ENERGY EFFICIENT BUILDING MODEL: A Case study for Proposed SL ARMY Headquarters

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(108888P)

Degree of Master of Science

Department of Electrical Engineering

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ABSTRACT

The Sri Lankan Tri forces Headquarters with Ministry of Defence office complex are schedule to be located in one place at Akuregoda Baththaramulla. This building complex will be one of the largest office complexes in Sri Lanka and to be accommodated for different nature functions except routine official duties. Therefore more attention has been given to improve the architectural view of the entire complex. In the mean time less attention has been given for energy optimizations issues. When the proposed design is thoroughly studied, many possibilities are available to improve energy efficiency of entire complex with some simple modifications. In order to optimize the energy use for illumination system and HVAC system, this case study has been done for selected building area of the total complex. The part of the building complex is selected to do the research and selected area is developed as a separate building model.

The research is mainly based on the finding of best wall to window ratio to optimize the energy consumption for illumination system and HVAC system of the selected building model. The calculation stages are done, maintaining the initial building parameters in human comfort zone as ASHRAE stranded and sun path over the location. The best orientation of the building model is obtained according to the north alignment. Then the condition of the building model is improved as an energy efficient model by replacing illumination system with LED luminaire, window glass with energy efficient low-e window glass and developing a building envelop.

Financial evaluation is done to all proposed building models with compare to the existing design for energy consumption. Then the lighting power density (LPD) is calculated for each building model and made a comparison with the maximum LPD values published by Sustainable Energy Authority.

The research methodology can be practiced in designing stage of any kind of a building to improve the energy efficiency effectively. It gives more opportunity for designers to develop more energy saving building environment, while maintain the human comfort in the same time.

DECLARATION

I declare that this is my own work and this thesis/dissertation[1] 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.

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Date: …………………………………..

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

…………………………………….

Dr. Asanka Rodrigo

ACKNOWLEDGEMENT

First and foremost I offer my sincerest gratitude to my supervisor, Dr Asanka S. Rodrigo, who supported me by stimulating suggestions and encouraging throughout my dissertation with his patience and knowledge. Also, I wish to convey my sincere gratitude to Professor. J. P. Karunadasa, Former Head of the Department of Electrical Engineering, and the other members of the academic staff of the Department of Electrical Engineering, for valuable suggestions and comments given throughout my study. In the same time, I offer my gratitude to Professor R A Attalage, Department of Mechanical Engineering, Dr Muzathik, ITUM, and Eng Chandana Dalugoda who gave me guidance in the special event of my study.

In addition I would like to thank the staff of the Post Graduate Office of the Faculty of Engineering of University of Moratuwa for helping in various ways to clarify the things related to my academic work in time with excellent cooperation and guidance. My sincere gratitude is also extended to the people who serve in the Department of Electrical Engineering office.

I must extended my gratitude to Commander of the Army, Colonel Commandant Cops of Engineer Services, Brigadier J A M R Jayasundara Director Engineer Services, Colonel (Engineer Services) and all of my superior staff and my subordinate staff to the opportunities given me to complete my studies successfully. Specially, I must thankful to computer section of Directorate of Engineer services for the grate support given me in all the way, during my study.

I would like to offer my special thanks to my colleagues and friends for giving their fullest co-operation throughout the time of research and writing of this dissertation.

I express my thanks and appreciation to my family for their understanding, motivation and patience. Lastly, but in no sense the least, I am thankful to all.

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Abbreviations

Abbreviation	Description
AC	Air Condition
AHQ	Army Head Quarters
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
Avg	Average
BF	By Pass Factor
C	Celsius
COP	Coefficient of performance
DB	Dry Bulb
DES	Directorate of Engineer Service
DP	Dew Point
ENE	East-northeast
F	Fahrenheit
GMT	Greenwich Mean Time
HQ	Head quarters
Hrs	Hours
HVAC	Heating ventilation and Air Conditioning
J	Joule
K	Kelvin
Lat	Latitude
LED	Light Emitting Diode
LHG	Latent Heat Gain
MOD	Ministry of Defence.
N/A	North alignment
NNW	North-North-West
RH	Relative Humidity
s	Seconds

SC	Shading Coefficient
SHG	Sensible Heat Gain
SHGF	Solar Heat Gain Factor
SSE	South-southeast
TR	Ton (Cooling load)
W	Watt
WB	Wet bulb
WSW	West-South-West
W/W ratio	Wall to window ratio

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Chapter 1

INTRODUCTION

1.1 Background

Energy efficiency is a growing policy which has been given many priorities by many countries around the world. This concept is widely recognized as the most cost effective and readily available means in order to address energy related issues, including energy security the social and economical imports of high energy price and global effect on the climatic change. At the same time energy efficiency has increased the comparativeness among involving parties to promote consumers benefits.

There are many motivations to improve energy efficiency reducing use of energy. Reducing the use of energy reduces the cost of energy and it may result in financial cost saving to consumers. Sometimes it may offset additional cost on implementing and energy efficiency technologies. However the effort to develop more energy efficient technologies and practices are being developed day by day. According to The International Energy Agency, improved energy efficiency in buildings, industrial process and transportations could reduce the worlds' energy needs in 2050 by one third.

Energy is generated from deferent sources and it can be classified in to two different types as nonrenewable and renewable. Basically, nonrenewable recourses such as fossil fuels and nuclear materials are removed from the earth and can be depleted. These sources have been the most used type of energy in the present world. Then the renewable resources, such as wind, water, solar, and geothermal come from sources that regenerator as fast as there are consumed and continuously available. Same as that bio fuel produced from food crops and other plants are replenished every growing season. In the early part of the twenty first century, renewable sources have become more popular than nonrenewable sources.

1.2 Energy Efficiency and Conservation

Energy efficiency and conservation is another concept to meet the challenge of limiting green house gasses emission and the climate change mitigation. From small scale house hole to mage scale factory level, this concept is implemented with the help of developing technologies. Energy efficiency is manly achieved from the appliances used to provide product and services, in the menace of less energy used than regular requirement. For examples, insulating buildings to used less energy for heating and cooling to achieve and maintain comfortable temperature. Installing LED, CFL or natural sky light reduces the amount of energy required to attain the same level of illumination compared to using traditional incandescent light bulbs. Another approach is implementation of hybrid technologies which can be done as solar power combination with electric power for illumination system and HVAC system in order to optimize the regular power consumption ext.

Energy efficiency has proved to be a cost effective strategy for building economies without necessarily grooving energy consumption. Therefore, most of the countries have already begun to implement energy efficiency measures, introducing building codes and appliance standards with strict efficiency requirement. Other than that, countries like USA, UK have implemented a “loading order” for new energy resources that puts energy efficiency first, renewable electricity supplies second and new fossil-fired plants last.

Energy conservation is boarder than energy efficiency in that it encompasses using less energy to achieve a lesser energy service, for example through behavior change as well as encompassing energy efficiency. Example for conservation, without energy efficiency improvement make rooms cool with in less time with pre-define temperature, used common transport in fact individual transports menace or working in a less bright lightly lit room, practice good behavior in energy serving.

Reducing energy uses a sense as a key solution to the problem of reducing green house gases emission. Accordingly to the international energy agency, improved energy efficiency in buildings, industrial process and transportation could reduce words energy need in 2050 by one third, and help to control global emission of green house gasses.

The emissions of green house gasses from buildings are significant and by adapting energy efficiency programs, situation can be changed by consideration to the concept of green building and energy efficient building. This concept has become more handy, since it has given more financial benefit as well as more environmental friendly. A green building and energy efficiency buildings deal with two different terms but both are involved in energy serving and less energy usage than regular behavior.

Green building they are also known as green construction or sustainable building, refers to structure and using process that is environmentally responsible and resource-efficient through outer building life cycle from sitting to designing, construction, operation, maintenance, renovation and demolition. In other words, green building designs involve find in the balance between home building and sustainable environment. That requires a close cooperation of the designing team, the architect and client at all project stages. The green building practice expense and complements the classical building design concern of economy, utility, durability and comfort.

Although the new technologies are constantly being developed to complement current practices in creating greener structure, the common objective is that green buildings are design to reduce the over roll impact of the built environment on human health and the natural environment by:

- Efficient using energy, water and other resources.
- Protecting occupant health and improving employ productivity.
- Reduce waste, pollution and environmental degradation.

Figure 1 1 An eco-house with a turf roof and solar panels

As high-performance buildings use less operating energy, embodied energy has assumed much greater importance – and may make up as much as 30% of the overall life cycle energy consumption. Studies such as the U.S. LCI (Life Cycle Inventory) Database Project show buildings built primarily with wood will have a lower embodied energy than those built primarily with brick, concrete, or steel.

To reduce operating energy use, designers use details that reduce air leakage through the building envelope (the barrier between conditioned and unconditioned space). They also specify high-performance windows and extra insulation in walls, ceilings, and floors. Another strategy, passive solar building design, is often implemented in low-energy homes. Designers orient windows and walls and place awnings, porches, and trees to shade windows and roofs during the summer while maximizing solar gain in the winter. In addition, effective window placement (day lighting) can provide more natural light and lessen the need for electric lighting during the day. Solar water heating further reduces energy costs.

Onsite generation of renewable energy through solar power, wind power, hydro power, or biomass can significantly reduce the environmental impact of the building. Power generation is generally the most expensive feature to add to a building.

In passive solar building design, windows, walls, and floors are made to collect, store, and distribute solar energy in the form of heat in the winter and reject solar heat in the summer. This is called passive solar design because, unlike active solar heating systems, it does not involve the use of mechanical and electrical devices.

The key to designing a passive solar building is to best take advantage of the local climate. Elements to be considered include window placement and size, and glazing type, thermal insulation, thermal mass, and shading. Passive solar design techniques can be applied most easily to new buildings, but existing buildings can be adapted or "retrofitted".

Energy efficient buildings (new constructions or renovated existing buildings) can be defined as buildings that are designed to provide a significant reduction of the energy need for heating and cooling, independently of the energy and of the equipments that will be chosen to heat or cool the building.

This can be achieved through the following elements:

- Bioclimatic architecture: shape and orientation of the building, solar protections, passive solar systems
- High performing building envelope: thorough insulation, high performing glazing and windows, air-sealed construction, avoidance of thermal bridges
- High performance controlled ventilation: mechanical insulation, heat recovery

Only when the building has been designed to minimize the energy loss, it makes sense to start looking at the energy source (including renewable energy) and at the heating and cooling equipments. This approach has been designated as the Trias Energetica concept.

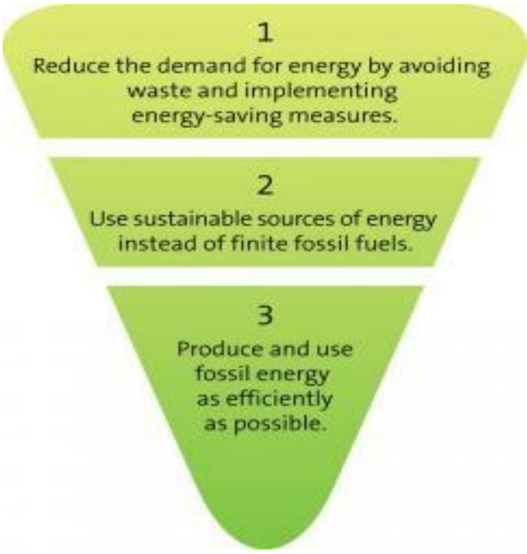


Figure 1 2 Trias Energetica concept

Following the principles of the Trias Energetica concept under mentioned 5-step approaches have been developed.

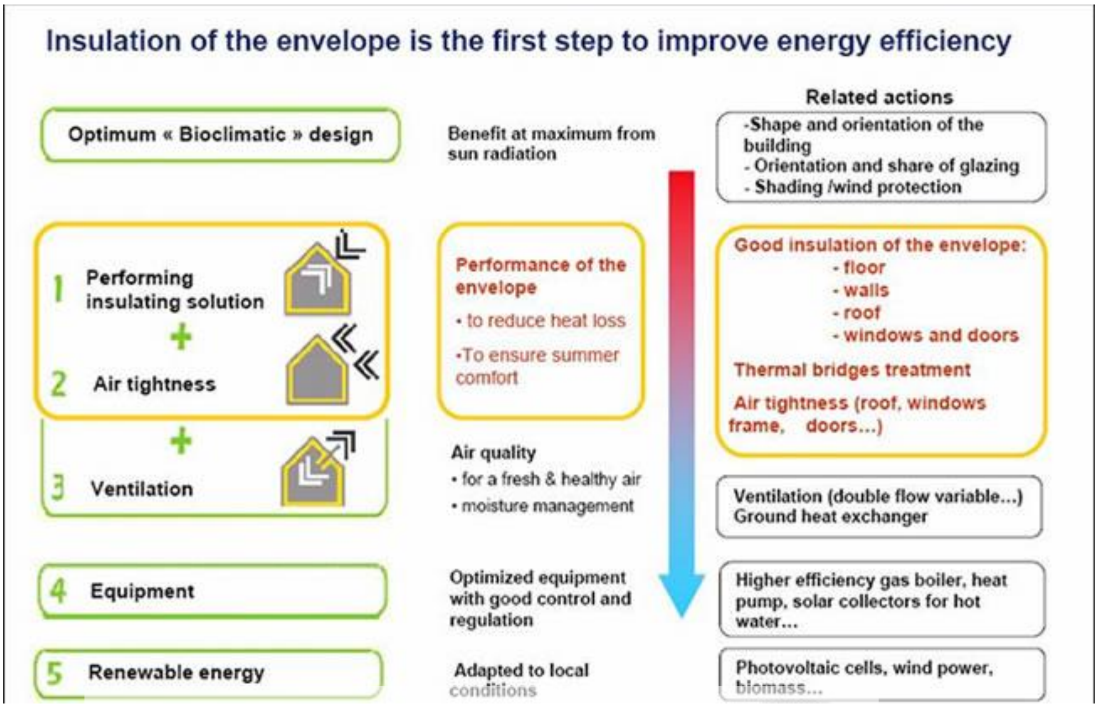


Figure 1.3 Approachers of Trias Energetica concept

1.3 Bioclimatic architecture

Bioclimatic architecture takes into account climate and environmental conditions to help achieve thermal and visual comfort inside. Bioclimatic design takes into account the local climate to make the best possible use of solar energy and other environmental sources, rather than working against them. Bioclimatic design includes the following principles:

- The shape of the building has to be compact to reduce the surfaces in contact with the exterior; the building and especially its openings are given an appropriate; interior spaces are laid out according to their heating requirements;

- Appropriate techniques are applied to the external envelope and its openings to protect the building from solar heat in winter as well as in summer; passive solar systems collect solar radiation, acting as "free" heating and lighting systems; the building is protected from the summer sun, primarily by shading but also by the appropriate treatment of the building envelope (i.e. use of reflective colours and surfaces).

Thermal insulation is a low-cost, widely available, proven technology that begins saving energy and money, and reducing emissions the moment it is installed. Well installed insulation ensures energy efficiency in every part of the building envelope including ground decks, roofs lofts, walls and facades. It is also well suited for pipes and boilers to reduce the energy loss of a building's technical installations. Insulation is as relevant in cold regions as in hot ones. In cold/cool regions, insulation keeps a building warm and limits the need for energy for heating whereas in hot/warm regions the same insulation systems keep the heat out and reduce the need for air conditioning.

- An exterior wall is well insulated when its thermal resistance (R value) is high, meaning the heat losses through it are small (reduced U value). Insulation is a key component of the wall to achieve a high R value (or a low U value) for the complete wall. The thermal resistance R of the installed insulation products has to be as high as possible.

Air tightness reduces air leakage – the uncontrolled flow of air through gaps and cracks in the construction (sometimes referred to as infiltration, exfiltration or draughts). Air leakages need to be reduced as much as possible in order to create efficient, controllable, comfortable, healthy and durable buildings with more stringent building regulations requiring better energy efficiency , air tightness is an increasingly important issue.

- Details that are vital to achieving good air tightness need to be identified at early design stage. The next and equally important step is to ensure these details are carried over into the construction phase. Careful attention must be paid to sealing gaps and ensuring the continuity of the air barrier. It is far simpler to design and build an airtight construction than to carry out remedial measures in a draughty home.

Consequences of air leakages : outside air may be drawn into the home through gaps in the walls, ground floor and ceiling (infiltration), resulting in uncomfortable inside thermal condition. In some cases, infiltration cool air can cool the surfaces of elements in the structure, leading to condensation. Warm air leaking out through gaps in the dwelling's envelope (exfiltration) is a major cause of heat loss and, consequently, wasted energy

A leaky dwelling will result in higher CO_2 emissions. The additional thermal loss will mean that a correctly sized HVAC system may not be able to meet the demand temperature. Draughts and localized heat spots can cause discomfort. In extreme cases, excessive infiltration may make rooms uncomfortably cold during cooler periods. Excessive air leakage can allow damp air to penetrate the building fabric, degrading the structure and reducing the effectiveness of the insulation. Air leakage paths often lead to dust marks on carpets and wall coverings that look unsightly.

Ventilation is the intended and controlled ingress and egress of air through buildings, delivering fresh air, and exhausting stale air through purpose-built ventilators in combination with the designed heating system and humidity control, and the fabric of the building itself.

- If the insulation is not done properly and ventilates too little, risk for warm humid air condensing on cold will be increased and poorly insulated surfaces will create moisture which allows for moulds and fungi to grow.
- A controlled ventilation strategy will satisfy the fresh air requirements of an airtight building. Air infiltration or opening of the window cannot be considered an acceptable alternative to designed ventilation.
- As the saying goes: 'build tight, ventilate right.'

Sri Lanka as a Tropical country gets solar radiation approximately for 12 hours per day, throughout the year. Therefore, it gives many possibilities to collect solar as an energy source in different forms for regular needs. This freely available energy source can be used effectively to fulfill day time energy requirements. Basically solar energy can be used directly for heating and lighting needs and indirectly as Photovoltaic energy. The direct use of solar energy mainly to fulfill building's energy requirements gets more than 75% efficiency with compare to the indirect use of solar energy, but getting such efficiency will depend mainly on the design and the location where building to be located. Even so, it is hard to see any motivation to use such freely available clean energy source in present energy related issues.

The Sri Lanka Defence Head Quarter complex is presently being constructed in Akuregoda, Pelawatta as a malty storied building complex in order to establish the Ministry of Defense, Tri Forces Head Quarters and Police Head Quarters together in one complex. This complex will be a one of the largest office complex in Sri Lanka in future. It is going to equip with all the modern office equipment, office environments and facilities in order to meet each and every administrative requirement of all defence forces. During the planning stage more consideration was given to develop more comfortable working environment each and every employee. The interior design also was made accordingly.

The total design of the building and all the other facilities included will demand considerable amount of energy during the functioning stage. This energy demand will be included to annual maintenance cost and further it will be an additional cost for future forecasting. With compare to the present development programmes launched by the government, allocation of such amount of funds to maintain government institutions of this nature will be a considerable factor in future events. Therefore the institutions which are depending mainly on government funds need to be optimized the expenditures with every possible menace.

The annual maintenance costs of those institutions are divided into different subsectors. Energy sector is one of the subsector pay lots of attention in annual budget of each institution. In the same way Sri Lanka Army annual energy cost also has taken more attention with compare to the other maintenance costs. The energy cost of Sri Lanka Army shall be divided further into different sub subsectors such as for petroleum products, electricity and fire woods. During this work only the cost make for electricity has been taken into consideration in fact of other energy sources.

In order to minimize the cost of electricity mainly in building complexes, the modern energy optimization techniques and concepts shall be applied during construction stages and functioning stages. However, at the designing stage of the proposed Defence Head Quarter complex, the main concentration has been given for architectural view in fact of giving more concentration on energy efficiency possibilities. Therefore this research work has been done to find the most suitable design to improve energy efficiency against the proposed design.

The proposed energy efficient building design was done with consideration to the different concepts. The main consideration was given to find the most suitable wall to window ratio against the wall to window ratio available in the proposed design as to obtain more solar intake for the internal illumination system while maintaining the comfortable working environment. The some improvements for the existing design were done to achieve the optimum conditions for walls and windows. In such case the building enveloping was done to maintain the preferable thermal condition and windows glasses were replaced with low E-glassless to collect more solar for illumination system, with less thermal intake.

It is more important to improve the human behavior towards the energy saving practices while achieving the technical improvements for any working environment to achieve more out come on energy optimization. Such situation could be maintained by enforcing some rules and regulations for equipment usage specially. This nature practices shall be done easily in military environment. In other establishments' working environments shall be improved with BMS to achieve the same out come without leaving additional burden to employee.

As an organization which maintain with government funds, Sri Lanka Army should have good practice on energy serving. The annual allocation for electricity and its' expenditure for last five years is mentioned in the table 1 1.

Table 1 1 Allocation for electricity for last five years

Year	Allocation – Rs (Mn)	Expenditure – Rs (Mn)
2009	1448	1667.3
2010	1767.34	1864.92
2011	1778.3	1978.27
2012	2108.9	2308.9
2013	3719.82	3790.35

Source: Annual reports of Directorate of Budget and Finance Management -SL Army

The table shows the allocation given for electricity has been over expended in every year. This situation evident, the future expenditure for electricity may increase remarkably during the functioning stage of new Head Quarter Complex. Such situation will be harder for Sri Lanka Army as a Government dependant organization due to future energy crisis and energy policies. Therefore it is needed to change the usual practice and to implement the techniques to optimize the usual energy consumption.

The Sri Lankan Sustainable Energy Authority has done a publication for Code of Practice for Energy Efficient Buildings in Sri Lanka in order to enhance the energy efficiency of the buildings to be constructed and for retrofits to commercial buildings. The main purpose of this effort is to introduce energy efficient design and retrofit to commercial buildings industrial facilities and large scale housing schemes to enable designing construction and maintenance to be carried out under minimal energy consumption without compromising the building's function, while maintaining the comfort and health of occupants. Further it has proposed to set a criteria and minimum standards for energy efficient design and retrofits in commercial buildings and provide criteria for determining compliance, then to encourage energy efficiency designs exceeding minimum standards.

This cord of practice covers the following building elements;

a. **Building enveloping: -** Under this heading it addresses the general principles of energy efficient envelop design, emendatory requirements and prescriptive requirements and the method of compliance.

b. **Ventilation and Air Conditioning: -** Under this heading it addresses the mandatory requirements for load calculations, designing and sizing of equipments, temperature adjusting, balancing and commissioning and finally the maintenance of the system.

c. **Lighting: -** Under this heading it covers the general principles of energy efficient lighting practices, mandatory and prescriptive requirements, maximum allowable power for illumination system, lighting consideration, strategies for energy efficient lighting and selection of appropriate components.

d. **Services water heating: -** Under this heading it addresses the general principles, mandatory and prescriptive requirements, selection of equipment and installation and design consideration.

Moreover, the cord gives the details for maximum power utilization for certain areas as Table 1.3. It specified Lighting Power Density for respective building elements which need to be adopted during design stage.

Table 1 2 Lighting Power Densities

Building Area Type	**LPD (W/m2)**	**Building Area Type**	**LPD (W/m2)**
Automotive Facility	9.7	Multifamily	7.5
Convention Centre	12.9	Museum	11.8
Dining: Bar Lounge/Leisure	14.0	Office	10.8
Dining: Cafeteria/Fast Food	15.1	Parking Garage	3.2
Dining: Family	17.2	Performing Arts Theatre	17.2
Dormitory/Hostel	10.8	Police/Fire Station	10.8
Gymnasium	11.8	Post Office/Town Hall	11.88
Healthcare-Clinic	10.8	Places of worship	14.0
Hospital/Health Care	12.9	Retail /Mall	16.1
Hotel	10.8	School/University	12.9
Library	14.0	Sports Arena	11.8
Manufacturing Facility	14.0	Transportation	10.8
Motel	10.8	Warehouse	8.6
Motion Picture Theatre	12.9	Workshop	15.1

Source: SLSEA Code of Practice for Energy Efficient Buildings in Sri Lanka 2009

SLSEA expects to develop a sustainable energy policy by applying the theories mentioned above. The Government also has taken lots of interest on same issue with the increasing power demand. Therefore as a Government organization, Sri Lanka Army also need to practice energy efficient ethics in their every action.

Sri Lanka Army energy need mainly fulfills by two commodities, i.e. by petroleum products and by electricity. As mention in above chapters, the demand for the energy is gradually increasing in every year. The expansion and improvements done to Sri Lanka Army have been affected to increase the energy demand. The total energy demand might not be able to fulfill up to desirable level with present energy related issues. Therefore it is much needed to use the available sources more efficiently than usual manner. The situation has been taken into consideration and number of non-technical measures has been already implemented to optimize the usage of energy. In the same way, adding some energy efficient technologies for the same concept, the outcome of the effort will be more effective. Sri Lanka Army's electricity consumption is generally done to function of office environments. Basically, the most of the office time are laid down during usual office hours. Therefore it is obvious the considerable amount of electricity consumes during day time. The day time electricity usage can be optimized with combination of naturally available energy sources as solar. The solar energy shall be used directly for building illumination and water heating and indirectly as electricity generation. Direct use of solar as an energy source is having 75% efficiency than use it indirectly as generating electricity for the same purpose. Since most of the office functions nature duties are taken place during day hours, the use of direct solar for illumination system shall be more effective. Intake direct solar to a building inside, affects to increase the internal thermal condition of the particular building. The proper balance need to be maintained in between these two systems. The amount of energy can be served against the energy to be consumed for proposed Army Head Quarters building was calculated by adding some modification to the existing design during the research work.

1.4 Background

Proposed MOD Office complex, Tri forces Headquarters and Police Headquarters are being constructed in Akuregoda, Pelawaththa area at present. It is a multi storied building complex which has been decided to do a combine installation of Tri Forces Head Quarters, Police Head Quarters and Ministry of Defense office complex together in one place. This will be a one of the biggest office complex in Sri Lanka and therefore more attention has been given for the Architectural view of the complex. The total building complex is concerned, supposes to consume huge amount of electrical energy in various forms such as illumination, HVAC, mechanical etc... This case study was done to find the possibility of improving energy efficiency specially electrical, of one selective part of the complex by integrating daylight and other natural climatic conditions with artificial conditions pertaining to the office environment.

1.5 Preliminary statement

The energy bill of Sri Lanka Army is getting increased in large amount with compare to the following year as mentioned in above chapter. This situation has been affected with the establishment of new military bases in selected areas of the country. Therefore the possibilities need to be find to optimize the energy usage in Sri Lanka Army without disturbing the routine duties.

1.6 Problem identification

Sri Lanka Army is one of a largest organization in Sir Lanka. After the war, in order to maintain the national security, military camps are established in identified areas of the country. These camps are constructed in a particular manner and they have to be fulfilled with all the infrastructure facilities, because it is very much essential Army to depend themselves without dealing with outside community. Therefore, Government allocates lots of funds in every year for maintenance of such organizations. The allocation to be reserved in the menace of Defence, discuss in every year Government budget forecast widely. Allocating such amount of money might become as critical issue in future events and therefore these organizations need to put more effort on utilizing the given allocation very efficiently. The total annual expenditure of Sri Lanka Army's concern, considerable percentage of given allocation spends to pay electricity bills in every year. Even though the situation is like that, nobody has taken much interest to minimize such expenditure. Such situation has become more critical when allocating fund to provision of electricity supplies for newly established camps. Most of the buildings in Sri Lanka Army are heavily energy consuming buildings and so far the actions have not been taken yet to modify the same as suitable for low energy consumption. Being a tropical country, Sri Lanka is very much near to the equator and therefore gets natural sun light more than 8 hours per day throughout the year. This condition can be used for building illumination during daytime integrating the natural sun light with artificial illumination system in order to minimize the power consumption for indoor illumination. In the same time with the proper coordination of relevant factors, development of internal heat load can be minimized with optimizing the power consumption for the HVAC system.

1.7 Long term problem identification

If the electricity consumption of Sri Lanka Army is not being optimized immediately, the Sri Lanka Army and the Government will face some of the following problems:

- Huge energy bills will get every year and in the same way the Government may need to allocate additional funds to maintain these nature organizations.

- As the funds are obtained as voted funds, the settlement of bills may not be taken place on time. Therefore the frequent disconnection of electricity supply will be experienced by own institutions due to delay settlement of electricity bills.

