ANALYSIS FOR OPTIMIZATION OF ENERGY EFFICIENCY IN OFFICE BUILDINGS IN SRI LANKA

Mirihana Kankanamge Tharanga Dilhan

(148612E)

Degree of Master of Science in Building Services Engineering

Department of Mechanical Engineering

University of Moratuwa
Sri Lanka

March 2019

ANALYSIS FOR OPTIMIZATION OF ENERGY EFFICIENCY IN OFFICE BUILDINGS IN SRI LANKA

Mirihana Kankanamge Tharanga Dilhan

(148612E)

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

Department of Mechanical Engineering

University of Moratuwa
Sri Lanka

March 2019

DECLARATION

“I declare that this is my own work and this thesis/dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis/dissertation, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

…………………………...   ………………...

Signature of the Candidate   Date

(M.K.T. Dilhan)

The above candidate has carried out research for the Masters thesis under my supervision.

…………………………...   ………………...

Signature of the Supervisor   Date

(Prof. K.K.C.K. Perera)

ABSTRACT

Energy consumed in the building sector consists of residential and commercial end users and it accounts for 20.1% of the total delivered energy consumed worldwide [22].Global primary energy demand is projected to increase by annual rate of 1.6% between 2004 and 2030[23].

There are building codes, Standards, Guidelines etc. to regulate and promote energy efficiency in building sector [page 33]. Sri Lanka also had focused on minimising these increasing trends during the past decade. “Code of Practice for Energy Efficient Buildings in Sri Lanka 2008” was introduced as an initiative. Sri Lankan government is carrying out various programmes, seminars and activities to encourage building owners, developers, designers to implement energy saving measures.

In this research three commercial buildings in Colombo region having 8, 8 & 10 floors and total floor areas of around 35 000 ft^2, 60 000 ft^2 & 90 000 ft^2 and monthly average energy consumption around 50 000 kWh, 70 000 kWh & 100 000 kWh were selected. The study and analysis were done to find out whether there are none-compliances of the selected buildings with ASHERAE 92.1-2007 standard and Code of Practice for Energy Efficient Buildings in Sri Lanka-2008 which are used by professionals in the subject and to find out whether there are opportunities to improve energy efficiency of already constructed buildings further by modelling those buildings in Trace 700 software by simulating various possible options.

None of the three selected buildings fully complied with the standards considered. Major weak points were poor building envelope sealing, insufficiency of usage of automatic controls, improper balancing of systems, poor lighting system efficiency , higher lighting power density and higher Solar Heat Gain Coefficient of vertical glazing.

Though Building Automation Systems (BAS) are installed, it was revealed that by adding/upgrading some new features/options to BAS and by eliminating the weaknesses found, there are still more opportunities to increase energy efficiency further significantly.

ACKNOWLEDGEMENT

I take this opportunity to thank my supervisor Prof. K.K.C.K Perera, Vice-chancellor, University of Moratuwa for his guidance throughout the research work as well as during the course, his encouragement and his patience on my mistakes and weak points.

I would like to thank all the lecturers in the post graduate course, including two coordinators Dr. M.A. Wijewardane and Dr. M.M.I.D. Manthilake who always gave guidance and encouraged patiently to complete this report.

And I would like to express my appreciation to the staff of the buildings studied who gave me required information and arranged access to the building services systems kindly.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Description
A	Ampere
AC	Air Conditioning
A.M.	Ante Meridiem
AHU	Air Handling Unit
ASHRAE	American Society of Heating Refrigeration and Air Conditioning Engineers
BAS	Building Automation System
BMS	Building Management System
CEB	Ceylon Electricity Board
CFM	Cubic Feet per Minute
CT	Cooling Tower
COP	Coefficient Of Performance
CFL	Compact Fluorescent Lamp
^oC	Celsius
DCV	Demand Control Ventilation
DDC	Direct Digital Control
EPF	Envelop Performance Factor
EER	Energy Efficiency Ratio
ft	Feet
^oF	Fahrenheit
GMT	Greenwich Mean Time
gpm/hp	Gallons per minute per horsepower
hp	Horsepower
HVAC	Heating, Ventilation and Air Conditioning
hp/CFM	Horsepower per Cubic Feet per Minute
IPLV	Integrated Part Load Value
kW	Kilowatt

kWh	Kilowatt-hours
KIP	Key Performance Indicators
LPD	Lighting Power Density
lm/W	Lumens per Watt
LCC	Life Cycle Cost
LED	Light Emitting Diode
m	Meter
mm	Millimetre
OTTV	Overall Thermal Transfer Value
PCM	Phase Change Material
PV	Photo Voltaic
P.M.	Post Meridiem
ppm	Parts Per Million
PIR	Passive Infra-Red
Rs	Sri Lankan rupees
SHGC	Solar Heat Gain Coefficient
T5	Tubular with 5/8” in diameter
Ton	Cooling capacity in Ton
UV	Ultra Violet
V	Volt
VFD	Variable Frequency Drive
VLT	Visual Light Transmittance
W	Watt
W/m^2	Watts per Square Meter
W/ft^2	Watts per Square Foot

1. INTRODUCTION

1.1 Background

Energy is one of the most discussed topic today because of its high demand and limitations in supply. The commercial building sector is one of the fastest growing energy consuming sectors. This is mainly due to the growth of commercial and public activities and their associated demand for heating, ventilation and air conditioning (HVAC).

Energy consumed in the building sector which consists of residential and commercial end users accounts for 20.1% of the total delivered energy consumed worldwide [22].

Global primary energy demand is projected to increase by annual rate of 1.6% between 2004 and 2030. Over 70% of the increase in energy demand over the projection period comes from developing countries. Global energy-related carbon-dioxide (CO_2) emissions increase by 1.7% per year between 2004 and 2030 [23].

In Sri Lanka, in 2013 57% of total electricity generation is by Hydro-power, 27% by thermal oil, 14% by coal and 2% by other means. Thermal oil and coal generates 40% electricity. Those plants release harmful by-products to the environment. Out of this electricity demand 37% is for domestic use, 27% for commercial use, 34% for industrial use and 1 % for street lighting [5].

According to Sri Lanka Sustainable Energy Authority, in 2014, total household and commercial energy demand was 48%, 26% for transport and 26% for industry of the country's total energy demand [6].

Therefore, it is essential to investigate whether there are opportunities to introduce new effective energy efficiency measures in the commercial and domestic buildings in Sri Lanka. On The other hand, rising energy costs encourage household and commercial sector to reduce their energy consumption rate. It is evident that more energy efficient buildings are more valuable in the property market than conventional buildings, which will increase the commercial incentive to invest in properties with improved sustainability performance.

In many occasions, low energy commercial buildings need lower investment cost than conventional ones, especially where integrated systems are used or natural cooling and/or ventilation is used. Even if the initial cost of an energy efficient building is greater than the conventional one, these additional costs will become economical within the expected lifetime of the building.

1.2 Problem Statement

Energy consumed in the buildings sector consists of residential and commercial end users and accounts for 20.1% of the total delivered energy consumed worldwide [22]. Global primary energy demand is projected to increase by annual rate of 1.6% between 2004 and 2030. Global energy-related carbon-dioxide (CO_2) emissions increase by 1.7% per year between 2004 and 2030[23].

Even though a great attention have been paid on improving the energy efficiency in buildings in Sri Lanka, there is still a 20 % electrical energy saving potential and 25% thermal energy saving potential in industrial and commercial sectors[24].

The main objective of this research is to investigate whether there are opportunities to introduce new effective energy efficiency measures in office buildings in Sri Lanka.

2. AIM AND OBJECTIVES

2.1 Aim

To identify the possible improvements in energy code compliance by studying the current level of compliance of office building in Sri Lanka with energy codes and

To investigate whether there are opportunities to introduce new effective energy efficiency measures in the office buildings in Sri Lanka.

2.2 Objectives

1) Select three buildings with many of building services systems are installed (Air Conditioning, Lighting, Pumping, Elevators, Computers & general office equipment etc.)

2) Collect data which represents the energy usage (Electricity Bills, kWh usage, BMS data, Energy Audits etc.), collect drawings, sketches and other documents which provide the details of selected buildings and systems installed. Take measurements like voltage, current, lux level, ventilation rate etc.

3) Find out whether the building have been design and constructed in compliance with ASHRAE 92.1-2007 or Code of Practice for Energy Efficient Building in Sri Lanka-2008

4) Study and find out other possible methods/steps which can be used to improve energy efficiency of buildings by using modelling facilities of Trace 700 software

3. LITERATURE REVIEW

Researches, experiments and surveys have been carried out in many countries regarding the optimum use of energy in building sector. As a result, various manufacturers have introduced successful technologies. Further experiments and researches are being done to improve the energy efficiency.This chapter will review the previous studies, publications/surveys done by various organizations/bodies and currently available technologies in this subject area.

3.1 Energy Efficiency in Buildings

An issue of concern in buildings is whether to focus energy efficiency programmes on new buildings or on already existing buildings. Most of the energy efficiency efforts realistically target new construction or, to a limited extent portions of existing buildings undergoing major renovation. Approximately 86% of building construction expenditures are related to renovation of existing buildings, not to new construction. For most of the new buildings, performance significantly deteriorates in the first three years of operation by as much as 30%. This implies that to effectively reach meaningful energy demand reduction in buildings, it is important to have a consistent energy efficiency programme for existing buildings also [1].

3.2 Systems which Consume Energy/Electricity

Following are some of the building services systems installed in commercial buildings in Sri Lanka.

1. Air Conditioning and Ventilation System
2. Lighting System
3. Fire Protection System
4. Plumbing System (Optimization)
5. Electrical System
6. Public Address System

7. Sound System
8. How Water System
9. Computer Network
10. Communication System
11. Fire Alarm System
12. Elevator/Escalator System
13. Duct System(Optimization)
14. Water Pumping System
15. Building Management System

3.3 Energy Percentages Used By Each System

Air Conditioning system uses 77% of the total energy demand, while lighting system 16%, pumping system 0.3 %, Electrical system (loses), Elevator/Escalator system 2.2 % and the balance by Office equipment & Others in a typical office building in Sri Lanka [19].

In US, Air Conditioning system uses 50% of the total energy demand, lighting system 10%, water heating 12%, Refrigeration 4% and other 24% [4].

In Hong Kong, Air-conditioning accounts for 30%, lighting 13%, office equipment 8% and cooking 8% respectively of the total electricity end-uses [25].

Therefore, it seems that the actual amounts varies according to geographical location, economic development and cultural orientation.

Energy optimization should mainly focus on high energy demanding systems like air conditioning system, lighting system etc. Then other systems, pumping, electrical, elevator/escalator, household appliances etc.

3.4 HVAC System

Heating, Ventilation, and Air-Conditioning (HVAC) system in buildings are used for improving indoor air quality and provision of adequate thermal comfort.

As mentioned above, HVAC systems in many buildings in Sri Lanka use around 77% of the total building energy demand. This indicates that planning of any electricity demand management system in the commercial and public building sector must lay emphasis on the efficiency of the HVAC system.

Clear understanding of processes and sub-systems of HVAC system is very important in performance improvement programs.

Energy efficiency improvement in HVAC system can be focused in following phases in the life cycle.

1) System Design
2) Installation and Commissioning
3) Operation and Maintenance
4) Management

3.4.1 System Design

A comfortable environment is broader than just controlling the temperature and humidity. Comfort parameters that are typically impacted by the HVAC system include dry-bulb temperature, humidity, fresh air, air movement, cleanliness of the air, noise levels etc.

Out of all the decisions made by owners, architects, engineers, and contractors during the design and construction phases of a building, the selection of the HVAC system tends to be a decision that is often reconsidered throughout the lifespan of the building. The building may be an architectural wonder, with modern lighting, fast elevators, easy access, modern parking, the finest furnishings, and superior energy efficiency. But if there are comfort related problems, all of the positives may go unnoticed.

The HVAC Design is a step by step process carried out by and experienced and qualified HVAC design engineer.

Design process involves the following steps in general

- Determination/selection of the design parameters of the conditioned space - weather data, room temperature, humidity, air quality, etc.
- Calculation of the cooling loads, heating loads, and air flow requirements
- Conceptual design. This involves selecting the type of system to suit the requirements and preparation of schematic diagrams to establish the system configuration
- Physical layout of the equipment and ductwork by using a software such as AutoCAD or similar or a manually.
- Calculation fan pressure drop.
- Equipment selection and specification. (Chillers, AC units, Dampers, Fans etc.)
- Depending on the HVAC system type, other design steps may involve chilled water pump pressure drop calculation, refrigerant pipe sizing calculation, etc.

3.4.1.1 Load Calculation

In air conditioning system design, load calculation plays a very important role. The parameters and data considered (weather data, inside temperature, humidity, air quality, internal loads, no of people inside, type of use of the building, building envelop details etc.) in load calculation should be accurate as much as possible because the result will determine the HVAC equipment sizes, duct sizes, space requirements, capacity of control panels etc.

Main problem in load calculation is collecting right data because those data may vary even after the air conditioning system design has been completed depending on the requirement of building owner or architectural requirements.

3.4.1.2 System Selection & Sizing

When selecting most suitable air conditioning system for a given building, there are some factors that may be valuable for the decision. The most-common factors that influence the selection of the HVAC system are:

1. Preference of the building owner
2. Available construction budget
3. Size and shape of the building
4. Architectural limitations
5. Function of the building
6. Life-cycle cost
7. Energy Efficiency
8. Ease of operation and maintenance
9. Time available for construction
10. Location of the building (climate etc.)
11. Warranty and After Sales Service

It is very important to give priority to select energy efficient equipment. Energy efficiency rating is an ideal parameter to select equipment with good efficiencies. Some of those ratings are

1. COP (Coefficient of Performance)
2. EER (Energy Efficiency Ratio)
3. SEER (Seasonal Energy Efficiency Ratio)
4. HSPF (Heating Seasonal Performance Factor)
5. AFUE (Annual Fuel Utilization Efficiency)
6. IPLV/NLPV (Integrated Part Load Value/ None-Standard Part Load Value)
7. kW/Ton (Kilo Watt per Ton)
8. Energy Star

One of the most common problems in the HVAC industry is the tendency to oversize equipment. Some contractors and customers prefer to select oversized units because of lack of confidence of the accuracy of the load calculation. Unfortunately, bigger units leads to higher installation cost, higher energy cost, higher operating cost, more space for machine rooms etc.

If the selected equipment are too small, and they don't provide adequate heating and/or cooling for the building. They will run at full load always and may lead to frequent breakdowns.

It is a good practice to try to make the air conditioning equipment to run at best efficiency operating point.

Therefore, air conditioning equipment should be properly sized and installed according to the manufacturer's recommendations to ensure efficient operation and extended lifespan.

3.4.1.3 Effective System Zoning

A HVAC system can be controlled via a single-zone approach or a multi-zone approach. With a single zone approach, all areas served by the system receive the same amount of heating, cooling or air conditioning as defined by the control logic of the unit. However, different areas can have different end energy use requirements depending on various factors [4].

Areas with similar end energy use requirements should be grouped and served from the same HVAC system. This will ensure the optimum amount of heating, cooling or ventilation is provided to the spaces when required [4].

Inside temperatures may be different even inside the same building, according to the amount of sunlight that reaches into the building and the direction the windows faces.

Zoned air conditioning systems allow the building to be divided into multiple separate zones. This types of air conditioning systems have more control over the heating and cooling system and provide individual control of temperature in each zone.

Electronically controlled modulating dampers, valves and electronic thermostats automatically adjust the temperature in each zone. This saves energy by not heating or cooling areas of the building where it's not required. Although zoning doesn't change the efficiency of an air conditioning system, it gets the most efficient use of the system.

3.4.1.4 Waste Heat/Energy Recovery

Waste-heat recovery devices recover thermal energy from exhaust air and transfer it to the incoming fresh-air supply. This can result in a reduction in the energy that would normally be needed to heat or cool air to the temperature requirements of the system. A correctly designed and installed heat recovery device can achieve savings upwards of 10% of the running cost of the HVAC system [4].

3.4.1.5 Building Envelop

The building envelope includes all exterior components of a building, such as walls, doors and windows, roof, floor that make up the shell of the building.

The building envelope covers four basic functions such as structural support, controlling moisture and humidity, controlling temperature and air pressure changes. While serving these different functions, the building envelope affects the energy use of the building. Space heating, cooling and ventilation account for the largest portion of end-use energy consumption in commercial buildings. Therefore it is very important to focus on building envelope when developing an energy management strategy.

3.4.1.6. Ducting System

Design and maintenance of the HVAC duct system is of great importance in energy efficiency improvement programs. Duct design involves the calculation of the cross sectional dimensions of the duct sections and deciding the duct layout arrangement, duct shapes, duct materials and duct construction methods including equipment and fittings to suite the purpose [7].

The use of optimisation techniques over conventional ones in duct design could realise savings in the range of 5% to 20% in life cycle cost. Studies have however failed to categorically ground optimisation techniques of design with the right design theory due to problems in ductwork pressure balancing the complexity of the combined supply and return flow analysis [7].

3.4.1.7 Thermal Storage

Thermal energy storage is like a battery for the air conditioning system of a building. It uses standard cooling equipment with one or more energy storage tanks to shift all or partial cooling load to off peak, night time hours.

There are three major types of thermal storage systems as below.

Ice Storage:

This utilizes the latent heat of fusion of ice for thermal storage. During off peak periods, the cooling system is used to make ice. Then the ice is melted to make chilled water when cooling is required.

Chilled Water Storage:

Chilled water is generated and stored during off peak hours and is used for cooling during peak hours. Since this method uses specific heat of water rather than the latent heat of fusion of ice as in ice storage, this requires about 4 times the storage capacity (volume) of an equivalent ice storage system.

Salt Storage (phase change material-PCM):

These are characterized by a high latent heat, which allows them to store large amounts of energy when the material transitions into different physical states. Typically, the phase transition occurs when the PCM melts, changing from a solid to liquid; however, the transition can also be a solid to solid transition as the crystalline structure of the material changes. They are often characterized by high costs. PCMs often have a low thermal conductivity which leads to a slow transient response. This makes it difficult to quickly store and access the energy stored within the PCM.

Existing chiller systems can easily be converted to salt storage or chilled water storage systems. For ice storage systems, a direct refrigerant system or glycol chillers are suitable.

3.4.2 Installation and Commissioning

Commissioning Process is a quality-focused process for enhancing the delivery of a project. The process focuses upon verifying and documenting that all of the commissioned systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet the Owner's Project Requirements [15].

Existing Building Commissioning Process is a quality-focused process for attaining the Current Facility Requirements of an existing facility and its systems and assemblies being commissioned. The process focuses on planning, investigating, implementing, verifying, and documenting that the facility and/or its systems and assemblies are operated and maintained to meet the Current Facility Requirements, with a program to maintain the enhancements for the remaining life of the facility [15].

Re-Commissioning is an application of the Commissioning Process requirements to a project that has been delivered using the Commissioning Process. Retro-Commissioning is the Commissioning Process applied to an existing facility that was not previously commissioned [15].

On-Going Commissioning Process is a continuation of the Commissioning Process well into Occupancy and Operations to continually improve the operation and performance of a facility to meet current and evolving Current Facility Requirements or Owner's Project Requirements. On-Going Commissioning Process activities occur throughout the life of the facility; some of these will be close to continuous in implementation, and others will be either scheduled or un-scheduled as needed [15].

For the best possible results, commissioning should be included in all phases of the design and construction process [16]

- pre-design
- design
- construction
- acceptance
- post-acceptance

Regardless of the commissioning process used, there are many benefits from commissioning. Some of these benefits are [16]

- Reduction of change orders and additional claims
- Fewer project delays
- Managed start-up requirements
- Shorter building turn-over transition period
- Less post-occupancy corrective work
- Minimized effects from design changes
- Improved indoor air quality and occupant productivity
- Better operation, maintenance and reliability
- Lower energy and operations costs
- Value-added quality construction

- Complete and useful O&M documentation
- Owner advocacy for design and construction decisions
- Documentation of the entire construction process

3.4.3 Operation and Maintenance

3.4.3.1 Operation

3.4.3.1.1 Time Schedules

Time schedules are the most basic level of automatic control. They are typically automatic on/off switches that operate in parallel to the occupancy pattern of an area. A time schedule can also be used to instigate a set-back pattern according to gradually increasing occupancy levels in the morning and decreasing levels in the evening. There are a number of methods of employing time schedules [4].

Time switch:- Services are switched on or off in accordance with time settings.

Seven-day programmer:- This is used for switching air conditioning systems on/off, or to a setback mode at different times during the week according to the occupancy levels.

Optimum time controls:- These switch the air conditioning systems on just in time to reach the required temperature at the start of occupation [4].

3.4.3.1.2 Set Points

Different offices/industries require various air conditioning set points depending on various factors, including the process going on in the area, activity level, occupancy levels, etc. The set points used in a facility should be confirmed by quality personnel, energy service team and the reasoning behind the implementation.

Control systems compare measured values (e.g. current, temperature) with a set point (e.g. temperature set by user). The control system will take the required actions to bring the system to desired operating point. Set points are critical to any control system.

Control systems have one or more sensors to report the measured parameters to a control device. The control logic of the device uses this information to determine whether heating or cooling is required. It is important to calibrate or check the performance of all sensors critical to the operation in a schedule to ensure the values report to control devices are accurate.

Typically, changing the space temperature set point by 1°C can affect the energy consumption of associated cooling or heating equipment by around 10 per cent. There are actually two effects at play in such a scenario: (1) a change to the set point (or the centre point of the control range) and (2) a change to the dead band (or the width of the control range), increasing the temperature gap between heating and cooling [3].

It is important to note that any changes to indoor temperature ranges should be applied gradually, for example by 0.3°C at a time, until a balance has been struck between achieving system energy savings and maintaining an acceptable standard of thermal comfort for building occupants. This gradual change will allow occupants to acclimatise to the changes [3].

3.4.3.1.3 Dead Band

A dead band is an area of a signal range where no action occurs. The purpose of a dead band on an air conditioning control system is to prevent repeated activation-deactivation cycles, often referred to as hunting. For example, in a typical workplace the heating should switch off when a temperature of 19°C has been reached and cooling should not come on until the temperature exceeds 20°C. The 1°C gap between the set points prevents simultaneous heating and cooling occurring, and is referred to as the dead band [4].

3.4.3.2 Operation and Maintenance

Operations and Maintenance are the decisions and actions regarding the control and upkeep of property and equipment. These are inclusive, but not limited to the following [17]:

1) Actions focused on scheduling, procedures, and work/systems control and optimization

2) Performance of routine, preventive, predictive, scheduled and unscheduled actions aimed at preventing equipment failure or decline with the goal of increasing efficiency, reliability, and safety.

Operational Efficiency represents the life-cycle cost-effective mix of preventive, predictive, and reliability-centered maintenance technologies, coupled with equipment calibration, tracking, and computerized maintenance management capabilities all targeting reliability, safety, occupant comfort, and system efficiency [17].

3.4.3.2.1 Measuring the Quality of Operation and Maintenance Program

Traditional thinking in the operation and maintenance field focused on a single metric, reliability, for program evaluation. Every operation and maintenance manager wants a reliable facility. However, this metric alone is not enough to evaluate or build a successful operation and maintenance program [17].

Beyond reliability, operation and maintenance managers need to be responsible for controlling costs, evaluating and implementing new technologies, tracking and reporting on health and safety issues, and expanding their program. To support these activities, the operation and maintenance manager must be aware of the various indicators that can be used to measure the quality or effectiveness of the operation and maintenance program. Not only are these metrics useful in assessing effectiveness, but also useful in cost justification of equipment purchases, program modifications, and staff hiring [17].

Below are a number of metrics that can be used to evaluate an operation and maintenance program. Not all of these metrics can be used in all situations; however, a program should use as many metrics as possible to better define deficiencies and, most importantly, publicize successes [17].

- **Capacity factor**– Relates actual plant or equipment operation to the full-capacity operation of the plant or equipment. This is a measure of actual operation compared to full-utilization operation.
- **Work orders generated/closed out**– Tracking of work orders generated and completed (closed out) over time allows the manager to better understand workloads and better schedule staff.
- **Backlog of corrective maintenance**– An indicator of workload issues and effectiveness of preventive/predictive maintenance programs.
- **Safety record**– Commonly tracked either by number of loss-of-time incidents or total number of reportable incidents. Useful in getting an overall safety picture.
- **Energy use**– A key indicator of equipment performance, level of efficiency achieved, and possible degradation.
- **Inventory control**– An accurate accounting of spare parts can be an important element in controlling costs. A monthly reconciliation of inventory “on the books” and “on the shelves” can provide a good measure of your cost control practices.
- **Overtime worked**– Weekly or monthly hours of overtime worked has workload, scheduling, and economic implications.
- **Environmental record**– Tracking of discharge levels (air and water) and non-compliance situations.
- **Absentee rate**– A high or varying absentee rate can be a signal of low worker morale and should be tracked. In addition, a high absentee rate can have a significant economic impact.
- **Staff turnover**– High turnover rates are also a sign of low worker morale. Significant costs are incurred in the hiring and training of new staff. Other costs include those associated with errors made by newly hired personnel that normally would not have been made by experienced staff.

3.4.3.2.2 Operation and Maintenance Contracting

In operation and maintenance services industry, there is a wide variety of service contract types ranging from full-coverage contracts to individual equipment contracts to simple inspection contracts. In a relatively new type of operation and maintenance contract, called End-Use or

End-Result contracting, the operation and maintenance contractor not only takes over all operation of the equipment, but also all operational risk. In this case, the contractor agrees to provide a certain level of comfort (space temperature, for instance) and then is compensated based on how well this is achieved [17].

When considering the use of an operation and maintenance contract, it is important that a plan be developed to select, contract with, and manage this contract. In its guide, titled Operation and Maintenance Service Contracts (PECI 1997), Portland Energy Conservation, Inc. did a particularly good job in presenting steps and actions to think about when considering an operation and maintenance contract. A summary of these steps are provided below [17]

- **Develop objectives for an operation and maintenance service contract, such as**
  - Provide maximum comfort for building occupants.
  - Improve operating efficiency of mechanical plant (boilers, chillers, cooling towers, etc.).
  - Apply preventive maintenance procedures to reduce chances of premature equipment failures.
  - Provide for periodic inspection of building systems to avoid emergency breakdown situations.
- **Develop and apply a screening process**. The screening process involves developing a series of questions specific to your site and expectations. The same set of questions should be asked to perspective contractors and their responses should be rated.
- **Select two to four potential contractors and obtain initial proposals based on each contractor's building assessments**. During the contractors' assessment process, communicate the objectives and expectations for the operation and maintenance service contract and allow each contractor to study the building documentation.
- **Develop the major contract requirements using the contractors' initial proposals**. Make sure to include the requirements for documentation and reporting. Contract requirements may also be developed by competent in-house staff or a third party.
- **Obtain final bids from the potential contractors based on the owner-developed requirements**.
  - Select the contractor and develop the final contract language and service plan.
  - Manage and oversee the contracts and documentation.
  - Periodically review the entire contract. Build a feedback process.

3.4.3.2.3 Improving Performance

Air conditioning system performance can be reduced with time, causing increase in operational costs. By the time the increases are noticed, higher utility bills and maintenance cost may have been paid. System optimization can bring the air conditioning system back to peak efficiency, lowering the energy consumption, risk of failure and operating costs [9].

HVAC System Optimization project typically includes these four steps [9]

1. **System Evaluation.**

   Baseline data collection on power usage, utility bills, climate trends and system performance.

2. **Analysis & Recommendations.**

   Assessment of equipment operating efficiency under varying load conditions; proposed solutions for system enhancement and performance improvements.

3. **Implementation.**

   Execution of action plan; system adjustments and retrofits.

4. **Ongoing Optimization.**

   Continuing partnership; monitoring and service for future improvements

Table 3.4.3.2.3 summarises the key optimisation strategies in general and provides guidance for their application for different types of air conditioning systems. The energy savings potential is specific to each strategy and non-cumulative; however, the identified energy-savings potential will naturally be greater with the adoption of two or more of these strategies [3].

Table 3.4.3.2.3: Energy Saving Potential & Guidelines

Page	Optimisation strategy	Energy-saving potential (Individual, non-cumulative)	Central water-cooled CHW system w/AHUs	Central water-cooled CHW system w/FCUs	Central air-cooled CHW system (AHU)	Central direct expansion (DX) plants – AHUs	Ducted direct expansion (DX) systems	Small direct expansion (DX) systems (split and packaged)	Operation 24/7	Regulated relative humidity (museums, galleries etc.)	Variable occupancy spaces	Enclosed spaces with combustion engines
13	1. Optimum start/stop	Up to 10% of total energy consumed by HVAC services	Y	Y	Y	Y	Y	N	N	N	Y	N/A
18	2. Space temperature set points and control bands	Up to 20% of total energy consumed by HVAC services	Y	Y	Y	Y	Y	Y	Y	Y (Limited)	Y	Y
24	3. Master air handling unit (AHU) supply air (S/A) temperature signal	Up to 15% of total energy consumed by HVAC services	Y	N	Y	Y	Y	N	Y	Y	Y	Y
29	4. Staging of compressors and chillers	Up to 10% of energy consumed by chillers	Y	Y	Y	Y	N	N	Y	Y	Y	Y
35	5. Duct static pressure reset (DSPR)	Up to 30% of energy consumed by fans serving AHUs	Y	N	Y	N	N	N	Y	Y	Y	N/A
40	6. Temperature reset: hot water (HW) temperature reset	Up to 5% of energy consumed by HW heaters	Y	Y	Y	Y[1]	Y[1]	N	Y	Y	Y	N/A
40	7. Temperature reset: chilled water (CHW) temperature reset	Up to 15% of energy consumed by chillers	Y	Y	Y	N	N	N	Y	Y (Limited)	Y	N/A
40	8. Temperature reset: condenser water (CW) temperature reset	Up to 15% of energy consumed by chillers	Y	Y	N	Y[2]	Y[2]	N	Y	Y	Y	N/A
45	9. Retrofit of electronic expansion valves (EEV)	Up to 15% of energy consumed by retrofitted AC compressors	Y	Y	Y	Y	Y	N	Y	Y	Y	N/A
49	10. Economy cycle	Up to 20% of energy consumed by AC compressors	Y	N	Y	Y[1]	Y[1]	N	Y	Y (Limited)	Y	N/A
54	11. Night purge	Up to 20% of energy consumed by AC compressors, during start-up time	Y	N	Y	Y	Y	N	N	N	Y	N/A
59	12. Demand control ventilation (DCV): carbon dioxide (CO_2)[3]	Up to 20% of space cooling and heating energy required for pre-treating of outdoor air (O/A)	Y	Y	Y	Y[2]	Y[2]	N	Y	Y	Y	N/A
59	13. DCV: carbon monoxide (CO)	Up to 80% of energy consumed by carpark ventilation fans	N/A	N/A	N/A	N/A	N/A	N/A	Y	N/A	Y	N/A
67	14. Optimised secondary chilled water (SCHW) pumping	Up to 30% of energy consumed by SCHW pumps	Y	Y	Y	N	N	N	Y	Y	Y	N/A
71	15. Variable head pressure control (air-cooled condensers)	Up to 30% of energy consumed by condenser fans	N	N	Y	Y[4]	Y[4]	N	Y	Y	Y	N/A
74	16. Variable head pressure control (water-cooled condensers)	Up to 30% of energy consumed by CW pumps	Y	Y	Y	Y[2]	Y[2]	N	Y	Y	Y	N/A
81	17. Energy management planning	Up to 50% of total energy consumed, depending on depth and commitment	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
86	18. Energy management training and awareness	Up to 10% of total energy consumed	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
88	19. Energy-efficiency maintenance	Up to 20% of total energy consumed by HVAC services	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
93	20. Management of system control software	Up to 10% of energy consumed by HVAC services	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Notes: 1 Hot water space air heating; 2 Water-cooled; 3 Not applicable for 100 per cent O/A supply applications (operating theatres, pet shops, morgues, laboratories with animals, battery rooms, etc); 4 Air-cooled

3.4.4 Management

Operation and maintenance management is a critical component of the overall program for efficiency improvement. The management function should bind the distinct parts of the program into a cohesive entity. It is good that the overall energy program should contain five very distinct functions: Operations, Maintenance, Engineering, Training, and Administration [17].

