

**ELECTRICAL ENERGY SAVING POTENTIAL
IN SRI LANKA OFFICE BUILDINGS - APPLICATION TO
OFFICE BUILDINGS IN COLOMBO**

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Degree of Master of Science in Building Services Engineering

Department of Mechanical Engineering

University of Moratuwa

Sri Lanka

February 2016

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Thesis submitted in partial fulfilment of the requirements for the award of
Master of Science in Building Services Engineering

Department of Mechanical Engineering

University of Moratuwa

Sri Lanka

February 2016

DECLARATION

I declare that the research work submitted in this dissertation is of my own investigation except where otherwise stated.

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I endorse the declaration by the candidate.

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Signature of the Supervisor

Date

(Prof. R. Attalage)

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Last but not least, I take this opportunity to express my appreciation and gratitude to my family for their encouragement, support and patience throughout the period of study.

ABSTRACT

This research study is focused on the applications to find out the potential cost effective energy saving measures (ESMs) to make projection of EUI (Energy Unit Intensity) values in kWh/m².year for high rise office buildings in Colombo, Sri Lanka, as it is a widely accepted fact that energy efficient building design measures and techniques are application specific.

Therefore, the objectives of this thesis include detailed study in relation to office building energy efficient measures (EEMs) and also study for office building energy saving potential using established Baseline Building parameters. This helps to quantify 'office buildings energy saving potential' and make projection of building energy consumption savings for new office buildings. This also helps to find out the potential energy saving measures to make projection of EUI values for office buildings in Colombo, Sri Lanka.

The results of this research are based on two selected office building applications in Colombo. The building categories subject to this research are one high-rise office building (height around 100m) and one medium-rise office building (height around 30m) in Colombo. Life cycle analysis is done using the present tariff structure of the Ceylon Electricity Board.

In most of the projects, the building sites are selected before the involvement of the design team. Also, within the limited site area, the building is orientated and the outer appearance of the building also finalized in order to maximize the useable capacity and aesthetics. Therefore, due to the above project constraints, some ESMs for building form such as aspect ratio of the building, orientation (reduced East-West faced windows) and WWR (window to wall ratios) are not considered in investigation.

The analyzing of the potential ESMs for the selected office buildings are limited to the following energy saving measures due to the project specific limitation mentioned above, current industry practices, modeling software analysis limitations, owners of the buildings planning to rent out the spaces to outside tenants, time frame limitation of this study, viz., Selective glazing for windows, Perimeter circulation space, Open office space at perimeter, Daylighting through windows, Energy efficient lamps and ballasts, Lighting controls and High Efficiency cooling equipment (i.e. efficient chillers).

TRACE 700 computer simulation software is used for modeling the buildings as it is a detailed simulation tool that computes building energy use based on the interactions between climate, building form and fabric, internal gains, HVAC systems and day lighting integration.

It has been found that incorporation of cost effective energy saving measures (ESMs) for high-rise office buildings in Colombo, Sri Lanka have greater potential to reduce annual electrical energy consumption by minimum 20 percent in comparison with a Baseline Building and it can also establish better EUI values for high-rise office buildings in Colombo, Sri Lanka.

Based on this study, it has been established that the EUI value for the high-rise office building in Colombo is 124 kWh/m².year and EUI value for the medium-rise office building in Colombo is 83 kWh/m².year.

Further it has been found that the payback periods for selected cost effective ESMs are between 2.3 and 3.8 years under Ceylon Electricity Board (CEB) present tariff structure (General Purpose tariff).



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It is recommended that further research be carried out in this area for both computer modeling and data collection from existing office buildings in Sri Lanka to establish a better and more precise EUI values and higher annual energy saving percentage for office buildings in Sri Lanka, as this study is limited to few ESMs and computer simulation has been done for only two office building applications.

Key Words: Energy Saving Measures (ESMs), Energy Efficient Measures (EEMs), Baseline Building, Benchmark, General Purpose Tariff, Energy Unit Intensity (EUI).

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LIST OF ABBREVIATIONS

AC	- Air Conditioning
ASHRAE	- American Society of Heating, Refrigerating and Air-Conditioning Engineers
AHU	- Air Handling Unit
BIPV	- Building Integrated Photovoltaic panels
BMS	- Building Management System
CAV	- Constant Air Volume
CEB	- Ceylon Electricity Board
cfm	- Cubic feet per minutes
COP	- Coefficient of Performance
EEMs	- Energy Efficient Measures
ESMs	- Energy Saving Measures
EUI	- Energy Unit Intensity
FCU	- Fan Coil Unit
GBCSL	- Green Building Council of Sri Lanka
HVAC	- Heating, Ventilation and Air Conditioning
IEA	- International Energy Agency
LED	- Light Emitting Diode
LPD	- Lighting Power Density
POE	- Post Occupancy Evaluation
PV	- Photovoltaic panels
QA	- Quality Assurance
QC	- Quality Control
ROI	- Return of Investment
SC	- Shading Coefficient
SHGF	- Solar Heat Gain Factor
TR	- Ton of Refrigerants
WWR	- Window to Wall Ratios
VAV	- Variable Air Volume
VE	- Value Engineering
VLT	- Visual Lights Transmittance
VSD	- Variable Speed Drives



1.0 INTRODUCTION

1.1 Background

Energy in the form of electricity is widely used in office buildings in Sri Lanka to operate equipment safely, efficiently and conveniently and for the comfort of its occupants and users. Such equipment includes air conditioning systems, artificial lighting, vertical transportation, ventilation, emergency systems, office equipment and infrastructure and other appliances. The International Energy Agency (IEA) estimates that residential, commercial, and public buildings account for about 40 percent of the world's energy consumption. [11]

Sri Lanka being a tropical country, the weather is humid and warm throughout the year. Due to consideration of issues such as congestion in the cities and urban areas and global warming, Air Conditioning accounts for a considerable amount of energy consumed by the building. The lighting loads for these types of buildings are significant as artificial lighting is being used throughout the day. Apart from the above two uses which account for most of the energy usage, loads such as small power (computers, office appliances like plug loads), Vertical Transportation (lifts and escalators), water pumping and mechanical ventilation systems for toilets and service areas, add significantly to the total. Therefore, in Sri Lanka, electricity is the significant form of energy used in office buildings.

Energy consumption in offices in Sri Lanka has been rising in recent years because Sri Lanka is a country that is currently undergoing rapid development in construction of buildings for commercial, retail and residential purposes, due to the expansion of city limits and due to the major investment opportunities created for external parties, since the ending of the ethnic conflict that prevailed in the country for over 3 decades.

Incorporating energy saving measures (ESMs), renewable energy technologies and integrating sustainability to designs have been a common practice among designers since not only does it reduce the consumption of energy significantly, but it also addresses the new regulations laid down by local authorities and the support provided by various bodies to promote these methods among the general public.

The Ceylon Electricity Board (CEB), a government owned entity, is the main power generation, transmission and distribution authority in Sri Lanka. In addition, there are private power generation companies which contribute to the national grid by electricity generated through means such as mini hydro and thermal. In order to meet the demand and to cater to the electrical power requirement in Sri Lanka, altogether 187 grid-connected power plants have been operated in the first half of 2014. [19]

Since rain can not be guaranteed throughout the year and due to the decrease in rainfall over the past few years, hydro power plants in the country cannot be operated as desired to its maximum capacity. Hence to satisfy the high demand, thermal power plants have to be operated, which has a higher unit cost. This has a huge impact on the economy of the country, apart from its catastrophic environmental impact from the discharged waste.

Due to these prevailing conditions, it has become a necessity to find other possible strategies which will reduce energy consumption in buildings and adverse impact on the environment.



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1.2 Research Objectives

The main objective of this research is to find out the potential cost effective energy saving measures (ESMs) to reduce annual electrical energy consumption. Further, it could be extended to make projection of EUI values for high rise office buildings in Colombo, Sri Lanka.

The specific objectives of this study can be listed as follows:

- (i) Identify the energy saving measures (ESMs) of office buildings by carrying out a detailed study.
- (ii) Establish energy saving potential in high rise office buildings in Colombo, Sri Lanka by using established Baseline Building parameters.
- (iii) To find out the potential ESMs to make better projections of EUI values for high rise office buildings in Colombo based on the selected two office building applications in Colombo.



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1.3 Scope of Thesis

Energy efficient building design techniques are application specific [2]. They also detail the process and level of encouragement required to assure that such strategies are considered and incorporated into the design process, beginning with the earliest project phases and continuing through construction and building occupancy.

In most of the projects, the building sites are selected before the involvement of the design team. Also, within the usually limited site area, the building is orientated and the outer appearance of the building is also finalized to maximize usable capacity and aesthetics.

Hence, due to the above project constraints, some ESMs such as aspect ratio of the building, orientation (reduced east-west faced windows) and WWR (window to wall ratios) are not considered in the investigation.

The scope of this study is to investigate potential energy savings for office buildings but it is limited to the following ESMs due to the project specific limitations and constraints mentioned above:

- 
- Perimeter Circulation Space
 - Open Office Space at Perimeter
 - Selective Glazing for Windows
 - Daylighting through Windows
 - Insulation
 - Air Leakage Control
 - Energy Efficient Lamps and Ballasts
 - Lighting Controls
 - High Efficiency Heating, Ventilation, and Cooling Equipment
 - Exhaust Air Heat Recovery
 - HVAC Controls with Integrated Building Management System (BMS)
 - Selecting Efficient Plug loads such as efficient computers, printers and office appliances

1.4 Approach and Methodology

Approach and Methodology of this research are listed as follows;

- Reviewing and studying the ESMs and techniques
- Carrying out two case studies for the selected office buildings in Colombo to find out the energy saving potential
- Identifying the available products, materials and equipment to be used in office buildings and analysis of feasibility to incorporate in design phase
- Define program characteristics (such as schedules, constructions, plug load densities and building geometry)
- Create baseline energy models
- Applying the selected ESMs for the selected two buildings to create energy efficient building model.
- Calculating initial cost and maintenance cost for both Baseline Building and ESMs incorporated buildings (different alternatives).
- Energy efficient model of each building that achieve energy savings, compared with the baseline model
- Comparing the life cycle cost and payback periods of different alternatives over baseline building.
- Based on the case studies make projection for EUI (Energy Unit Intensity) values for energy efficient high rise office buildings in Colombo, Sri Lanka.

1.5 Contribution

The contribution of this research is towards identifying cost effective energy saving measures (ESMs) to aid designers whom consider low energy consuming (energy efficient) high rise and medium rise office buildings in Colombo. With the help of the outcome of this research, designers and project stake holders can carry out a pre-assessment whether they can consider these ESMs for their new buildings.

2.0 LITERATURE REVIEW

2.1 Introduction

Integrating energy efficiency, renewable energy and sustainable design features in to all Sri Lankan buildings has become a priority in recent years for designers, facility managers, contractors and other professionals involved in the building sector.

These progressive design strategies have been regulated through Sustainable Energy Authority Sri Lanka (Energy Code 2008), Ministry of Environmental and Green Building Council of Sri Lanka (GBCSL). There are extensive opportunities to achieve the goals set forth in the regulations, whether in new building design or building renovations.

This literature review discusses the first category which is the design process for new high rise office building facilities. Since energy efficient office buildings reduce both resource attenuation and adverse environmental impacts of pollution produced by energy production.

This literature review is being looking at what energy efficient design means, specific strategies to be addressed, where and when to apply energy efficient strategies and how evaluating their cost effectiveness.

The energy efficient design process begins when the occupant's needs are assessed and a project budget is established. The proposed building is carefully sited and its programmed spaces are carefully arranged to reduce energy use for cooling and lighting. Its cooling loads are minimized by designing standard building elements windows, walls, and roofs. These passive solar design strategies also require that particular attention be paid to building orientation and glazing.

The whole building approach is easily worth the time and effort, as it can save 30% or more in energy costs over a conventional building designed in accordance with the minimum ASHRAE Standards. Besides, energy efficient design does not necessarily have to result in increased construction costs. [1]

2.2 Energy Efficient Design for New High-Rise Office Building

Energy efficient design for new high rise office building is not the result of applying one or more isolated technologies and it is an integrated whole building process that requires encouragement and action on part of the design team throughout the entire project phases that are design phase, procurement phase, installation phase, testing and commissioning, and measurement and verification during operation phase.

The energy efficient design is not a case of where the discrete technology should be installed, on the other hand where it is integrated with the other components of the building to create an energy efficient building.

When considering about integrated whole building design, it is important to think through not only the isolated components but also how the various elements can work together to achieve low energy consumption.

It is possible to construct the buildings that use less energy without compromising the building's functionality or occupant comfort by conducting a careful design process. Whole building design considers the energy related impacts and interactions of all building components, including the building site, its envelope (walls, windows, doors, and roof), ventilation, Air conditioning system, lighting controls and equipment.

Permanent advocacy of energy efficient design strategies is essential to realizing the goal. Therefore, it is important that at least one technically smart member of the design team be designated as the energy consultant. Energy consultant should perform the following useful functions;

- ✓ Introducing team members to design strategies that are appropriate to building type, size and location.
- ✓ Maintaining enthusiasm for the integration of energy efficient design strategies as central components of the overall design solution.
- ✓ Ensuring that these strategies are not abandoned or eliminated during the later phases of the project.
- ✓ Overseeing construction to ensure that the strategies are not compromised by field changes.