- Power Generation cost may increase eventually and new power plants may need to be established to fulfill upcoming electricity demand. Since the most of the renewable energy sources (mainly the hydro power) are being utilized in their maximum capacity, fossil fuel burned power generation units may need to be established. Such situation may be reason to increase global warming and cause more environmental impact.

1.8 Objectives

The main objectives of the study are,

- Study the total energy consumption for illumination system and HVAC system of selected area of proposed building complex during identified time period and the effect of existing building design and construction method for the energy consumption.

- Study the methods for energy optimization of the selected building model with possible modification

- Study the effects of climatic condition for energy consumption of the building and the combination of the same with internal office condition to optimization of energy efficiency.

- Propose the modification which could be done to the proposed building complex to improve energy efficiency against the existing conditions and financial evaluation.

- Propose the most suitable W/W ratio and orientation to be maintained for Sri Lankan building construction scenario for energy optimization.

- Propose new values for Lighting Power Density by improving the value introduced by Code of Practice for Energy Efficient Building in Sri Lanka.

Chapter 2

LITRETUER REWIEV

2.1 Descriptions of main parameters - Lighting

2.1.1 Illumination

The process of seeing any object with use of light which illuminates with the environment in the scene is called illumination.

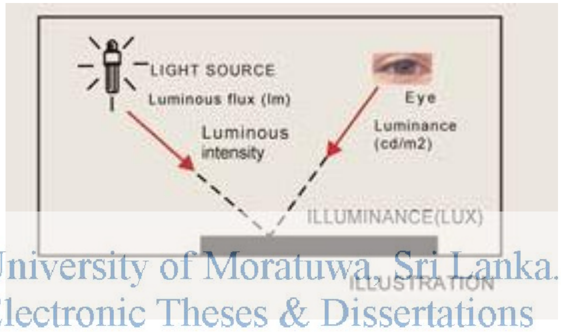


Figure 2.1 Illustration for lighting properties

2.1.2 Luminous Flux

Luminous flux is the quantity of the energy of the light emitted per second in all directions. The unit of luminous flux is lumen (lm). One lumen is the luminous flux of the uniform point light source that has luminous intensity of 1 candela and is contained in one unit of spatial angle (or 1 Steradian). Steradian is the spatial angle that limits the surface area of the sphere equal to the square of the radius. This concept is shown in the figure for 1 m radius of the sphere. Since the area of sphere is $4pr^2$ then the luminous flux of the point light source is 4p lumens.

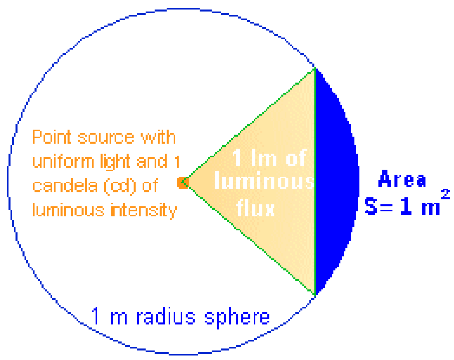


Figure 2 2 Illustration for luminous flux

2.1.3 Luminous Intensity

Luminous intensity is the ability to emit light into a given direction, or it is the luminous flux that is radiated by the light source in a given direction within the unit of the spatial angel. If the point light source emits Ø lumens into a small spatial angel ß, the luminous intensity is I=Ø/ß. The unit of luminous intensity is candela. There is a standard that details the candela definition. This includes the standard light source and the physical conditions of the measurement.

2.1.4 Illuminance (Illumination)

This definition determines the amount of light that covers a surface. If Ø is the luminous flux and S is the area of the given surface then the illuminance E is determined by E=Ø/S. The unit of illumination in SI system is lx, and in foot-pound system it is foot-candle. One lx is the illuminance of 1 m^2 surface area uniformly lighted by 1 lm of luminous flux. The following drawing explains this definition. One foot-candle is 10.76 lux.

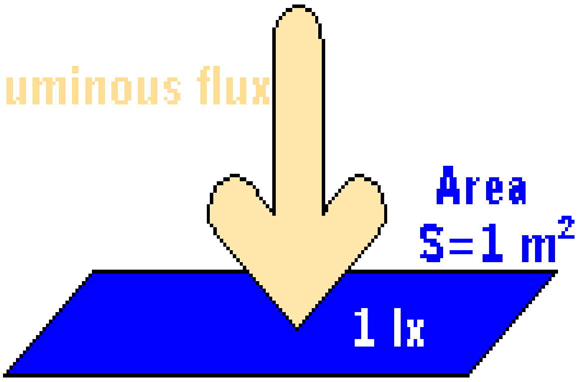


Figure 2 3 Illustration for illuminance

2.1.5 Luminance

Luminance L is the luminous intensity emitted by the surface area of 1 cm² (or 1 m²) of the light source. Mathematically it is L=I/S where I is the luminous intensity and S is the area of the source surface perpendicular to the given direction. The unit of luminance is cd/m² or cd/cm² (in some applications lm/cm² or Lambert can be used). The following figure shows the concept.

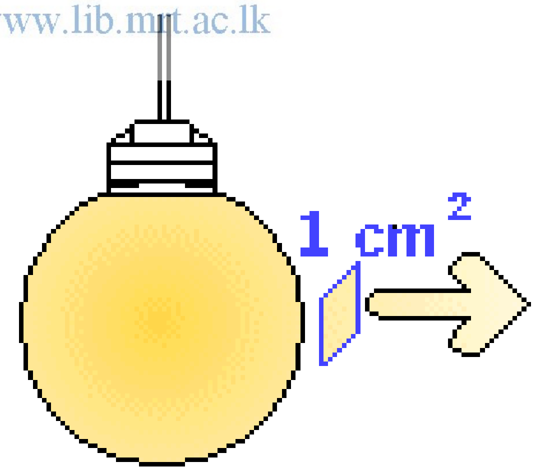


Figure 2 4 Illustration for luminance

2.2 Dialux light building software

Dialux is the most commonly use software for light simulation for both indoor and outdoor. It professionally calculates and checks all lighting parameters for interiors and exteriors, roads and tunnels, providing clear and accurate results according to the latest interior décor regulations. The luminaires (lamps, LED spotlights, floodlights, ceiling fixtures) included in the programme come with detailed descriptions and technical specifications such as power rate, intensity and luminous flux, luminance diagrams and isolux photometric curves. Therefore lighting designers can then rely on a software system and it is constantly updated with the lighting components manufactured by leading world manufacturers. This software has been used to do the lighting calculation for all the time where it was necessary.

2.2.1 Daylight Integration

Good day lighting design makes diffuse daylight the primary illumination, provides gentle uniform light throughout the space, and enables occupants to control the daylight. Getting daylight into a space is not difficult. But controlling is the real challenge. Good design avoids glare, direct sunlight penetration, and too much daylight. An excess of direct sunlight, as opposed to diffuse daylight spread uniformly throughout the space, can cause glare and contrast problems, heat gain, and lost energy savings opportunities.

Daylight integration facility with interior illumination arrangement is available with Dialux light building software. It was considered for the each calculation stagers in order to optimize the power consumption for lighting system throughout the research work.

2.2.2 Daylight factors

Daylight Factor (DF) is the ratio between the actual illumination at a point inside a room (E_i) and the illumination possible from an unobstructed hemisphere of the same sky (E_o). Daylight factors can be used specify recommended levels of daylight for various interiors and tasks. Table 2.1 list a selection of recommendations for interiors where daylight from side windows is a major source of light. Daylight factors vary for different points within a room so it is usual to quote average values or minimum levels.

Table 2 1 Recommended daylight levels

Location	Average DF (%)	Min DF (%)	Surface
General Office	5	2	Desks
Classroom	5	2	Desks
Entrance hall	2	0.6	Working plane
Library	5	1.5	tables
Drawing office	5	2.5	boards
Sports hall	5	3.5	Working plane

Source: CIBS Code of interior lighting

Daylight reaching a particular point inside a room is made up of three principal components. The sky component (SC) is the light received directly from the sky. The externally reflection component (ERC) is the light received directly by reflection from buildings and landscape outside the room. The Internally reflected component (IRC) is the light received from surfaces inside the room.

2.2.3 Recommended illuminance level

Table 2 2 Recommended lux level for office environment

Location	Illuminance (Lux)		
	Low	Base	High
Offices			
Accounting	200	300	500
Audio Visual areas	200	300	500
Conference areas	200	300	500
General and private offices	200	300	500
Libraries	200	300	500
Lobbies, lounges and reception areas	100	150	200
Off-set printing and duplicating area	200	300	500

Above tables provide details for desirable illuminance levels for selected general areas. Therefore, keeping it as the references minimum illuminance level was taken as 300 Lux for office environment for further calculations.

2.3 Descriptions of main parameters - HVAC

The HVAC system is the highest energy consuming unit in almost all office environments. Therefore it is needed to reserve additional budget in every allocation as they get high energy bill usually. During the research this factor was deeply discussed. Certain areas of ASHRAE standards and Code of Practice for Energy Efficient Buildings in Sri Lanka - 2009 were taken as the guideline for the research. Following factors were taken in to consideration throughout the calculation.

1. Number of occupancy was taken as 45 people where as the ASHRAE standard 62 in office space 100m^2 7 people shall be occupy in a office space.
2. Fresh Air intake to the room was taken as 8.5 l/s per person.
3. Outdoor condition was taken as 32 C° (DB), 29 C° (WB), 80% RH.
4. Indoor condition was taken as 24 C° (DB), 13 C° (WB), 50% RH.
5. Floor area was 450m^2.

2.3.1 HVAC System

Details of the Air conditioning system, which was considered during calculation, is as follows:

1. Cooling capacity: 40 kW, 136500 BTU/hrs
2. Power input: 11.2 kW
3. COP: 3.75 kW/kW
4. Brand: LG

2.4 Theoretical details

2.4.1 Relative Humidity (RH)

This is the ratio of the partial pressure of water vapor in an air-water mixture to the saturated vapor pressure of water at a given temperature. The relative humidity of air depends on temperature and the pressure of the system of concerned.

Relative humidity is normally expressed as a percentage and is calculated by using the following equation

$$\phi = \frac{e_w}{e^*_w} \times 100\%$$

Where:- (ϕ)- relative humidity

(e_w) - partial pressure of water vapor (H_2O)

(e^*_w) - vapor pressure of water at a given temperature

2.4.2 Dry-bulb temperature (DBT)

The temperature of air measured by a thermometer freely exposed to the air. DBT is the temperature of environments air temperature, and it is the true thermodynamic temperature. It indicates the amount of heat in the air and it is directly proportional to the mean kinetic energy of the air molecules. Temperature is usually measured in degrees Celsius (°C), Kelvin (K), or Fahrenheit (°F).

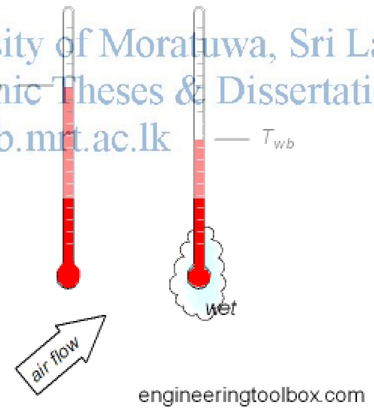


Figure 2 5 Illustration for DB Temp and WB Temp

Dry bulb temperature does not indicate the amount of moisture in the air. In construction, it is an important consideration when designing a HVAC system for any particular building for a certain climate condition.

2.4.3 Wet-bulb temperature

This is the thermodynamic property of a mixture of air and water vapor. The value indicated by a wet-bulb thermometer often provides an adequate approximation of the thermodynamic wet-bulb temperature.

A wet-bulb thermometer is an instrument which may be used to assume the amount of moisture in the air. If a moist cloth wick is placed over a thermometer bulb, the evaporation of moisture from the wick will lower the thermometer reading (temperature). If the air surrounding a wet-bulb thermometer is dry, evaporation from the moist wick will be more rapid than if the air is moist. When the air is saturated, no water will evaporate from the wick and the temperature of the wet-bulb thermometer will be the same as the reading on the dry-bulb thermometer. However, if the air is not saturated, water will evaporate from the wick causing the temperature reading to be lower.

2.4.4 R-Value

The R-value is a measure of thermal resistance used in the building and construction industry. Under uniform conditions it is the ratio of the temperature difference across an insulator and the heat flux (heat transfer per unit area per unit time, $\dot{Q}_A$) through it or $R = \Delta T / \dot{Q}_A$. The R-value being discussed is the unit thermal resistance. This is used for a unit value of any particular material. It is expressed as the thickness of the material divided by the thermal conductivity. For the thermal resistance of an entire section of material, instead of the unit resistance, divide the unit thermal resistance by the area of the material. R-value is the reciprocal of U-value.

2.4.5 U-factor

The U-factor is the overall heat transfer coefficient that describes how well a material conducts heat. It measures the rate of heat transfer through a element over a given area under standardized conditions. The usual standard is at a temperature gradient of 24

°C (75 °F), at 50% humidity with no wind (a smaller *U-factor* is better at reducing heat transfer).

U is the inverse of *R* with SI units of W/(m²K) and US units of BTU/(h °F ft²);

$$U = \frac{1}{R} = \frac{\dot{Q}_A}{\Delta T} = \frac{k}{L}$$

Where: *k* is the material's thermal conductivity and *L* is its thickness.

2.4.6 Sensible Heat

This is the heat absorbed or given off by a substance that is NOT in the process of changing its physical state. Sensible heat can be sensed, or measured, with a thermometer, and the addition or removal of sensible heat will always cause a change in the temperature of the substance.

2.4.7 Latent Heat

This is the heat absorbed or given off by a substance while it is changing its physical state. The heat absorbed or given off does not cause a temperature change in the substance- the heat is latent or hidden. In other words, sensible heat is the heat that affects the temperature of things; latent heat is the heat that affects the physical state of things.

2.4.8 Shading coefficient

This is a value that determines one type of thermal performance of glass units. It is basically the ratio of solar gain (due to direct sunlight) passing through a glass unit to the solar energy which passes through 3mm Clear Float Glass . It is referred to as an indicator to how the glass is thermally insulating (shading) the interior when there is direct sunlight on the panel or window.

The shading coefficient (SC) depends on the color of glass and degree of reflectivity. It also depends on the type of reflective metal oxides for the case of reflective glass. Sputter-coated reflective and/or sputter-coated low-emissivity glasses tend to have lower SC compared to the same prolifically-coated reflective and/or low-emissivity glass.

It is usually a value ranging from 1.00 to 0.00, but experiments show that the value of the SC is between 0.98~0.10.

It is known that the SC value plays a significant role in the selection of glass, specially at high-temperature areas. Usually at those areas, low SC is needed to lower the solar heat gain through the glass. It works with the direct sunlight, and with the absence of sunlight SC loses its significance in design.

2.4.9 The Psychrometric Chart

The psychrometric chart shows graphically the parameters relating to water moisture in air. This application note describes the purpose and use of the psychrometric chart as it affects the HVAC engineer or technician.

Air comprises approximately 78% nitrogen, 21% oxygen, and 1% other gases. But air is never dry, even in a desert. Two-thirds of the earth's surface is covered with water and this, along with other surface water and rain, maintain low pressure water vapor to be suspended in the air making up part of the 1% of other gases.

The psychrometric chart indicates the properties of this water vapor through the following parameters, each of which is explained in more detail below:

- Dry bulb temperature
- Wet bulb temperature (also known as saturation temperature)
- Dew point temperature
- Relative Humidity
- Moisture Content (also known as humidity ratio)
- Enthalpy (also known as total heat)
- Specific Volume (the inverse of density)

Any psychrometric chart is valid at a certain pressure of air. The pressure of air is related to the height above (or below) sea level. The chart provided by Power Knot is valid at sea level (760 mm of Hg). Corrections must be made for different altitudes before calculations. When calculating if any two of the parameters above is known, other five values could be calculated from the chart.

The psychrometrics chart is much important in the HVAC industry because:

- People feel comfortable over a narrow range of temperature and humidity
- Machines (especially electronic machines) operate over a specific range of temperature and humidity
- To calculate the amount of heating or cooling required for a certain space requires knowledge of the moisture content of the air

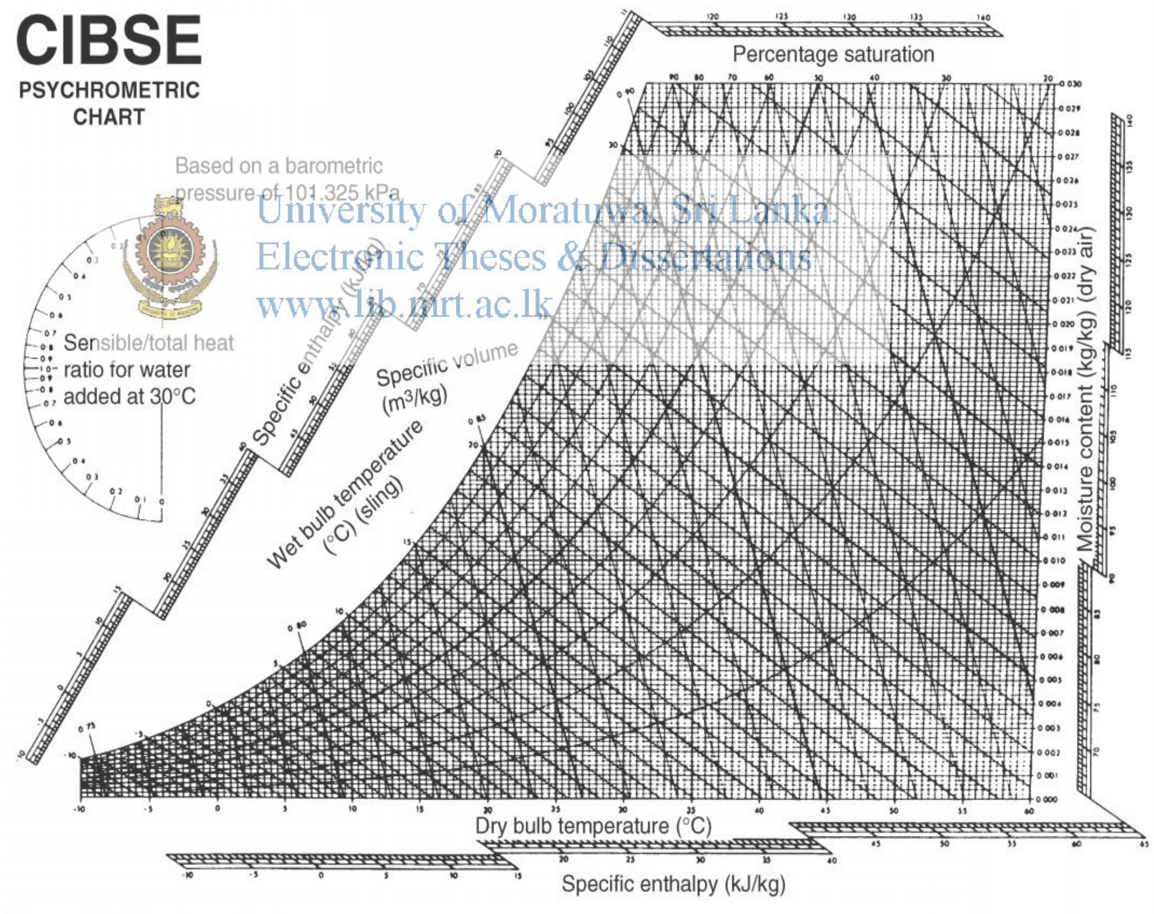


Figure 2 6 The Psychrometric Chart

2.4.10 Properties on the Chart

- Dry bulb (DB) temperature

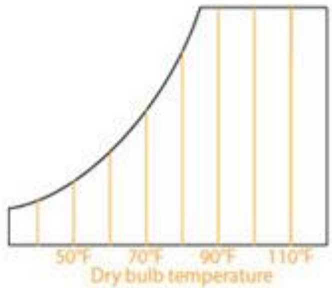


Figure 2 7 Dry Bulb temperature line

DB temperature is shown as the horizontal axis of the chart

- Wet bulb (WB) temperature

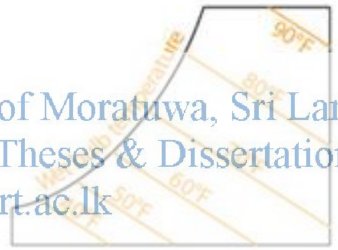


Figure 2 8 Wet Bulb temperature line

WB temperature is indicated by diagonal lines on the chart.

- Relative humidity (RH)

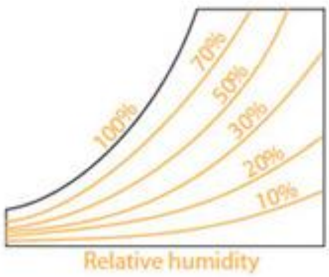


Figure 2 9 Relative humidity line

Lines of constant relative humidity are shown as exponential lines on the psychrometric chart. The line at 100% is referred to as the saturation line.

- Dew Point (DP) temperature

This is the temperature of the air at which a moist air sample reaches water vapor saturation. It is equivalent to a wet bulb temperature at 100% relative humidity. At this combination of temperature and humidity, further removal of heat results in water vapor condensing into liquid.

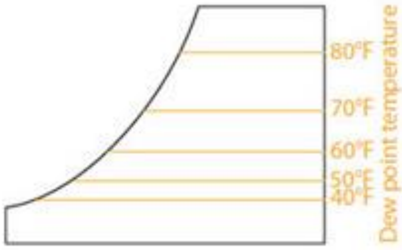


Figure 2 10 Dew Point temperature lines

At saturation, the dew point temperature equals the wet bulb temperature, which also equals the dry bulb temperature, and the RH is 100%. This temperature is shown as horizontal lines on the chart.

- Moisture content

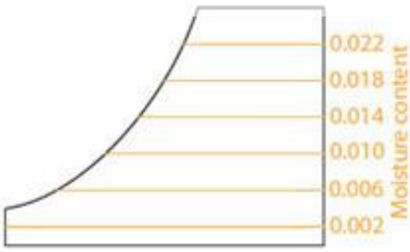


Figure 2 11 Moisture content lines

This is also known as the humidity ratio and is usually designated as W. It is the proportion of the mass of water vapor per unit mass of dry air. Humidity ratio is dimensionless, but in the US it is usually expressed as pounds of moisture per pound of dry air; elsewhere it may be expressed as grams of water per kilogram of dry air or as a percentage. The moisture content is the vertical axis of the chart.

- Enthalpy (total heat)

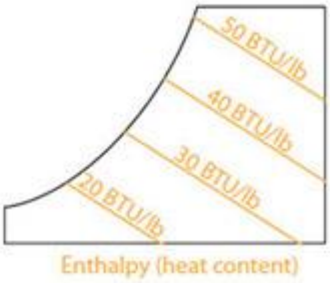


Figure 2 12 Enthalpy lines

Enthalpy (usually designated as h) is the total amount of heat energy of the moist air and therefore includes the amount of heat of the dry air and the water vapor in the air. In the approximation of ideal gases, lines of constant enthalpy are parallel to lines of constant WB temperature. Thus the enthalpy is indicated by diagonal lines on the chart.

In the US, enthalpy is measured in BTU per pound of dry air; elsewhere it is measured in Joules per kilogram of air.

- Specific volume

This is the inverse of density. Specific volume is therefore the volume per unit mass of the air sample. This is shown as diagonal lines on the chart.

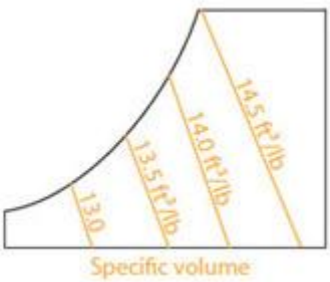


Figure 2 13 Specific volume lines

In the US, this is measured by cubic feet per pound of dry air; elsewhere it is measured by cubic meters per kilogram of dry air.

- Comfort zones

People feel comfortable within a small range of temperatures and humidities. The ranges vary based on the respective area. In the northern hemisphere, people typically wear more clothes in winter than in summer. Therefore, rooms are maintained at cooler temperatures in winter than in summer.

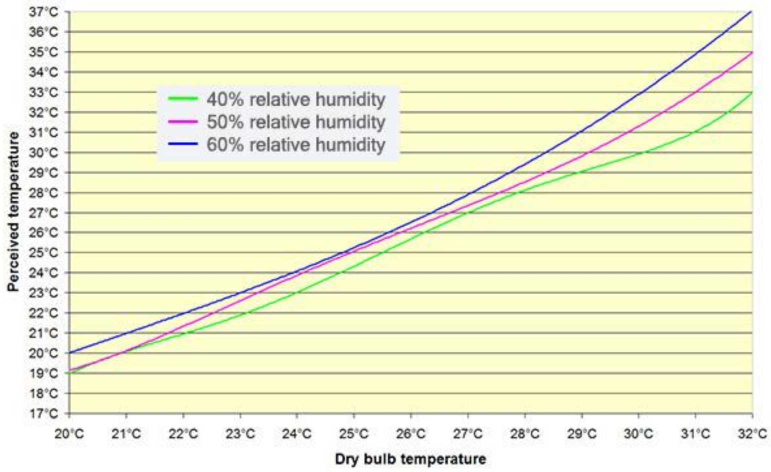


Figure 2 14 Comfort zones

People are sensitive to humidity because water evaporates from the skin and this evaporation cools the body. At a high humidity, water evaporates from the skin slowly, therefore it feels warmer. At a low humidity, water evaporates faster and feels colder. The effect of perceived increase in temperature with increase in humidity is referred to as the Heat Index and is shown graphically in the above figure.

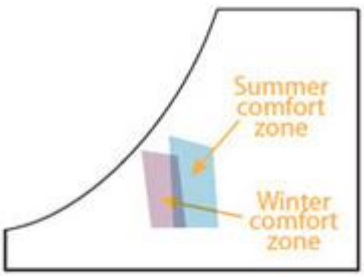


Figure 2 15 Comfort zones in Psychrometric Chart

The psychrometric chart shows the two comfort zones typically acceptable specially for US citizens.

2.5 CLTD method

The cooling load calculation procedure that will be explained here is called the CLTD/CLF method. This method first introduced in the 1979 ASHRAE Cooling and Heating Load Manual. The CLTD/CLF method is regarded as a reasonably accurate approximation of the total heat gains through a building envelope for the purposes of sizing HVAC equipment. This method was developed as a simpler calculation alternative to difficult and bulky calculation methods as used previously. Errors taken place, when using the CLTD/CLF method tends to be less than use of other methods. This procedure is relatively easy to understand and use. The CLTD/CLF method can be carried out manually or by using a computer.

2.6 Human comfort and productivity improvement

2.6.1 Thermal comfort

Thermal and atmospheric conditions in an enclosed space are usually controlled in order to ensure the health and comfort of the occupants. The former it was referred as Comfort Conditioning and the latter is called Process Air Conditioning. Complete the process of air conditioning requirements as suitable for any particular place, specific equipment or operations are involved. Specifications are generally available from the producer or manufacturer, and the ASHRAE (American Society of Heating, Refrigerating, and Air- Conditioning Engineers) Handbook of Applications provides a description of acceptable conditions for a number of generic industrial processes. Once the necessary conditions for process or machinery operation are established, attention must be paid to providing acceptable comfort, or at least relief from discomfort or physiological stress, for any people also occupying the space.

It can be considered as human beings are very versatile “machines” having the capacity to adapt to wide variations in their working environment while continuing to function, their productivity does vary according to the conditions in their immediate environment. Benefits associated with improvements in thermal environment and lighting quality include:

- Increased attentiveness and fewer errors
- Increased productivity and improved quality of products
- and services
- Lower rates of absenteeism and employee turnover
- Fewer accidents
- Reduced health hazards such as respiratory illnesses

Indeed, in many cases, air conditioning and illumination costs can be justified on the basis of increased profits.

Air conditioning and electric lights have given the less impotency of large windows, which provided light and ventilation for buildings. Although windows are much important for architectural view, day lighting, and natural ventilation, windowless interior spaces now are used to a much greater extent. Conditioned air, which is cleaner and humidity controlled along with the interior lighting level contributes to reduced maintenance of the space.