Beyond establishing and facilitating the Operations, Maintenance, Engineering, Training and Administration links, operation and maintenance managers have the responsibility of interfacing with other department managers and making their case for ever-shrinking budgets. Their roles also include project implementation functions as well as the need to maintain persistence of the program and its goals [17].

3.4.4.1 Ownership of buildings

Optimization of air conditioning system is sometimes as simple as changing control algorithms, altering set points and control schedules, and attending minor repairs and fine adjustments to existing equipment and systems.

To achieve the benefits of optimised controls, it is essential for building owners and facility managers to see optimisation as an investment rather than a cost, while directing building operators and service providers to include controls optimisation within their responsibilities and key performance indicators (KPIs) [3].

Tenants also have the capacity and responsibility to follow energy efficiency measures. Therefore, tenants must not be ignored when planning for energy efficiency in air conditioning systems. Barriers created by ownership and management structures in buildings is another issue worth taking into account.

3.4.4.2 Use of the building

Air conditioning systems are often built to suit building environment and operations. As an example a personal office or multiple working space office with various zones may have customized thermostat settings or a programmable thermostat whereas an entertainment theatre or hall would successfully use a single thermal setting as the air conditioning system is a single zone type. Where the public or a large number of people are allowed into the building recommends that a clearly visible placard explaining the details of operations and contact numbers of the staff to report malfunctioning of the air conditioning systems to must be displayed therein [8].

3.4.4.3 Accountability for energy management

Importance of an energy manager to be responsible for energy management programs should be highlighted. It is important to appoint a member of the company and then give him a related training for the task, appointing of a qualified and experienced person, use of an outside consultant or the use of a specialist energy management service provider. Whichever method selected for having somebody responsible for energy management, the main issue will be to formulate and implement an energy management programme.

3.4.4.4 Energy Consumption Budget

Finance is the means by which the success of the energy saving program will finally be judged.

This implies that it would be important to have a firm budget for energy consumption, to formulate a focussed energy management programme. Then the actual energy consumption can be benchmarked against the budget.

3.5 Lighting System

In addition to the air conditioning system, lighting systems is very important system to be focused at in energy saving measures.

Lighting system in a typical commercial building in Sri Lanka consumes 15% or more of the total energy demand of the building [19].

Lighting is a large and rapidly growing source of energy demand. Lighting is a substantial energy consumer, and a major component of the service costs in many buildings.

It should be noted that energy efficient equipment/components available in the market do not provide energy savings by themselves. A proper lighting system design should be carried out. In brief, not only energy-efficient equipment but also an energy-efficient lighting system design is required to achieve good results in energy saving.

3.5.1 Office Lighting

Office lighting accounts for 20% of all electrical energy generated in the world and thus presents a great opportunity for making energy savings at a global scale [20]. Therefore, it is worthy of understanding why artificial lighting uses that much energy and what lighting technologies are employed in offices so that areas of improvement can be identified.

Using daylight in providing light to offices is the most efficient, healthy and desirable way of lighting. However, there are many occasions where only daylight is not sufficient to provide the required levels of light throughout the occupied spaces of an office. Building orientation and the shape of the building, window sizes and number of windows in combination with the variable light levels provided by the sun and the sky conditions account for the varying daylight levels inside offices which can create a situation where minimum required light levels are not achieved. In addition, associated solar heat gains are usually entered to offices together with the daylight. Therefore, shading and solar heat rejecting glazing methods are often used to minimize solar gains and as a result, the daylight levels within offices are reduced. This typically results the need of artificial lighting even in the day time in many offices.

3.5.2 Energy Efficient Lighting

Building designers have started to implement energy saving technologies and energy efficient lighting systems such as tubular fluorescents with electronic ballasts, the use of sensor-based control systems etc. As building standards become stricter and the cost savings available by using new technologies is demonstrated, technologies designed for easy installation/integration in existing buildings will be able to capture the potential savings that will exist throughout the building lifetime.

The replacement of incandescent lamps by fluorescent lamps of the old T8 fluorescent lamps with T5 fluorescent lamps with electronic ballast will add energy savings. The introduction of new innovative LED lighting systems will accelerate savings in the near future.

Findings show that energy saving by LEDs is 32% compared with CFLs, and 174% compared with incandescent. In the manufacturing phase, LEDs consume 700% and CFL consumes 375% energy to manufacture an incandescent bulb. Energy loss in generation and distribution when LED, CFL and incandescent bulbs used for lighting shows 130% excess losses by CFL and 760% excess losses by conventional bulbs, compared with losses caused by LED [12].

3.5.3 Use of Controls

Modern lighting systems need light sources, ballasts/driver, luminaries, and electronic/electrical controls. Part of the electric power supplied to the lighting unit is transformed into light, while the rest is wasted as loss. Saving of energy requires the use of energy-efficient components, suitable control logic and the use of daylight.

3.5.4 Occupancy Sensors, Lamp Dimmers, and Ballast Control Systems

A wide variety of components are available in the market for building lighting installations. One of the most commonly used energy saving components is the occupancy sensor. Occupancy sensors use different technologies to detect the presence of people in the space and turn off lights when the space is unoccupied. Occupancy sensors use passive infrared technology, sound responsive technology, ultrasonic technology, or a combination of these to offer enhanced performance. Sound responsive sensors essentially work like a microphone and pick up local noise. Some sophisticated sensors are capable of learning background sounds over time and filtering them out to determine sounds most precisely correlated to occupancy. Passive infrared sensors are essentially heat sensors that detect the presence of warm bodies but require line-of-sight to the occupant. Ultrasonic sensors detect changes in the return of emitted high frequency waves which signal movement. Dual-technology sensors incorporate passive infrared and a second technology to minimize errors. Typically both sensors must be triggered to turn on the light but only one must be triggered to keep the lights on. Examinations of installations in real buildings have shown that the use of occupancy sensors can save up to 26 percent of lighting-related energy in private office spaces [13].

Dimmers and light sensors are very effective lighting energy saving tools. Typically a photodiode sensor is used and calibrated to maintain a set point where the incident light energy at the work plane is equivalent to the required illuminance. In an open loop system, the light sensor is angled towards the daylight coming direction and the room lights are dimmed in accordance with the measured daylight contribution. In a closed loop system, the light sensor is located to determine the total light level on the work plane and it adjusts the artificial light source as required to maintain the desired light level. The dimming effect can be obtained either by the use of a continuous dimming system in which all lights are capable of dimming through a wide range of fractional output or bi-level dimming in which a dimming effect is obtained by switching off individual lamps to vary the output. Significant savings may be possible by the implementation of daylight-linked dimming systems.

Study of a large federal office building in San Francisco found a 27% light energy use savings from automated dimming controls installed in private offices with external windows but noted that the savings would have been higher if the target light level had been adjusted to a lower, task-tuned level [13].

A study of lighting controls in atrium spaces found that use of a continuous dimming system saved 68% of lighting energy while an automatic on/off system saved only 31.5% of lighting energy during the time of main occupancy for the facility [14].

3.5.5 Light and heat portions produced by light sources

All light sources emit both light and heat in the form of convection, conduction and radiation. Yet, the portion of light and heat emitted varies depending on the type of the lamp technology. As a result, each type has a different thermal behaviour [11].

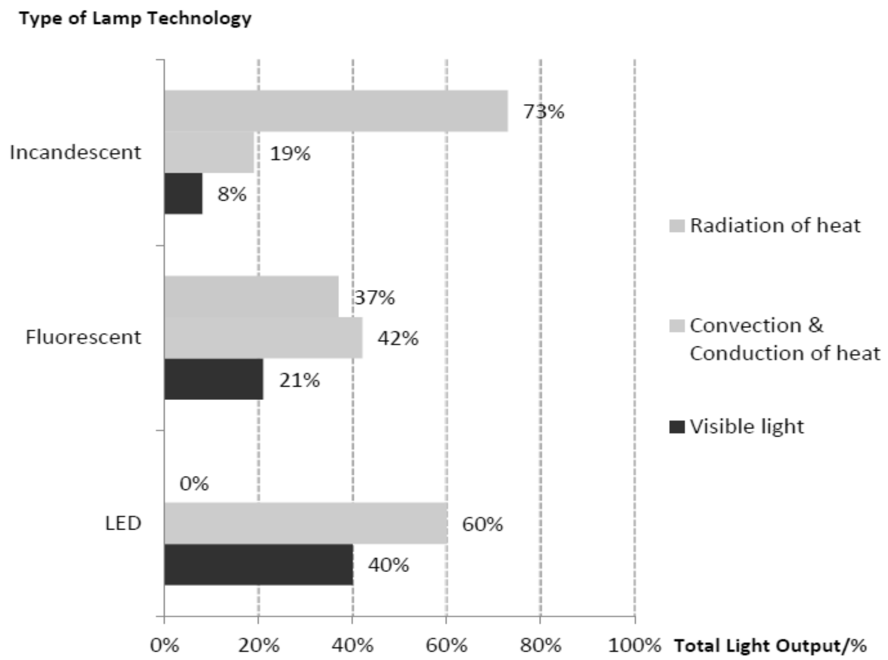


Figure 3.5.5: Type of Lamp Technology and Their Total Light Output

Judging from Figure, LED lamps generate more light and less heat compared to other types of lamp technology, such as incandescent and fluorescent lamps, rendering them more energy efficient. LEDs' luminous output appears to be around five times higher when compared to incandescent lamps and around two times when compared to fluorescent ones. On the other side, radiation, convection and conduction cover around 92% of the total energy use for lighting in incandescent lamps, 63% in fluorescent lamps and only 40% in LEDs [11].

Smart lighting systems make use of the prosperous LED lamp technology and therefore, take advantage of the constantly developing LED's contribution to the energy balance [11].

3.5.6 Power Factor

Most modern electrical/electronic devices draw both active power and reactive power; LED and CFL bulbs are electronic devices which have comparatively low power factor. Due to this low power factor it draws a higher current as it needs higher reactive power [12].

Therefore, it would be useful to have a Power Factor Corrector (Capacitor Bank) in the system.

3.6 Controls, BMS and System Integration

3.6.1 Controls

Automatic controls are better than manual controls in general. Energy efficient control systems are now more advanced with the use of fuzzy-logic control systems.

These control systems provide energy savings via several approaches including by providing the stability of a control system, by fine turned operation of controllers, by real-time optimisation of related parameters, by utilising the strategies which would not otherwise be possible with classical control systems and by enabling the system to optimise heating and cooling based on occupancy patterns [2].

3.6.2 Occupancy-based control

Occupancy-based control of a HVAC system allows for the automatic switching of HVAC equipment if the presence of occupants in an area is detected. This ensures zonal air conditioning is only operational when required. The most common form of occupancy detection is passive infrared (PIR) sensors. This type of control strategy is suitable for areas that are occupied intermittently.

It is also possible to optimize the energy consumption and indoor air quality according to the number of people in a zone at any given time. Typically, for this to function accurately, levels of CO_2 are measured in the occupied zone and used as the control input. If there are more people in a space, this will create a higher level of CO_2 in that area. The speed of the ventilation fan can be increased to maintain the desired level of CO_2. As the occupancy density decreases, so too will the level of CO_2. This in turn will reduce the speed of the ventilation to maintain the desired level of CO_2 [4].

This type of control is suitable when the occupancy density of an area varies significantly throughout the occupied hours.

3.6.3 Building Management System (BMS)

Air conditioning controls regulate the air conditioning system of zoned areas, usually through a sensing devices that compares the actual state of the space like its temperature/humidity, with a target state. Then the control system decides what action needs to be taken (start the heating, cooling etc.).

These control systems range from built-in proprietary controllers up to direct digital controls (DDC) or building management system (BMS) controls.

A BMS may consists of a large number of DDCs that communicate through a communication network and report to a computer, referred to as a head-end, supervisor or operator workstation. This main computer sends control parameters such as set points and time schedules through the system and to individual controllers of the system. The controllers can send operational/control information such as temperature, alarms and system performance back to the main computer.

BMS is a valuable tool in optimization process of air conditioning and other building services systems. In addition to providing control logics and supervisory functions, BMSs can perform diagnostics, indicate trends and record performance. BMSs can be different in the way they manage plant equipment, the way they represent the control system and the quality/accuracy of the data produced. Checking the possibility for updating or upgrading a BMS system is often the first step in any energy-efficiency improvement process.

It is important to make sure that optimization capabilities of existing BMS and DDCs are not disabled. Building operation staff should understand the value of the optimization of the system and schedules need to be checked periodically to make sure that they remain aligned with building use.

BMSs have steadily reduced in price over the past 30 years. They have also become more user-friendly and reliable, providing they are specified correctly, installed and commissioned by competent personnel and their operators are trained on their functionality. Any BMS installed within the last 5 to 10 years is likely to be capable of employing optimisation strategies [3].

3.7 Other Methods Commonly Used in Buildings to Save Energy

3.7.1 Solar Energy

Solar power systems collect the energy of radiation from the sun and convert it into usable energy. Since sun's energy is a renewable resource, solar power is sustainable and does little harm to the environment. Solar power is commonly used in following modes.

Solar Photovoltaic (PV) Panels (electricity)

This is the most popular solar energy system in creating electricity from sunlight. Falling panel and equipment prices, grid-tied systems and tax incentives etc. have pushed this form of solar energy systems into the mainstream.

Ceylon Electricity Board has introduced a Net Metering System. People can install solar electricity generation system on their roof tops and supply the excess electricity generated to the National grid. In return, the amount of kWhs they supplied to the grid will be deducted from their monthly electricity bills. If the amount of kWhs supplied to the grid is more than the bill amount, CEB will pay for that additional kWhs.

2. Solar Thermal (Hot Water)

Solar thermal is using the radiation from the sun to heat water. Solar thermal water can be used in many interesting ways. Frequently it is used for the most cost-effective water conservation subject of hot water; showering, sinks, clothes washers and dishwashers. Solar thermal can also be used in radiant floor heating systems.

3. Passive Solar Design

It generally includes directional orientation, building shape, overhangs and can also include other ways to block unwanted sunlight in warmer seasons. Invite the winter sun, reject the summer sun etc.

Passive solar design is an important form of solar energy control for houses and buildings. It’s the only one capable of zero-extra upfront costs, need no maintenance, and will lasts as long as the building.

3.7.2 Rain Water Harvesting

In urban areas, buildings are usually constructed with flat concrete roof tops. Therefore, rainwater can be stored in rooftop tanks if it is considered in the design stage.

This collected rainwater can be used to flush toilets, washing machines, watering the garden and washing vehicle etc. where drinking quality is not required. Since the water is stored on rooftop additional pumping energy will not be required. This will be an additional energy saving in addition to the saving in water bills.

If people in the city do rainwater harvesting in wherever possible, it will reduced the drinking quality water demand and in turn it will reduce the energy demand in city drinking water treatment plants.

3.8 Energy Efficiency and Life Cycle cost analysis

Like any other projects, the financial benefits of air conditioning systems must be effectively examined before commencement of works. Selling energy conservation proposal to the owner of a building requires a good sense of financial logical argument.

Decisions having the main impact on the cost of air conditioning system are taken during the preliminary phase and hence financial analysis must be taken at this stage. Life-Cycle Cost (LCC) analysis is becoming more and more popular among professionals in the built environment as the preferred tool for financial evaluation. By LCC analysis, all factors that affects the total system cost in the lifetime are identified and quantified. Subjective factors such as fuel/energy cost adjustments, components reliability, and maintenance costs are also included. LCC analysis can be used to assess the financial impacts of any decision by comparing two or more alternatives.

For air conditioning systems, the key issues for LCC are annual cost comparison based on analysis of energy costs, capital cost and maintenance costs.

3.9 Energy Efficiency Standards (Codes) for Buildings

In many countries, the oil supply crisis of the early 1970s catalysed the development of energy efficiency requirements for buildings and energy efficient building codes have been introduced and used since then [10].

3.9.1 Types of Building Codes/Regulations

Energy efficiency requirements can be set in different ways and the basic types are [10]:

1. **Prescriptive.** This method sets separate energy efficiency requirements for each building part and for each part of the equipment. Individual components must achieve compliance with their specific targets.
2. **Trade-off.** Values are set for each part of the building, but a trade-off can be made so some values are better and some are worse than the requirements.
3. **Model building.** Values are set as in the trade-off, and a model building with the same shape is calculated with those values. A calculation has to demonstrate that the actual building will be as good as the model building.
4. **Energy frame.** An overall framework establishes the standard for a building's maximum energy loss. A calculation of the building has to show that this maximum is respected.
5. **Performance.** Energy performance requirements are based on a building's overall consumption of energy or fossil fuel or the building's implied emissions of greenhouse gas

3.9.2 Purpose of Building Energy Codes

Energy codes and standards set minimum efficiency requirements for new and renovated buildings, assuring reductions in energy use and emissions over the life of the building. Energy codes are a subset of building codes which establish baseline requirements and govern building construction. Code buildings are more comfortable and cost-effective to operate assuring energy, economic and environmental benefits. The reduction in energy expenditures also correlates to a mitigated dependency on foreign oil which impacts national economic security. In light of these fundamental environmental issues, economic challenges, and uncertain energy costs, building energy codes are a key component of sound public policy.

3.9.3 Benefits of Building Energy Codes

As a building's operation and environmental impact is largely determined by upfront decisions, energy codes present a unique opportunity to assure savings through efficient building design, technologies, and construction practices. Once a building is constructed, it is significantly more expensive to achieve higher efficiency levels. Energy codes ensure that a building's energy use is included as a fundamental part of the design and construction process; making this early investment in energy efficiency will pay dividends to owners and occupants for years into the future [21].

Who benefits from energy codes?

- Consumers and homebuyers can be assured that they have purchased or rented a home that meets minimum standards for energy efficiency, and as a result they will see significantly lower utility bills.
- The construction industry can have a documented advantage over existing homes, as well as a level playing field, with respect to minimum energy efficiency requirements.
- Code officials can be confident that new and renovated buildings are designed and built to meet industry standards for quality and comfort, thus improving consumer protection.
- Utilities can benefit from supporting energy codes through access to cost-benefit data to use in determining future investments and attribution of savings to efficiency programs. Additionally, codes can provide better energy forecasting and decreased peak demand.
- State and local governments can reduce energy demand and greenhouse gas emissions, while ensuring that their constituents live and work in comfortable buildings with low utility bills.

[21]

3.9.4 Examples for energy codes available in the world

1. America –
   ANSI/ASHRAE/IES Standard 90.1 *Energy Standard for Buildings Except Low-Rise Residential Buildings*
   ANSI/ASHRAE Standard 90.2 *Energy Efficient Design of Low-Rise Residential Buildings*

ANSI/ASHRAE/IES Standard 100 *Energy Conservation in Existing Buildings*

ANSI/ASHRAE Standard 105 *Standard Methods of Measuring and Expressing Building Energy Performance*

NFPA 900: Building Energy Code

2. Malaysia – Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings
3. Philippines – The National Building Code of Philippines
4. India – Energy Conservation Building Code
5. Sri Lanka-Code of Practice for Energy Efficient Buildings in Sri Lanka – 2008
6. International Energy Conservation Code (IECC)

4. METHODOLOGY

4.1 Selection of three building in Colombo region

Considering the scale of the buildings (no of floors, total floor area, energy consumption rate etc.), services systems installed, availability of at least basic data such as layout drawings, system details, equipment details, no of occupants, energy consumption, operating schedule etc. and visitability/accessibility etc. three buildings designed and constructed between 2008 and 2012 were selected for this study.

4.2 Collection of available data of selected buildings

Required data for the analysis of the above three buildings were collected as follows.

A. Layout Drawings, Schematic Diagrams and related documents
B. Construction material data (walls, roof, fenestration etc.)
C. Arrangement and details of Building Services Systems
D. Building usage and operation schedules
E. No of occupants in the building/occupant density
F. Current energy usage by
  a. Electricity bills/electricity meter (kWh)
  b. Water bills/water meter (m^3)
  c. BMS data
  d. Energy audit data
  e. Ampere meter/Volt meter readings etc.
G. Discussion with staff

4.3 Verification of compliance of selected buildings with standards

The buildings were verified against the following standards

1. ASHRAE Standard 90.1 - 2007 and
2. Code of practice for Energy Efficient Buildings in Sri Lanka – 2008

All of the above building were designed and constructed between year 2008 and 2012. Therefore, codes of above years were considered for compliance.

4.4 Analysis of the selected buildings with different configurations/options

A building model was created for each building in Trace 700 software and then following system configurations/options were simulated by making/adding those changes to each created model.

1. Performance when satisfying the minimum requirements of the ASHRAE 90.1-2007 and Code of Practice for Energy Efficient Buildings in Sri Lanka – 2008 (ex:- Budget building)
2. Other possible energy saving methods as below
    a. Demand control ventilation
    b. Heat rejection films on window glass
    c. Chilled water set-point resetting
    d. Using VFD chilled water pumps
    e. Using VFD cooling tower and condenser water pumps
    f. Increasing indoor (room) temperature set-point
    g. Optimum start/stop control
    h. Energy Recovery
    i. Change of HVAC equipment types
    j. Lighting System (Day lighting etc.)
    k. Usage of renewable energy
    l. Thermal Energy Storage
    m. Usage of energy efficient equipment

Though there may be a large number of energy saving/harvesting methods applicable to buildings, this study is limited to above methods which are discussed often and can be implemented in Sri Lankan buildings easily using local contractors and local agents/suppliers of equipment and materials.

Then it will be possible to understand the benefits in the buildings in which some systems are already implemented, what sections should be given more priority in designing new buildings and the possibilities of improving the energy efficiency of already constructed buildings.

5. SELECTION OF BUILDINGS FOR ANALYSIS

Considering the scale of the buildings (no of floors, total floor area, energy consumption rate etc.), services systems installed, availability of at least basic data such as layout drawings, system details, equipment details, no of occupants, energy consumption, operating schedule etc. and visitability/accessibility etc. following three buildings designed and constructed between 2008 and 2012 were selected for this study.

1. Ceylon Petroleum Corporation Head Office Building – Colombo 09
2. Peoples Leasing Property Development Ltd. Head Office Building – Colombo 08
3. Ceylinco Life Insurance Head Office Building – Colombo 05

5.1 Ceylon Petroleum Corporation Head Office Building

This building consists of Eight (08) floors and one (01) basement. It is located at No. 609, Danister De Silva Mw, Colombo 09. Normal working time is from 8.15 A.M up to 04.20 P.M.. Security staff are working 24 hours. But they are in a separate room which is outside of the building.

Total floor area	92,000 ft^2
Monthly Energy Consumption	90,000-120,000 kWh
Location	Longitude 6.8 N, Latitude 79.8 E
Height from sea level	50 ft
Length & width (Approx.)	211 ft, 115 ft
Current air conditioning system	Central air conditioning with 03 nos air cooled chillers, Ducted AHUs at each floor

5.2 Peoples' Leasing Property Development Head Office Building

This building consists of ten (10) floors and one (1) basement. It is located at No. 1161, Maradana Road, Colombo 09. Normal working time is from 08.30 A.M. to 05.00 P.M.

Security staff are working 24 hours. But they are in a separate room which is outside of the conditioned area of the building.

Total floor area	60,034 ft^2
Monthly Energy Consumption	55,000-70,000 kWh
Location	Longitude 6.8 N, Latitude 79.8 E
Height from sea level	60 ft
Length & width (Approx.)	190 ft, 54 ft
Current air conditioning system	Water cooled packaged air conditioners at each floor

5.3 Ceylinco Life Insurance Head Office Building

This building consists of eight (08) floors and one (01) basement. It is located at No. 106, Havelock Road, Colombo 05. Normal working time is from 08.30 A.M. to 05.00 P.M.. Security staff are working 24 hours. But they are in a room which is outside of the conditioned area of the building.

Total floor area	36,055 ft^2
Monthly Energy Consumption	40,000-55,000 kWh
Location	Longitude 6.8 N, Latitude 79.8 E
Height from sea level	40 ft
Length & width (Approx.)	120 ft, 55 ft
Current air conditioning system	Water cooled packaged air conditioners at each floor

6. SOFTWARE FOR THE MODELING OF BUILDINGS

6.1 General requirements

Software for this analysis should satisfy the requirement of ASHRAE 90.1 as follows. The simulation program shall have the ability to explicitly model all of the following

- Minimum of 1400 hours per year
- Hourly variations in occupancy, lighting power, miscellaneous equipment power, thermostat set points and HVAC system operation defined separately for each day of the week and holidays.
- Thermal mass effect
- Ten or more thermal zones
- Part-load performance curves for mechanical equipment
- Capacity and efficiency correction curves for mechanical cooling and heating equipment

Further the simulation shall have the ability to either

- Directly determine the design energy cost and energy cost budget
  Or
- Produce hourly reports of energy used by energy source suitable for determining the design energy cost and energy cost budget using a separate calculation engine.

It shall be capable of,

- Performing design load calculations to determine required HVAC equipment capacities and air & water flow rates.

- Performing the simulation using hourly values of climatic data such as temperature and humidity from representative climatic data for the city.

By considering these factors Trane Trace 700 software (2009-version 6.2.4) which satisfies the above requirements and used by many professionals in the field was selected for this work.

6.2 Overview of the Trane Trace 700 Software

This software was developed by Trane Air Conditioners Manufacturing Company and later many professionals started using it for their design purposes. Trane Company has included facilities to do design in compliance with AHSHRAE 90.1. User can select to used ASHRAE standards or their own values/conditions. Energy saving options like cold storages, energy recovery equipment are included as options in the software. Whether data not available in the software can be downloaded and whether files from other software like EnergyPlus, Equest etc. also can be used. Following are some of the capabilities of the software.

- Cooling & Heating Load calculation
- Yearly energy calculation
- Usability of custom whether data
- Almost all HVAC equipment types can be added
- No of rooms, zones, systems, plants etc. has not limited.
- Material data can be entered for new materials.
- Usage schedules, equipment on/off schedules, equipment efficiencies /efficacies, unloading curves
- Energy cost calculations based on cost structure of the country or city.
- Building energy mass effect

7. REQUIREMENTS FOR COMPLIANCE IN BRIEF

Verification of the compliance of buildings are done based on ASHRAE standard 90.1-2007 and Code of Practice for Energy Efficient Buildings in Sri Lanka 2008 in chapter 8. For clarity and easiness of understanding of compliance checking process in next chapter, compliance paths of each standard and what each section is related to have been summarized below.

7.1 Requirements for compliance with ASHRAE 90.1-2007

The scope of the ASHRAE 90.1-2007 comprises of sections such as new buildings, addition to existing buildings, alterations to existing buildings, replacement of portions of existing buildings, changes in space conditioning etc.. Particular requirements of each category are described separately in the standard. In this study only the new buildings section is considered because the aim is to find out whether the building design complies with the standard.

For a New building to comply with ASHRAE 90.1-2007, two paths have been mentioned as follows

1) **Path 01 (Compliance with the provisions of sections 5, 6, 7, 8, 9 & 10 in the standard)**

The building should satisfy the provisions of sections 5, 6,7,8,9 & 10 in the standard. These sections describe the requirements to be satisfied by each component or the system in the building which affects finally the energy consumption by the building. Section classification used in the standard is as follows

1. Section 05

Specifies the requirements for the **Building Envelop** to be fulfilled (construction materials, glasses, roof, floor, insulation etc.)

2. Section 06

Specifies the requirements for **Heating, Ventilation and Air Conditioning system** to be fulfilled (chillers, Fans, cooling coils, cooling towers, duct system & hydronic systems etc.)

3. Section 07

Specifies the requirements for **Service Water Heating** to be fulfilled (Hot water system and the related equipment in the building etc.)

4. Section 08

Specifies the requirements for **Power** distribution system to be fulfilled (electrical power distribution system and related equipment, voltage drops etc.)

5. Section 09

Specifies the requirements for building interior and exterior **Lighting** systems and related components to be fulfilled (lighting power density, controls, efficacy & efficiency of luminaires/lamps etc.)

6. Section 10

Specifies the requirements for **Other Equipment** to be fulfilled such as electrical motors

OR

2) **Path 02 (Energy Cost Budget Method)**

In this method, a computer program is used to calculate the design energy cost for the proposed building design and to calculate the energy cost budget for a budget building design. Two results will be compared in addition to compliance verification with mandatory requirements (further description has been given later).

7.1.1 Path 01 - Compliance with the provisions of sections 5, 6, 7, 8, 9 & 10 in the standard

Each of these sections has General Requirements, Mandatory Requirements, Prescriptive Requirements, Trade-off Options, Minimum equipment efficiency requirements, simplified approach etc. and the compliance path has been described each section.

7.1.1.1 Section 5 - Compliance with building envelope

This section specifies the requirements for building envelope. Compliance path specified by the standard for this section is as follows. The building should comply with

- **General Requirements** (space conditioning categories, envelop alterations, climate etc.)
- **Mandatory Requirements** (Insulation, Fenestration & doors, Air Leakage, Loading deck whether seals, vestibules etc.)

and one of the following

- **Prescriptive Requirements** (U-value of envelop construction assemblies, R-value of insulation related to roof, wall, floor, opaque door, U-value and SHGC of glazing & skylight etc.)

