to different regions, for example BREEAM GCC, BREEAM Hong Kong, BREEAM Canada, and BREEAM International. The certification process involves first registering the project, then data has to be collected, and the assessor will calculate the rating and the overall scope. This process is illustrated in Figure 1 [18].

Figure 1: BREEAM certification process [18]

LEED, on the other hand, focuses on sustainable site, water efficiency, renewable resources, streamlined indoor environment, and innovation. LEED was created in the USA by the Green Buildings Council in 1998, and since that there have been different versions used around the world in Canada, Spain, China, and India. It can be stated that LEED and BREEAM are considered as the fundamental points for every new rating system. The process model is shown in Figure 2 [19].

Figure 2: LEED certification process [19]

Estidama is an energy ratting tool developed by the Abu Dhabi government, and it is the first rating method developed in the Middle East. Estidama means sustainability in Arabic and was developed in 2008 by the Abu Dhabi Urban Planning Council [20]. The development of Estidama is associated with the pearl green building rating system, which sets green rules and regulations that need to be followed in buildings design, construction and operation. There are seven different principals which have to be considered: natural system, livable building, precious water, energy, materials, innovative practices, and integrating development processes. Those categories cover different aspects of the building and community. The government of Abu Dhabi set Estidama as a mandatory rule for new building construction and at least a 1 or 2 pearl rating must be achieved [20]. Figure 3 illustrates the Estidama process.
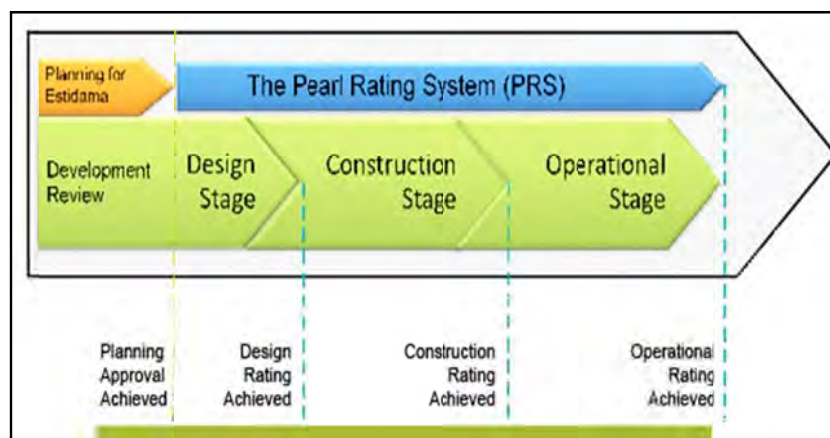
Figure 3: Estidama process [20]

The DGNB method was designed by the German Sustainable Building Council (DGNB – Deutsche Gesellschaft für Nachhaltiges Bauen e.V.) in 2007 by 16 initiators from various subject areas within the construction and real-estate sectors. One year later, around 121 organizations were assigned to the DGNB, and today more than 1,100 members around the world are working to develop and improve the system [21]. The green concept of the DGNB system is based on: environmental, economic, sociocultural, and functional aspects; technology; and the site. The analysis is based on the life cycle of the overall performance of a building or urban district [21]. Figure 4 shows the DGNB process.
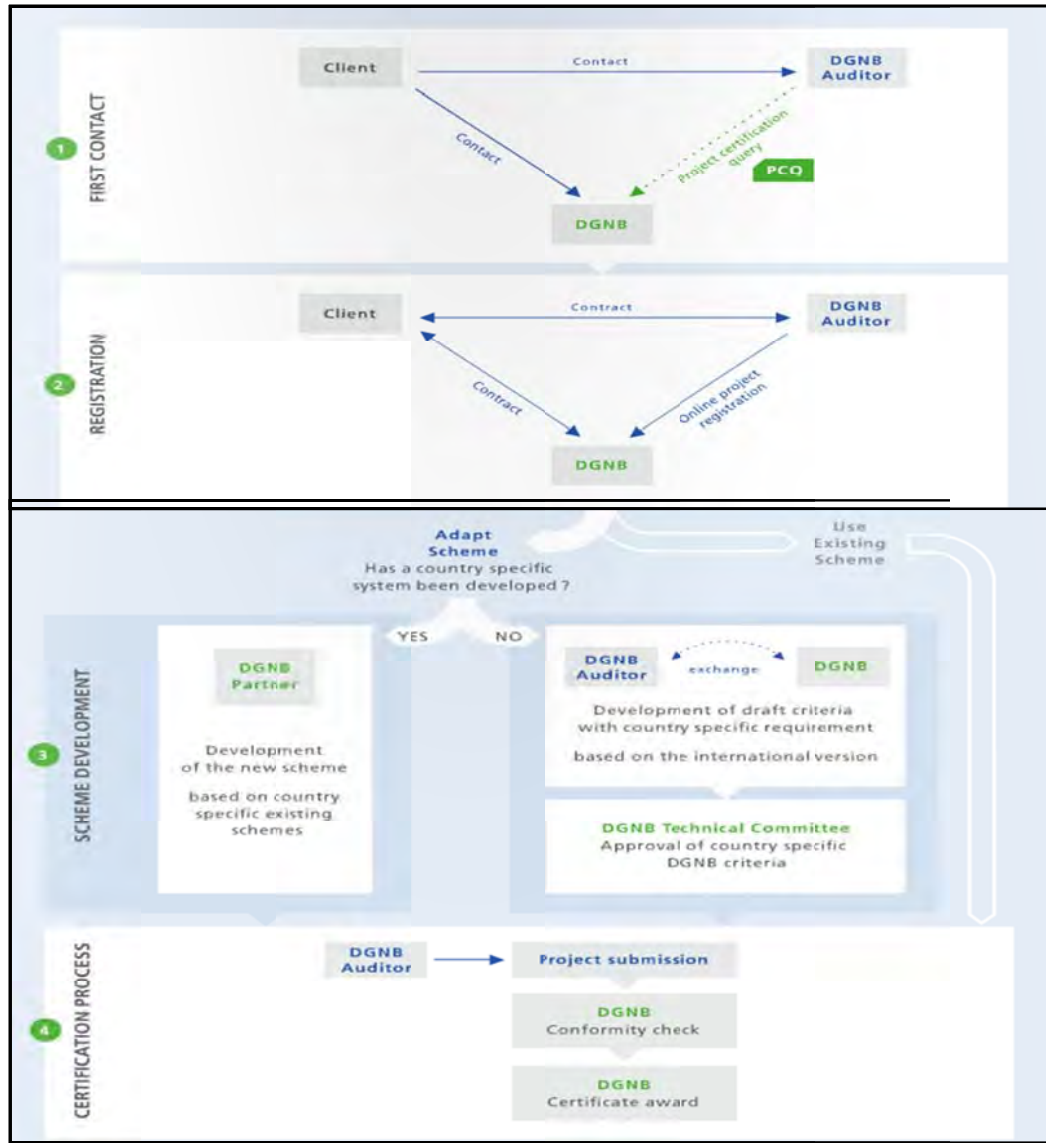
Figure 4: DGNB process [21]

2.2 Retrofitting Standards and the Need for Strategy Development

Existing buildings were constructed in a time when energy and water were less expensive and less consideration was taken into their consumption; in addition, the environmental pollution of those buildings and their effect on their surroundings have been a major issue recently in most countries. Older, existing buildings generally use significantly more energy and water than new buildings of the same size and function [22]. According to the institute for building efficiency, existing buildings that are 18 years and older make up more than 70% of the built environment by square footage, which offers great opportunities to conserve them into better, healthier and more productive work environments [22].

The Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding in 2008 have discussed the use and benefits of applying the Guiding Principle, to develop a multi-step process for converting existing buildings into high performance sustainable buildings. The process includes reviewing more than 30 different environmental performance aspects that integrate and coordinate the effort of facility managers, facility operations, maintenance contractors, technical experts and project managers to advance the energy efficiency of the building, decrease the use of water, improve management of storm water, enhance indoor air quality, and standardize and document maintenance green operations. The federal leadership of the green principle (guiding principle) has set specific documents that projects must follow; those documents addressed the following principles [22]:

1. Employ Integrated Principles: Creating a comprehensive building management plan that establishes basic protocols and provides a reference for sustainable practices, operations, and procedures.

2. Optimize Energy Performance: Reducing the energy by 20% compared to the 2003 baseline through a set of mechanical system replacements, onsite renewable energy, re-commissioning and rightsizing of equipment, maximizing the use of daylight, developing lighting and building control systems, and by benchmarking and tracking the consumption and performance of the building and the retrofitting.

3. Protect and Conserve Water: Minimizing water consumption, encouraging water harvesting and reuse, and improving the storm water management of the building.

4. Enhance Indoor Environmental Quality: Standardizing the air conditioning system, performing a full study of indoor ventilation to meet building requirements.

5. Reduce Environmental Impact of Materials: Creating plans, policies and procedures to ensure indoor environmental efficiency (such as materials and products used).

Retrofitting has a major impact on reducing energy consumption and environmental emissions due to the existing condition of the building. In 2010, the United States building sector showed an average use of 50% of the total energy, and had attributed 50% of the total CO_2 emissions to the environment [23]. The need to retrofit the energy consumption in buildings is an essential process that needs to be

investigated in more detail to set a global awareness of the advantages of retrofitting [22]-[24]. To accomplish a successful retrofitting project, there are multiple activities and strategies that have to be considered and developed in the coming future [24]. The five phases in the process of retrofitting are:

- Project setup and pre retrofit survey: In this phase the project target needs to be set, and the budget and program of work have to be determined by the owner. Furthermore, the building holder has to take responsibility for planning and implementing the retrofitting.
- Energy audit and performance analysis: The building data (such as energy performance, usage breakdowns, and areas with energy waste) has to be analyzed.
- Identification of refurbishment methods: This part takes into consideration risk assessment methods, energy savings estimation, and economic analysis.
- Site implementation and commissioning: This phase reviews the methods which have to be implemented on-site.
- Validation and verification: In this stage, a post-occupancy survey needs to be performed in order spread project awareness.

In addition to the five phases mentioned, the authors have listed the overall strategies that need to be developed and considered in order to perform a rehabilitation of a building's energy and condition [24]. The needed strategies listed by the authors are:

1. A systematic approach for sustainable building retrofits

This strategy defines the need for a well-developed retrofitting framework which contains strategic planning, models, and activities in the building retrofit process.

2. Building energy auditing data

This method investigates energy usage and cost, which vary every year depending on the overall performance of the building and the surrounding environment. Thus, the need for updated rates for every year provides accurate results that are significant for measuring the efficient performance of the building. Referring to the ASHRAE Handbook [25], the energy analysis processes that need to be done on a yearly basis and can be divided into three different levels:

Level 1: walk through assessment,
Level 2: energy survey and analysis,

Level 3: detailed energy analysis.

3. Building performance assessment and diagnostics of building condition

During the building's lifecycle, the building experiences a gradual reduction in overall performance. This reduction is due to unexpected failures, fluctuating energy consumption, and deterioration of the building's geometry. As a result, the effect of building envelope causes significant thermal comfort disturbance to occupants [26], [27]. To rehabilitate the building, all aspects related to diagnosis, benchmarking of energy use, and operational problems need to be considered. Those issues are addressed in some standards and sustainability guides, yet there is not much information about them. In addition, there are no accurate devices that capture the failures of the building's equipment and the imbedded issues in the building's condition [27].

4. Quantification of energy conservation by integrated and advanced software

To prioritize the renovation process, assessor must estimate and quantify energy consumption through energy simulation and modeling programs. Such programs need to be developed to eliminate the issues with platform integration; this will allow them to perform an overall analysis. An example of the current programs are EnergyPlus, e-QUEST, DOE-2, ESP-r, BLAST, HVACSIM+, TRNSYS, etc. However, the introduction of BIM has made export and import to various analysis software to be possible, but other issues have arisen when integrating BIM [28], [29].

5. Economic analysis

Economic analysis of a retrofitting project does not only depend on the initial cost of retrofitting. Instead, multi analysis methods needs to be considered and developed in order to determine if the undertaken rehabilitation process is financially efficient [13], [30]. Such analyses include: net present value (NPV), internal rate of return (IRR), overall rate of return (ORR), benefit-cost ratio (BCR), discounted payback period (DPP), and simple payback period (SPP).

6. Risk assessment

The following method points to the need to develop an integrated risk matrix that combines all the risks associated with retrofitting building performance. Those risks are from previous lessons learned about retrofitting situations implemented on buildings in various climate zone projects. This risk assessment should include expected value analysis, life cycle cost, and disadvantages of investments [30].

7. Measurement and verification of energy savings

The aim of this method is to estimate the real energy savings through implementation processes which are not the estimated savings. For example, energy savings is calculated by the difference between the pre- and post-retrofit periods, then the results account for the energy difference from non-energy factors [31].

Previous studies on the rehabilitation of buildings' energy performance have shown significant benefits from upgrading the as-built condition and retrofitting the energy systems. As the retrofitting process is still under development, great benefits can result from undertaking set standards and developed procedures. Furthermore, the USA, EU, worldwide governments, and different international organizations are making an effort to increase sustainable retrofitting awareness, technologies, methodologies and applications.

2.3 Retrofitting Analysis

Over the past few years, the concern of efficient consumption of energy, especially for existing buildings, has been raised as a serious issue in developing countries. Bearing in mind that the majority of buildings were constructed without a forecasted energy performance, assessing this performance and investigating the best intervention practices are the current focus of much research. The following sections illustrate some of the latest retrofitting analysis approaches developed.

2.3.1 Advanced retrofitting analysis decision making methodology.

Achieving energy efficient reduction targets depends on the decisions made and the procedures implemented for such movements. The energy retrofit decisions are based on the evaluation of the associated risks, the resulting benefits, and the implemented technology [26]. Since the procedure of energy reduction is implemented in specific buildings, the conventional city scale energy reduction measures cannot be generalized to be applicable on a city, district, or cluster level [26]. The authors proposed an advanced methodology for retrofitting interventions that takes into consideration different scales and risk management. The proposed approach is a three-step probabilistic methodology:

1) Normative Energy Model: This stage consists of developing energy models for all different types of buildings where all information related to building

characteristics and occupant's end use of energy is inserted. The information is gathered by official audits that can be generalized to similar buildings with the same characteristics but on a bigger scale.

2) Bayesian Calibration: In this stage, all normative energy models' consumption for each type of building are calibrated according to their importance factors. These factors are related to the amount of consumption and risk associated.

3) Uncertainty Analysis: This stage consists of testing the factors on a specific type of building that will estimate the overall reduction in energy. This is done because different reduction factors can be applied to different types of consumptions for each type of building. The outcomes of this approach approximate the probability of meeting a specific target of energy reduction in large scale buildings and the associated risks of this approach [26]. The developed method was intended to assist President Obama's initiative of 20% energy reduction in commercial buildings in the US by 2020.

2.3.2 Energy analysis models and simulations.

Simulation models are considered very effective techniques in the analysis of retrofitting strategies for domestic and non-domestic buildings [32]. The authors used thermal energy simulation and modeling methods to analyze non-domestic buildings in Cork, Ireland, where they used static simulation modeling and dynamic simulation modeling. The static simulation degree days method, focused on heating degree days (where the outside temperature is lower than the set base), cooling degree days (where the outside temperature is higher) and growing degree days (where the inside temperature is higher than the soil temperature). However, the dynamic modeling method used the IES (Integrated Environmental Solution) and VE (Virtual Environment) applications which contain interface modules like ModelIT, SunCast, and Apache [33], [34]. Through the analysis of the mentioned methods by the authors [32], the results showed that the static dynamic simulation model can provide a reduction of 53.32% by applying different alternative retrofitting strategies, whereas the dynamic simulation model resulted in a 48% reduction. This study illustrated the benefits of using retrofitting analysis simulations for decision making processes. Also, it shows that the static simulation model can serve as an effective tool for the retrofitting analysis of non-domestic buildings [32].

A study done at Cambridge University by Rysanek and Choudhary in 2012, investigated an energy simulation system platform which provides simulation for energy used in carbon reducing retrofit. It focused on the operation, control, and potential upgrade of the HVAC system. The authors illustrated the need to analyze buildings' energy by using whole building energy models' steady and dynamic phases, as the resulting values should be normalized among the whole building consumption to include the variation in demand. The reason for using the normalized values of the overall performance is to eliminate reducing energy under peak demands, and the effect of fluctuation in energy consumption through the studied period [35].

2.3.3 Building thermal analysis.

The heat transfer coefficient in buildings, also referred as the U-value, is one of the main indicators of how much energy is required for cooling or heating spaces [36]. In order to determine the existing heat transfer coefficient in existing buildings, Fokaides and Kalogirou have utilized the infrared (IR) thermography scan for capturing the building exterior's U-values [37]. The experiment outcomes illustrated how accurate the results are by implementing the IR thermography scan. One of the main benefits of using the IR thermography scan is the ability to capture the surface thermal distribution among its overall range of scan, even if the temperature gradient varies significantly between one point and another along the surface [38]. The results of the scan are presented as RGB color distribution among a surface layer with their temperature values indicated.

In the authors' work [37], the calculated U-values were averaged between the summer and winter seasons to decrease the effect of temperature variation. In addition, the surface temperature results were validated with the use of a flux meter and the resulting U-Values were compared to the standard values published by the European National (EN), and by the means of measurement method to the resulting U-values from the use of a thermohygrometer. In addition, due to the non-steady heat transfer at the building surfaces, the space is either heated or cooled with a known temperature for 3 hours and the building elements under study are not exposed to the sun a couple of hours before and during the experiment [37]. The validated results from the flux meters and the IR thermography resulted in a deviation of less than 5% when compared by means of the average method with the thermohygrometer results,

and the difference between the EN standards and the validated results varied between 10-20%, which was considered as an acceptable difference range to the author [37].

2.3.4 Façade retrofitting analysis.

With the increased concern on energy demand and consumption, the potential savings from retrofitting existing projects has offered significant benefits worldwide. In building structure, elements life cycle vary considerably from one to another. For instance, interior fittings last up to a couple of months, whereas a building exterior shell lasts for more than 30 years. As a result, the intervention on a building's façade determines the retrofitting duration cycle which is estimated to range between 25-30 years [39]. In a closer study, Figure 5 illustrates a sustainable multi-criterion assessment methodology for determining the best intervention strategy for the building façade structure analysis [39].
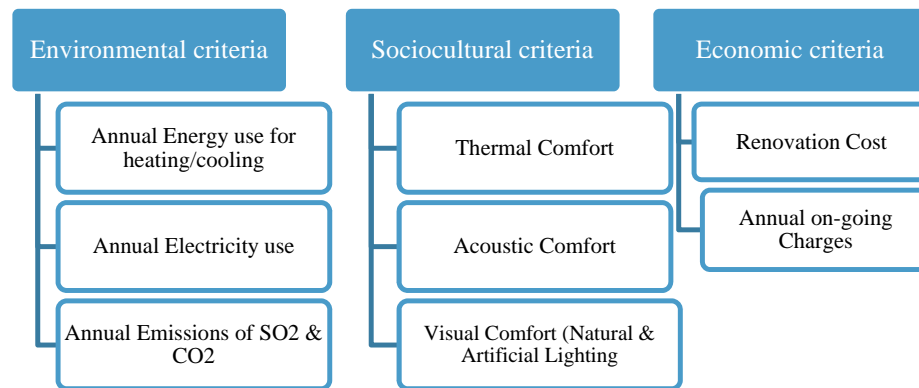
Figure 5: Office Building Sustainable criteria for retrofitting assessment [39]

By giving a weight for each criterion and applying fuzzy logic, in which the decision maker is controlling the intensity of the performance difference, the result of the assessment determines one of the following strategies [39]:

1. The stabilization strategy (STA): A strategy in which neither the appearance nor the substances of the building elements are changed. This strategy consists of gradual interventions and controlling.
2. The substitution strategy (SUB): A strategy which consists of changing the exterior elements, where both appearance and substance of the building will be changed.