On the other hand, this improvement to building for comfort has come with the greater expense for equipment installation, maintenance, and specially for energy costs. A substantial portion of the energy consumed in buildings is related to the maintenance of comfortable environmental conditions. This refers to approximately 60 percent of the total energy consumption of office building is directed toward this task.

2.6.2 Comfort Conditions

Besides considering architectural concepts, the human environment must provide light and thermal comfort. Comfort is best defined as the absence of discomfort. People feel uncomfortable when they are too hot or too cold, or when the illuminace level is high or low against the task. Positive comfort conditions do not cause unpleasant sensations of temperature, drafts, humidity, or other aspects of the environment.

Human beings are essentially constant-temperature animals with a normal internal body temperature of about 98.6^{0}F (37.0^{0}C). Heat is produced in the body as a result of metabolic activity, so its production can be controlled, to some extent, by controlling metabolism. In such case the body rejects heat at the proper rate in order to maintain thermal equilibrium.

If the internal temperature rises or falls beyond its normal range, mental and physical operation is curtailed, and if the temperature deviation is extreme, serious physiological disorders or even death can result.

2.6.3 The Comfort Chart

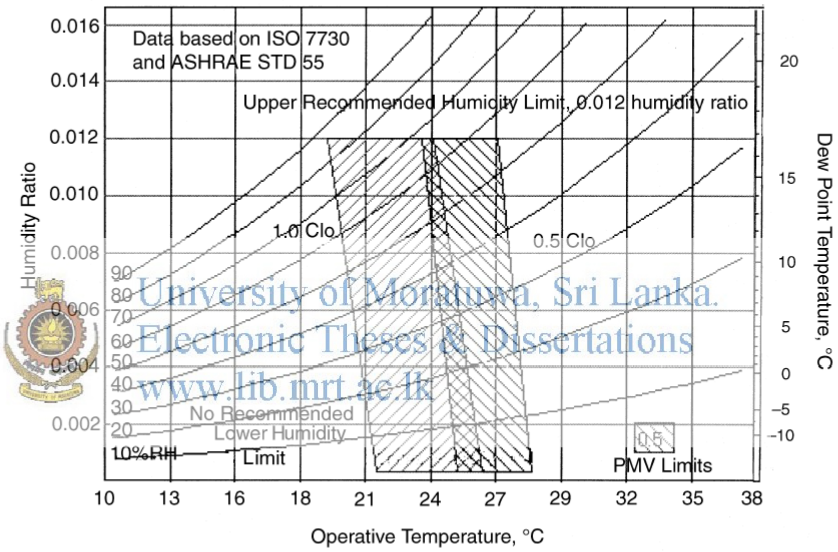


Figure 2 16 Comfort chart

The comfort chart, shown in Figure correlates the perception of comfort with the various environmental factors known to influence it. The dry-bulb temperature is indicated along the bottom. The right side of the chart contains a dew point scale, and the left side a wet-bulb temperature scale indicating guide marks for imaginary lines sloping diagonally down from left to right. The lines curving upward from left to right represent RHs.

Notice that the comfort chart in Figure is derived from the Psychrometric Chart. A description of the Psychrometric Chart and its importance is addressed in above Chapters. Two comfort envelopes or zones are defined by the shaded regions on the comfort chart—one for winter and one for summer. The thermal conditions within these envelopes are estimated to be acceptable to 80 percent of the occupants. To satisfy 90 percent of the people, the limits of the acceptable comfort zone are sharply reduced to one-third of the above ranges. The zones overlap in the 73^{0}F to 75^{0}F (23^{0}C to 24^{0}C) range. Under these conditions, thermal comfort can be defined in terms of two variables: dry-bulb air temperature and humidity.

The comfort chart was developed from ASHRAE research, which has usually been limited to lightly clothed occupants engaged in sedentary activities. The reasoning behind this approach is that 90 percent of people’s indoor work and leisure time is spent at or near the sedentary activity level. In line with this rationale, the comfort envelope defined separately and strictly applies only to sedentary and slightly active, normally clothed persons at low air velocities. For other conditions, the comfort zone must be adjusted accordingly.

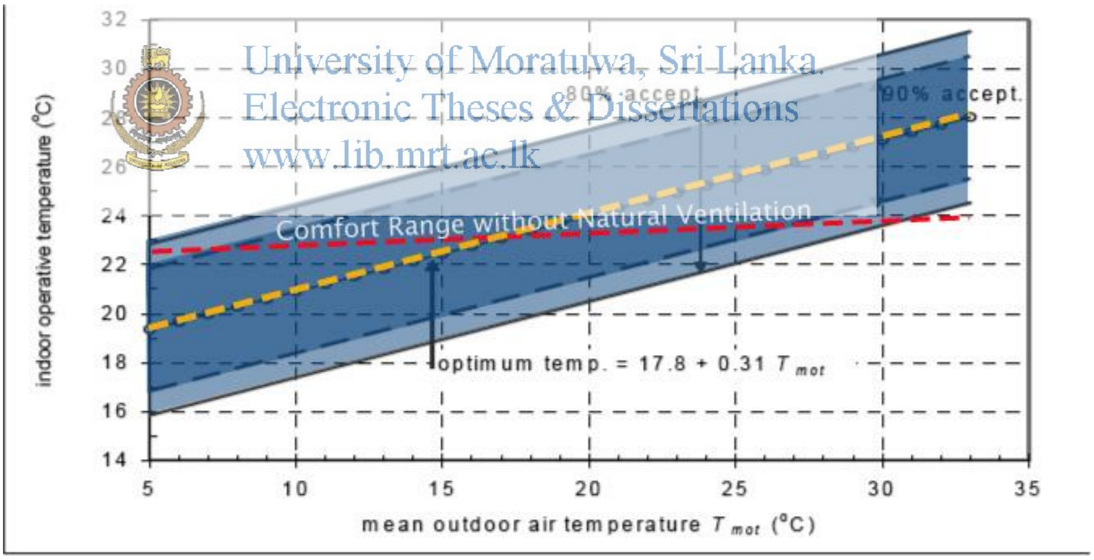


Figure 2 17 Comfort range

2.6.4 ASHRAE’s Thermal Comfort Standard

ASHRAE’s Standard 55, Thermal Environmental Conditions for Human Occupancy, describes the combinations of indoor space conditions and personal factors necessary to provide comfort. It addresses the interactions between temperature, thermal radiation, humidity, air speed, personal activity level, and clothing. The standard recommends conditions that have been found experimentally to be acceptable to at least 80 % of the occupants within a space. The operative temperature range for a office building occupants in summer clothes is 73^0F to 79^0 F (22.5^0C to 26^0C). These values are based on 60 percent RH, an activity level of approximately 1.2 met, and an air speed low enough to avoid drafts. The standard includes a chart that relates the allowable air speed to room air temperature and the turbulence of the air. However, as the temperature decreases, comfort depends more and more on maintaining a uniform distribution of clothing insulation over the entire body, especially the hands and feet. For sedentary occupancy of more than an hour, the operative temperature should not drop below 65^0F (18^0C).

Throughout the research work in door thermal conditions were maintained as follows;

- DB temperature as 240 C
- WB temperature as 130 C
- RH as 50 %
- Moisture content as 0.009 kg/kg air
- Enthalpy as 50 KJ/ Kg air
- Average illuminance level as 300 Lux

All those values of thermal condition exist within the range of human comfort zone as mentioned in above chapters. Same as that the average illuminance level also exists within the range of desirable level. Therefore it says that all the calculations have been done while maintaining the human comfort level inside the office environment.

In order to get optimum energy efficiency, electricity consumption of illumination system and HVAC system can be controlled separately as suitable for the indoor condition. Illumination system can be included with Lux level sensors in combination with the lighting system operating system to maintain the average Lux level as 300 Lux in all time. In the same time the total lighting system can be grouped according to the internal arrangement of the office and then Lux level sensors can be included for each group separately as suitable to the requirement. This arrangement will facilitate to get the desirable Lux level for total area concern as well as to get the optimum energy consumption. Then the HVAC system can be installed with DC Inverter type

Multi Split system with temperature sensors which have the facility to control the internal heat load as suitable for the requirement. This system shall be automated with each other operating system to control the electricity consumption according to the internal condition as to get the optimum energy consumption. All the systems mentioned above can be included with a Building Management System (BMS) as more convenient to the situation.

Chapter 3

METHODOLIGY

3.1 Methodology for case study

The research methodology for this case study is mainly based on the analization of energy consumption for illumination system and HVAC system with day light integration of the selected area of proposed Army Headquarter office. During the stagers of calculation for illumination system, Dialux software is used. Internal illumination level is maintained averagely as 300lux, wall to window ratio is changed from 75% to 0% in 5% intervals for each calculation stagers.

During the stage of energy consumption for HVAC system, CLTD, CLF methods are used. The same calculation stagers are done as same method done for the energy consumption for illumination system. Internal condition of the building is maintained in human comfort zone as mentioned in ASHRE standards.

The following steps are followed during the case study in order to design the proposed building models.

3.1.1 Collection of data

The collection of most relevant data is the most important part to obtain the desirable solution. Following data are collected for continue with the research work.

- The construction details and the method of the building model. The details of material to be used to construct walls, roof, floor, windows with window glass. The wall thickness, roof angles, thickness of the floor concrete, the colour code of internal painting are obtained separately. Since the selected building area is a multi storied building, condition of the upper floor and under floors are obtained.

- The climatic details of the selected location and variation of the sun path over the location.
- The grid coordination details such as latitudes and longitudes.
- The orientation of the building with respective to the north alignment.
- Inside illuminance level of existing building due to natural sun light.
- The details of the internal condition of office environment for human comfort zone (ASHRAE stranded 55).
- The number of occupancy to be occupied in the building.
- The time duration for usual office working hours.

3.1.2 Calculation process

The selected building model is simulated in Dialux light building software with the appropriate building properties. The north alignment is set according to the existing building design. The location of the building is selected as Sri Jayawardanapura which is already available in software. The appropriate luminaires are selected from the Dialux plug-in, as same as the luminaires to be used for building illumination system in proposed office complex. Illuminance level of the building model inside is selected as 300 lux according to the ASHRAE standers. Wall colours and floor tile colours are selected to improve the internal illluminance level. The climatic condition of the location is selected as clean climatic environment. The time duration for calculation is taken as usual office working hours from 0900 hours to 1700 hours.

The first stage calculation is done for a randomly selected date as 21.03.2011. During the calculation wall to window ratio is reduced from 75% to 0% in 5% intervals in order to calculate the power consumption for illumination system by maintaining the internal average lux level as 300 lux. Obtained results are represented in graphical format for analization.

Since the calculation done for randomly taken date is not given more convenient out come for best wall to window ratio, calculations are done according to the sun path over the location. In such situation the dates are inserted as 21.06.2011 and 21.12.2011 and calculations are done by Dialux software by reducing wall to window ratio as per the method mentioned above. Two different data pattern is received for the two dates mentioned above and the average values of obtained results are taken for analization to get more convention answer.

During the next stage, wall to window ratio is kept as 55% (the wall to window ratio of existing building design) and calculation are done by changing the north alignment by 45^0 intervals to get the best orientation of the building for the selected location. Dialux software is used for the calculation and data are obtained according to the sun path over the location. The average values of obtain results for two levels are taken for analization to get more convention answer as same as done in above stage.

In the next stage, the condition of the building is improved by replacing existing luminaires by more energy efficient LED luminaires and window glass are replaced by low-e energy efficient window glass. The calculations are done by Dialux software and data are obtained according to the sun path over the location. The average values of obtain results for two levels are taken for analization to get more convention answer as done in above stages.

The calculations are done with Luman method to find the number of luminaires to be used in the same building model to get comparison with software calculated values and manual calculated values.

The power consumption for HVAC system is calculated by using CLTD, CLF method. The same random date taken for power consumption calculation, for illumination system is taken for power consumption calculation for HVAC system as first stage. Properties of the building and the condition of the building and the time duration are taken as same as the said above. Wall to window ratio is reduced from 75% to 0% as usual and power consumption for illumination system for the same time duration is taken for the calculation.

The calculations are done in next stage, according to the same method mentioned above as to sun path over the location. The average values of obtain results for two levels are taken for analization to get more convention answer.

All the calculations stages done to find the power consumptions for HVAC system is done by developing the CLTD, CLF method in MS Excel work sheet which is able to save more time during calculation stages.

During the next stage power consumption for HVAC system is calculated by keeping wall to window ratio as 55% and changing the building orientation in 45^0 intervals with north alignment in order to get the optimum power consumption for best building orientation. The calculation are done according to the sun path over the location and the average values of obtain results for two levels are taken for analization to get more convention answer.

The energy efficient building model is develop with energy efficient LED luminaires, low-e window glass and building enveloping with polystyrene layers for all the walls which are subjected to heat transferring. Calculations are done as previous stages by changing wall to window ratio from 75% to 0% by 5% intervals and variation of the sun path over the location. The average values of obtain results for two levels are taken for analization to get more convention answer.

The calculated average values for same stages of power consumption for illumination system and HVAC system are added together for analization. The obtained values are represented in graphical representation to obtain the optimization values for power consumption against the wall to window ratio. The detail obtain as power consumption are converted for energy consumption for farther calculation.

A financial evaluation is done to find the payback period for each building model by calculating the energy bill for one month period. The lighting power density also calculated for each building model and compared with the maximum lighting power density values given by the Code of Practice for Energy Efficient Buildings in Sri Lanka - 2008

Chapter 4

MODLING FOR POWER CONSUMPTION; CASE STUDY FOR PROPOSE ARMY HEADQUATER OFFICE

4.1 Selection of the building model

The Directorate of Engineer Services is one branch of proposed Army Headquarters complex which suppose to be located in fourth floor of the complex. Stepping on to the concept, one part of it was selected to do the case study for this research in order to improve energy efficiency against the existing design while integrating day light for illumination for office work and optimizing the thermal condition for comfortable working environment with some practical modifications.

The complete arrangement of the 4th floor of the complex shows in Appendix "A". The floor consists with the Directorate of Engineer Services and all sub sections pertaining to the Directorate. The selected sub section is at bottom left most corner of the Appendix "A" in pink colour. A enlarge version of selected section shows in Figure 212 and dimensions of the same are as follows.

Length	- 30 m
Height	- 3 m
Width	- 15 m

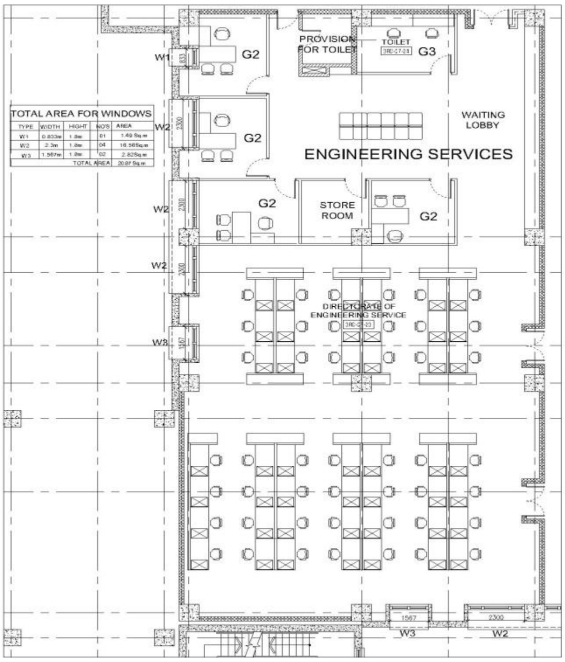


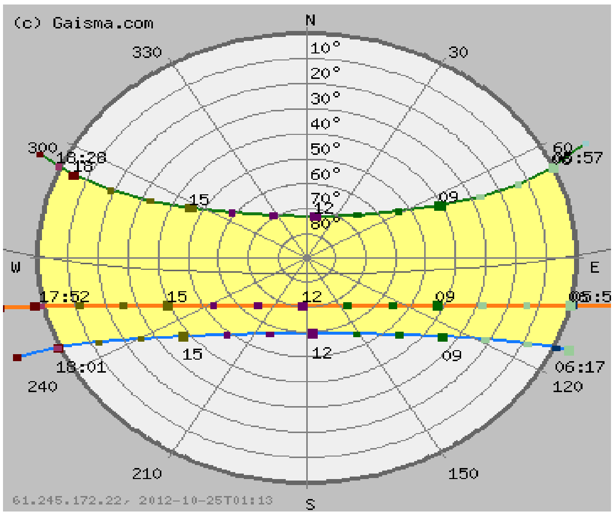
Figure 4 1 Selected section from fourth floor

4.1.1 Condition of the selected building model

All walls of the selected model were considered as constructed with cement hollow blocks and with general cement plaster. Floor and roof were considered as made with concrete and connected to another floor. Painting of all walls and ceiling were considered as painted with white paint in order to get more positive approaches to improve internal Lux level. Floor tiles colour was considered as more towards white to get the same effect as mentioned above. The roof and the floor of the model were considered as improved areas, during the calculations of heat load. A few windows were available as Figure: 2.2 in one side of the building focusing towards east and the total window area concerned against the wall area was about 55%. Assumed windows were made with general materials with normal plan glasses. Orientation of the building as located respective to the true North was 245°.

4.1.2 Geographical setup of the location

The geographical setup is concerned, the location Akuregoda, Pelawaththa locate within the longitude 80.13° and latitude 6.10°. The time specification from GMT gets 5 hours 30 minutes deviation.



21/06/2011

21/12/2011

Figure 4 2 Sun path over Sri Lanka

Source: www.gaisma.com

4.1.3 Sun path over the location

The Figure 2.2 shows the sun behavior over Sri Lanka and it was considered for the calculation for daylight integration and cooling load. It changes the altitude between 21 June and 21 December in every year.

4.2 Calculation methodology

The calculations done to analyze the power consumption were mainly focused to illumination system and HVAC system. Initial calculations for both the system were done in stagers and in last stage total consumption was evaluated to finalize solution.

4.3 The illumination system

The power consumption for illumination system was calculated with simulating in the "Dialux 4.11" light building software for each stagers against the each W/W ratio. Throughout the each calculation stagers day light integration was done to the existing illumination system inside the building model. The selection of the relevant luminaires was done from the "Dialux Plug-ins" and the details of the selected luminaire shows in Figure 4.1. The condition of the building was maintained as it was and W/W ratio was reduced from 75% to 0% in 5% intervals for each calculation. Throughout the calculation W/W ratio was reduced from bottom of the window to top of the window. This method was adopted because it causes to minimize the glare and discomfort of the occupants. In order to maintain visual comfort of the occupant illuminace level was maintained approximately within the range of "300 Lux" while integrating the day light in to the simulation.

4.3.1 Details of the selected luminaire

The luminaire taken for the calculation is one of the most commonly used type for office nature building illumination systems. This type has been proposed to use for the internal illumination system of the proposed Army HQ complex.

Type: - Philips CR200B 4xTL5-24W HFP GT

Power: - 105 W

Luminous Flux (lamp):- 7000 lm

Luminous Flux (luminaire):- 5110 lm

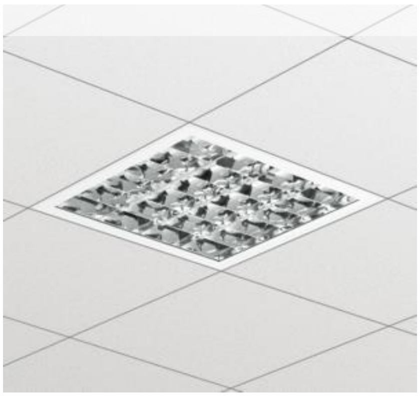


Figure 4 3 The selected luminaire

4.3.2 Consideration to the time duration for calculations

Throughout the calculations 5 time durations were selected in order to cover more office hours in a working day as 0900 hrs, 1100 hrs, 1300 hrs 1500 hrs and 1700 hrs. The calculation date was taken randomly as 21.03.2011.

4.3.3 The enclosed model

At the initial stage of calculation, total building model was considered as enclosed one. In such case Dialux software calculation was given as 35 luminaires required to maintain approximate 300 Lux on the working plane. Keeping that figure as the base, W/W ratio was kept as 75% for first calculation and there after it was reduced to 0% gradually as mentioned above. The windrow height was 2.25m at 75% W/W ratio with compare to the building area and distance from floor level to window was 0.75m.

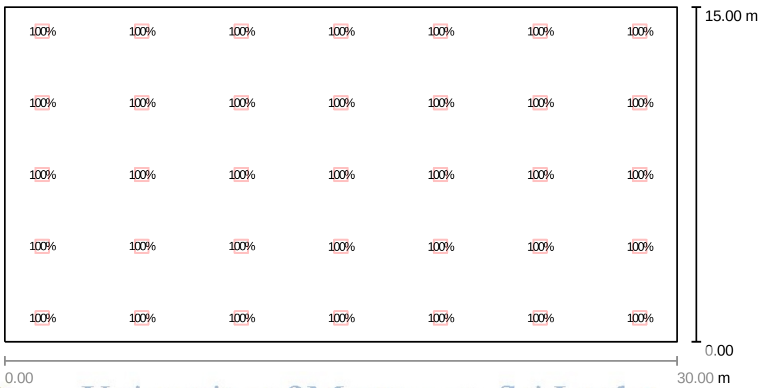


Figure 4 4 Luminaire layout plan

4.3.4 The first stage calculation

The power consumed details for lighting system for the date taken randomly, i.e. 21/03/2011 were obtained with simulating the Dialux software as predict in the table 41.

Table 4 1 Power consumption for lighting (W/W ratio Vs time)

W/W	**Power (W) consumed as Time variation**				
Ratio	**0900 Hrs**	**1100 Hrs**	**1300 Hrs**	**1500 Hrs**	**1700 Hrs**
75	0	735	1470	1470	2205
70	0	735	1470	1470	2205
65	0	735	2205	2205	2940
60	0	1470	2205	2205	2940
55	0	1470	2205	2205	2940
50	0	1470	2205	2205	2940
45	0	1470	2205	2205	2940
40	0	1470	2205	2205	2940
35	735	2205	2205	2205	3675
30	735	2205	2205	2940	3675
25	1470	2205	2940	2940	3675
20	1470	2205	2940	2940	3675
15	1470	2940	2940	3675	3675
10	2205	2940	3675	3675	3675
5	2940	3675	3675	3675	3675
0	3675	3675	3675	3675	3675

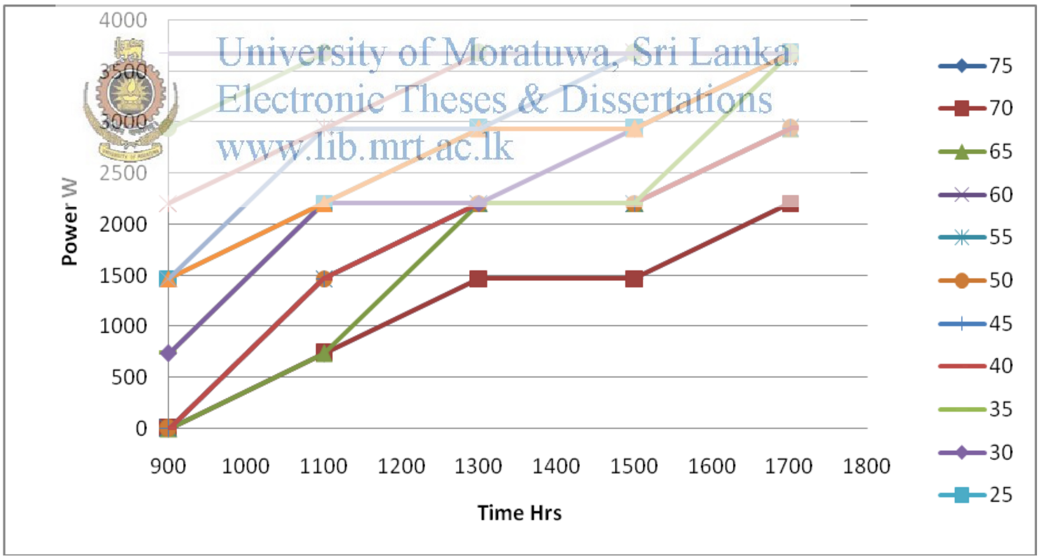


Figure 4 5 Graphical representation of the data in Table 3.1

The each graph shows the power consumption for respective W/W ratio. In the same way, area under each graph, gives Power (W) x Time (Hours) multiplication which gives the energy (Joules) consumption for lighting for respective W/W ratio.

The graph of power consumption for lighting at 35% W/W ratio was taken as the example for model calculation.

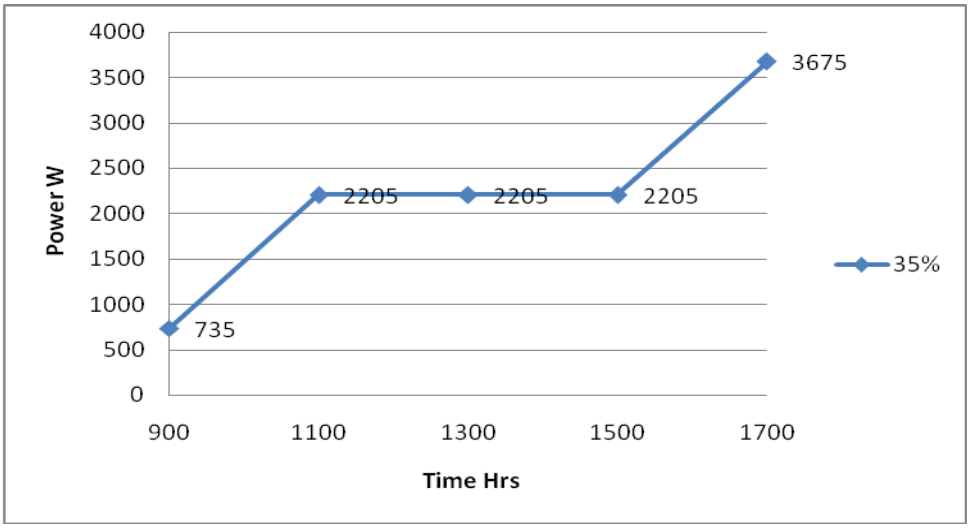


Figure 4 6 Power consumption at 35% W/W ratio

Area = ½(735+2205)x2 + 2205x4 + ½(2205+3675)x2

= 17640 WHrs

Where; W= J/s, Ws = J

Hence,

Area = 17640x3600 = 63504000 J

= **63504 kJ**

The Graph in Figure 3.4 donates the details for power consumption for lighting, for the particular W/W ratio. In the same way, all the areas underneath of each graph of Figure 3.3 were calculated separately and got the power consumption for lighting for respective W/W ratio.

The same method was adopted and developed a formula in MS Excel work sheet in order to calculate energy consumption for further calculation stagers.

Table 4 2 Energy consumption for lighting as per the W/W ratio.

W/W Ratio	**Energy (kJ)**	**W/W Ratio**	**Energy (kJ)**
75	34398	35	63504
70	34398	30	68796
65	47628	25	76734
60	52920	20	76734
55	52920	15	87318
50	52920	10	95256
45	52920	5	103194
40	52920	0	105840

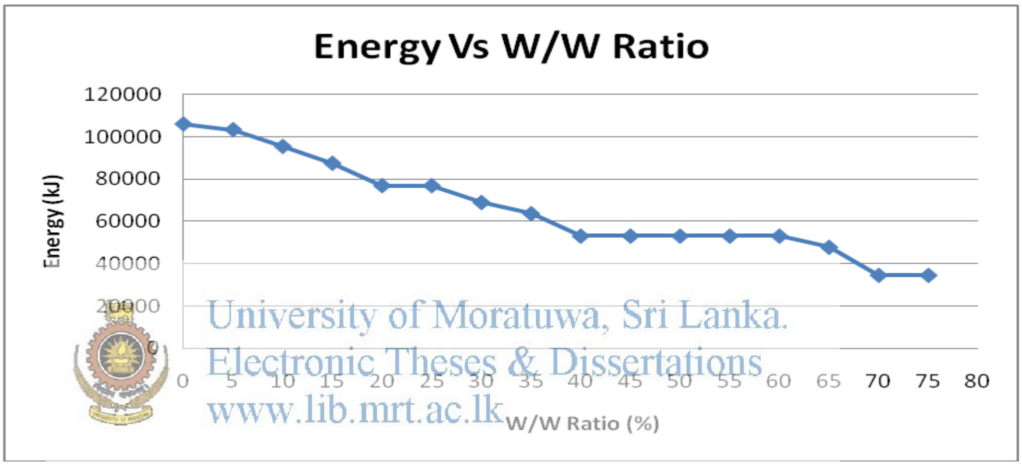


Figure 4 7 Graphical representation of data in Table 3.2

According to the graph above the energy/power consumption remain as same for certain W/W ratios which can be identified from the graph as 75%, 70%, from 60% to 40% and from 25% to 20%.