Or

- **Trade-off Option**(General, Mandatory, Submittals, product information and installation requirements should be complied and the Envelop Performance Factor(EPF) of proposed building should be less than that of budget building)

Related tables in chapter 8 are table 8.1.1.1, 8.1.1.2, 8.1.1.3 and 8.1.4

7.1.1.2 Section 6 - Compliance with Heating, Ventilation and Air Conditioning System

This section describes the requirements to be satisfied by mechanical equipment and systems serving the heating, cooling or ventilating needs of new building briefly as below

- **General Requirements** (new buildings, additions to existing buildings, alteration to HVAC systems in existing buildings. No requirements have been mentioned for new buildings in the section)
- **Submittals** (Submittals of compliance documentation: Drawings of systems, Operation & maintenance manuals, air system & hydronic system balancing reports, system commissioning documents)
- **Minimum Equipment Efficiencies**
  Specifies minimum equipment efficiencies such as cooling equipment (room air conditioners, chillers, condensing units etc.), heating equipment (furnaces, boilers etc.), heat rejection equipment (cooling towers, air cooled condensers etc.), minimum duct insulation and minimum pipe insulation etc.

And one of following

- **Simplified Approach**
  For buildings with two story or less and floor area less than 25,000 ft^2 and complies with section 6.3.2. (Therefore, not applicable to the buildings considered in this study)

Or

- **Mandatory**(minimum equipment efficiencies, verification of equipment efficiencies based on information provided by manufacturer, labeling requirements),

  & Prescriptive Requirements (economizers, simultaneous cooling and heating limitations, air system design and control, hydronic system design and control, heat rejection equipment, energy recovery, exhaust hoods, radiant heating systems, hot gas bypass limitation)

Related tables in chapter 8 are table 8.1.2.1, 8.1.2.2, 8.1.2.3, 8.1.2.4, 8.1.2.5, 8.1.2.6 and 8.1.2.7

7.1.1.3 Section 7 - Compliance with service water heating

Hot water service had not been installed in the buildings considered in this study which are general office buildings in Colombo region where there is warm climate throughout the year.

7.1.1.4 Section 8 - Compliance with power

This section covers all requirements to be satisfied by all building power distribution systems. For the building to comply with this section in the standard it should comply with the following under section 8.

- **General Requirements**(states that requirements are applied to all building power distribution systems)
- **Mandatory Requirements** (voltage drop in feeders and branch circuits)
- **Submittals** (drawings of actual installation, operating & maintenance manuals)

Related tables in chapter 8 are table 8.1.3.1.1, 8.1.3.1.2 and 8.1.3.1.3.

7.1.1.5 Section 9 - Compliance with lighting

This section covers the requirement for interior space lighting, exterior lighting (like facades, illuminated roofs, architectural features, entrances, exits, loading docks, and canopies) and exterior building ground lighting.

For the building to comply with this section in the standard it should comply with the following under section 9.

- **General Requirements** (scope, lighting alterations, installed interior lighting power, luminaire wattage)

- **Mandatory Requirements**(lighting control, space control, exterior lighting control, tandem wiring, exit signs, exterior building ground lighting, exterior building lighting power)

And the Prescriptive Requirements by either

- o **Building Area Method** (method of calculating interior lighting power allowance by building area method)

  Or
- o **Space by Space Method** (method of calculating interior lighting power allowance in space-by-space method, additional interior lighting power)

Related tables in chapter 8 are table 8.1.4.1, 8.1.4.2, 8.1.4.3.1 and 8.1.4.3.2

7.1.1.6. Section 10 - Compliance with other equipment

This section describes requirements to be fulfilled by all equipment which are not covered in previous sections and only the equipment included in this section.

For the building to comply with this section in the standard it should comply with following under section 10

- **General Requirements**(new buildings, additions to existing building, alterations to existing building)
- **Mandatory Requirements** (requirements for electrical motors)

7.1.2 Path 02 - Energy Cost Budget Method

This is an alternative to the prescriptive provisions of this standard. It may be employed for evaluating the compliance of all proposed designs except designs with no mechanical system.

Budget building design is a computer representation of a hypothetical design based on the actual proposed building design which satisfies the minimum ASHRAE 90.1 requirements and the conditions specified under this topic in ASHRAE 90.1.This representation is used as the basis for calculating the energy cost budget.

Energy cost budget is the annual energy cost for the budget building design intended to use in determining minimum compliance with this standard.

Modeling requirements for calculating design cost and energy cost budget is given in table 11.3.1 in the ASHRAE standard 90.1-2007.

Compliance Requirements

- All mandatory requirements in above mentioned sections (5.4, 6.4, 7.4, 8.4, 9.4, 10.4)
- Proposed building design should comply with all above mandatory requirements
- Design energy cost should not exceed energy cost budget as calculated by the simulation program
- Energy efficiency level of components in the building design meet or exceed the efficiency levels used to calculate the design energy cost

Since all these buildings are office building which are operating in day time (day time hours according to CEB electricity rate structure) number of kWh is proportional to the energy cost. (Only energy source is electricity from CEB).

7.2 Requirements for compliance with Code of Practice for Energy Efficient Buildings in Sri Lanka – 2008

This code of practice comprises of requirements for design and/or retrofit of commercial buildings and industrial installations. Building elements covered in the code are Building Envelop, Ventilation & Air Conditioning, Lighting, Electrical Power & Distribution and Service Water Heating.

Section 1 is introduction. The code has been summarized from section 2 onwards as bellow.

7.2.1 Section 2 - Lighting

This section specifies the requirements to be satisfied by interior space lighting, exterior area lighting (facades, entrances, exit ways, loading docks etc.) and other areas (roads, grounds etc.) where lighting is installed which are powered by the building electrical system. For the compliance following should be fulfilled.

- **Mandatory requirements** (Lighting controls, maximum allowable power for illumination systems, exterior lighting power)
- **Prescriptive requirements** (General and task lighting considerations, selection of appropriate components)

Related tables in chapter 8 are table 8.3.1.1, 8.3.1.2, 8.3.1.3 and 8.3.1.4

7.2.2. Section 3 - Ventilation and Air Conditioning

This section specifies the requirements to be satisfied by ventilation and air conditioning systems of the building. For the compliance following should be fulfilled.

- **Mandatory requirements** (Load calculations, System and equipment sizing, Fan system design criteria, pumping system design criteria, separate air distribution systems, temperature controls, off-hour controls, piping insulation, air handling system insulation, air handling system ducts, A/C equipment, testing adjusting balancing and commissioning, water treatment, maintenance)

Related tables in chapter 8 are table 8.3.2.1, 8.3.2.2 and 8.3.2.3

7.2.3 Section 4 - Building Envelop

This section describes the requirements to be satisfied by the building envelop. The compliance is achieved by meeting the overall requirement OTTV subject to satisfying prescriptive criteria of each building envelop sub elements.

- **Mandatory requirements** (U values for determining OTTV values, envelop sealing, air leakage, national building regulations)
- **Prescriptive requirements** (External wall with/without fenestration, roofs, windows)

Related tables are table 8.3.3.1, 8.3.3.2 and 8.3.3.3

7.2.4 Section 5 – Electrical Power and Distribution

This section specifies the requirements for all building electrical systems except extra low voltage systems if wired separately.

- Mandatory requirements (Electrical distribution system, Transformers, Electric motors)
- Prescriptive requirements (Additional metering, motor life cycle cost)
- Design considerations (Transformer selection)

7.2.5 Section 6 – Service Water Heating

This does not apply to these buildings because these are office buildings and hot water systems had not been installed.

8. VERIFICATION OF THE COMPLIANCE OF SELECTED BUILDINGS

8.1 Compliance with ASHRAE Standard 90.1 – 2007 - Path 01

8.1.1 Building Envelope

8.1.1.1 Mandatory Requirements – Building Envelop Sealing

Table 8.1.1.1: Mandatory Requirements - Building Envelop Sealing

Parameter	Condition in Considered Building	Compliance
Building No.01-Ceylon Petroleum Corporation		
Joints around fenestration and door frames	There is wool gasket. But door gap is more than that so not sealed. Entrance exit doors no gasket	Not comply
Junctions between walls & foundations, walls at corners, walls and floors, walls and roofs	Brick walls/partition plastered well to foundation/ floors and walls and walls. Sealed	Comply
Openings at penetrations of utility services through roofs, walls and floors	No gasket provided. Not all four sides sealed.	Not comply
Site-build fenestration and doors	Partly sealed	Not comply
Joints, seams and penetrations of vapor retarders	Sealed	Comply
Building No.02 – Peoples Leasing Building		
Joints around fenestration and door frames	Doors are not sealed well (there are gaps. Entrance exit doors no gasket	Not comply
Junctions between walls & foundations, walls at corners, walls and floors, walls and roofs	Brick walls/partition plastered well to foundation/ floors and walls and walls. Sealed	Comply
Openings at penetrations of utility services through roofs, walls and floors	No gasket provided. Not all four sides sealed.	Not comply

Site-build fenestration and doors	Not sealed well	Not comply
Joints, seams and penetrations of vapor retarders	Sealed	Comply
Building No.03 – Ceylinco Life Insurance Building		
Joints around fenestration and door frames	Door gap is more than the gasket provide. So not sealed well. Entrance exit doors no gasket.	Not comply
Junctions between walls & foundations, walls at corners, walls and floors, walls and roofs	Brick walls/partition plastered well to foundation/ floors and walls and walls. Sealed	Comply
Openings at penetrations of utility services through roofs, walls and floors	No gasket provided. Not all four sides sealed.	Not comply
Site-build fenestration and doors	Not sealed well	Not comply
Joints, seams and penetrations of vapor retarders	Sealed	Comply

8.1.1.2 Prescriptive Requirements – Construction Materials

Table 8.1.1.2: Prescriptive Requirements - Construction Materials of Buildings

Opaque Element	Code Requirement		Building Considered		Code Compliance
	Assembly Maximum	Insulation Min. R-Value/SHGC	Assembly Maximum	Insulation Min. R-Value/SHGC	
Building No. 01 Ceylon Petroleum Corporation					
9” Common Brick Wall	U-0.580	Not Required	U-0.322	Not Insulated	Comply
9” Common Brick Wall with cladding	U-0.580	Not Required	U-0.249	Not Insulated	Comply
5” Concrete Floor	U-0.322	Not Required	U-0.181	Not Insulated	Comply
1” Wood Door	U-1.45	Not Specified	U-0.215	Not Available	Comply
5” Concrete roof with 2” insulation	U-0.063	R-15.0	U-0.082	R-40	Not Comply
Vertical Glazing ¼”	U-1.20	SHGC-0.25	U-0.95	SHGC-0.67	Not Comply

Building No. 02-Peoples' Leasing Head Office Building					
9" Common Brick Wall	U-0.580	Not Required	U-0.322	Not Insulated	Comply
5" Concrete Floor	U-0.322	Not Required	U-0.181	Not Insulated	Comply
1" Wood Door	U-1.45	Not Specified	U-0.215	Not Available	Comply
5" Concrete roof with 2" insulation	U-0.063	R-15.0	U-0.0821	R-40	Not Comply
Vertical Glazing 1/4"	U-1.20	SHGC-0.25	U-0.95	SHGC-0.67	Not Comply
Vertical Glazing 1/2"	U-1.20	SHGC-0.25	U-1.04	SHGC-0.88 (No intl. shading)	Not Comply
Vertical Glazing 3/8"	U-1.20	SHGC-0.25	U-1.04	SHGC-0.92 (No intl shading)	Not Comply
Building No.03-Ceylinco Life Insurance Head Office Building					
9" Common Brick Wall	U-0.580	Not Required	U-0.322	Not Insulated	Comply
12" Concrete Floor(beamless)	U-0.322	Not Required	U-0.088	Not Insulated	Comply
1" Wood Door	U-1.45	Not Specified	U-0.215	Not Available	Comply
6" Concrete roof with 2" insulation	U-0.063	R-15.0	U-0.077	R-40	Not Comply
Vertical Glazing 1/4"	U-1.20	SHGC-0.25	U-0.95	-	Not Comply
Vertical Glazing 3/8"	U-1.20	SHGC-0.25	U-1.04	SHGC-0.92 (No intl. shading)	Not Comply

8.1.1.3 Prescriptive Requirements – Fenestration area requirements

Table 8.1.1.3: Prescriptive Requirements - Fenestration area requirements

Requirement	Building No.01	Building No.02	Building No.03
$\frac{\text{Vertical Fenestration Area}}{\text{Gross Wall Area}} < 40\%$	30% Comply	32% Comply	25% comply
$\frac{\text{Skylight Fenestration Area}}{\text{Gross Roof Area}} < 5\%$	No skylight. Comply	No skylight. Comply	No skylight. Comply

8.1.1.4 Trade-Off Option – Building Envelop

Table 8.1.1.4: Trade-Off Option – Building Envelop

Building	General Requirements	Mandatory Provisions	$\frac{\text{EPF of Proposed Building}}{\text{EPF of Budget Building}}$ <=1 (Requirement)
Building No.01-Ceylong Petroleum	Comply	Not comply	1.4-Not Comply
Building No.02-Peoples' Leasing Head Office	Not comply	Not comply	0.9-Comply
Building No.03-Ceylinco Insurance Head Office	Not comply	Not comply	0.9-Comply

8.1.2 Heating, Ventilation and Air Conditioning System

8.1.2.1 Mandatory Requirements – Minimum Equipment Efficiencies

Table 8.1.2.1: Mandatory Requirements - Minimum Equipment Efficiencies

Equipment	Minimum Efficiency Required	Available Efficiency	Compliance
Building No.01-Ceylon Petroleum Corporation			
Air Cooled Water Chiller	2.8 COP 3.05 IPLV	COP = 3.1	Comply
Building No.02-Peoples' Leasing Head Office Building			
Water Cooled Unitary	11.0 EER	EER = 11.0	Comply
Cooling Tower	38.0 gpm/hp	46 gpm/hp	Comply
Building No.03-Ceylinco Life Insurance Head Office Building			
Water Cooled Unitary	11.0 EER	EER = 11.0	Comply
Cooling Tower	38.0 gpm/hp	44 gpm/hp	Comply

8.1.2.2 Mandatory Requirements – Control Requirements

Table 8.1.2.2: Mandatory Requirements - Control requirements

Control Requirement	Building No.01-Ceylon Petroleum Corporation		Building No.02-Peoples' Leasing Head Office		Building No.03-Ceylinco Life Head Office	
	Availability	Compliance	Availability	Compliance	Availability	Compliance
Zone Thermostatic Control	Available	Comply	Available	Comply	Available	Comply
Dead Band	N/A (Cooling only design)	N/A (Cooling only design)	N/A (Cooling only design)	N/A (Cooling only design)	N/A (Cooling only design)	N/A (Cooling only design)
Automatic Shutdown	Not available	Not Comply	Available	Comply	Available	Comply
Optimum Start Control	Not available	Not Comply	Not available	Not comply	Not available	Not comply
Zone Isolation	Available	Comply	Available	Comply	Available	Comply
Gravity Hoods	Not available	Not Comply	Available	Comply	Available	Comply
Ventilation Fan Controls	Not used	Not Comply	Available	Comply	Available	Comply
Demand Control Ventilation	Not used	Not Comply	Available	Comply	Available	Comply

8.1.2.3 Mandatory Requirements – Insulation

Table 8.1.2.3: Mandatory Requirements - Insulation

Location	Minimum Requirement	Available Value	Compliance
Building No.01-Ceylon Petroleum Corporation			
Duct Insulation	None (return via plenum)	R-3.5	Comply
Pipe Insulation Thickness (1 ½"-8" pipes)	1.0	1.0	Comply

Building No.02-Peoples' Leasing Head Office			
Duct Insulation	None (return via plenum)	R-3.5	Comply
Pipe Insulation Thickness (1 ½"-8" pipes)	1.0	1.0	Comply
Building No.03-Ceylinco Insurance Head Office			
Duct Insulation	None (return via plenum)	R-3.5	Comply
Pipe Insulation Thickness (1 ½"-8" pipes)	1.0	1.0	Comply

8.1.2.4 Prescriptive Requirements – Economizers/Hydronic Controls

Table 8.1.2.4: Prescriptive Requirements - Economizers/Hydronic controls

Requirement	Building No.01	Building No.02	Building No.03
Economizers	Not available. Not required in this climatic zone. [Comply]	Not available. Not required in this climatic zone. [Comply]	Not available. Not required in this climatic zone. [Comply]

8.1.2.5 Prescriptive Requirements – Fan Power Limitation

Table 8.1.2.5: Prescriptive Requirements - Fan Power Limitation

Equipment	hp/CFM	Compliance
Building No.01-Ceylon Petroleum Corporation		
AHU Fan/Blower 7.5hp	0.0007	Comply
AHU Fan/Blower 5.0hp	0.0008	Comply
Exhaust fan 5hp	0.0009	Comply
Exhaust fan 3 hp	0.0009	Comply

Building No.02-Peoples' Leasing Head Office		
Exhaust fan 5 hp	0.008	Comply
Exhaust fan 2 hp	0.008	Comply
Building No.03-Ceylinco Life Insurance Head Office		
Exhaust fan 2 hp	0.008	Comply

Note

	Constant Volume	Variable Volume
Option 1: Fan System Motor Nameplate hp	hp < CFM_S*0.0011	hp < CFM_S *0.0015
Option 2: Fan System bhp	bhp < CFM_S*0.00094+A	bhp < CFM_S * 0.0013 + A

Fans which use less than 1 hp are exempted.

8.1.2.6 Prescriptive Requirements – Hydronic System Design and Control

Table 8.1.2.6: Prescriptive Requirements - Hydronic System Design and Control

CRITERIA	Building No.01	Building No.02	Building No.03
Pumps(VFD) should be capable of reducing flow rates to 50% or less	No VFD [Comply]	Met [Comply]	Met [Comply]
Pump isolation capability	Not met [Not Comply]	No Chilled Water[Comply]	No Chilled Water[Comply]
Chilled water temperature reset control	Not met [Not Comply]	No Chilled Water[Comply]	No Chilled Water [Comply]
Cooling tower fan speed control requirement(for motor > 0.75hp)	No CT [Comply]	Not met [Not Comply]	Not met [Not Comply]

Note: Exhaust air energy recovery is not required since air flow is lower than 5000 CFM and outdoor air supply is less than 70%

8.1.2.7 Submittals – System Balancing

Table 8.1.2.7: Submittals - System Balancing

Requirement	Building No.01	Building No.02	Building No.03
Air System Balancing	Not done well/A lot of unbalances-fan speed not adjusted as required [Not Comply]	Not done well-fan speed not adjusted as required. Air flow not balanced well. [Not Comply]	Done well-fan speed not adjusted as required. Air flow not balanced well. [Not Comply]
Hydronic System Balancing	Pump speed not adjusted as required. Water flow out of balance [Not Comply]	Pump speed not adjusted as required. Water flow out of balance [Not Comply]	Pump speed not adjusted as required. Water flow out of balance [Not Comply]

8.1.3 Power

8.1.3.1 Mandatory Requirements - Voltage Drop

Table 8.1.3.1.1: Building 01 – Ceylon Petroleum Building -Voltage Drop

Location	Voltage Drop/ (%)	Requirement /(%)	Compliance
Chiller supply(at chiller)	2.3 %	3%	Comply
Chillers feeder end (Longest feeder)	1.9 %	2%	Comply
Furthest point(one of light)	2.7 %	3%	Comply

Table 8.1.3.1.2: Building 02 – Peoples Leasing Building -Voltage Drop

Location	Voltage Drop/ (%)	Requirement /(%)	Compliance
Condenser Pump supply	2.7 %	3%	Comply
Condenser Pump feeder end (Longest feeder)	1.3 %	2%	Comply
Furthest point(one of light)	2.7 %	3%	Comply

Table 8.1.3.1.3: Building 03 – Ceylinco Life Insurance Building -Voltage Drop

Location	Voltage Drop/ (%)	Requirement /(%)	Compliance
Condenser Pump supply	2.4 %	3%	Comply
Condenser Pump feeder end (Longest feeder)	1.1 %	2%	Comply
Furthest point(one of light)	2.3 %	3%	Comply

Condition to be satisfied (voltage drops):

Feeders < 2% at design load, Branch circuits < 3% at design load

8.1.4 Lighting

8.1.4.1 Mandatory Requirements – Control Requirements of Lighting

Table 8.1.4.1: Mandatory Requirements - Control requirements of lighting

Criteria	Building No.01	Building No.02	Building No.03
Automatic lighting shut off	Not available [Not comply]	Not available [Not Comply]	Not available [Not comply]
Space Control	Switches control more than one space lighting [Not Comply]	Switches are in the relevant space. [Comply]	Switches are in the relevant space. [Comply]
Exterior lighting control	No such controls are used – [Not Comply]	Timer Controls [Comply]	Timer Controls [Comply]
Tandem wiring	Used-[Comply]	Used-[Comply]	Used-[Comply]
Exit sign wattage < 5-7W	7W[Comply]	5W[Comply]	5W[Comply]
Exterior Building Ground Lighting greater than 100W Luminaire min 60lm/W	80 lm/W [Comply]	74 lm/W [Comply]	Less than 100 W [Comply]

8.1.4.2 Mandatory Requirements - Lighting Power Density for Building Exteriors

Table 8.1.4.2: Mandatory Requirements - LPD for Building Exteriors

Criteria	Building No.01	Building No.02	Building No.03
Building Grounds - Walkaways 0.2W/ft^2	0.15 - Comply	0.11 - Comply	0.09 - Comply
Building Entrance - 30W/ft & Other door - 20W/ft	20W & 10W [Comply]	20W & 10W [Comply]	20W & 10W [Comply]
Uncovered Parking areas-0.15 W/ft^2	0.07 W/ft^2 [Comply]	0.07 W/ft^2 [Comply]	0.07 W/ft^2 [Comply]

8.1.4.3 Building Area Method & Space by Space Method

8.1.4.3.1 Prescriptive Requirements – Building Area Method

Table 8.1.4.3.1: Prescriptive Requirements - Building Area Method

Parameter	Building No.01	Building No.02	Building No.03
Allowed lighting power	92 kW	60 kW	36 kW
Installed lighting power	133 kW	54 kW	31 kW
Compliance	Not comply	Comply	Comply

8.1.4.3.2 Prescriptive Requirements – Space by Space Method

Table 8.1.4.3.2: Prescriptive Requirements - Space by Space Method

<table>
<tr><th>Parameter</th><th>Building No.01</th><th>Building No.02</th><th>Building No.03</th></tr>
<tr><td>Allowed lighting power</td><td>100 kW</td><td rowspan="3">Already complied in building area method. This calculation not required</td><td rowspan="3">Already complied in building area method. This calculation not required</td></tr>
<tr><td>Installed lighting power</td><td>132 kW</td></tr>
<tr><td>Compliance</td><td>Not comply</td></tr>
</table>

8.2. Compliance with ASHRAE Standard 90.1 – 2007 - Path 02 (Energy Cost Budget Method)

Table 8.2.1: Compliance with mandatory requirements in section 5, 6, 7, 8, 9 and 10

Building	Compliance With Each Section					Overall Compliance
	90.1 Section 5.4	90.1 Section 6.4	90.1 Section 8.4	90.1 Section 9.4	90.1 Section 10.4	
Building No.01	No	No	Yes	No	Yes	No
Building No.02	No	No	Yes	No	Yes	No
Building No.03	No	No	Yes	No	Yes	No

Table 8.2.2: Annual Energy consumption of Budget Building vs. Proposed Building

Building	Annual Energy Consumption/(kWh)		Requirement is,
	Budget Building	Proposed Building	Proposed Building <= Budget Building
Building No.01	1,011,484	1,048,860	Not comply
Building No.01	529,291	490,669	Comply
Building No.01	383,511	374,935	Comply

Note:

Section 5.4 (Envelop)-Insulation, Fenestration & Doors and Air Leakage

Section 6.4(HVAC)-Minimum efficiencies, controls, system construction & insulation

Section 7.4(Water Heating)-Not relevant for considered buildings

Section 8.4(Power)-Voltage drop

Section 9.4(Lighting)-Lighting control, Tandem wiring, Exit signs, Exterior lighting

Section 10.4(Other)-Electric motor performance

Compliance check of these section have been covered in previous sections. Therefore, only the result have been mentioned above.

8.3 Compliance with Code of Practice for Energy Efficient Buildings in Sri Lanka - 2008

8.3.1.1 Mandatory Requirements – Lighting Controls

Table 8.3.1.1: Mandatory Requirements – Lighting Controls

Requirement	Building No.01	Building No.02	Building No.03
Area controls for spaces to switch on off lights independently	Some manual controls are outside of space [Not comply]	Manual control available [Comply]	Manual control available [Comply]
Automatic lighting Shut off for interior areas	Not available [Not comply]	Via BAS [Comply]	Via BAS [Comply]
Exterior lighting control	Not available [Not comply]	Via BAS [Comply]	Via BAS [Comply]

8.3.1.2 Mandatory Requirements – Lighting Power Densities

Table 8.3.1.2: Mandatory Requirements - Lighting power densities

Location	Requirement	Provided	Compliance
Building No.01			
Office Area	10.8 W/m^2	15.6 W/m^2	Not Comply
Dining	15.1 W/m^2	12.9 W/m^2	Comply
Building Entrance	98.4 W/linear m	40 W/ linear m	Comply
Building No.02			
Office Area	10.8 W/m^2	9.7 W/m^2	Comply
Dining	15.1 W/m^2	9.7 W/m^2	Comply
Building Entrance	98.4 W/linear m	45 W/ linear m	Comply
Building No.03			
Office Area	10.8 W/m^2	9.2 W/m^2	Comply
Dining	15.1 W/m^2	10.8 W/m^2	Comply
Building Entrance	98.4 W/linear m	30 W/ linear m	Comply

8.3.1.3 Prescriptive Requirements – Lighting Source Selection

Table 8.3.1.3: Prescriptive Requirements - Lighting source selection

Location	Source Requirement	Building 01	Building 02	Building 02
General Lighting	Fluorescent Lamps with appropriate color	Fluorescent used [Comply]	Fluorescent used [Comply]	Fluorescent used [Comply]
Down lights Ceiling under 4m	Compact fluorescent	Compact fluorescent used [Comply]	Compact fluorescent used [Comply]	Compact fluorescent used [Comply]
Down lights Ceiling over 4m	High pressure sodium vapor or metal halide	High pressure metal halide used [comply]	High pressure metal halide used [Comply]	High pressure metal halide used [Comply]

8.3.1.4 Prescriptive Requirements – Minimum Lamp Efficacy

Table 8.3.1.4: Prescriptive Requirements - Minimum lamp efficacy

Lamp	Requirement	Provided	Compliance
Building No.01			
Linear fluorescent lamp 2 ft 18W	55 lm/W	58 lm/W	Not Comply
Linear fluorescent lamp 4 ft 36W	66 lm/W	69 lm/W	Not Comply
Integral compact fluorescent lamp 11W	52 lm/W	53 lm/W	Not Comply
Integral compact fluorescent lamp 20W	57 lm/W	60 lm/W	Not Comply
HID metal halide 150 W	76 lm/W	80 lm/W	Comply
Building No.02			
Linear fluorescent lamp 2 ft 18W	55 lm/W	58 lm/W	Not comply
Linear fluorescent lamp 4 ft 36W	66 lm/W	66 lm/W	Comply
Integral compact fluorescent lamp 11W	52 lm/W	53 lm/W	Not comply
Integral compact fluorescent lamp 20W	57 lm/W	60 lm/W	Not comply

HID metal halide 150 W	76 lm/W	80 lm/W	Comply
Building No.03			
Linear fluorescent lamp 2 ft 18W	55 lm/W	58 lm/W	Not comply
Linear fluorescent lamp 4 ft 36W	66 lm/W	66 lm/W	Comply
Integral compact fluorescent lamp 11W	52 lm/W	50 lm/W	Comply
Integral compact fluorescent lamp 20W	57 lm/W	54 lm/W	Comply
HID metal halide 100 W	53 lm/W	72 lm/W	Comply

Minimum requirement for LED lamps are not given in this code. Therefore, those cannot be compared for compliance.

8.3.2. Ventilation and Air Conditioning

8.3.2.1 Mandatory Requirements – Ventilation and Air Conditioning Controls

Table 8.3.2.1: Mandatory Requirements – Ventilation and Air Conditioning Controls

Requirement	Building No.01	Building No.02	Building No.03
Temperature Controls			
Each zone shall have individual thermostat	Comply	Comply	Comply
Thermostats should not be able to set below 24 C	Adjustable [Not comply]	Adjustable [Not comply]	Adjustable [Not comply]
Off-hour Controls			
Automatic equipment shut down during non-use	Not available [Not comply]	Available [Comply]	Available [Comply]

8.3.2.2 Mandatory Requirements – Chilled Water Piping and Air Duct Insulation

Chilled water piping and Air Handling systems have to be insulated according to the given requirements and the minimum equipment performance mentioned have to be satisfied as bellow.

Table 8.3.2.2: Mandatory Requirements – Piping & Duct Insulation

Requirement	Building No.01	Building No.02	Building No.03
Chilled water piping insulation			
Nominal pipe size 32-50 mm >= 13mm	25 mm [Comply]	25 mm [Comply]	25 mm [Comply]
Nominal pipe size 63 mm & above >= 38mm	50 mm [Comply]	50 mm [Comply]	50 mm [Comply]
Air handling system duct insulation			
Supply air duct >= R-0.38	R-0.61[Comply]	R-.61[Comply]	R-0.61[Comply]

Note: R unit is m^2W/K

8.3.2.3 Mandatory Requirements – Air Conditioning Equipment Minimum Performance

Table 8.3.2.3: Mandatory Requirements-Air Con. Equipment Minimum Performance

Equipment	Minimum Efficiency Required	Available Efficiency	Compliance
Building No.01-Ceylon Petroleum Corporation			
Air Cooled Water Chiller	2.8 COP 3.05 IPLV	COP = 3.1	Comply
Building No.02-Peoples' Leasing Head Office Building			
Water Cooled Unitary	11.0 EER	EER = 11.0	Comply
Cooling Tower	38.0 gpm/hp	46 gpm/hp	Comply
Building No.03-Ceylinco Life Insurance Head Office Building			
Water Cooled Unitary	11.0 EER	EER = 11.0	Comply
Cooling Tower	38.0 gpm/hp	44 gpm/hp	Comply

8.3.3 Building Envelop

8.3.3.1 Mandatory Requirements – Building Envelop Sealing

Building envelop should have a good sealing in the locations like joints around fenestration, junctions between walls & foundations, Openings at penetrations etc.