[2]

Urban Office Buildings

In highly controlled areas, this translates into height limits and tight controls over facade treatment. As a result, many of these buildings include or consist of towers that shade and are shaded by neighboring buildings, a factor that may significantly affect the design and sizing of the mechanical cooling system.

Curtain walls are the most common enclosures for office buildings. The energy efficient building design strategy for flat curtain walls is typically defensive in nature, limiting the boring and often unattractive result from the overuse of glass and by a lack of orientation specific facades. There has been a stylistic revolt against all glass buildings, which has led to more articulated facades, variation in building facade treatments and a reappearance in the use of masonry. These factors greatly enhance energy efficient building design possibilities by creating opportunities to tune facades to suit their orientation and the activities taking place [2]. In most cases, thoughtful strategies will be needed to reduce solar gain. Exterior sunscreens or new glazing types can both strengthen the facade and provide substantial cooling load reduction.

An excellent way to take advantage of energy efficient building design is to move as many private offices away from the facade as possible. In this way, more light can be directed further into the building and more of the building's users can enjoy access to views and natural lighting. This scenario increases in productivity and enables the adoption of more energy efficient HVAC strategies. [1]

2.3 Advantages of Low-Energy Building Design

One key element of energy efficient building design is the inventive use of the basic form and enclosure of a building to save energy while enhancing occupant comfort.

Energy efficient building design combines energy conservation strategies and energy efficient technologies. Some of these are high efficient lighting and lighting controls, spectrally selective glazing, high efficient equipment and appliance and heat recovery equipment.

Energy efficient design represents both electrical load reduction strategy and the incorporation of renewable energy sources. Many energy efficient building design strategies result in an absolute reduction in the use of power produced from relevant power generation sources. These innovations can save energy, reduce costs and preserve natural resources while reducing environmental pollution. Energy efficient building design strategies including various daylighting techniques can also provide a renewed sense of connection with the outdoors for occupants. Efficient design can also inspire planning concepts such as from open office spaces at the building's perimeter.

More difficult to measure are the increases in workplace performance and productivity that are often achieved through whole building design and its resulting economic value. Nonetheless, organizations housed in energy efficient buildings have reported that their indoor environments help retain employees, reduce tension, promote health, encourage communication, reduce absenteeism and improve the work environment. [2]



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2.4 Energy Saving Measures and Techniques for the High Rise Office Buildings

Energy efficient building design techniques are application specific [2]. It also details the process and level of encouragement required to assure such strategies are considered and incorporated into the design process, beginning with the earliest project phases and continues through construction and building occupancy.

As energy efficiency concepts and technologies must merge with all other building elements, one of the most important energy saving tools is the use of computer modeling and design software [2]. This strategy should be used early in the design process to analyze the efficiency and cost effectiveness of applicant strategies. Detailed computer simulation results are then referred to throughout the design process and through the value engineering (VE) phase, to ensure that the building will efficiently perform as intended and also that subsequent changes to the design in the interest of cost cutting do not adversely affect performance.

For a particular project, the specific energy saving techniques, strategies and mechanisms to be deployed will vary greatly, depending on building and space type. Their selection and configuration will also be influenced by the followings;

- ✓ Climate
- ✓ Internal heat gains from occupants and their activities, lights and electrical equipment
- ✓ Building size and massing
- ✓ Illumination (lighting) requirements
- ✓ Hours of operation
- ✓ Costs for electricity and other energy sources (Solar PV panels, fuel)

Basic energy saving techniques

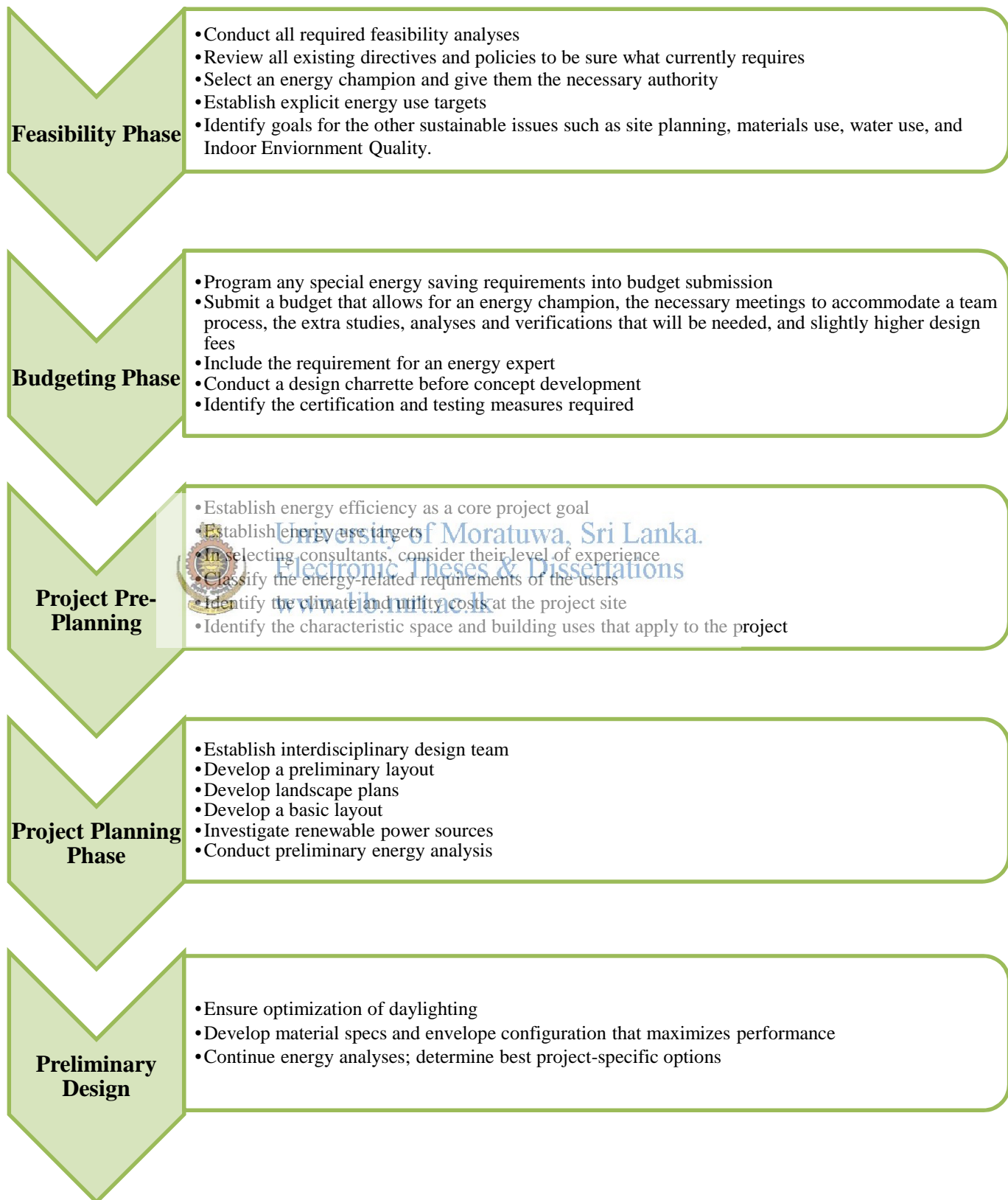
Followings are the basic energy saving techniques should be used to reduce building energy use.

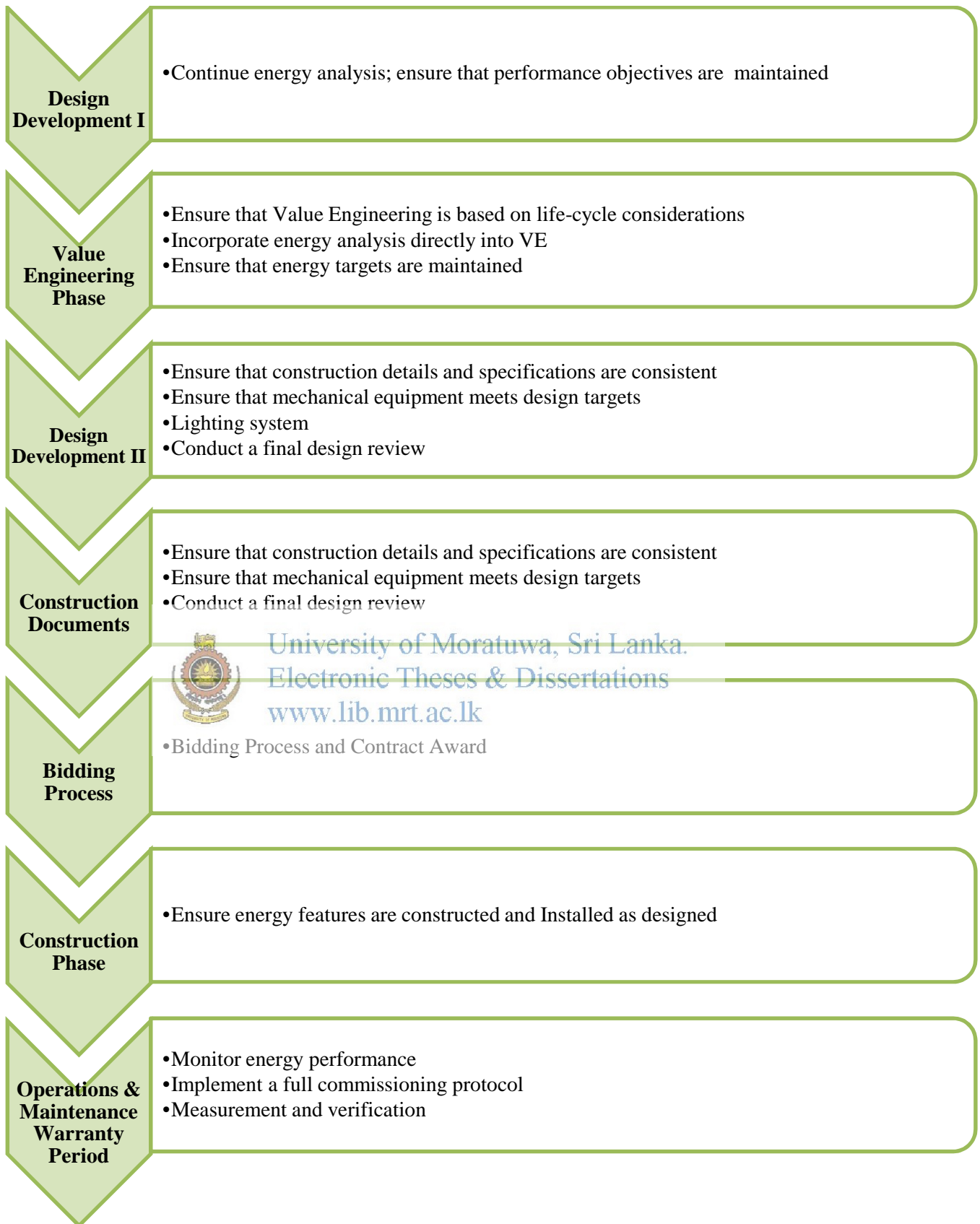
- ✓ Organizing the building configuration and massing to reduce loads.
- ✓ Reducing cooling loads by eliminating undesirable solar heat gain.
- ✓ Using natural light as a substitute for electrical (artificial) lighting.
- ✓ Using natural ventilation whenever possible.
- ✓ Using more efficient HVAC equipment to satisfy reduced loads.
- ✓ Selecting efficient lighting fixtures for artificial lights
- ✓ Selecting efficient plug loads such as efficient computers, printers and office appliances
- ✓ Using computerized building control systems (BMS - Building Management System)

2.5 Phases of an Energy Efficient Building Project

The phases of a project and action items of each phase are illustrate in the Figure 2.1 below.

Figure 2.1: Phases of Energy Efficient Building Project [2]





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2.6 Integrating Energy Efficient Concepts into the Design Process

2.6.1 Feasibility Phase

The feasibility phase is normally when building managers or other decision makers determine that a project will be built to address a particular need. At this stage, the enabling premises of energy efficient design and construction need to be defined and established. Defining parameters, establishing general goals, identifying policies, directives and enabling legislation will guide and drive the process.

During feasibility phase, it is required to consider following items with regards to energy efficiency;

- ✓ Review all existing directives and policies to be ensure of what requires in the way of energy performance, materials usage (i.e. quality, durability, recycled content) energy saving features, impact on indoor environmental quality, daylighting, use of renewable energy sources, contracting issues and other relevant concerns.
- ✓ Select an energy consultant and give them the authority to make decisions relating to energy efficient design and construction practices.
- ✓ Establish energy use targets that exceed those described in the standards

2.6.2 Budgeting Phase

Some projects may be constructed using standard designs which completed for similar projects. Be certain that specific energy efficient goals have been accounted for each project.

During budgeting phase, it is required to consider following items with regards to energy efficiency;

- ✓ Submit a budget that allows for an energy consultant, the additional studies, analyses, verifications that will be needed and slightly higher design fees.


- ✓ It is required to ensure that energy efficient building components and strategies will be adopted early in the planning and design stages, when these elements can be incorporated at the lowest possible cost.
- ✓ Identify the certification and testing measures required to ensure compliance with energy targets.

[2]

2.6.3 Project Pre-Planning Stage

It is essential that the budget established at this time be based on all factors that will influence costs, including the incorporation of energy efficient design strategies.