3. The <u>double-skin façade strategy</u> (DSF): A strategy that consists of enhancing the current façade by adding additional glass skin. This strategy changes the appearance of the building, whereas the main built substance remains the same.

2.3.5 Green roof retrofitting analysis.

The implementation of green roof retrofitting has significant benefits in saving energy and reducing CO2 emissions for the building sector. Green roofs work through an inactive method that cools and reduces solar radiation during the summer and acts as a barrier for cold in the winter. Other benefits for green roof retrofitting are attracting new species, reducing urban greenhouse effects, and managing and recycling of storm water [40]. Another study performed in Australia, shows that 15% of buildings which have potential of greening the roof because of their orientation and oversharing in which their environments has a good potential to grow various type of sedum [41], [42]. The following literature review will illustrate some of the latest studies of implementing green roof retrofitting in buildings. There are two different types of green roofs implemented in most countries, those types are [40]:

1. Extensive type: Have lightweight structure, thin subtract layer, and low level of sedum or lawn. This type is very good for European countries; however hot countries the subtract layer and vegetation will have difficulty surviving in the warm climate. Therefore, technology needs to be developed in order for this type to be adapted [43].
2. Intensive type: Have a thicker layer of subtract so trees and shrubs can be planted. This type is better used in warm-humid countries.

One of the leading countries in the use of green roof technology is Germany, where there are around 13.5 Km^2 of green roof exists and 80% of the existing green roof is of the extensive type [44]. In the UK, green roof retrofitting covers around 0.93 km^2 of London city [45]. The main objectives of implementing green roof technology lie in its potential savings. The key factors that determine the applicability of green roofs are: whether the building has poor insulation and high energy consumption and CO_2 emissions, the time the building was built, the followed regulations, the thickness of the soil layer, and the conductivity of the soil which will increase with the moisture level [46].

According to a study conducted on applied green roof retrofitting on existing buildings, the heat and solar radiation decreased by an average of 70-90% in the summer and 10-30% heat loss was registered in the winter [46]. Even in the hot climate, vegetation roofs gain less heat and the temperature of the roof cools the surrounding air during the night, where the black roof accumulate heat and returns it back during the night [48]. Another advantage of using vegetation roofs is to improve thermal mass and decrease annual energy consumption. The major problem with existing buildings is that they were built under the past building regulations where the U-value of the roof was $1.42W/m^2/°K$ in 1995, while the current UK regulation U-value of roofs is $0.22W/m^2/°K$ [48]. This shows a significant difference in the roof insulation where green roof retrofitting is able to improve it. In addition, UK universities' research shows that 50% of the NDBS (non-domestic building stock) was built before 1965 when insulation was not required in for this type of buildings. Thus if the building will be retrofitted, the amount of carbon dioxide and the maintenance cost will have a significant impact on the UK environment and owner of the building [49].

In 2005, Alcazar designed a multi-residential building in Madrid, Spain, while incorporating thermal performance, moisture, and energy flow simulation models through an ESP (Environmental System Performance) program [50]. The authors' roof design consisted of three alternatives: a normal concrete roof, a green roof, and a green roof containing water storage. The results of the study showed that the U-value of the green roof is 0.42; the U-value of a normal concrete roof is 0.59, and green roof with water storage is 0.38 [50]. It can be clearly seen that green roofs can dramatically reduce annual energy demand for cooling by controlling the heat transfer to the area below the roof. Furthermore, the author added that different thicknesses of the soil layer significantly affect the value of heat transfer, where the thicker the soil layer, the better insulation performance it creates [50].

The impact of using green roofs was studied for 3 days in July by a group of researchers on two buildings in Athens, Greece. Both buildings had similar insulation properties but in one of the buildings green roof technology was implemented. The results of the study showed that the building without the green roof was 30 degrees Celsius for 68% of the period, whereas the building with green roof technology recorded 30 degrees for 15% of the study period [51].

Mechanical modeling was also used to analyze cooling performance during the summer for buildings with green roofs [47]. The author's investigation showed that if the density of the soil is higher, then the thermal conductivity is better. In addition, increasing the soil layer by 100 mm causes the thermal resistance of dry soil and 40% clay soil to rise by 0.4 $m^2/°K/W$ and 0.063 $m^2/°K/W$, respectively. One of the existing mathematical analyses that can calculate energy transfer when implementing green roof retrofitting was developed by Sailor [52]. The developed model helps to simulate a green roof and analyze heat exchange and transfer, soil heat conductance and storage, and moisture effect on the buildings which need to be retrofitted. The author's developed model is currently used in the US by the Department of Energy for analyzing the possible benefits of implementing green roof retrofitting in their projects [52].

2.4 Financial analysis of building retrofit.

In 2011, Carol Menassa investigated the value of investing in sustainable modernization of existing buildings related to life cycle cost [30]. She considered traditional net presented value method (NPV) to prioritize and evaluate retrofit over time, and also to develop a framework for single or multistory phase investment assessment. In addition, the author used the CAPM (capital assets pricing model) for analysis and to discover solutions for increasing the value of the building and the green space, and to decrease operation and maintenance costs [30].

The characteristics of investments in existing building retrofits show no evidence of financial decision framework that analyze and estimate retrofit measures and shows long term economic benefits for building stakeholders [53]. Likewise, traditional evaluation methods focus on payback period or internal rate of return during the life cycle. Although the NPV method takes into consideration maximizing returns investments, there are also serial limitations and barriers like the requirement of accurate discounted rate, associated investment uncertainties), and determining cash flows strategic values that could create future grow [53].

The retrofitting process is very challenging for decision makers in relation to the benefits of investment such as saving from effectual energy consumption, occupant satisfaction, and investments payoffs. Those challenges are controlled by the investment model assumptions and parameters which assist in estimating investment payoffs and considering risks of unknown factors in the investments' [30]. Previous

research in this area assumed the value of assets that change under uncertainty to follow the lognormal or the GBM (Geometric Browning Motion) process; thus the same equation is used to calculate the change of the value of the expected benefits V from the sustainable renovation of the existing building [30].

dV/V = (µv − §v)dt + Óvdz

Where V = value of the price stock, µv is market equilibrium of return when retrofitting is completed; §v is the rate of return shortfall; and Óv = future benefits from retrofitting.

By estimating the future benefits, the evaluation on the investment decision in the sustainable retrofit of a project can be determined whether it should occur now or in the future [30]. The author have developed a decision making framework for sustainable retrofit investment decision and summarized in Table 1.

Table 1: Retrofit investment decision options [30]

Option	Description	Application to investments in sustainably retrofitting existing buildings
Option to stage	The costs/benefits of a preceding stage at completed determines if subsequent stages should be undertaken	Depending on the overall assigned budget, the sustainable retrofitting is divided into different stages, and each stage Cost/Benefits are estimated once completed in order to decide the action of next stage.
Option to abandon	Stop the retrofitting any time prior to completion and reassign resources to other projects	A detailed analysis of the existing performance might results that the cost of completion is very high, the owner of the project might decide to abandon the work.
Option to defer	Postponing the decision to invest in retrofitting the project without compromising the benefits of retrofit	The investment in the sustainable retrofit of the building can be postponed until financing rates are acceptable by the owner or until occupants can arrange a stay location during the retrofitting period on their cost
Option to grow	The investments in retrofitting multiple owned projects by the owner depends on the results of a base project retrofitting	The decision to invest in multiple owned projects can be decided once the benefits of retrofitting a pilot project exceeds the costs associated
Option to reduce	Reduce the retrofitting scope and decrease enhancements costs	The decision to reduce the retrofitting scope once the cost of retrofitting exceeds the allocated investment of the process. As an example, retrofitting the HVAC system cost might exceeds the allocated budget, where in this case the owner will decide whether to limit the investment to retrofit the HVAC system or limit the scope of retrofitting other systems

The benefits of implementing energy efficiency measures were presented as: higher savings that are generated from operation expenses and the additional value added to the property. As part of applying the energy efficiency measures to the building is recovered immediately, because of the increase in the property value, the remaining part will pay off through the savings of implementing those efficiency measures. The cost of investment which is considered profitable when the value is less than the net present value (NPV), which is the cost of energy savings, plus the amount of the increase in the property value due to implementing the energy performance (V) [13].

$I < NPV + V$

$V = P2\text{-}P1$ (P1 & P2 are the market value of the building after and before retrofitting, respectively)

$$NPV = \sum_{j=0}^{J}[(ES)j.(CE)j \sum_{n=0}^{tr}(\frac{1}{1+i})^\wedge n]$$

Where *ES* represents the annual energy savings by estimating the difference between the energy demand of the building before (*ED1*) and the energy demand after retrofitting (*ED2*), *ES = ED1-ED2,* j represents the type of energy (e.g. *j*=1 for gas, *j*=2 for electricity, *j*=3 for district heating, etc.), *CE* is the actual cost of a unit of energy, *i* is the discount rate, and *tr* is the lifetime of the retrofitting [46].

2.5 Office Building Retrofit

In 2009, the carbon trust organization in the UK issued a technical report on the benefits and estimated outcomes of retrofitting existing commercial buildings. The report stated that by implementing energy efficiency retrofitting on existing commercial buildings, the CO_2 emissions and energy consumption can be reduced up to 15% [54]. Similarly in the US, according to a statewide energy performance study on the efficient consumption of energy in existing commercial buildings, energy retrofit actions can result in up to an 18% reduction in California, and around 12% in Washington, Oregon, and Idaho [55], [56].

In the European Union countries, each member state is required to follow a set of energy reduction policies that are established by the parliament of energy performance each year [4]. The authors have explored the potential of energy savings in a specific type of office buildings that are located in three different climate zones in Europe, as this type of office buildings is the common type of offices in Europe where

benchmark data and energy models are available [4]. In their research, lighting and HVAC systems were considered as the main potential systems for energy reduction, as both systems consume between 90-93% of the total office energy of the chosen type of office building [4].

Table 2 summarizes the results of energy consumption by adapting two energy reduction scenarios on the same energy benchmark model. The scenarios are lighting controls with PV panels as a renewable source of energy and insulation enhancement (U-values) of the office envelope [4]. The results of the study illustrate the reduction in the total demand of energy in each of the office buildings, and the enhanced U-values and the lighting control effects were based on the author's literature review and calculations on the same benchmark model.

Table 2: Summary of energy reduction scenarios compared to the base reference energy consumption [4]

Base Case: Base U-values, With Zero Lighting Control							
Location	U-Wall W/ m²/°K	U-Window W/ m²/°K	Lighting Demand KWh/m^2	Heating Demand KWh/m^2	Cooling Demand KWh/m^2	DHW & AUX. Energy KWh/m^2	Total Demand KWh/m^2
Tallinn	0.2	3.16	39.02	53.08	8.68	7.15	107.93
Madrid	0.66	3.16	39.02	12.78	21.90	7.15	80.85
London	0.3	3.16	39.02	15.59	12.83	7.15	74.59
Base case scenario is conducted with 30% of glazing, the simulation was performed in Energyplus Software, and the data are from the Green Public Procurement Technical Report (2011) of the benchmarked model.							
Energy Reduction: Enhanced U-Values, With 100% lighting Control & PV panels as renewable energy source							
Location	U-Wall W/ m²/°K	U-Window W/ m²/°K	Lighting Demand KWh/m^2	Heating Demand KWh/m^2	Cooling Demand KWh/m^2	DHW & AUX. Energy KWh/m^2	Total Demand KWh/m^2
Tallinn	0.1	1.776	17	49.19	7.23	7.15	80.57
Madrid	0.15	1.776	11.16	7.75	21.29	7.15	47.35
London	0.12	1.776	15.16	13.04	9.54	7.15	44.89
Energy Reduction scenario is conducted on the same benchmark model with 30% of glazing, total lighting control, and PV Panels.							

The increase in energy demand and the impact of this demand on the built up environment have raised a global concern in regards to the efficiency of the energy used and the potential interventions of reducing the consumption [3]. According to the International Energy Agency (IEA) report, the primary energy and the CO_2 emissions of the commercial building sector have grown in the last two decades to 49% and 43%, respectively, and the estimated annual increase of energy and CO_2 emissions ranges between 1.7% and 2% [6]. The reason for this continuous increase is associated with economic developments, growth in population, and expansion of the building sector and services. Among services, the HVAC system in office buildings is considered to be one of the main energy consuming systems, which consumes approximately 50% of the building's energy according to Pérez-Lombard [3].

In 2003, the EIA report on energy consumption in commercial buildings in the USA estimated that office buildings' energy consumption is around 293 $kWh/m^2/year$ [58]. Also in 2008, the US energy consumption of commercial buildings was estimated to be 20% of the total US energy [22] (Tables 3A and 3B summarize the percentages of energy used by building type and end use in the USA and UK, where equipment, HVAC, and lighting systems consumed around 77-83% of the office energy [2], [5], [58], [59].

Table 3: (A) Energy use in commercial sector by building type (B) Energy consumption in offices by end use. Source: [2], [5], [58], [59].

(A) Energy use in the Commercial sector by building type			(B) Energy consumption in offices by end use		
Building type	USA (%)	UK (%)	Energy end uses	USA (%)	UK (%)
Retail	32	22	HVAC	48	55
Offices	18	17	Lighting	22	17
Hotels and restaurants	14	16	Equipment (appliances)	13	5
Schools	1	10	DHW	4	10
Hospitals	9	6	Food preparation	1	4
Leisure	6	6	Refrigeration	2	5
Others	8	23	Others	10	4

As the energy consumption in office buildings will continue to increase, the need for assessing energy efficiency performances, adapting advanced technologies, investigating energy reduction policies, and raising awareness of individual behaviors will contribute to a better sustainable [3]. Existing office buildings' cooling energy

consumption is likely to increase in the coming future. The reason for this increase is due to global warming and the inefficient design of the predicted end-use in those buildings [60]. The effect of the end-use is mainly related to the internal heat produced by office equipment and lighting, as this heat causes an increase in the required cooling demand to satisfy occupants' thermal comfort [61]. Approximating the produced internal heat ensures controlling the efficiency of the installed system and the required performance that impact the consumption of energy. The produced heat from lighting and office equipment is determined from the amount of electricity consumed for both systems, as the relation of electricity use is the same amount of heat transfer in watts as shown below [62]:

Internal heat gain = Amount of electricity required for lighting (W) + Amount of electricity required for office equipment (W)

In conventional office design, the estimation of small power demands, office equipment, is based on benchmark values that do not present the actual rates since detailed estimates are rarely taken into consideration [60]. According to the Energy Consumption Guide 19, the benchmarks for typical and good practice electrical consumption of an air-conditioned office building are 47 KWh/m^2 and 36 KWh/m^2, respectively [63], whereas the established the benchmark value for office equipment should be used as the load density, which was estimated to be 15 W/m^2 [60]. The British Council for offices has argued that the benchmark value after analyzing typical office buildings in the UK, and has proved that more than one third of the analyzed equipment's load densities were more than 15 W/m^2 [63]. In 2012, the Chartered Institution of Building Services Engineers Guide F established an updated benchmark value of office equipment's load density. The updated value is equal to 25 W/m^2 and has suggested the use of 140-150 W/desk as a more appropriate value of load density representation when occupancy details are available [64].

Computers and all of their parts are responsible for 66% of the total office equipment's energy demand [60]. The estimated consumption was a result of analyzing 25 office buildings' small loads energy consumption in California. The authors emphasized the significant heat gain from computers and the need to establish updated and accurate benchmarks for small load energy consumption in office buildings, as this will help in estimating the accurate internal heat affecting the cooling demand [60]. On the other hand, the Advanced Engineering Design Guide has

stated that efficient operation of office equipment should include lower energy consumption when connected, and advanced power management of equipment use [1]. The guide emphasized the importance of using equipment with Energy Star ratings for achieving effective energy performance, especially in office buildings, also stated that equipment with an Energy Star tag consumes less wattage during operation and contains advanced sleep and standby modes compared to non-Energy Star rated equipment [1].

A study on the amount of equipment's energy use have estimated the reduction in Energy Star rated equipment power density compared to non-rated in an office building in the USA [65]. The result of the authors' study proved a reduction in equipment power density from 8.1 W/m^2 to 6 W/m^2 when Energy Star equipment was used. Table 4 demonstrates the authors' study results for specific equipment [65].

Table 4: Energy Star Rated Equipment Energy Consumption, Source: [65]

Plug Load Equipment Inventory	Baseline			Advanced		
	Qty	Plug Load, Each, W	Plug Load, W	Qty	Plug Load, Each, W	Plug Load, W
Computer—servers	8	65	520	8	54	432
Computer—desktop[a]	134	65	8710	89	54	4806
Computer—laptop[a]	134	19	2546	179	17	3043
Monitor—server—LCDs	8	35	280	8	24	192
Monitor—desktop—LCDs	268	35	9380	268	24	6432
Laser printer—network	8	215	1720	8	180	1440
Copy machine	4	1100	4400	4	500	2000
Fax machine	8	35	280	8	17	136
Water cooler	8	350	2800	8	193	1544
Refrigerator	8	76	608	8	65	520
Vending machine	4	770	3080	4	770	3080
Coffeemaker	4	1050	4200	4	1050	4200
Portable heaters, fans, etc.[b]	30	30	900	30	30	900
Other small appliances, chargers	250	4	1000	250	4	1000
Total plug load, W	40,424			29,725		
Plug load density, W/ft^2	0.75			0.55		

Due to the need for assessing office buildings' energy consumption, the association for the conservation of energy has established benchmark energy usage for equipment and lighting in office buildings [66]. The benefits of using the benchmarked values are to estimate the energy consumption and the internal heat gain that affects the cooling demand. In addition, when office retrofitting projects are considered, those values provide a good starting point for the analysis of

uncertainties. Table 5 summarizes the benchmark values for typical and good practice of consumption [66].

Table 5: Benchmark values for offices: typical and good practice of consumption [66]

Benchmarks	Lighting		Equipment's		Catering		Computer room	
	Typical	Good Practice	Typical	Good Practice	Typical	Good Practice	Typical	Good Practice
W/m^2	20	12	18	15				
KWh/m^2/yr	32	23	60	29	15	13	105	87

According to Hestnes and Kofoed, the purpose of rehabilitating office buildings is to optimize the energy performance while maintaining thermal, visual and air comfort, whereas other restrictions such as climate, building shape, structure, and interior and exterior building elements need to be considered in retrofitting interventions [67]. In 2002, Dascalaki and Santamouris investigated the effect of office type and climate zone on the total energy consumption by comparing 5 office building types for two different climate zones. The different climate zones that were considered in the authors' study are: Southern Mediterranean (SM) and North Costal (NC), whereas the 5 different types of office buildings are [68], [69]:

- Type A - Free standing heavy core dependent open plan
- Type B - Enclosed heavy skin,
- Type C - Free standing heavy skin,
- Type D - Free standing light skin dependent open plan
- Type E - Enclosed light skin.