4.4 Second stage calculation

The second stage calculations were done with the Lumon method to find the number of luminaire need to obtain minimum 300 Lux in same office space. The Lumon method is widely used in theoretical aspects fro illumination calculations. The output of this method is more relevant, with compare to the other lighting calculation methods.

4.4.1 Lumon Method

Useful Lumens = Average illuminence x working area

= 300 x 30 x 15

= 135000 lumens

Installed Lumens $= \dfrac{\text{Useful Lumens}}{\mathbf{U} \times \mathbf{M}}$

Where; **U**: - Utilization Factor, **M**: - Maintenance Factor,

U = 0.6, **M** = 0.8 for general office environment

$\therefore$ Installed Lumens $= \dfrac{135000}{0.6 \times 0.8}$

= 281250 lm

Selected luminaire $= \dfrac{281250}{7000}$

No of luminaires needs = **<u>40 Nos</u>**

As Dialux calculation, No of luminaire needs = **<u>35 Nos</u>**

Note : As wall reflection factors and other illumination factors had been deeply considered in simulating with Dialux software, it gives the optimum numbers of luminaires to be used with compare to the Lumon method. Therefore it can be concluded that Dialux software can be used for further calculation of the selected building model.

4.4.2 At site readings

The illuminance level was measured in general climatic condition, inside a existing building in order to check the accuracy of the calculated data. The Lux meter reading was as follows.

- Date : 01.12.2012
- North Alignment : 240°
- Distance to window, from reading point

  Vertical = 0.75m; Horizontal = 0.75m

Table 4 3 At site readings

Time(Hrs)	Reading(Lux)	Time(Hrs)	Reading(Lux)
900	16450	1330	570
930	21570	1400	520
1000	1850	1430	470
1030	1660	1500	440
1100	1560	1530	410
1130	1290	1600	380
1200	1080	1630	270
1230	820	1700	240
1300	700		

4.4.3 Model comparison

The same building model considered to obtain above reading was imported to simulate into Dialux software and the calculations were done for the same time duration. A calculation point which was same to the place Lux meter kept was inserted to the simulating model. The reading at calculation point of the Dilux output was taken into consideration.

Table 4 4 Simulated building model data at calculation point

Time(Hrs)	Reading(Lux)	Time(Hrs)	Reading(Lux)
900	17482	1330	661
930	22557	1400	613
1000	2119	1430	576
1030	1865	1500	544
1100	1606	1530	511
1130	1364	1600	471
1200	1143	1630	417
1230	951	1700	343
1300	780		

The readings obtained from two methods were inserted into graphical mode to find the comparability of each other.

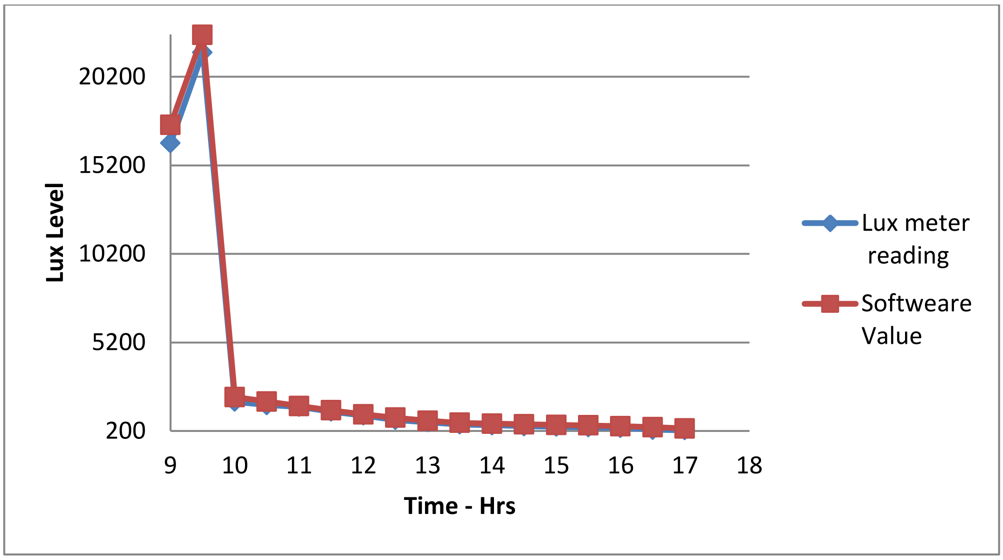


Figure 4 8 Model comparisons with graphical data

As the details of the two graphs predicted in Figure: 3.6 were not much visible to identify the difference between each other, lower values were taken separately for further reference.

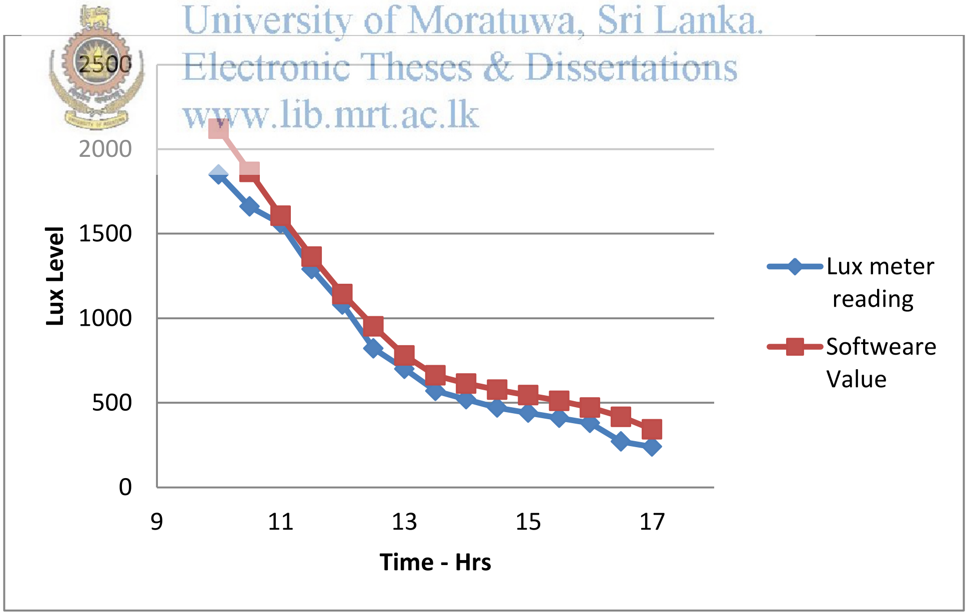


Figure 4 9 Model comparisons with graphical data (lower values)

There were some deviations observed in the graphical patterns when comparing the measured data and the calculated data. These nature deviations can be accepted when it is considering with ground factors of selected location and factors included in Dialux software during separate calculation. With reference to those details, the assumption can be made as the measured data and simulated data are substantially relevant to each other. Then the simulating details obtaining from Dialux software for the selected building model can be used for the all stage calculations of this research work.

4.5 Third Stage calculation

The same building model and the luminaire were considered and power consumption to maintain 300 Lux was calculated by changing the North Alignment (NA) from 0° to 360° by 45° intervals. Throughout the calculations W/W ratio was maintain as 55% which was complied with the existing situation.

Table 4 5 Power consumption Vs North alignment

North Alignment	**Power (W) consumed as Time variation**				
	900 Hrs	**1100 Hrs**	**1300 Hrs**	**1500 Hrs**	**1700 Hrs**
0	1470	2205	2205	2205	2205
45	2205	2205	1470	0	0
90	2205	2205	735	0	0
135	2205	2205	735	0	0
180	1470	1470	1470	1470	2205
225	0	1470	2205	2205	2940
270	0	1470	2205	2205	2940
315	0	1470	2205	2205	2940
360	1470	2205	2205	2205	2205

Same method, mentioned in first stage calculation, was adopted to calculate energy consumption.

Table 4 6 Energy consumption Vs North alignment

North Alignment	**Energy (kJ)**	**North Alignment**	**Energy (kJ)**
0	30429	225	26460
45	17199	270	26460
90	14553	315	26460
135	14553	360	30429
180	22491		

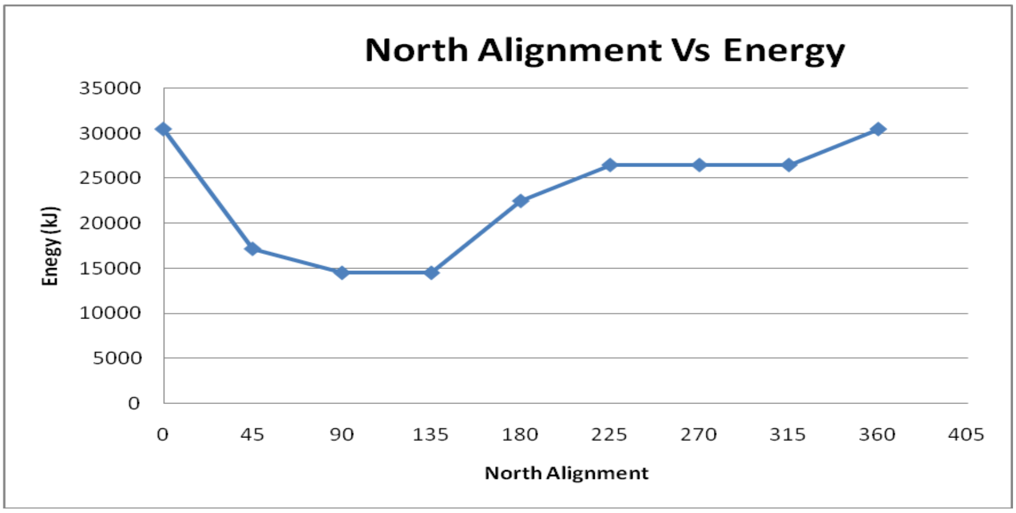


Figure 4 10 Graphical representation of data in Table 4.6

Note: - Even the North Alignment is changed, energy consumption remains as same form 90^0 to 135^0 and from 225^0 to 315^0. The Daylight factor remained unchanged with respective to the North Alignment of the building hence the power consumption remained as unchanged.

The calculation done for random date above, had not given the reasonable solution for optimum energy consumption for desirable W/W ratio. Therefore, all the calculations were done according to the sun path variation over Sri Lanka, which changes in between 21.06.2011 and 21.12.2011 during the particular year concerned. The same calculation method was adopted for every stages of calculation.

4.6 Fourth Stage Calculation

The same building model and the luminaire were considered for calculation during this stage. In order to get the optimum solution, W/W ratio has been reduced from 75% to 0% in 5% intervals as did in earlier stages and power consumption for lighting was calculated for 2 separate dates respectively as 21.06.2011 and 21.12.2011. In addition to that extra calculation was done to 40% of W/W ratio because the critical point of calculation was fund in between the particular area.

Table 4 7 Power consumption for lighting Vs W/W ratio as 21/06/2011

W/W RATIO	**Power (W) consumed as Time variation**				
	900 Hrs	**1100 Hrs**	**1300 Hrs**	**1500 Hrs**	**1700 Hrs**
75	0	735	1470	1470	2205
65	735	1470	2205	2205	2205
55	735	1470	2205	2205	2205
45	1470	2205	2205	2205	2205
40	1470	2205	2205	2205	2205
35	1470	2205	2205	2205	2940
25	2205	2205	2940	2940	2940
15	2205	2940	2940	3675	3675
5	3675	3675	3675	3675	3675
0	3675	3675	3675	3675	3675

Table 4 8 Power consumption for lighting Vs W/W ratio as 21/12/2011.

W/W Ratio	**Power (W) consumes as Time variation**				
	900 Hrs	**1100 Hrs**	**1300 Hrs**	**1500 Hrs**	**1700 Hrs**
75	0	1470	1470	2205	2940
65	0	1470	1470	2205	2940
55	735	1470	2205	2205	2940
45	735	1470	2205	2205	3675
40	1470	2205	2205	2205	3675
35	1470	2205	2205	2205	3675
25	1470	2205	2940	2940	3675
15	2205	2940	2940	3675	3675
5	3675	3675	3675	3675	3675
0	3675	3675	3675	3675	3675

The energy consumption was calculated using the same method. The reduction of W/W ratio was done in 10% intervals during the calculations and that was changed to 5% intervals W/W ratio from 45% to 35% where as the critical point for W/W ratio was found in between this range.

Table 4 9 Energy consumption Vs W/W ratio as to sun path.

W/W Ratio-%		75	65	55	45	40
Date	**21/06/2011**	34398	52920	52920	60858	60858
	21/12/2011	47628	47628	55566	58212	66150
W/W Ratio-%		35	25	15	5	0
Date	**21/06/2011**	63504	76734	89964	105840	105840
	21/12/2011	66150	76734	89964	105840	105840

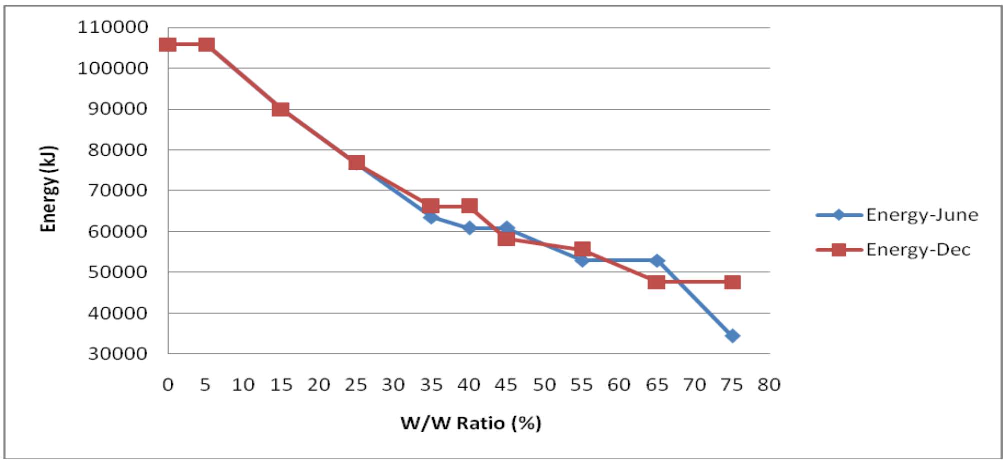


Figure 4 11 Graphical representation of data in Table 4.9

Note:- Power consumption for lighting as W/W ratio changes in between the two lines of the graph above for all circumstances through the year.

4.7 Fifth Stage Calculation

The W/W ratio was maintained throughout the calculation as 55%, and then the power consumption was obtained by changing the North Alignment according the sun path.

Table 4 10 Power consumption for lighting Vs North Alignment as to sun path.

North Alignment	Date	Power (W) consumed as Time variation			
		900 Hrs	1100 Hrs	1300 Hrs	1500 Hrs
0	21/06/2011	1470	2205	2205	2205
	21/12/2011	3675	2205	2205	2940
45	21/06/2011	2205	2205	2205	1470
	21/12/2011	3675	2205	2205	2940
90	21/06/2011	2205	2205	2205	735
	21/12/2011	3675	2205	2205	735
135	21/06/2011	2205	1470	735	0
	21/12/2011	2940	1470	0	0
180	21/06/2011	1470	735	0	0
	21/12/2011	2940	0	0	0
225	21/06/2012	0	0	0	1470
	21/12/2012	2940	0	0	2205
270	21/06/2013	0	0	1470	1470
	21/12/2013	2940	1470	2205	2940
315	21/06/2014	0	1470	2205	2205
	21/12/2014	2940	2205	2205	2940

Table 4 11 Energy for lighting Vs North Alignment as to sun path

		Energy(kJ) consumption			
North Alignment		**0**	**45**	**90**	**135**
Date	**21/06/2011**	22491	22491	21168	11907
	21/12/2011	27783	27783	23814	10584
North Alignment		180	225	270	315
Date	**21/06/2011**	5292	2646	7938	17199
	21/12/2011	5292	9261	23814	26460

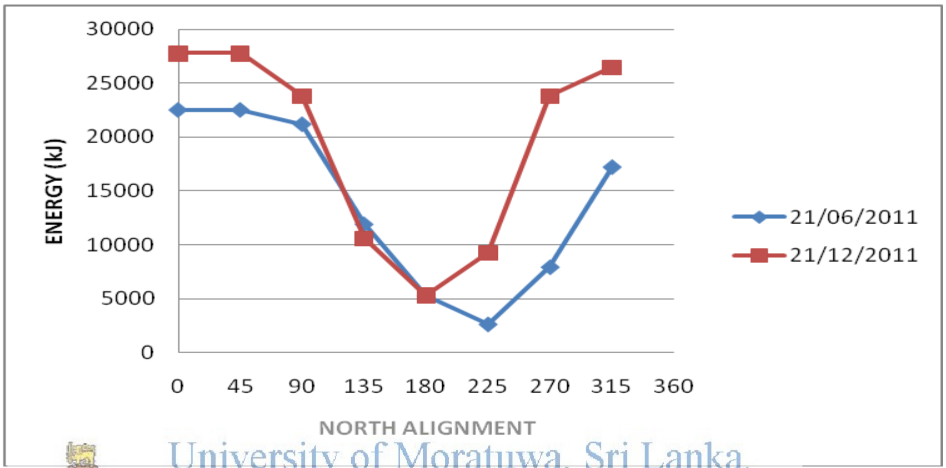


Figure 4 12 Graphical representations of data in Table 4.11

According to the above Figure, the power consumption for lighting laid in between these two graphs for any given date of the year. Further it shows that the power consumption does not change N/A in between 90^0 to 180^0 remarkably, as the other areas show a considerable difference. Since the day light factor remained as same with compare to the building orientation the energy consumption also will not be changed.

In order to obtain more convenient solution average values of the details given in Table 3.10 was taken for further consideration.

Table 4 12 Average of the values in Table 3.10

North Alignment	**0**	**45**	**90**	**135**
Energy	25137	25137	22491	11245.5
North Alignment	180	225	270	315
Energy	5292	5953.5	15876	21829.5

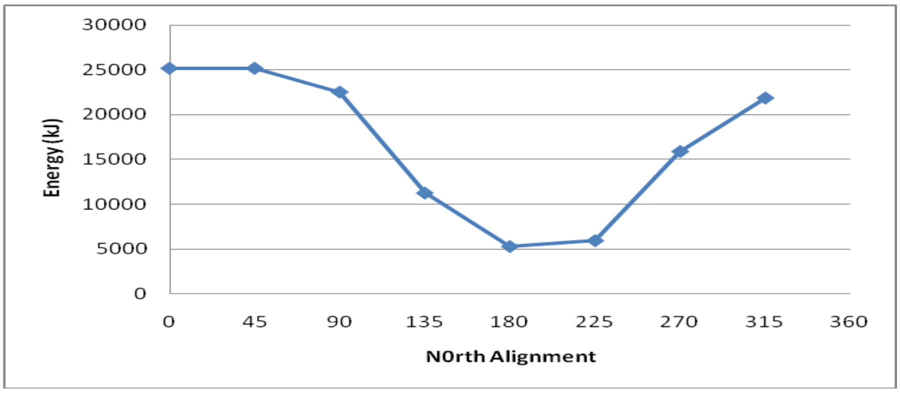


Figure 4 13 Graphical representations of data in Table 4.12.

According to the Figure 3.9 best orientation for the respective building model for optimum energy consumption of lighting was obtained at 180^0.

4.8 Sixth Stage Calculation

The north alignment of the building model was kept as 180^0 and other conditions were maintained as same and the power consumption was calculated according to the sun path. The Dialux software was used as same as in previous stages throughout the calculation. The average illumination level was maintained as 300 Lux throughout the calculation.

Table 4 13 Power consumption for lighting Vs W/W ratio on 21/06/2011

W/W Ratio	Power (W) consumed as Time variation				
	900 Hrs	1100 Hrs	1300 Hrs	1500 Hrs	1700 Hrs
75	1470	1470	1470	1470	2205
65	2205	2205	2205	2205	2205
55	2205	2205	2205	2205	2205
45	2205	2205	2205	2205	2205
40	2205	2205	2205	2205	2205
35	2205	2205	2205	2205	2940
30	2940	2940	2940	2940	2940
25	2940	2940	2940	2940	2940
15	3675	3675	3675	3675	3675
5	3675	3675	3675	3675	3675
0	3675	3675	3675	3675	3675

Table 4 14 Energy consumption for lighting Vs W/W ratio on 21/06/2011

W/W Ratio	75	65	55	45	40	35
Energy (kJ)	44982	63504	63504	63504	63504	66150
W/W Ratio	30	25	15	5	0	
Energy (kJ)	84672	84672	105840	105840	105840	

Table 4 15 Power consumption for lighting Vs W/W ratio on 21/12/2011

W/W Ratio	Power (W) consumed as Time variation				
	900 Hrs	1100 Hrs	1300 Hrs	1500 Hrs	1700 Hrs
75	735	735	735	735	2205
65	735	735	735	735	2205
55	1470	1470	1470	1470	2940
45	1470	1470	1470	1470	2940
40	1470	1470	1470	1470	2940
35	1470	1470	1470	1470	3675
30	2205	2205	2205	2205	3675
25	2205	2205	2205	2205	3675
15	2205	2205	2205	2205	3675
5	3675	3675	3675	3675	3675
0	3675	3675	3675	3675	3675

Table 4 16 Energy consumption for lighting Vs W/W ratio on 21/12/2011

W/W Ratio	75	65	55	45	40	35
Energy (kJ)	26460	26460	47628	47628	47628	50274
W/W Ratio	30	25	15	5	0	
Energy (kJ)	68796	68796	68796	105840	105840	

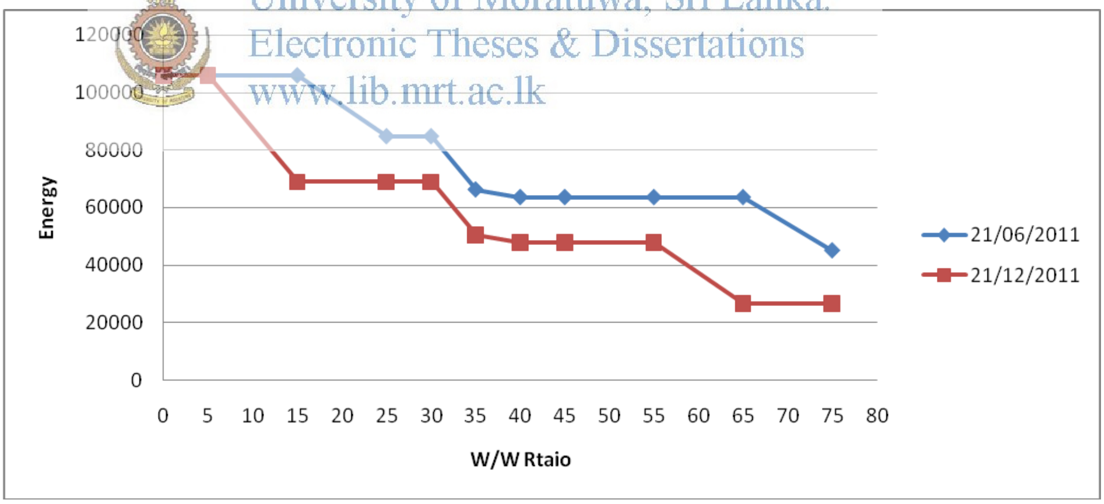


Figure 4 14 Graphical representations of data in Table 4.15

Energy consumption for any particular day for the year concerned to be laid in between these two graphs. The areas shown as energy consumption unchanged against the W/W ratio occurs due to the constant Daylight factor.

4.9 Seventh stage Calculation

In order to improve energy efficiency further, the existing luminaires were replaced by more energy efficient luminaires and window glass was replaced with VISTACOOL and SOLACOOL with sun gate 500 Low-E glasses. The calculations were done simulating with Dialux software to find the power consumption for each W/W ratio. Other conditions of the building were maintained as same.

Details of the luminaire

Type: - Philips CR 4343 W30L1201 x LED 88/830 AC - MLO

Power: - 77 W

Luminous Flux: - 6000 lm

Figure 4 15 LED luminaire

In the initial calculation stage a totally enclosed model was taken in to consideration. According to the calculations the number of luminaires needed to maintain average 300 Lux was 30 in numbers. This result was taken as the base for further calculations.

Table 4 17 Power consumption for lighting against W/W ratio on 21/06/2011

W/W Ratio	Power (W) consumed as Time variation					Energy (kJ)
	900 Hrs	1100 Hrs	1300 Hrs	1500 Hrs	1700 Hrs	
75	0	924	1386	1386	1386	31601
65	0	924	1386	1386	1386	31601
55	462	924	1386	1386	1386	33264
45	462	924	1386	1386	1848	34927
35	924	1386	1386	1848	1848	43243
25	924	1386	1848	1848	2310	48233
15	1386	1848	2310	2310	2310	59875
5	1386	2310	2310	2310	2310	63202
0	2310	2310	2310	2310	2310	66528

Table 4 18 Power consumption for lighting against W/W ratio on 21/12/2011

W/W Ratio	Power (W) consumed as Time variation					Energy (kJ)
	900 Hrs	1100 Hrs	1300 Hrs	1500 Hrs	1700 Hrs	
75	0	462	1386	1386	1848	29938
65	0	462	1386	1386	1848	29938
55	0	924	1386	1386	1848	33264
45	0	924	1386	1386	2310	34927
35	462	1386	1386	1848	2310	43243
25	924	1386	1848	2310	2310	51559
15	1386	1386	2310	2310	2310	56549
5	2310	2310	2310	2310	2310	66528
0	2310	2310	2310	2310	2310	66528

Table 4 19 Energy consumption for lighting on 21/06/2011 and 21/12/2011

W/W Ratio	Energy (kJ)-06	Energy (kJ)-12	W/W Ratio	Energy (kJ)-06	Energy (kJ)-12
75	31601	29938	25	48233	51559
65	31601	29938	15	59875	56549
55	33264	33264	5	63202	66528
45	34927	34927	0	66528	66528
35	43243	43243			

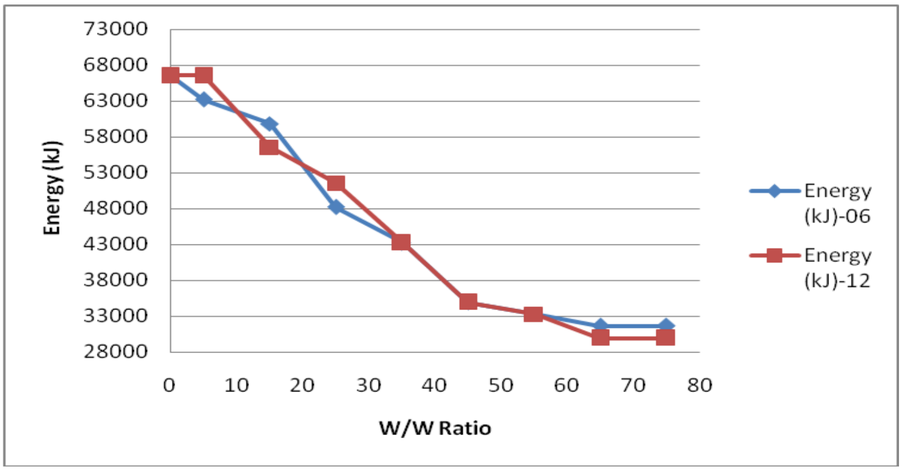


Figure 4 16 Graphical representations of data in Table 4.18.

Note:- It was not given a remarkable different in between the two graphs above and therefore it can be assumed the energy consumption was not changed much as to sun path for the selected building model.