During project pre-planning stage, it is required to consider following items with regards to energy efficiency;

- ✓ Select appropriate energy efficient design strategies.
- ✓  Identify the team members who will be responsible for evaluating and incorporating the strategies at each phase.
- ✓ Identify the appropriate evaluation tools to use at each phase
- ✓ Establish energy efficient design as a core project goal.
- ✓ Use case studies and passive solar performance maps to help determine appropriate strategies for the specific project type at hand.
- ✓ Establish energy use targets that applicable codes and standards.

Strategies to Consider During Project Pre-Planning Phase

(i) User Energy Needs Assessment

It is a fairly rigorous and systematic evaluation that considers occupancy, operating hours and all aspects of the interior and exterior climates. This assessment produces more precise energy use requirements which helps determine the applicability of energy efficient building strategies.

Classify users on the basis of specific needs that directly relate to specific energy efficient building strategies. In addition to temperature, humidity and general lighting standards, focuses on other user needs such as the desire for exterior views and natural daylight, tolerance to moving air and temperature swings and the type of automatic lighting control.

(ii) Building-Appropriate Site Selection

This process involves choosing a site that fully supports the energy reduction strategies contemplated for the project. Proper siting increases the chances that many other energy efficient building strategies can be implemented. This strategy is appropriate for all new building projects.

However, for many projects, the site may have been selected before the professional's involvement.

(iii) Complementary Building Uses

This process involves defining the nature of the facility and then matching the end use with complementary energy needs and minimizing the resulting wastes.

At the earliest stages of project conception and site selection, consider co-locating any types of facilities where the waste products of one can be used to provide needed energy for another or where construction based support services can be shared. [2]

2.6.4 Project Planning Stage

The design consultants (Architects and Engineers) prepare initial and schematic design options. In this stage, options for placing the proposed building on the site and massing alternatives are evaluated. Fundamental energy efficient design strategies are also assessed for applicability to a specific project. Design consultants generally present their design options and analyses to the project personnel for review and evaluation. At the conclusion of this phase, the design should clearly indicate which energy efficient design strategies have been incorporated in sufficient detail so that cooling and heating loads can be estimated and so system options can be examined.

During project planning phase, it is required to consider following items with regards to energy efficiency;

- ✓ Develop preliminary layouts that optimize the solar gain.
- ✓ Develop a basic layout that maximizes the use of daylighting. Consider building orientation, the size and placement of windows and top lighting.
- ✓ Investigate using renewable power sources as part of the facility's overall power supply.
- ✓ Conduct a preliminary energy analysis (analysis tools depend on scale of project). Can be used Carrier, Trace, DOE and other applicable computer simulation tools for larger and more complex projects.

Strategies to Consider During Project Planning Phase

(i) Perimeter Circulation Space

This passive solar strategy uses circulation (corridors) and casual meeting spaces as buffers between the facade and the interior conditioned spaces. The strategy is appropriate in buildings needing large areas for circulation, waiting, and casual meetings in the office buildings.

As perimeter circulation plans generally require slightly more total floor area, it is necessary to examine user needs and evaluate the strategy in light of the overall budget. If the strategy is acceptable, look for buffer spaces that can be located along the building's exterior particularly along the south facade. [2]

(ii) Extended Plan


By extending the plan to produce a longer, narrower footprint, can be created more exterior wall surface. Elongating the building in an east-west direction makes the most sense from the standpoint of daylighting and passive solar heating in cold climatic conditions [2]. This is best accomplished early in the design process, as modifying the basic building form may occasion a slight increase in the construction budget.

2.6.5 Schematic Design (or Preliminary Design) Phase

In energy efficient building design, the building envelope is also thought of as a membrane that manages between the interior spaces and the outside environment.

During Schematic design phase, it is required to consider following items with regards to energy efficiency;

- ✓ Consider perimeter access to light and views
- ✓ Develop material specifications and a building envelope configuration that maximizes energy performance. Consider window shape and placement, shading devices, differentiated facades, reflective roofing, induced ventilation, nighttime cooling ventilation and selective glazing.
- ✓ Continue energy analyses to determine best project specific options. In addition to first cost, consider durability and long term energy performance.

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Strategies to Consider During Schematic Design Phase
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(i) Selective Glazing for Walls

Glass products are now available with a wide range of performance attributes that allow designers to carefully select the amount of solar gain, visible light and heat that they allow to pass through.

Solar heat is measured by the properties of shading coefficient (SC) and Solar Heat Gain Factor (SHGF). An SC of 1.0 applies to clear 1/8inch thick glass with other glasses that admit a lesser amount of solar heat having a lower SC (e.g., 0.50 for a tinted glass that admits 50% as much solar heat as 1/8 inch clear glass). The term SHGF is considered to be equal to a value of 0.86 times the SC. [2]

Single glazing is about R-1 or 1/1 for a U-factor of about 1.0. Double glazing is about R-2 for a U-factor of about 0.50. Commercially available low-e glass typically ranges in U-factor from about 0.35 down to 0.10, depending on the type and number of coatings and the fills (dry air or argon) used in the spaces between glazing layers. [2]

When considering various building envelope components, glazing almost always has the most significant effect on heating, cooling and lighting energy use. The glazing technology has progressed more dramatically in the last decades.

It is required to use computer analysis to investigate alternate glazing and narrow the field to those most beneficial to admitting daylight and saving energy within the project budget. Glazing technology has now advanced to the point that alternative glazing with very different performance characteristics (Performance Glazing).

(ii) Shading Devices

Fixed (manual) or movable (motorized) devices located inside or outside the glazing are used to control direct and indirect solar gain. Shading should be used to provide cost effective, aesthetically acceptable, functionally effective solar control.

This strategy works well on south facades where overhangs provide effective shading for work space. Shading west facades is critical to reduce peak cooling loads.

A wide range of shading devices are available, including overhangs (for south facades), fins (for east and west facades), interior blinds, louvers and special glazing. Reflective shading devices can further control solar heat gain and glare.

Shading devices without moving parts are generally preferable. Movable shading devices on the exterior are difficult to maintain in corrosive environments. [1]

(iii) Daylighting through Windows

Using daylighting for the building through windows can eliminate artificial lighting, reduce energy costs, and improve occupant health, comfort and productivity. Daylighting use through windows is best accomplished on facades that have a clear view of the sky, generally the sky at angles of 30 degrees or more above the horizon. [2]

Place of the glazing window high on the wall, so that daylight penetration is deeper. Consider the enhanced use of daylighting by installing light shelves on south facades. Recognize the interdependencies in glazing, light fixtures and controls and HVAC systems.

Daylighting is a major component of energy efficient buildings and it is required to be given significant time and attention.

(iv) Window Geometry

Windows should be shaped and located in a manner that minimizes glare and unwanted solar gain and maximizes useful daylight and desirable solar heating. Shape, size and location of windows are very important considerations in the energy efficient building projects.

The design team should consider functional criteria to the size, proportion and location of windows. It is important to avoid incorporating more window area than is beneficial to the building occupants and that is needed to enhance energy efficient performance.

It is required to be taken window decisions based on occupant activities and energy efficient performance rather than simply for aesthetic purposes meaning reduce glass area whenever possible. To minimize glare, and enhance daylighting benefits, substitute horizontal strips of high windows and scattered small windows in lieu of a few large ones.

The best way to evaluate the lighting effects of window geometry and configuration is through computer analysis programs.

(v) Differentiated Facades

The designer creates variations in the facade design in response to changes in orientation, the use of space behind the facade and the energy efficient design strategies being employed.

Differential facade is one of the basic and effective energy efficient building strategies, using different facades is really an approach to design and style that is driven by function. For the uniformity, designers sometimes put overhangs on all facades, even though they may only provide significant energy benefits on the south side. Such an approach can greatly compromise the basic cost effectiveness of the strategy and should generally be avoided. [2]

(vi) Insulation

A well-insulated building envelope reduces energy use, controls moisture, enhances comfort and protects the energy saving potential of passive solar design.

The design consultants are necessary to identify the optimum amount of building insulation to use in the walls, roof and floor construction.

Begin by incorporating insulation levels required by code or standard, then use computer analysis to investigate optimum insulation amounts. For buildings with mass walls, use computer analysis to determine the relative advantages of placing the insulation on the inside or on the outside of the mass. Detail assemblies containing insulation to avoid thermal bridges, where conductive elements penetrate the insulation and short circuit the system by conducting heat. Particularly in hot climates, where using more insulation to enclose a sealed building will cause it to behave like a thermos bottle trapping heat and using even more energy. [1]

(vii) Air Leakage Control

Air retarder systems are used to reduce air leakage into or out of a building. Air leakage control is considered to be standard energy efficient procedure in cold climates. Install air impermeable components that are sealed at the joints and penetrations to create a continuous, airtight membrane around the building. However, that air retarders placed on the cold side of the insulation must be vapor permeable to avoid trapping moisture within the walls. [2]

Designers of many building types attempt to reduce air infiltration by maintaining the indoor space at a higher pressure than the outside ambient air.

Where masonry construction, bituminous membranes are sprayed or trowel applied to serve as air retarders, with bitumen based sheets typically used in curtain wall construction. Evaluate the benefits of an air retarder not only for improved energy use, but also for reduced wall maintenance and repair costs. Also need to evaluate the air leakage characteristics of manufactured components such as windows, doors and curtain walls. [1]

2.6.6 Design Development Phase

During design development phase, the design team attention should shift to identifying efficient lighting and HVAC systems. The design team should continue energy analysis and the Trade-off process.

Strategies to Consider During Design Development Phase

(i) Energy-Efficient Lamps and Ballasts

Identifying and using application specific, high efficiency lamps and ballasts. Minimize the amount of electrical power required by lighting systems, while still meeting the task specific needs of building occupants. The savings will be greatest in buildings with long hours of occupancy and in areas with high electrical utility rates.

Use T-5 lamps and compatible electronic ballasts for general ambient lighting. Compact fluorescent lamps should replace incandescent or halogen lamps in down lights, as they only use about one third the electrical power. Determine what lamp and ballast combinations work best with other strategies (i.e., day lighting, shading, lighting controls). Use LED exit lights with an estimated life of 30 years or more to enhance building safety and all but eliminate required maintenance. [2]

Compact fluorescent lamps also provide maintenance savings, as the lamps last 10 to 20 times longer than the incandescent they replace. [2]

(ii) Lighting Controls

This strategy significantly reduces lighting based electricity demand. Lighting controls automatically adjust lighting levels in response to daylight availability. Other controls automatically turn lights off in response to unoccupied space.

Dimming controls are used in conjunction with building designs that encourage entry of natural daylight. Occupancy sensors are best used in spaces that have intermittent occupancy such as conference rooms and storage areas.

Automatic daylight dimming controls either provide light levels in discrete steps or through continuous dimming, based on light levels sensed. Dimming systems can also be used to dim newly installed lamps when their light output is greater than its requirement.

Occupancy sensors are used to turn off lights and sometimes HVAC in unoccupied areas. They are made with multiple activation technologies, including those that sense body heat (infrared) as well as those that detect motion (ultrasound) [1]. Some sensors employ more than one technology as a means of eliminating false signals. Manual switching and time clocks can also be used to control certain day lit spaces.

Automatic lighting control functions are often included in a computerized energy management system (such as BMS systems) that also controls the HVAC, fire safety, and security systems.

(iii) High Efficiency Heating, Ventilation, and Cooling Equipment

This category of equipment offers operating efficiencies far greater than those afforded by systems designed to simply meet applicable codes or standards. Integrate more efficient equipment whenever it can be shown to be cost effective. These systems are appropriate for use with large loads, long operating hours and high energy prices.

There are various types of efficient cooling and heating equipment that can readily address the specific needs and operating patterns of a given building. Some owners require that alternate systems be subjected to a life cycle cost analysis. If such an exercise is conducted, it should involve detailed computer analysis (such as DOE, Trace and Carrier) rather than a process that simply confirms the selection of a preferred system. The design team should prepare a list of performance criteria for equipment required by applicable codes and standards to be used as a basis for comparing more efficient equipment options.

In some application, the cost premium for more efficient equipment is small. The computer analyses are required along with some form of rigorous life cycle cost analysis. Consider using modular equipment (three small chillers instead of one large chiller or a dual compressor chiller) and variable speed equipment (variable speed chiller) for greater flexibility in achieving targeted reductions in energy use. [2]

The energy consultant should be careful thought the design process to size the systems, components and equipment appropriately.


(iv) Exhaust Air Heat Recovery

This process involves the recovery of useful heat from the air being dispelled from a building. Apply this strategy in buildings with large populations or significant ventilation requirements. Transfer 50% to 70% of the heat that would otherwise be lost to the incoming air stream. [2]

Various types of heat exchangers are in use today, including heat wheels, plate and fin air-to-air heat exchangers and heat pipes.

Depending on the application, potential contamination of the incoming air stream may need to be monitored.

(v) Economizer Cycle Ventilation

 Contributing to energy reduction and good indoor air quality, this strategy introduces a varying amount of ventilation air to cool the building in combination with normal air conditioning. Avoid using the AC compressors or other mechanical cooling method when ambient air can provide some or all of the needed cooling. Look to buildings in cool climates where there is low relative humidity. [1]

(vi) Night Time Cooling Ventilation

This strategy is appropriate for hot, dry climates where the diurnal temperature difference (between day and night) often exceeds 30°F to 35°F. [1]

Night time cooling ventilation should be provided for high volume, fan powered ventilation of large areas during cool, dry nights. Cool the building with outside air as a means of saving more power than the sum of the power drawn by the ventilating fan, plus what is needed to overcome any excessive humidity the following day.