The results of the authors' investigation of the effect of office type and climate on energy consumption are summarized in Table 6. From the results it can be seen that architectural, structural and interior design aspects affect the office building's energy performance. Office type A shows the highest energy consumption among the other types in both climate zones, whereas office type B shows the lowest energy consumption in the SM climate zone, and type E in the NC region [68], [69]. Buildings equipment and type of installed services have huge impact on the energy performance of the building, whereas in the author's work, the main considered service is the HVAC system [68].

Table 6: Energy consumption based on the effect of office type and climate zone [68]

Building Type	Building Characteristics	Building equipment	Region	Total Energy consumption	Result
A	Open Plan Massive Floor Huge Glazing	Central HVAC	SM NC	195kWh/m2 355kWh/m2	Very high
B	Small interior spaces Sheltered location Double glazed windows	Centrally controlled HVAC	SM NC	69kWh/m2 153kWh/m2	Medium
C	Non-Sheltered glazing Non double glazed windows Small rooms Satisfied level of natural lighting	Non controlled HVAC	SM NC	169kWh/m2 328kWh/m2	High
D	Non-Sheltered glazing Direct solar gain Unnecessary ventilation	Non effective HVAC use	SM NC	183kWh/m2 307kWh/m2	High
E	Height insulated envelope Air tightness Double glazed windows Passive heating from solar gain	Controlled HVAC	SM NC	70kWh/m2 70kWh/m2	Low

The authors have also conducted different energy retrofitting scenarios on the 5 types of office building to estimate the amount of possible energy reduction. In their research, the authors focused on the passive solar/cooling and lighting retrofitting strategies of offices. The authors identified the main building characteristics such as exterior building elements, the building envelope, orientation, meteorological situation, indoor temperature, building systems, and annual energy consumption in order to test the best possible intervention procedures including [69]:

1. Improvements of building envelope.
2. Reduction or elimination of air conditioning.
3. Enhancement of lighting system.
4. Upgrading the building HVAC, and domestic hot water system.
5. Use of Passive systems

Table 7 summarizes the authors' results of applying the different retrofitting scenarios on each type of the mentioned buildings, and the possible reduction percentages in energy to each building type.

Table 7: The energy consumption based on different retrofitting scenarios [69]

Building Type	Energy consumption purpose	Retrofitting scenarios	Energy reduction %
A	Heating Lighting	Insulate building envelope Passive Systems Lighting enhancement HVAC	21% 34% 66% 60-42%
B	HVAC Envelope	Insulate building envelope/Air tightness/glazing/ HVAC/Cooling	55% 55%
C	Ventilation system Envelope	Passive Systems Techniques Controlled Ventilation strategies Passive heating and Cooling	30% 38% 80%
D	Heating and cooling envelope	Improvements of U value/ Passive systems techniques Daylight sensors	24-44% 78% 50%
E	HVAC	Passive Ventilation Solar shading devices	48% 40%

As it illustrated in the results, Dascalaki and Santamouris discovered that the enormous energy consumption in office buildings can be reduced by improvements to the building envelope and U-value of exterior elements [69]. Those improvements affect the cooling/heating demands which can be achieved by window improvement/replacement and applying shading systems. In terms of energy efficient lighting scenarios, the authors suggested the use of time-scheduled control, dimming system, high-efficiency fluorescent lamps with electronic ballast, daylight compensation and also increase natural lighting; those improvements will enhance the lighting system and reduce the power consumption. Also, passive systems such as night ventilation, evaporative coolers to pre-cool the fresh air, and ceiling fans in the major zones can significantly improve energy consumption [68], [69].

2.6 Sustainable BIM for Existing Buildings

In the past ten years, a growing interest in implementing advanced technology and innovation in the AEC industry had been introduced, as the shift from traditional 2D design to 3D smart design was introduced in the industry with building information modeling (BIM). While BIM is implemented on new projects, the

majority of buildings (existing) did not follow the technological trend of this development. According to extensive research on the benefits of applying BIM on existing buildings, uncertainties of existing building conditions can be overcome and the ineffective documentation of the building situation can be achieved [70]. The authors' work shows the need of using BIM for existing buildings and discusses the results of the main challenges of implementing BIM. The results were summarized as (1) the big effort needed for modeling the existing situation of the building and translating the information into BIM objects (2) updating and maintaining the information in BIM (3) handling of uncertainties due to lost data and information, in addition to relations in BIM occurring in existing buildings [70].

The use of BIM is suitable and more responsive for large and complex projects where it is applied to commercial, residential, educational, healthcare and many other special projects [70]. Less than 10% of the respondents using BIM for existing buildings were facility managers, owners or deconstruction managers. Figure 6 illustrates some of the issues of implementing BIM according to the survey's results and the summary of other publications [28], [29]. Despite the increasing BIM usage for new projects, implementing BIM for existing buildings is currently in the development stage. This is because the potential benefits and functionalities of BIM for existing buildings are various. These benefits include simplification of calculating and optimizing alternative solutions, enhancing project management and risk mitigation to limit cost, decreased duration of facility management, efficient deconstruction measures, and accurate estimation of building life cycle (LC) [70].
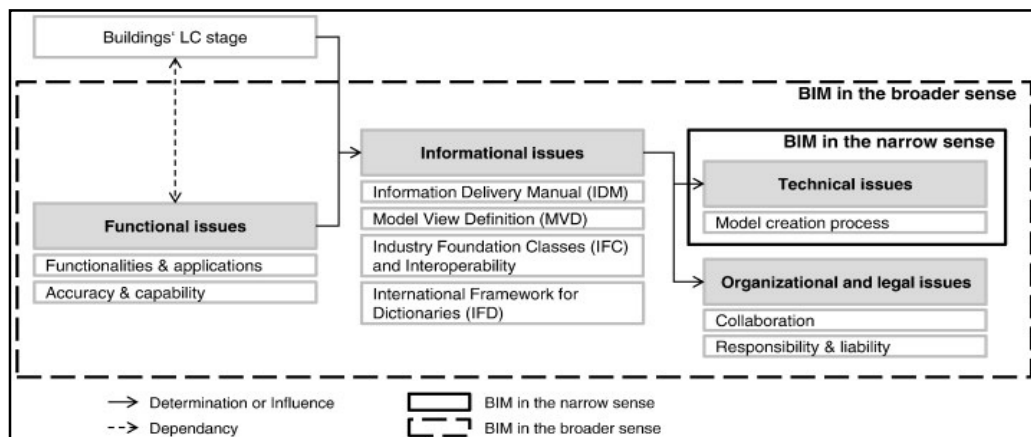

Figure 6: Relations between building life cycle (LC) stage as well as functional, informational, technical and organizational issues of BIM [70]

Building facility management (FM) is the process including multidisciplinary tasks, analysis, and overall view of the property elements to manage and control the performance of the building throughout its whole life cycle [71]. Thus, a vast amount of information and data are needed to be able to perform efficient FM to a building. BIM, on the other hand, provides information and data in one model which acts as a database for FM. Implementing BIM provides undeveloped opportunities that support FM procedures and outcomes with its functionalities of visualization, analysis, control, and data management [71]. In most cases, project owners' main focus is on the initial cost of constructing the project; however, the cost of maintenance and operation through the building life-cycle could be many times more than the initial cost [71]. Efficient and accurate maintenance and building management are able to reduce the annual cost of the building through its lifespan to add up to approximately $15.8 billion as reported by a NIST study [72].

The integration of BIM for FM practices promises vast benefits in areas such as project commissioning and delivery closeout, QA/QC, management of building energy, building maintenance, repairing parts, and management of building spaces [73]. Another important benefit of BIM integration in FM practices is the ability to allocate building components efficiently in the building. The allocation of those components in effective and faster ways saves money and time and ensures the best work performance [73]. In addition to the ability to stream data analysis of energy from the building to the BIM model to enable FM practices to be applied, as accurate and effective information readings to specific components reduces the time and effort required to avoid ineffective decisions [73]. The digital assets that should be contained in BIM during both stages of design and construction are [71]:

1. Equipment and systems: HVAC, plumbing, electrical, fire/life safety, specialty equipment, building sensor networks, and networking systems.

2. Data: manufacturer/vendor information (i.e., serial, model, and part numbers), location information (i.e., building, floor, room, and zone where the equipment is located), description (i.e., type, asset number, equipment group, criticality, and status), and attributes (i.e., weight, power, energy consumption).

3. Documents: specifications, warranties, operation and maintenance manuals, manufacturer instructions, certificates, and test reports.

4. Alternatives: design and construction alternative options to meet value, quality and time targets.

To ensure the effectiveness of BIM implementation in FM, some challenges should be taken into consideration while managing and controlling the work. Such challenges include:

- Loading data and marinating the BIM model.

- Interoperability issues between BIM and FM, and Insufficient legal framework.

- Collaboration between owners and project stakeholders for model utilization of adopting new technology.

- Investment in the integration between BIM and FM (cost and training).

2.7 As-built BIM for Retrofitting, Analysis, and Laser Scanning Integration

Retrofitting an existing building to reach the target reduction in energy consumption and CO_2 emissions is the main topic of published work done through BIM [74]. The methodology includes the use of technological development in the area of design management and virtual modeling, which are BIM and 3D laser scanning to perform energy analysis, rehabilitation operation studies and to find optimum solutions to enhance the existing condition of the building. The reason for using BIM is due to the ability to coordinate all information from all trades and to capture existing conditions that help in the retrofitting work [74]. The main difficulty in retrofitting existing buildings is the early stage of preparing for the process, which requires the exhaustive documentation, analysis, and gathering all information from parties involved in the construction of the project and the work done through the life cycle of the building [75].

To overcome the difficulties faced in capturing the existing condition of the building, the lack of information, and to perform faster energy analysis, a proposed combination of automatic thermographic and RGB texture of as-built BIM modeled through laser scanning was developed [74]. In this process, once all thermographic, visible and geometric data is acquired, the proposed methodology aims at the geometric referencing of the images within the point cloud, which is carried out through the extraction of corresponding features from the images. Combining a process that contains thermographic, visible, 3D point cloud, and the subsequent calculation of the homographic transformation of each image to the point cloud through its epipolar geometry of the building [74], [75], an as-built BIM model of the existing building situation can be developed. Figure 7 illustrates the sequence of the

proposed methodology by the authors to achieve the end results (as-built textured BIM model).
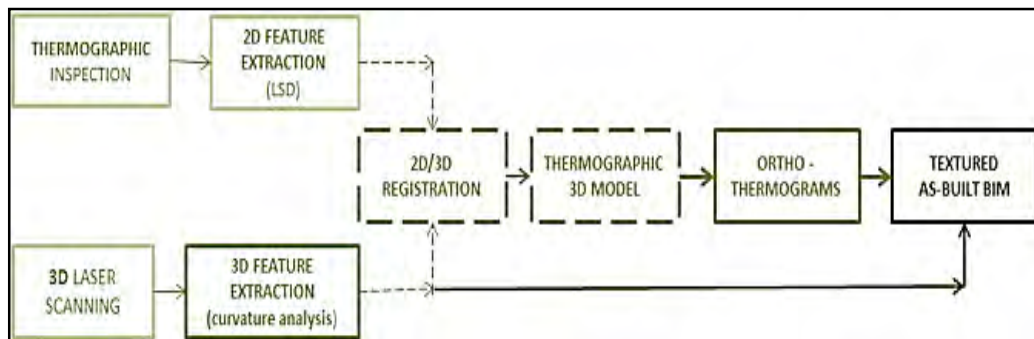

Figure 7: Schema of the proposed working methodology for the generation of a textured 3D model and its consequent textured as-built BIM [74].

Capturing the existing condition of the building is considered as one of the main obstacles to perform any analysis related to enhancing the as-built condition of the building [76]. Nevertheless, with the huge development and the advanced technology available nowadays in the industry, overcoming this difficulty is introduced by integrating laser scanning and BIM [77]. The combination of laser scanning and BIM provides a vast range of advantages for decision making in regards to reconstructing, expanding, demolishing, or retrofitting the building. Also, the high accuracy data, geometry, services and building elements that are collected through this approach can be used for multiple analysis purposes which helps in overcoming the limitations faced with the traditional procedures of evaluating the existing state of the building [28], [71], [76]-[78]. It was estimated that the effect of inaccurate information related to the existing building condition cost around $0.23\$/ft^2$ for maintenance and operation work in the United States, which raise the need for adopting advanced technologies over the conventional methods of capturing the existing condition of the building [78].

The procedure of integrating laser scanning to the BIM model consists mainly of four steps [78]: 1) Data Collection: where the target structure is scanned and all the point cloud data are registered according to the scan point coordinates, 2) Data Processing: this step consists of filtering, noise removing, and combing all scanned data into one file with X,Y, Z coordinates, 03) Geometric Modeling: all scanned objects and element points are reconstructed by the line segment detector (LSD).

4) BIM Modeling: where all the reconstructed objects and elements in Step 3 are assigned to their categories, material properties, construction relationship, and modified dimensions.

As an example, a CAD representation of a wall element in a model will be set of independent planar surfaces, while a BIM representation of a wall in a model will be a single, parametric element with multiple construction layers and relationships with other entities [79]. To prove the advantages of integrating BIM and laser scanning over traditional CAD methods a pilot study on retrofitting the Aberdeen's Tivoil theatre in UK was implemented [77]. The results of the study demonstrated the argued advantages of this combination compared to traditional CAD methods. As such, it was able to capture the building exterior and interior in a shorter time frame and with higher accuracy; this included material properties, detailing, decorations, furniture, colors, and fixed objects [77]. In addition, the ability to scan inaccessible locations helped in determining the existing hidden services and their condition, the ability to perform multi discipline analysis on the existing condition, and to test alternatives for the renovation design.

In another study performed on an existing structure, the integration of BIM and laser scanning to evaluate whether the building should be retrofitted or demolished [80]. The decision of the authors work was based on evaluating the potential failure of concrete due to existing cracks in the structure, which was captured by the laser scanning and integrated in the 3D BIM model for structural stability analysis [80].

Insulation refurbishment is considered as one of the fundamental techniques for reducing energy consumption in existing buildings. As insulation controls the thermal envelope of building properties, better insulation provides better air tightening and reduces thermal bridges which results in less cost and use of energy [81]. The authors utilized the 3D BIM and laser scanning technology for insulation retrofitting of an existing building in Germany. The aim of the authors' project was to capture the exact as-built condition of the building exterior in order to determine the best installation approach of the prefabricated timber wood frames, to enhance the building envelope insulation [81]. The need of an accurate as-built condition of the building exterior is because of: the ±0.5 cm tolerance of the prefabricated frames, the ability of studying multi frame design options in a 3D virtual environment, the need to determine the outfitting management of the project with less cost and time frame

compared to usual procedures, and to generate an as-built retrofitted BIM model with all insulation information embedded for further analysis requirements [81].

With the increasing cost and environmental issues in building due to energy, the need for sustainable properties with minimum and efficient energy use is rising. Effective decisions regarding sustainable solutions in the building design can be best performed during either the early design or pre-construction stages [82]. Hence, implementing BIM in those early stages has a huge benefit for analyzing different alternatives for a better optimized sustainable design. One of the main benefits of BIM implementation prior to construction and approval of design is the ability of integrating the model into different smart environmental software platforms which allows multidisciplinary data to be integrated in one model. Such software includes Ecotect, Green Building Studio (GBS), and Virtual Environment (VE), which are evaluated to test their suitability for BIM-based sustainability analysis [82]. The results of the evaluation performed by the authors concluded that VE software is the best in terms of analysis capabilities, although it lacks the ability to perform acoustic analysis. Implementing BIM creates an environmentally-friendly facility which allows achieving successful sustainable design aspects [79], [82]. Such design aspects are:

- Allocating building orientation (which helps to minimize the cost of energy to be used in the facility).
- Applying building massing (which helps in analyzing and optimizing the building form and envelope).
- Ability to perform day lighting analysis.
- Water harvesting.
- Ability to perform energy modeling (which helps in reducing the need of energy in certain locations and to study different renewable sources of energy, such as introducing solar panels).
- Allocate best use of sustainable materials in the facility.

The adoption of BIM in construction projects enhances the quality of data gathered and inserted into the project model, and as a result efficient decisions on issues related to building performance that impact the surrounding environment can be easily made. However, this implementation has to be effectively tested and understood before implementing [83], as the objectives and deliverables from

combining both BIM and sustainable design benefits prevents the synthesis between them. But the basic aspects of both approaches are the same; those aspects are integrative design, multiple collaboration between project stakeholder, shared aim-setting, and the efficient quick presentation of complex issues to enable quick and accurate decision-making [83]. The vast acceptance of BIM implementation in the AEC industry has pushed multiple development attempts to quantify and calculate BIM adoption benefits in relation to information systems. However, due to the weak acceptance of the industry and the unsuccessful existing methodologies that compare data among different projects, it is an inefficient process [83]. In addition, the current industry best practices in this field do not take into consideration the cultural environment aspect, and the social negotiation and coordination aspect that possibly would affect the outcomes of the process.

2.7.1 BIM in GCC and UK case study.

Managing and generating data throughout the building life cycle is one of the benefits of applying BIM technology. BIM is presented as an efficient and accurate 3D smart model that serves various applications in the AEC industry; it has also been identified as a 3-dimensional dynamic process that can be applied in any stage of the project delivery. BIM can be applied in the early design stage, final design stage, onsite coordination and construction, project pricing and tendering, quantities taken or the as-built facility model. In addition, depending on the required scope of the BIM model in a specific stage of the project, the integration with different software platforms that serve different disciplines can be achieved.

According Cerda and Martin [84], BIM serves as a combined shared knowledge resource of information and data about the property, which forms a reliable reference for decision making through the facility life cycle, if set properly. With a narrow view on the implementation of BIM in the GCC construction industry, various mega projects were delivered using BIM technology [84]. Examples of mega GCC construction projects delivered or on progress through BIM are the 5 stars hospitals in Abu Dhabi (Al Mafraq and Cleveland Clinic Hospital), Al Dar HQ (Lens Shape) and Abu Dhabi Capital gate project (a slope of 18 degrees), the Dubai Expo 2020 project and many more. Each of those complex projects has a unique design or a construction issue that could not be overcome without BIM [84], [85]. As there are multiple benefits of implementing BIM in AEC projects, one interesting benefit of

such implementation is the exploration of reducing energy consumption through BIM Facility Management [85].

The government of the UK aims to reduce greenhouse emissions in the housing sector by 80% by 2050, where In this case the construction sector is mandated to implement BIM from 2016 [86]. BIM implementation for the refurbishment of the public sector is very low due to of lack of education and financial support [86]. In addition, the professionals are aware of the BIM advantages but they don't like to change the process of work, or provide the training. BIM for refurbishment has significant role in identifying barriers, cost, and helping the decision making process [84]. Furthermore, BIM integrates and coordinates problems during the construction life cycle, BIM process reduces of 38% of the total project cost during the construction stage and between 19-40% in the design stage. BIM implementation in refurbishment projects has lot of benefits for example it provides a 3D model, cost benefits analysis, effective management, and 4D and 5D analysis [83]-[85].