Table 8.3.3.1: Mandatory Requirements - Envelope Sealing

Checked Parameter	Condition in Considered Building	Compliance
Building No.01		
Joints around fenestration and door frames	Not sealed	Not comply
Junctions between walls & foundations, walls at corners, walls and floors, walls and roofs	Sealed	Comply
Openings at penetrations of utility services through roofs, walls and floors	Sealed	Comply
Site-build fenestration and doors	Partly sealed	Not comply
Joints, seams and penetrations of vapor retarders	Sealed	Comply
Building No. 02		
Joints around fenestration and door frames	Not sealed	Not comply
Junctions between walls & foundations, walls at corners, walls and floors, walls and roofs	Sealed	Comply
Openings at penetrations of utility services through roofs, walls and floors	Sealed	Comply
Site-build fenestration and doors	Partly sealed	Not comply
Joints, seams and penetrations of vapor retarders	Sealed	Comply

Building No.03		
Joints around fenestration and door frames	Not sealed	Not comply
Junctions between walls & foundations, walls at corners, walls and floors, walls and roofs	Sealed	Comply
Openings at penetrations of utility services through roofs, walls and floors	Sealed	Comply
Site-build fenestration and doors	Partly sealed	Not comply
Joints, seams and penetrations of vapor retarders	Sealed	Comply

8.3.3.2 Building Envelop Performance - OTTV

Table 8.3.3.2: Building Envelop Performance - OTTV

Parameter	Building No.01	Building No.02	Building No.03
(a) Area weighted OTTV	58 W/m^2	38 W/m^2	40 W/m^2
(b) OTTV with all prescriptive values	50 W/m^2	46 W/m^2	47 W/m^2
Compliance ($a \leq b \leq 50$ W/m$^{2)}$	Not comply	Comply	Comply

8.3.3.3 Prescriptive Requirements

Table 8.3.3.3: Prescriptive Requirements

	Building No.01	Building No.02	Building No.03
Mean Visual Light Transmittance (VLT) > 0.15 for all fenestrations	1/4" glass 0.79 (value without internal shading) [Comply]	1/4",3/8”,1/2” glasses 0.79,0.754 ,0.722 (value without internal shading) [Comply]	1/4",3/8” glasses 0.79,0.722 (value without internal shading) [Comply]
Maximum U-Factor value for roof < 0.40 Wm-2k-1	0.47 Wm-2k-1 [Not comply]	0.47 Wm-2k-1 [Not Comply]	0.44 Wm-2k-1 [Comply]

9.0 MODELING OF SELECTED BUILDINGS

9.1 Basic Internal Load Data for the Building Models

Following are the basic internal load values entered to the software for calculations/analysis in general. Unloading curves of chillers, packaged units, pumps and fan curves provided by the software were used. Available values/data of equipment installed in buildings considered (COP/EER, fan efficiency etc.) were entered additionally.

Table 9.1: Basic internal load data used for building models

No	Parameter	Value/Description		
		Building No.01	**Building No.02**	**Building No.03**
01	Occupancy			
	Office	142 ft^2/Person	133 ft^2/Person	120 ft^2/Person
	Canteen	10 ft^2/Person	10 ft^2/Person	10 ft^2/Person
	Auditorium	6.7 ft^2/Person	6.7 ft^2/Person	6.7 ft^2/Person
02	Metabolic Rate/(Sensible/Latent)			
	Office	250/200 BTU/h	250/200 BTU/h	250/200 BTU/h
	Canteen	275/275 BTU/h	275/275 BTU/h	275/275 BTU/h
	Auditorium	225/105 BTU/h	225/105 BTU/h	225/105 BTU/h
03	Temperature Set Points			
	Cooling Dry Bulb	75 ^{0}F	75 ^{0}F	75 ^{0}F
	Heating Dry Bulb	70 ^{0}F	70 ^{0}F	70 ^{0}F
	Cooling Drift Point	81 ^{0}F	81 ^{0}F	81 ^{0}F
	Heating Drift Point	64 ^{0}F	64 ^{0}F	64 ^{0}F
04	Ventilation Rate	6 CFM/Person	5 CFM/Person	5 CFM/Person
05	Lighting Power Density			
	Office	1.45 W/m^2	0.9 W/m^2	0.85 W/m^2
	Canteen	1.20 W/m^2	-	0.90 W/m^2
	Auditorium	1.00 W/m^2	-	0.90 W/m^2
06	Computer Heat Generation	100 W	100 W	100 W
07	Computer/Person	0.6	0.9	0.95
07	Time Zone	GMT + 6.00	GMT + 6.00	GMT + 6.00
08	Latitude, Longitude	6.82 N, 79.88 E	6.82 N, 79.88 E	6.82 N, 79.88 E
09	Altitude	15-20 m	15-20 m	15-20 m

Occupancy, Density, Ventilation rate, Lighting Power Density, computer power, computers per person are actual values and the rest are standard values.

9.2 Building Construction Material Data

Building construction material data which were selected/created in the software are given below.

Table 9.2: Construction material properties used for models

No	Construction Type	Detail
01	9" Common brick wall with 0.75" plaster on both sides, outer color gray, inner color white	Outside color = Gray U-Value = 0.322 Btu/h.ft^2.F Heat Capacity = 20.5 Btu/ft2.lb.F Outside shortwave (solar) absorptivity = 0.77 Outside long wave (thermal) emissivity = 0.77 Inside shortwave absorptivity = 0.65 Inside long wave (thermal) emissivity = 0.9 Inside visible (hemispherical) reflectance = 0.5
02	9" Brick Wall with Outside Gray Cladding work, inside white	U-Factor = 0.248 Btu/h.ft^2.F Heat capacity = 20.74 Btu/ft2.lb.F Outside shortwave (solar) absorptivity = 0.77 Outside long wave (thermal) emissivity = 0.77 Inside shortwave absorptivity = 0.65 Inside long wave (thermal) emissivity = 0.9 Inside visible (hemispherical) reflectance = 0.5
03	9" Brick Wall with Outside Red Cladding work, inside white	U-Factor = 0.248 Btu/h.ft^2.F Heat capacity = 20.74 Btu/ft2.lb.F Outside shortwave (solar) absorptivity = 0.7 Outside long wave (thermal) emissivity = 0.7 Inside shortwave absorptivity = 0.65 Inside long wave (thermal) emissivity = 0.9 Inside visible (hemispherical) reflectance = 0.5
04	4" Common Brick partition with 0.75" plaster on both sides, color white	U-Factor = 0.462 Btu/h.ft^2.F Heat capacity = 8 Btu/ft2.lb.F Outside shortwave (solar) absorptivity = 0.9 Outside long wave (thermal) emissivity = 0.9 Inside shortwave absorptivity = 0.65 Inside long wave (thermal) emissivity = 0.9 Inside visible (hemispherical) reflectance = 0.5
05	0.75" Gypsum Frame, color white	U-Factor = 0.388 Btu/h.ft^2.F Heat capacity = 2.5 Btu/ft2.lb.F Outside shortwave (solar) absorptivity = 0.9 Outside long wave (thermal) emissivity = 0.9 Inside shortwave absorptivity = 0.65

		Inside long wave (thermal) emissivity = 0.9 Inside visible (hemispherical) reflectance = 0.5
06	5" Light Weight concrete roof slab,2" insulation	U-Factor = 0.0821 Btu/h.ft^2.F Heat capacity = 5.315 Btu/ft2.lb.F Outside shortwave (solar) absorptivity = 0.9 Outside long wave (thermal) emissivity = 0.9 Inside shortwave absorptivity = 0.65 Inside long wave (thermal) emissivity = 0.9 Inside visible (hemispherical) reflectance = 0.7
07	8" Light Weight Concrete Wall with 0.75 plaster on both sides	U-Factor = 0.125 Btu/h.ft^2.F Heat capacity = 7.8 Btu/ft2.lb.F Outside shortwave (solar) absorptivity = 0.77 Outside long wave (thermal) emissivity = 0.77 Inside shortwave absorptivity = 0.65 Inside long wave (thermal) emissivity = 0.9 Inside visible (hemispherical) reflectance = 0.5
08	12" Light Weight Concrete Floor	U-Factor = 0.0879 Btu/h.ft^2.F Heat capacity = 8.0 Btu/ft2.lb.F Outside shortwave (solar) absorptivity = 0.9 Outside long wave (thermal) emissivity = 0.9 Inside shortwave absorptivity = 0.65 Inside long wave (thermal) emissivity = 0.9 Inside visible (hemispherical) reflectance = 0.2
09	5" Light Weight Concrete Floor	U-Factor = 0.181 Btu/h.ft^2.F Heat capacity = 3.33 Btu/ft2.lb.F Outside shortwave (solar) absorptivity = 0.9 Outside long wave (thermal) emissivity = 0.9 Inside shortwave absorptivity = 0.65 Inside long wave (thermal) emissivity = 0.9 Inside visible (hemispherical) reflectance = 0.2
10	Single Clear 1/4" Window Glass	No of panes = single U-Factor(Summer) = 0.95 Btu/h.ft^2.F Shading coefficient = 0.95 Visible transmissivity = 0.779 Inside visible reflectivity = 0.114 Solar transmissivity = 0.692 Inside solar reflectivity = 0.129 Outside long wave emissivity = 0.84 Inside long wave emissivity = 0.84
11	Single Clear 3/8" Window Glass	No of panes = single U-Factor(Summer) = 1.04 Btu/h.ft^2.F Shading coefficient = 0.92 Visible transmissivity = 0.754 Inside visible reflectivity = 0.135 Solar transmissivity = 0.552 Inside solar reflectivity = 0.115 Outside long wave emissivity = 0.84 Inside long wave emissivity = 0.84
12	Single Clear 1/2" Window Glass	No of panes = single U-Factor(Summer) = 1.04 Btu/h.ft^2.F Shading coefficient = 0.88

		Visible transmissivity = 0.722 Inside visible reflectivity = 0.18 Solar transmissivity = 0.614 Inside solar reflectivity = 0.162 Outside long wave emissivity = 0.84 Inside long wave emissivity = 0.84

Outer wall of all three building were constructed by 9" brick wall with plaster on both sides. In building no.01 (Ceylon Petroleum Corporation building) front walls had cladding with red and gray color. Floor slab of Building no.03 (Ceylinco Life Insurance building) was 12 inches thick (beamless slab). However its roof was normal 5" concrete like in other two buildings. Floor slab of Building no. 01 & 02 were 5" concrete. Roof of all three buildings were 5" with 2" insulation. Partitions were common 0.75 gypsum boards except in wash room areas where it was 4" brick wall. Other details have been given in relevant sections.

9.3 Occupancy Schedules Used for Each Building

Table 9.3.1: Occupancy variation with time of the day - Building No.01

Monday to Friday (All floors working)		Saturday (All floors working)	
Time	**Occupants**	**Time**	**Occupants**
00.00-08.00	0 %	00.00-08.00	0 %
08.00-09.00	70 %	08.00-09.00	30 %
09.00-12.00	100 %	09.00-12.00	60 %
12.00-13.00	85 %	12.00-13.00	30 %
13.00-16.00	100 %	13.00-16.00	50 %
16.00-17.00	60%	16.00-17.00	30%
17.00-00.00	0 %	17.00-00.00	0 %

Though occupant density changes 70% 85 % etc. lighting load does not change in the same manner because the lighting in the office is switched on when the office is open. However, some lamps may be switched off where possible (or may be out of order), some executives' room lights may have been switched off. So the lighting schedule was considered as 90% of total lighting power on weekdays and 70% of on Saturday.

Table 9.3.2: Occupancy variation with time of the day - Building No.02

Monday to Friday (All floors working)		Saturday (Only 1-3 floors working)		Sunday (Only 1 floor working)	
Time	**Occupancy**	**Time**	**Occupancy**	**Time**	**Occupancy**
00.00-08.00	0 %	00.00-08.00	0 %	00.00-08.00	0 %
08.00-09.00	50 %	08.00-09.00	10%	08.00-09.00	10%
09.00-12.00	100 %	09.00-12.00	15%	09.00-12.00	15%
12.00-13.00	100 %	12.00-13.00	15%	12.00-13.00	15%
13.00-17.00	100 %	13.00-17.00	15%	13.00-17.00	15%
17.00-18.00	30%	17.00-18.00	15%	17.00-18.00	15%
18.00-00.00	0%	18.00-00.00	0%	18.00-00.00	0%

Above percentages are percentage of the total number of occupants considered to find the occupancy density of the building. When only 1-3 floors are working Air Conditioning & lighting of all other floors were not considered for energy calculation.

Lighting schedule was used as 90% of total lighting power on weekdays, and 80% on Saturday and Sunday on the operating floors as per the occupancy schedule (some floors are not working on weekends).

Table 9.3.3: Occupancy variation with time of the day - Building No.03

Monday to Friday (All floors working)	
Time	**Occupancy**
00.00-08.00	0 %
08.00-09.00	50 %
09.00-12.00	100 %
12.00-13.00	100 %
13.00-17.00	100 %
17.00-00.00	0%

On Saturdays and Sundays office is closed. Only the security staff is working and they are in a room which is outside of the building considered. Lighting schedule was used as 95% of total lighting power in office working hours.

9.4 Creation of Models for Each Building

Three building models were created for three buildings considered. Later, changes in the relevant parameters were made to get the new model for analysis like adding Demand Control ventilation, chilled water temperature reset etc. when it is required to study the effect of it.

9.4.1 Building Model 01 - Ceylon Petroleum Corporation Head Office Building

1) Internal loads are as per table 9.1 column 3
2) Construction materials types are as per table 9.2 Walls - type 02(front), type 03(front), type 01(other). Partition - type 04 & type 07 (elevator shaft). Roof - type 06.Floor - type 09.Slab - type 09 Glass-type 10
3) Wall areas, window areas were added based on the drawings/sketches collected. A summary of entered data is attached in appendix A.
4) The system category was selected as constant volume none mixing. Current system does not use VFDs for supply air fans and there is no heating system installed
5) System type was selected as fan coil chilled water ducted.
6) Each floor Air Handling Unit consists of 04 cooling coils and a forward curve centrifugal fan (constant volume). Therefore, floor was divided into 4 zones (as per drawings) and assigned 4 fan coil for each zone
7) Three (03) air cooled chillers were included in the cooling plant. Current building is cooled by three air cooled chillers. Electrical resistant heating unit was added to the heating plant though heating is not actually used, to satisfy the ASHRAE requirement.
8) 03 chiller were equal in size. Therefore, no special sequencing was added.
9) COP of 2.8 which was found in an energy audit done by building maintenance department was used (COP at installation was 3.0). 7% has been reduced in 7 years.

10) Chilled water pumping arrangement is in primary secondary method (constant volume). Head for primary pumps as 35ft and for secondary pumps as 46ft were used based on the pressure meter readings in pump room.
11) Software default primary pump ("Cnst vol chill water pump") and secondary pump ("Cnst vol chill water pump") was used because performance curves are available in the software
12) Default fan efficiencies were used (motor-90%, mechanical-75%) for fan ("FC Centrifugal const vol"). fan pressure was taken as 0.6 in.wg (based on data) and full load energy rate as 0.000321 kW/Cfm-in wg.
13) Computer power was taken as 100W. It was decided after measuring the actual current & voltage with UPS connected.
14) Elevator was taking as an average of 7.5 kW. The plant room was cooled by fan coils. That load was added to the cooling plant.
15) All the features or values not mentioned in this documents were the same values or selected features by the software itself.

9.4.2 Building Model 02 - Peoples Leasing Head Office Building

1) Internal loads are as per table 9.1 column 4
2) Construction materials types are as per table 9.2 Walls - type 01. Partition - type 04 & type 07 (elevator shaft). Roof - type 06.Floor - type 09.Slab - type 09. Glass - type 10 (general), type 11(1-3 floors south side), type 12(1-3 floors west side)
3) Wall areas, window areas were added based on the drawings collected. A summary of entered data is attached in appendix B.
4) The system category was selected as constant volume none mixing. VFD is not used and since it is packaged unit VFD cannot be used. No heating system is installed.
5) System type was selected as packaged terminal air conditioner
6) There is one packaged (unitary) air conditioner at each floor. There are five ceiling concealed water cooled ducted air conditioners in 10^{th} floor and one in 1^{st} floor and one in 3^{rd} floor. They were also considered in same type and

category. Working area was considered as one zone because the temperature is controlled by the single thermostat at packaged air conditioner.

7) 18 packaged air conditioners were include in the cooling plant. Electrical resistant heating unit was added to heating plant though heating is not actually used, to satisfy the ASHRAE requirement.
8) Efficiency value given by software for “Default water cooled unitary” (0.797 kW/Ton) was used with a change to allow for performance reduction due to aging. 10% reduction assumed for 10 years because energy audit in building no 01 revealed 7% reduction in chiller for 7 years. Therefore, 0.88 kW/Ton used.
9) “VV Cond Wtr Pump” was used as condenser water pumps with 65ft total head. This building uses VFDs for condenser water pumps.
10) Default fan efficiencies were used (motor-90%, mechanical-75%) for fan (“FC Centrifugal const vol”). fan pressure was taken as 0.6 in.wg (based on data) and full load energy rate as 0.000321 kW/Cfm-in wg.
11) Demand control ventilation was added to function according to ASHRAE 62.1-2007 with single set point and outdoor CO_2 400 ppm. This building uses this feature via BMS
12) Computer power was taken as 100W. It was decided after measuring the actual voltage & current with UPS connected.

9.4.3 Building Model 03 - Ceylinco Life Insurance Head Office Building

1) Internal loads are as per table 9.1 column 5
2) Construction materials types are as per table 9.2 Walls - type 01. Partition - type 04 & type 07 (elevator shaft). Roof - type 06. Floor - type 09. Slab - type 08. Glass - type 10 (general), type 11 (8 floors west side)
3) Wall areas, window areas were added based on the drawings collected. A summary of entered data is attached in appendix C.
4) The system category was selected as constant volume none mixing. VFD is not used and since it is packaged unit VFD cannot be used. No heating system is installed.

5) System type was selected as packaged terminal air conditioner
6) There are two packaged (unitary) air conditioner at each floor up to 7th floor. There are five ceiling concealed water cooled ducted air conditioners in 7th floor. There is one packaged air conditioner in 8th floor and two in 8th Mezzanine floor. They were also considered in same type and category. Working area was considered as one zone because the temperature is controlled by the single thermostat at packaged air conditioner.
7) 16 packaged air conditioners were include in cooling plant. Electrical resistant heating unit was added to heating plant though heating is not actually used, to satisfy the ASHRAE requirement.
8) Efficiency value given by software for "Default water cooled unitary" (0.797 kW/Ton) was used with a change to allow for performance reduction due to aging. 10% reduction assumed for 10 years because energy audit in building no 01 revealed 7% reduction in chiller for 7 years. Therefore, 0.88 kW/Ton used.
9) "VV Cond Wtr Pump" was used as condenser water pumps with 65ft total head. This building uses VFDs for condenser water pumps.
10) Default fan efficiencies were used (motor-90%, mechanical-75%) for fan ("FC Centrifugal const vol"). fan pressure was taken as 0.6 in.wg and full load energy rate as 0.000321 kW/Cfm-in wg.
11) Demand control ventilation was added to function according to ASHRAE 62.1-2007 with single set point and outdoor CO_2 400 ppm. This building uses this feature via BMS
12) Sun control film was used with properties SHGC = 0.39, U-Value = 1.02 Btu/h.ft2.F, Solar energy rejected = 68% and visible light transmitted = 42% (as per data) because this building has applied it from the commissioning.
13) Computer power was taken as 100W. It was decided after measuring the actual voltage & current with UPS connected.

Computer server rooms of three selected buildings are operated 24 hours a day and are air conditioned by precision air conditioners (Not connected to central system).

10.0 ANALYSIS OF THE SELECTED BUILDINGS

10.1 Comparison of actual annual energy consumption vs. annual energy consumption given by Trace 700 Software

This is to get an assurance that the software has been used properly, it gives accurate results for Sri Lankan weather data, actual data has been entered correctly and the software itself is suitable for this study.

Following is the cooling demand profile of the building no. 01 in May 2018. At 2.00 P.M. two 120 Ton (rated power) chillers were in operation and the load percentage of chillers were 91% and 84% as indicated by the control console of the chillers. So the demand is simply 120 x 0.91 + 120 x 0.74 = 198 Tons. In an energy audit done by Industrial Services Bureau, Sri Lanka, in November 2018 the COP of chillers were 2.8 (performance had been reduced). In chiller online brochure it is was 3.0. So the actual building load should be 198 x 2.8/3.0 = 184.8 Tons. According to the bar char bellow which was given by software it is 180 Ton. In the same energy audit average chiller load was 85 Ton in November. So the building load was 85x2 = 170 Ton. By software it is 168 Tons in November.

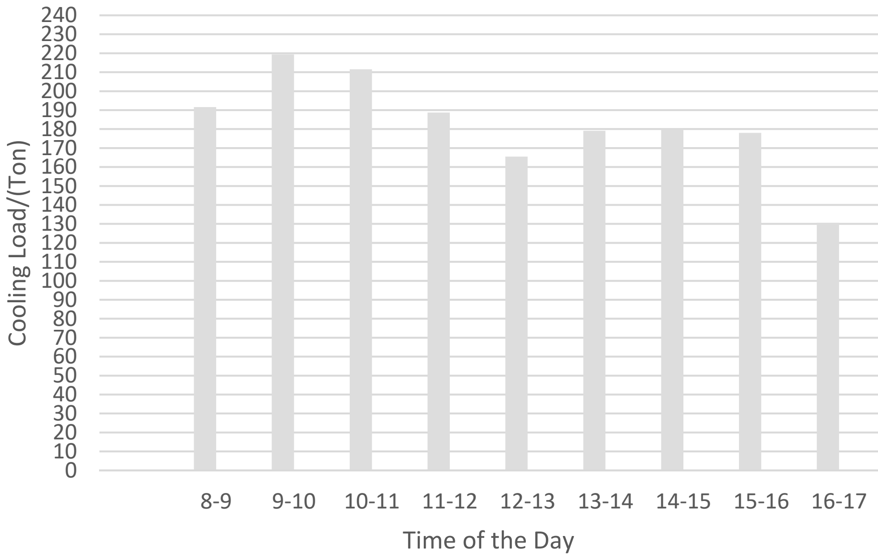


Figure 10.1.1: Cooling Load of Building No.01 Vs Time of the day

Monthly energy consumption in May 2018 was 113, 307 kWh (Day time). Software gives 94,832 kWh for the same month without the electrical energy for Server Room (5,850 kWh), 10 Nos 12,000 BTU/h & 10 Nos 24,000 BTU/h Air Conditioners and lights (6,182 kWh) of stores building which is around 50m away and ventilation fans. So the building energy should be 94,832 kWh + 5,850 kWh + 6,182 kWh +293 kWh = 107,157 kWh.

The building peak power demand in May 2018 was 550 kW. The software gives 482 kW. So with above additional equipments; Server Room & ACs 482 kW + 32.2 kW + 15 kWh= 529.2 kW.

These differences in power (kW) can occur mainly due to changes in weather, occupancy, equipment efficiencies, envelop properties, equipment which can work only once sometimes like water pumps (instantaneous power) and equipment not considered like telephone system, CCTV etc.

When comparing options for maximizing energy efficiency software result of one option will be compared against another result of another option given by the software. Therefore, the comparison of options will be relative and there will not be significant percentage errors.

The above value comparison between the actual values of energy & power with those given by software shows us that even for real value prediction also this software can be used with satisfactory reliability and the methods and procedures used in this study was correct.

10.2 Current Situation of the Selected Buildings

It is important to know Current annual energy consumption percentage by Air Conditioning System, Lighting System, building envelop components, ventilation etc. of considered buildings to get an overall idea and to compare later how this could have been if more energy conservation measures had been followed and when comply with ASHRAE minimum requirements. Annual energy consumption of each building are given below as percentages.

Building Air Conditioning system power demand depends on individual power demand of each element of the building such as walls, windows, roof etc. It is important to know what element is using more power.

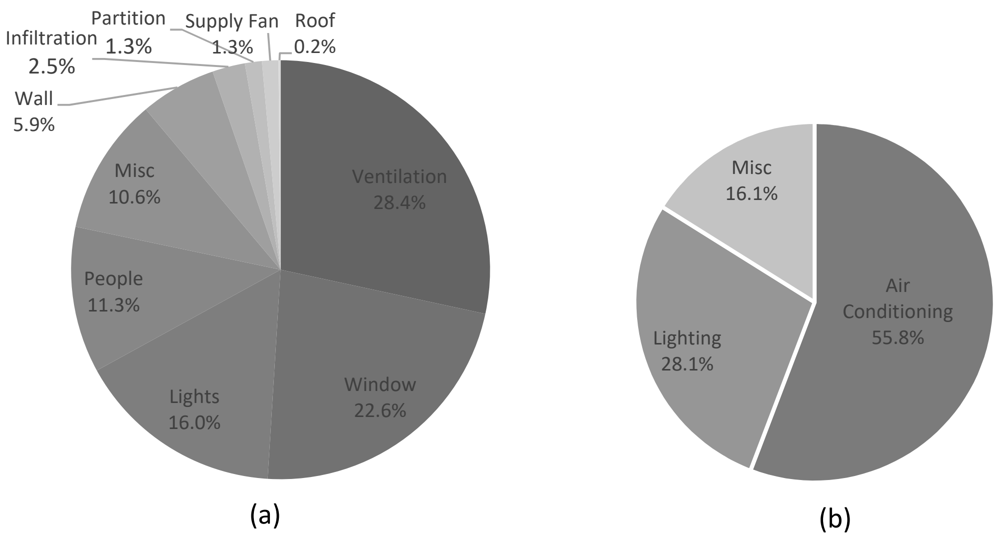


Figure 10.2.1: Current Building Load by Each Element at coil peak-Building No.01-Ceylon Petroleum Corporation. (a)-Cooling Load. (b)-Electrical Power Consumption

Lighting power density of Building No. 01 was obviously high at 1.45 W/ft^2 while ASHRAE allows 1.0 W/ft^2 maximum for this type of buildings.

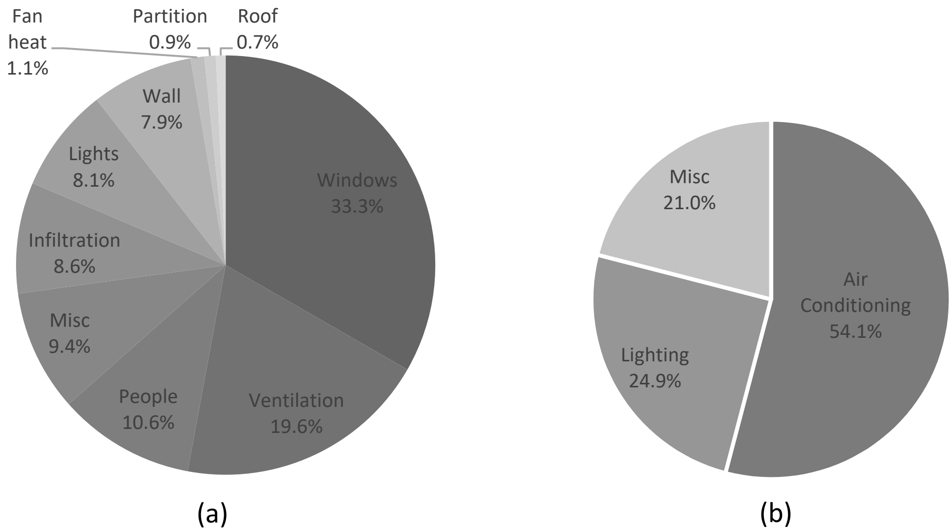


Figure 10.2.2: Current Building Load by Each Element at coil peak-Building No.02-Peoples Leasing Building. (a)-Cooling Load. (b)-Electrical Power Consumption

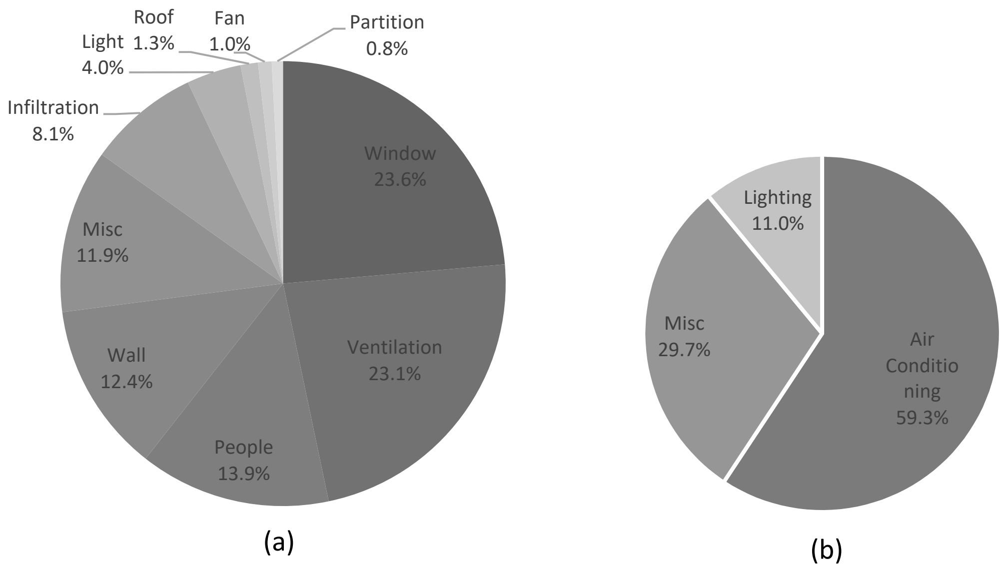


Figure 10.2.3: Current Building Load by Each Element at coil peak-Building No.03-Ceylinco Life Insurance Building. (a)-Cooling Load. (b)-Electrical Power Consumption

10.3 Peak Demand and Annual Energy Consumption when satisfying the minimum requirements of ASHRAE 90.1-2007

As per the ASHRAE 90.1-2007, following parameters which have been given as minimum requirements were considered and entered to Trane 700 software and computed the peak demand and annual energy consumption.

- Wall to window ratio was unchanged (similar to the actual building since it is less than 40%)
- Building construction materials (Envelope) as follows

LOCATION	CONDUCTIVITY	INSULATION/SHGC
Walls	U-0.580	Not require by Standard for mass walls
Roof	U-0.063	R-15 Insulation alone
Vertical Glazing	U-1.20	SHGC-0.25
Opaque door	U-1.450	NR
Floors	U-0.322	NR

- HVAC System(Equipment efficiencies)

EQUIPMENT	EFFICIENCY
Air-cooled water chiller	COP = 3
Water-cooled packaged unit	EER = 11
Supply air fan	$Hp < CFM_s \times 0.0011$
Water pumps	Efficiency = 65% @ 75 ft

- Insulation: Duct insulation – R-3.5, Pipe insulation: for 1 ½”-8” pipes 1” thick
- Lighting power density = 1.0 W/m^2
- Building envelop is sealed well at joints around fenestrations, doors, between walls and foundation, at wall corners, Openings for utility services etc.
- Usage of controls such as zone thermostatic controls, off-hour controls, automatic shutdown, optimum start controls, ventilation fan controls and demand control ventilation,

Maximum Cooling load (Peak demand), the annual total energy consumption and the percentage difference if ASHRAE 90.1-2007 had been followed, are as follows for the selected three buildings.