This strategy relies on moving large quantities of air in an economical manner and requires a secure source of intake ventilation that can be directed into spaces to be cooled.

(vii) HVAC Controls

The proper use of controls and building automation reduces energy consumption and electrical peak demand. Specify controls that maintain intended design conditions, including temperature, humidity and airflow rate throughout the building.

Require to keep control systems as simple as possible. Avoid controls that offer little in the way of improved operations or energy savings, especially if they complicate the system and add features that require frequent maintenance or are subject to malfunction. Evaluate the use of variable speed drives (VSD) on all large pumps and fans serving loads that only occasionally function at peak capacity. In large spaces with varying occupancies (i.e. auditoriums, large meeting rooms, cafeterias), investigate control strategies (e.g. the use of carbon dioxide sensors) that regulate the amount of outside air in accordance with actual occupancy.

HVAC control systems can often be integrated into computerized systems that also control lighting, fire safety and security.

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Plug load strategies for low energy buildings are illustrate in Table 2.1 below.

Table 2.1: Plug Load Reduction Strategies

Plug Loads	Base Building	Low Energy Buildings
Computers	200 W desktop computers using screen savers	50 W Laptop Computers using standby mode
Printers and copiers	Single function devices, occupants with personal devices, approximately 15 users per shared device	Multi-function devices, no occupants with personal devices, approximately 30 to 50 users per shared device
Phones	15 W conventional phones	2 W Phones
Task lights	35 W fluorescent task lights	6 W LED task lights

[2]

2.6.7 Value Engineering (VE) Phase

During value engineering phase, it is required to consider following items with regards to energy efficiency;

- ✓ Ensure that Value Engineering (VE) analysis is based on life cycle considerations rather than solely on cutting initial construction costs.
- ✓ Incorporate energy analysis directly into the VE process.
- ✓ Be certain that energy targets for the facility are maintained during VE.

2.6.8 Construction Documents Phase

During Construction documents phase, it is required to consider following items with regards to energy efficiency;

- ✓ Ensure that construction details and specifications are consistent with energy use targets and strategies.
- ✓ Be sure that mechanical and electrical system details and equipment sizing meet design targets.
- ✓ Confirm that lighting system details and equipment specifications are consistent with energy design intent.
- ✓ Before documents are sent out for bid, conduct a final energy design review.

2.6.9 Bidding and Contract Award Phase

During Bidding and Contract Award phase, it is required to consider following items with regards to energy efficiency;

- ✓ If cutting costs is required due to high bids, advocate preserving energy saving features in lieu of more easily replaceable or aesthetic components.
- ✓ Conduct additional energy analyses as necessary to ensure that intended energy performance targets are still intact.

2.6.10 Construction Phase

During construction phase, it is needed to ensure that energy features are constructed or installed as designed.

2.6.11 Turn Over to Occupants Phase

It is required to be verified that occupants understand the building systems and the proper use of energy efficient equipment and features of the building.

2.6.12 Commissioning and Warranty Period Phase

During this phase, it is required to consider following items with regards to energy efficiency;

- ✓ Verify occupant comfort and understanding of building operation using a Post Occupancy Evaluation
- ✓ Monitor the energy performance of the facility once per quarter during the warranty period and fine tune the system as needed.
- ✓ Develop and implement a full commissioning protocol where feasible and measurement and verifications



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2.7 What to Avoid for Energy Efficient Building Design

Some Energy efficient buildings design fail to meet the expected energy savings because the energy efficient technologies incorporated into the design are not correctly integrated into the building. This may be due to a lack of understanding on the part of some team members as to the relationships between the specific energy technologies needed to reduce a given building's energy use and the effective integration of these technologies into the design.

Changing just one of the recommended building components changes the total environment and the effectiveness of the remaining technologies. Therefore, it is vital that all team members understand how each of the technologies interacts with all other building components in a given environment conditions.

When choosing energy saving technologies, team members should be convinced of claims for unrealistically high levels of performance and should avoid dependence on proprietary devices. It is not good practice to have a design that relies on a particular technology for which only one product is available.

2.8 Design Considerations and Computer Modeling

A base case design a code compliant building design without energy efficient design features is needed for comparison purposes in analyzing the cost and effectiveness of the energy efficient design strategies identified for consideration. The base case building is automatically created through the normal design process. Some energy efficient building design technologies need to be applied during the early stages of the project, such as authorization, site selection, budgeting and programming. In some instances, the base case building may already include some energy efficient design features. Anticipating energy efficient design strategies early in the project can also influence the choice of a base case.

2.8.1 What is Base Case Building



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Building owners, designers, managers, and operators want to reduce their building's energy consumption and energy costs. They should have following questions;

- ✓ Which of the many possible energy saving measures (ESMs) should be implemented?
- ✓ How to financially or operationally justify the ESMs selected?
- ✓ How to verify that the ESMs actually saved energy?

[4]

The key element in addressing all of above questions is an energy baseline. An energy baseline commonly refers to a representation of the energy consumption of a building and can be in the form of either, a calibrated model of the building current configuration and operation or a set of energy end use measurements that characterize the energy use of the building.

An energy baseline represents the energy use of a building in its current state, using either a calibrated energy simulation model or measured energy data. [4]

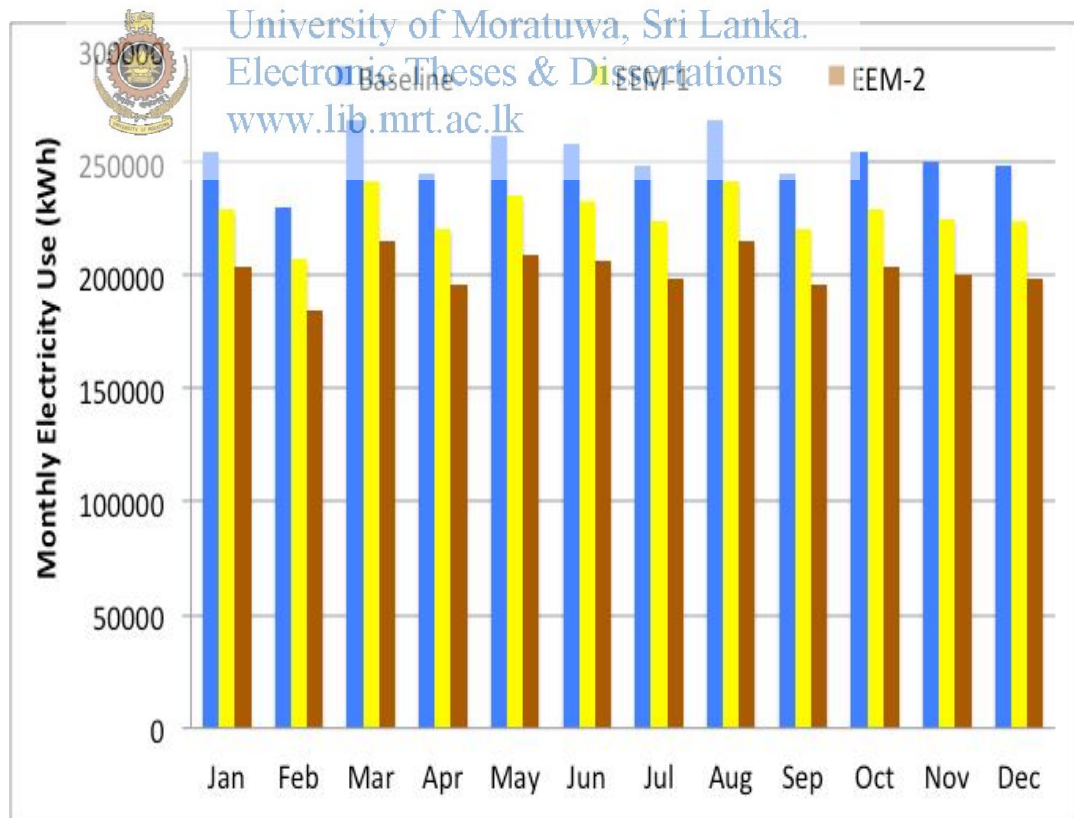
2.8.2 Why Important Base Case Building

In absent of Base case building, the stakeholders of the project are unable to do the followings for energy efficient buildings;

- ✓ Quantitatively evaluate an array of potential ESMs
- ✓ Quantitatively evaluate the interactions of multiple ESMs (e.g. building shell and cooling load)
- ✓ Measure performance of ESMs that have been implemented

Baseline energy models are better suited technically to evaluate ESMs where the measures are more complex, and where it is important to capture the effects of the measures on multiple systems.

Figure 2.2: Example of Output Report by Trace 700 Computer Modeling Software (Comparisons of Energy use for different Alternatives) [3]



2.8.3 Energy Modeling

Sophisticated software programs that allow users to predict a building's energy performance (e.g. eQUEST, DOE-2, Trace 700, Carrier). Computer models can be very powerful tools for predicting the performance of single or multiple ESMs and identifying the best bang for the lowest options. The model can also be used to evaluate and optimize energy saving control strategies. To increase confidence in the predictions, energy models need to be calibrated with actual building energy data.

2.8.4 Required data to Establish a Baseline Building

(i) Building Properties

- ✓ Specific dimensions of floors and spaces/zones
- ✓ Function of building; occupancy type by space
- ✓ Slab, floor, wall, ceiling, and roof constructions and materials
- ✓ Window sizes and/or window-to-wall-ratio
- ✓ Window type and makes and models
- ✓ Window covering types and makes and models
- ✓ Wall, floor, roof insulation U-values
- ✓ Installed lighting rated power by space; lighting control specifications
- ✓ Any significant plug loads (e.g. data centers)

(ii) HVAC System Properties

- ✓ Compile submittals for all HVAC components and the make and model information for all of the following: Chillers, Fans and fan motors, Pumps and pump motors, Cooling towers, Heat exchangers, Terminal unit equipment, VAV boxes
- ✓ Compile control sequences for all AHUs, VAVs and economizers

(iii) Operation Schedule and Set Points

- ✓ HVAC set points and schedules : Chilled water supply temperature, Supply air temperature, Economizer control temperature or enthalpy set points
- ✓ Zone temperature set points

- ✓ Lighting schedules
- ✓ Occupancy schedule

(iv) Whole Building Utility Meter Data

- ✓ Energy use and demand data available from utilities
- ✓ For buildings in high demand rate categories, 15minute interval data may be available for electricity
- ✓ For buildings with multiple meters identify which systems or areas of the building are on which meter

2.9 Strategy Interaction

An important energy efficient design approach involves rank ordering a list of candidate technologies. At each step in a series of computer driven energy simulations, candidate strategies are ranked in order of cost effectiveness relative to the base case design. The top ranked strategy would be the one that produces the largest energy savings for the smallest investment the one with the shortest simple payback.



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Designing energy efficient buildings with Energy simulation computer software like DOE, Trace and Carrier (Design tools) can perform this task automatically. Modeling is a powerful tool, particularly for quantifying the interaction of multiple ESMs with each other and with existing building components and systems.

2.10 Design Analysis Tools

Generally cost effectiveness of the buildings needs to be measured using an appropriate design and analysis tool such as those described below.

DOE /eQuest: An energy analysis software program that calculates the hour-by-hour energy use of a building, given detailed information on the building's location, construction, operation and HVAC systems.

Trace 700: An energy analysis software program that calculates the hour-by-hour energy use of a building, given detailed information on the building's location, construction, operation and HVAC systems.

2.11 Possibilities for Energy Savings

Energy savings will vary, depending on climate, building type and energy saving strategies selected. In new office buildings, it is economically realistic to reduce energy costs by 30% or more below national averages if an optimum mix of energy efficient design strategies is applied. [2]

Better design techniques and superior technologies have largely eliminated any negative impacts associated with energy efficient building design, such as overheating due to uncontrolled solar gain.

2.12 Maintenance of Energy Efficient Building

A well designed energy efficient building requires less maintenance than one that relies on large mechanical systems. Unlike other technologies, well integrated energy efficient building design is much less dependent on hardware and equipment, so there is little to go wrong. [2]

When properly implemented, energy efficient building design can reduce heating and cooling loads to allow for equipment downsizes and reductions in maintenance costs.



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2.13 Energy Unit Intensity

Energy Unit Intensity is a rate of energy use in the buildings and also type of energy benchmark that is commonly used in the buildings energy analysis. The EUI is generally expressed in units of kWh/m² (kilowatt hours per square meters) or kWh/ft² (kilowatt hours per square feet). In most building types, EUI is expressed as energy per unit floor area per year. Energy Unit Intensity can be calculated dividing the total energy consumed in the building in one year by the total gross floor area of the building.

EUIs are in general used as a standard unit of measurement for energy analysis in the buildings and these EUIs have been studied for use as whole buildings energy design target.

EUIs are an attempt to normalize energy use relative to a primary determinant of energy use (building floor area) such that the energy uses of many buildings are comparable. EUI values of the different buildings can be used as indicator of inefficient buildings or systems where improvements can be made.