2.8 Benchmarking

Benchmarking the energy consumption and system performance provides a beneficial source of information that helps in analyzing the building retrofit options and the existing condition. The ability to make faster decisions, estimates, and referencing data are some of the significant benefits of using benchmarks. Through benchmarking, building owners and tenants can be aware of how much energy can be reduced by retrofitting the energy systems in the building when compared to enhanced conditions [87]. The estimates can be made on the amount of cost savings associated with operation and maintenance costs, energy consumption reduction, and performed retrofitting alternatives and improvements. In addition, quantifying the amount of minimum energy input is needed to run the systems and services in relation to the whole building performance [87]. Using information collected from utility bills, BMS, and EMS monitoring systems represent the building consumption monitoring, whereas benchmarking the energy retrofits provides detailed elements analysis, and possible interventions of each system. The applicability of using benchmark data depends on investigating the level of similarity between the existing and previous projects. As there are different factors that have to be considered while applying the resulting outcomes, those factors are in the context of climate, consumption of

resources, regulation and policies, historical impact, culture, building characteristics, and geographical atmosphere [87].

According to a study on energy performance assessment methods, there are different benchmarking methods that can be used depending on the condition of analysis, relative similarity, and desired outcomes of the benchmarking method [88]. The authors argue that the most relevant method is benchmarking the whole building instead of just relying on separate systems. The process of investigating the whole building's energy performance reflects all systems' integration which is causing the certain energy performance. However, benchmarking the energy systems separately does not take into consideration the condition of the building that affected the performance of the energy systems [88]. Another method is related to using statistical data from organization reports and studies. An example is the US DOE/EIA Commercial Building Energy Consumption (CBECS) report on commercial buildings analysis and energy consumption [2], [58]. This data is considered as an important and trusted source of information in the US, where energy analysis software tools are based on the published reports. An example is the Energy Star tool, which is used to establish annual energy consumptions of proposed commercial projects.

One of the biggest issues in estimating existing buildings' energy performance is related to the whole building or floor utility metering [89]. The implementation of separate metering for end use of energy was recently taken into consideration in new buildings' sustainable regulations. The main benefit of adapting this regulation is to provide more accurate benchmarks of the energy end use in buildings which will assist in analyzing possible interventions in the future [89]. The author has analyzed a potential retrofitting project in Saudi Arabia by testing the applicability of using similar climate zone benchmark data and best developed approaches to be applied for non-residential buildings. The conclusion of the author's investigation was that the developed metrics are not applicable to be implemented in the country due to the harsh climate and building conditions. Nevertheless, the need for developed benchmarking tools that represent each country's condition is a necessity that should be considered [89].

Energy benchmarking can be used to motivate poor referenced [90] buildings that have similar characteristics, and it will act as a base reference for monitoring the building performance through the life-cycle. In addition, benchmarking information results are shared with media functions as a public measure of used energy in

buildings [90]. There are two types of benchmarking systems where each is performed using different methods. Those types are public benchmarking and internal benchmarking. Improving the efficiency of energy used is a significant process to develop a sustainable building, and benchmarking the improved performance should take into consideration some certain criteria that affect the end results of the developed facility [90]. The factors that affect energy benchmarking systems are: (1) unexpected weather conditions, (2) facility characteristics (height, area, number of floors, age, etc), (3) building management and owners' view of the future need and the aim of benchmarking, and (4) building occupants' utilization of devices [90]. The building's energy performance should be normalized before benchmarking, taking into consideration benchmarking factors.

According to this benchmarking systems literature review, there are six main mathematical methods to develop a benchmarked system [90]:

- Simple normalization system.

- Ordinary least square (OLS) (regression analysis).

- Data envelopment analysis (DEA).

- Stochastic frontier analysis (SFA).

- Model-based method (simulation).

- Artificial Neural Network (ANN).

Each of those mathematical methods used in benchmarking systems have advantages and disadvantages. For instance, the simple normalization system is only applicable for small size referencing, and it cannot be used to run multi benchmarked elements. As the benchmarked system developed using the DEA method or model-based method is only applicable for the referenced building and to perform a performance study after a certain time, calculations have to be run again by the same user. On the other hand, OLS and SFA methods can be used by different users and allows for a larger sample size of elements to be referenced. The ANN system method was a proposed as an ideal solution to overcome inefficiencies in the other systems, yet it has not been integrated or tested in a real benchmarked project [90].

Hotel facilities are considered one of the most extensive sectors in buildings that use vast amounts of energy. The type of activity in hotels requires double use of energy compared to other buildings of the same size and height [91]. In addition to the extensive use of energy in hospitality buildings, they also have an adverse effect

on the surrounding environments through the discharge of greenhouse gases, waste water, and green pollution in general [92]. A study on benchmarking energy consumption and greenhouse gas emissions in a hotel building in Singapore showed that carbon intensity ranking is rather sensitive to the normalizing denominator chosen. Therefore, carbon intensity estimated for the hotels must not be interpreted arbitrarily [92].

There are different methodologies and procedures applied to benchmark facilities performances in the industry. The common way of analyzing buildings performances according to benchmarked system is by assuming a standardized reference for such analysis; however, each building has unique characteristics that cannot be analyzed according to a standardized benchmark system. According to [93], there are four benchmarking methodologies to compare projects to each another; those approaches are averages, medians, simple ranking benchmark, normalized ranking benchmark, customized benchmarking system, and model-based benchmarking.

Average comparisons in benchmarking systems are quick, easily implemented, and most suitable for comparing energy efficiency in similar projects. However, while comparing similar buildings the energy use in one of them might be significantly high and as a result the averages benchmarking obtained is not accurate.

Median benchmarking systems are less sensitive to extremes, but buildings' energy performance might be either below or above the median benchmark used [92]. However, precautions for such an issue should be taken into consideration in order not to limit the benchmark results.

On the other hand, a ranking benchmarking system is considered better compared to averages and medians systems. The reason is because ranking benchmarking systems rank buildings' energy performances in a distribution curve, which provides better comparisons between different groups of projects that ideally have the same characteristics. According to Bordass, building energy performance that lies in the best quartile is noted as efficient practices for similar facilities to upgrade and improve their energy performances [94]. However, this ranking does not consider facilities' functionality and the difference in operation between the compared buildings. As a result, to achieve a fair, effective and accurate comparison, normalization of factors that causes inefficient comparison should be applied. The normalized ranking benchmark system offers great opportunities to normalize such

factors in buildings, and allow regression techniques to be applied which improve the normalization of factors [94].

The customized benchmarking system is an approach that enables comparing and analyzing individual areas compared to the overall performance of the building or similar areas in other buildings. In addition, the energy breakdown to end users and components can be applied through this type of benchmarking [95]. The reason for the rare implementation of this benchmarking approach is because of the huge amount of information, time, and effort needed to establish it.

The model benchmarking approach is a system that uses mathematical models to establish energy usage. This system is constructed through setting the minimum amount of energy to be used for certain components and the benchmark system compares the ratio of the set metric to the usage [96].

Chapter 3: Research Methodology

This research delivers a framework for benchmarking energy retrofit systems through building information modeling (BIM) for office buildings in climate zone 1. The combinations of building characteristics, BIM, and analysis of main energy retrofit through a developed benchmarking tool have been considered in the overall framework. The framework provides a methodology to compare possible energy reductions according to standard and sustainable conditions through retrofit analyses. The retrofit analyses have been developed in a tool that considers the main energy consuming systems, which are office equipment, lighting, and HVAC systems. The integration between laser scanning and BIM is also applied to capture the as-built existing condition of the building/floor and to provide the required data for analysis. In addition, an air conditioned office building in the UAE will illustrate each and every step of the proposed framework. The following sections will explain each stage of the developed framework, and the overall framework is shown in Appendix A.

3.1 Existing Building – Commercial (Office Type)

The literature review in Chapter 2 showed the significant benefits of retrofitting existing buildings. Therefore, the focus of this research is on commercial buildings and specially office-type buildings. The reason for this is due to the huge amount of energy consumed in those buildings, the ability to efficiently analyze the main energy consuming systems, and the great reduction results that can be achieved. Although retrofitting other types of commercial buildings is also beneficial, however, the developed approach and the aspects considered are only applicable to climate zone 1 office buildings.

3.2 Building Characteristics

The second stage of the framework focuses on the office building characteristics. Those characteristics are important for understanding the performance of the building, the effect of each aspect, and to assist in analyzing the existing building condition. While analyzing retrofitting projects, relying on benchmark analysis will allow faster and more accurate decision making, estimated outcomes, and achieve reduction targets by studying advanced procedures. The building
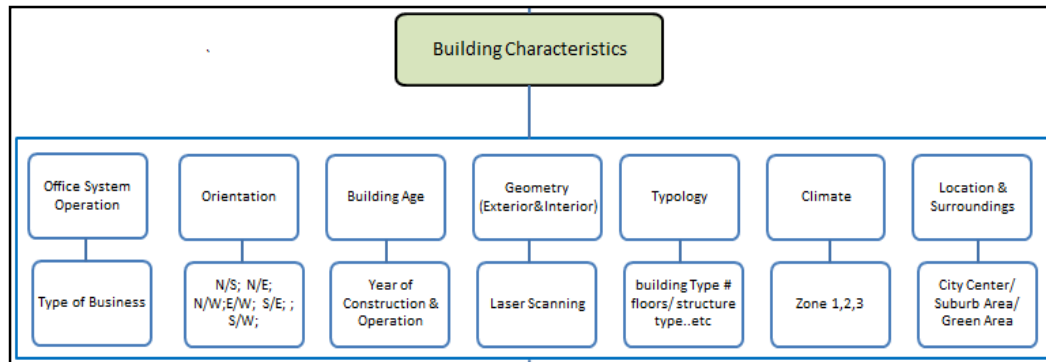
characteristics considered are shown in Figure 8.

Figure 8: Office building characteristics

3.2.1 Office system operation.

Office system operation refers to the type of activity being performed in the office space which is causing additional energy use. Understanding the specific activity helps in determining the approximate energy consumption for the equipment and estimating the internal heat gain. As an example, the energy performance of a recruitment office is different than the performance of a design consultant office, where computer rooms, heavy use of workstations, different types of printers, and people's activities in the office are all factors considered in the total energy consumption and internal heat gain (which is considered in the cooling demand).

3.2.2 Orientation.

Orientation of the building refers to where the building is located on the site according to the cardinal directions. Figure 9 shows building directions that can be elongated along the North-South, East-West, North-East, South-East, South-West, and North-West. As the sun path is very dynamic and changes its angle according to site altitude, or even day or time of year, the need to define the building orientation is important for understanding the effect of sun radiation on the exterior elements of the building which translates to the end energy performance. This effect is mainly related to the amount of heat and light entering the building through the exterior exposed elements that require a certain cooling/heating demand and lighting power density (LPD). The sun path also controls the desired U-value (heat transfer coefficient) of the building's exposed elements to meet certain performance requirements. In addition, the need to understand the sun path is fundamental in analyzing the possible

retrofit interventions for the building elements and determining whether the retrofitting outcomes will require an external source of energy to be implemented, such as passive heating and cooling systems, natural lighting, or PV panels.
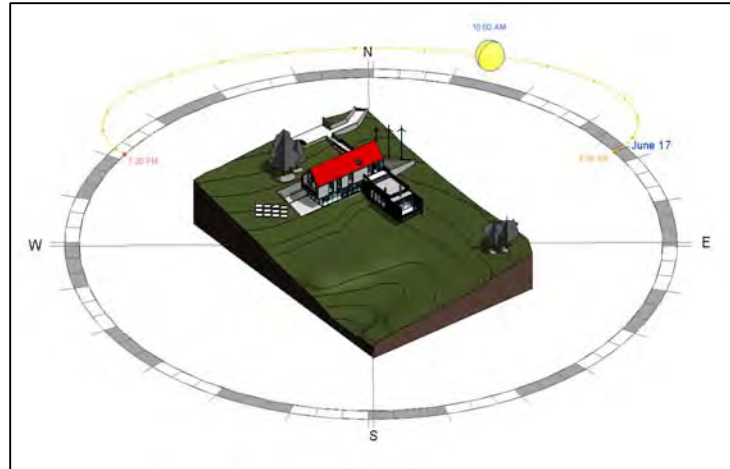

Figure 9: Example of orientation and sun-path study

3.2.3 Building age.

The building age states the time the building was constructed and started operation. The importance of determining the building age is to be able to understand the building regulations and codes conducted at the time it was designed and constructed, and also to be able to determine the materials, technologies and applied systems at that time. Determining the building age will assist in connecting the relation between the energy performances and benchmarking energy reductions of similar age buildings.

3.2.4 Building geometry.

The geometry of the building refers to both exterior and interior building properties which contain the features that energy design is based on. Such design properties are the layout, patterns, areas, volumes, heights, components and their existing condition; occupants, equipment, and lighting sources. The exterior building geometry defines the building shape, walls, roof, and external building components such as façade, windows, and architectural detailing. Those elements control the building envelope, and their properties are used to calculate the amount of heat gain/loss in the building. By determining the interior geometry, the estimated energy

demand can be calculated according to the interior existing condition of the building by inserting the required information in the benchmarking tool.

In order to capture the as-built existing condition of the building interior and exterior that might be changed or modified through the years, the use of laser scanning will be implemented in this study. Laser scans are considered to be one of the most efficient and accurate techniques for measuring and representing the building interior and exterior elements and their existing condition. Also, the scan results will be able to determine the level of use of the interior spaces, occupants, and machines. The way laser scanning works is by analyzing solid surfaces in the 3D environment, as each scanning point represents the scanned surfaces in million pixels with almost ± 2 mm ranging error, and with a measurement speed that can reach up to 976,000 pt/s [97]. Each scan results in millions of point clouds that are set according to the coordinates of the scanning point. Then, the overall points are combined in one 3D model where line segment detectors (LSD) are applied between the points. After applying the LSD, filtering and noise removing are performed to the combined scan model in order to reduce the file size, and to get a better visualization of the scanned elements. Once the point cloud model is ready, the result data is inserted into a BIM model in order to convert the points into accurate element representations and categories. Figure 10 presents an example of the 3D scans and the resulting BIM model.
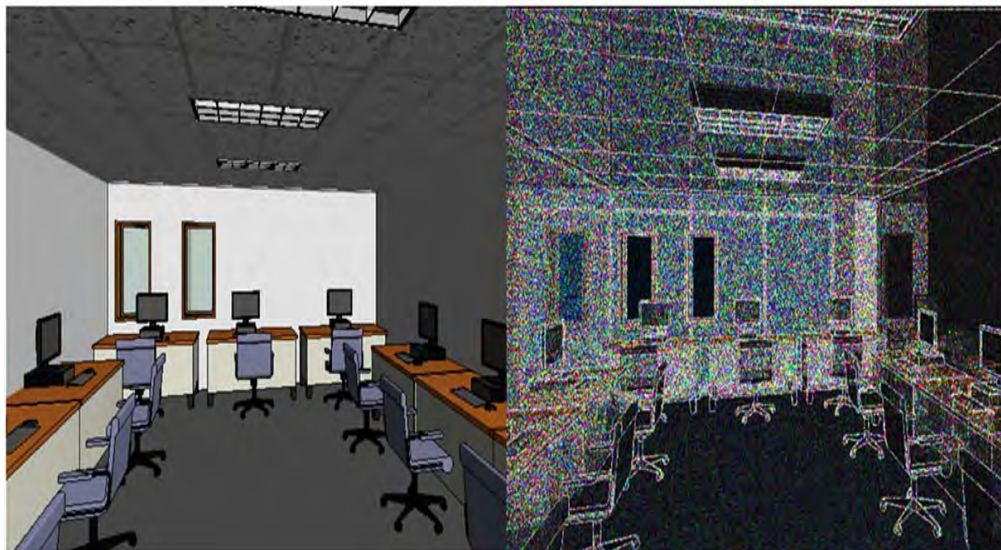

Figure 10: Laser scan and re-construction of points in BIM

3.2.5 Typology.

Building typology refers to the type office building, the number of floors, the structure of the building, and the operations' space utilization and working hours. The need to identify those typologies will be reflected in the retrofitting analysis and the required energy calculations. This study applies to the following listed office types, which are the most common types of climate zone 1 offices:

- Open office, central air conditioning
- Open office, split unit air conditioning
- Closed office, central air conditioning
- Closed office, split unit air conditioning

The structure of the office building refers to the way the offices are located, either they are around the inner parameter of the building next to the façade or in the middle of the building surrounded by the building structure. Determining the offices layout is important in order to set the benchmark analysis for the HVAC system, and the effect outside temperature on the required cooling demand. The following representations of the building heights are considered:

- Small office building: up to 3 floors
- Medium rise office: between 3 to 10 floors
- High rise office: higher than 10 story floors

The space utilization and number of working hours in offices are to be considered accurately since underestimating those factors will result in less energy supply than demand requires and inefficient energy calculations. In general analysis procedures, the office area is to be considered 100% utilized unless specified. As for the operation working hours, they are calculated according to the office occupants' use and the office policy of official timings, which are usually 9-10 hours/day and 5-6 days/week.

3.2.6 Location and surroundings.

Location refers to the building's geographical position (latitude and longitude of the building corners), and also the country, city, state, and region in which the building is located. The building can also be labeled by different context areas such as urban (city center, city) or suburban (suburbs, or rural area). The building's surroundings describes the type of neighborhood buildings, structures, agriculture, and fields. The location and surrounding information are important when analyzing

the building retrofit for energy reduction. In addition, the information will assist in understanding the relation between energy consumption and the location of the existing office building.

3.2.7 Climate.

Climate zone defines the division based on average temperature and rainfall through the year. In common practices, the division of climate zones follows ASHRAE Standards which are: very hot-humid or dry; hot-humid or dry; warm-humid or dry; warm-marine; mixed humid or dry; mixed marine; cold humid or dry or marine, very cold, subarctic [62]. Table 8 below refers to the ASHRAE climate zone types, and will be used in this framework for determining standard values for the specific climate zone.