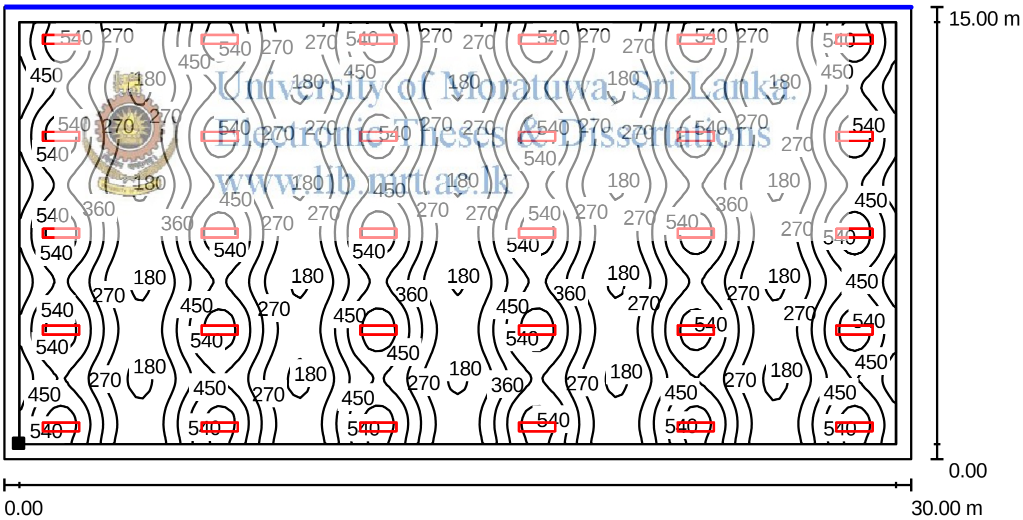


Figure 4 17 Luminaire arrangement and Isolines W/W ratio at 0%

4.10 HVAC System

Power consumption for HVAC system was calculated with CLTD, CLF method which is basically known as a hand calculation method. This method was more suitable for step by step calculations which were done by reducing the W/W ratio to find the power consumption for different levels. Since the design for HVAC system was not much complex, the software available as eQUEST and ENER-WIN, were not needed to get more feasible solutions. The CLTD, CLF method became more faster when it was formulated into a MS Excel work sheet. In the same way different stages of calculation were included into separate sheets which were easier to pick up values for further calculations.

4.10.1 Heat load calculation – CLTD, CLF Method

CLTD,CLF method was used for all the calculation stages as example given below.
Roof : Assume space above the roof as a conditions space since no heat transfer to the room.

Roof = **<u>0 W</u>**

Walls : $CLTD_{(corrected)} = (CLTD + LM) \times K + (25.5 - T_R) + (To - 29.4)$

Wall, $q_{wall} = UA \times CLTD_{(corrected)}$

ENE: - $(2.36\ W/m^2\ K \times 45m^2)$ [(6+0)+1 CLTD + (25.5 - 24) C° + (32 - 29.4) C°]

= **1072.62 W**

SSE $_{(Glass)}$:- $(2.36\ W/m^2\ K \times 54m^2)$ [(5-1.6) x 1 CLTD+(25.5 - 24) C°+ (32 - 29.4) C°]

= **955.8 W**

WSW: - $(2.36\ W/m^2\ K \times 45m^2)$ [(5 - 1.1) x 1 CLTD + (25.5 - 24) C° + (32 - 29.4) C°]

= **849.6 W**

NNW: - $(2.36\ W/m^2\ K \times 90m^2)$ [(4 - 1.1) x 1 CLTD + (25.5 - 24) C° + (32 - 29.4) C°]

= **1486.8 W**

Total heat gain from walls = **<u>4364.82 W</u>**

Glass (conduction):- $CLTD_{(corrected)} = CLTD + (25.5 - tr) + (to - 29.4)$

Glass (conduction) $q_{(con)} = UA \times CLTD_{corrected}$

$q_{cond} = (5.85\ W/m^2\ K \times 36\ m^2)$ [1 CLTD + 25.5 - 24) C° + (32 - 29.4)]

= **<u>1074.06 W</u>**

Glass - Solar A (SL) (SHGF) (CLF)

$q_{solar} = 36m^2 \times 1 \times 347\ W/m^2 \times 0.38$ = **<u>4746.96 W</u>**

Internal Sensible load

People, q_{sen} = N (SHG) (CLF)

$q_{sen} = 45 \times 75\ W \times 0.05$ = **<u>168.75 W</u>**

Lights, q = (heat gain) (CLF) Input = W x ful x fsa

q_{light} = 0 x 0.9 x 1 = **<u>0 W</u>**

Ventilation sensible heat gain (By pass) q_{sen} = 1.25 x Q - BF x (to - tr)

q_{sen} = 1.23 x 127.5 w x 0.1 x (32 - 24) = **<u>125.46 W</u>**

Internal latent heat load

People, q_{lat} = N (LHG) (CLF)

q_{lat} = 45 x 55 W x 0.05 = **<u>123.75 W</u>**

Ventilation sensible heat gain (By pass) q_{lat} = 3010 x Q x BF x (Wo - Wr)

q_{lat} = 3010 x 127.5 x 0.1 x (0.026 - 0.009) = **<u>652.42 W</u>**

Ventilation sensible heat gain q_{sen} = 1.23 x Q x (1 - BF) x (to - tr)

q_{sen} = 1.23 x 127.5 w x (1 - 0.1) x (32 - 24) = **<u>1129.14 W</u>**

Ventilation latent heat gain q_{tot} = 3010 x Q x (1 - BF) x (Wo - Wr)

q_{tat} = 3010 x 127.5 x (1 - 0.1) x (0.026 - 0.009) = **<u>5871.75 W</u>**

The total cooling load = **18275 W** (cooling)

(Summation of all under lined values) = **62351 BTU/hr**

= **5 TR**

The selected A/C unit COP is 3.75, and therefore power consumption for calculated stage:-

18275/3.75 = **<u>4873.33 W</u>** (electrical)

4.10.2 Second Stage Calculation

The same building model taken for energy calculations for lighting system with same building conditions was taken into consideration throughout for this stage calculation. The calculation date was taken as 21.03.2012 which was the same date taken for lighting calculation.

Table 4 20 Power consumption for HVAC system Vs W/W ratio

W/W Ratio	Power (W) consumed as Time variation				
	900 Hrs	1100 Hrs	1300 Hrs	1500 Hrs	1700 Hrs
75	6384	8230	8939	8673	8657
70	6203	7967	8670	8453	8483
65	6021	7703	8586	8419	8494
60	5840	7626	8317	8200	8320
55	5659	7362	8048	7981	8146
50	5477	7099	7779	7761	7972
45	5296	6836	7510	7542	7798
40	5114	6573	7241	7323	7624
35	5118	6496	6972	7104	7636
30	4936	6232	6703	7069	7462
25	4755	5969	6620	6850	7288
20	4573	5706	6351	6631	7114
15	4392	5628	6082	6597	6940
10	4581	5365	5998	6378	6766
5	4585	5287	5729	6158	6592
0	4588	5024	5460	5939	6418

The same method used to calculate the energy consumption in above stagers was taken in to consideration during this stage also to calculate energy consumption for HVAC system.

Table 4 21 Energy for HVAC system Vs W/W ratio

W/W RATIO	Energy (kJ)	W/W RATIO	Energy (kJ)
75	120101	35	97013
70	116757	30	94335
65	115079	25	91657
60	112403	20	88313
55	109057	15	86302
50	105712	10	84291
45	102368	5	81947
40	99023	0	78934

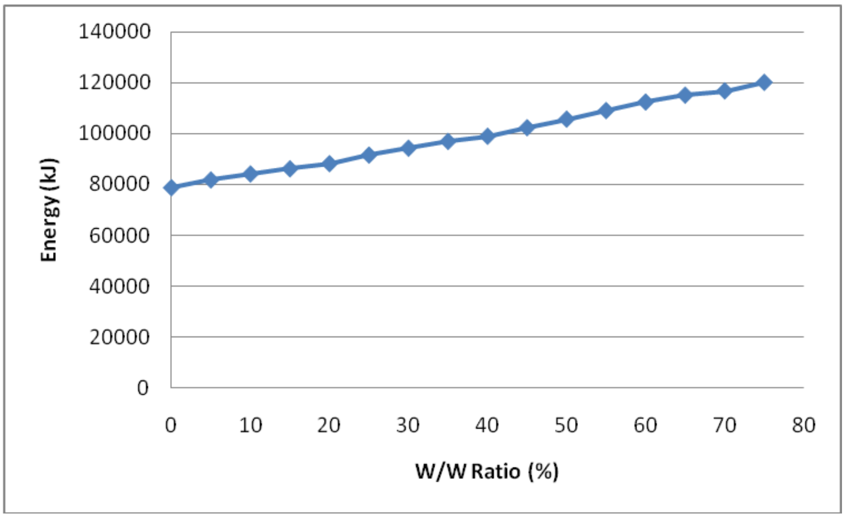


Figure 4 18 Graphical representations of data in Table 4.20.

It can be observed that the energy consumption for HVAC system changes gradually from W/W ratio 0% to 75% as graph above. The maximum consumption of energy was observed 75% of W/W ratio and minimum at 0%.

4.10.3 Third Stage Calculation

During this stage calculation the W/W ratio of the same building model kept as 55% as take in lighting load calculation and the other conditions of the building was kept as same. North Alignment was changed from 0° to 360° in 45° intervals and power consumption was calculated as follows.

Table 4 22 Power Consumption for HVAC system as to North Alignment

W/W Ratio	Power (W) consumed as Time variation				
	900 Hrs	1100 Hrs	1300 Hrs	1500 Hrs	1700 Hrs
0	5718	6692	7535	8025	8386
45	6174	7098	7727	8746	10982
90	6405	7366	8752	11608	13068
135	6430	7459	9100	11097	11890
180	5355	6484	7473	7733	7910
225	8890	10487	10264	9933	9858
270	10238	10665	10174	9897	9813
315	7987	8187	8571	8879	9137
360	5718	6692	7535	8025	8386

The energy consumption was calculated with the same method and the following data was received.

Table 4 23 Energy Consumption for HVAC system Vs North Alignment

North Alignment	Energy (kJ)	North Alignment	Energy (kJ)
0	105499	225	144206
45	115737	270	146743
90	134865	315	123117
135	132538	360	105499
180	101957		

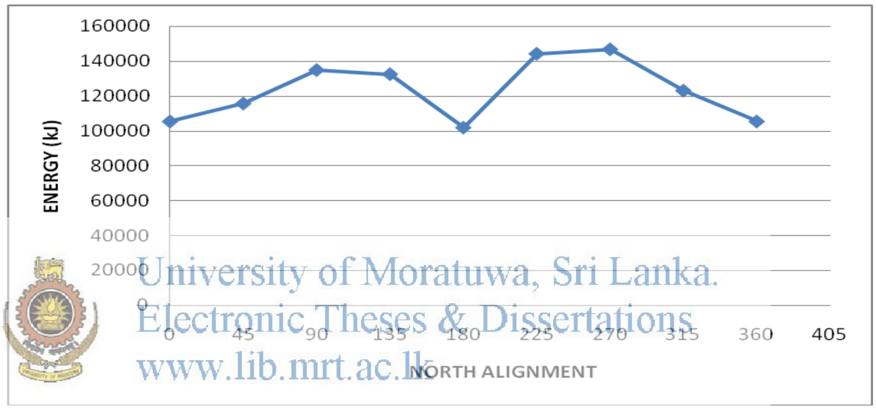


Figure 4 19 Graphical representation of data in Table 4.22

The consumption of energy for HVAC system varies significantly against the North Alignment according to the above graph and optimum consumption observed at North Alignment 180^0. The exposed wall area to the solar radiation of the building was high form sunrise to the sunset. Therefore more heat gain was developed inside the building and the energy needed to maintain desirable thermal condition was increased.

4.10.4 Fourth Stage Calculation

During the fourth stage calculation the conditions of the building model were maintained same and the power consumption for HVAC system was calculated according to the sun path. The W/W ratio was changed from 75% to 0% in 10% intervals as previous methods.

Table 4 24 Electricity Consumption Vs W/W ratio as 21/06/2011

W/W Ratio	**Power (W) consumed as Time variation**				
	900 Hrs	**1100 Hrs**	**1300 Hrs**	**1500 Hrs**	**1700 Hrs**
75	3290	4483	5234	5434	5757
65	3307	4459	5193	5430	5613
55	3138	4250	4966	5241	5469
45	3155	4226	4740	5052	5326
40	3071	3961	4466	4796	5093
35	2987	4017	4513	4862	5367
25	3003	3808	4472	4858	5224
15	2834	3784	4246	4854	5264
5	3036	3760	4205	4665	5122
0	2952	3656	4092	4571	5050

Table 4 25 Electricity Consumption Vs W/W ratio as 21/12/2011

W/W Ratio	**Power (W) consumed as Time variation**				
	900 Hrs	**1100 Hrs**	**1300 Hrs**	**1500 Hrs**	**1700 Hrs**
75	6829	9924	10384	9615	9099
65	6185	8974	9432	8854	8495
55	5725	8024	8664	8092	7890
45	5081	7075	7711	7330	7471
40	4944	6785	7235	6949	6889
35	4622	6311	6759	6569	6867
25	3978	5361	5991	5992	6263
15	3518	4597	5038	5416	5659
5	3245	3833	4271	4654	5054
0	2922	3358	3794	4273	4752

The energy consumption was calculated according to the usual method.

Table 4 26 Energy Consumption Vs W/W ratio as to sun path

W/W Ratio		75	65	55	45	40
Date	**21/06/2011**	141653	140701	135078	131458	124598
	21/12/2011	272787	249111	227435	204428	193579
W/W Ratio		35	25	15	5	0
Date	**21/06/2011**	126499	124212	121921	120307	117495
	21/12/2011	182754	161744	141404	121731	109892

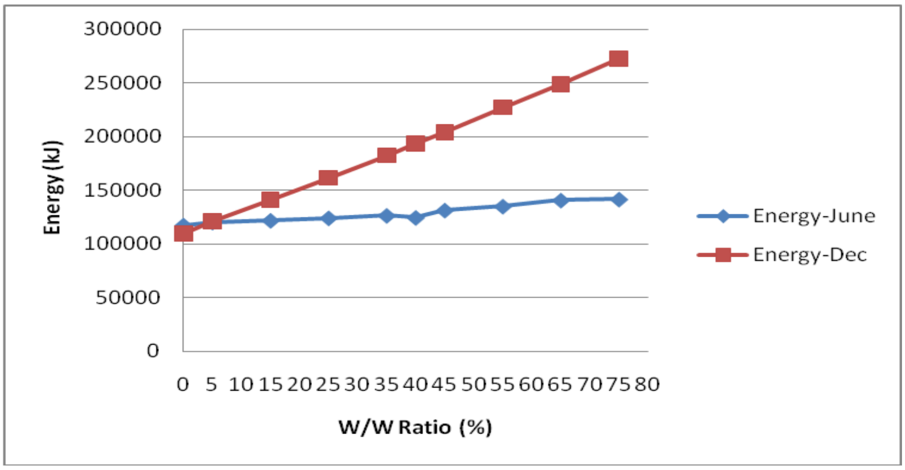


Figure 4 20 Graphical representation of data in Table 4.25

It is observed a significant variation of energy consumption in between the two identical dates. The changers occurred in exposed area of the building for the thermal radiation due to sun path has coursed the changers in energy consumption for HVAC system. The energy consumption for any given date lies in between the two graphs above.

4.10.5 Fifth Stage Calculation

During this stage calculation the W/W ratio was maintained as 55% and all other conditions of the building model was maintained as same. The power consumption for HVAC system was calculated against the sun path.

Table 4 27 Power Consumption Vs North Alignment as to sun path.

North Alignment	Date	Power (W) consumed as Time variation			
		900 Hrs	1100 Hrs	1300 Hrs	1500 Hrs
0	21/06/2011	5257	6534	7629	8145
	21/12/2011	4739	5123	5937	6609
45	21/06/2011	4417	5404	6261	7717
	21/12/2011	4183	4593	5311	6309
90	21/06/2011	4439	5361	6629	8640
	21/12/2011	4941	5507	6818	8978
135	21/06/2011	3945	4708	5756	6664
	21/12/2011	5015	5794	7914	10696
180	21/06/2011	3685	4467	5155	5446
	21/12/2011	5249	6879	8755	8778
225	21/06/2012	4701	5537	5664	6143
	21/12/2012	9080	9804	9067	9022
270	21/06/2013	7534	7669	7578	7418
	21/12/2013	8684	8420	8066	8049
315	21/06/2014	6903	6914	7192	7438
	21/12/2014	4828	4905	5344	5982

The energy consumption for the same system was calculated with the usual method.

Table 4 28 Energy Vs North Alignment as to sun path

North Alignment		0	45	90	135
Date	**21/06/2011**	75111	63837	66706	56769
	21/12/2011	60243	54541	69424	77627
North Alignment		180	225	270	315
Date	**21/06/2011**	51073	59843	81805	76598
	21/12/2011	81530	100519	89470	56357

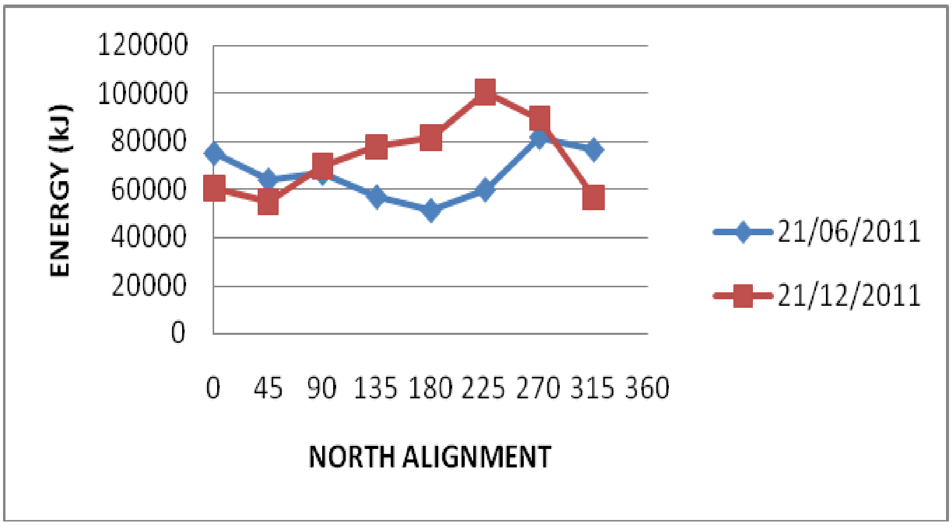


Figure 4 21 Graphical representations of data in Table 4.27

It is observed a considerable variation in between the two graphs of the above figure. The changers occurred in exposed area of the building for the thermal radiation due to orientation of the building has coursed the changers in energy consumption for HVAC system. The energy consumption for the HVAC system, varies in between the two graphs for any given date and building orientation of the particular year.

In order to obtain more desirable solution for further calculations the average values of the data were taken in Table 3.27.

Table 4 29 Energy (Average) Vs North alignment as to sun path

North Alignment	0	45	90	135
Energy(Avg)	67677	59189	68065	67198
North Alignment	180	225	270	315
Energy(Avg)	66302	80181	85637	66477

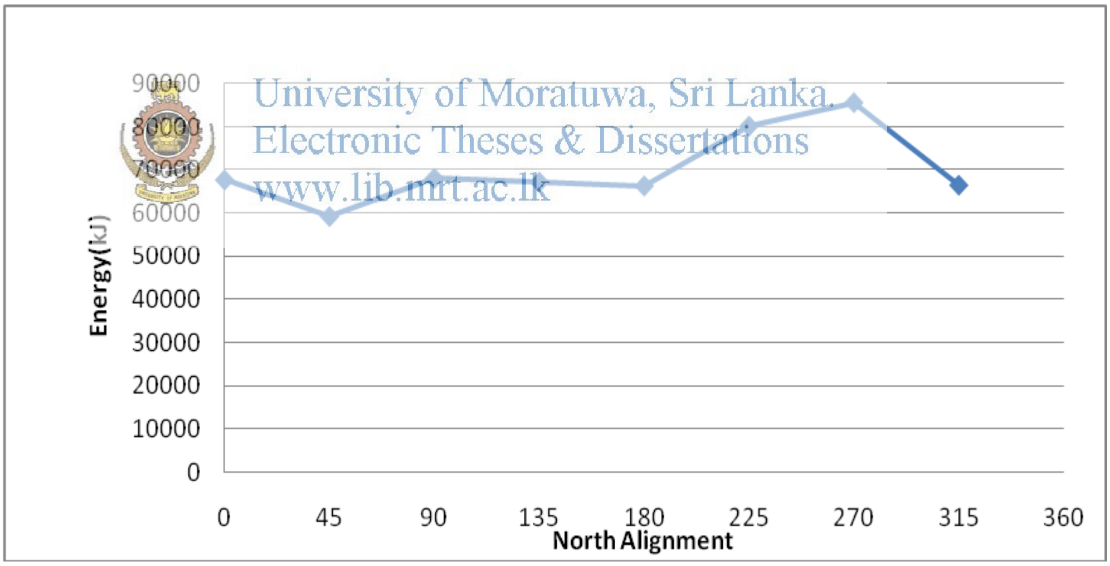


Figure 4 22 Table 4 30Graphical representation of data in Table 4.28

The graph in above figure shows the variation of energy consumption for average values. According to that the minimum value is observed at North Alignment 45^0 and maximum in North Alignment 275^0.

Chapter 5

ANALYSIS

5.1 Total energy consumption

5.1.1 Total energy consumption for first stage calculation

The summation of the energy consumption data of random date i.e. 21/03/2011 for HVAC system and lighting system against respective W/W ratios were taken into consideration in order to calculate the total energy consumption.

Table 5 1 Energy (Lighting + A/C) Vs W/W ratio (calculation done 21/03/2011)

W/W RATIO	Energy (kJ)Ligt	Energy (kJ)AC	Energy (kJ)Total	W/W RATIO	Energy (kJ)Ligt	Energy (kJ)AC	Energy (kJ)Total
75	17199	120101	137300	35	31752	97013	128765
70	17199	116757	133956	30	34398	94335	128733
65	23814	115079	138893	25	38367	91657	130024
60	26460	112403	138863	20	38367	88313	126680
55	26460	109057	135517	15	43659	86302	129961
50	26460	105712	132172	10	47628	84291	131919
45	26460	102368	128828	5	51597	81947	133544
40	26460	99023	125483	0	52920	78934	131854

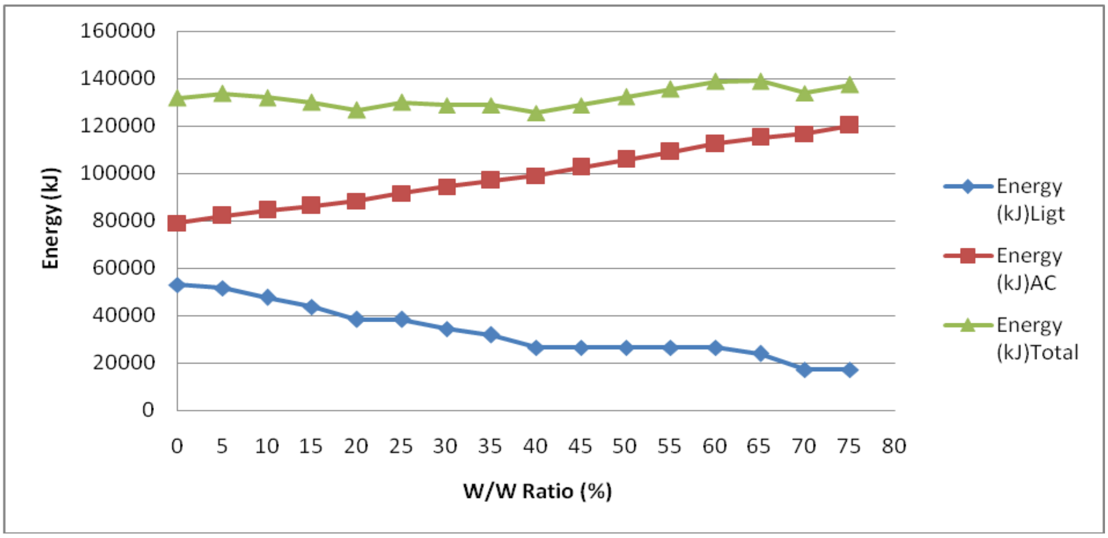


Figure 5 1 Graphical representation of data in Table 5.1

An enlarge view of the total energy consumption was taken separately for further consideration.

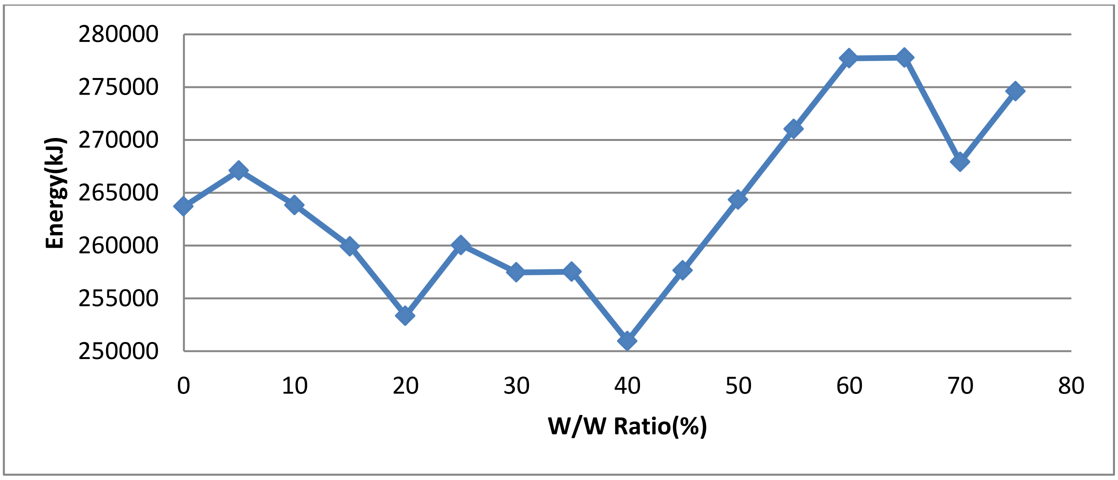


Figure 5 2 Enlarge view of the summation (Energy (kJ) Total)

It is observed in above graph, the minimum energy consumption receives at 40% of W/W ratio. In the same way W/W ratio at 20% and 70% the graph shows significant variation with compare to other areas. This situation can be described with using the gradient of the each graph separately.

Table 5 2 Gradient of the each graph in Figure 4.1

W/W Ratio	Gradient (Light)	Gradient (AC)	Gradient (Total)	W/W Ratio	Gradient (Light)	Gradient (AC)	Gradient (Total)
75	0	1337.748	1337.748	35	-1058.4	1071.529	13.12941
70	-2646	671.1933	-1974.81	30	-1587.6	1071.126	-516.474
65	-1058.4	1070.521	12.12101	25	0	1337.345	1337.345
60	0	1338.151	1338.151	20	-2116.8	804.5042	-1312.3
55	0	1338.151	1338.151	15	-1587.6	804.3025	-783.297
50	0	1337.748	1337.748	10	-1587.6	937.6134	-649.987
45	0	1337.748	1337.748	5	-529.2	1205.445	676.2454
40	-2116.8	803.8992	-1312.9	0	21168	31573.51	52741.51

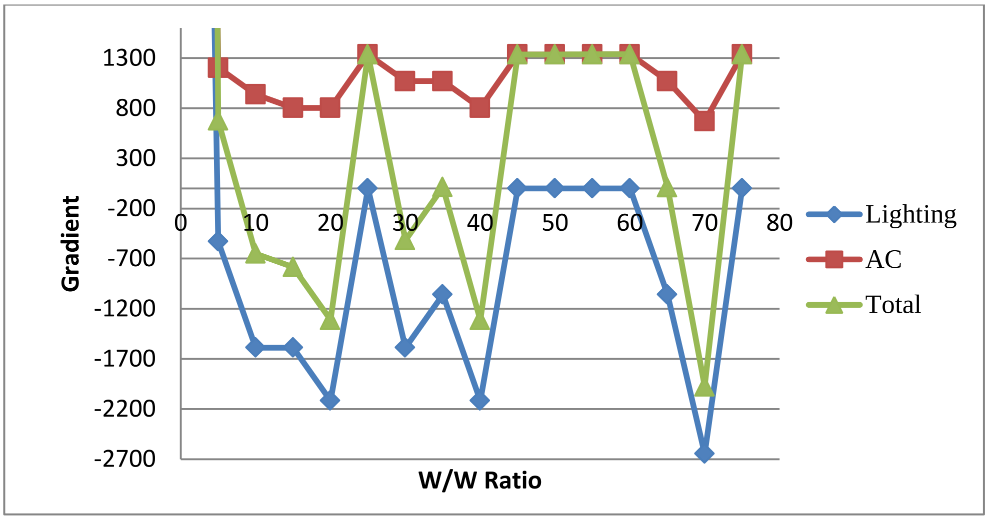


Figure 5 3 Gradient of the graphs in Figure 5.1

The above figure shows the lowest values at W/W ratios 20%, 40% and 70% of all three graphs. It says the rate of change of energy consumption for lighting and for AC is less with compare to other W/W ratios. In the same way the summation of those values became lower than the adjacent values. For further consideration those remarkable areas for lowest gradient shall be taken as following table.