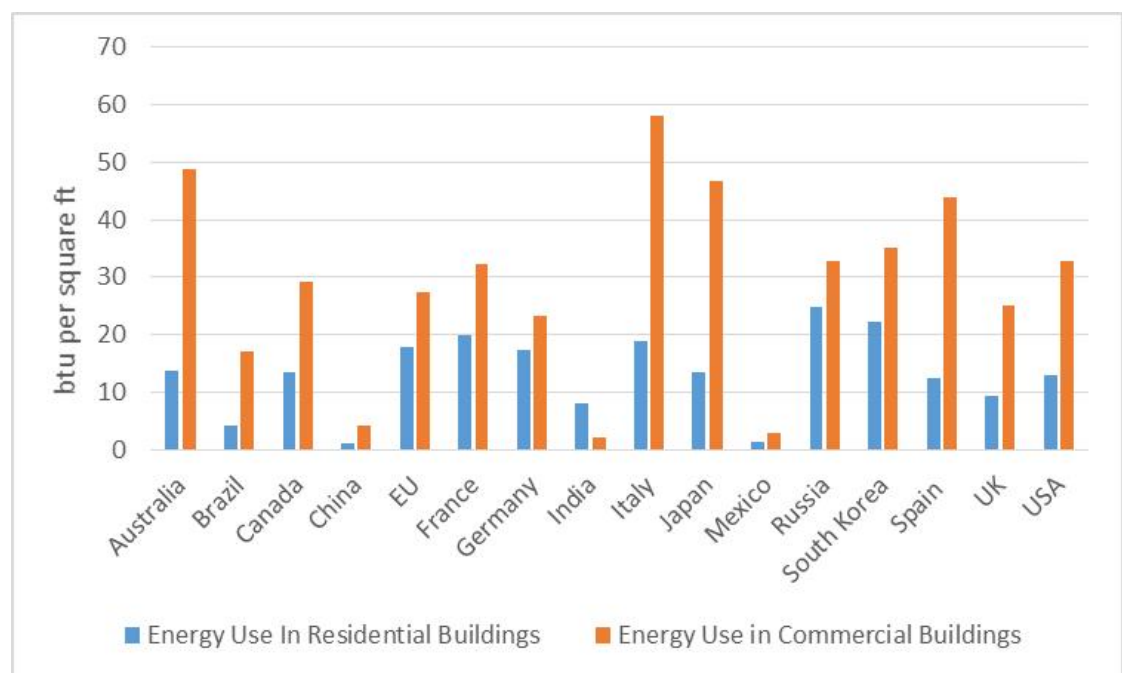
The development of EUIs can be approached in several ways including localize sampling by utilities, performance modeling, load shape estimation, prototype analysis, through consensus estimates, and large scale public sampling.

International Energy Consumption Trends in the Commercial Building Sector

Growth in the commercial sector has been rapid in the recent past to increased interest in understanding sectorial energy use and opportunities for efficiency improvement. There has been a tendency, as international economies grow toward more specialized services for the share of national energy use held by the commercial sector to grow relative to other sectors [18].

Figure 2.3 illustrate the EUI value of total commercial and residential buildings for different countries such as Australia, USA, France, Germany, India, etc.

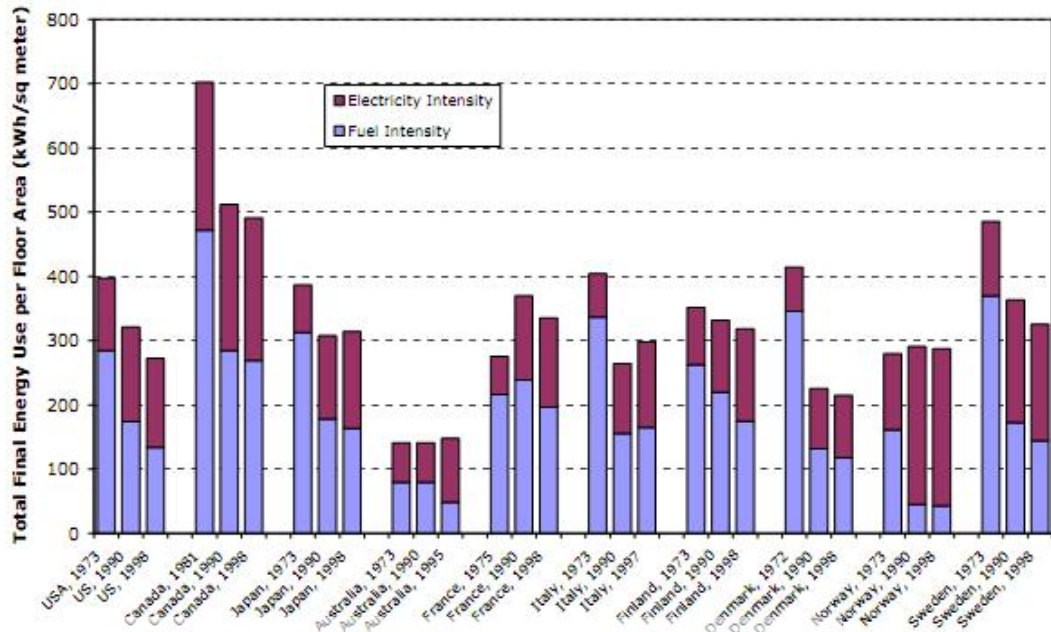
Figure 2.3: EUI Values for commercial and residential buildings



Sources: Energy consumption: IEA, [11]

Figure 2.4 illustrate the evolution of services sector and Annual Energy electricity and Fuel use per unit floor area in several developed countries.

Figure 2.4: Evolution of services sector and Annual Energy electricity and Fuel use



Sources: Energy consumption:  www.lib.mrt.ac.lk & Dissertations

It is a great difficulty in comparing relative performance of commercial buildings is that there are varied levels of expected amenities and comfort conditions in different parts of the world. However, Table 2.2 shows the EUI values of commercial building for different region of the world.

Table 2.2: Energy Consumption, Floor Area and EUI of Commercial Buildings

Location/ Region	GWh/year	Sq M, millions	kWh/m ²
North America	2,326,000	7,900	294
Europe	2,085,000	7,400	284
Pacific	651,000	2,400	274
China	668,000	2,600	261
Asia (other)	960,000	3,900	248
Former Soviet Union	659,000	2,600	253
Other	1,261,000	5,800	216
World	8,609,000	32,500	265

Source: Hinge & MacDonald, [17]

3.0 RESEARCH METHODOLOGY

This section describes the methodology and assumptions that are used to develop, at an early stage of the design of buildings, factors that can achieve potential energy savings. Starting with an overall approach to modeling energy savings in two selected office buildings in Colombo as named below, including energy and economic metrics and the scope of energy saving measures considered, it is described how the models that have a potential energy saving are used to illustrate energy saving. The summary, including the results of the engineering review of the models and the results of the activity as supporting evidence will conclude the report.

Selected Applications:

- 1.0 High-rise office building: Access Tower II, Commercial office building in Colombo 02.
- 2.0 Medium-rise office building: CECB Phase II, office building in Colombo 07.

Guiding Principles:

Achieving potential energy savings cost effectively requires an integrated building design approach that analyzes buildings as whole systems rather than as disconnected collections of individually engineered sub-systems. The following guiding principles are used to develop a list of prospective energy saving measures (ESMs):

- The energy saving measures for the two selected office buildings are limited to technologies that can be modeled with TRACE 700 computer modeling and analysis software.
- Calculation of building energy use and percentage energy savings relative to a conventional, same scale, Baseline Building.
- Calculation of Building energy in several ways, depending on from where the energy is assumed as originating and which categories of energy consumption are included in the calculation.

Percent Energy Savings:

Percent energy savings of the selected buildings are measured with respect to a similar capacity Base Building (conventional building with the standard parameters).

Assumptions:

- 1.0 The percent energy savings goal is based on net site energy use (Site Energy is energy directly consumed at the building. It is typically measured with utility meters).
- 2.0 When analyzing the economic feasibility (i.e. payback periods) of the different ESMs for the buildings, only initial equipment and/or system installation cost for the ESMs is taken in to consideration.
- 3.0 The maintenance and replacement cost of both Baseline Building and the energy efficient buildings (different Alternatives) are equivalent.

Steps to determine Energy savings and EUI value:

The following steps are considered in determining energy savings;

- Reviewing and studying the energy saving measures and techniques
- Carrying out two case studies for selected office buildings in Colombo to find out the energy saving potential
- Identifying the available products, materials, equipment to be used in office buildings and analyzing the feasibility to incorporate in the design phase
- Define program characteristics (such as schedules, constructions, plug load densities and building geometry)
- Create baseline energy models
- Applying selected ESMs to the two buildings (that are indicated above to the baseline models) to create energy efficient model.
- Calculating initial cost and maintenance cost for the both Baseline Building and the ESMs incorporated building (different alternatives)
- Energy efficient model of each building that achieves energy savings, compared with the baseline model
- Comparing the life cycle cost and payback periods of different alternatives over the Baseline Building.
- Based on the case studies, make projection of EUI values for energy efficient office buildings in Colombo, Sri Lanka.

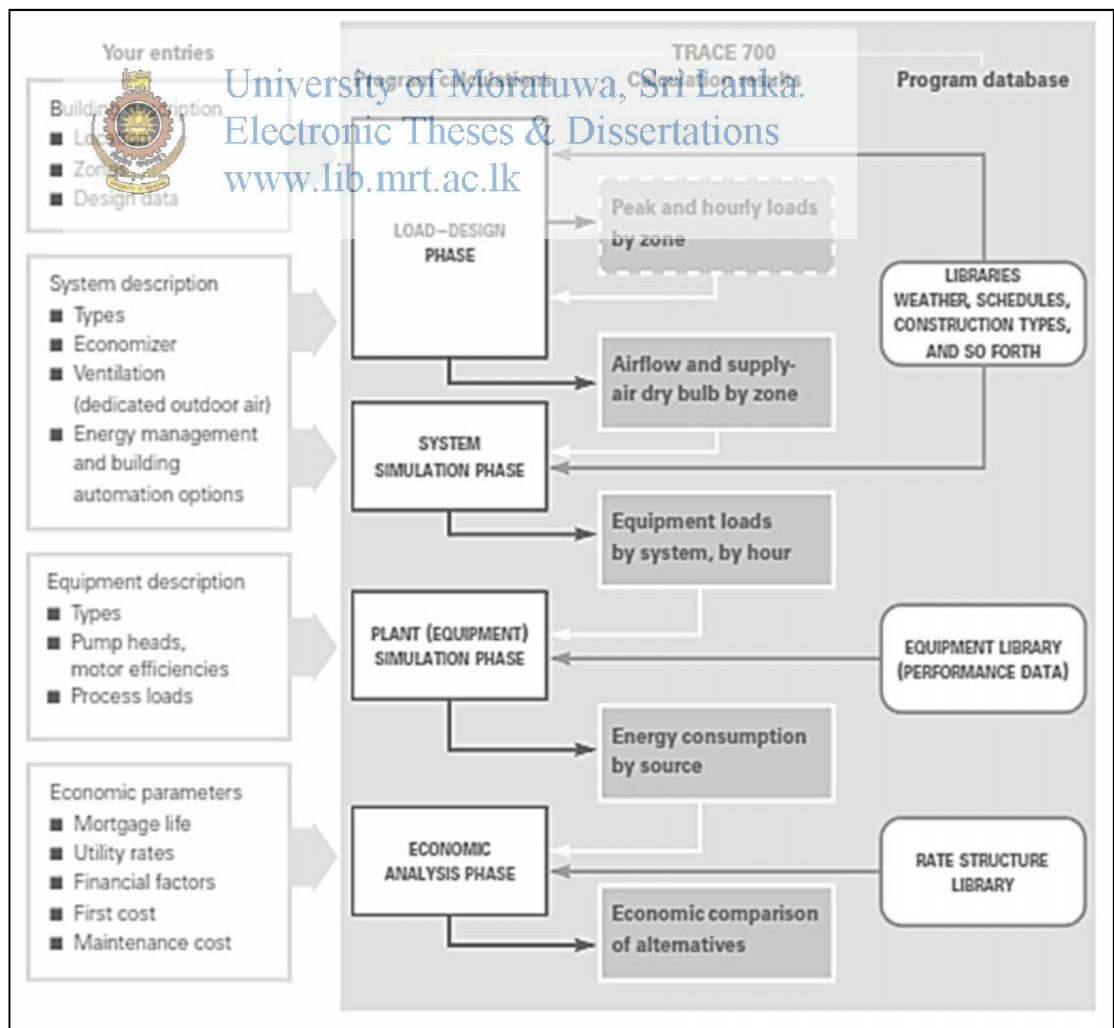
Methodology for Building Energy Modeling

The TRACE 700 computer simulation software is selected as it is a detailed simulation tool that computes building energy use based on the interactions between climate, building form and fabric, internal gains, HVAC systems and daylighting integration systems.

TRACE 700 a publicly available building simulation engine and a heavily tested building simulation program.

Figure 3.1 illustrates the functional arrangement of TRACE 700 in block diagram form with the relationships between the four calculation phases shown. It also summarizes the type of information that must be provided at each phase, the kind of results to expect at each phase and where data from the TRACE 700 libraries is used.