Table 8: International climate zone [62]

International Climate Zone Definitions

Zone Number	Zone Name	Thermal Criteria (I-P Units)	Thermal Criteria (SI Units)
1A and 1B	Very Hot –Humid (1A) Dry (1B)	$9000 < CDD50°F$	$5000 < CDD10°C$
2A and 2B	Hot-Humid (2A) Dry (2B)	$6300 < CDD50°F \leq 9000$	$3500 < CDD10°C \leq 5000$
3A and 3B	Warm – Humid (3A) Dry (3B)	$4500 < CDD50°F \leq 6300$	$2500 < CDD10°C < 3500$
3C	Warm – Marine (3C)	$CDD50°F \leq 4500$ AND $HDD65°F \leq 3600$	$CDD10°C \leq 2500$ AND $HDD18°C \leq 2000$
4A and 4B	Mixed-Humid (4A) Dry (4B)	$CDD50°F \leq 4500$ AND $3600 < HDD65°F \leq 5400$	$CDD10°C \leq 2500$ AND $HDD18°C \leq 3000$
4C	Mixed – Marine (4C)	$3600 < HDD65°F \leq 5400$	$2000 < HDD18°C \leq 3000$
5A, 5B, and 5C	Cool-Humid (5A) Dry (5B) Marine (5C)	$5400 < HDD65°F \leq 7200$	$3000 < HDD18°C \leq 4000$
6A and 6B	Cold – Humid (6A) Dry (6B)	$7200 < HDD65°F \leq 9000$	$4000 < HDD18°C \leq 5000$
7	Very Cold	$9000 < HDD65°F \leq 12600$	$5000 < HDD18°C \leq 7000$
8	Subarctic	$12600 < HDD65°F$	$7000 < HDD18°C$

3.3 Development of As-Built BIM Model

Stage three of the proposed framework consists of developing an as-built BIM model, which represents the existing condition of the building's interior, exterior and characteristics. The reconstructions of the laser scanning results are integrated in this

stage of the framework. Actual representation of element sizes, naming, categories, parameters, and desired data to be extracted are assigned in this stage. Some of the extracted data and information from the BIM model are used in the benchmarking tool in order to analyze the existing condition of the building/floor. The as-built BIM model will also provide a base condition of the office building which will allow different retrofitting strategy analyses to be performed in further studies by the user. Also, the open platform integration of the BIM model will allow the export and import into different environmental analysis software, this is important when the intervention analysis decision is to use renewable energy. In this framework, the information extracted from the BIM model and used in the benchmarking tool analysis is shown in Figure 11.
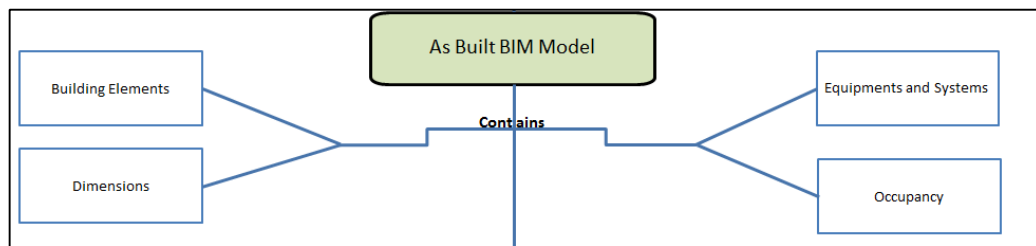
Figure 11: As built BIM model stage graphical representation

3.4 Analysis of Main Office Energy Consumption

The energy consumption in office buildings is mainly caused by office equipment, HVAC, and lighting systems; those three energy systems contribute to almost 90% of the total energy demand in offices [1]. Thus, the retrofitting analysis of those three systems can estimate the amount of the total achievable energy reduction. This analysis has been implemented in a developed benchmarking tool that performs separate and overall energy systems analysis. The aim of energy retrofitting in office buildings is to reduce the consumed energy while maintaining comfortable and workable conditions that meet occupants' needs. The total energy demand is reflected in the building/floor utility bill, which indicates the overall existing systems' energy performance. However, this performance does not indicate the breakdown of energy end use, where the utility metering represents the whole office floor or building. Thus, an extensive literature review on the amount of offices' end use breakdown was performed in Chapter 2. The reason for this investigation is to determine the possible range of percentages for climate zone 1 offices and to evaluate whether the outcomes

of the analytical framework are close to previous published studies. The percentages of the main energy consuming systems from the total demand in climate zone 1 office buildings are determined as follows:

- The use of 5-10% energy consumption for uncontrolled/accurately measured consumptions in offices (under a category named "others"). The percentage of others' energy consumption depends on the office operation and existing condition (the percentage is set at 5% in the developed tool, whereas it can be changed according to the tool user).
- Estimating the percentages of systems' energy use in an office floor, through capturing the office's existing conditions and calculating the percentage of use from the provided utility bill.

Moreover, in order to estimate the possible overall energy reduction, the developed tool will analyze the energy systems performance as follows:

- Normalizing the monthly utility bill consumption by dividing the total consumption by the total number of working hours per month or day (the unit will be in watts). The reason for this step is to eliminate the effect of fluctuation in energy consumption.
- Calculating the average of consumption.
- Analyzing each of the systems separately according to existing, standard, and sustainable conditions.
- Integrating the analyzed performance conditions for each of the systems to estimate the overall performance and possible reduction.

The following sections will introduce the procedure of analyzing the lighting, equipment, and cooling (HVAC) consumptions in the developed benchmarking tool.

3.4.1 Lighting energy.

In office buildings, lighting is considered the second main energy consuming system which accounts for almost 15-25% of the total energy use and the internal heat produced by the system. This heat is measured when the lighting design in buildings is accomplished, by determining the type, size, and performance of the chosen lights. While in existing office buildings, the designed lighting performance varies according to the type of performed operation, office geometry and characteristics. There are

different approaches to estimate the required lighting performance in office buildings, while in the case of existing buildings the best approach that will be followed in the developed tool is by determining the lighting power density (LPD). LPD is defined as the maximum lighting power per unit area [98]. The analysis of lighting energy performance in the proposed benchmarking tool will be performed according to the following steps:

1. Calculating the total power used by the existing lighting fixtures captured through the laser scans and by checking the types and power specifications of each.

2. Calculating the percentage of lighting energy usage from the total energy consumption (which is the utility bill meter), using the result of Step 1.

3. Estimating the existing LPD.

4. Calculating the standard and sustainable lighting consumption according to standard and sustainable LPDs.

5. Comparing the existing lighting performance with Step 5 results and estimating the amount of possible energy reductions (percentage difference).

3.4.2 Office equipment.

Estimating the power consumption of equipment and the internal heat produced are some of the challenges faced in the retrofitting analysis procedure. The reason is that the consideration of equipment performance and calculations are based on full utilization among the whole working hours of the day; therefore the resulting operation values will be overestimated. Capturing the accurate performance of equipment consumption is determined by extensive operation study and special metering that records an average rate of performance through the whole study period. However, there are different methods implemented in retrofitting analysis which overcome this challenge. One of the methods is by considering full utilization of the equipment and adjusting the values by considering a reduction factor of 0.85 [98]. Another method, which is considered in this framework, suggests normalizing the consumption values and setting the analysis and percentage differences to the normalized consumptions [1], [65]. The consumption of office equipment is estimated to vary between 10-20% of the total energy demand in office buildings (according to questionnaire results and the literature review). The following steps are considered in order to perform the energy retrofit analysis of office equipment:

1. Calculating the total energy consumed by the existing equipment captured through the laser scan by investigating the rated energy consumption in watts on the equipment, or by referring to the ASHRAE 2009 Standards.

2. Estimating the percentage of existing equipment energy usage from the total energy consumed by dividing the step 1 result by the total normalized energy consumption from the utility bill.

3. Quantifying the number of Energy Star rated and non-rated equipment.

4. Estimating the possible consumption of Energy Star rated equipment.

5. Comparing the amount of possible advanced energy consumption if Energy Star rated equipment is used (compared to non-rated) in the existing condition, and then calculating the percentage difference between both consumptions.

3.4.3 HVAC system (cooling energy) analysis.

In HVAC system analysis, determining the existing heat transfer coefficient (U-value) of the building's exposed elements is considered one of the most significant indicators of the HVAC system performance. The U-value is defined according to ASHRAE standards as the amount of transmitted heat in time through material unit area in watts/m^2/°K caused by the difference in temperature between inside and outside [98]. Enhancing the U-value of the exposed elements is one of the retrofitting procedures followed instead of replacing all the components or demolishing the existing ones. The enhancement of the U-value is achieved by improving the insulation of the exposed elements to reduce the heat gain from the environment and to maintain the supplied cooled air temperature. In this study, the analysis of the effect of the U-value on the total cooling demand will be examined in the developed tool. This examination will begin by determining the existing U-value in terms of $U_{adjusted}$, which is affecting the existing cooling demand (in addition to the internal heat gain by lighting, equipment, people, and others). Then it will compare the results of improving the U-value to the total HVAC energy consumption by using standard and sustainable values. The following equations will be used to calculate the required heat removal load (cooling demand) in building floors and the existing $U_{adjusted}$ value [98], which are created in the tool [98]:

$-\quad Q_{Cooling} = \sum UA\,\Delta t_{(for\ each\ of\ the\ exposed\ elements)} + Q_{(Total\ internal\ heat\ gain)}$

- $Q_{Cooling} = (((\sum_{Wall\,i}^{Wall\,n} UA) + (\sum_{Window\,i}^{Window\,n} UA) + \sum_{Element\,i}^{Element\,n} UA)) + \Delta t +$
  $Q_{Lighting\,Heat} + Q_{equipment\,heat} + Q_{people\,heat} + Q_{heat\,from\,other\,energy\,consumers}$

- Since: $\sum UA\,\Delta t_{(for\,each\,of\,the\,exposed\,elements)}$ can be equal to $U_{adjusted} * \Delta t \sum A$

- Where, $U_{adjusted} = \dfrac{U1A1 + U2A2 + U3A3 + \cdots + UnAn}{A1 + A2 + A3 + \cdots + An}$

- Hence, total Q $_{(Cooling)} = U_{adjusted} * \Delta t \sum A + Q_{lighting\,heat} + Q_{equipment\,heat} +$
  $Q_{people\,heat} + Q_{heat\,from\,other\,consumers}$

Qcooling = the total heat removal (cooling load) required, *A* = area of exposed wall or window, *U* = heat transfer coefficient of each element, *Uadjusted* = averaged U value of the exterior elements, *Δt* = Difference between inside and outside temperatures, *Qlighting heat* = internal heat gain from lighting, *Qequipment heat* = internal heat gain from equipment, *Qpeople heat* = internal heat gain from occupants utilizing all rooms to max capacity, *Qheat by others* = internal heat gain from other electrical equipment usages.

According to the literature review in Chapter 2, the HVAC system in climate zone 1 office buildings consumes almost 45-60% of the total energy demand. Once the percentages of the existing lighting and equipment are determined, and by fixing a 5% rate for other uses, the percentage of the existing HVAC energy consumption can be determined. Then by multiplying the percentage of HVAC consumption by the total utility bill meter, the resulted outcome refers to the amount of electrical power consumed by the HVAC system. This electrical power is then converted to cooling load produced by multiplying the resulting value with the coefficient of performance (COP) of the chiller equipment, and by a reduction factor of 20% which is related to the usual factor of safety considered in design and other consumptions of internal equipment in the air handling unit (AHU) [98]. The COP factor is defined as the ratio of the heat removal (cooling supply) to the rate of energy input [98]:

$$COP = \frac{HEAT\ Removal\ (Cooling\ Load)}{Power\ Input}$$

The COP factor of the chiller equipment can be found attached on the equipment, which is usually on the roof of the building, or by investigating the equipment supplier specifications. Once the total heat load removal (cooling load) of the existing condition is determined, and the internal heat gain from lighting, equipment, people, and others are also calculated, then the U-value of the existing condition can be

determined as [98]:

$$U_{adj.} = \frac{Qcooling - Qlighting\ heat - Qequipment\ heat - Q\ people\ heat - Qother\ use\ heat}{\Delta t * \sum A}$$

3.5 Results analysis

Once the analysis for each of the systems' performance is accomplished, the tool will summarize the results in comparison tables and graphs for both separate and combined performances. Although the analysis is performed on each of the systems separately, the effect of lighting and equipment enhanced conditions on the HVAC energy is also considered and the final overall system's energy performance result will determine the amount of possible overall energy use reduction. If the analysis results were considered unsatisfying, then standard and sustainable reference values can be updated to reflect desired energy performance and consumption reduction.

Chapter 4: Analytical Framework

In order to illustrate the proposed framework methodology and the possibility of achieving energy reduction through retrofitting analysis by the developed benchmarking tool, a benchmarking for energy retrofit systems through BIM of an office building in Abu Dhabi, UAE (climate zone 1) will be conducted. The calculations and detailed analysis of the existing condition and systems' performance are conducted on one floor of the building. The outcomes and deliverables of this case study are:

- Prove the possibility of reducing energy consumption in existing office buildings by capturing the existing condition, performance of the systems, and retrofitting analysis through the developed benchmarking tool.
- Benchmark the percentage breakdown for energy end use in office buildings in climate zone 1, specifically in the UAE.
- Benchmark the resulting data of the retrofit analysis and the applicability of utilizing it for another office project.
- Building an as-built BIM model that represents the current condition of the building for future analysis or intervention studies by the owner.

The structure of the study will follow the research methodology outlined in Chapter 3. The reference pages used are attached in Appendix C.

4.1 Building Study

Al-Seham tower is a commercial office building located in the capital city of UAE (ABU DHABI). The tower is mostly used for corporate offices and other private entities. The main energy systems considered in the retrofitting analysis are office equipment, HVAC systems, and lighting. There are no physical interventions performed on the building in this study, as the procedure was only to analyze the current condition, and to identify the possibilities of reducing the energy consumption in one of the building's floors due to the existing performance by adapting the developed framework. The characteristics of the building are as follows:

Office System Operation: This study focused on one floor of the building (12th floor), which was occupied by TYFC Global marketing.

At TYFC the total number of occupants is 59 people, and the number of occupants fully utilizing all spaces is 85.

Building Age: The building was constructed in 1992 with regular annual maintenance since then. TYFC Global started operation in Al-Seham tower in 1996.

Climate zone: According to climate zoning standards [62], the weather conditions in the UAE are considered to be climate zone 1, which represents a very hot Dry/Humid condition.

Orientation: The orientation of the building according to the sun path is N/E and illustrated in Figure 12.
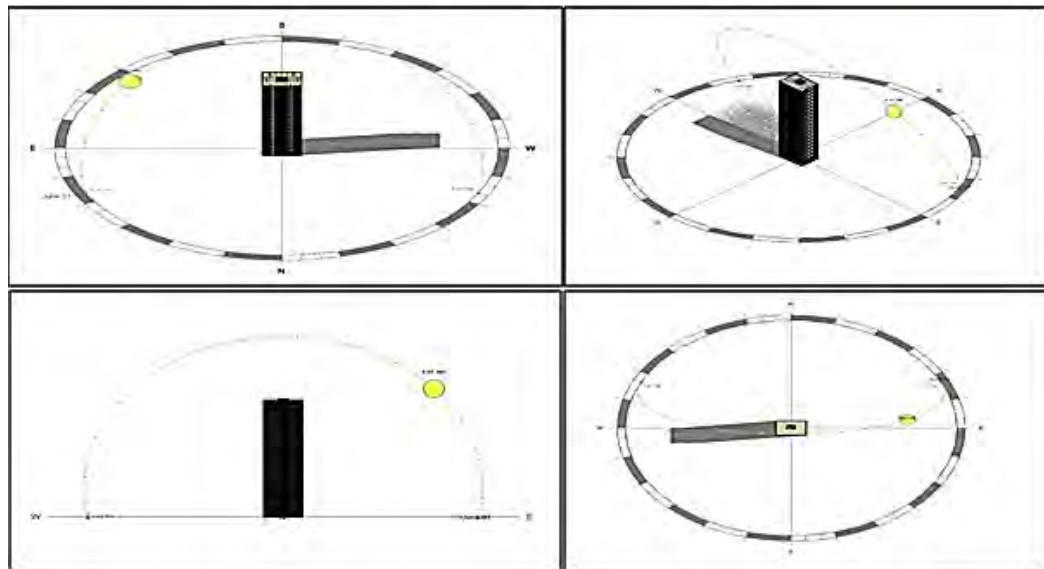
Figure 12: Building orientation and sun-path

Typology: The building is considered to be a high rise office building which consists of 20 floors, and with central air conditioning systems. The studied 12th floor of TYFC Company is a closed office type, where offices are located next to the façade and elevators and stairs are in the middle (the layout of the office building is shown in the BIM results part). The official working hours are 9.5 hrs/day 5 days/week.

Location and Surroundings: The building is located in the Abu Dhabi city center area (Al Markezeyah region) surrounded by a mix of commercial and residential buildings next to the street.

Geometry: In order to capture the geometry characteristics of the building exterior, and the existing interior condition of the studied floor, two 3D laser scanning devices

were used with a scanning range of 0.6 – 130 and 330 m, respectively. The laser scanning was applied to each surface, room, ceiling, and corridor in the floor with different angels to get accurate results. As explained in the research methodology, each scan is set to the scanning point coordinates and the overall scans are combined in one 3D point cloud model to be imported to a BIM program for reconstructing the surveyed points. However, before importing the laser scan results into BIM, there was a need for refining and removing noise from the scans in order to decrease the file size and to allow accurate reconstruction of the points. Examples of the final scanning results of the interior and exterior are shown in Figures 13 to 16. Figure 13 shows the laser scanning survey of the building exterior and surrounding from a street view point, whereas Figure 14 shows a part of the scanning range results of the front elevation of the building. This scan is done similarly to the other elevations of the building.
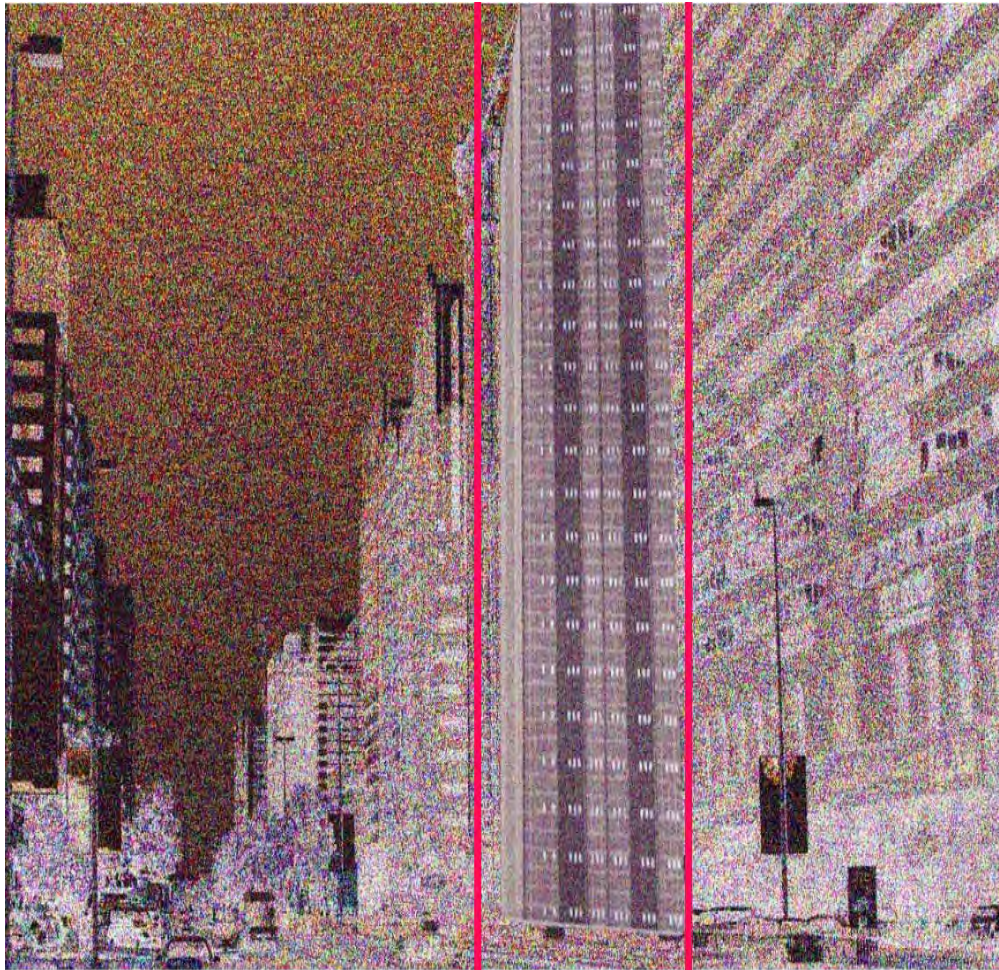
Figure 13: Laser scan of building exterior and surrounding
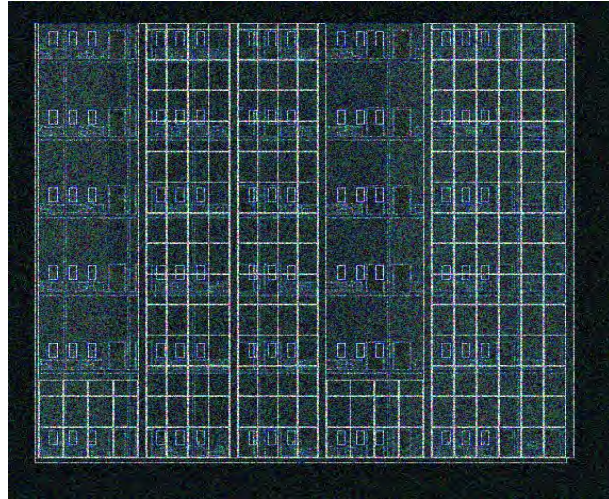
Figure 14: Laser scan - building exterior front elevation