Table 10.3.1: Comparison of peak demand & annual energy consumption of current building and the same building with minimum ASHRAE 92.1-2007 requirements

BUILDING	PEAK COOLING DEMAND/ELECTRICITY NOW/(kW)	PEAK COOLING DEMAND/ELECTRICITY FOR ASHRAE MIN REQUIREMENT /(kW)	REDUCTION		ANNUAL ENERGY CONSUMPTION NOW/(kWh)	ANNUAL ENERGY CONSUMPTION FOR ASHRAE MINIMUM REQUIREMENTS/(kWh)	REDUCTION
Building No.01	519 kW	496 kW	4.4%		1,061,366	1,047,292	1.3%
Building No.02	245 kW	260 kW	-6.1%		529,291	685,432	-29.5%
Building No.03	189 kW	188 kW	0.5%		365,912	399,822	-9.3%

Higher annual energy consumption in building No. 02 and 03 if constructed/modified to meet the minimum requirements of ASHRAE 92.1-2007 is indicating that current buildings performs better in the energy consumption. It should be mainly due to the usage of controls in the air conditioning system such as demand control ventilation, VFD condenser water pumps etc. and efficient equipment along with the low Lighting Power Density, low U values of construction materials.

10.4 Finding the amount of energy which can be saved by applying various system options/configurations

There may be various methods for saving energy consumption in buildings. Some should be implemented at the construction stage and some methods can be implemented later also. In the energy saving process, more attention should be given to the highest energy consuming systems because even 1% saving may be a considerable amount of energy and money. As seen in the current status of these three buildings (10.2) air conditioning system consumes more than 55% and lighting system consumes around 20%. Miscellaneous load was mainly the office computer load.

Therefore, some of the system options/configurations related to air conditioning system and lighting system were studied using the building models created and the result was compared with the model of the current building (current situation) to evaluate the possible energy saving and the energy saving the buildings have already gained which will be useful for other building owners to know. Even if some methods have been implemented, it is important to know whether further improvement is possible.

10.4.1 Demand Control Ventilation (DCV)

In this method, CO_2 sensors are used in occupied spaces to detect CO_2 level. When the CO_2 level goes beyond 1000 ppm, control module or the BMS will open the fresh air damper allowing more fresh air to enter the air supply to the occupied space to maintain the CO_2 level below 1000 ppm (Building No.02 uses separate fans to force fresh air into the building when CO_2 level goes high). When the CO_2 level goes below 1000 ppm BMS will close the fresh air damper appropriately to save the electricity consumption. In Many BMSs, the default set-point is this (As per ASHRAE 62-1989 also) and many BMS in Sri Lanka use that value unchanged.

1) Building No.01 - Ceylon Petroleum Corporation Head Office Building

Building No. 01-Ceylon Petroleum Corporation doesn't use Demand Control Ventilation in the current ventilation system. By applying the Demand Control Ventilation in Building No. 01 model, following result was received.

There was a reduction in annual energy consumption as below.

Current annual energy consumption	1,048,860 kWh
Current annual energy consumption	1,009,136 kWh
Reduction in annual energy consumption	39,724 kWh (3.8%)

2) Building No.02 - Peoples Leasing Head Office Building

This building has implemented Demand Control Ventilation from the commissioning of the building. Following is the amount of energy they have saved by this method.

Current annual energy consumption with DCV	490,669 kWh
Annual energy consumption without DCV	501,225 kWh
Reduction in annual energy consumption they have achieved by DCV	10,556 kWh (2.1%)

3) Building No.03 - Ceylinco Life Insurance Head Office Building

This building also has implemented Demand Control Ventilation from the commissioning of the building. Following is the amount of energy they have saved by this method.

Current annual energy consumption with DCV	374,935 kWh
Annual energy consumption without DCV	394,450 kWh
Reduction in annual energy consumption they have achieved by DCV	19,515 kWh (4.9%)

10.4.2 Usage of heat rejection films on window glass

Sun Control Films are designed to reduce the amount of solar heat transmission through window glass by increasing the solar reflection (not necessarily visible reflection) and solar absorption through the glass. Typical colored or dyed films work primarily through increased absorption. The color absorbs the solar energy at the glass, thus reducing the direct transmission into the room. These films are not as effective as reflective films for reducing heat.

Reflective films are films that have been precision coated with metals. These metalized films are designed to increase the solar energy reflection of the glass. Reflective films range from moderate to excellent in solar performance (heat gain reduction).Sun Control Films are made to be transparent and optically clear. The ultraviolet protection is built into the adhesive system to provide longevity to the film as well as provide UV protection for occupants and office furnishings [26].

By applying a sun control film available in Sri Lanka with the properties SHGC = 0.39, U-Value = 1.02 Btu/h.ft^2.F, Solar energy rejected = 68% and visible light transmitted = 42% gave following results.

This kind of sun control films can be applied even after the completion of the construction of the building.

1) Building No. 01 - Ceylon Petroleum Corporation Head Office Building

Current annual energy consumption	1,048,860 kWh
Annual energy consumption with sun control films	1,036,846 kWh
Reduction in annual energy consumption by sun control films	12,014 kWh (1.1%)

2) Building No. 02 - Peoples Leasing Head Office Building

Current annual energy consumption	490,669 kWh
Annual energy consumption with sun control films	489,927 kWh
Reduction in annual energy consumption by sun control films	742 kWh (0.2%)

3) Building No. 03- Ceylinco Life Insurance Head Office Building

This building already has implemented this method. Following is the amount of energy they have saved by using heat reflective films on window glass.

Current annual energy consumption with Sun Control	374,935 kWh
Annual energy consumption without sun control films	375,685 kWh
Reduction in annual energy consumption by sun control films	80 kWh (0.2%)

10.4.3 Chilled water set-point resetting

Chilled-water-reset adjusts the set point of the chilled water sent to the cooling equipment such as Air Handling Units, Fan Coil units etc. to improve the efficiency of the chiller reducing the energy consumption of the chiller and the total energy consumption of the building.

Normally, when the building load is less than design conditions, the set-point temperature is raised to a level such that the system can still supply the demanded cooling load of the building.

For the BMS or the control module, maximum chilled water reset has to be specified. When the chilled water temperature goes up, chiller load is reduced and so the refrigerant flow etc. Manufacturers specify the minimum chiller load for the healthy operation and extended lifetime of the chiller. Normally it is around 20% of the full load. In this case, 5ºF temperature reset was used.

Maximum demand doesn't change because the chiller output chilled water temperature has been decided and set to suit the design cooling load and chilled water temperature reset technique will raise the temperature of chilled water from that point upwards with lowering building cooling demand.

Increasing the chilled-water temperature in VFD systems increases the energy consumption of pumping, and it may sometimes more than the savings in chiller efficiency.

Only the building No. 01 using a chiller system and the result was like this.

Current annual energy consumption	1,048,860 kWh
Annual energy consumption with chilled water set point changing	1,035,745 kWh
Reduction in annual energy consumption due to set point changing	13,115kWh (1.3%)

10.4.4 Using VFD chilled water pumps

In a two pipe chilled water system like in the building No. 01, when the building cooling load reduces the control valves of cooling coils of air handling units and fan coils closes some amount (modulating type valves) or completely (on/off type valve) and then additional pressure will build up against the chilled water pumps which makes the chilled water circulation throughout the hydronic system. This is an unnecessary energy waste.

If the rotation speed of the chilled water pumps are controlled by using Variable Frequency Drives (VFD) by BMS or the control module to maintain the chilled water supply pressure at the pumping room end while ensuring the required chilled water flow, it will save some pumping energy.

Building No. 01 gave following result when using VFD pumps in chilled water side.

Current annual energy consumption	1,048,860 kWh
Annual energy consumption with VFD pumps	1,021,815 kWh
Reduction in annual energy consumption with VFD pumps	27,045 kWh (2.6%)

This technique can be implemented even now with complete BMS or without BMS using electronic controls.

10.4.5 Using VFD cooling tower and condenser water pumps

A cooling tower rejects the heat from a water cooled condenser by spraying water over a fill while drawing outside air through it. As the heat rejection load and ambient wet bulb change, the cooling tower fans must move either more or less air to produce the desired water temperature. One common method for controlling the speed of the cooling tower fans is to use variable frequency drives (VFDs). This approach offers several benefits

- Tight control of tower water temperature.
- Fan power varies with the cube of the speed, resulting in great potential for energy savings.
- In addition to avoiding gearbox or motor wear, fans operate more quietly at low speeds when equipped with variable frequency drives than with other methods of modulation.
  [Trace700 user manual 2007]

Building No.02 & 03 uses cooling towers for condenser cooling. Following result was received after adding VFD cooling tower and condenser water pumps to the model.

1) Building No. 02 - Peoples Leasing Building Head Office Building

Current annual energy consumption with VFD pumps	490,669 kWh
Annual energy consumption without VFD pumps	499,992 kWh
Reduction in annual energy consumption achieved with VFD pumps	9,323 kWh (1.9%)

If both VFD Condenser pumps and VFD cooling tower was used annual energy consumption	478,044 kWh
Reduction in annual energy consumption by VFD pumps & VFD cooling tower combination	21,948 kWh (4.4%)

2) Building No. 03 - Ceylinco Life Insurance Head Office Building

Current annual energy consumption without VFD pumps	374,935 kWh
Annual energy consumption with VFD pumps	382,701 kWh
Reduction in annual energy consumption they have achieved with VFD pumps	7,766 kWh (2.0%)

Annual energy consumption with VFD pumps & VFD cooling tower	365,219 kWh
Reduction in annual energy consumption by VFD pumps & VFD cooling tower combination	17,019 kWh (4.6%)

10.4.6 Increasing indoor (room) temperature set-point by 2 ^{0}F (1 ^{0}C)

If the temperature of the conditioned area is increased by increasing the set point of the thermostat (eg-: from 75 ^{0}F or 24 ^{0}C up to 77 ^{0}F or 25 ^{0}C) the effort by the Chiller to cool the room will be less. This will reduced the energy consumption as well. Building No.01 and 03 have manually tested this method recently (not yet implemented). According to the maintenance staff of those buildings, only 2% of the occupants felt it. Therefore, this is also a method which can be implemented.

Increasing the temperature by 0.5 ^{o}F etc. and keeping that setting for a few days (to allow time for occupants to adapt) before going to the next step will be more successful.

Following are the results for three buildings.

1) Building No. 01 - Ceylon Petroleum Corporation Head Office Building

Current annual energy consumption	1,048,860 kWh
Annual energy consumption with 2^{o}F increment	1,035,745 kWh
Reduction in annual energy consumption with 2 ^{0}F increment	13,115 kWh (1.3%)

2) Building No. 02 - Peoples Leasing Building Head Office Building

Current annual energy consumption	490,669 kWh
Annual energy consumption with 2^{o}F increment	471,412 kWh
Reduction in annual energy consumption with 2 ^{0}F increment	19,257 kWh (3.9%)

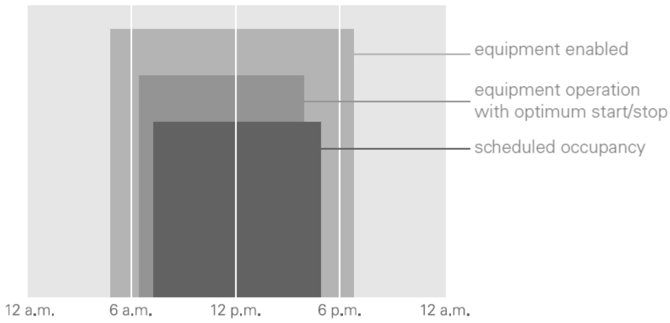
3) Building No. 03 - Ceylinco Life Insurance Head Office Building

Current annual energy consumption	374,935 kWh
Annual energy consumption with 2^{o}F increment	357,105 kWh
Reduction in annual energy consumption with 2 ^{0}F increment	17,830 kWh (4.8%)

10.4.7 Optimum start/stop control

Optimum start and stop is a control strategy which uses the thermal storage capacity of the building to reduce the duration of equipment operation. A building constructed of low density materials like wood etc. respond more quickly to the operation of the HVAC system than buildings constructed of high density materials such as brick, concrete block etc.. Knowing the time taken to achieve the target temperature in the space lets us minimize the length of time that the HVAC system operates before the occupied period begins. Therefore, selecting equipment starting/stopping times based on occupancy schedules, ambient conditions and the thermal characteristics of the building can save some energy without sacrificing comfort.

In software, it is done by controlling the start/stop times of main supply fans. If the supply fans of fan coils stop, no energy will be taken from chilled water and chiller energy consumption will be reduced accordingly. Temperature increase of 2 or 4 ^{0}F in that time will not affect the comfort or efficiency of the employees but saves some energy.



For buildings considered,

1) Building No. 01 - Ceylon Petroleum Corporation Head Office Building

Energy Consumption without optimum start/stop control	1,048,860 kWh
Energy Consumption with optimum start/stop control	1,013,843 kWh
Reduction in energy consumption	35,017 kWh (3.3 %)

2) Building No. 02 - Peoples Leasing Building Head Office Building

Energy Consumption without optimum start/stop control	490,669 kWh
Energy Consumption with optimum start/stop control	467,621 kWh
Reduction in energy consumption	23,048 kWh (4.7 %)

3) Building No. 03 - Ceylinco Life Insurance Head Office Building.

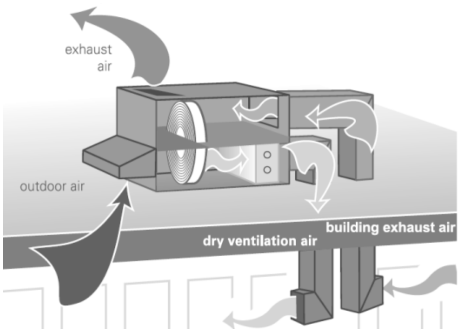
Energy Consumption without optimum start/stop control	374,935 kWh
Energy Consumption with optimum start/stop control	368,036 kWh
Reduction in energy consumption	6,899 kWh (1.8 %)

10.4.8 Energy Recovery

One of the main recoverable energy waste (of the buildings considered) is the exhaust air from the conditioned space which is at 75 ^{0}F (24 ^{0}C) & RH of 55% approximately. This air has been brought to that temperature from average outside temperature of around 84 ^{0}F (29C) and RH around 80-90% by air conditioning equipment by consuming energy (electricity in these buildings).

Since both temperature and relative humidity are changing in the process, enthalpy wheel was considered. While recovering energy, some energy is consumed by the recovery mechanism also for its motors and for balancing of the pressure drop due to added resistance of the recovery equipment.

No hot water is used in these buildings. Therefore, heat recovery for hot water generation cannot be used. Only air-to-air heat recovery can be used.



According to the result from the Trane 700 software,

1) Building No. 01 - Ceylon Petroleum Corporation Head Office Building

Current annual energy consumption	1,048,860 kWh
Annual energy consumption with energy recovery	986,072 kWh
Reduction in annual energy consumption with above energy recovery	62,788 kWh (6.0 %)

2) Building No. 02 - Peoples' Leasing Building Head Office Building

Current annual energy consumption	490,669 kWh
Annual energy consumption with energy recovery	465,387 kWh
Reduction in annual energy consumption with above energy recovery	25,282 kWh (5.2%)

3) Building No. 03 - Ceylinco Life Insurance Head Office Building

Current annual energy consumption	374,935 kWh
Annual energy consumption with energy recovery	360,280 kWh
Reduction in annual energy consumption with above energy recovery	14,655 kWh (3.9%)

10.4.9 Change of HVAC equipment types

In Sri Lanka high rise building are air conditioned using water-cooled and air-cooled packaged units, water-cooled and air-cooled chillers and air-cooled variable refrigerant volume/flow (VRV/VRF) system. Apartment type buildings use split air conditioners.

Peak electricity demand and annual electric energy consumption will depend on the type of equipment used and the system configurations also.

System type and configuration selection may depend on the building application, cooling capacity, water and air quality of the location, availability of spare parts, service agents, past experience of trouble free running etc..

In the area considered, water and air quality has no issues. Therefore, both systems can be used. Service agents are available for almost all air conditioner makes in Sri Lanka. The modeling was done regarding the following systems which are frequently considered by building owners and designers in respect of energy efficiency.

- Centrifugal water-cooled chillers
- Variable Refrigerant Flow units

1) Building No.01 - Ceylon Petroleum Corporation Head Office Building

Equipment Type	Reduction in Peak Demand(Electricity)	Reduction in Annual Energy Consumption
Water Cooled Centrifugal Chiller + Screw Chillers	476-360=116 kW (24.4%)	1,048,860-844,130= kWh (19.6%)
VRF Systems (Cooling Only Type)	476-445= 31 kW (6.5%)	1,048,860-1,002,808= kWh (4.4%)

2) Building No.02 - Peoples Leasing Head Office Building

Equipment Type	Reduction in Peak Demand(Electricity)	Reduction in Annual Energy Consumption
Water Cooled Centrifugal Chiller + Screw Chillers	239-208=31 kW (12.9%)	490,669- 457,013= 33,656 kWh (6.9%)
VRF Systems (Cooling Only Type)	239-265 = -26 kW (-10.9%)	490,669-519,379 = -28,710 kWh (-5.9%)

3) Building No.03 - Ceylinco Life Insurance Head Office Building

Equipment Type	Reduction in Peak Demand(Electricity)	Reduction in Annual Energy Consumption
Water Cooled Centrifugal Chiller + Screw Chillers	183-146= 37kW (20.2%)	374,935- 327,128= 47,807 kWh (12.8%)
VRF Systems(Cooling Only Type)	183-184= -1 kW (-0.5%)	374,935- 386,010=-11,075 kWh (-3.0%)

10.4.10 Lighting System (Day lighting etc.)

Lighting system can be made more efficient by using efficient lamps, luminaries, lighting controls with occupancy sensors, correct lighting arrangement, usage of day-lighting etc. Not only the correct lighting arrangement but also correct HVAC air diffuser locations or the air conditioning system arrangement is not easy in these buildings because table/seating/workstation arrangement and the executive room arrangements are changed depending on the organization's policy/staff changes etc.. It is clearly visible in some locations that diffuser arrangement is similar to an arrangement for a corridor, but interior arrangement has been changed later and now working tables are there and the corridor has been shifted even after the commissioning of the building.

Therefore, only the usage of daylighting is considered here. In Colombo area, nearby tall buildings are obstacles for this method. For the building No. 02, only upper 5 floors were considered for daylight usage through side walls. East west walls can used for solar panels.

While using light, heat gain should also be minimized because it adds additional load to the air conditioning system. This can be accomplished by using heat absorbing/rejecting films on window glass.

In building no.01 and 03, upper 4 floors were used for day-lighting method. When using sun control films, it affects day lighting also because it affects visible transitivity of solar radiation.

1) Building No. 01 - Ceylon Petroleum Corporation Head Office Building

Current annual energy consumption	1,048,860 kWh
Energy consumption with daylighting controls	937,859 kWh
Reduction in annual energy consumption with day lighting control	111,001 kWh (10.6 %)

2) Building No. 02 - Peoples Leasing Head Office Building

Current annual energy consumption	490,669 kWh
Energy consumption with daylighting controls	432,835 kWh
Reduction in annual energy consumption with day lighting control	57,834 kWh (11.7 %)

3) Building No. 03-Ceylinco Life Insurance Head Office Building

Current annual energy consumption	374,935 kWh
Energy consumption with daylighting controls	346,289 kWh
Reduction in annual energy consumption with day lighting control	28,646 kWh (7.6 %)

10.4.11 Usage of renewable energy (Solar Panel)

Usage of available renewable energy should be considered as it is encourage by the government and environmentalist also. In regard to these buildings main such savings/options are usage of solar pv panels and collection and usage of rain water for building usage.

CEB has introduced a net metering system by which the people who produce more energy by solar panels than their own requirement in daytime can supply that excess energy to the national grid. Later they will have savings in their monthly bill and if they have supplied more energy than the value of their monthly bill, CEB will pay them for that excess amount of energy.

For these buildings, the available area for solar pv panels can be considered as side walls facing east and west directions and the roof top area. (Not total area can be used.)

Unit charge of electricity in working hours of these buildings is Rs. 22.70/kWh. CEB pay Rs. 22.00/kWh. Therefore, direct usage of solar electricity is more cost effective in these type of buildings than supplying electricity to CEB through net metering and get reduction in monthly bills later.

Net metering is useful for houses. But for office buildings where major share of electrical energy is used at daytime, it is more economical to use solar electricity directly.

Following is the result of simulation for the selected buildings. Solar panel efficiency was taken as 16%.

1) Building No. 01 - Ceylon Petroleum Corporation Head Office Building

Side wall area of east (75% top 4 floors) = 2685 ft^2
Side wall area of west (75% top 4 floors) = 2685 ft^2
Roof top area = 12,850 ft^2

If 75% of the east wall area is used for solar panels,
Possible energy harvesting per month average = 2,391 kWh
Energy received per unit area = 0.89 kWh/ft^2

If 75% of the west wall area is used for solar panels,
Possible energy harvesting per month average = 2,332 kWh
Energy received per unit area = 0.87 kWh/ft^2

If 75% of the roof area is used for solar panels,

Possible energy harvesting per month average	17,834 kWh
Energy received per unit area	1.388 kWh/ft^2
Possible solar electrical energy as a percentage of monthly energy consumption of the building	18.0 %

2) Building No. 02 - Peoples Leasing Head Office Building

Side wall area of east = 2,000 ft^2
Side wall area of west = 2,000 ft^2

Roof top area = 7,445 ft^2

If 75% of the east area is used for solar panels,

Possible energy harvesting per month average = 1,317 kWh

Energy received per unit area = 0.66 kWh/ft^2

If 75% of the east area is used for solar panels,

Possible energy harvesting per month average = 1,282 kWh

Energy received per unit area = 0.64 kWh/ft^2

If 75% of the roof area is used for solar panels,

Possible energy harvesting per month average	10,325 kWh
Energy received per unit area	1.387 kWh/ft^2
Possible solar electrical energy as a percentage of monthly energy consumption of the building	16.6 %

3) Building No. 03 - Ceylinco Life Insurance Head Office Building

Side wall area of east = 1,313 ft^2

Side wall area of west = 1,313 ft^2

Roof top area = 4,500 ft^2

If 75% of the east area is used for solar panels,

Possible energy harvesting per month average = 1,147 kWh

Energy received per unit area = 0.87 kWh/ft^2

If 75% of the east area is used for solar panels,

Possible energy harvesting per month average = 1,116 kWh

Energy received per unit area = 0.85 kWh/ft^2

If 75% of the roof area is used for solar panels,

Possible energy harvesting per month average	8,313 kWh
Energy received per unit area	1.847 kWh/ft^2
Possible solar electrical energy as a percentage of monthly energy consumption of the building	17.0 %

10.4.12 Thermal Energy Storage

Many buildings in Sri Lanka is not using thermal storage in air conditioning systems including these considered buildings in Colombo.

Mainly, there are two uses of thermal storage. One is to reduce the peak demand by storing energy in chilled water, ice or other phase change material (latent energy) and use it in the peak demand hours to reduce the chiller load and thereby the peak power demand from electricity. Required capacity of the cooling equipment will also be reduced. The other use is to make chilled water or ice in off peak or the time period in which the electricity cost is low and use that ice to make chilled water in the time period when the electricity cost is high (peak time).

To store energy in the form of chilled water it requires a larger volume than ice storage and it is not practical for high rise buildings especially in areas like Colombo where square feet value of land is very high. Therefore, only the ice storage was considered.

Effectiveness of using this method depends mainly on the electricity rate structure of Colombo for office buildings and market value of the floor area.

One of the key problems in this regard is finding space for thermal storage; Ice making chiller, insulated ice tank with ice making equipment etc. because surrounding ground area and below ground area (basement) are used for car parking etc. This is a main reason for resent buildings to have chillers at roof top (to allow space for parking & architectural features at ground level) which were in ground level in old buildings for easy maintenance. The roof top area also is used for entertainment, gathering/party area and related architectural features/utilities in many new buildings. Therefore, the benefit will have to be compared against the floor value of the location.

We can simply consider it as follows. Assume each floor of the building has an area allocated for ice storage and ice height is 7 feet after allowing for insulation, framework, piping and maintenance. (Because one location is not easy to find for large ice/chilled water storage)

According to current rate structure of Ceylon Electricity Board (CEB) in Colombo region, charges are as below (Customer category GP-3)

Time Interval	**Energy Charge/(LKR/kWh)**
Peak(18.30)	25.50
Day(5.30-18.30)	20.70
Off peak(22.30-05.30)	14.35

A 500 Ton centrifugal chiller will make ice at 0.78 kW/Ton and make chilled water at 0.65 kW/Ton (Trane software manual 2008, p66). (This is for relative comparison only).

Cost for making 1 Ton ice at off peak hours = Rs 14.35 x 0.78
= Rs11.19

Cost for making 1 Ton chilled water at day time = Rs 20.70 x 0.65
= Rs 13.46

Profit by using ice thermal storage per day per Ton (neglecting losses) = Rs 2.26

Required floor area = 5.5 ft^2

The floor renting income in this area is around Rs. 70/ft^2/month.
Therefore, income per day by renting = Rs. 2.33

This shows that even without considering the equipment cost, installation cost, maintenance cost, space cost for equipment etc., the usage of ice thermal storage is not economical based on the current rate structure of electricity and the value of the floor area in considered Colombo region.

10.4.13 Using Efficient Equipment and Identified effective BAS features

Efficiency of lighting (available in market) has been improved significantly during the last 5 years with the development of high efficacy LEDs and compact fluorescent lamps. Out of the cooling equipment, centrifugal chillers and VRF systems have gained improvements. Earlier centrifugal chillers were mainly used for above 500 Ton loads. Now centrifugal chiller are available from makes available in Sri Lanka from 120 Ton with efficiency of around 0.5 kW/Ton (default value given by Trace 700 software also for "Centrifugal 2-stage" equipment type. Some makes have advertised 0.478 kW/Ton at full load and 0.296 kW/Ton IPLV). Building no.01 has tested new LED lamps replacing current 2 feet fluorescent lamps in a selected area and they have achieved approximately 0.5 W/ft^2 Lighting Power Density with illuminance of around 300 (280 measured) lux at table level in a sample test done and occupants have not felt any difference than current LPD of 1.45W/ft^2 with around 350 lux. Therefore, let's assume the LPD as 0.5 W/ft^2 as the value for simulation. They have a plan to replace all lamps with the tested lamps. Efficiency of water pumps, Supply fans has not improved in the same manner.

Therefore, assume that the buildings have BASs with features Demand Control Ventilation, VFD condenser water pumps and VFD cooling towers, VFD chilled water pumps, Optimum start/stop control, Air-to-air energy recovery and daylighting system. Consider that only the cooling and lighting equipment are replaced with high efficient centrifugal chillers and high efficacy lamps as previously discussed.

1) Building No.01 - Ceylon Petroleum Corporation Head Office Building

Current annual energy consumption	1,048,860 kWh
Energy consumption with efficient equipment and controls	592,345 kWh
Reduction in annual energy consumption	456,515 kWh (43.5 %)

2) Building No.02 - Peoples Leasing Head Office Building

Current annual energy consumption	490,669 kWh
Energy consumption with efficient equipment and controls	346,364 kWh
Reduction in annual energy consumption	144,305 kWh (29.4%)

3) Building No.03 - Ceylinco Life Insurance Head Office Building

Current annual energy consumption	374,935 kWh
Energy consumption with efficient equipment and controls	288,698 kWh
Reduction in annual energy consumption	86,237 kWh (23.0 %)

Because the cooling demand of this building is less than 120 Ton, centrifugal chiller might not be practical. Therefore, high efficient VRF system can also be considered.

11. RESULTS & DISCUSSION

Results of the study can be summarized in two sections. That is, the result of the verification of compliance of three selected buildings against ASHRAE 90.1-2007 & Code of Practice for Energy Efficient Buildings in Sri Lanka 2008 and the result of the investigation to find out whether there are opportunities to introduce new energy efficiency measures in the buildings considered.

In the verification of the three selected buildings against ASHRAE 90.1-2007 and Code of Practice for Energy Efficient Buildings in Sri Lanka in chapter 8, it was found that none of the buildings complied completely with the building energy codes considered.

However, building no. 02 & 03 performed better in energy consumption than the hypothetical building which satisfies the minimum requirements of ASHRAE 90.1 standard (Budget building) mainly because those buildings have more efficient cooling equipment, less lighting power density than the minimum requirements of ASHRAE standard and because those buildings had integrated central equipment controlling via Building Automation Systems (BAS).

11.1 Identified sections which need to be improved with respect to ASHRAE 90.1-2007 & Code of Practice for Energy Efficient Buildings in Sri Lanka 2008

In the comparison of current condition with the building energy codes following areas had non-conformities to the standards.

Building No.01	Building No.02	Building No.03
• Roof insulation • SHGC of vertical glazing • Building envelop sealing • Equipment control requirements • Hydronic system design & control • System balancing • Efficacy of lamps • Lighting power density	• Roof insulation • SHGC of vertical glazing • Building envelop sealing • Equipment control requirements • Hydronic system design & control • System balancing • Efficacy of lamps	• Roof insulation • SHGC of vertical glazing • Building envelop sealing • Equipment control requirements • Hydronic system design & control • System balancing • Efficacy of lamps

When the building models in software were made comply with ASHRAE 90.1 (if the actual buildings had made so), energy consumption of building No.01-Ceylon Petroleum Corporation was reduced while that of building no. 02 & 03 was increased.

Main reasons for building no 02 & building no 03 to increase energy consumption when complying to ASHRAE 90.1 minimum requirements are

a) They already have more efficient equipment than the minimum code requirement
b) Lighting power density is lower than the maximum allowed level in code
c) U values of building envelop is lower than minimum code requirement except in roof

11.2 Energy savings given by the software model for various configuration options in buildings as percentages

In addition to make the buildings comply with the standards, there are some other system configurations/options which may give more energy efficiency in the buildings. Following are the options/configurations considered in the software model and their possible energy savings predicted by the software.

Table 11.2: Possible Energy Savings by various options/configurations

No	Modification/Option Considered	Percentage Energy Reduction			Already Implemented or Not		
		Building No.01	Building No.02	Building No.03	Building No.01	Building No.02	Building No.03
01	Demand Control Ventilation	3.8%	2.1%	4.9%	No	Yes	Yes
02	Heat rejection films on widow glass	1.1%	0.2%	0.2%	No	No	Yes
03	Chilled water set-point resetting	1.3%	N/A	N/A	No	N/A	N/A
04	VFD Chilled water pumps	2.6%	N/A	N/A	No	N/A	N/A
05	VFD condenser water pumps	N/A	1.9%	2.0%	N/A	Yes	Yes
06	VFD cooling tower & condenser water pump combination	N/A	4.4%	4.6%	N/A	No	No
07	Increasing indoor temperature set-point by 2^0F	1.3%	3.9%	4.8%	No	No	No
08	Optimum start & stop control	3.3%	4.7%	1.8%	No	No	No
09	Energy recovery(Enthalpy wheel)	6.0%	5.2%	3.9%	No	No	No
10	Usage of water-cooled centrifugal chillers	19.6%	6.9%	12.8%	No	No	No
11	Usage of VRF system(Air cooled)	4.4%	-5.9%	-3.0%	No	No	No
12	Usage of daylighting	10.6%	11.7%	7.6%	No	No	No
13	Usage of solar panels (Energy per month/monthly energy consumption). Roof top only	18.0%	16.6%	17.0%	No	No	Yes
14	Thermal energy storage	N/E	N/E	N/E	No	No	No

N/E-Not effective. N/A-Not applicable.