Figure 3.1: The Functional Arrangement of TRACE 700 [3]



Selection of Climatic Zone

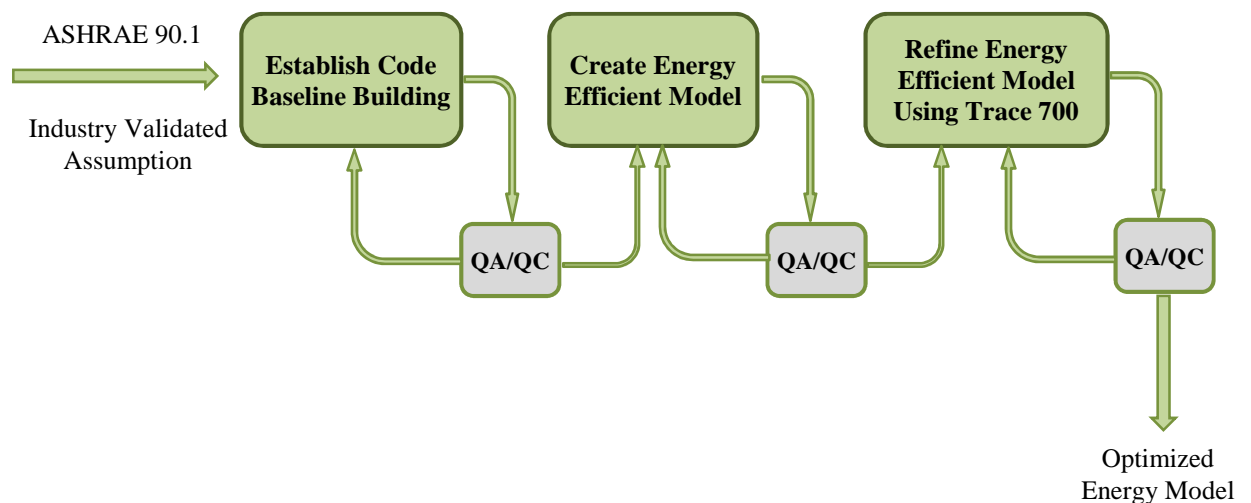
The Colombo weather file is used in Energy simulations for the selected office buildings.

Modeling Protocol

The modeling process followed a four step sequence as illustrated in Figure 3.2,

- Create a Baseline Building model for each office building by using established codes and standards.
- Create an energy efficient building model incorporating feasible cost effective ESMs for each building.
- Refine the preliminary energy efficient model using TRACE 700.
- Perform a QA/QC (Quality Assurance / Quality Control) assessment on the baseline and energy efficient models to ensure that the simulated buildings can meet their loads and provide the required indoor environment; if not, rerun the models and optimize the energy model.


Figure 3.2 : Modeling Protocol Flow Chart



4.0 ANALYTICAL FRAMEWORK

This research study is focused on the applications to find out the potential cost effective energy saving measures to make projection of better EUI (Energy Unit Intensity) value for one high-rise office building (Access Tower II office building, 30 storied) and one medium-rise office building (CECB Head office Phase II, 09 storied) in Colombo Sri Lanka, as energy efficient measures and techniques for the building design is application specific [2].

As in the case of many projects, both building sites have been selected before the involvement of the design team, and also, within the limited site area the buildings had already been placed in their orientations. Further, the outer appearance of the buildings had been finalized to maximize the useable capacity and aesthetics. Accordingly, some building form ESMs such as aspect ratio of the building, orientation (reduced east-west faced windows) and WWR (Window to Wall Ratios) are not considered in the analyzing process.

 The analysis of the potential ESMs for the two selected office buildings are limited to the following energy saving measures due to the project specific limitations and constraints mentioned above.

- ✓ Perimeter Circulation Space
- ✓ Open Office Space at Perimeter
- ✓ Selective Glazing for Windows
- ✓ Daylight through Windows
- ✓ Insulation
- ✓ Air Leakage Control
- ✓ Energy Efficient Lamps and Ballasts
- ✓ Lighting Controls
- ✓ High Efficiency Heating, Ventilation, and Cooling Equipment
- ✓ Exhaust Air Heat Recovery
- ✓ Economizer Cycle Ventilation
- ✓ HVAC Controls with Integrated Building Control System
- ✓ Selecting Efficient Plug loads such as efficient computers, printers and office appliances and Building Integrated Photovoltaic Systems

Analysis of the potential ESMs for the selected buildings are further narrowed down to the following energy saving measures by considering the current local building industry practices, modeling software analysis limitations, the office spaces that the owners of the buildings intend renting out to external tenants and time frame limitation of this study;

1. Selective Glazing for Windows
2. Perimeter Circulation Space
3. Open Office Space at Perimeter
4. Daylight through Windows
5. Energy Efficient Lamps and Ballasts
6. Lighting Controls
7. High Efficiency Cooling Equipment

General Conditions and Schedules for both Applications



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The internal temperature and humidity conditions, lighting levels and ventilation requirements required to be maintained inside the buildings are as follows:

Temperature: $24^{\circ}\text{C} \pm 1^{\circ}\text{C}$

Humidity: 55% - 60%

Lighting level: 250 – 300 lux

Ventilation: ASHRAE 62.1, 2004

Energy: ASHRAE 90.1, 2004

Thermal Comfort: ASHRAE 55, 2004

Building Operating Hours: 7.00 am to 7.00 pm

Working Days per Week: 5 Days per Week

ALTERNATIVES FOR BUILDING MODELING

The analytical frame work of this study is confined to investigation of the prospects of incorporation of ESMs for each Application using five Alternatives (including Alternative 1 for Baseline Building). Summary of the Alternatives used in the analytical process are indicated in Table 4.1 below.

Alternative 1: Baseline Building considering minimum requirement in the standards and material used in current local construction practices.

Alternative 2: Analyze potential energy saving using “Selective glazing for window” only

Alternative 3: Analyze potential energy saving only considering “Perimeter circulation space, open office spaces at perimeter, daylighting through windows, energy efficient lighting fixtures and lighting control system”

Alternative 4: Analyze potential energy saving using only “High efficiency cooling equipment (i.e. energy efficient chiller)”

Alternative 5: Analyze potential energy saving using all ESMs considered in this study which are, “Selective glazing for window, perimeter circulation space, open office spaces at perimeter, daylighting through windows, energy efficient lighting fixtures, lighting control system and high efficiency cooling equipment”

Table 4.1: Summary of the Alternatives for Building Modeling

Alternatives	Energy Saving Measures (ESMs)
Alternative 1	Baseline Building
Alternative 2	1. Selective Glazing for Windows
Alternative 3	2. Perimeter Circulation Space 3. Open Office Space at Perimeter 4. Daylighting through Windows 5. Energy Efficient Lamps and Ballasts 6. Lighting Controls
Alternative 4	7. High Efficiency Cooling Equipment
Alternative 5	All ESMs in Alternatives 2,3, and 4

Equations Used


1. Energy Saving Percentage

$$\text{Saving percentage} = [1 - (\text{kWh of Alternative N} / \text{kWh of Alternative 1})] \times 100\%$$

Where:

- kWh of Alternative 1 : Total energy consumption (kWh) of Baseline building per Annum.
- kWh of Alternative N : Total energy consumption (kWh) of proposed energy efficient building (in Alternative N, N = 2, 3, 4, 5) per Annum.

2. Energy Unit Intensity (kWh/m². year)



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$$EUI = \left[\frac{\text{Total energy consumption (kWh) of the building per Annum}}{\text{Total Floor Area of the building}} \right] / (\text{kWh}/\text{m}^2 \cdot \text{year})$$

3. Economic Analysis (Using Computer Software)

- Calculate the payback period of the different Alternatives compared with the Baseline Building which is Alternative 1.
- Economic analysis is done using Trace 700 computer simulation software.
- Payback periods of the different Alternatives are based on the initial Equipment installation cost.
- Operational electrical energy cost is calculated by Trace 700 using General Purpose tariff structure established by Ceylon Electricity Board, Sri Lanka.

5.0 COMPUTER MODELING AND SIMULATION BY TRACE 700

GENERAL INPUT DATA FOR BOTH APPLICATIONS

Building Elements:

Floor: 150 mm thick concrete

Walls: 200 mm thick common brick with plasters (U-factor: $1.92 \text{ W/m}^2.\text{K}$)

Windows: Double glazing with aluminum frame

Roof: Concrete slab with insulation (U-factor: $0.53 \text{ W/m}^2.\text{K}$)

Building Occupancy (Average):

Office Spaces: 01 person per 80 ft^2

Computer workstations:

Assume 95% of the persons in each office space have computers and other plugged loads as per the standard values

Ventilation Requirements: CAM (Constant Air Volume) system as per the ASHRAE 62.1



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Conditions to be maintained inside Office spaces and Lobbies:

Dry bulb Temperature: $24^{\circ}\text{C} \pm 1^{\circ}\text{C}$

Relative humidity: 55% to 60%

Outside Conditions: Use the Colombo weather file for computer simulation

Dry bulb Temperature: $32^{\circ}\text{C} - 34^{\circ}\text{C}$ (approximately)

Relative humidity: 80% to 85% (approximately)

TRACE 700 has the facility to create rooms and zones within the building. The dimensions of floors, walls, roofs, doors and windows, orientation of walls, internal conditions, loads, ventilation requirements, and construction materials of each room-zone within the building were input to the software and the weather file for Colombo, Sri Lanka was selected.

Create air cooling and distribution systems for a building in TRACE700 depending on the building requirements.

APPLICATION - 01: ACCESS TOWER II, HIGH RISE OFFICE BUILDING

Building Description

Access Tower II building consists of following main floor levels;

Table 5.1: Access Tower II - Floor Levels

Floor level	Description	Floor Area (m ²)	Floor Height (m)
Basement	Water sump, Pump rooms	350	4.20
Ground	Anchor, Lobby, Service Core, Electrical Rooms, Parking	1300	5.00
1 st to 8 th	Parking, Service Core	1600	2.90
9 th floor	Office, Service Core, plant room	1200	3.75
10 th to 27 th	Office, Service Core	1035	3.75
28 th floor	Penthouse, Service Core	1000	5.00
29 th floor	Plant room	250	4.60

Total floor area of Access Tower II = 35,530 m²

Total floor area (without parking floors) = 22,730 m²

Total building height = 105 m



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The rooms/zones created within the building are assigned to air cooling and distribution systems created for the building as follows;

Table 5.2: Rooms/Zones assigned to HVAC systems for Access Tower II Model

Floor level	Description	System
Basement	Water sump, Pump rooms	Mechanical Ventilation
Ground	Anchor, Entrance Lobby and Lift Lobby	02 No Air Handling Units
	Service Core, Electrical Rooms, Parking	Mechanical Ventilation
1 st to 8 th	Parking, Service Core	Mechanical Ventilation
9 th floor	Office spaces and Lift lobby	02 No Air Handling Units per floor + FCUs
	Service Core, plant room	Mechanical Ventilation and/or FCUs
10 th to 27 th floor	Office spaces and Lift lobby	02 No Air Handling Units per floor + FCUs
	Service Core	Mechanical Ventilation and/or FCUs
28 th floor	Penthouse	01 No Air Handling Unit + FCUs
	Service Core	Mechanical Ventilation and/or FCUs
29 th floor	Plant room	Mechanical Ventilation and/or FCUs

The cooling plants are assigned in TRACE 700 and adjusted according to selected equipment parameters. The type of cooling plants available in TRACE 700 are air cooled chiller, water cooled chiller, air cooled unitary, water cooled unitary, etc.

The following cooling plants have been selected to meet the system requirements.

Type and No. of Chillers: 02 nos. Water cooled Screw type Chillers, capacity of each chiller, 400 TR.

Chilled Water System Arrangement: Parallel Chiller arrangement with Primary chilled water pumps, Secondary chilled water pumps, cooling towers and Condenser water pumps, selected as appropriate.

Plug Loads

Average Plug Load density for the high rise office building: 6.4 W/m²

Energy Saving Measures (ESMs) Considered for Access Tower II

The computer modeling and simulation was carried out by using TRACE 700 for the different Alternatives described in Table 5.3 below.



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Table 5.3: ESMs used in different Alternatives for Access Tower II building Model

Alternatives	Energy Saving Measures (ESMs)
Alternative 1	Baseline Building
Alternative 2	1. Selective Glazing for Windows
Alternative 3	2. Perimeter Circulation Space 3. Open Office Space at Perimeter 4. Daylighting through Windows 5. T5 Lamps and electronic ballasts 6. Automatic lighting control system
Alternative 4	7. Efficient chiller (better COP value)
Alternative 5	All ESMs in Alternatives 2,3, and 4

Selective Glazing for Windows (for Alternative 2 and Alternative 5)

Table 5.4: Glass Curtain (Window) Constructions for Access Tower II Model

Properties	Alternative 1 Base Building	Alternatives 2, 5 Energy Efficient Access Tower
SC *	0.81	0.65
VLT *	0.68	0.64
U-factor (W/m ² .K) *	3.12	2.42
WWR	80%	80%

Note: *

- i. Alternative 1: SC, VLT and U factor values for Alternative 1 are selected based on the current local construction practices for Glass windows installation.
- ii. Alternatives 2 & 5: SC, VLT and U factor values for Alternatives 2 & 5 are selected by considering cost effective, available performance glazing products in different manufactures suitable for local conditions.



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T5 Lamps and Electronic ballasts (for Alternative 3 and Alternative 5)

Table 5.5: Lighting Power Density for Access Tower II Model

Key	Alternative 1 Base Building (W/m ²)	Alternatives 3, 5 Energy Efficient Access Tower (W/m ²)
LPD - Lighting Power Density *	9.50	7.50

Note: *

- i. Alternative 1: LPD value for Alternative 1 is selected based on the minimum LPD values established in Sustainable Energy Authority, Sri Lanka and ASHRAE 90.1.
- ii. Alternatives 3 & 5: LPD value for Alternatives 3 & 5 is selected based on calculated power of lighting systems which are installed with T5 lighting fixtures together with electronic ballast, to achieve average illumination level of 250 lux level in office buildings in Colombo.