Table 5 3 Comparison for low energy consuming areas

W/W RATIO	Energy (kJ)Light	Energy (kJ)AC	Energy (kJ)Total	Gradient Light	Gradient AC	Gradient Total
75	34398	240203	274601	0	1337.748	1337.748
70	34398	233514	267912	-2646	671.1933	-1974.81
65	47628	230158	277786	-1058.4	1070.521	12.12101
45	52920	204735	257655	0	1337.748	1337.748
40	52920	198046	250966	-2116.8	803.8992	-1312.9
35	63504	194027	257531	-1058.4	1071.529	13.12941
25	76734	183314	260048	0	1337.345	1337.345
20	76734	176627	253361	-2116.8	804.5042	-1312.3
15	87318	172604	259922	-1587.6	804.3025	-783.297

When comparing to the details at the Figure 4.4 and the Table 4.3, it shows the changes of gradient at the W/W ratios from 70% to75%, from 35% to 40% and from 20% to 25% of the lighting graph as from “0” to some value, AC graph as small value to high value and total energy consumption graph as from minus value to high positive value. Further it says the energy consumption for lighting does not change with the W/W ratio but it changers with the energy for AC system comparatively to high value.

That was observed within the particular range of W/W ratio internal light level (daylight factor) was maintained as same but the thermal condition was increased. In the same way the energy for lighting system was maintained in same value and the energy for AC system was increased. According to that at the points of W/W ratio 20%, 40% and 70% the total value of the energy consumption for both the system was less with compare to the adjacent value.

5.1.2 Total energy consumption for second stage calculation

The calculations done for the random date (21/03/2011) in previous stages were not much convenient for a logical solution. Therefore calculations were done again for the same building model according to the sun path variation over the selected location in order to get some average result for optimum energy consumption for best W/W ratio.

Table 5 4 Total energy consumption as 21/06/2011

W/W Ratio	Energy for Lighting	Energy for HVAC	Total
75	34398	141653	176051
65	52920	140701	193621
55	52920	135078	187998
45	60858	131458	192316
40	60858	124598	185456
35	63504	126499	190003
30	71442	120968	192410
25	76734	124212	200946
15	89964	121921	211885
5	105840	120307	226147
0	105840	117495	223335

Table 5 5 Total energy consumption as 21/12/2011

W/W Ratio	Energy for Lighting	Energy for HVAC	Total
75	47628	272787	320415
65	47628	249111	296739
55	55566	227435	283001
45	58212	204428	262640
40	66150	193579	259729
35	66150	182754	248904
30	71442	172248	243690
25	76734	161744	238478
15	89964	141404	231368
5	105840	121731	227571
0	105840	109892	215732

The total energy consumption for the two separate dates are taken into a separate table as mentioned below to continue with further calculation.

Table 5 6 Energy consumption against W/W Ratio as to Sun path.

W/W Ratio	Energy (21/06/2011)	Energy (21/12/2011)
75	176051	320415
65	193621	296739
55	187998	283001
45	192316	262640
40	185456	259729
35	190003	248904
30	192410	243690
25	200946	238478
15	211885	231368
5	226147	227571
0	223335	215732

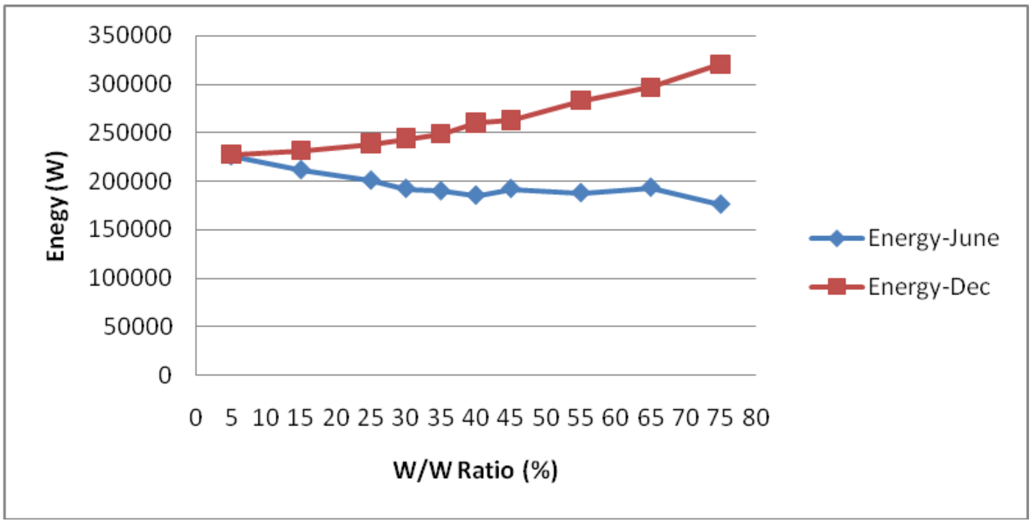


Figure 5 4 Graphical representation of data in Table 5.5

The total energy consumption for total system for any given date of any particular year lays in between these two graphs. Therefore to get the optimum solution the average values were taken as mentioned below.

Table 5 7 Average values of Energy consumption against W/W Ratio as to Sun path.

W/W Ratio	Energy (21/06/2011)	Energy (21/12/2011)	AVG
75	176051	320415	248233
65	193621	296739	245180
55	187998	283001	235499
45	192316	262640	227478
40	185456	259729	222593
35	190003	248904	219454
30	192410	243690	218050
25	200946	238478	219712
15	211885	231368	221627
5	226147	227571	226859
0	223335	215732	219533

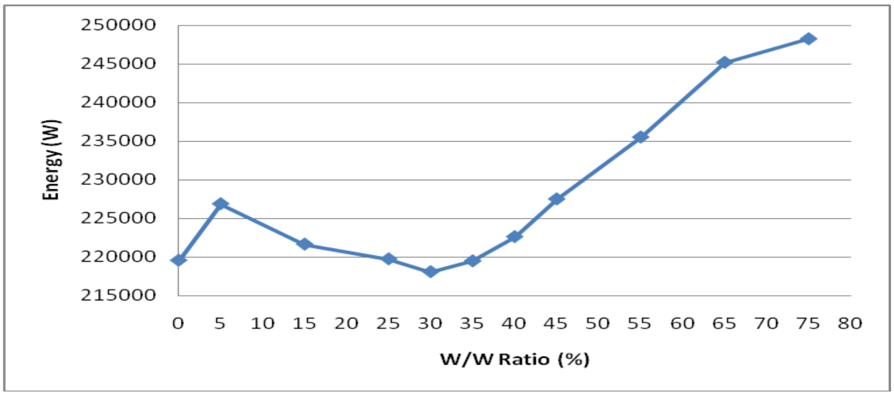


Figure 5 5 Graphical representation for Energy-Avg Vs W/W Ratio

Recommendation-01

It is observed that according to the above graph the best W/W ratio is **30%** for the selected building model with the existing orientation for optimum energy consumption.

5.1.3 Total energy consumption for third stage calculation

During this stage the total energy consumption was calculated for different orientation of the building model as mentioned below. The W/W ratio was maintained as 55% throughout the calculation.

Table 5 8 Energy (Lighting + HVAC) Vs North alignment as to sun path

North Alignment	Date	Energy (kJ) Lighting	Energy (kJ) HVAC	Energy (kJ) Total
0	21/06/2011	22491	75111	97602
	21/12/2011	27783	60243	88026
45	21/06/2011	22491	63837	86328
	21/12/2011	27783	54541	82324
90	21/06/2011	21168	66706	87874
	21/12/2011	23814	69424	93238
135	21/06/2011	11907	56769	68676
	21/12/2011	10584	77627	88211
180	21/06/2011	5292	51073	56365
	21/12/2011	5292	81530	86822
225	21/06/2012	2646	59843	62489
	21/12/2012	9261	100519	109780
270	21/06/2013	7938	81805	89743
	21/12/2013	23814	89470	113284
315	21/06/2014	17199	76598	93797
	21/12/2014	26460	56357	82817

All the details received from above calculation are taken into one table as mentioned below.

Table 5 9 Energy (summarized) Vs North alignment

North Alignment		0	45	90	135
Date	**21/06/2011**	97602	86328	87874	68676
	21/12/2011	88026	82324	93238	88211
North Alignment		180	225	270	315
Date	**21/06/2011**	56365	62489	89743	93797
	21/12/2011	86822	109780	113284	82817

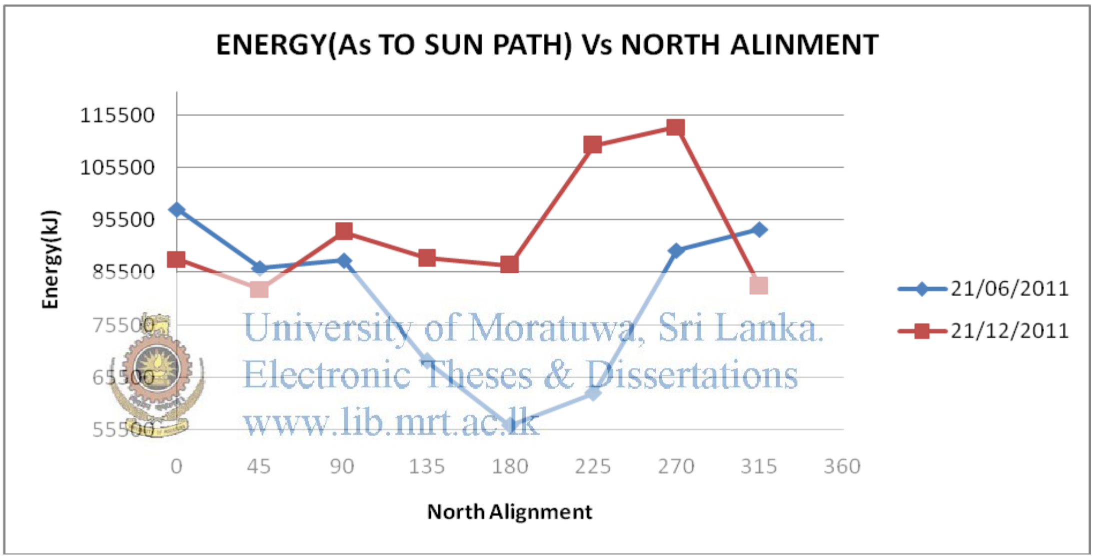


Figure 5 6 Graphical representation of Table 5.8

It is observed a significant different in between these two graphs for two different dates. Therefore the average values of the data were taken to get more convenient out come.

Table 5 10 Average values of data in Table 5.8

N/A	0	45	90	135	180	225	270	315
Energy(Avg)	92814	84326	90556	78443	71594	86135	101513	88307

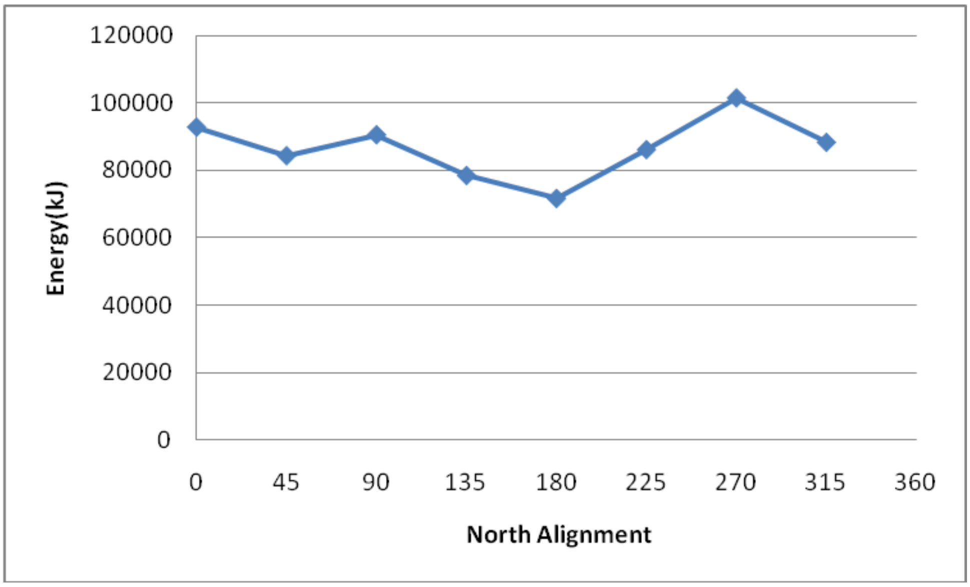


Figure 5 7 Graphical representation of Table 5.9

Recommendation-02

According to the graph above, the best orientation for the optimum energy consumption is **180°** for the selected building model with the selected conditions.

5.1.4 Total energy consumption for fourth stage calculation

In order to improve the energy efficiency of the entire building model the following modifications were done.

1. The existing luminairs were replaced with Philips CR 4343 W30L1201 x LED 88/830 AC – MLO where as the numbers of luminars were reduced up to 30 as to maintain 300 Lux.

2. A polystyrene layer between hollow cement block wall and cement plaster were added where as the U value was improved from 2.36 W/W^2 C° to 0.59 W/W^2 C°.

3. The window glass was replaced with sun gate 500 (2) + clear Low E glass where as the shedding coefficient was improved from 1 to 0.71 and U value was improved from 5.85 W/m^2 C° to 1.75 W/m^2 C°.

Energy consumption for lighting and HVAC systems were calculated with considering all the modifications mentioned above for the random date (21.03.2011). The W/W ratio was reduced from 75% to 0% during calculation. This building model was referred as the improved model for further calculations also.

Table 5 11 Energy Vs W/W ratio for improved model

W/W Ratio	Total (21/06/2011)	Total (21/12/2011)	W/W Ratio	Total (21/06/2011)	Total (21/12/2011)
75	120063	215863	25	122288	158958
65	116346	199067	15	133009	148409
55	114711	186437	5	134456	144110
45	113078	171724	0	135924	135711
35	119771	165341			

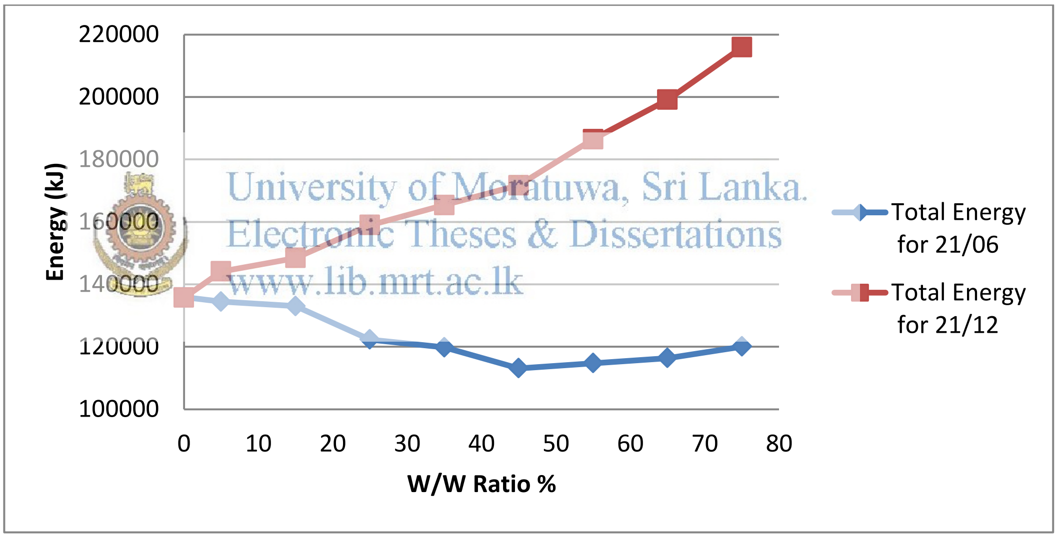


Figure 5 8 Graphical representation of Table 5.10

Since there is a significant different between two graphs, the average values of the data were taken into consideration for further calculations.

Table 5 12 Average values of data in Table 5.10

W/W Ratio	75	65	55	45	35
AVG	167963	157707	150574	142401	142556
W/W Ratio	25	15	5	0	
AVG	140623	140709	139283	135817	

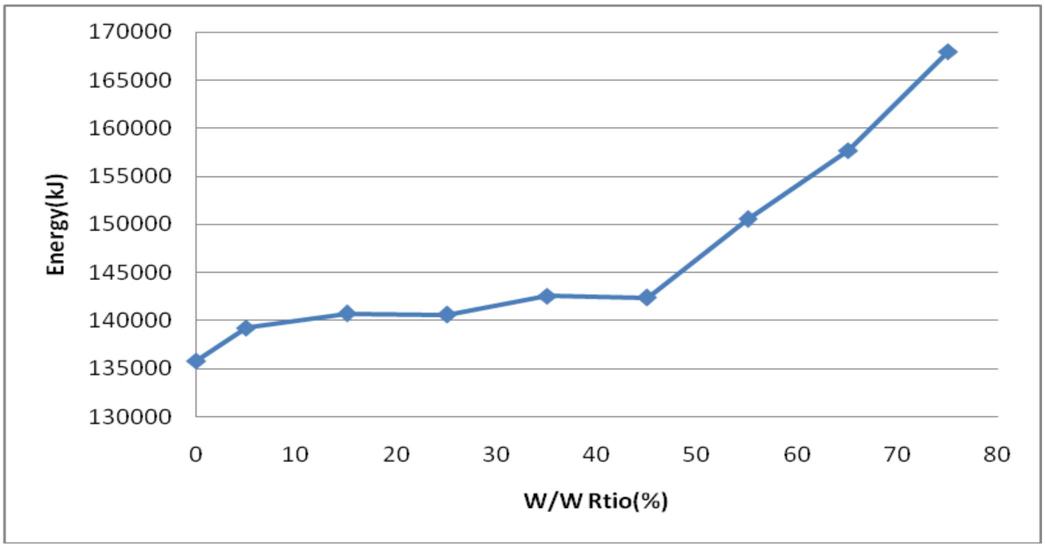


Figure 5 9 Graphical representation of Table 5.11

Recommendation-03

According to the graph above, the best w/w ratio for the improved building model is **0%** for optimum energy consumption.

5.1.5 Total energy consumption for fifth stage calculation

According to the Recommendation-02 and Figure 4.7, the best orientation of the building model is North alignment 180° for optimum energy consumption. Then the North alignment of the building was kept as same and W/W ratio was changed from 75% to 0% in order to calculate the energy consumption for lighting system and HVAC system. The same building model was taken for consideration and the calculations were done base on the Sun Path over Sri Lanka.

Table 5 13 Energy Vs W/W ratio (North Alignment 180°)

W/W Ratio	Total energy (21/06)	Total energy (21/12)	W/W Ratio	Total energy (21/06)	Total energy (21/12)
75	185359	263543	30	204050	207498
65	201660	243751	25	200968	217603
55	194771	250466	15	220339	197811
45	187881	230677	5	213329	224405
40	184436	220782	0	209882	214512
35	184305	214201			

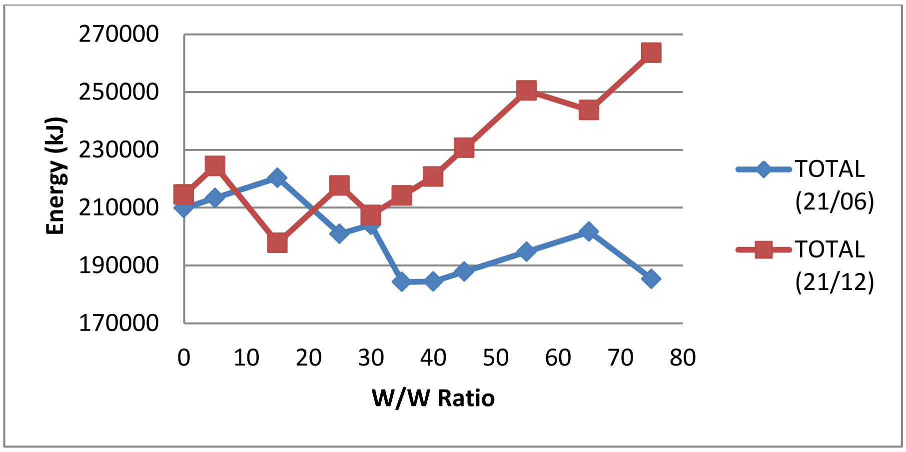


Figure 5 10 Graphical representation of Table 5.12

Since there is a remarkable deferent between two graphs, the average values of the same was taken into consideration to get more convenient out come.

Table 5 14 Average value of data in Table 5.12

W/W Ratio	75	65	55	45	40	35
AVG	224451	222706	222619	209279	202609	199253
W/W Ratio	30	25	15	5	0	
AVG	205774	209286	209075	218867	212197	

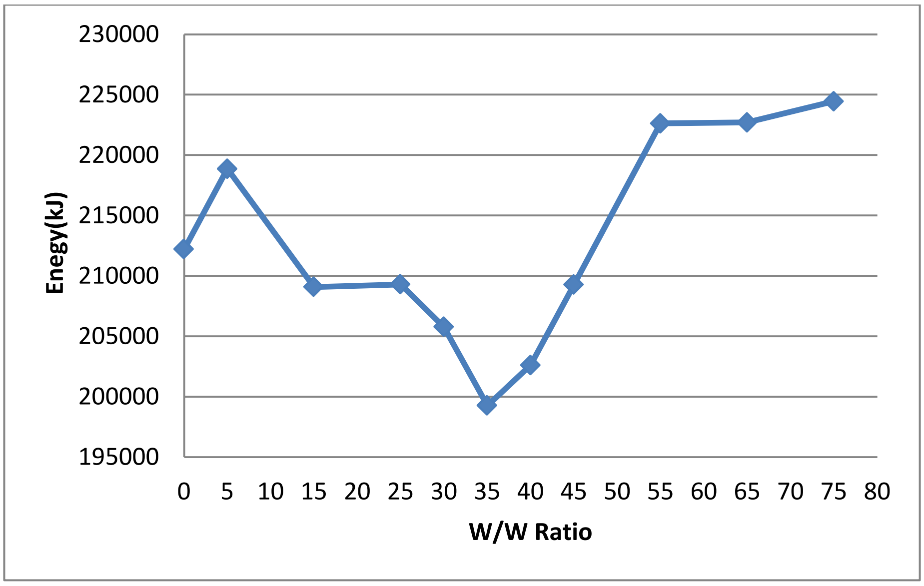


Figure 5 11 Graphical representation of Table 5.13

Recommendation-04

According to the graph above, it is observed the best W/W ratio is **35%** at North Alignment 180° in order to obtain the optimum energy consumption.

5.1.6 Model comparison

A model comparison was done for 3 building models on calculated data in order to find the difference of energy consumption for each model.

Table 5 15 Comparison of each calculated model, Energy Vs W/W ratio.

W/W Ratio	Energy (kJ)Basic	Energy (kJ)Best	Energy (kJ)IMP
75	248233	224451	167963
65	245180	222706	157707
55	235499	222619	150574
45	227478	209279	142401
35	219454	199253	142556
25	219712	209286	140623
15	221627	209075	140709
5	226859	218867	139283
0	219533	212197	135817

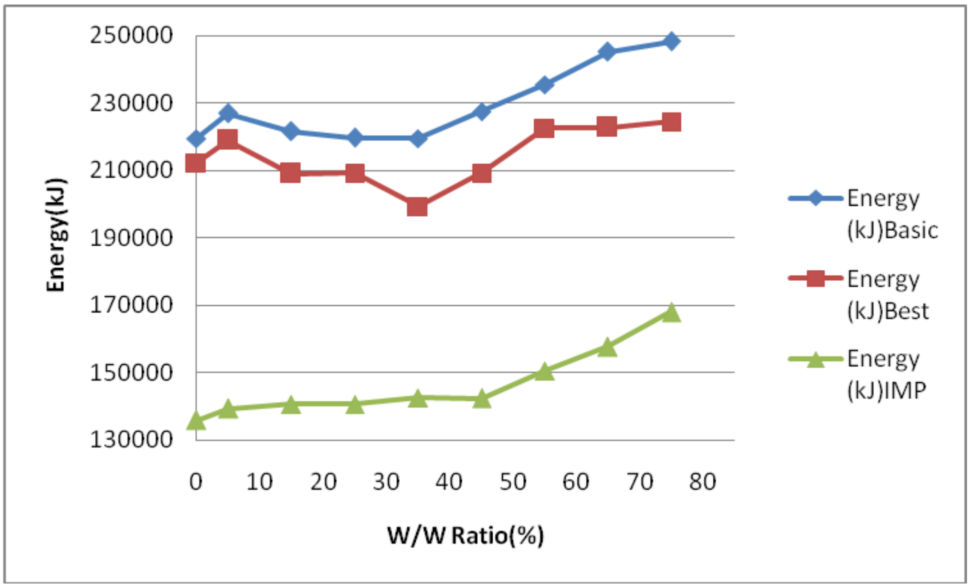


Figure 5 12 Graphical representation of Table 5.14

5.2 Evaluation

5.2.1 Power consumption for a month

The power consumption was calculated for one month period with following assumptions. The office functioning duration was considered as 8 hours per working day and 5 working days per week and Saturday as a half day. Then it was taken as total 22 working days per month.

For the existing (basic) model with 55% W/W ratio;

Energy consumption per day (Table 4.6) = 235499 kJ

Electricity consumption per day $= \frac{235499 \text{ kJ}}{3600 \text{ s}} = 65.4 \text{ kWhr}$

Where : $W = \frac{J}{s}$ $kW = \frac{kJ}{s}$ kWs= kJ, $\frac{kWJ}{3600\ s} = \frac{kJ}{3600} = kWhr$

Per month = 65.4 x 22 = **<u>1439.1 KWhr</u>**

For the existing (basic) model with 30% W/W ratio;

Energy consumption per day (Table4.6) = 218050 kJ

Electricity consumption per day $= \frac{218050 \text{ kJ}}{3600 \text{ s}} = 60.5 \text{ kWhr}$

Per month = 60.5 x 22 = **<u>1332.5 KWhr</u>**

For the improved model (LED + envelop + Low E Glass) with 0% W/W ratio

Energy per day = 135817 kJ

Electricity per day $= \frac{135817 \text{ kJ}}{3600 \text{ s}} = 37.7 \text{ KWhr}$

Electricity per month = 37.7 x 22 = **<u>829.9 KWh</u>**

For the best W/W ratio with best orientation model with 35% W/W ratio

Energy per day = 199253 kJ

$$\text{Electricity per day} = \frac{199253 \text{ kJ}}{3600 \text{ s}} = 55.3 \text{ kWhr}$$

Per month = 55.3 x 22 = **<u>1217.6 kWhr</u>**

5.2.2 Cost per Month

Table 5 16 Cost for electricity for a month

Power Factor :- 0.9							
Cost per Unit :- Rs.19.40							
Cost per kVA :- Rs.850/=							
Fixed Charge :- Rs.3000/=							
Building Model	**W/W Ratio**	**Per month (kWhrs)**	**Average**	**Chargers (Rs)**			**Total (Rs)**
				Units	**M' Demand**	**Fixed**	
Basic	55%	1439.1	65.4	27918.54	61766.67	3000	92685.21
Basic	30%	1332.5	60.5	25850.5	57138.89	3000	85989.39
Improved	0%	829.9	37.7	16100.06	35605.56	3000	54705.62
Best	35%	1217.6	55.3	23621.44	52227.78	3000	78849.22

5.2.3 Payback period

Construction cost for Basic model with 55% of W/W ratio = Rs. 13,279,156.77

Construction cost for Basic model with 35% of W/W ratio = Rs. 13,210,857.42

Construction cost for Basic model with 30% of W/W ratio = Rs. 13,195,282.52

Construction cost for Improved model with 0% of W/W ratio = Rs. 16,050,752.90

For calculation point of view following construction rates were considered

Square foot rate for basic construction type = Rs. 2200.00

(Source: Design Branch Directorate of Engineer Services Army Headquarters)

Cost per luminaire - Florescent type = Rs. 62300.00

(Source: Philips luminaire local argent- Hayleys)

Cost per luminaire - LED type = Rs. 158400.00

(Source: Philips luminaire local argent- Hayleys)

The calculations done above represent the following details:

1. The energy efficient model i.e. 30% W/W ratio model can be constructed to a less construction cost with compare to the basic model i.e. 55% W/W ratio model. Therefore the payback period is no need to be considered. In the same way the modification to the existing building model to improve the energy efficiency, i.e. to construct as a 35% W/W ratio model, can be done into a lesser price with compare to the 55% W/W ratio model. Therefore the payback period is no need to be considered.