There are a many “No” s in the above summary table. That means there are still more opportunities to improve building energy efficiencies by implementing those methods/options which saves energy as indicated in the table but haven’t been implemented in the considered buildings yet.

11.3 Energy savings by applying the identified methods/options in table 11.2, efficient cooling equipment and low LPD

Even though table 11.2 shows the energy savings by various options, adding those all methods/options in the system will not save efficiency equivalent to the addition of those percentages because implementing one method may affect another equipment to run at low efficiency. For example, raising the chilled-water temperature in variable volume systems increases the efficiency of the chiller, but it will increase the energy consumption of chilled water pumps. However, increasing equipment efficiencies will not affect any other system's efficiencies negatively.

By using centrifugal chillers and low LPD with LED lamps with above options implemented in the model, following result was received.

Building	Energy saving from the current situation
Building No. 01 - Ceylon Petroleum Corporation Head Office Building	43.5%
Building No. 02 - Peoples Leasing Head Office Building	29.4%
Building No. 03 - Ceylinco Life Insurance Head Office Building	23.0%

This seems to be too large values. But it resulted mainly because of increment in the cooling energy efficiencies (from 2.8 COP to 7 COP in building 01, 4.4 COP to 7 COP in building 02& 03), reduction in power for lighting systems (1.45 W/ft2 to 0.5 W/ft^2& 0.9 W/ft^2 & 0.85 W/ft^2 to 0.5 W/ft^2), usage of daylighting which is currently not being used and because of the usage of BAS features which are currently not being used.

11.4 Satisfactory Improvements observed in design and construction of considered buildings regarding energy consumption

Building construction architecture/tradition and the technology of any country varies with time and various requirements of the people and government, economy, new inventions etc. It was noticed that building designers, constructors and the users had special focus/practices as follows. Building envelop performs well relative to the considered standards mainly because of 9" brick outer wall which have been a usual practice for many years in Sri Lanka.

11.4.1 Building Orientation

In all of the three buildings, windows/fenestrations have been put on north walls mainly and only on a limited area in the east and west walls which are directly connected to the conditioned area.

Long side of all selected buildings face north/south directions. This reduces heat coming in through the building envelope and then the energy demand for cooling.

11.4.2 Window area

All the selected buildings have used around 30% of total wall area for windows. This is a good trend compared to old buildings in Sri Lanka. However, none of the buildings have used daylighting systems and those windows were not used for any purpose expected from a window like opening, getting sun light, looking outside etc.. It can be seen by the figures 10.2.1, 10.2.2 and 10.2.3 that window heat is between 15-20% of the total cooling demand of the building. Therefore, if the windows are not used to get day light or any other purpose, the area of windows can be further reduced to save energy.

11.4.3 Energy Efficient Equipment

Cooling equipment of all the selected buildings were performing better than the required level. While the condition is so, maintenance staff of all the buildings were planning to further improving the efficiency, allocating budget for new efficient equipment etc. Building no. 01 has 03 air cooled chillers. They are now planning to install water cooled condensers to the current air cooled chillers or purchase new water cooled chillers and install high efficacy led lamps which will reduce their lighting power density by around 50%.

11.4.5 Control Systems

Though the building no.01 doesn't have a Building Automation System (BAS), they had called proposals for building automation systems. Building no 02 & building no 03 already have installed Building Automation Systems. They are now planning to upgrade those systems to latest ones along with new hardware.

11.4.6 Dedication of the staff

It was seen that the management of the considered buildings have identified the importance of correct decision making in building energy related matters. They have the practice of getting instructions from experts in the subject before implementation of a new method or special repair in addition to the proposals received from the contractors/suppliers. Technical staff had tried some methods manually according to their knowledge like variation of start stop time, temperature set point changing, air duct modification etc. just as simple researches.

11.4.7 Impact of the Regulations

It is true that there should be standards and regulations related to building energy like the two standards/codes considered in this study. Some people may believe that without energy standards/codes it would not be easy to improve the energy efficiency of buildings.

What was seen in this study was somewhat different. Staff of any of the considered buildings did not have a good understanding of any of the energy standards/codes considered here. However, energy performance of building no 02 & building no 03 are better than the minimum requirements of the standards/codes. Building no 01 also may become like that soon because they have also started measures to improve energy efficiency and related consultation. All these buildings have recruited qualified maintenance staff. All these improvements are not because of any influence/force by any standard or regulation. Therefore, improving the knowledge of the related staff of buildings and encouraging building owners to recruit competent/qualified staff may result in much better buildings than enforcing of standards/codes. Therefore, while maintaining the standards/codes as basic guideline, it will be much effective to focus on recruiting competent/qualified staff and improving the knowledge of current staff.

11.4.8 Energy Waste due to infiltration or unnecessary fresh air coming in

Current status of the buildings shows that infiltration (excess fresh air coming in) due to the poor sealing of buildings should get more attention. None of the buildings had paid much attention on this matter. Sometimes entrance swing doors are kept open. Gap between the door and floor/door frame is unnecessarily high, door sealing methods have not been implemented properly. In some locations, even if the door sealing may had done earlier, later when the door was replaced, attention had not been given for sealing. Air is escaped from utility ducts through poorly sealed access doors. Many people including majority of technicians had no idea of the amount of energy waste due to infiltration or unnecessary fresh coming in (fresh air load). Therefore, more attention have to be paid on the issue.

12. CONCLUSIONS

Conclusions can be drawn under two main topics considered in the study. That is, in relation to building energy codes and the availability of opportunities to further improve the energy efficiency of considered category of buildings.

By studying the above three buildings which belong to well reputed companies in Sri Lanka, it is fair to consider that office buildings designed and constructed between 5-10 years ago do not fully comply with the requirements of ASHRAE 90.1-2007 or Code of Practice for Energy Efficient Buildings in Sri Lanka-2008.

Attention given to features like performance of building envelop, cooling equipment efficiencies, building orientation, window to wall ratio are satisfactory. Attitude and dedication of the management and technical staff regarding the energy efficiency of the buildings have been fallen in right direction.

Although, three selected buildings do not satisfy the considered standards/codes in all the aspects in the given compliance paths of those codes, some buildings perform better than the hypothetical building which satisfies the minimum requirements of energy standards/codes considered by using efficient equipment, better performance of envelop and usage of automatic control systems like Building Automations Systems. Therefore, by eliminating found non-compliances alone, these building can be made to perform better with further improved efficiencies.

It was noticed that, it would be more effective to improve the knowledge and attitude of technical staff related to key energy consuming systems in the effort reducing the energy waste.

Although, many measures have been applied to improve energy efficiency of buildings, there are still possible opportunities to improve energy efficiency significantly further as found in this study in relation to the standards/codes and other practical system configurations/options like proper sealing of building envelope, improving shading coefficient of vertical glazing, reducing lighting power density by using high efficacy lamps, usage of day lighting, using automatic controls for air conditioning system equipment and lighting system, using solar energy etc. For all above considered configurations and options, required accessories and components are available to purchase from local dealers. Only the correct planning and decision making are required.

13. REFERENCE LIST

[1] G.V.R. Holeness, Improving Energy Efficiency in existing buildings. ASHRAE journal Vol. 50, January 2008.

[2] K.W. Roth, D. Westphalen, J. Dieckmann, S.D. Hamilton and W. Goetzler , Energy Consumption Characteristics of Commercial Building HVAC systems Volume iii: Energy Savings Potential, Report Prepared by Building Technologies Program, Department of Energy, United States of America, 2002.

[3] New South Wales Government. Office of Environment & Heritage, I am your Optimization Guide, 2015

[4] Sustainable Energy Ireland, HVAC System Optimization Methodology, 2009.

[5] Ceylon Electricity Board, Annual Report, 2013

[6] Sri Lanka Sustainable Energy Authority, Sri Lanka Energy Balance, 2007.

[7] D.T. Claasen, New procedures to reduce cost in HVAC systems. PhD thesis, Potchefstroom Christian University of Higher Education, Potchefstroom, 2003.

[8] D.R. Wulfinghoff, Energy Efficincy Manual, Energy Institute Press,1999.

[9] Carrier Corporation, HVAC System Optimization, 2001.

[10] Jens Laustesen, Energy Efficiency requirements in building codes, energy efficiency policies for new buildings, International Energy Agency, Paris Cedex 15, France, 2008.

[11] LED Academy. (2012). *LED thermal.* Retrieved from LED Academy. Available: http://www.omslighting.com/

[12] Sri Lanka Energy Manager's Association, Journal, Vol 17, 2014.

[13] J.D. Jennings, F.M. Rubinstein, D. DiBartolomeo, & S.L. Blanc, Comparison of control options in private offices in an advanced lighting controls testbed. Journal of the Illuminating Engineering Society, 2000.

[14] M.R. Atif & A.D. Galasiu, Energy performance of daylight-linked automatic lighting control systems in large atrium spaces: Report on two field monitored case studies. Energy and Buildings, 2003.

[15] American Society of Heating Refrigeration and Air Conditioning Engineers, standard 202p, 2012.

[16] AABC Commissioning Group, Washington, AGC Commissioning Guideline for Building Owners, Design Professionals and Commissioning Service Providers, 2005.

[17] The Collaborative for High Performance Schools (2004), Best Practices Manual, volume iv. Available: https://chps.net/best-practices-manual.html

[18] A Student's Guide to Global Climate Change (2018). Available: https://www3.epa.gov/climatechange/kids/solutions/technologies/solar.html

[19] Technical Seminar on Accreditation, Delivering Confidence in the Provision of Energy Organized by Sri Lanka Accreditation Board for Conformity Assessment & Sri Lanka Sustainable Energy Authority, 2014.

[20] National Renewable Energy Laboratory, U.S. Department of Energy, Assessing and Reducing Plug and Process Loads in Office Buildings, 2013.

[21] U.S. Department of Energy, Achieving Energy Savings and Emission Reductions from Building Energy Codes, 2015.

[22] U.S. Energy Information Administration, International Energy Outlook 2016, 2016.

[23] International Energy Agency, World energy outlook 2006, 2006.

[24] United Nations Development Programme, Sri Lanka Rapid Assessment and Gap Analysis, 2012.

[25] Energy Saving Plan for Hong Kong's Built Environment 2015~2025, 2015.

[26] 3M United Kingdom, How Do Sun Control Films Work. Available: https://www.3m.co.uk/3M/en_GB/car-wrapping-uk/resources/faq/how-do-3m-sun-control-films-work/

APPENDIX A: DATA OF BUILDING 01 - CEYLON PETROLEUM CORPORATION HEAD OFFICE BUILDING

Appendix A contains some of the details used for simulation, verification, calculation and other information of the building no.01 (Ceylon Petroleum Corporation Head Office Building) which may be useful to the reader. Data/information/values which were available/used in previous sections of this report have not been repeated here.

Table A.1: Building No. 01 - Main Energy Consuming Equipment Details

NO	ITEM	CAPACITY	QTY	MAKE/MODEL
1	Air cooled chiller	450 kW	3	Carrier/30XA0452
2	Air Handling Unit(01)	72 kW	1	Carrier/3GAJOH34 HL37
3	Air Handling Unit(02)	140 kW	8	Carrier/3GAJOH34 HL99
4	Fan coil unit	10 kW	2	Carrier
5	Fan coil unit	9 kW	7	Carrier
6	Fan coil unit	3.5 kW	2	Carrier
7	Primary chilled water pump	20 l/s @ 11m	4	Grunfoss
8	Secondary chilled water pump set 01(Standby/Running)	35 l/S @ 11m	2	Grunfoss
9	Secondary chilled water pump set 02(Standby/Running)	12 l/s @ 7m	2	Grunfoss
10	Secondary chilled water pump set 03(Standby/Running)	5 l/s @ 10m	2	Grunfoss

Table A.2: Building No.01 - Monthly Energy Consumption Data

MONTH/YEAR	ENERGY CONSUMPTION
Jan/2018	101,000 kWh
May/2018	110,125 kWh
Nov/2018	98,000 kWh

Table A.3: Building No. 01 - Water consumption data

MONTH/YEAR	NO OF UNITS
Oct/2018	1,128 m^3
May/2018	1,237 m^3
Nov/2018	1,145 m^3

Table A.4: Building No. 01 - Building Envelop details

NO	ELEMENT	AREA
01	North walls(total)	9,282 ft^2
02	East walls(total)	8,681 ft^2
03	South walls(total)	15,197 ft^2
04	West walls(total)	2,384 ft^2
05	North windows(total)	2,133 ft^2
06	East windows(total)	3,231 ft^2
07	South windows(total)	4,074 ft^2
08	West windows(total)	1,062 ft^2
09	Partitions(total)	29,189 ft^2
10	Roof(total)	10,206 ft^2
11	Ground floor(conditioned)	5,659 ft^2

The above are not the building total areas but the areas related to envelop of the conditioned space.

Table A.5: Ceylon Petroleum Corporation Building – Building Areas

BUILDING AREAS
By Trane

System	Zone Room	Number of Duplicate Floors	Number of Duplicate Rooms	Floor Area/ Duplicate Room ft²	Total Floor Area ft²	Partition Area ft²	Int Door Area ft²	Exposed Floor Area ft²	Skylight Area ft²	Net Roof Area ft²	Window Area ft²	Window/ Wall %	Ext Door Area ft²	Net Wall Area ft²
Alternative 1														
	7F-Room01CP	1	1	1,830	1,830	388	0	0	0	1,830	639	52	0	580
	7F-Room02CP	1	1	3,000	3,000	913	0	0	0	3,000	420	35	0	768
	7F-Room03CP	1	1	1,585	1,585	350	0	0	0	1,585	303	43	0	410
	7F-Room04CP	1	1	2,600	2,600	895	0	0	0	2,600	180	87	0	26
	7F-Room05CP	1	1	501	501	250	0	0	0	501	45	4	0	1,049
7F-FC					9,516	2,795	0	0	0	9,516	1,587	36	0	2,832
	6F-Room01CP	1	1	1,830	1,830	388	0	0	0	0	639	52	0	580
	6F-Room02CP	1	1	3,000	3,000	913	0	0	0	0	420	35	0	768
	6F-Room03CP	1	1	1,585	1,585	350	0	0	0	0	117	43	0	158
	6F-Room04CP	1	1	2,600	2,600	895	0	0	0	0	180	87	0	26
	6F-Room05CP	1	1	501	501	250	0	0	0	0	45	4	0	1,049
6F-FC					9,516	2,795	0	0	0	0	1,401	35	0	2,580
	5F-Room01CP	1	1	1,830	1,830	388	0	0	0	0	639	52	0	580
	5F-Room02CP	1	1	3,000	3,000	913	0	0	0	0	420	35	0	768
	5F-Room03CP	1	1	1,585	1,585	350	0	0	0	0	303	43	0	410
	5F-Room04CP	1	1	2,600	2,600	895	0	0	0	0	180	87	0	26
	5F-Room05CP	1	1	501	501	250	0	0	0	0	45	4	0	1,049
5F-FC					9,516	2,795	0	0	0	0	1,587	36	0	2,832
	4F-Room01CP	1	1	1,830	1,830	388	0	0	0	0	639	52	0	580
	4F-Room02CP	1	1	3,000	3,000	913	0	0	0	0	420	35	0	768
	4F-Room03CP	1	1	1,585	1,585	350	0	0	0	0	303	43	0	410
	4F-Room04CP	1	1	2,600	2,600	895	0	0	0	0	180	87	0	26
	4F-Room05CP	1	1	501	501	250	0	0	0	0	45	4	0	1,049
4F-FC					9,516	2,795	0	0	0	0	1,587	36	0	2,832
	3F-Room01	1	1	1,830	1,830	388	0	0	0	0	639	52	0	580
	3F-Room02	1	1	3,000	3,000	913	0	0	0	0	420	35	0	768
	3F-Room03	1	1	1,585	1,585	350	0	0	0	0	303	43	0	410
	3F-Room04	1	1	2,600	2,600	895	0	0	0	0	180	87	0	26
	3F-Room05	1	1	501	501	250	0	0	0	0	45	4	0	1,049
3F-FC					9,516	2,795	0	0	0	0	1,587	36	0	2,832
	2F-Room01	1	1	1,400	1,400	388	0	0	0	0	216	38	0	359
	2F-Room02	1	1	2,120	2,120	350	0	0	0	0	432	36	0	768
	2F-Room03	1	1	2,460	2,460	713	0	0	0	0	312	44	0	401
	2F-Room04	1	1	3,050	3,050	876	0	0	0	0	0	0	0	0
	2F-Room05	1	1	2,920	2,920	599	0	0	0	0	0	0	0	1,513

Project Name: CPC Project
Dataset Name: CPC_CURR_SHADCUR.TRC

TRACE® 700 v6.2.4 calculated at 02:36 PM on 03/12/2019
Building Areas Report Page 1 of 2

BUILDING AREAS
By Trane

System	Zone Room	Number of Duplicate Floors	Number of Duplicate Rooms	Floor Area/ Duplicate Room ft²	Total Floor Area ft²	Partition Area ft²	Int Door Area ft²	Exposed Floor Area ft²	Skylight Area ft²	Net Roof Area ft²	Window Area ft²	Window/ Wall %	Ext Door Area ft²	Net Wall Area ft²
2F-FC					11,950	2,925	0	0	0	0	960	24	0	3,040
	1F-Room01	1	1	2,475	2,475	288	0	0	0	0	312	21	0	1,201
	1F-Room02	1	1	2,285	2,285	763	0	0	0	0	432	36	0	781
	1F-Room03	1	1	2,325	2,325	513	0	0	0	0	312	44	0	401
	1F-Romm04	1	1	3,740	3,740	1,389	0	0	0	0	0	0	0	0
	1F-Room05	1	1	2,375	2,375	0	0	0	0	0	0	0	0	838
	1F-Room06	1	1	785	785	499	0	0	0	0	120	14	0	755
1F-FC					13,985	3,450	0	0	0	0	1,176	23	0	3,974
	MZ-Room01	1	1	5,175	5,175	2,530	0	0	0	0	117	17	0	589
	MZ-Room02	1	1	3,370	3,370	600	0	0	0	0	420	34	0	811
	MZ-Room03	1	1	1,975	1,975	836	0	0	0	0	0	0	0	231
	MZ-Room04	1	1	1,595	1,595	0	0	0	0	0	0	0	0	225
	MZ-Room05	1	1	431	431	194	0	0	0	0	24	3	0	882
MZ-FC					12,546	4,160	0	0	0	0	561	17	0	2,739
	GF-Room03	1	1	450	450	194	0	90	0	0	54	6	0	821
	GF-Room01	1	1	4,560	4,560	3,071	0	315	0	0	0	0	0	431
	GF-Room02	1	1	865	865	1,142	0	131	0	0	0	0	0	0
GF-FC					5,875	4,407	0	536	0	0	54	4	0	1,252
	RF	1	1	690	690	880	0	0	0	690	0	0	0	420
RF					690	880	0	0	0	690	0	0	0	420

Total building Window Area: 10,500 ft² **Total building Wall Area: 35,833 ft²** **Building Total Window %: 29.3%**

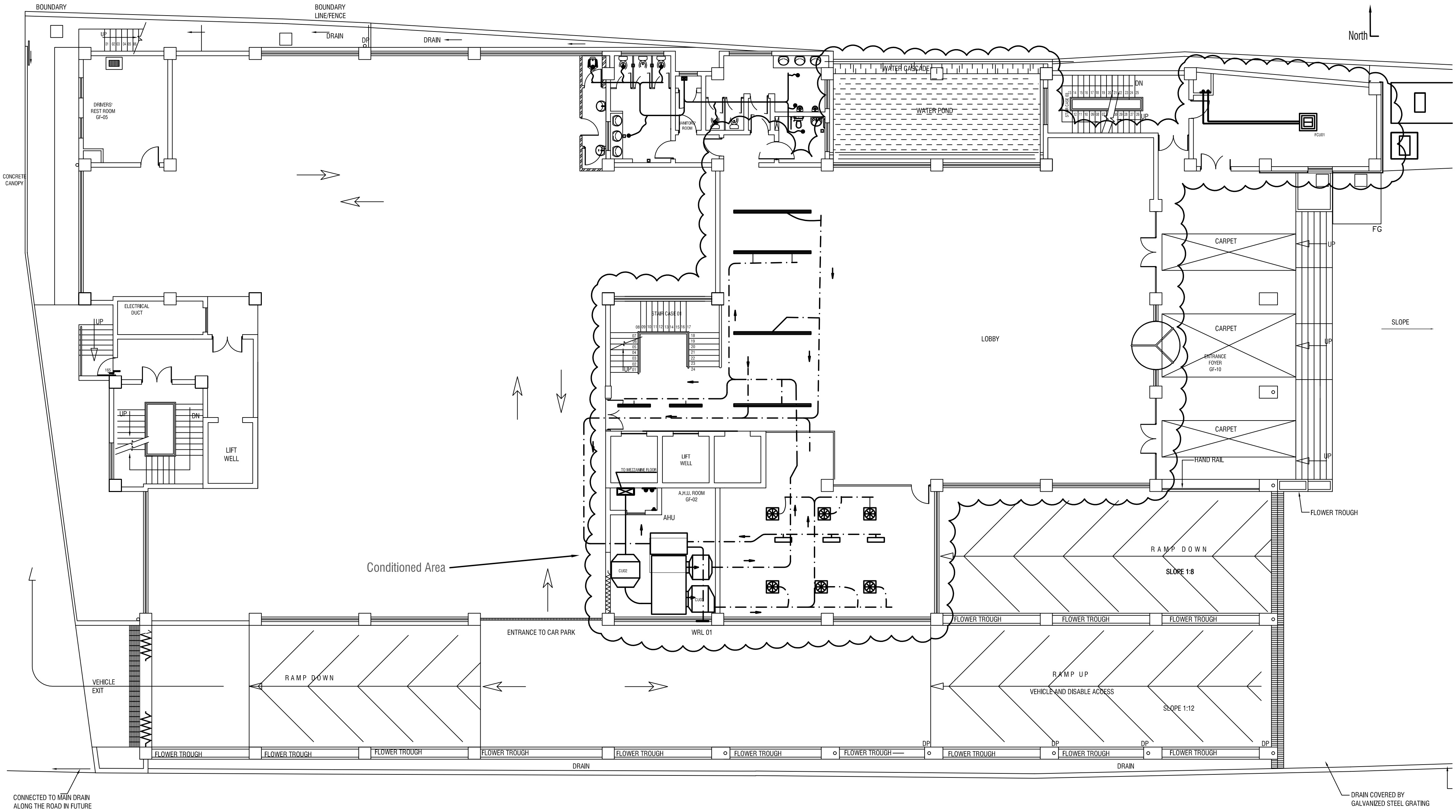


Figure A.1: Ceylon Petroleum Corporation Head Office Building - Ground Floor

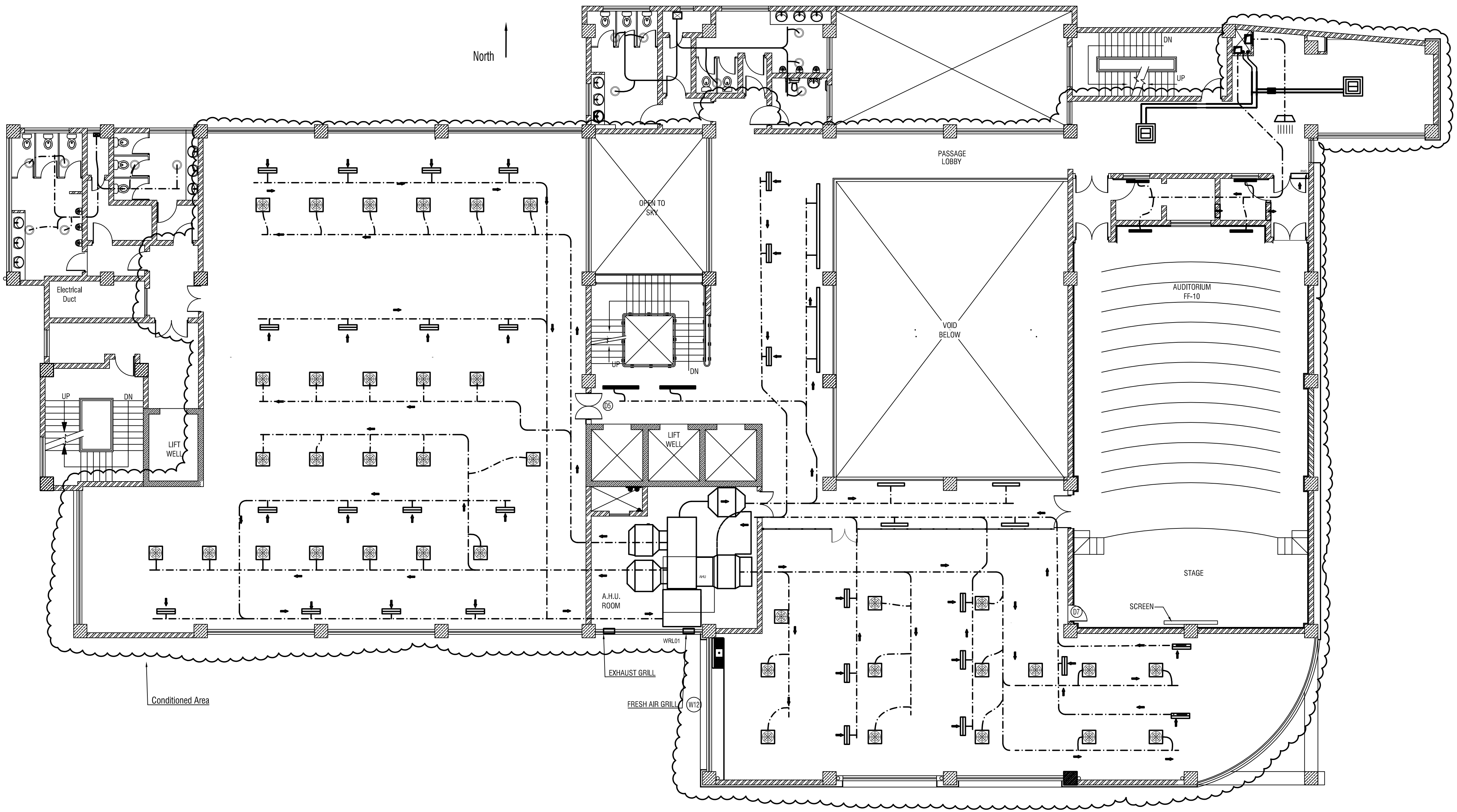


Figure A.2: Ceylon Petroleum Corporation Head Office Building - First Floor

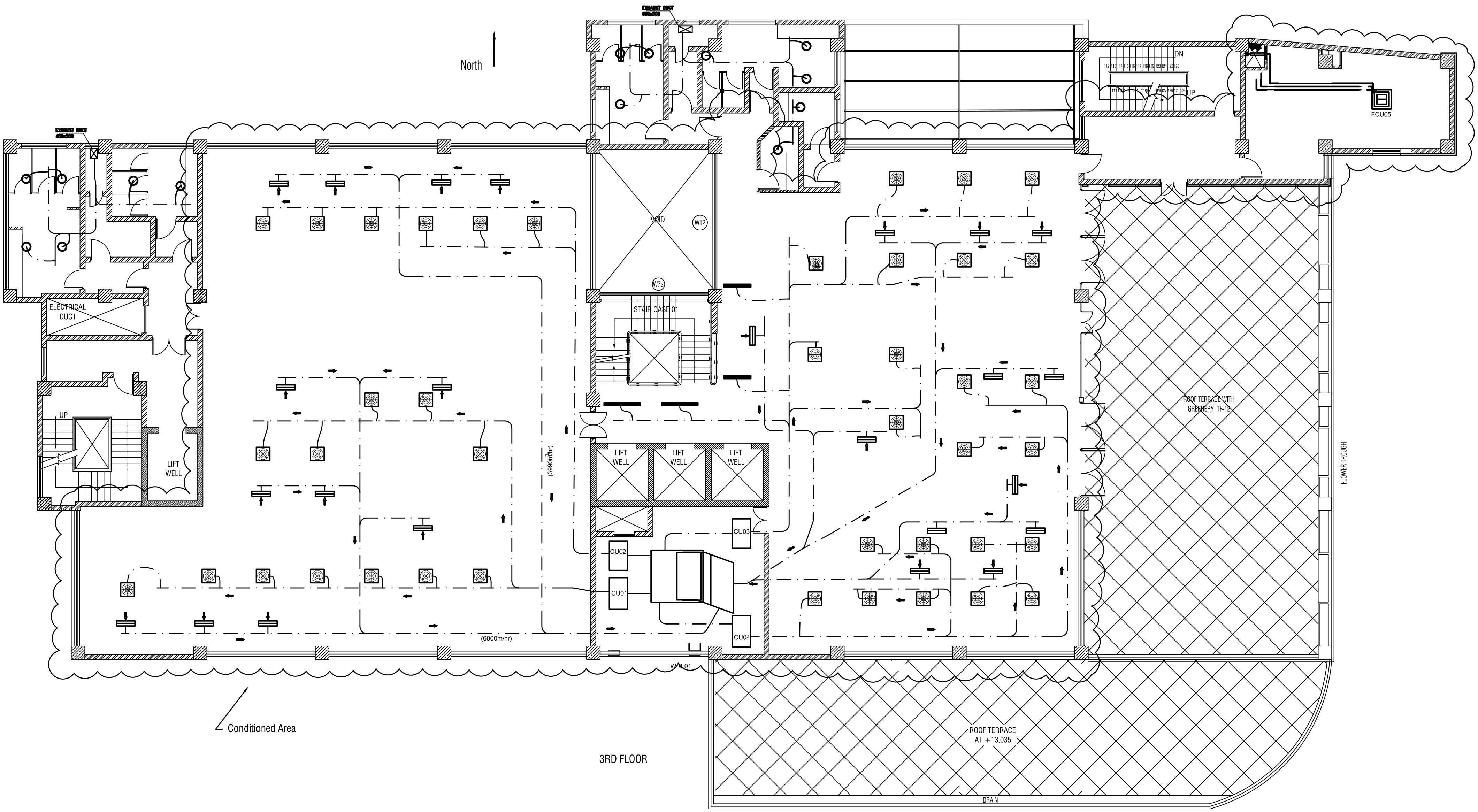


Figure A.3: Ceylon Petroleum Corporation Head Office Building - 2 to 6 Typical Floor