Daylighting through Windows (for Alternative 3 and Alternative 5)

Table 5.6: Daylighting Controls and Equipment for Access Tower II Model

Key	Alternative 1 Base Building	Alternatives 3, 5 Energy Efficient Access Tower
Daylighting use and control	No day light used	Daylighting use and control *

*Note: **

Use light sensors and dimming controls to perimeter zones with windows (perimeter zones were limited to a depth of 4.0 m to ensure quality side lighting). To model day lighting, one light sensor is placed in each zone in the center of the zone at a height of 2.95 ft (0.90 m) from the floor level. The dimming controls are continuous; they start dimming when the lighting set point is exceeded, linearly decreasing until the lighting set point is met or the input power decreases to 30% of its maximum (where the light output is 20% of its maximum), whichever is achieved first. Based on industry feedback, a day lighting set point of 250 lux level was chosen.



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Efficient Chiller - better COP value (for Alternative 4 and Alternative 5)

Table 5.7: HVAC system Equipment for Access Tower II Model

Equipment	Alternative 1 Base Building	Alternatives 4, 5 Energy Efficient Access Tower
Chiller COP *	5.5	6.4
No of Chiller	02 Screw Chillers	02 Screw Chillers

*Note: **

- i. Alternative 1: COP value for Alternative 1 is selected based on the minimum equipment efficiency requirement of water chilling package for a 400 TR, water cooled, electrically operated screw chiller established in ASHRAE 90.1.
- ii. Alternatives 4 & 5: COP value for Alternatives 4 & 5 is selected by considering cost effective, available energy efficient screw chiller products of different chiller manufactures (such as Daikin, Yoke, Trane, Carrier, Dunham Bush, etc.) suitable for local conditions.

Equipment Installation Cost of different Alternatives

Table 5.8: Equipment Installation Cost of different Alternatives for Access Tower II

Alternatives	Equipment Installation Cost (US\$)
Alternative 1 : Baseline	1,426,310.00
Alternative 2 : Performance Glazing	2,086,492.00
Alternative 3 : Open Office space and circulation space at perimeter, Daylighting, T5 lamps and electronic ballast, Automatic control	1,548,187.00
Alternative 4 : Efficient Chillers	1,472,111.00
Alternative 5 : Energy Efficient Model (All ESMs)	2,254,170.00

Architectural drawings and Equipment installation cost for different ESMs

(i) The Architectural drawings of the Access Tower II building are enclosed in Appendix C-1.

(ii) The equipment installation costs of the proposed ESMs for Access Tower II building are enclosed in Appendix B.



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APPLICATION- 02: CECB HEAD OFFICE PHASE II, MEDIUM-RISE BUILDING

Building Description

CECB Phase II building consists of following main floor levels;

Table 5.9: CECB Head Office Phase II - Floor Levels

Floor level	Description	Floor Area (m ²)	Floor Height (m)
Ground	Lobby, Service Core, Electrical Rooms, Parking	220	2.90
1 st to 7 th	Office, Service Core	265	3.25
8 th floor	Multi-function Hall, Service Core	265	4.10
Roof terrace	Plant room	170	3.60

Total floor area of CECB Phase II	= 2,510 m ²
Total floor area (without parking area)	= 2,290 m ²
Total building height	= 33 m

The rooms/zones created within the building are assigned to air cooling/distribution systems created for the building as follows:

Table 5.10: Rooms/Zones assigned to HVAC systems for CECB Phase II Model

Floor level	Description	System
Ground	Entrance Lobby, Lift Lobby and Parking	Natural Ventilation
	Service Core, Electrical Rooms	Mechanical Ventilation
1 st to 7 th floor	Office spaces and Lift lobby	Air Handling Unit
	Service Core, plant room	Mechanical Ventilation
8 th floor	Multi-function hall and Lift lobby	Ceiling Concealed Ducted FCUs
	Service Core, Electrical Rooms	Mechanical Ventilation
Roof terrace	Plant room	Mechanical Ventilation

The cooling plants are assigned in TRACE 700 and are adjusted according to selected equipment parameters. The following cooling plants have been selected to meet the system requirements.

Type and No. of Chillers: 01 number, water cooled, Screw type chiller (with standby chiller), capacity of chiller, 60 TR.

Chilled Water System Arrangement: Parallel Chiller arrangement with Primary chilled water pumps, Secondary chilled water pumps, Cooling towers and Condenser water pumps, selected as appropriate.

Plug Loads

Average Plug Load density for the medium rise office building: 10.5 W/m²

Energy Saving Measures (ESMs) Considered for CECB Phase II

The computer modeling and simulation was carried out by using TRACE 700 for the different Alternatives described in Table 5.11 below.

Table 5.11: ESMs used in different Alternatives for CECB Phase II Model

Alternatives	Energy Saving Measures (ESMs)
Alternative 1	Baseline Building
Alternative 2	Efficient chiller (better COP value)
Alternative 3	Selective Glazing for Windows
Alternative 4	Perimeter Circulation Space Open Office Space at Perimeter Daylighting through Windows T5 Lamps and electronic ballasts Automatic lighting control system
Alternative 5	All ESMs in Alternatives 2,3, and 4



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Selective Glazing for Windows (for Alternative 3 and Alternative 5)

Table 5.12: Glass Curtain (Window) Constructions for CECB Phase II Model

Properties	Alternative 1 Base Building	Alternatives 3, 5 Energy Efficient CECB Model
SC *	0.82	0.57
VLT *	0.68	0.64
U-factor (W/m ² .K) *	3.41	2.71
WWR	35%	35%

*Note: **

- i. Alternative 1: SC, VLT and U factor values for Alternative 1 are selected based on the current local construction practices for Glass windows installation.
- ii. Alternatives 3 & 5: SC, VLT and U factor values for Alternatives 3 & 5 are selected by considering cost effective, available performance glazing products in different manufactures suitable for local climatic conditions.

T5 Lamps and Electronic ballasts (for Alternative 4 and Alternative 5)

Table 5.13: Lighting Power Density for CECB Phase II Model

Key	Alternative 1 Base Building (W/m ²)	Alternatives 4, 5 Energy Efficient CECB Model (W/m ²)
LPD - Lighting Power Density *	10.0	7.50

Note: *

- i. Alternative 1: LPD value for Alternative 1 is selected based on the minimum LPD values established in Sustainable Energy Authority, Sri Lanka and ASHRAE 90.1.
- ii. Alternatives 4 & 5: LPD value for Alternatives 4 & 5 is selected based on calculated power of lighting systems which are installed with T5 lighting fixtures together with electronic ballast, to achieve average illumination level of 250 lux level in office buildings at Colombo.



Table 5.14: Daylighting Controls and Equipment for CECB Phase II Model

Key	Alternative 1 Base Building	Alternatives 4, 5 Energy Efficient CECB Model
Daylighting use and control	No day light used	Daylighting use and control *

Note: *

Use light sensors and dimming controls to perimeter zones with windows (perimeter zones were limited to a depth of 4.0 m to ensure quality side lighting). To model day lighting, one light sensor is placed in each zone in the center of the zone at a height of 2.95 ft (0.90 m) from the floor. The dimming controls are continuous; they start dimming when the lighting set point is exceeded, linearly decreasing until the lighting set point is met or the input power decreases to 30% of its maximum (where the light output is 20% of its maximum), whichever is achieved first. Based on industry feedback, a day lighting set point of 250 lux level was chosen.

Efficient chiller - better COP value (for Alternative 2 and Alternative 5)

Table 5.15: HVAC system Equipment for CECB Phase II Model

Equipment	Alternative 1 Base Building	Alternatives 2, 5 Energy Efficient CECB Model
Chiller COP *	4.4	5.0
No of Chiller	01 Screw Chiller	01 Screw Chiller

*Note: **

- i. Alternative 1: COP value for Alternative 1 is selected based on the minimum equipment efficiency requirement of water chilling package for a 60 TR, water cooled, electrically operated screw chiller established in ASHRAE 90.1.
- ii. Alternatives 2 & 5: COP value for Alternatives 2 & 5 is selected by considering cost effective, available energy efficient screw chiller products of different chiller manufactures (such as Daikin, Yoke, Trane, Carrier, Dunham Bush, etc.) suitable for local conditions.


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Table 5.16 : Equipment Installation Cost of different Alternatives for CECB Phase II

Alternatives	Equipment Installation Cost (US\$)	ESMs Investment Cost Deviations / US\$	
		(+5%) 5 percent increase of ESMs Investment	(-5%) 5 percent decrease of ESMs Investment
Alternative 1 : Baseline	104,704.00	104,704.00	104,704.00
Alternative 2: Efficient Chillers	109,856.00	111,831.20	107,880.80
Alternative 3 : Performance Glazing	127,704.00	131,729.10	123,678.90
Alternative 4 : Daylighting & T5 lamp	117,354.00	118,629.00	116,079.00
Alternative 5 : All ESMs for CECB	145,506.00	152,781.30	138,230.70

Architectural drawings and Equipment installation cost of ESMs

- (i) The architectural drawings of the CECB Phase II Model building are enclosed in Appendix C-2.
- (ii) The equipment installation costs of the proposed ESMs for CECB Phase II Model building are enclosed in Appendix B.



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6.0 OBSERVATIONS, CONCLUSIONS AND RECOMMENDATIONS

Summary of Research

(A) Analysis of the potential Energy Saving Measures (ESMs) for the two selected office buildings is limited to the following ESMs;

1. Selective glazing for Windows
2. Perimeter circulation space and Open office space at perimeter
3. Daylighting use through windows
4. Energy efficient lighting fixtures (T5 lamps with electronic ballast)
5. Lighting control (Automatic control system using sensors)
6. Efficient cooling equipment (Efficient Chillers)

(B) The two office building applications selected for this thesis are;

- i. Application 01 - High rise office building

[Access Tower II, commercial office building, No of floors: 30, Height: 105 meters, Total Floor area: 35,530 m²]

- ii. Application 02 - Medium rise office building
[CECB Phase II, office building, No of floors: 09, Height: 33 meters, Total Floor area: 2,510 m²]

(C) TRACE 700 computer simulation software was used for Energy modeling the two selected office building applications.

(D) Alternatives used in each building application are summarized in Table 6.1;

Table 6.1: Summary of Alternatives used for different ESMs

Application 01 : Access Tower II		Application 02 : CECB Phase II	
Alternatives	Energy Saving Measures (ESMs)	Alternatives	Energy Saving Measures (ESMs)
Alternative 1	Baseline Building	Alternative 1	Baseline Building
Alternative 2	Selective Glazing for Windows	Alternative 2	Efficient chiller (better COP value)
Alternative 3	Perimeter Circulation Space Open Office Space at Perimeter Daylighting through Windows T5 Lamps and electronic ballasts Automatic lighting control system	Alternative 3	Selective Glazing for Windows
		Alternative 4	Perimeter Circulation Space Open Office Space at Perimeter Daylighting through Windows T5 Lamps and electronic ballasts Automatic lighting control system
Alternative 4	Efficient chiller (better COP value)		
Alternative 5	All ESMs in Alternatives 2,3, and 4	Alternative 5	All ESMs in Alternatives 2,3, and 4

OBSERVATIONS

The following observations are made from the reports generated by the TRACE 700 energy simulation software during the computer modeling and analysis carried out for the two applications that are high-rise office building, Access Tower II office building and medium-rise office building, CECB Head office Phase II. [The reports, tables and graphs generated from the TRACE 700 software are enclosed in Appendix A, Appendix A-1 for Access Tower II and Appendix A-2 for CECB Head Office Phase II]

The results of the computer simulations for the two building applications are summarized in Table 6.1, Table 6.2 and Table 6.3 below.