Figures 15 to 17 illustrate examples of the laser scanning results for two offices and corridor areas in the analyzed floor. Those scans represent the as built condition of the interior elements as points, where the actual elements representation such as building elements, furniture, and systems are reconstructed in the BIM model.
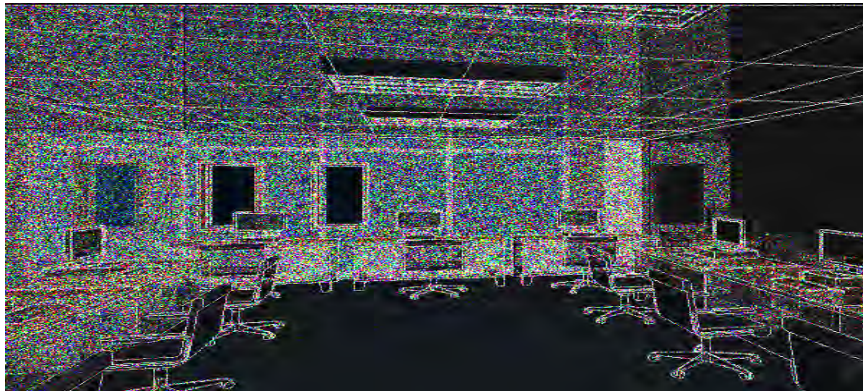
Figure 15: Laser scan of office interior
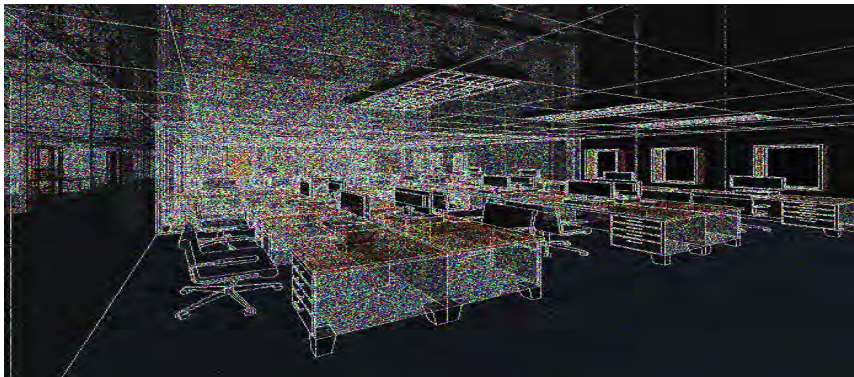
Figure 16: Laser scan of office building interior
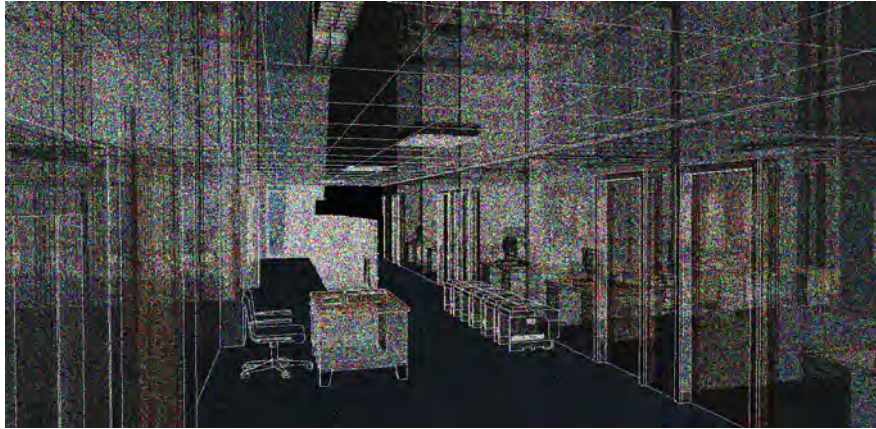
Figure 17: Laser scan of office corridor

Development of As-Built BIM Model: After capturing the existing condition of the building exterior and interior by the 3D laser scans, the overall 3D point cloud model was imported to Revit software. Revit is one of the leading BIM intelligent software packages, where accurate representation of elements, categories, sizes, equipment, fixtures, occupants and structures are assigned, modeled and documented in quantity reports. Those reports were used to analyze the current energy consumption breakdown, and provide data to estimate and calculate the possible reduction. Such data include areas, volumes, count of elements, etc. In addition to the benefits of integrating the 3D laser scans and BIM, all the building characteristics that are gathered are inserted to establish an as-built 3D BIM model. This model can be further used to study possible interventions and applicable retrofitting procedures to be applied. However, this study focuses on using the BIM model for retrofitting analysis only. Retrofitting analysis refers to the extraction of specific information related to the building/floor characteristics. Figures below 18 to 24 represent the results of the developed BIM model from the building characteristics and the reconstruction of the laser scanning points. Figure 18 shows the inserted characteristics information (location, weather data and site) of the building in the BIM model. The location is Abudhabi city center-Al markazeyah area, and the assigned weather data is from Al-Bateen metrological station. This information will assist in further analyses studies for the suitable renewable sources of energy to be implemented by the owner. Figure 19 represents the result of reconstructed laser scanning survey data of the exterior building façade in the BIM model. Whereas, the comparison of the interior office area developed through BIM software and the laser

73

scanning results can be seen in Figures 20 and 21.The reconstruction and elements representation are illustrated in both comparison Figures.
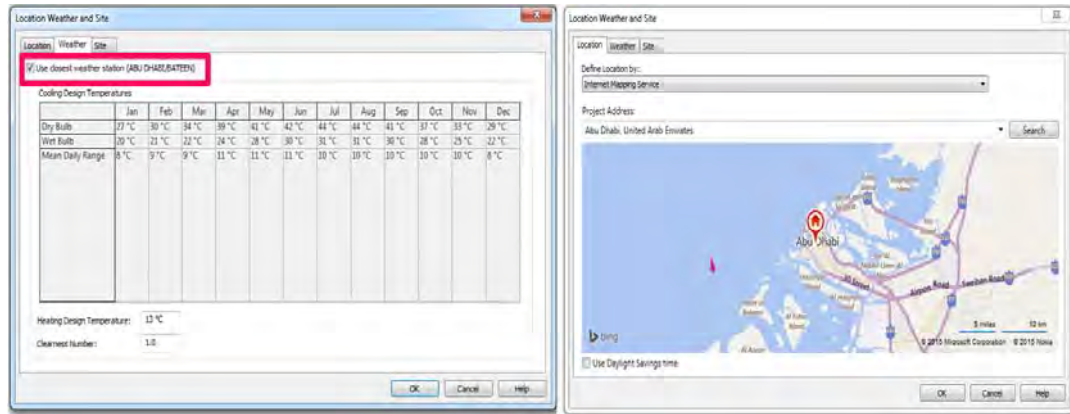
Figure 18: BIM model-building location, weather data, and site
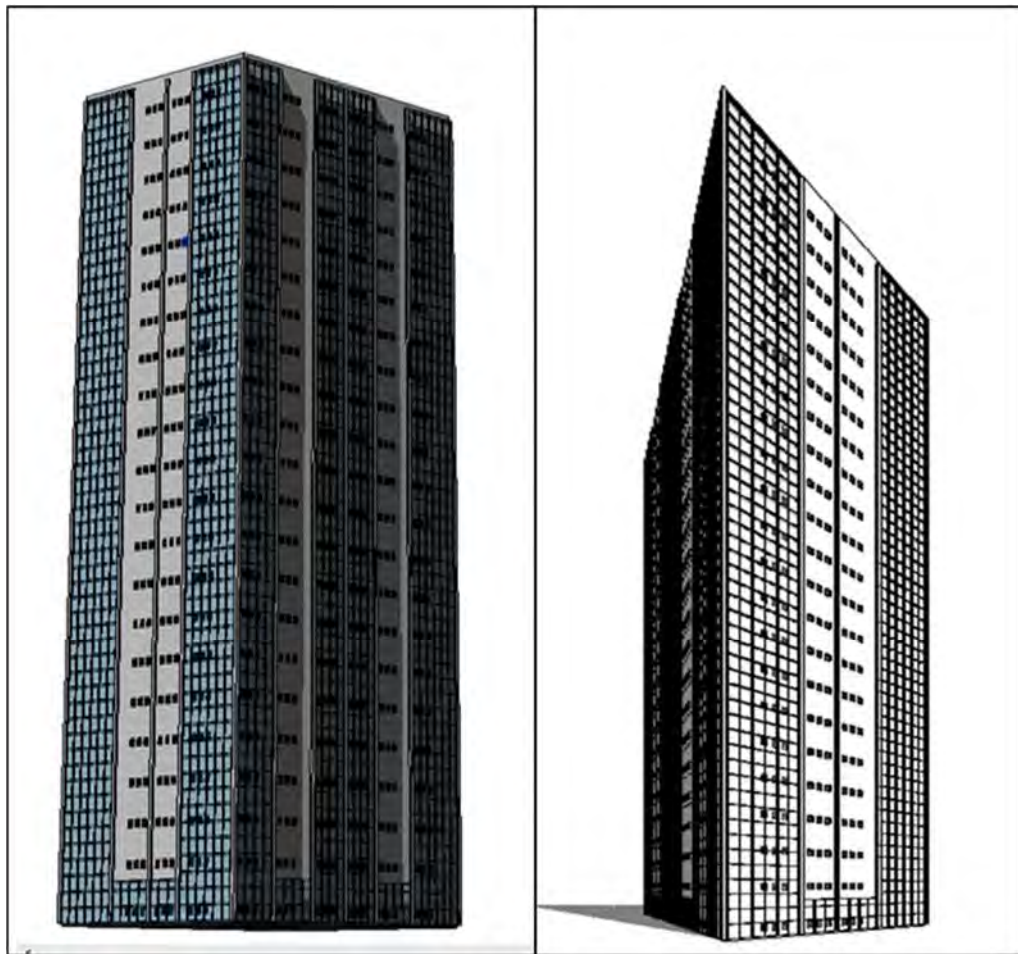
Figure 19: BIM model –building 3D elevation view
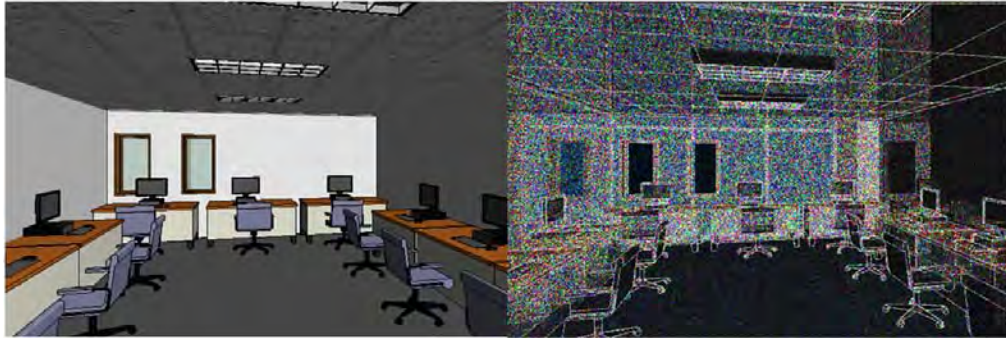
Figure 20: Interior office BIM VS laser scanning results
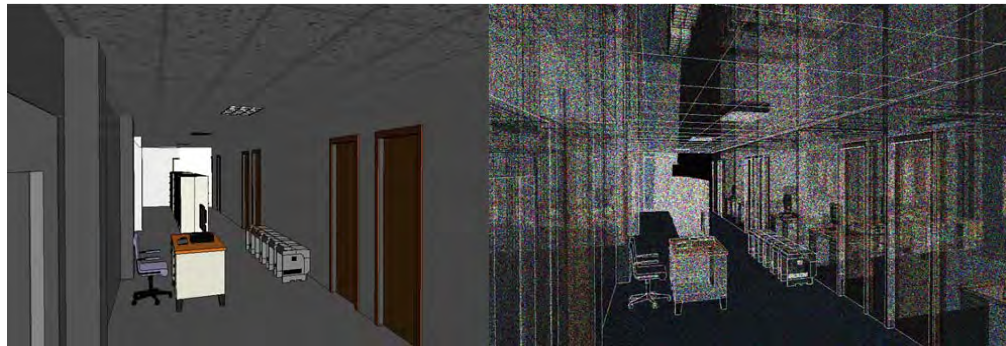
Figure 21: Corridor BIM VS laser scanning results
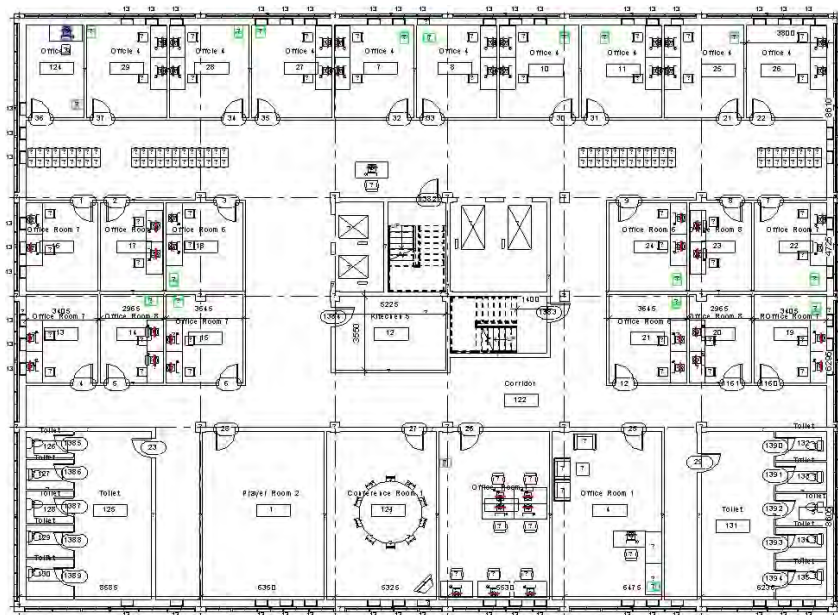
Figure 22: BIM model – office floor layout and office equipment

Figure 22 represents the results of the office floor layout developed in the BIM model. Computers, monitors, and printers found in the office are indicated on the plan and the total quantity of them are extracted and shown in Figure 23.

<Generic Model Schedule>			
A	B	C	D
Type	Count	Description	Comments
Desktop comput	55	Monitor and workstation	95 Watt per Desktop computer + 4x$0 Watt Laptop

<Electrical Equipment Schedule>		
A	B	C
Type	Count	Wattage
Dell_Color_Laser_Printer_5110cn_3303	15	135

Figure 23: BIM model–snapshot of office equipment schedules (computers & printers)
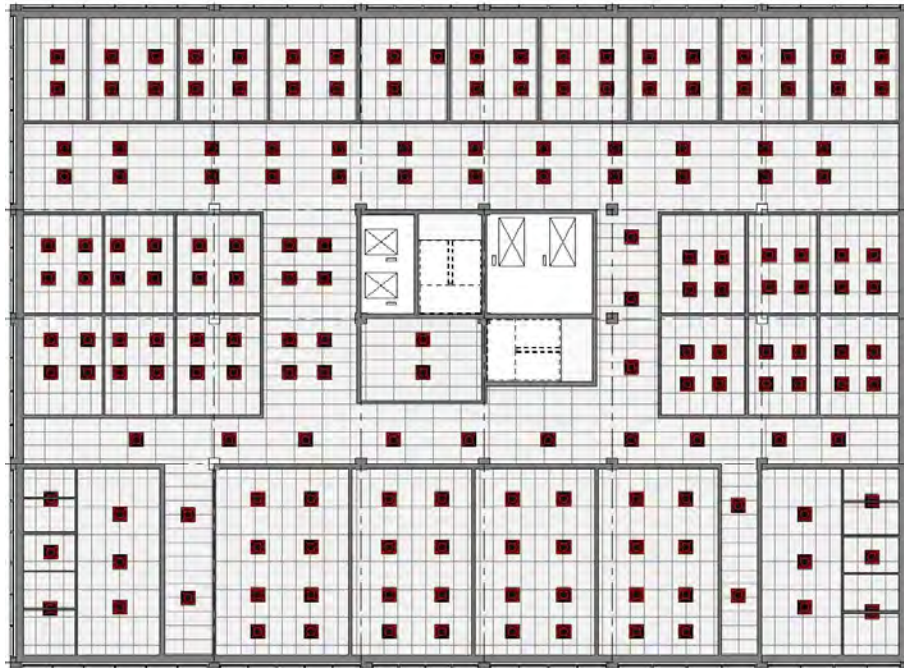
Figure 24: BIM model – ceiling plan lighting fixtures view

<Lighting Fixture Schedule>				
A	B	C	D	E
Type	Count	Efficacy	Wattage	Lamp
0600x0600mm(2 Lamp) - 277V	180	60 lm/W	40 W	T-12

Figure 25: BIM model – lighting fixtures extracted schedule

Figures 24 and 25 above presents the lighting fixtures layout and schedule respectively. The data extracted from the BIM model is used in the lighting system benchmarking analysis. Figure 26 illustrates the area information extracted from the BIM model and used in the developed benchmarking tool analysis. The areas indicated in the schedule snapshot are the total office floor gross area and the excluded area (lifts and Stairs). In addition, Figure 27 represents the 3D cut section of

the analyzed office floor in the office building.