2. The construction cost of the improved model is higher than the construction cost of existing building model i.e. 55% W/W ratio model. Therefore the payback period shall be calculated as follows;

The construction cost deference between the two models

= Rs. (16,050,752.90 - 13,279,156.77)

= **Rs. 2,771,596.13**

The cost deferent between the energy bills

= Rs. (92685.21 – 54705.62)

= **Rs. 37979.59**

To calculate the simple payback period

= 2,771,596.13 / 37979.59

= **73**

= 73 / 12(1Year)

= **<u>6 Years</u>**

The total payback period for this particular model is 6 years.

More over the Code of Practice for Energy Efficient Buildings in Sri Lanka – 2008 has not offered any descriptive details for maximum power density for HVAC system for the building types as mentioned on table above.

5.2.4 Comparison for the LPD for each building model

For the existing building model:

The optimum energy consumption was received at W/W ratio 30%

Energy consumption for illumination system = 71442 kJ (W/W ratio 30% avg)

= 71442000 J

The time duration taken for calculation = 8 Hrs (8 x 3600 = 28800 s)

Where as; W = J/s,

Total Power consumption for illumination system = 71442000 ÷ 28800

= 2480.6 W

The building area = 30m x 15m

= 450 m^2

Therefore, the LPD = 2480.6 ÷ 450

= **5.5 Wm^{-2}**

For the basic building model:

The optimum energy consumption was received at W/W ratio 35%.

Energy consumption for illumination system = 58212 kJ (W/W ratio 35% avg)

Therefore, the LPD = **4.5 Wm^{-2}**

For the improved building model:

The optimum energy consumption was received at W/W ratio 0%.

Energy consumption for illumination system = 66528 kJ (W/W ratio 0% avg)

Therefore, the LPD = **5.13 Wm^{-2}**

According to the Code of Practice for Energy Efficient Buildings in Sri Lanka – 2008 the LPD for office is 10.8 W/m^2 . The case study has offered significantly lower values for each building model for LPD.

More over the Code of Practice for Energy Efficient Buildings in Sri Lanka – 2008 has not offered any descriptive details for maximum power density for HVAC system for the building types as mentioned on table above.

Chapter 6

ANALYSIS FOR OTHER LOCATIONS

6.1 Power consumption for illumination

The same calculation method was conducted to find the most reasonable W/W Ratio of the same building model for optimum energy consumption as it applicable to all areas of Sri Lanka. During the calculations the values of the Latitudes and Longitudes of the different locations were taken into consideration. Those values were inserted to Dialux software and W/W Ratio was calculated for same building model with same orientation, in order to maintain the average illuminance level minimum 300 Lux inside the building. In such case following results were obtained.

Jaffna Lat:- 9.75 & Long:- 79.95

Table 6 1 Power consumption for lighting against W/W ratio for building model at Jaffna

W/W Ratio	Power (W) consumed as Time variation				
	900 Hrs	1100 Hrs	1300 Hrs	1500 Hrs	1700 Hrs
75	0	1470	1470	1470	2940
65	0	1470	2205	2205	2940
55	735	1470	2205	2205	2940
45	1470	2205	2205	2205	2940
35	1470	2205	2205	2205	3675
25	2205	2205	2940	2940	3675
15	2205	2940	3675	3675	3675
5	3675	3675	3675	3675	3675

Mannar Lat:- 8.96 & Long:- 79.9

Table 6 2 Power consumption for lighting against W/W ratio for building model in Mannar

W/W Ratio	Power (W) consumed as Time variation				
	900 Hrs	1100 Hrs	1300 Hrs	1500 Hrs	1700 Hrs
75	0	1470	1470	1470	2940
65	0	1470	2205	2205	2940
55	735	1470	2205	2205	2940
45	1470	2205	2205	2205	2940
35	1470	2205	2205	2205	3675
25	2205	2205	2940	2940	3675
15	2205	2940	3675	3675	3675
5	3675	3675	3675	3675	3675

Mullativu Lat:- 9.26 & Long:- 80.81

Table 6 3 Power consumption for lighting against W/W ratio for building model in Mullativu

W/W Ratio	Power (W) consumed as Time variation				
	900 Hrs	1100 Hrs	1300 Hrs	1500 Hrs	1700 Hrs
75	0	1470	1470	1470	2940
65	0	1470	2205	2205	2940
55	735	1470	2205	2205	2940
45	1470	2205	2205	2205	2940
35	1470	2205	2205	2205	3675
25	2205	2205	2940	2940	3675
15	2205	2940	3675	3675	3675
5	3675	3675	3675	3675	3675

Trincomalee Lat:- 8.5 & Long:- 81.23

Table 6 4 Power consumption for lighting againstW/W ratio for building model in Trincomalee

W/W Ratio	Power (W) consumed as Time variation				
	900 Hrs	1100 Hrs	1300 Hrs	1500 Hrs	1700 Hrs
75	0	1470	1470	1470	2940
65	0	1470	2205	2205	2940
55	735	1470	2205	2205	2940
45	1470	2205	2205	2205	2940
35	1470	2205	2205	2205	3675
25	2205	2205	2940	2940	3675
15	2205	2940	3675	3675	3675
5	3675	3675	3675	3675	3675

Anuradhapura Lat:- 8.35 & Long:- 80.38

Table 6 5 Power consumption for lighting against W/W ratio for building model in Anuradhapura

W/W Ratio	Power (W) consumed as Time variation				
	900 Hrs	1100 Hrs	1300 Hrs	1500 Hrs	1700 Hrs
75	0	1470	1470	1470	2940
65	0	1470	2205	2205	2940
55	735	1470	2205	2205	2940
45	1470	2205	2205	2205	2940
35	1470	2205	2205	2205	3675
25	2205	2205	2940	2940	3675
15	2205	2940	3675	3675	3675
5	3675	3675	3675	3675	3675

Puttalam Lat:- 8.03 & Long:- 79.83

Table 6 6 Power consumption for lighting against W/W ratio for building model in Puttalam

W/W Ratio	Power (W) consumed as Time variation				
	900 Hrs	1100 Hrs	1300 Hrs	1500 Hrs	1700 Hrs
75	0	1470	1470	1470	2940
65	0	1470	2205	2205	2940
55	735	1470	2205	2205	2940
45	1470	2205	2205	2205	2940
35	1470	2205	2205	2205	3675
25	2205	2205	2940	2940	3675
15	2205	2940	3675	3675	3675
5	3675	3675	3675	3675	3675

Kandy Lat:- 7.2 & Long:- 80.63

Table 6 7 Power consumption for lighting against W/W ratio for building model in Kandy

W/W Ratio	Power (W) consumed as Time variation				
	900 Hrs	1100 Hrs	1300 Hrs	1500 Hrs	1700 Hrs
75	0	1470	1470	1470	2940
65	0	1470	2205	2205	2940
55	735	1470	2205	2205	2940
45	1470	2205	2205	2205	2940
35	1470	2205	2205	2205	3675
25	2205	2205	2940	2940	3675
15	2205	2940	3675	3675	3675
5	3675	3675	3675	3675	3675

Rathnapura Lat:- 6.66 & Long:- 80.38

Table 6 8 Power consumption for lighting against W/W ratio for building model in Rathnapura

W/W Ratio	Power (W) consumed as Time variation				
	900 Hrs	1100 Hrs	1300 Hrs	1500 Hrs	1700 Hrs
75	0	1470	1470	1470	2940
65	0	1470	2205	2205	2940
55	735	1470	2205	2205	2940
45	1470	2205	2205	2205	2940
35	1470	2205	2205	2205	3675
25	2205	2205	2940	2940	3675
15	2205	2940	3675	3675	3675
5	3675	3675	3675	3675	3675

Badulla Lat:- 6.98 & Long:- 81.05

Table 6 9 Power consumption for lighting against W/W ratio for building model in Badulla

W/W Ratio	Power (W) consumed as Time variation				
	900 Hrs	1100 Hrs	1300 Hrs	1500 Hrs	1700 Hrs
75	0	1470	1470	1470	2940
65	0	1470	2205	2205	2940
55	735	1470	2205	2205	2940
45	1470	2205	2205	2205	2940
35	1470	2205	2205	2205	3675
25	2205	2205	2940	2940	3675
15	2205	2940	3675	3675	3675
5	3675	3675	3675	3675	3675

Batticalo Lat:- 7.72 & Long:- 81.7

Table 6 10 Power consumption for lighting against W/W ratio for building model in Batticalo

W/W Ratio	Power (W) consumed as Time variation				
	900 Hrs	1100 Hrs	1300 Hrs	1500 Hrs	1700 Hrs
75	0	1470	1470	1470	2940
65	0	1470	2205	2205	2940
55	735	1470	2205	2205	2940
45	1470	2205	2205	2205	2940
35	1470	2205	2205	2205	3675
25	2205	2205	2940	2940	3675
15	2205	2940	3675	3675	3675
5	3675	3675	3675	3675	3675

Galle Lat:- 6.05 & Long:- 80.2

Table 6 11 Power consumption for lighting against W/W ratio for building model in Galle

W/W Ratio	Power (W) consumed as Time variation				
	900 Hrs	1100 Hrs	1300 Hrs	1500 Hrs	1700 Hrs
75	0	1470	1470	1470	2940
65	0	1470	2205	2205	2940
55	735	1470	2205	2205	2940
45	1470	2205	2205	2205	2940
35	1470	2205	2205	2205	3675
25	2205	2205	2940	2940	3675
15	2205	2940	3675	3675	3675
5	3675	3675	3675	3675	3675

Matara Lat:- 5.93 & Long:- 80.53

Table 6 12 Power consumption for lighting against W/W ratio for building model in Matara

W/W Ratio	Power (W) consumed as Time variation				
	900 Hrs	1100 Hrs	1300 Hrs	1500 Hrs	1700 Hrs
75	0	1470	1470	1470	2940
65	0	1470	2205	2205	2940
55	735	1470	2205	2205	2940
45	1470	2205	2205	2205	2940
35	1470	2205	2205	2205	3675
25	2205	2205	2940	2940	3675
15	2205	2940	3675	3675	3675
5	3675	3675	3675	3675	3675

Hambantota Lat:- 6.21 & Long:- 81.02

Table 6 13 Power consumption for lighting against W/W ratio for building model in Hambantota

W/W Ratio	Power (W) consumed as Time variation				
	900 Hrs	1100 Hrs	1300 Hrs	1500 Hrs	1700 Hrs
75	0	1470	1470	1470	2940
65	0	1470	2205	2205	2940
55	735	1470	2205	2205	2940
45	1470	2205	2205	2205	2940
35	1470	2205	2205	2205	3675
25	2205	2205	2940	2940	3675
15	2205	2940	3675	3675	3675
5	3675	3675	3675	3675	3675

6.2 Recommendation

According to the obtained results as shown above, the power consumption for lighting of all the areas are same. In the same way, without doing further calculation an assumption can be made as the power consumption for AC also same for the selected building model. Therefore, the best W/W ratio for optimum energy consumption will not be changed according to the area concerned in Sri Lanka.

6.3 Calculation to find best W/W ratio for other areas

The best orientation for the same building model was calculated as did it in initial stage. During the calculation W/W ratio maintained as 55% and the condition of the building maintained as same. The table 5.15 shows the variation of energy consumption for respective North Alignment.

Table 6 14 Energy consumption vs North Alignment as to sun path

North Alignment	0	45	90	135
Energy 21/06	218932	206949	225367	200172
Energy 21/12	208596	191036	235529	245746
North Alignment	180	225	270	315
Energy 21/06	194771	204370	251576	222015
Energy 21/12	250466	285461	261850	197677

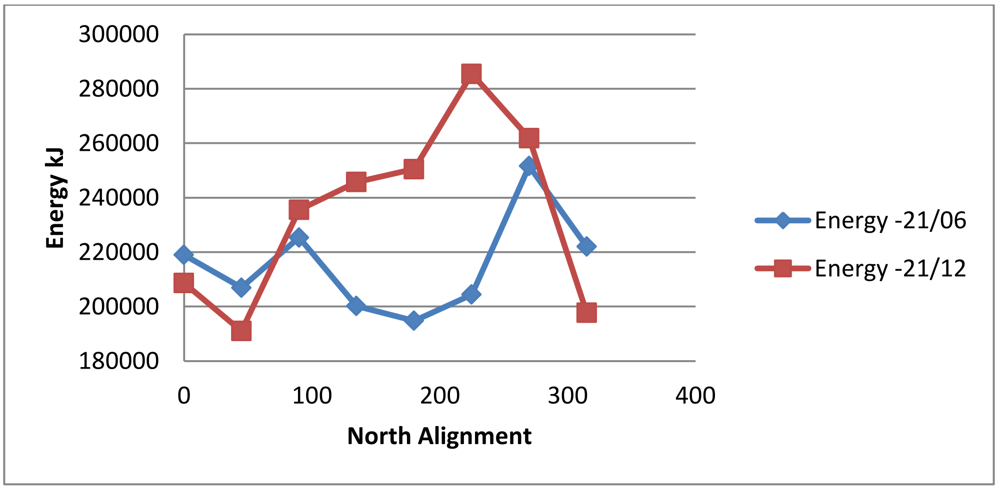


Figure 6 1 Graphical representation of Table 5.14

In order to obtain a more convenient value the average values or the above details were taken into consideration.

Table 6 15 Average values of the data in Table 5.14

North Alignment	0	45	90	135
Energy Avg	213764	198992	230448	222959
North Alignment	180	225	270	315
Energy Avg	222619	244915	256713	209846

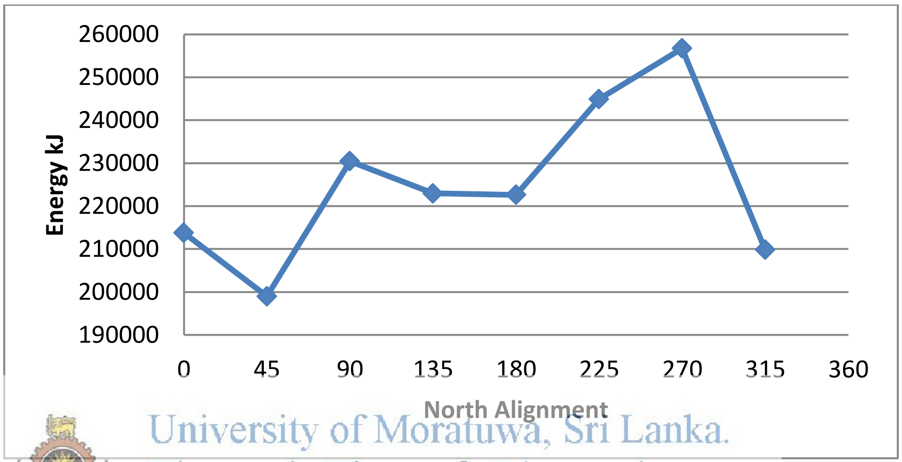


Figure 6 2 Graphical representation of Table 5.15

Recommendation:

According to the graph in Figure 5.2, the best orientation for the buildings in other areas of Sri Lanka is observed as North Alignment **45^0**.

Maintaining the North Alignment as 45^0, the calculations were done to find the best W/W ratio for the other areas of Sri Lanka. The same building model was considered for the calculation and the condition of the building was maintained as same. The Table 7.3 shows the variation of energy consumption for respective W/W ratio.

Table 6 16 Energy consumption Vs W/W ratio as to sun path

W/W Ratio	Energy 21/06	Energy 21/12
75	216610	183103
65	206809	190270
55	206949	190800
45	203773	191334
35	193970	188555
25	197422	198838
15	197560	209498
5	217576	216657
0	211021	213608

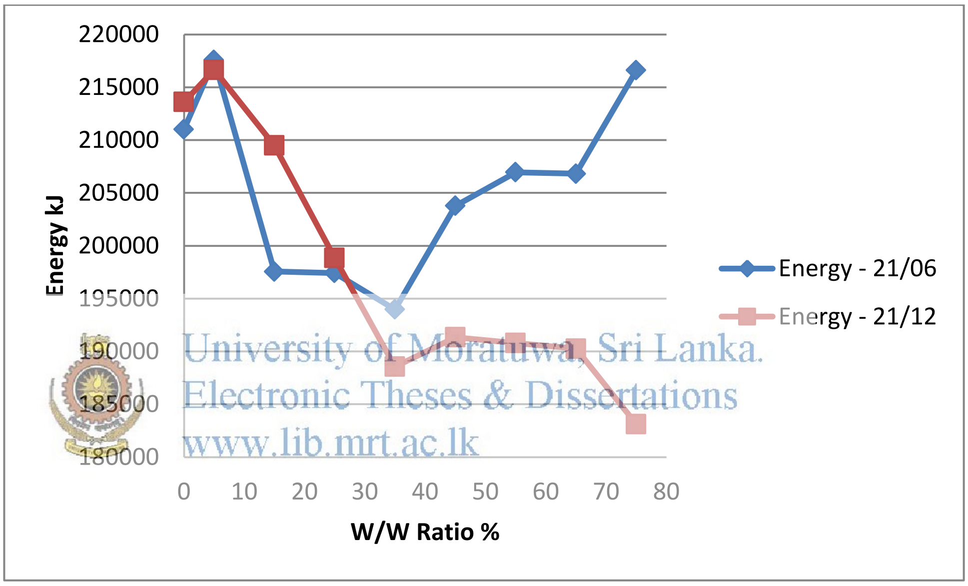


Figure 6 3 Graphical representation of Table 5.16

Table 6 17 Average values of the data in Table 5.16

W/W Ratio	75	65	55	45	35
Energy - AVG	199857	198539	198874	197554	191263
W/W Ratio	25	15	5	0	
Energy - AVG	198130	203529	217117	212314	

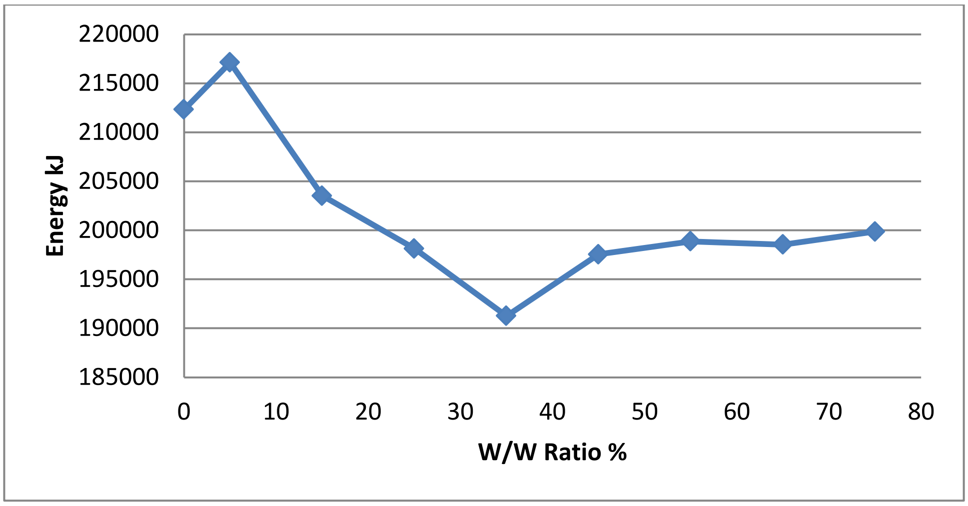


Figure 6 4 Graphical representation of Table 5.17

Recommendation:

According to the graph in Figure 5.4, the best W/W Ratio for the buildings in other areas of Sri Lanka to obtain optimum energy consumption is **35 %**.

Chapter 7

DISCUSSION

This research was mainly focused on the energy optimization. The proposed defense head quarter complex at Baththaramulla was taken as case study. The illumination system and the HVAC system were taken into consideration because these two sectors are identified as the most energy consuming sectors in most of the building concerned. As all the office functions are taken place in day time, the large portions of electricity bills are paid for day time consumption. The total electricity bill is concerned major part pays to the illumination system and HVAC system, with compare to the other electrical consuming units. Therefore the all calculations done throughout the research work are mainly focused to the day time.

The Dialux software was used to do calculation for the lighting system. So that, the luminaries arrangement and the number of luminaries needed for the building for particular arrangement was decided by the software. However, the selection of type of luminaries to be installed as suitable to office environment was done according to the personal preference. Moreover, the internal arrangement of furniture and other equipments, and the internal building arrangement were also not considered during the calculation stage. In order to enhance the concept of energy efficiency, the colour of the ceiling, walls and floor were selected as appropriate. The windows were considered as frame less, because at the initial calculation it was found that there were no different for daylight intake in between frame less windows and with frame windows. The glasses of the windows were taken as basic window glass for the major calculations because it was needed to commence from the most basic stage. The basic illuminance level was taken as 300 lux , as input to the software, but the equal distribution of the illuminance level was not obtained. The pattern of illumination distribution shows in iso lux curves and value charts in Appendix A. However with some additional modification to the riffed design the Lux level can be made distribute to more equal up to desirable level. In the same time the glare prevention action can be considered in the most suitable way appropriate to the selected designed. In addition to that, the building inside arrangement can be improved further with adding furniture, column arrangement and other additional accessories. With all those improvements the output to the calculations would have to be more desirable with compare to the already obtained product. Sometimes the luminary arrangement can be improved more, with user define method in the software. The angle and the positioning of the luminaries can be changed to enhance the concept of equal distribution of lux level, by focusing the luminaries to low illuminated areas.

The HVAC system considered throughout the calculations was focused only to the capacity of selected building model. It was a split type unit and not a centralized chiller system. But for the energy evaluation nature works the selected system is far enough to consider. Even though the internal unit arrangement of the whole system was not accounted deeply the same was based on the assumptions made. The energy evaluation mainly based on the manual calculation method such as CLTD, CLF method in fact of software based calculation. The software wildly used for HVAC system evaluation as EnerWin and Equest were not given desirable solution to calculate the energy usage in step by step as manual calculations. The HVAC system used for research work was wildly available in the market, but there are more energy efficient systems also available in the market with the same capacity.

The work done here can be improved further with getting consideration to the additional techniques and concepts towards the energy saving. Mainly the energy saving can be improved with good conduct of employees and with enforcing more rules basically on equipment handling. Sometimes that is may not be possible for most of the organizations and it may be an additional burning for the employees also. BMS gives the total solution for these nature establishments as it can avoid the individual handling of equipments which involves serving more energy.

Being a tropical country Sri Lanka gets more solar radiation throughout the day. As same as that the solar gives lots of energy generation opportunities, it will cause the increase of internal thermal condition of the building. Sometimes the basic methods can be used to prevent the entering of solar radiation into the building such as using of curtaining and vertical blinds. Tinting of glass also is one of the method used to serve energy in most of the building glasses. Specially the windows need to be improved towards passive solar buildings concept in tropical countries. The motorized louvers also can be used more effectively to improve the energy efficiency of buildings. Other than those technical approaches the concept of green building also involves to serve energy from usual consumption. In the same way building internal colour cord gives considerable participation towards maintenance of internal illumination level. Other way around it involves serving energy to be used for lighting system.

The HVAC system also can be installed with VAVS and VSD run systems as it serve more energy than usual system. Further, HVAC systems have been improved as hybrid systems integrating with solar energy and electrical power to improve energy efficiency. Even This technology is not widely use in Sri Lanka some countries use them effectively in their building services systems.

According to the research work, it was found that the most energy efficient building models were obtained as total enclosed model with LED luminairs based on the building location. The selected building model exposed to high solar radiation, according to the geographical situation, the construction cost of the total system was comparatively higher than other models. Then the payback period was not logical within desirable period. Therefore, decisions to be made during the designing stage of such system with compare to the back ground need to be maintained as energy saving or cost minimizing.

The Code of Practice for Energy Efficient Buildings in Sri Lanka – 2008 has offered the criteria for maximum allowable power for illumination systems for different types of buildings. The classification of buildings have been done on the general type of using and the lighting power density has been given as W/m^2 against the each type of building area.

According to the Table 1 2 the maximum lighting power density (LPD) for the illumination system of office type building is **10.8 Wm^{-2}** . However at the analization stage it shows that the LPD of all the building model taken for the case study, are significantly lower than the maximum allowable limit given in the building cord.

Chapter 8

CONCLUSION

The concepts on energy conservation, energy efficiency and energy saving have been taken special attention by all the countries in the world. Depletion of available fossil fuel energy sources and the increase of global warming and its bad effects on global setup happened to be the main reasons to implement these concepts. These are applied for all energy related fields and special concerned has been given for energy usage in building sector as it consumed considerable amount of energy with compare to other sectors. Accordingly concept on energy efficient building has been implemented worldwide.

However, it can be seen in Sri Lanka the concept of improvement of energy efficiency is not applying positively. The main attention has been given to improve Architectural view of the buildings at the designing stage and less attention has been given on application of energy efficiency improvement with using available climatic benefits. The methodologies of this research can be applied to the building construction process to enhance the energy efficiency of the buildings. As Sri Lanka locates in tropical zone, natural sunlight can be obtained for nearly 12 hours per day during the whole year. This situation can be taken as a benefit to integrate day light to the internal illumination system of the buildings. However application of this concept may tend to increase of internal heat load of the building. Therefore additional amount of energy may be needed for HVAC system to maintain thermal comfort as desirable. The energy need to maintain the conformability for both the systems can be optimized with proper calculation process. As this process is mainly depending on the wall to window ratio of the building, the best wall to window ratio is calculated for different building models to optimize energy consumption during the research.

This research work is focused to the building suppose to be located the Directorate of Engineer Services in proposed Army Head Quarter complex. In the first stage, the best wall to window ratio is calculated for the existing condition of the selected building model. Then the best orientation for optimum energy consumption is calculated for existing building conditions as second stage. During the third stage the best orientation with best wall to window ratio is calculated for the same building model for optimum energy consumption.

The existing condition of the building is developed by replacing the illumination system with energy efficient LED luminaires and window glasses with Low-E energy efficient glasses. Walls of the building are improved by developing the building envelop to improve the thermal conditions. Then the best wall to window ratio and best orientation for the improved building model is calculated to optimize the energy consumption.

All the calculations in each stage is done according to the sun path variation over the location in order to get the most convenient solution. In addition to that he LPDs are calculated for each building model and it is proven that the calculated values are significantly lower than the maximum values authorized by Sri Lanka Sustainable Energy Authority (Table 1 2).

The construction cost of each building model is calculated separately and it is found that the construction cost of energy efficient building models are considerably lower than the existing building construction cost.

Different technologies exist in modern world to improve energy efficiency in buildings. Most of them are high cost involving projects. Therefore it is doubted that the possibility of implementing such technologies in Sri Lankan building engineering. In facts that, applying the methodology in the research work the energy efficiency of the building can be improved by giving the attention in designing stage without involving additional cost.