Table 6.2: Comparison of Whole-building Energy Consumption, Energy Saving Percentage and EUI Values for the different Alternatives

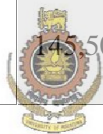
	Alternatives	Annual Energy Consumption (kWh/year)	Energy saving Percentage (%) with Baseline	EUI Value (kWh/m².year)
Application 01: Access Tower II, (High-rise office building, height - 105 meters)				
1	Alternative 1 : Baseline	3,386,000		149.0
2	Alternative 2 : Performance Glazing	3,078,000	9.1%	135.4
3	Alternative 3 : Open office spaces and circulation spaces at perimeter, Daylighting, T5 lighting fixtures, lighting controls	3,221,000	4.9%	141.2
4	Alternative 4 : Efficient Chillers	3,295,000	2.7%	145.0
5	Alternative 5 : All ESMs for Access	2,813,000	17.0%	123.7
Application 02: CECB Office Phase II, (Medium-rise office building, height - 33 meters)				
1	Alternative 1 : Baseline	224,000		101.8
2	Alternative 2 : Efficient Chillers	209,000	6.7%	95.0
3	Alternative 3 : Performance Glazing	207,000	7.6%	94.1
4	Alternative 4 : Open office spaces and circulation spaces at perimeter, Daylighting, T5 lighting fixtures, lighting controls	191,000	14.7%	86.8
5	Alternative 5 : All ESMs for CECB	181,000	19.2%	82.3

Table 6.3: Comparison of Equipment Installation Cost and Payback Period for the Alternatives

Combinations of Alternatives	Equipment Installation Cost for Baseline (US\$)	Equipment Installation Cost for ESMs (US\$)	Payback period (Year)	Rank
<i>Application 01: Access Tower II, (High rise office building)</i>				
Alt 1 with Alt 2 (Performance Glazing)	1,426,290.00	2,086,491.00	9.1	4
Alt 1 with Alt 3 (Daylighting & T5 lamp)	1,426,290.00	1,548,167.00	3.8	3
Alt 1 with Alt 4 (Efficient Chillers)	1,426,290.00	1,472,091.00	2.5	1
Alt 1 with Alt 5 (All ESMs for Access)	1,426,290.00	2,254,170.00	3.4	2
<i>Application 02: CECB Head Office Phase II, (Medium rise office building)</i>				
Alt 1 with Alt 2 (Efficient Chillers)	104,705.00	109,855.00	2.3	1
Alt 1 with Alt 3 (Performance Glazing)	104,705.00	127,705.00	9.5	4
Alt 1 with Alt 4 (Daylighting & T5 lamp)	104,705.00	117,355.00	2.6	2
Alt 1 with Alt 5 (All ESMs for CECB)	104,705.00	145,505.00	6.7	3

Table 6.4: Comparison of Payback Period Variation with ESMs Installation Investment Cost Deviation within $\pm 5\%$ for CECB Phase II Building

Combinations of Alternative	Equipment Installation Cost / US\$	Pay Back Period/ Year	Payback Period Variation with Equipment Installation Cost Changes for the ESMs					
			(+5%) 5 percent increase of ESMs Investment			(-5%) 5 percent decrease of ESMs Investment		
			Investment Cost	Pay Back Period (Year)	% Deviation	Investment Cost	Pay Back Period (Year)	% Deviation
Alternatives 1 & 2	109,856.00	2.3	111,831.20	3.2	+ 39%	107,880.80	1.4	- 39%
Alternatives 1 & 3	127,704.00	9.5	131,729.10	11.1	+ 17%	123,678.90	7.8	- 18%
Alternatives 1 & 4	117,354.00	2.6	118,629.00	2.9	+ 12%	116,079.00	2.3	- 12%
Alternatives 1 & 5	145,506.00	6.7	152,781.30	7.9	+ 18%	138,230.70	5.5	- 18%



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CONCLUSIONS

The following conclusions were arrived at after analyzing the above results generated from the TRACE 700 computer simulation software.

Economic Considerations (Payback Periods)

1. Alternatives with Performance glazing, ESM of both office buildings (Alternative 2 for Access building and Alternative 3 for CECB building), which are performance glazing alone, without integrating daylighting and perimeter circulation space, are not economical and payback periods are more than 09 years. Hence, this ESM (Performance Glazing without integration of daylight system) is not an economically viable solution when compared to the other Alternatives.
2. Alternatives with Daylight integration and efficient T5 light fixture, ESMs of both office buildings (Alternative 3 for Access building and Alternative 4 for CECB building), which are efficient lighting fixtures together with integration of daylight system and perimeter circulation space, are economical and the payback periods of ESMs are less than 3.8 years for both applications. Therefore, this group of ESMs (which are efficient light fixtures, daylight integration and perimeter circulation and open office spaces at perimeter, lighting control system) are economically viable solutions.
3. Alternatives with efficient Chiller in both office buildings (Alternative 4 for Access building and Alternative 2 for CECB building), which are using energy efficient chillers, are more economical and payback periods are less than 2.5 years for both applications. This ESM (using efficient Chiller) is hence an economically viable solution.
4. Conclusions in respect of Alternative 5, which is, using all ESMs for both building applications considered in this study are as follows;
 - For high-rise Access Tower office building it is more economical, payback period is less than 4.0 years and is a better solution (i.e. introducing all ESMs considered in this study) if initial investment is affordable when comparing to life cycle cost.

- For medium-rise CECB Phase II office building it is not as economical and its payback period is more than 6.0 years. Therefore, integrating all ESMs considered in this study to the CECB building is not much of an economical solution considering the current Sri Lankan economy.

5. Payback Period Variation with the ESMs Equipment Installation Cost Changes for CECB Phase II office building are as follows;

- When initial equipment installation costs of ESMs are increased by five percent (+5%), payback period of the ESMs increase by a minimum of 18 percent (payback increase by 18%).
- When initial equipment installation costs of ESMs are decreased by five percent (-5%), payback period of the ESMs are reduced by a minimum of 18 percent (payback fall down by 18%).

EUI (Energy Unit Intensity) Values

6. Based on the two case studies, it can be established that better EUI values for high rise office buildings in Colombo, Sri Lanka are as follows;

- For high-rise office building in Colombo based on the Access Tower II building application:

EUI value is 123.7 kWh/m².year

- For medium-rise office building in Colombo based on the CECB Phase II building application:

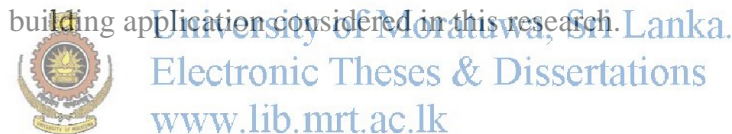
EUI value is 82.3 kWh/m².year

Table 6.5: Established EUI Values for the Office Buildings in Colombo

Office Building Type	No of Floors	Total Building Height (m)	Total Floor Area (m ²)		Establish EUI Value for Office Building in Colombo (kWh/m ² .year)
			Including Car Park	Without Car Park	
High-rise	30	105	35,530	22,730	124.0
Medium-rise	09	33	2,510	2,290	83.0

According to the above results in Table 6.4, EUI value of the high rise office building application is higher than that of the medium rise office building application selected in this research and the difference is 41 kWh/m².year. Identified reasons for EUI value difference between the above two applications are as follows;

- i. WWR of the high rise office building is 80% while that of the medium rise office building is 35%, i.e., WWR of the high rise building is 2.3 times higher with compared to the medium rise office building application. Therefore, the high rise office application has a higher solar heat gain percentage when compared to the medium rise office application in this research.
- ii. Medium rise office building considered in this reach is a narrow building. It has greater potential to use daylight throughout the day during building operating hours. Therefore, electrical power consumption for artificial lights in the medium rise building is reduced and heat gain due to artificial lights in the medium rise building is also reduced when compared with the high rise office



Electrical Energy Saving Potential

7. By integrating the ESMs which are considered in this study, a high-rise office building in Colombo, has potential to save electrical energy by a minimum of 17%. Hence, ESMs integrated high rise office building is 17% more efficient than the conventional (Baseline) high rise office building in Colombo.
8. By integrating the ESMs which are considered in this study, a medium-rise office building in Colombo, has potential to save electrical energy by a minimum of 19%. Hence, ESMs integrated medium-rise office building is 19% more efficient than the conventional (Baseline) medium-rise office building in Colombo.

Table 6.6: Electrical Energy Saving Potential in Colombo office buildings

Office Building Type	No of Floors	Total Building Height (m)	Total Floor Area (m ²)	Electrical Energy Saving Potential (%)	Introduce ESMs
High-rise	30	105	35,530	17%	Group of ESMs - A
Medium-rise	09	33	2,510	19%	Group of ESMs - A

Note : Group of ESMs-A are selective glazing for windows, perimeter circulation space, open office space at perimeter, daylighting through windows, energy efficient lamps and ballasts, lighting controls, and efficient chillers

This study has not considered the following ESMs which can be easily incorporated in to a building; VSD driven pump and fans, Heat recovery systems, Building Management Systems. Therefore, properly designed new office buildings in Colombo have greater potential to save more than 20% electrical energy by integrating economical ESMs discussed in this study.



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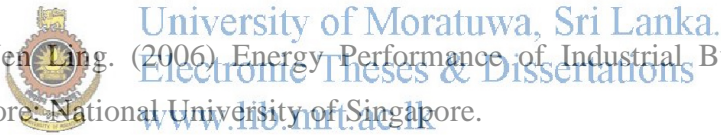
RECOMENDATIONS

- 1.0 Introducing Performance Glazing for windows without integrating daylight for the office building (both High-rise and Medium-rise) in Colombo, Sri Lanka is not an economical solution.
- 2.0 Introducing Energy efficient lighting system together with daylight integration system and perimeter circulation or office spaces for the office building (both High-rise and Medium-rise) in Colombo, Sri Lanka is an economical solution.
- 3.0 Introducing efficient chiller system for office buildings (both High-rise and Medium-rise) in Colombo, Sri Lanka is an economical solution.
- 4.0 New office building designs for Colombo can save more than 20% electrical energy by incorporating the following ESMs and also carrying out a proper ‘whole-building’ energy simulation using Computer modeling software,

Recommended ESMs are: Selective glazing for windows, perimeter circulation space, open office space at perimeter, daylight through windows, energy efficient lamps and ballasts, lighting controls, high efficiency cooling equipment, VSD driven pumps and fans, Heat recovery system, Building Management System.

- 5.0 Based on this study, established EUI values for these office buildings in Colombo are as follows;
High-rise building - 124.0 kWh/m².year
Medium-rise building - 83.0 kWh/m².year
- 6.0 It is recommended to carry out further research work in this area by conducting both Computer modeling and data collection from existing office buildings in Sri Lanka to establish better and more precise EUI values for office buildings in Sri Lanka due to the following;
 - i. This study is limited to a few ESMs (which are discussed in Section 4)
 - ii. The number of samples considered in this research (i.e. two office building applications in Colombo)
 - iii. ESMs and techniques are application specific as noted in [2]

REFERENCES

1. NREL. Matthew Leach, Chad Lobato, Adam Hirsch, Shanti Pless, and Paul Torcellini (2010), NREL/TP-550-49213, Technical Support Document, Strategies for 50% Energy Savings in Large Office Buildings. Golden, Colorado: National Renewable Energy Laboratory, National Laboratory of the U.S. Department of Energy.
2. Federal Energy Management Program, (2001) DOE/EE-0249, Low-Energy Building Design Guidelines. Golden, USA: U.S. Department of Energy by the National Renewable Energy Laboratory, a DOE national laboratory.
3. TRACE 700 software, (2008) User Manual - Version 6.2, developed by Trane Air Conditioning Systems and Service Co. Ltd, USA
4. Energy Efficiency and Renewable Energy, (May 2011) CREEA-WB Whole Building Baseline Webinar, Building Technologies Program. Golden, Colorado: U.S. Department of Energy.
5. Chia Yen Ling. (2006) Energy Performance of Industrial Buildings in Singapore. Singapore: National University of Singapore.

6. NREL. M. Deru, B. Griffith, and P. Torcellini, (2006) NREL/TP-550-39834, Establishing Benchmarks for DOE Commercial Building R&D and Program Evaluation. Golden, Colorado: National Renewable Energy Laboratory, National Laboratory of the U.S. Department of Energy.
7. The Warren center. (2009) Low Energy High Rise building Research Study, Final Research Report. Australia: National Project Consultants Pty Ltd and Exergy Australia Ptd Limited.
8. National Institute of Building Sciences, (2011) Data Needs for Achieving High-Performance Buildings. NW, Suite 700 Washington: National Institute of Building Sciences with New Buildings Institute and the National Environmental Balancing Bureau.
9. Cui Qi, (2006) Office Building Energy Saving Potential in Singapore. Singapore: Department of Building National University of Singapore.

10. Clare Dykes, (2012) User Perception Benchmarks for Commercial and Institutional Buildings in New Zealand. Wellington: The School of Architecture, Victoria University of Wellington.
11. IEA, (2013) Technology Roadmap, Energy efficient building envelopes. Paris, France: International Energy Agency.
12. TAC, (2000) Leading Techniques for Energy Savings in Commercial Office Buildings. WP-Offices energy - US: Schneider Electric, www.tac.com.
13. ASHRAE. (2007) Standard 90.1-2007, Energy Standard for Building Except Low rise Residential Building. Atlanta GA: American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.
14. ASHRAE. (2004) Standard 62.1-2004, Ventilation for Acceptable Indoor Air Quality. Atlanta GA: American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.
15. ASHRAE. (2004) Standard 55-2004, Thermal Environmental Condition for Human Occupancy. Atlanta GA: American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.
16. ASHRAE. (2002) Handbook of. SI Edition, Atlanta GA: American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.
17. Adam Hinge, Paolo Bertoldi, Paul Waide (2006), Comparing Commercial Building Energy Use Around the World: International Energy Agency. USA. Sustainable Energy Partnerships. European Commission
18. Jayamaha, L. (2006) Energy-efficient building systems - Green strategies for operation and maintenance. New York: McGraw-Hill.
19. Public Utility Commission of Sri Lanka, Generation Performance in Sri Lanka – 2014 (First Half), www.pucsl.gov.lk.

APPENDICES



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APPENDIX A: REPORTS GENERATED FROM TRACE-700 SOFTWARE



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APPENDIX A-1: ACCESS TOWER II BUILDING



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APPENDIX A-2: CECB PHASE II BUILDING



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APPENDIX B: Equipment Supply and Installation Cost

Equipment Installation Cost For Access Tower II Building

Equipment / Materials/ Systems	Equipment Installation Cost* / US\$	
	Base Building	Considering ESMs
Glazing Material	1,100,335.88	1,760,537.40
Lighting System	188,550.00	310,427.00
Chillers	137,405.00	183,206.00

Equipment Installation Cost for CECB Phase II Building

Equipment / Materials/ Systems	Equipment Installation Cost* / US\$	
	Base Building	Considering ESMs
Glazing Material	57,502.00	80,502.00
Lighting System	12,850.00	25,500.00
Chillers	34,352.00	39,504.00

Note : Above costs are taken from prevailing market price in Sri Lanka.*

APPENDIX C: ARCHITECTURAL DRAWINGS



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APPENDIX C-1: ACCESS TOWER II BUILDING



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