<Area Schedule (Gross Building)>		
A	B	C
Area	Comments	Name
987 m²	Gross Floor Area of energy analysis	Total FloorArea
57 m²	Excluded Area of Stairs and Elevators	Excluded Area

Figure 26: BIM model – area schedule snapshot
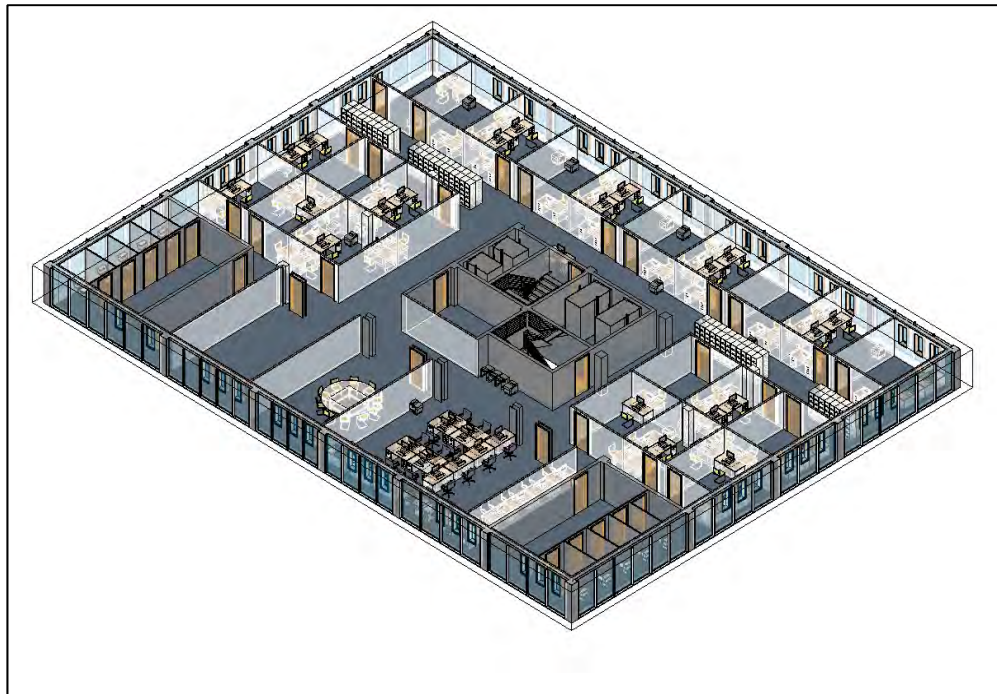
Figure 27: BIM model - 3D views of interior

Analysis of main energy consumption: The retrofitting analyses for the three main energy-consuming systems in the 12th floor (TYFC company) office are HVAC, lighting, and office equipment. A 4-months utility bill of energy consumption was provided by the office representative; however, this information does not include an energy end use breakdown since the meters are set for the whole office floor. The energy readings of the 4 months are as follows: 11,693,215 W/month, 11,636,182 W/month, 11,652,369 W/month, and 11,673,546 W/month. In order to capture the most accurate existing performance and to get better representative values of the existing condition, the average of those consumptions were taken and then normalized to watts. Normalizing the average value is done by dividing the total average consumption by the number of working hours in a month. According to TYFC, the

official working hours per month are equal to 190 hours. Thus, the average normalized value is equal to:

$$\frac{\sum(11693215 + 11636182 + 11652369 + 11673546)}{4 * 190} = 61389\ W$$

In addition, the COP factor of the chiller equipment which was based on the roof was equal to 2; this value refers to the efficiency of the cooling load to energy input. The office floor's gross area was equal to $987m^2$, the total exposed wall area was equal to $774m^2$, and the total exposed window area was equal to $40m^2$.

The analysis calculation of the existing lighting and office equipment consumption results were used to estimate the percentages of energy use from the total average energy consumption indicated in the utility bills. The estimated percentages were found to be almost 23% for lighting and 17% for office equipment. Also, by setting the "others" category consumption to be 5%, the resulting percentage of HVAC system energy use was calculated to be 55%. The estimated percentages of the existing office energy condition are considered acceptable since they are within ± 5% of the ranges found in the literature review. The reason for this difference is related to the country's weather conditions and the traditional office building design in the country. Figure 28 illustrates the percentages found for the energy end use break down. The obtained percentages are used in the calculations of the next sections (HVAC, lighting, and equipment).
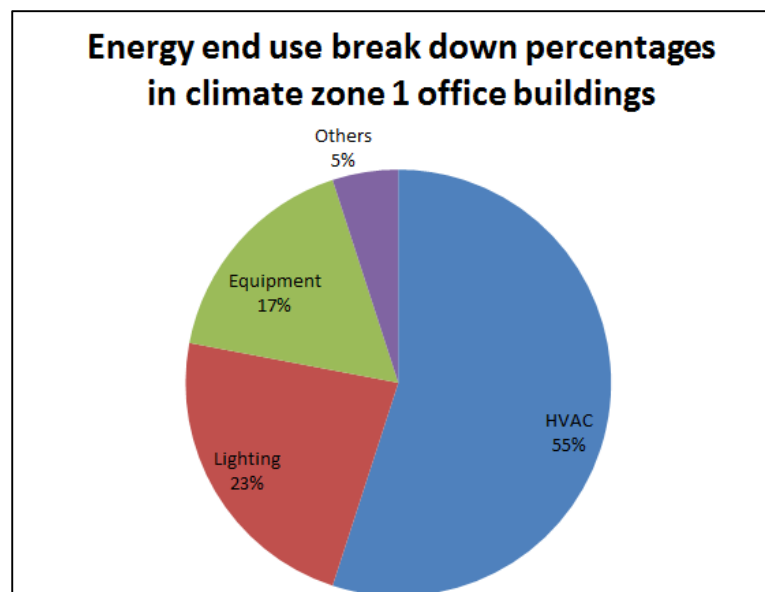
Figure 28: Climate zone 1 office buildings energy end use

Analysis of Lighting Energy: According to the integrated laser scanning and BIM results, the number of lighting fixtures (Troffer) existing in the office are 180 fixtures with 2 lamps in each (see Figure 22). The type and energy of lamps are investigated manually and found to be T12 fluorescent lamps of 40 watt/lamp. Table 9 illustrates the retrofitting analysis calculations on the potential energy reduction of lighting energy, as the percentage difference between the existing condition compared to standard, and sustainable requirements proves the possibility to achieve better energy performance. Also it is important to demonstrate that the amount of heat gain is reduced with the reduction of energy. This reduction in heat gain will decrease the cooling demand of the HVAC system, and increase the efficiency of the heat load removal. The sustainable lighting requirement calculations utilized the lighting power density value published by Estidama [99] and the existing lamps, yet greater reductions in both energy and heat can be achieved by implementing advanced lights such as tube LED lights. LED lights consume almost half of the fluorescent tubes' energy and internal heat gain [1]. The difference in lighting consumption between the percentage in the utility bill and the number of estimated fixtures is due to the rounding of numbers and the assumption of fixed working hours per month. The summary of energy consumption and the percentage difference for each of the conditions are shown in Figure 29.

Table 9: Lighting energy benchmark calculation

Utility Bill Lighting energy	Existing Lighting energy
61389*23% = 14119.5 W	**180*2*40 = 14000 W**
Avg. $= \frac{14119.5+14000}{2} = 14059.75 \cong 14060$	
The Lighting power Density $= \frac{Total\ energy}{Gross\ area} = \frac{14060}{987} \cong 14.25\ W/m2$	
Heat Gain from existing Lighting condition is 14060 W	
Existing Lighting monthly consumption=14060*190 hr/month =2,671.4 KWhr/month	
Standard lighting Consumption in offices [98] = 12 W/m2	
Standard Lighting monthly Energy = 12*987*190 = 2,250.36 KWhr/month	
Heat Gain is 11844 W, Percentage difference = 17.11%	
Sustainable lighting Consumption in offices [99] = 9.7 W/m2	
Sustainable lighting Monthly Energy = 9.7*987*190 = 1,819 KWhr/month	
Heat Gain from is 9574 W , Percentage difference = 37.97%	
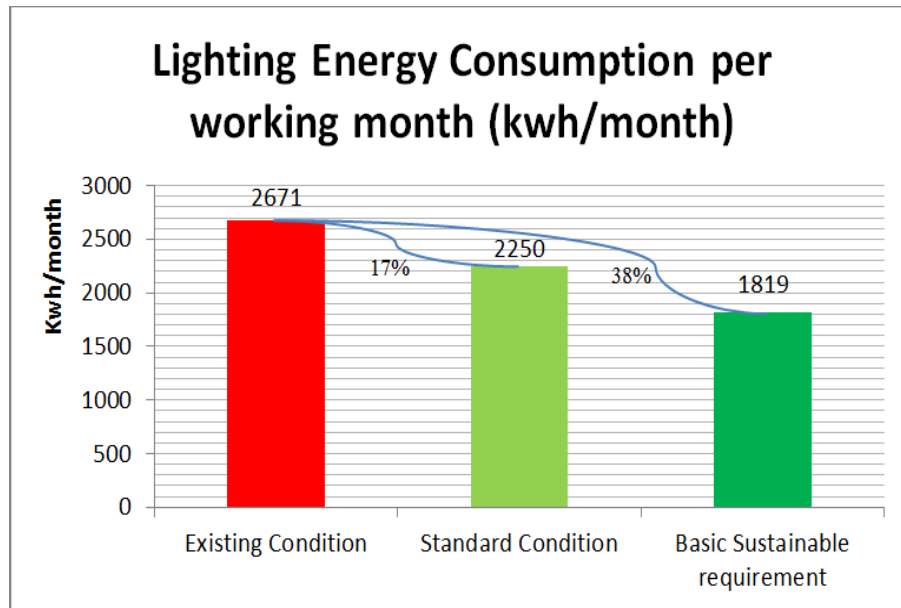
Figure 29: Lighting energy consumption

Analysis of Office Equipment Energy: Similar to the lighting analysis, the calculated energy consumption of office equipment is based on the volume of equipment captured through the existing condition scan of the office floor and illustrated in the BIM results. The amount of this consumption is then converted to a percentage of use from the total average utility bill. The percentage of equipment use of energy in the office was estimated to be 17% of the total energy consumption. Table 10 summarizes the equipment found in the TYFC office and the calculation analysis. The difference between utility bill consumption and captured condition calculation consumption is due to the fluctuation of usage and the standby/sleep condition of the equipment.

However, the average of both consumptions was taken in order to calculate the existing performance of the office and to use the value in the cooling energy analysis. The estimate of existing equipment performance efficiency was based on ensuring that an Energy Star tag exists, where almost none of the surveyed equipment had Energy Star rating tags on them except the refrigerator and microwave. The advanced consumption wattage refers to Table 4 in Chapter 2 [65]. Although it is difficult to control equipment performance to achieve a specific consumption target, it is more important to determine the amount of heat gain from equipment usage. The amount of heat produced is balanced by the amount of heat load removal.

Table 10: Office equipment energy benchmark calculation

Existing Equipment Consumption					Advanced Consumption	
Equipment	Qty.	W/Equip.	Total (Watt)	Utility Bill	W/Equip	Total
Computers (Desktops & Monitors)	55	95	5225	61389*17% = 9822.24 (Watt)	78	4290
Laptops	4	40	160		17	68
Multifunction Printer	15	135	2430		100	1800
Projector	1	274	274		230	230
Copy Machines	1	800	800		600	600
Fridge (0.4m3)	1	690	690		690	690
Microwave	1	600	600		600	600
Water Cooler	1	700	700		406	406
Total Consumption (Watt)			10474	10436.13	8684	
Average Consumption (Watt)			10455			
Internal Heat Gain from equipment is considered as (Watt)			10455		8684	
Total Monthly Consumption (KWh/month)			1966.6		1649.96	

Analysis of Office Cooling Energy: The consumption of the HVAC system from the total energy usage was estimated to be 55%. This consumption provides heat removal (cooling load) to the office space, which is mainly caused by the effect of the building's thermal envelope and heat gain from lighting, equipment, people, and other energy consumptions in the space. As the U-value of the exposed elements is considered to be the main indicator of system performance, the followed reverse calculations were performed in order to determine the existing U-value. The existing U-value will be found based on Uadjusted which was explained in the research methodology. Since the information related to number of people, lighting, and equipment were obtained and calculated in previous sections according to the existing condition, the resulting Uadjusted value will control for the performance of the system.

As mentioned earlier, the COP factor of the chiller equipment was found to be 2 by investigating the equipment on the roof. Also, a reduction of 20% from the total

consumption was applied. This reduction is due to the design safety factor which is always considered while calculating the cooling load, and due to the energy consumed by the fans, motor, compressor, and pumps of the air handling unit (AHU) [98]. The difference in temperature was taken as the worst case which is 50° outside. Table 11 illustrates the results of calculating the Uadjusted value.

The results of the retrofitting analysis of cooling energy and enhancement of floor exposed elements' thermal conductivity, showed in the table above, have proven the potential energy reduction of the existing condition. The percentage difference between the existing condition compared to standard and sustainable requirements proves the possibility to achieve better energy performance and greater savings. The analysis for both standard and sustainable conditions was based on using the same chiller equipment while enhancing the exposed elements' insulation. Changing the existing chiller to advanced performance with higher COP will result in significant reductions in both energy consumed and money spent on bills. Also, the calculation results were conducted only on the effect of cooling load and energy used, without considering the standard and sustainable reductions from lighting and equipment. The summary of the total energy consumed for cooling in KW-hr/month for each of the conditions, and the percentage difference are shown in Figure 30.
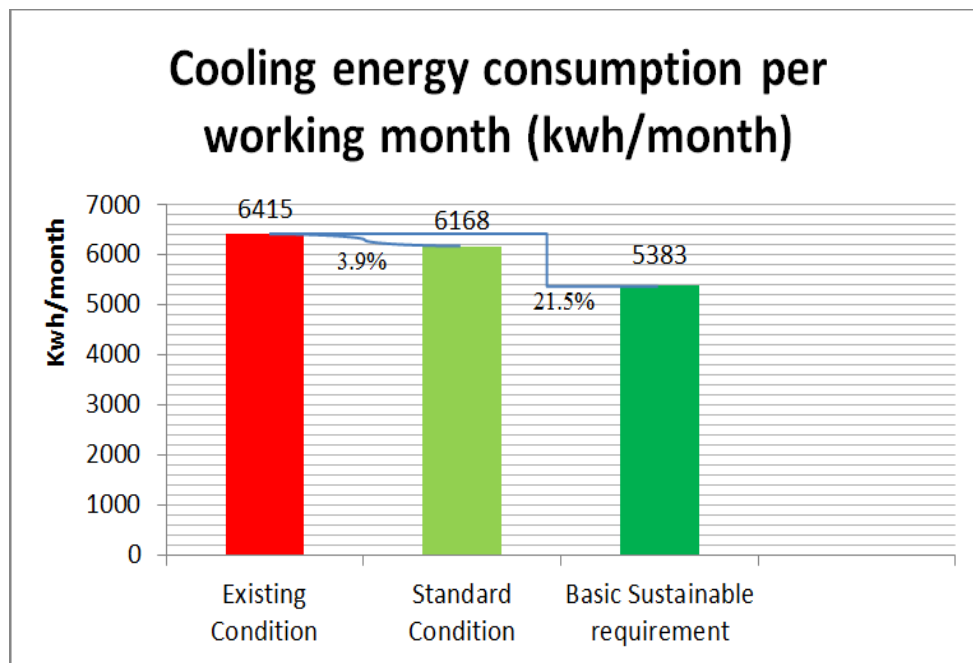
Figure 30: Cooling energy consumption

Table 11: HVAC energy benchmark calculation

Existing Uadjusted calculations				
Floor Avg. Utility Meter (Watt/month) =			61389	
Consumption	HVAC	Lighting	Equipment	Others
Percentage use	55.00%	23.00%	17.00%	5.00%
Energy Used (Watt)	33763.95	14119.5	10436.13	3069.45
Energy calculated from existing condition scan results (Watt)	-20%	14000	10474	
Energy consumption Used to find Uadjusted (Watt)	27011.16	14060	10455	3069.45
Heat from People, occupying all rooms (Watt)	85pp*115watt/pp = 9775			
Δt°& Exposed area (m2)	28° & 800 (wall = 774, window = 40) m2			
Existing Uadjusted (W/m^2/°K)	$=\dfrac{27011.16*2-14060-10455-3069.45-9775}{814*28}=0.731$			
Standard Uadjusted Cooling energy calculations				
Exposed wall and windows U-values = 0.57, 2.1 W/m^2/°K, respectively. Source: Dubai building code specification [100]				
Standard Uadjusted $=\dfrac{(0.57*774+40*2.1)}{814}=0.64$				
Qcooling = (0.64*814*28)+(14060+10455+3069.45+9775) = 51946.33W				
Energy input for Standard Qcooling $=\dfrac{51946.33}{2*0.8}=32466.46\ W$				
% Difference $=\dfrac{33763.95-32466.46}{(33763.95+32466.46)/2}*100\cong 4\ \%$				
Sustainable Uadjusted Cooling energy calculations				
Exposed wall and windows U-values = 0.29 & 1.5 W/m^2/°K, respectively. Source: Estidama RE-2 Requirements [101]				
Sustainable Uadjusted $=\dfrac{(0.29*774+40*1.5)}{814}=0.35$				
Qcooling = (0.35*814*28)+(14060+10455+3069.45+9775) = 45336.65W				
Energy input for Sustainable Qcooling $=\dfrac{45336.65}{2*0.8}=28335.41\ W$				
% Difference $=\dfrac{33763.95-28335.41}{(33763.95+28335.41)/2}*100=17.48\ \%$				
Summary of Cooling load required KWh/month				
Existing = 10,264.23		Standard = 9,869.8		Sustainable = 8,613.96

Overall performance and systems energy analyses results: The retrofitting analyses of the energy systems have proven a certain amount of consumption reduction for each of the analyzed conditions. This reduction was illustrated by considering each of the systems separately. In order to estimate the overall performance of the analyzed office floor and the possible overall reduction in energy consumption, the integration between the results of the standard, sustainable, and advanced conditions of lighting, cooling, and office equipment energies are considered. The effect of enhancing both the lighting and equipment will reduce the amount of heat generated, which is accounted for in the cooling calculation. Table 12 summarizes the benchmarking tool results of each of the systems condition consumption, the integrated HVAC performance, and the overall energy systems consumption. Figure 31 combines the overall performance of the retrofitting analyses by the developed tool and illustrates the possible energy reduction. (Note: the advanced equipment energy consumption is used in both the Standard and Sustainable conditions).