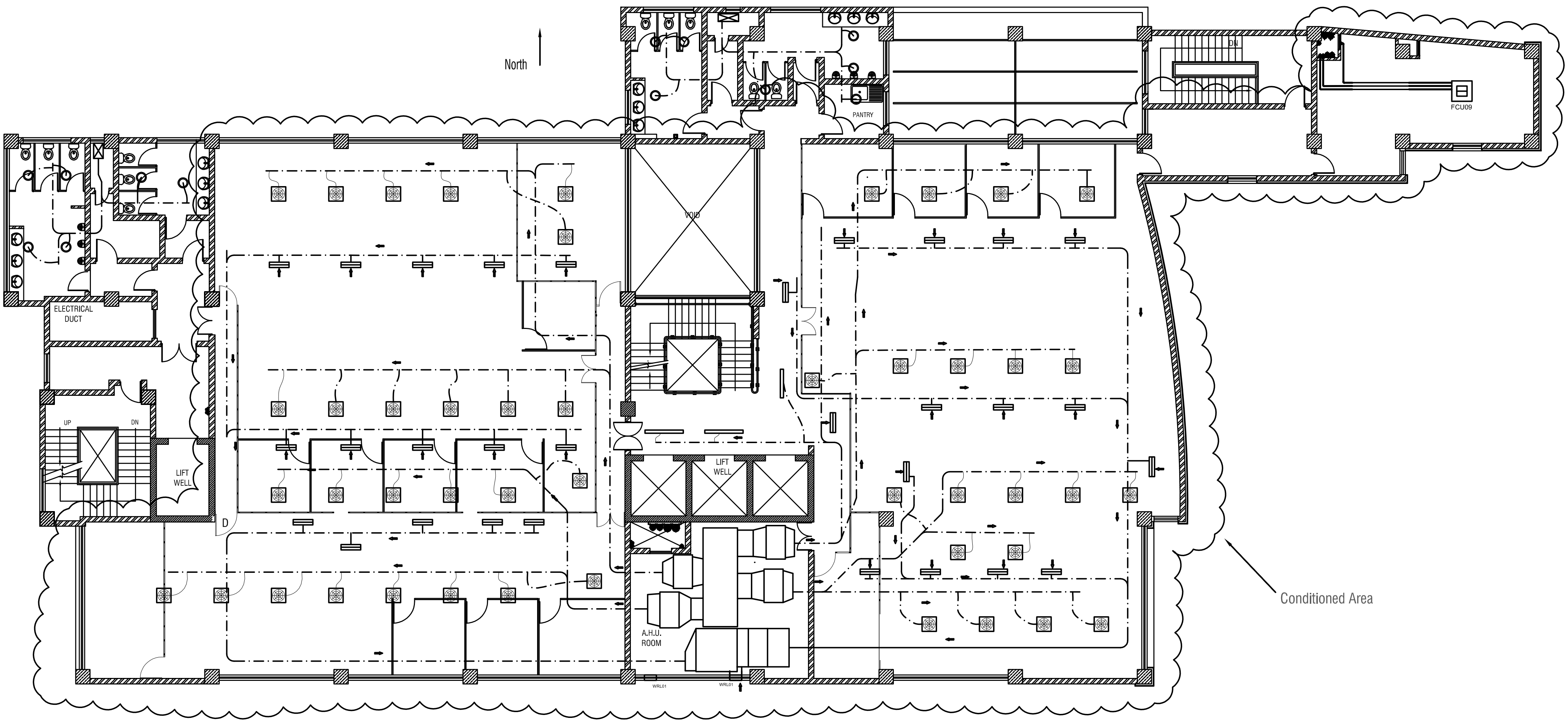


Figure A.4: Ceylon Petroleum Corporation Head Office Building - Seventh Floor

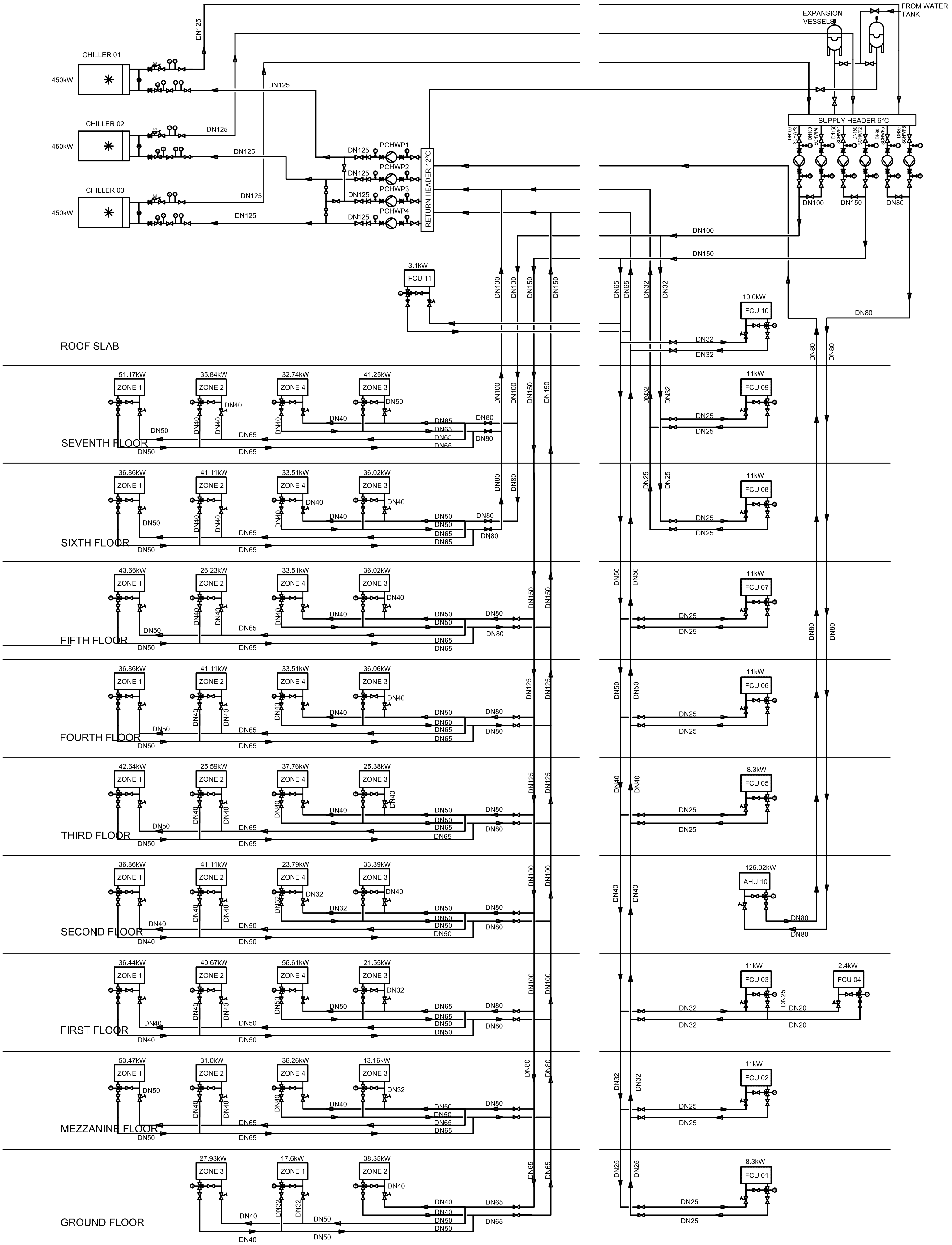


Figure A.5: Ceylon Petroleum Corporation - Schematic Diagram(AC)

APPENDIX B: DATA OF BUILDING 02 - PEOPLES' LEASING BUILDING HEAD OFFICE BUILDING

Appendix B contains some of the details used for simulation, verification, calculation and other information of the building no.02 (Peoples Leasing Property Development Head Office Building) which may be useful to the reader. Data/information/values which were available/used in previous sections of this report have not been repeated here.

Table B.1: Building No. 02 - Equipment Details

NO	EQUIPMENT	CAPACITY	QTY	DETAIL
1	Water-cooled packaged air conditioner 1-3 floors	67.4 kW	3	Mitsubishi/PW-20
2	Water-cooled packaged air conditioner 4-9 floors	98.8 kW	6	Mitsubishi/PW-30
3	Water-cooled packaged air conditioner 10th floor	50.0 kW	1	Mitsubishi/PW-15
4	Counter floor bottle type cooling tower	580 kW	3	Mesan 175
5	Water-cooled ceiling conceiled 1st floor	28.7 kW	2	TEMPERZONE / HWP290
6	Water-cooled ceiling conceiled 10th floor-R01 & R05	9.9 kW	1	TEMPERZONE / HWP96
7	Water-cooled ceiling conceiled 10th floor-R02	11.8 kW	1	TEMPERZONE / HWP117
8	Water-cooled ceiling conceiled 10th floor-R03	13.9 kW	1	TEMPERZONE / HWP139
9	Water-cooled ceiling conceiled 10th floor-R04	18.9 kW	1	TEMPERZONE / HWP190
10	Condenser water pump	1657 l/m@20M	3	Grunfos/NKG125

Table B.2: Building No. 02 - Monthly Energy Consumption Data (1 up to 10 floors)

MONTH/YEAR	ENERGY CONSUMPTION
Sep/2018	47,873 kWh
Oct/2018	50,330 kWh
Nov/2018	48,648 kWh

Above table does not include energy for elevators, cooling towers and condenser water pumps, ground floor car lift, ground & basement power.

Table B.3: Building No. 02 - Monthly water consumption data

MONTH/YEAR	NO OF UNITS
May/2018	957 m^3
June/2018	914 m^3
July/2018	946 m^3

Table B.4: Building No. 02- Building Envelop details

NO	ELEMENT	AREA
01	North walls(total)	14,172 ft2
02	East walls(total)	138 ft2
03	South walls(total)	14,416 ft2
04	West walls(total)	6,127 ft2
05	North windows(total)	6,163 ft2
06	East windows(total)	10,507 ft2
07	South windows(total)	4,344 ft^2
08	West windows(total)	504 ft^2
09	Partitions	21,402 ft^2
10	Roof	4,790 ft^2
11	Ground floor(conditioned)	7,143 ft^2

The above are not the building total areas but the areas related to envelop of the conditioned space.

Table B.5: Peoples Leasing Building – Building Areas

BUILDING AREAS
By Trane

System Zone	Room	Number of Duplicate Floors	Number of Duplicate Rooms	Floor Area/ Duplicate Room ft²	Total Floor Area ft²	Partition Area ft²	Int Door Area ft²	Exposed Floor Area ft²	Skylight Area ft²	Net Roof Area ft²	Window Area ft²	Window/ Wall %	Ext Door Area ft²	Net Wall Area ft²
Alternative 1														
	1FL-RM01	1	1	5,228	5,228	1,564	0	5,228	0	0	883	54	0	743
1FL-PAC					5,228	1,564	0	5,228	0	0	883	54	0	743
	2FL-RM01CP_1FL	1	1	5,228	5,228	1,564	0	0	0	0	883	54	0	743
2FL-PAC					5,228	1,564	0	0	0	0	883	54	0	743
	3FL-RM01CP_1FL	1	1	5,228	5,228	1,564	0	0	0	0	883	54	0	743
3FL-PAC					5,228	1,564	0	0	0	0	883	54	0	743
	4FL-RM01	1	1	5,153	5,153	2,790	0	0	0	0	467	15	0	2,584
4FL-PAC					5,153	2,790	0	0	0	0	467	15	0	2,584
	5FL-RM01	1	1	5,788	5,788	2,334	0	0	0	0	831	23	0	2,857
5FL-PAC					5,788	2,334	0	0	0	0	831	23	0	2,857
	6FL-RM01CP_5FL	1	1	5,788	5,788	2,334	0	0	0	0	831	23	0	2,857
6FL-PAC					5,788	2,334	0	0	0	0	831	23	0	2,857
	7FL-RM01CP_5FL	1	1	5,788	5,788	2,334	0	0	0	0	831	23	0	2,857
7FL-PAC					5,788	2,334	0	0	0	0	831	23	0	2,857
	8FL-RM01CP_5FL	1	1	5,788	5,788	2,334	0	0	0	0	831	23	0	2,857
8FL-PAC					5,788	2,334	0	0	0	0	831	23	0	2,857
	9FL-RM01CP_5FL	1	1	5,788	5,788	2,334	0	0	0	0	831	23	0	2,857
9FL-PAC					5,788	2,334	0	0	0	0	831	23	0	2,857
	10FL-RM01	1	1	650	650	621	0	0	0	650	100	15	0	550
10FL-PAC01					650	621	0	0	0	650	100	15	0	550
	10FL-RM02	1	1	710	710	408	0	0	0	710	46	16	0	242
10FL-PAC02					710	408	0	0	0	710	46	16	0	242
	10FL-RM03	1	1	564	564	0	0	0	0	564	102	31	0	223
10FL-PAC03					564	0	0	0	0	564	102	31	0	223
	10FL-RM04	1	1	420	420	0	0	0	0	420	38	16	0	200
10FL-PAC04					420	0	0	0	0	420	38	16	0	200
	10FL-RM05	1	1	1,759	1,759	1,510	0	0	0	1,759	106	6	0	1,657
10FL-PAC05					1,759	1,510	0	0	0	1,759	106	6	0	1,657
	1FL-RM02	1	1	1,915	1,915	225	0	1,915	0	0	1,108	74	0	393
1FL-PAC02					1,915	225	0	1,915	0	0	1,108	74	0	393
	2FL-RM02CP_1FL	1	1	1,915	1,915	225	0	0	0	0	1,108	74	0	393
	3FL-RM02CP_1FL	1	1	1,915	1,915	225	0	0	0	0	1,108	74	0	393
3FL-PAC02					3,830	450	0	0	0	0	2,215	74	0	785
	10FL-RM06	1	1	409	409	0	0	0	0	409	0	0	0	325
10FL-PAC06					409	0	0	0	0	409	0	0	0	325

BUILDING AREAS
By Trane

System	Zone	Room	Number of Duplicate Floors	Number of Duplicate Rooms	Floor Area/ Duplicate Room ft²	Total Floor Area ft²	Partition Area ft²	Int Door Area ft²	Exposed Floor Area ft²	Skylight Area ft²	Net Roof Area ft²	Window Area ft²	Window/ Wall %	Ext Door Area ft²	Net Wall Area ft²
		MA_RM	1	1	3	3	275	0	0	0	3	24	6	24	361
MA_RM						3	275	0	0	0	3	24	6	24	361

Total building Window Area: 11,008 ft² **Total building Wall Area: 34,835 ft²** **Building Total Window %: 31.6%**

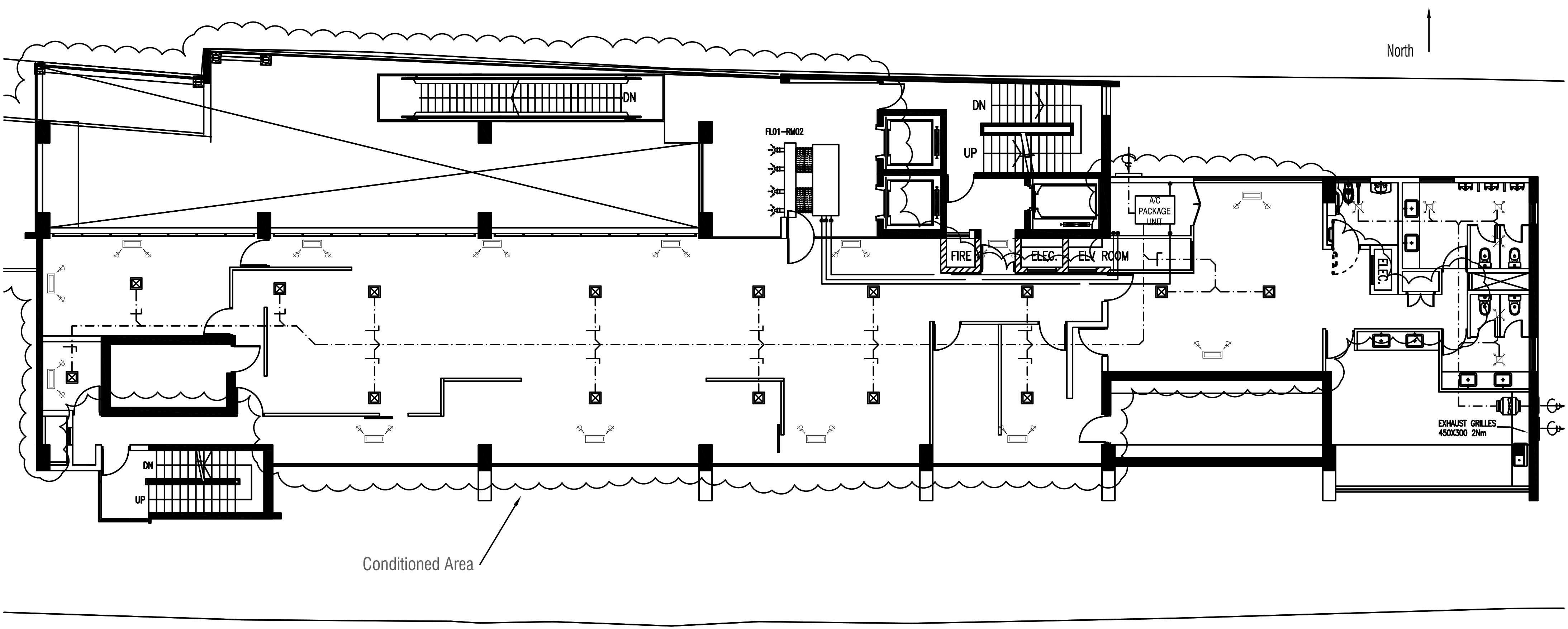


Figure B.1: Peoples Leasing Building – 1 to 3 Typical Floor

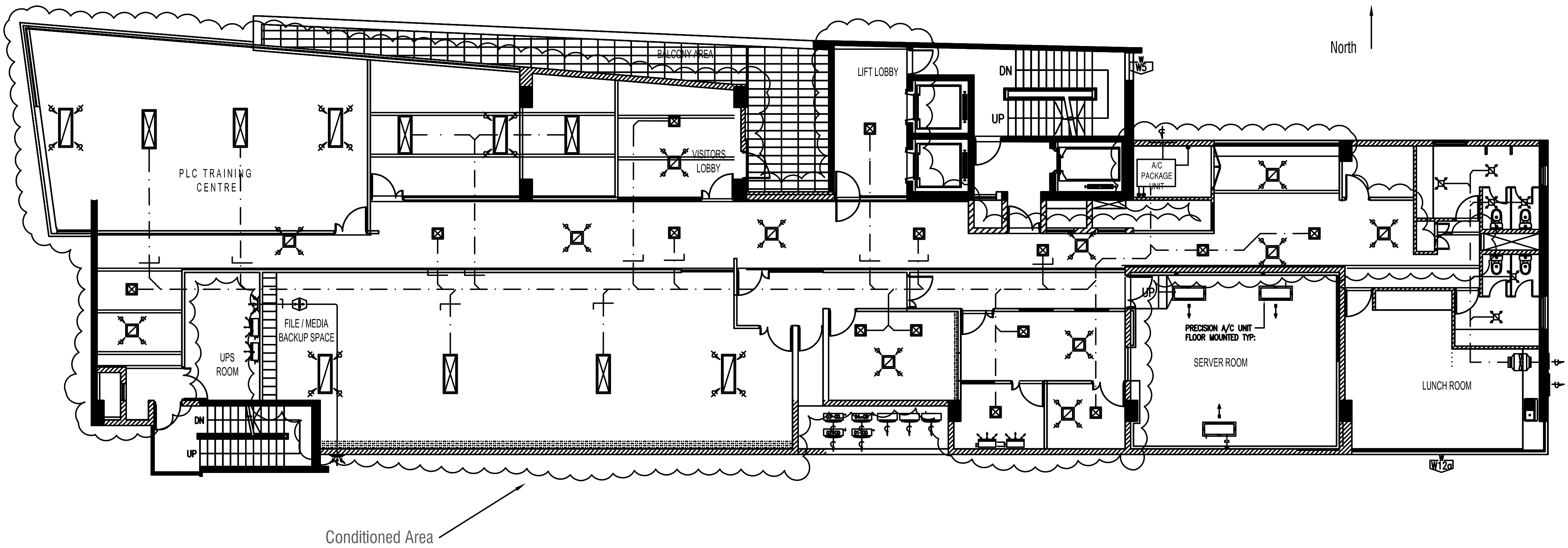


Figure B.2: Peoples Leasing Building – Fourth Floor

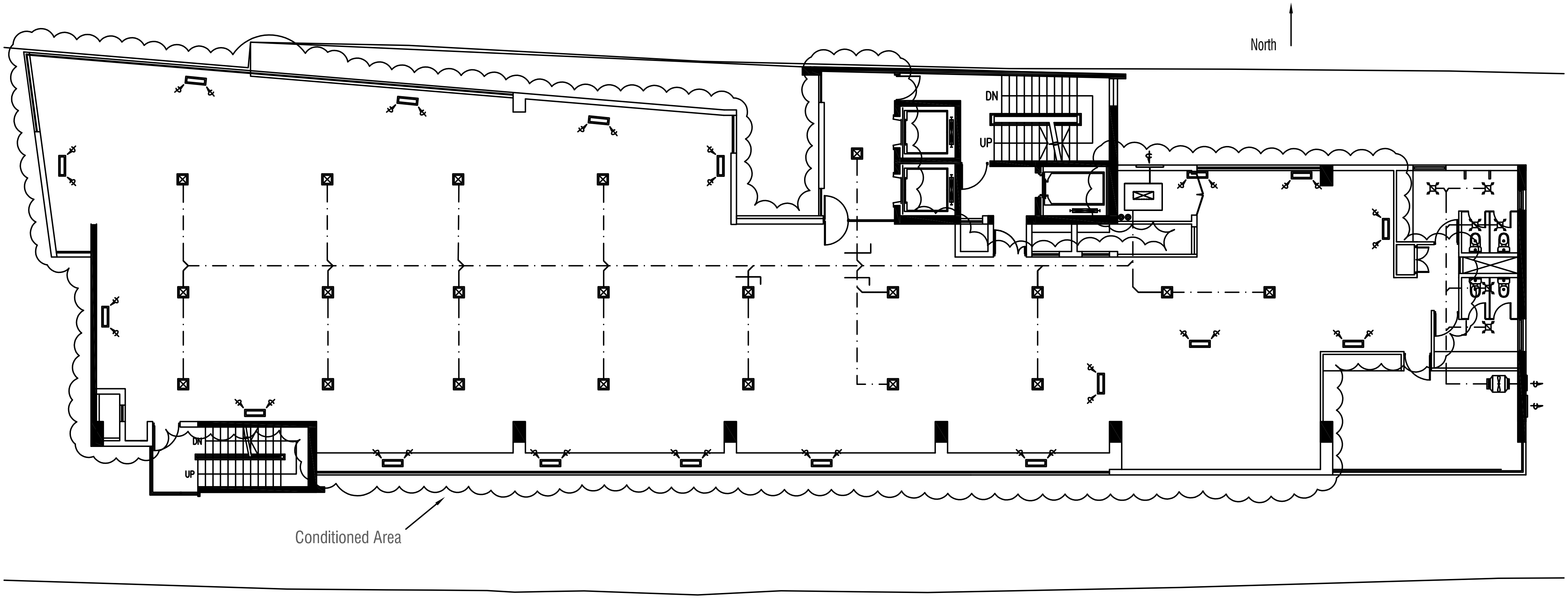


Figure B.3: Peoples Leasing Building – 5 to 9 Typical Floor

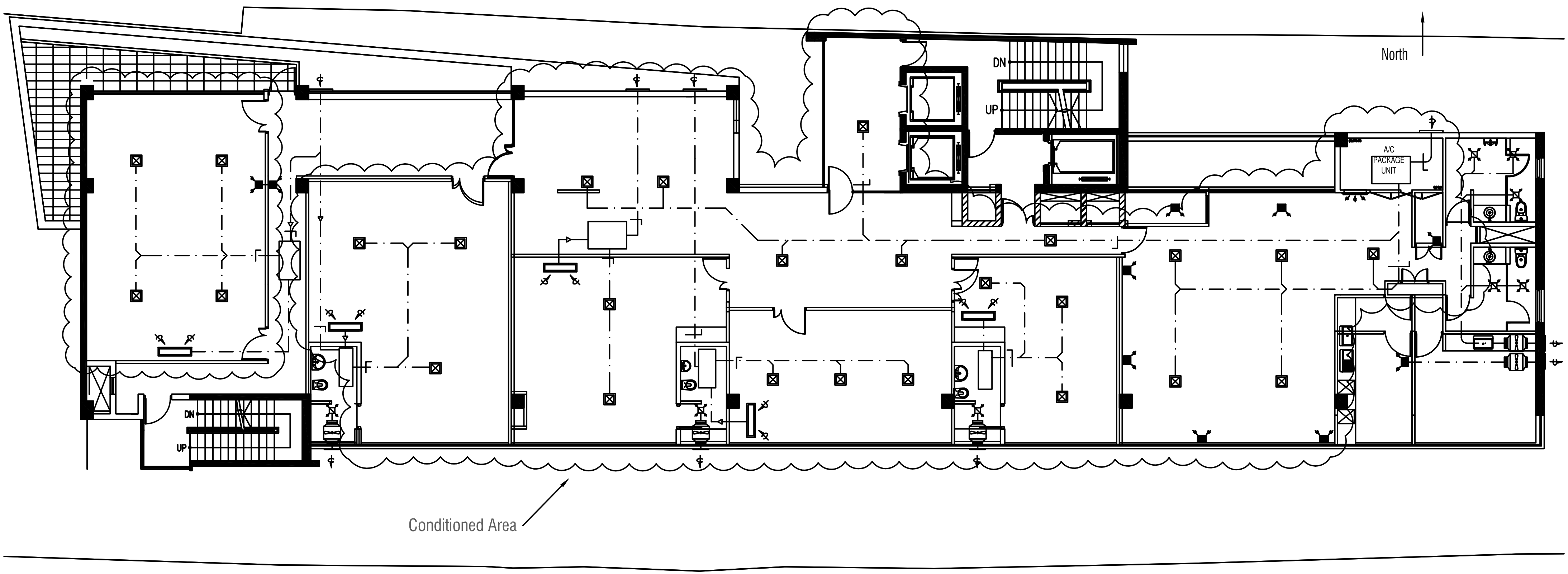


Figure B.4: Peoples Leasing Building – Tenth Floor

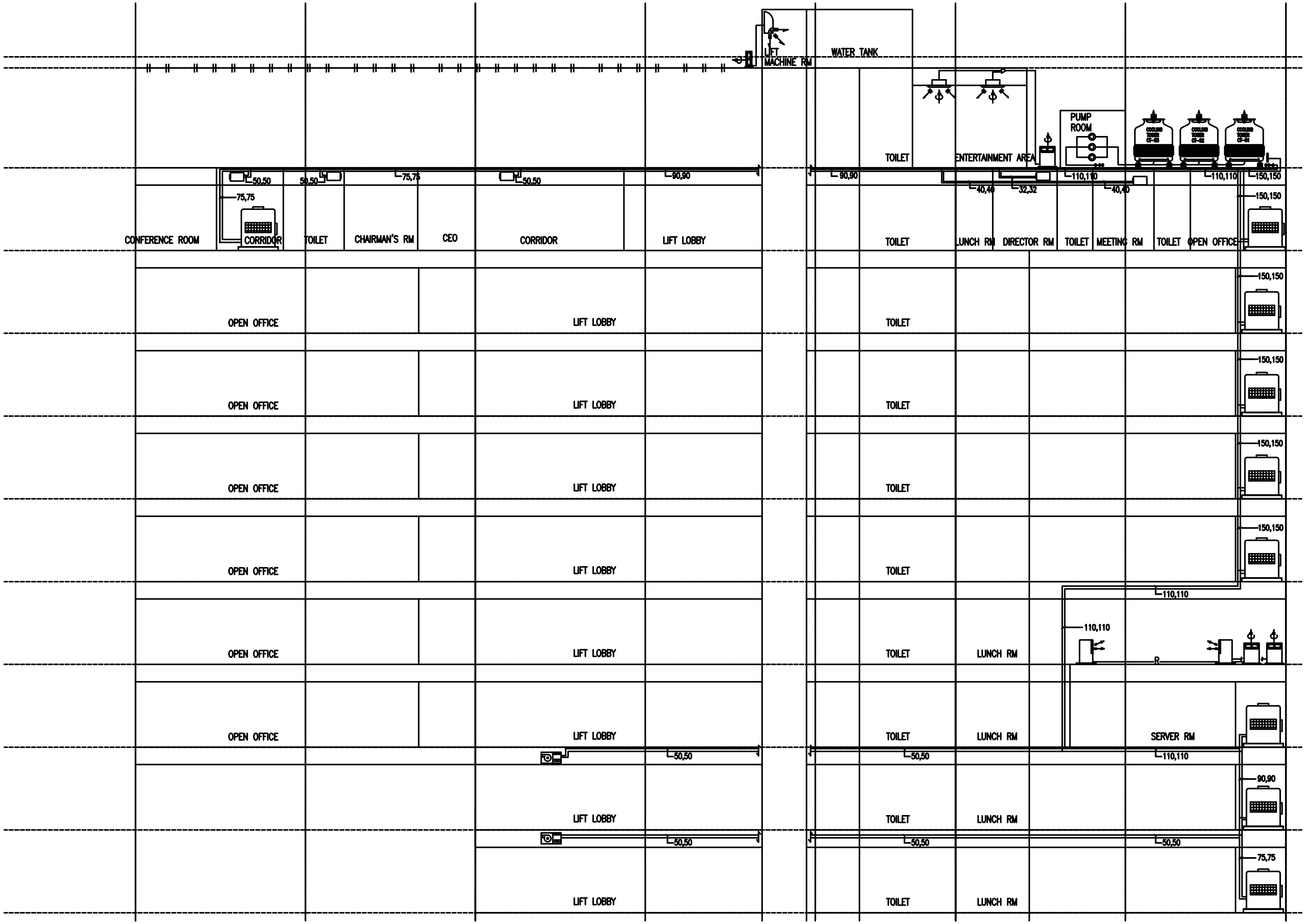


Figure B.5: Peoples Leasing Building – Schematic Diagram(AC)

APPENDIX C: DATA OF BUILDING 03 - CEYLINCO LIFE INSURANCE HEAD OFFICE BUILDING

Appendix C contains some of the details used for simulation, verification, calculation and other information of the building no.03 (Ceylinco Life Insurance Head Office Building) which may be useful to the reader. Data/information/values which were available/used in previous sections of this report have not been repeated here.