Table 12: Overall cooling load energy

Separate Energy Systems Analyses Results			
Energy/Condition	Existing (W)	Standard (W)	Sustainable (W)
HVAC	33763.95	32466.46	28335.41
Lighting	14060	11844	9574
Office Equipment	10455	8684	8684
Total	58278.95	52994.46	46593.41
Percentage Difference		9.50%	22.29%

HVAC System Energy Performance by Integrating Lighting and Equipment Enhanced Conditions			
Condition	Existing	Standard	Sustainable
HVAC Energy Consumption (W)	33763.95	29974.6	24424.8
Percentage Difference		11.89%	32.10%

Overall Energy Systems Analyses Results			
(By Combing the enhancement condition for each of the systems)			
Condition	Existing	Standard	Sustainable
Energy Consumption (W/month)	11656196	10178689.5	8692927.5
Percentage Difference		13.53%	29.12%
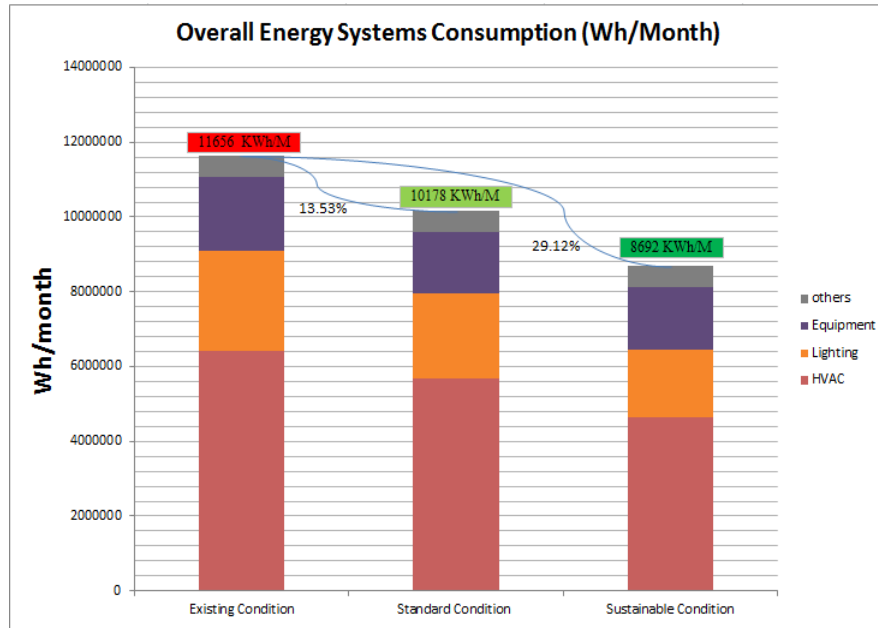
Figure 31: Overall energy consumption

The resulted percentage difference between each of the conditions represents the amount of potential energy reduction and savings. By utilizing the developed benchmarking tool, the retrofitting analyses of the office floor was achieved and the results proved the ability to enhance the office existing condition. The obtained results can be achieved by implementing the enhancements considered for each of the systems according to the performed analyses. In addition, the implementation of different retrofitting scenarios can be studied through the developed as-built 3D BIM model by the user. As the BIM model will serve as a base data for extracting the required information for retrofitting actions.

Chapter 5: Conclusion and Recommendations

6.1 Conclusion

An advanced framework for benchmarking the energy retrofit systems in office buildings is crucial for determining efficient interventions, accurate energy performance estimates and reductions. The framework developed in this thesis is utilized in order to efficiently analyze existing energy performance, and benchmark this performance to achievable standard and sustainable conditions in climate zone 1 office buildings. The energy systems analyzed in the proposed framework are office equipment, HVAC and lighting systems. Those three systems are estimated to consume the most energy accounting for almost 95% of the total energy consumption in the building. Two techniques were used to facilitate the analysis of the energy systems: a developed benchmarking tool and the integration of BIM and laser scanning. BIM and laser scanning are implemented to capture the as-built condition of the building/floor and to provide a model for future analysis and applicable refurbishment studies. The benchmarking tool is based on analysis of the building's existing condition. It consists of information extracted from the BIM model, the chosen standard and sustainable parameters, and the physical inspection of each element's energy consumption.

Furthermore, this tool provides the analysis results for each of the systems separately and for the overall integrated performance of the systems. This overall performance indicates the total achievable energy reduction. For the HVAC system, the benchmark analysis is based on enhancing the heat transfer coefficient (U-value) of the building envelope. The lighting system analysis is based on the lighting power density of the utilized spaces, and the office equipment analysis is performed according to the usage of Energy Star rated equipment. It is important to develop this framework because there are no set standards or procedures for benchmarking the energy retrofit analyses, especially in climate zone 1 office buildings. The framework also helps overcome the challenges and uncertainties associated with retrofitting buildings. Such challenges are the ability to utilize the latest advanced technology (platforms integration) in capturing the existing condition of the building, and estimating the energy end use breakdown. In existing buildings, the utility metering is per the whole building or floor, as information related to specific systems' energy

consumption is not reflected in the utility bill metering. However, the developed tool estimates the energy end use breakdown percentages by considering the normalized average monthly utility readings.

The framework was verified by analyzing an office building in Abu Dhabi, UAE. Our results showed an overall reduction of 14% and 29% compared to standard and sustainable conditions, respectively. Also, the energy end use breakdown was estimated to be 23% for lighting, 17% for office equipment, and 55% for the HVAC system. The analytical framework proved the applicability of utilizing the proposed approach for benchmarking energy retrofit systems in climate zone 1. It also estimated potential reductions according to the enhanced energy condition parameters.

Existing buildings that are 15 or more years old are the majority of buildings in developed countries. These buildings have almost twice the energy effect as newly built ones. This is because of the implementation of green designs and sustainable theories were recently introduced as a law for new buildings. Also the recent level of developed technologies has allowed efficient optimization of energy systems achieving nearly net zero energy use. Energy retrofitting of existing buildings promises great benefits in reducing harmful environmental and financial impacts due to the existing performance of the energy systems; energy retrofitting also increases a building's life span.

6.2 Recommendations

This research proposes an overall framework for benchmarking the energy retrofit systems in climate zone 1 office buildings in order to efficiently analyze the existing energy condition and compare it with enhanced performances. Retrofitting buildings due to their impact is a recent focus and area of research. As countries are moving into greener and more sustainable practices, the grey area of retrofitting buildings needs to be investigated in more detail in further researches. According to this research, the following recommendations are proposed to be considered in further studies:

- Setting a standard retrofit procedure for each climate zone and type of buildings.

- Implementing separate energy metering in buildings, which will provide necessary data for further studies.

- A standard benchmarking model for each type of buildings can be further developed.

- Publication of benchmarking data should be pursued.

- The effect of each building characteristic can be added as a weighted factor when benchmark results are to be used for another project.

- Additional retrofitting parameters and scenarios can be added.

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Appendix A: Framework for Benchmarking Energy Retrofit systems through BIM

Appendix B: Benchmarking Tool Sheets

Office Building Characteristics											
Office System operation											
Enter the type of Business Operation					Remarks:						
Orientation											
Enter the Orientation & Weather Data Location					Remarks:						
Building Age											
Enter the Age of the Building					Remarks:						
Typology											
Office Condition	Closed/open, central/split systems		Number of		Offices arrangement			Working hrs/Day		Working hrs/Week	
Location					**Surroundings**						
Geometry											
Laser Scanning Device		Device prop.	Accuracy		Scanning Speed		Ranging Error		Scanning Range		
other laser device used		Device prop.	Accuracy		Scanning Speed		Ranging Error		Scanning Range		
BIM Integration Software used			Additional Software if used				Level of Modeling Detail (LOD)				

Note: in order to perform an effective retrofitting analysis, the monthly utility bills consumption is averaged and divided by the number of working hours per month. This will result in an average normalized energy consumption (Watt in working month, W) to be used in the systems energy analysis calculation. Enter the monthly utility energy consumption in the below spaces	Avg.

Monthly recorded consumptions (W)												#DIV/0!

Lighting System Energy Benchmark of Office Floor					

From BIM
Inspection
Input

Existing Lighting Consumption

The following data are found from the results of		laser scanning and BIM integration,		in addition to physical inspection	
Number of lighting Fixtures (troffers)		Other lighting Fixtures		Additional lights	
Size of Fixture		Size of Fixture		Size (if applies)	
Number of bulb/tube lights in each fixture		Number of bulb/tube lights in each fixture		Number of lights (if applies)	
Type of lights		Type of lights		Type of lights	
Watt of each		Watt of each		Watt of each	
Total Wattage, (W)	0	Total Wattage, (W)	0	Total Wattage, (W)	0
Total Gross Area, (m2)		Total Gross Area, (m2)		Total Gross Area, (m2)	
LPD (W/m2)	#DIV/0!	LPD (W/m2)	#DIV/0!	LPD (W/m2)	#DIV/0!
Total Wattage, (W)	0				
Percentage of lighting Use = ((∑total wattage/Utility average normalized consumption)*100)				#DIV/0!	

Standard Lighting Consumption

The Standard lighting consumption is based on Standard Lighting Power Density (LPD), (W/m2). This value will set the required Total Wattage of the area, and it is obtained from country's Standards and regulation.

Standard LPD option 1 (W/m2)		Total Gross Area (m2)	0	Standard Condition Lighting Energy Consumption (W)	0
Standard LPD option 2 (W/m2)		Total Gross Area (m2)	0	Standard Condition Lighting Energy Consumption (W)	0
Standard LPD option 3 (W/m2)		Total Gross Area (m2)	0	Standard Condition Lighting Energy Consumption (W)	0
Total Lighting Energy of chosen standard condition (W)		0	Internal Heat Gain (W)	0	Percentage Difference	#DIV/0!

Sustainable Lighting Consumption

The Sustainable lighting consumption is based on Sustainable Lighting Power Density (LPD), (W/m2). This value will set the required Total Wattage of the area, which is obtained from country's standards and regulations, trusted sources, and sustainability guides for climate zone 1

Sustainable LPD option 1 (W/m2)		Total Gross Area (m2)	0	Sustainable Condition Lighting Energy Consumption (W)	0
Sustainable LPD option 2 (W/m2)		Total Gross Area (m2)	0	Sustainable Condition Lighting Energy Consumption (W)	0
Sustainable LPD option 3 (W/m2)		Total Gross Area (m2)	0	Sustainable Condition Lighting Energy Consumption (W)	0
Total Lighting Energy of chosen standard condition (W)		0	Internal Heat Gain (W)	0	Percentage Difference	#DIV/0!

Equipment System Energy Benchmark of Office Floor							
Existing Equipment Consumption				**Advanced Equipment Consumption**			
The following data are found from the results of		laser scanning and BIM integration,		Equipment advanced energy consumption is determined by checking if the Energy Star Rating Tag exists, if not, then existing equipment consumption is compared to the advance Energy Star rating equipment. (Enter the quantity of Rated and non Rated)			
also physical investigation and the use of equipment energy references (ASHRAE)							
Equipment	**Quantity**	**Watt/Equipment**	**Total Consumption**	**Energy Star Rated**		**Watt/Equipment**	**Total Consumption**
Computer Desktop			0	√	X 0		0
Monitor			0	√	X 0		0
Laptop			0	√	X 0		0
Advertising Screen			0	√	X 0		0
TV			0	√	X 0		0
Projector			0	√	X 0		0
Copy Machine			0	√	X 0		0
Plotter			0	√	X 0		0
Multifunction Laser Printers			0	√	X 0		0
Fax			0	√	X 0		0
Water Cooler			0	√	X 0		0
Microwave			0	√	X 0		0
Fridge			0	√	X 0		0
Coffee Maker			0	√	X 0		0
Kettle			0	√	X 0		0
Electronic Refreshers			0	√	X 0		0
Others							
Total Energy (W)			0	**Total Energy (W)**			0
Percentage Difference			#DIV/0!				

Legend:
- From BIM
- Inspection
- Input
- √ Qt. Input

Percentage of Equipment Energy= ((∑total Energy/Utility average normalized consumption)*100) — #DIV/0!

Note: The Advanced Energy Consumption is Used in the Overall Standard and Sustainable Consumptions and Calculations

HVAC System Energy Benchmark of Office Floor

In order to perform the retrofitting analysis for the energy benchmark of HVAC system, the following required data fields need to be

Those data are obtained from the integration of BIM and Laser Scanning results

Exposed areas (m2) of:	Walls		Windows		Curtains		Columns		Roof		Floor	
Exposed Thick. (m) of:	Walls		Windows		Curtains		Columns		Roof		Floor	

Number of people fully occupying all spaces		**Total Height of Floor (m2)**	**Office interior ceiling height (m)**

	From BIM
	Inspection
	Input
	% Red. Input

Note: The internal Heat Gain is assumed to be equal to the electrical consumption of lighting , equipment, and others. By entering the four fields below, the existing HVAC energy, cooling load, and the resulted U-Value of the existing condition will be automatically calculated.
As for Others category, it is recommended to use 5%. The Difference in temperature in climate zone 1 is 28 ± 2°

The COP factor tag of the Chiller equipment which is based on the roof of the building or by investigating the Chiller specs.		**2**
Energy Consumption of Others category (Between 5 - 10 %)	**Temperature Difference between outside and inside (Δt)**	**28**
Amount of percentage reduction related to the considered factor of Safety during design and AHU electrical operating equipment, the range is between 20% - 35% (to verify the results, multi percentage reduction analysis have to be considered).		**25.00%**

Existing HVAC Energy Analysis (Through Estimating the Existing U-value)

Percentage of HVAC energy consumption	#DIV/0!	HVAC Consumed energy (W)	#DIV/0!	Cooling load consumed energy (W)	#DIV/0!
Existing condition U-Value (which is found as U-adjusted Value for all exposed elements affecting the thermal envelope and cooling load)					#DIV/0!

Standard HVAC Energy Analysis (Through Using Standard U-value)

Standard U-Value (W/m2.K°) of exposed:	Walls		Windows		Curtains		Columns		Roof		Floor	

The standard U-Values are based on the elements thickness and are found in the country's standard building specification and international references. By entering the standard value for each exposed element, the effect will result the required cooling energy and HVAC performance.

Standard Cooling energy required (W)	#DIV/0!	Resulting HVAC Energy (W)	#DIV/0!	**Percentage difference**	**#DIV/0!**

Sustainable HVAC Energy Analysis (Through Using Standard U-value)

Sustainable U-Value (W/m2.K°) of exposed:	Walls		Windows		Curtains		Columns		Roof		Floor	

The sustainable U-Values are based on the elements thickness and are found in the country's sustainable building regulations and references. By entering the sustainable value for each exposed element, the effect will result the required cooling energy and HVAC performance.

Standard Cooling energy required (W)	#DIV/0!	Resulting HVAC Energy (W)	#DIV/0!	**Percentage difference**	**#DIV/0!**

The Standard and Sustainable conditions were based on the existing condition for lighting and office equipments
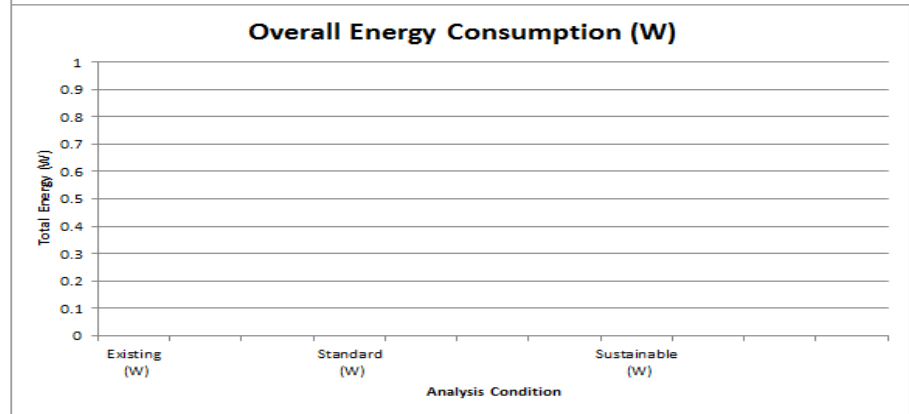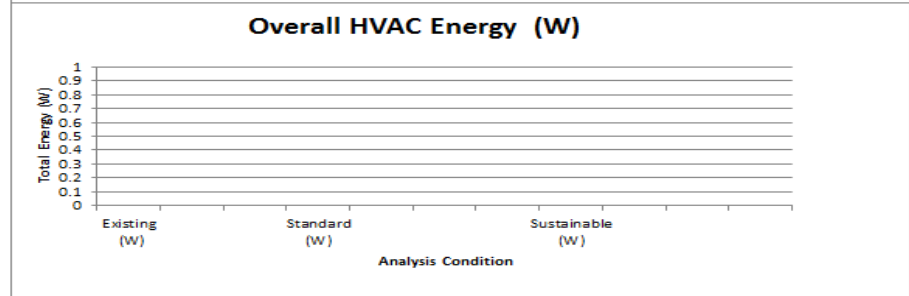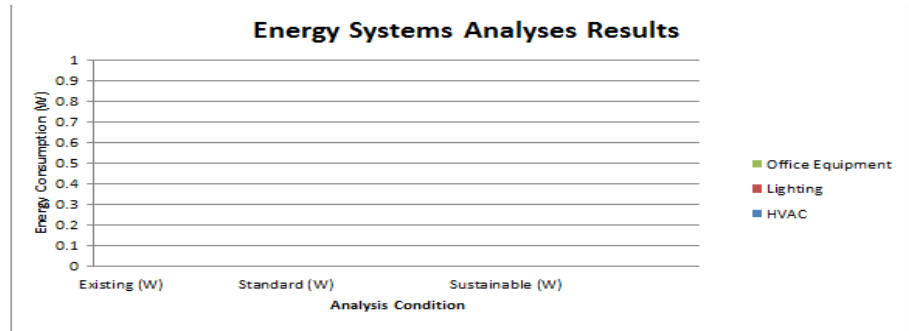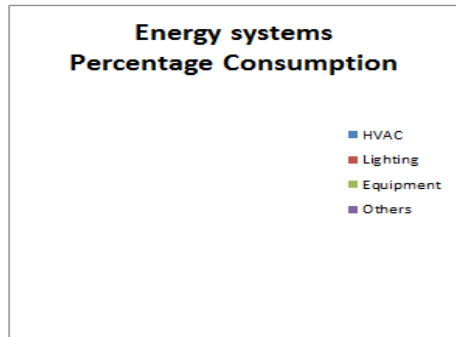
Separate Energy Systems Analyses Results

Energy/Condition	Existing (W)	Standard (W)	Sustainable (W)
HVAC	#DIV/0!	#DIV/0!	#DIV/0!
Lighting	0	0	0
Office Equipment	0	0	0
Total	#DIV/0!	#DIV/0!	#DIV/0!
Percentage Difference		#DIV/0!	#DIV/0!

HVAC System Energy Performance by Integrating Lighting and Equipment Enhanced Conditions

Condition	Existing (W)	Standard (W)	Sustainable (W)
HVAC Energy Consumption (W)	#DIV/0!	#DIV/0!	#DIV/0!
Percentage Difference		#DIV/0!	#DIV/0!

Overall Energy Systems Analyses Results
(By Combing the enhancement condition for each of the systems)

Condition	Existing (W)	Standard (W)	Sustainable (W)
Energy Consumption (W/month)	#DIV/0!	#DIV/0!	#DIV/0!
Percentage Difference		#DIV/0!	#DIV/0!

Energy System	Percentage Consumption
HVAC	#DIV/0!
Lighting	#DIV/0!
Equipment	#DIV/0!
Others	0.00%

Energy systems Percentage Consumption

- HVAC
- Lighting
- Equipment
- Others

Energy Systems Analyses Results

- Office Equipment
- Lighting
- HVAC

Overall HVAC Energy (W)

Overall Energy Consumption (W)

104

Vita

Ahmad Hussein El-mani was born on December 3rd, 1989, in Abu Dhabi, UAE. He was educated in local public schools and graduated with a Bachelor of Science in Civil Engineering from the American University of Sharjah (AUS) in 2012. He graduated with Minor in Engineering Management and Minor in Environmental and Water of Engineering.

Mr. Elmani began a Master's of Science in Civil Engineering, concentrating on Construction Management at the American University of Sharjah in 2012. He currently works as a BIM Engineer and Client relation officer at iTech Management Consultancy in Abu Dhabi, UAE. He is also a member of the American Society of Civil Engineers, the International Engineering Association and the BIM Engineers association.