Table C.1: Building No. 03 - Equipment Details

NO	ITEM	CAPACITY	QTY	MAKE/MODEL
1	Water cooled packaged air conditioner L1,L3,L4	33 kW	6	HITACHI/RP-10WL5
2	Water cooled packaged air conditioner L2	45 kW	1	HITACHI/RP-15WL5
3	Water cooled packaged air conditioner L5 & L6	28 kW	4	HITACHI/RP-10WL5
4	Water cooled packaged air conditioner L7	15 kW	1	HITACHI/RP-5WL5
5	Water cooled packaged air conditioner L7	20 kW	1	HITACHI/RP-8WL5
7	Water cooled packaged air conditioner L7	33 kW	1	HITACHI/RP-10WL5
8	Ceiling concealed water cooled ducted	5.3 kW	1	-
9	Ceiling concealed water cooled ducted	8.2 kW	1	-
10	Water cooled packaged air conditioner L8 & L8M	41 kW	2	HITACHI/RP-10WL5
11	Water cooled packaged air conditioner L8M	68 kW	1	HITACHI/RP-20WL5
12	Water cooled packaged air conditioner L8M	24 kW	1	HITACHI/RP-8WL6

Table C.2: Building No. 03 - Monthly Energy Consumption Data

MONTH/YEAR	ENERGY CONSUMPTION
Jan/2019	34,950 kWh
Dec/2018	32,680 kWh
Sep/2017	30,770 kWh

Table C.3: Building No. 03 - Monthly water consumption data

MONTH/YEAR	NO OF UNITS
Feb/2018	330 m^3
Apr/2018	271 m^3
Nov/2018	325 m^3

Table C.4: Building No. 03 - Building Envelop details

NO	ELEMENT	AREA
01	North walls(total)	11,227 ft2
02	East walls(total)	2,771 ft2
03	South walls(total)	3,301 ft2
04	West walls(total)	4,424 ft2
05	North windows(total)	2,657 ft2
06	East windows(total)	678 ft2
07	South windows(total)	307 ft^2
08	West windows(total)	1,833 ft^2
09	Partitions	10,668 ft^2
10	Roof	4,738 ft^2
11	Ground floor(conditioned)	3,035 ft^2

The above are not the building total areas but the areas related to envelop of the conditioned space.

Table C.5: Ceylinco Life Insurance Building – Building Areas

BUILDING AREAS
By Trane

System	Zone Room	Number of Duplicate Floors	Number of Duplicate Rooms	Floor Area/ Duplicate Room ft²	Total Floor Area ft²	Partition Area ft²	Int Door Area ft²	Exposed Floor Area ft²	Skylight Area ft²	Net Roof Area ft²	Window Area ft²	Window/ Wall %	Ext Door Area ft²	Net Wall Area ft²
Alternative 1														
	1FL-RM01	1	1	4,110	4,110	1,239	0	3,035	0	0	575	25	0	1,719
1FL-PAC01					4,110	1,239	0	3,035	0	0	575	25	0	1,719
	2FL-RM01_CPnEDI_1FL	1	1	3,431	3,431	1,322	0	0	0	0	454	20	0	1,851
2FL-PAC01					3,431	1,322	0	0	0	0	454	20	0	1,851
	3FL-RM01_CP_1FL	1	1	4,110	4,110	1,239	0	0	0	0	575	25	0	1,719
3FL-PAC01					4,110	1,239	0	0	0	0	575	25	0	1,719
	4FL-RM01_CP_1FL	1	1	4,110	4,110	1,239	0	0	0	0	575	25	0	1,719
4FL-PAC01					4,110	1,239	0	0	0	0	575	25	0	1,719
	5FL-RM01	1	1	4,486	4,486	1,134	0	0	0	0	591	22	0	2,040
5FL-PAC01					4,486	1,134	0	0	0	0	591	22	0	2,040
	6FL-RM01_CP_5FL	1	1	4,486	4,486	1,134	0	0	0	0	591	22	0	2,040
6FL-PAC01					4,486	1,134	0	0	0	0	591	22	0	2,040
	7FL-RM01	1	1	1,237	1,237	0	0	0	0	0	76	10	0	691
7FL-PAC01					1,237	0	0	0	0	0	76	10	0	691
	7FL-RM02	1	1	385	385	0	0	0	0	0	39	15	0	224
7FL-PAC02					385	0	0	0	0	0	39	15	0	224
	7FL-RM03	1	1	384	384	0	0	0	0	0	110	42	0	152
7FL-PAC03					384	0	0	0	0	0	110	42	0	152
	7FL-RM04	1	1	2,287	2,287	424	0	0	0	0	223	37	0	376
7FL-PAC04					2,287	424	0	0	0	0	223	37	0	376
	7FL-RM05	1	1	678	678	242	0	0	0	0	0	0	0	336
7FL-PAC05					678	242	0	0	0	0	0	0	0	336
	8FL AUDI-RM02	1	1	1,166	1,166	273	0	0	0	0	667	65	0	352
8FL AUDI-PAC02					1,166	273	0	0	0	0	667	65	0	352
	8FL AUDI-RM01	1	1	1,027	1,027	914	0	0	0	0	187	40	0	285
	8FL MEZ-RM01	1	1	522	522	559	0	0	0	522	56	22	0	196
8FL MEZ-PAC01					1,549	1,473	0	0	0	522	243	34	0	482
	8FL MEZ-RM02	1	1	1,226	1,226	273	0	0	0	1,226	672	66	0	352
8FL MEZ-PAC02					1,226	273	0	0	0	1,226	672	66	0	352
	8FL-AUDI	1	1	2,410	2,410	672	0	0	0	2,410	84	4	0	2,184
8FL AUDI-PAC					2,410	672	0	0	0	2,410	84	4	0	2,184
	RF	1	1	550	550	0	0	0	0	550	0	0	0	0
RF					550	0	0	0	0	550	0	0	0	0

BUILDING AREAS

By Trane

System Zone Room	Number of Duplicate Floors	Number of Duplicate Rooms	Floor Area/ Duplicate Room ft²	Total Floor Area ft²	Partition Area ft²	Int Door Area ft²	Exposed Floor Area ft²	Skylight Area ft²	Net Roof Area ft²	Window Area ft²	Window/ Wall %	Ext Door Area ft²	Net Wall Area ft²

Total building Window Area: 5,474 ft² **Total building Wall Area: 21,709 ft²** **Building Total Window %: 25.2%**

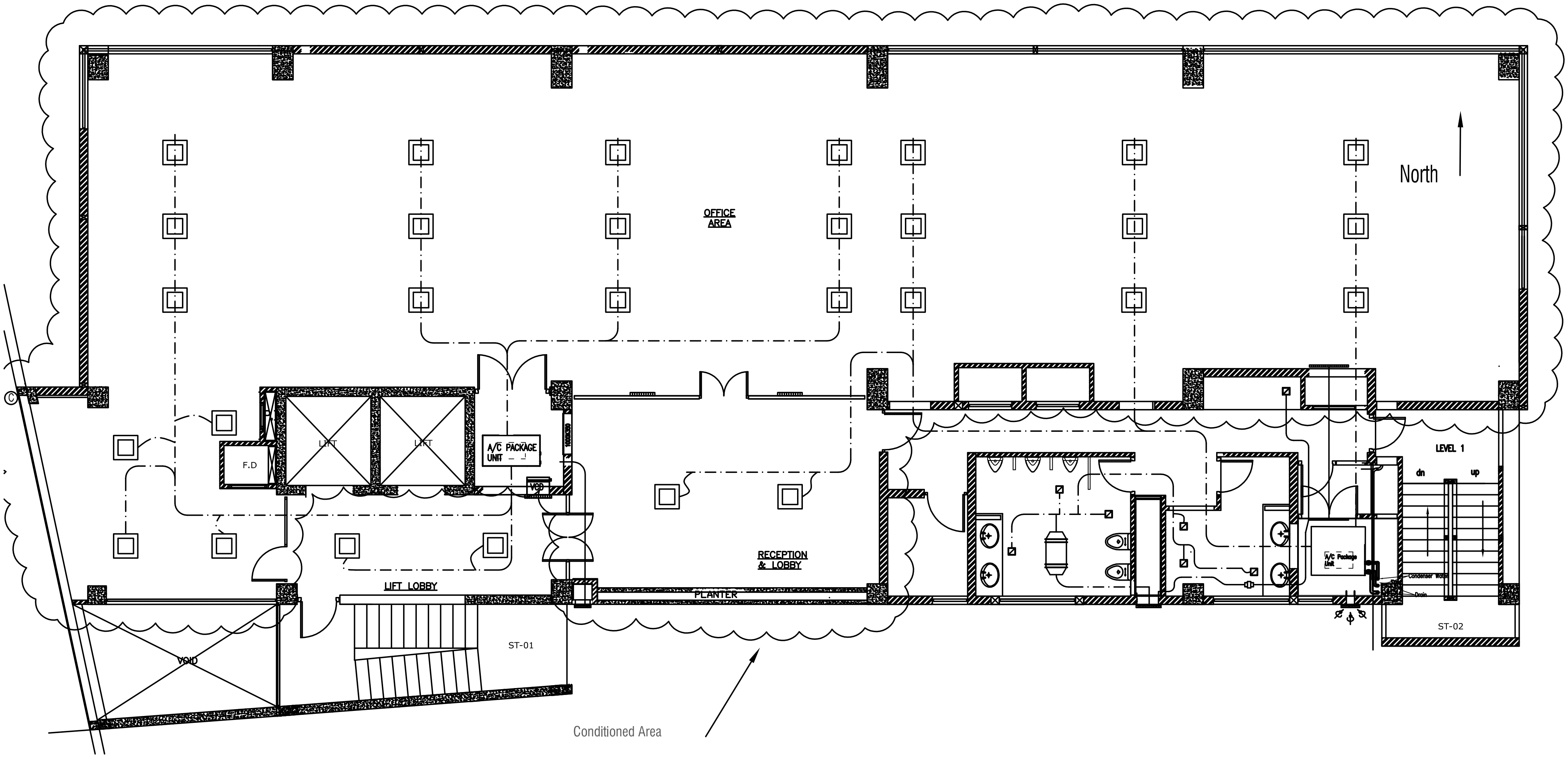


Figure C.1: Ceylinco Life Insurance Building - 1 to 6 Typical Floor

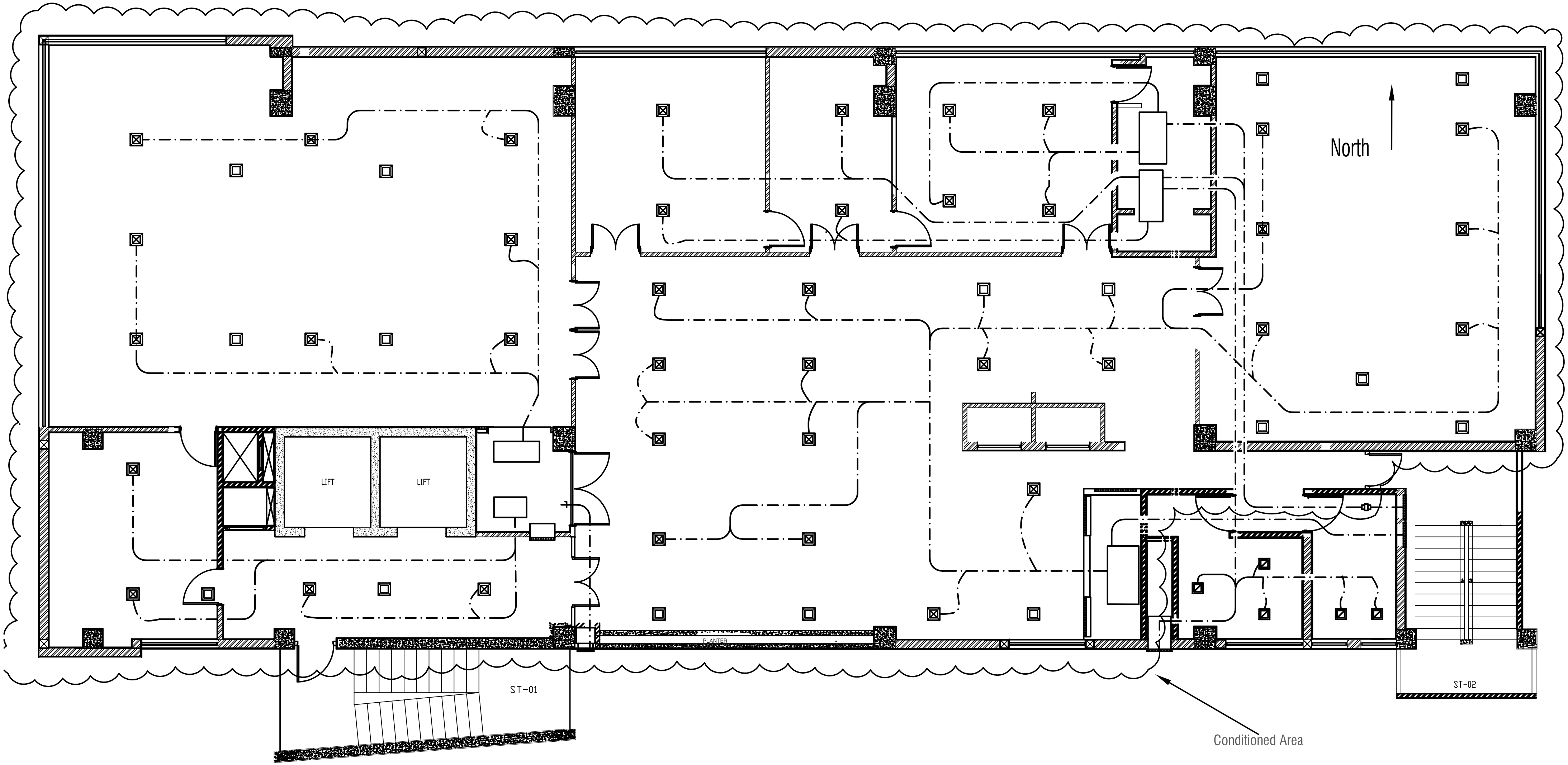


Figure C.2: Ceylinco Life Insurance Building - Seventh Floor

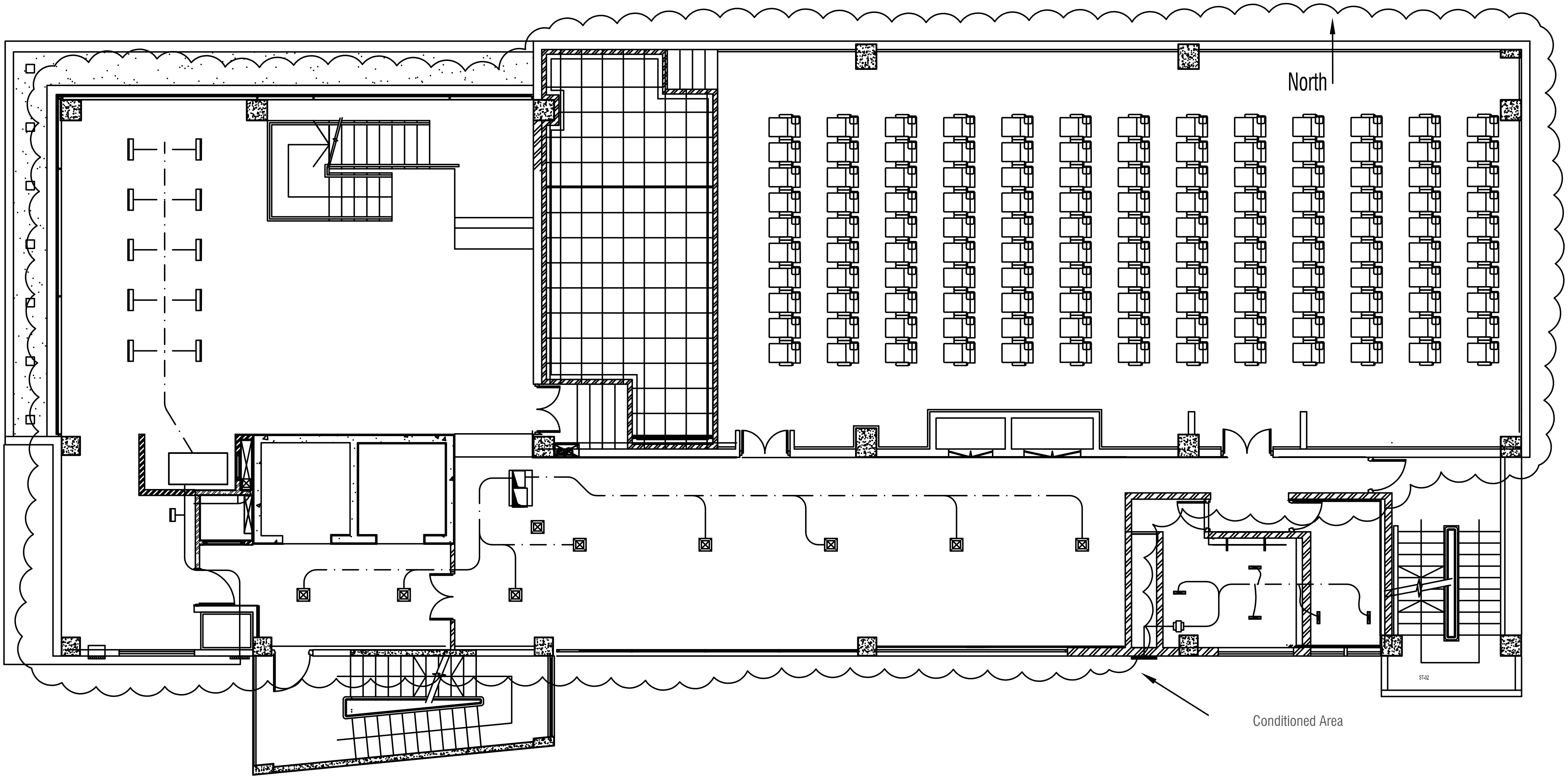


Figure C.3: Ceylinco Life Insurance Building - Eighth Floor

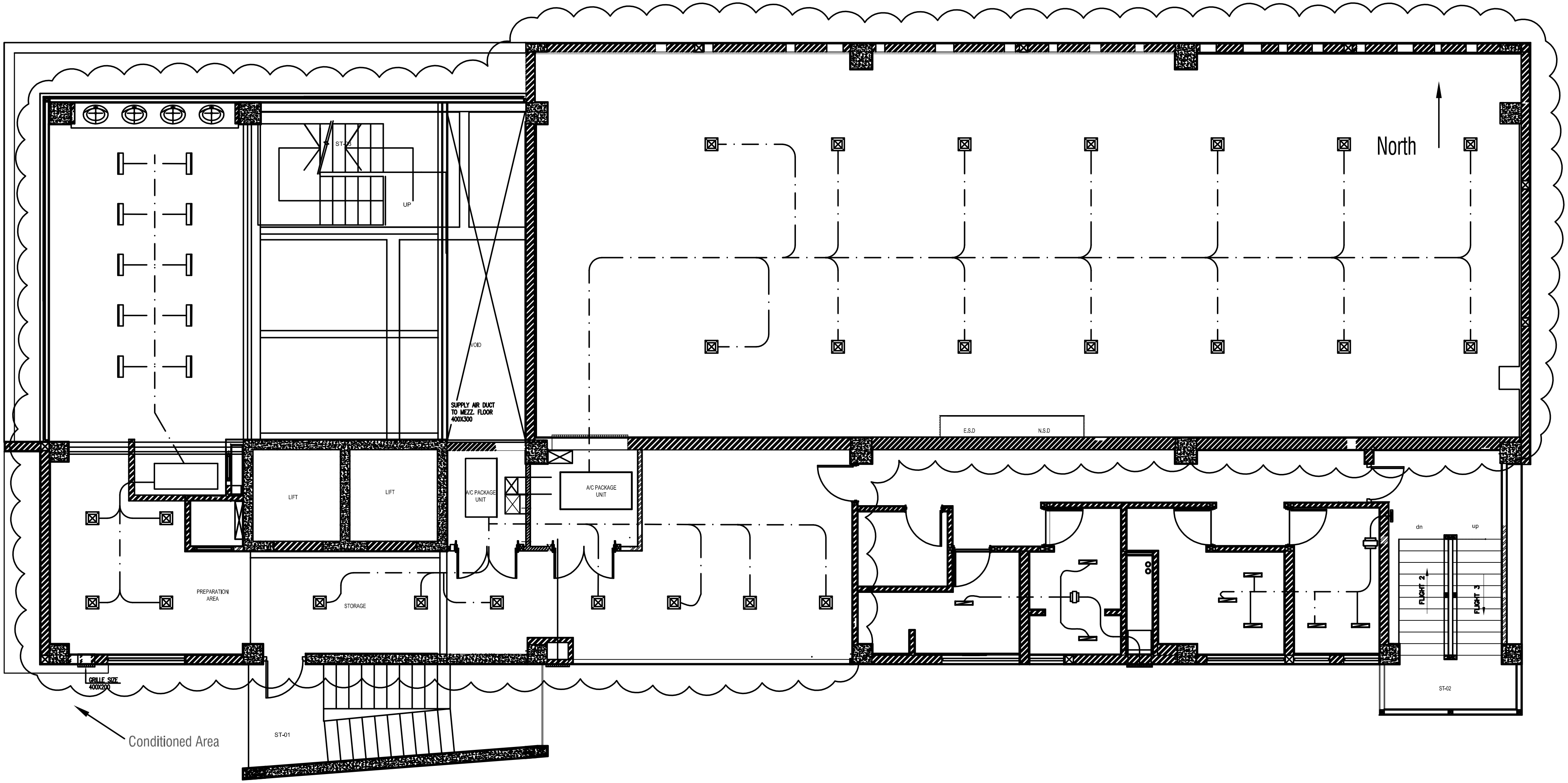


Figure C.4: Ceylinco Life Insurance Building - Eighth Mezzanine Floor

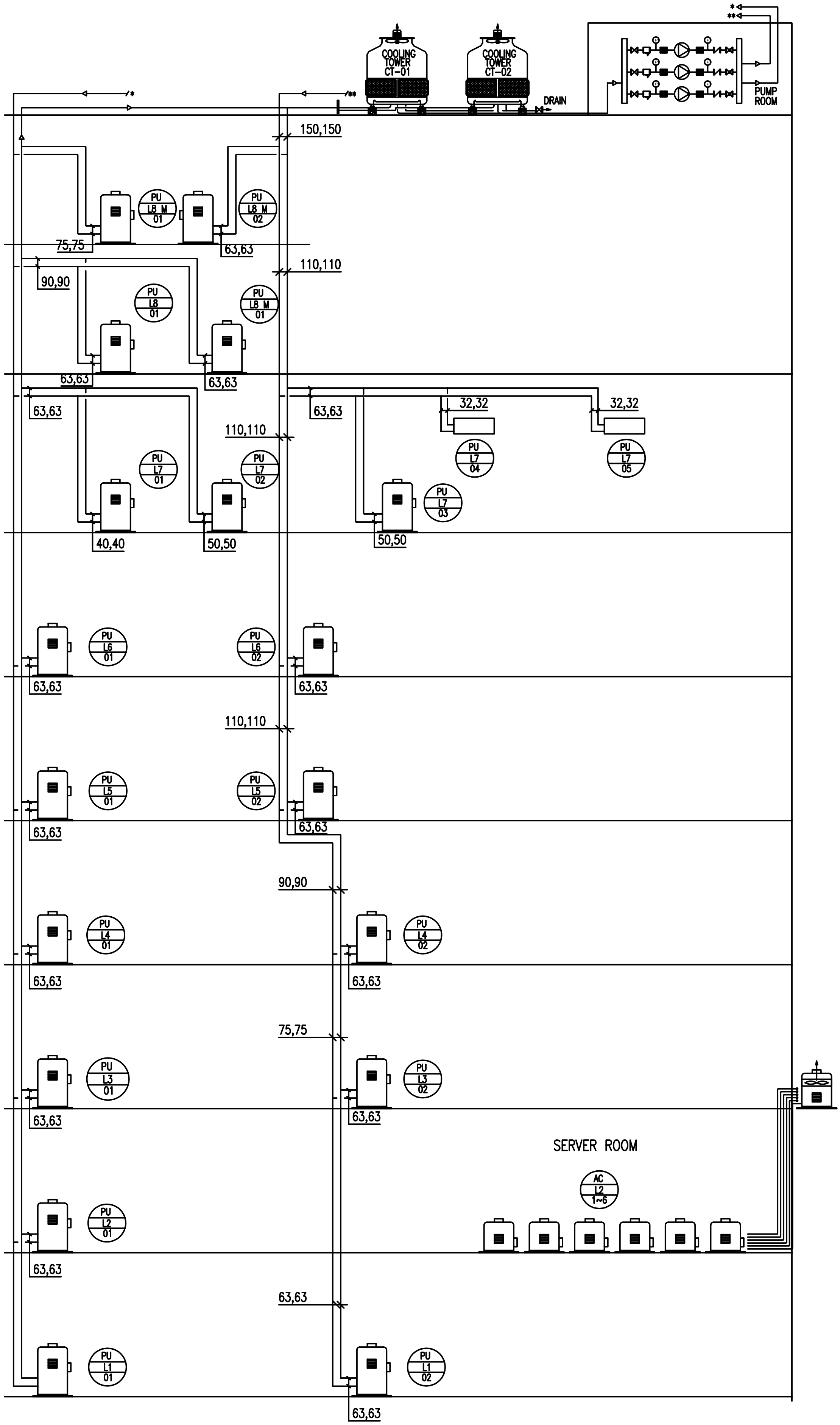


Figure C.5: Ceylinco Life Insurance Building - Schematic Diagram(AC)

APPENDIX D: MODEL INPUT DATA

Following are the features/values/options selected to simulate the effect of each modification to the building models. Other options/inputs were kept as they were (as given by the Trace 700 software).

1. Demand Control Ventilation (DCV)

PARAMETER	VALUE/SELECTION
CO_2 Sensor Location	Room
System ventilation flag	"ASHRAE Std 62.1-2004/2007 w/ Vent Rest"
ASHRAE Std 62.1-2004/2007 people averaging	No
ASHRAE Std 62.1 max vent ratio	Blank (as per software)
CO_2 based DCV	Single set point
System Category	Variable volume
System Type	VAV w/baseboard heating
Outside CO_2 concentration	400 ppm

2. Usage of heat rejection films on glass

A new internal shading was created using the sample given with properties of the heat rejection film used as below

PARAMETER	VALUE
Overall summer U-value	0.95 BTU/h.ft^2.^{0}F
Overall shading coefficient	0.39
Overall visible transmissivity	0.42
Inside visible reflectivity	0.15
Overall solar transmissivity	0.20
Inside solar reflectivity	0.15
Inside long wave emissivity	0.90

Then this was applied to each window as an internal shading.

3. Chilled water set point resetting

There is an option in the cooling equipment controls section to input the value if the chilled water resetting technique is to be simulated. By default this option is not applied and the value is 0. For this simulation the value was set to 5^0F.

4. Using VFD chilled water pumps

"Var vol chill water pump" was selected as the primary chilled water pump type. Full load energy 0.000536 kW/ton-ft wg. Control type-"with equipment".

PARAMETER	VALUE/SELECTION
Full load energy	0.000536 kW/ton-ft wg
Control type	" with equipment"
Unloading curve	"Variable vol. Chilled Water Pump

5. Increasing indoor (room) temperature set-point by 2^0F (1^0C)

To simulate this dry bulb temperature set point of all thermostat templates created were increase by 2^0F. Cooling drift point was set to 77 ^{0}F. Heating dry bulb temperature and drift point were left unchanged at 70^0F and 64^0F. Relative humidity was left at 50%.

6. Optimum start/stop control

In addition to the office working hour schedules and lighting schedules, optimum start and optimum stop schedules were created. In the optimum start time within which the software has to find best start time was given as from 06.00 A.M to 09.00 A.M. Optimus stop time range was given as 04.00 P.M. to 06.00 P.M. In the lockout table, conditions were set so that if the cooling dry bulb temperature becomes greater than set point by 3^0F or heating dry bulb is less than set point, the supply fan will not stop.

7. Energy recovery (Enthalpy Wheel)

In the system options Enthalpy Wheel was selected as the type under the air-to-air energy recovery/transfer with following details

PARAMETER	VALUE/SELECTION
Type	Enthalpy wheel
Supply side deck	Ventilation up stream
Exhaust side deck	System exhaust
Cooling effectiveness at 100% & 75% airflows	75 % & 75% (for both Sensible & Latent)
Heating effectiveness at 100% & 75% airflows	75 % & 75% (for both Sensible & Latent)

Parasitic energy and pressure drop was neglected.

8. Change of equipment type

For building no.01, options/values in the current model were changed to that of centrifugal chiller. For building no. 02 & 03, all water cooled unitary air conditioners were removed and added a centrifugal chiller to the cooling plant. Then all current air side systems were attached to that chiller. The chiller detail was set as below.

8.1 Centrifugal chiller

PARAMETER	VALUE
Equipment category	Water cooled chiller
Equipment type	Centrifugal 2-stage
Energy rate-cooling	0.5 kW/Ton(default)
Primary chilled water pump type	Var vol chill water pump
Condenser water pump type	VV Cond Wtr Pump
Chilled water pump full load energy	0.000536 kW/ton-ft wg
Chilled water pump control type	“ with equipment”
Chilled water pump unloading curve	“Variable vol. Chilled Water Pump

Chilled water pump full load energy	0.000469 kW/ton-ft wg
Chilled water pump control type	" with equipment"
Chilled water pump unloading curve	"Variable vol. Chilled Water Pump
Heat rejection equipment type	"Cooling tower for Cent. Chillers"
Cooling tower energy consumption	0.066 kW/Ton
Cooling tower approach, range and wet bulb temperature	7 ^{0}F,10 ^{0}F,78 ^{0}F
Cooling tower design water flow rate, make up water flow rate	3 gpm/Ton , 3.2 gal/Ton-h
Cooling tower unloading curve	C-Tower on/off

8.2 VRF System

PARAMETER	VALUE
Equipment category	Air cooled unitary
Equipment type	VRF cooling only
Energy rate-cooling	3.21 COP (default)
Heat rejection equipment	VRF condensing unit

9. Usage of daylighting

For this simulation, a new daylighting definition was created as below. Occupancy schedule was selected as the daylighting schedule in the floors selected for daylighing.

PARAMETER	VALUE/OPTION
Daylighting geometry type	Based on glass dimensions
Atmospheric moisture	Summer & Winter-0.70
Atmospheric turbidity	0.12
Inside visible reflectivity	0.70
Lighting control type	Continuous
Percentage of space affected	100%
Glass visible transitivity	0.90
Inside visible reflectivity	0.15

10. Using Efficient Equipment and Identified Effective BAS Features

For this simulation Lighting Power Density was set to 0.5 W/ft^2. Cooling equipment category was selected as water cooled chiller and the equipment type was selected as centrifugal 2-stage with the values and parameters as in centrifugal chiller property table in page 144. With the energy rate of 0.5 kW/Ton. Then the above options were added as changes to the building model.