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Appendix A: Sample Calculations of Dialux Software

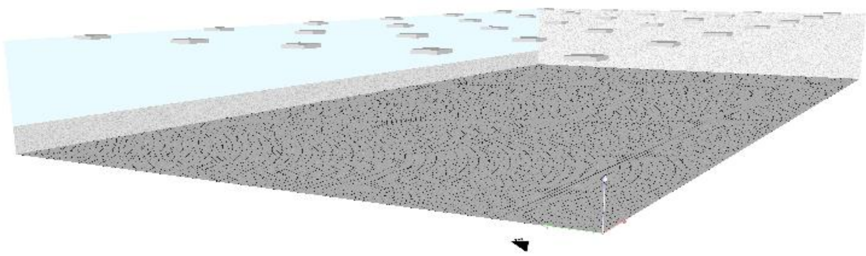


Figure A.1: 3D Arrengment of luminaire in selected building model

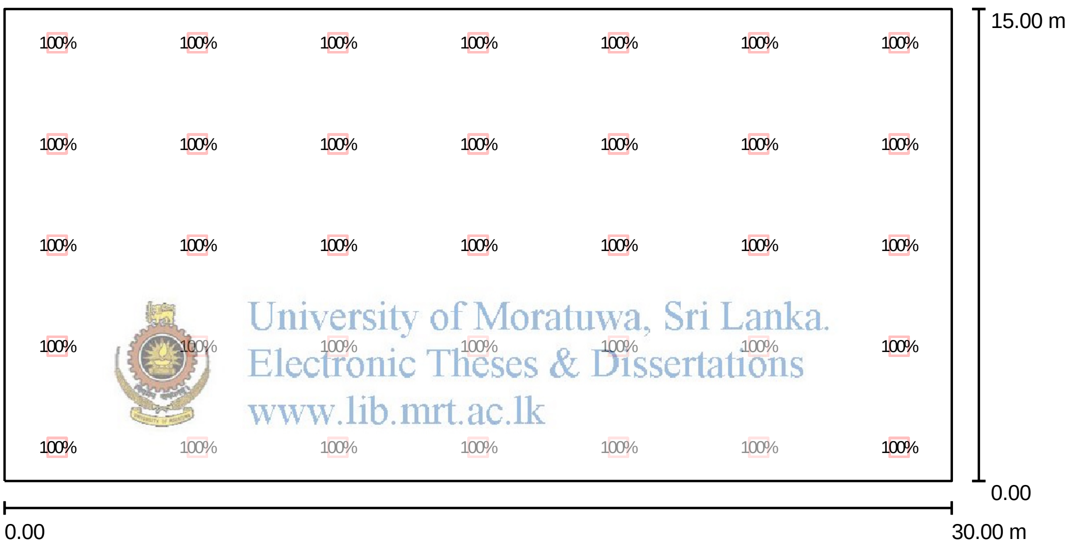


Figure A.2 : Luminaire arrangement and illumination level W/W ratio at 0%

Daylight parameters:
Location: Sri Jaywardanapura, Longitude: 80.13°, Latitude: 6.10°,
North deviation: 245.0°
Date: 21.03.2011, Time:09:00:00 (+5 hours difference to GMT)
Reference sky type: Clear sky

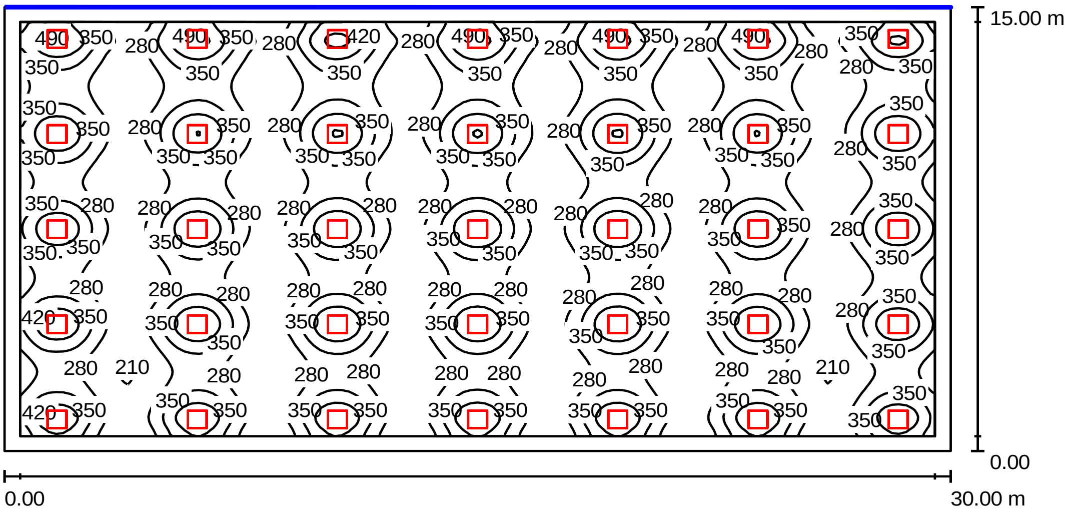


Figure A.3- Isoline arrangement

Photometric results

Total Luminous Flux:	178850 lm
Total Load:	3675.0 W
Light loss factor:	0.67
Boundary Zone:	0.500 m

475	301	273	477	358	250	438	425	251	369	477	276	313	488	318	267	473	381	248	412	434
378	271	259	388	314	243	367	356	242	324	390	257	286	395	287	255	389	325	236	348	358
308	247	242	322	278	232	316	310	233	290	326	242	261	328	259	240	326	284	224	300	304
459	296	278	463	355	257	428	417	255	367	462	276	312	475	317	272	458	371	250	402	423
440	285	266	444	341	243	411	400	242	353	444	265	300	454	305	260	439	357	236	388	408
298	234	227	308	264	217	299	292	217	275	310	228	247	310	246	226	309	271	212	286	293
382	262	248	388	308	231	364	355	228	318	389	245	275	396	279	243	386	320	224	345	360
461	289	268	463	351	243	425	414	243	362	462	267	304	475	311	260	457	367	235	401	423
317	238	231	326	274	219	314	307	218	283	327	230	252	329	253	228	326	280	212	299	307
352	250	238	360	291	223	341	333	220	300	360	235	263	366	266	234	359	302	217	324	336
484	298	274	485	361	250	442	430	249	374	482	273	311	499	320	267	478	379	243	417	441
330	242	230	338	279	217	322	314	214	286	338	227	252	343	254	226	338	286	213	307	318
303	234	224	314	265	211	302	295	211	274	314	224	244	317	244	220	314	271	208	290	295
477	293	266	474	352	240	434	420	237	362	474	264	303	487	311	257	469	373	233	408	432

15.00 m
0.00
0.00
30.00 m

Figure A.4: Luminaire arrangement and Value Chart W/W ratio at 0%

Values in Lux, Scale 1 : 215

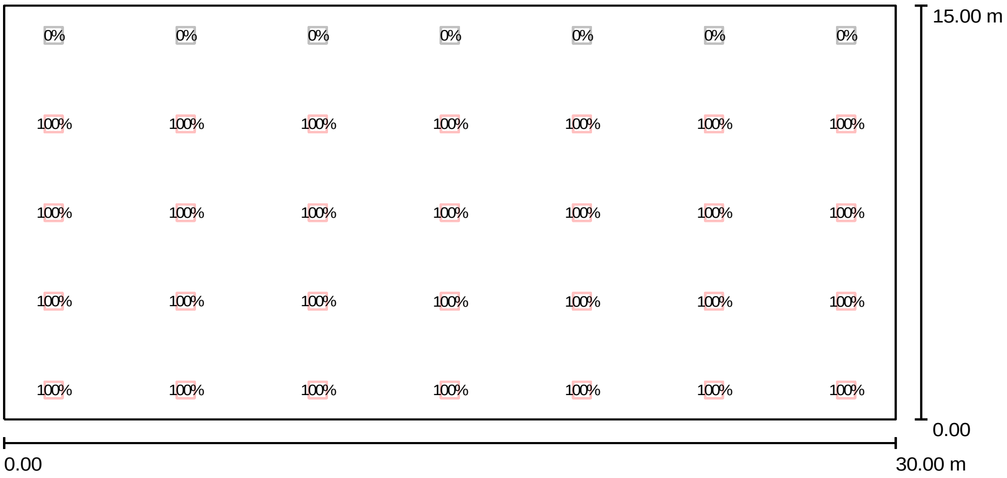


Figure A.5: Luminaire arrangement and illumination level W/W ratio at 5%
Scale 1 : 215

Daylight parameters:
Location: Sri Jaywardanapura, Longitude: 80.13°, Latitude: 6.10°,
North deviation: 245.0°
Date: 21.03.2011, Time:09:00:00 (+5 hours difference to GMT)
Reference sky type: Clear sky

Figure A.6: Luminaire arrangement and Isolines W/W ratio at 5%

Photometric results

Total Luminous Flux: 143080 lm

Total Load: 2940 W

Light loss factor: 0.67

Boundary Zone: 0.500 m

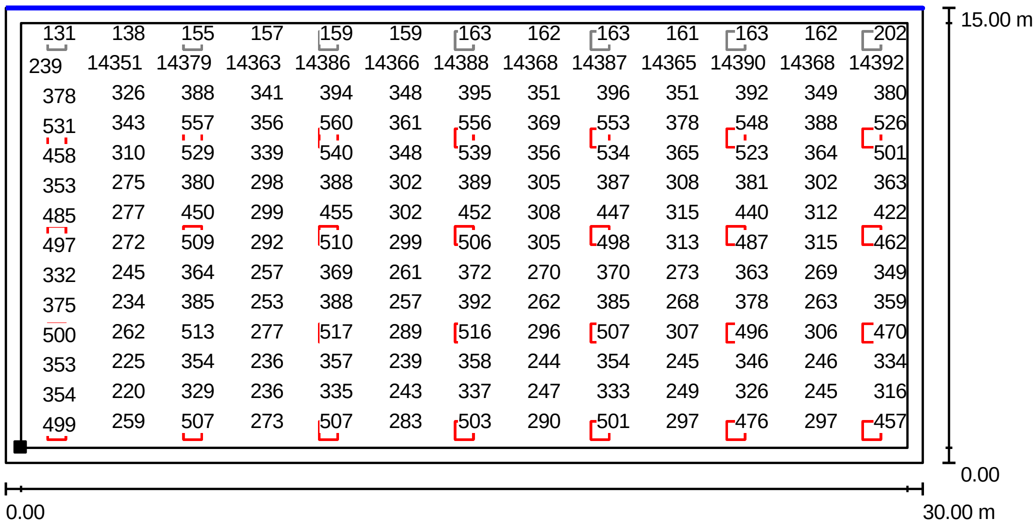


Figure A.7: Luminaire arrangement and Value Chart W/W ratio at 5%

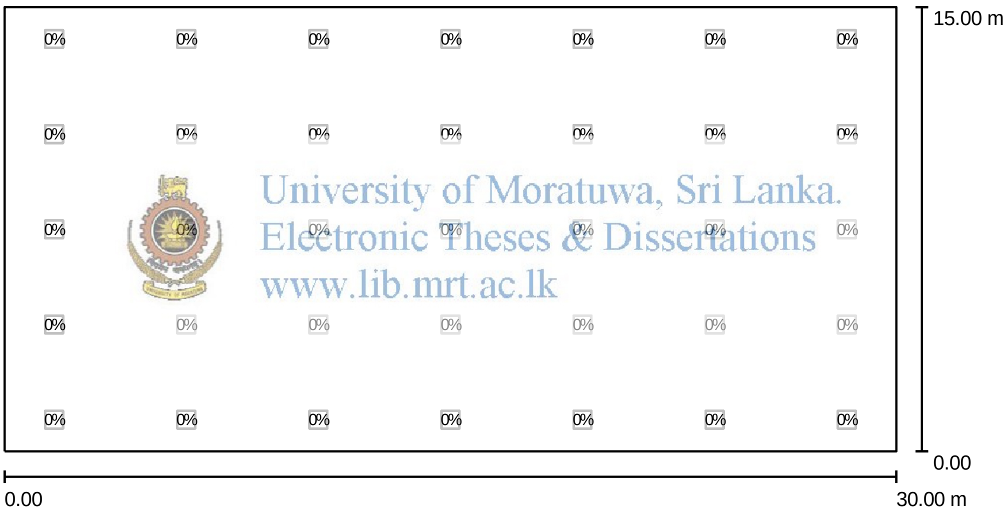


Figure A.8: Luminaire arrangement and illumination level W/W ratio at 75%

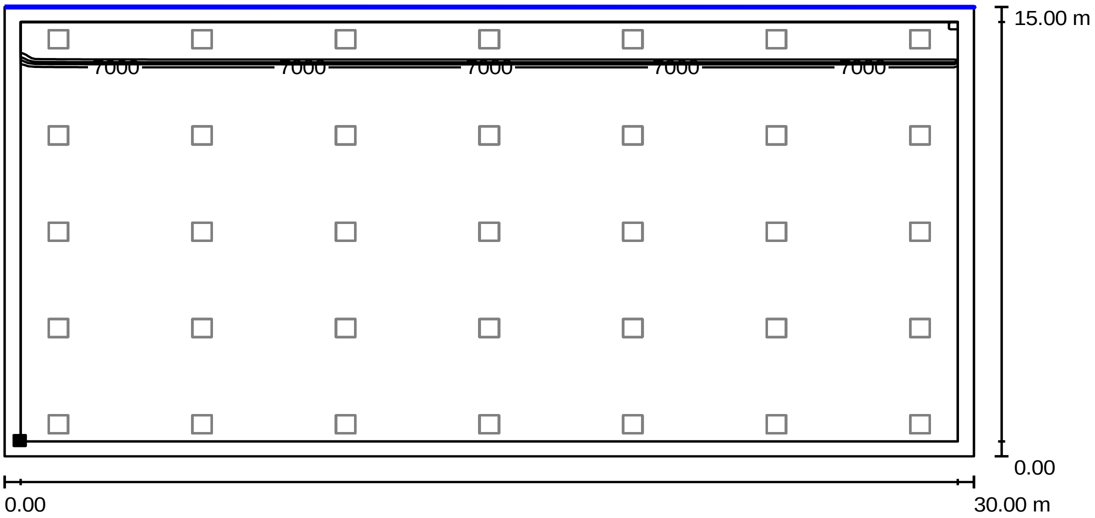
Scale 1 : 215

Daylight parameters:

Location: Sri Jaywardanapura, Longitude: 80.13°, Latitude: 6.10°, North deviation: 245.0°

Date: 21.03.2011, Time:09:00:00 (+5 hours difference to GMT)

Reference sky type: Clear sky



Values in Lux, Scale 1:21

Figure A 9: Luminaire arrangement and Isoline arrangement W/W ratio at 75%

Photometric results

Total Luminous Flux:	0 lm
Total Load:	0.0 W
Light loss factor:	0.67
Boundary Zone:	0.500 m

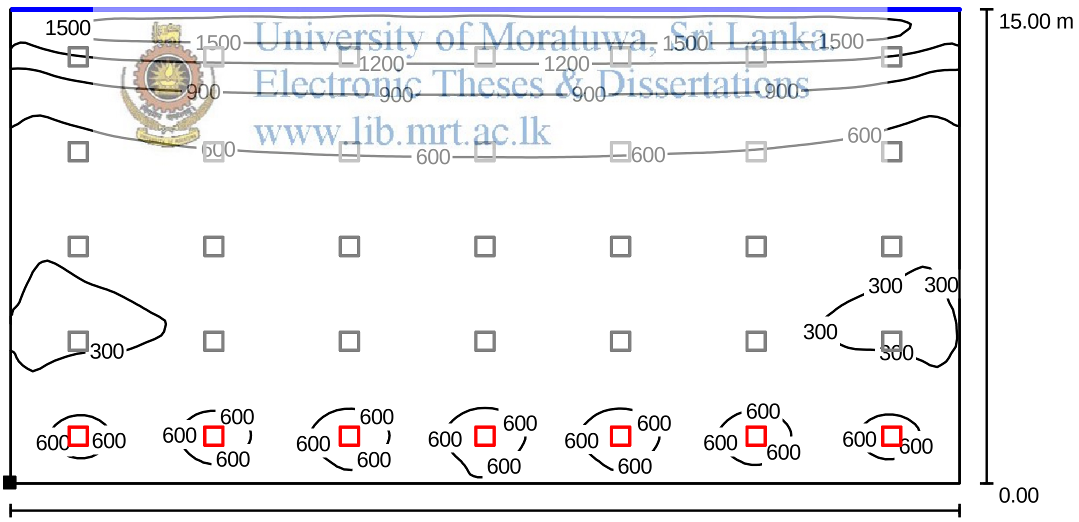


Figure A.10: Luminaire arrangement and illumination level W/W ratio at 65%

Scale 1 : 215

Daylight parameters:

Location: Sri Jaywardanapura, Longitude: 80.13°, Latitude: 6.10°, North deviation: 245.0°

Date: 21.06.2011, Time:15:00:00 (+5 hours difference to GMT)

Reference sky type: Clear sky

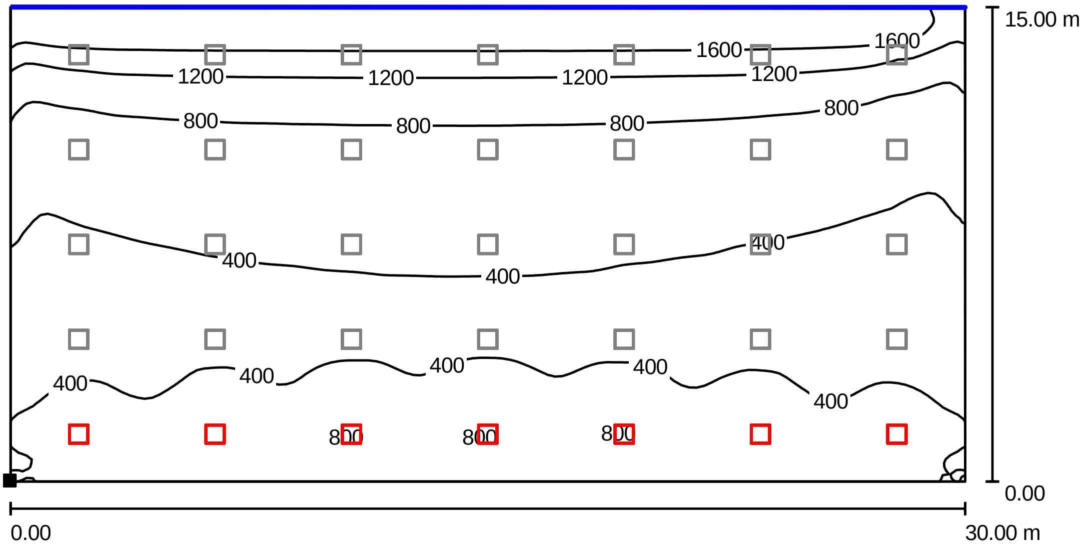


Figure A.11: Luminaire arrangement and illumination level W/W ratio at 65%

Scale 1 : 215

Daylight parameters:

Location: Sri Jaywardanapura, Longitude: 80.13°, Latitude: 6.10°, North deviation: 245.0°

Date: 21.12.2011, Time:15:00:00 (+5 hours difference to GMT)

Reference sky type: Clear sky

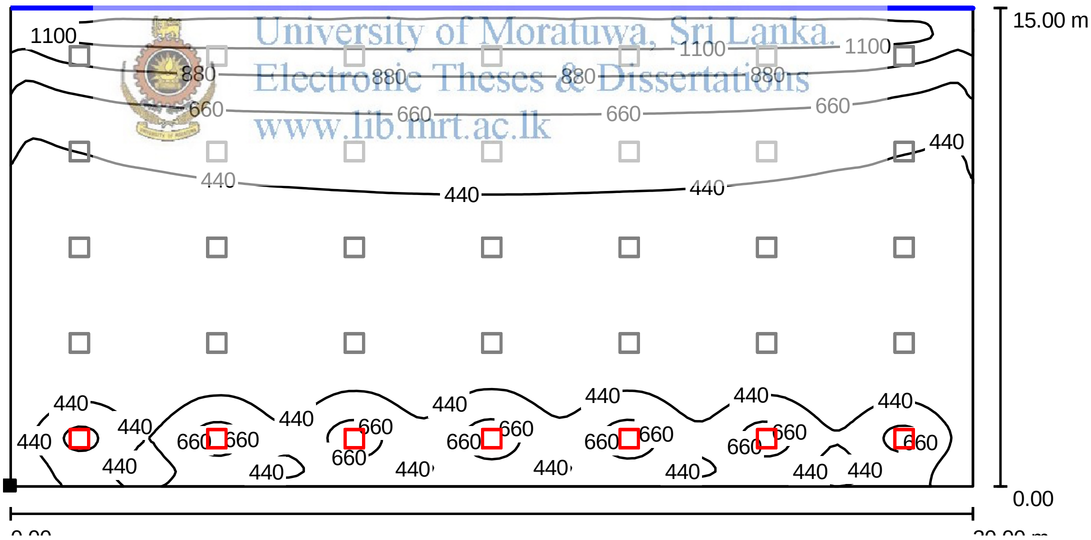


Figure A.12: Luminaire arrangement and illumination level W/W ratio at 65%

Scale 1 : 215

Daylight parameters:

Location: Sri Jaywardanapura, Longitude: 80.13°, Latitude: 6.10°, North deviation: 245.0°

Date: 21.06.2011, Time:15:00:00 (+5 hours difference to GMT)

Reference sky type: Clear sky

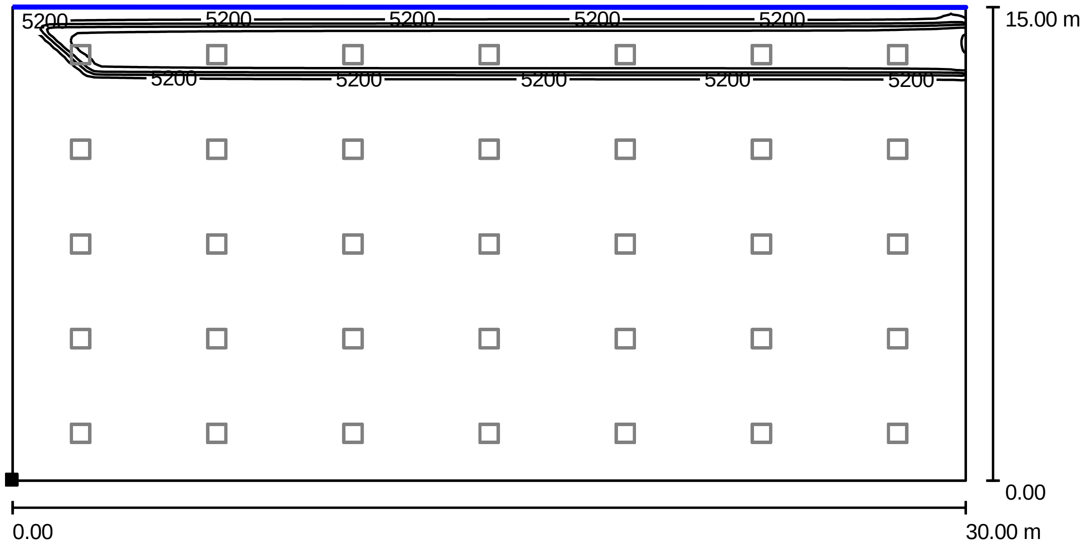


Figure A.13: Luminaire arrangement and illumination level W/W ratio at 55%

Scale 1 : 215
Daylight parameters:
Location: Sri Jaywardanapura, Longitude: 80.13°, Latitude: 6.10°, North deviation: 245.0°
Date: 21.06.2011, Time:09:00:00 (+5 hours difference to GMT)
Reference sky type: Clear sky

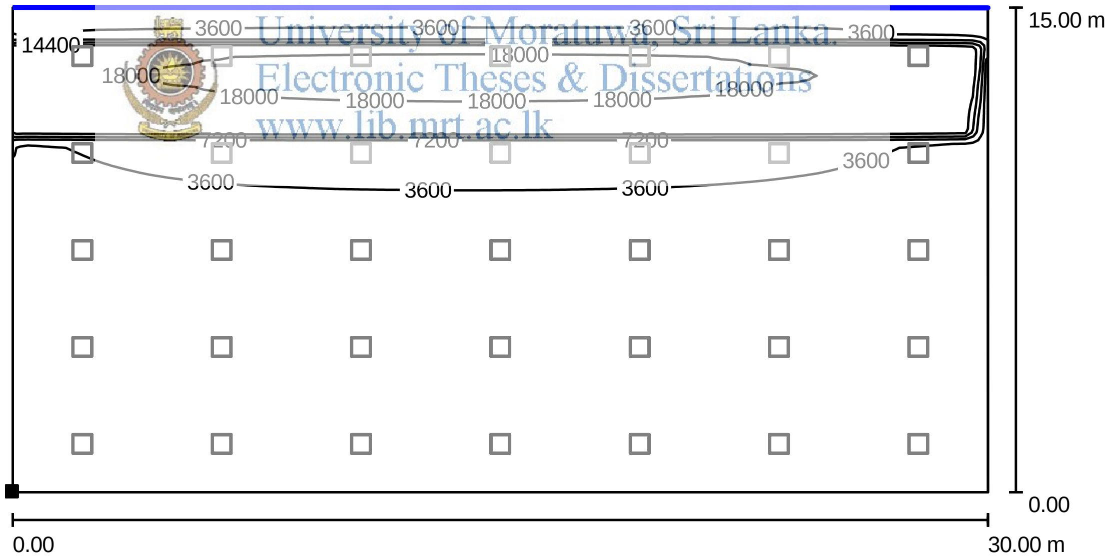


Figure A.14: Luminaire arrangement and illumination level W/W ratio at 55%

Scale 1 : 215
Daylight parameters:
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Date: 21.12.2011, Time:09:00:00 (+5 hours difference to GMT)
Reference sky type: Clear sky

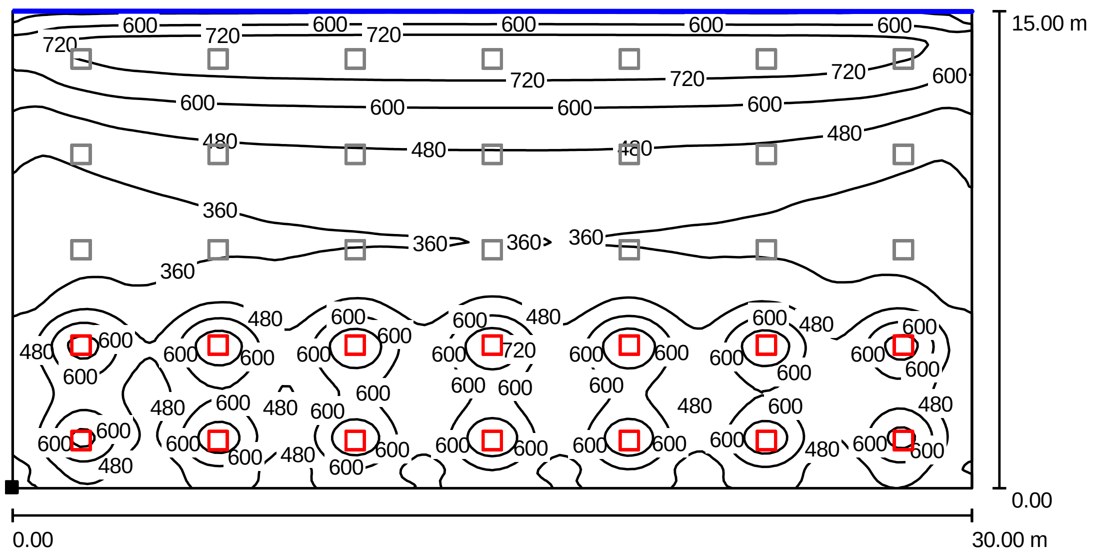

Figure A.15: Luminaire arrangement and illumination level W/W ratio at 55%

Scale 1 : 215

Daylight parameters:

Location: Sri Jaywardanapura, Longitude: 80.13°, Latitude: 6.10°, North deviation: 245.0°

Date: 21.06.2011, Time:17:00:00 (+5 hours difference to GMT)

Reference sky type: Clear sky

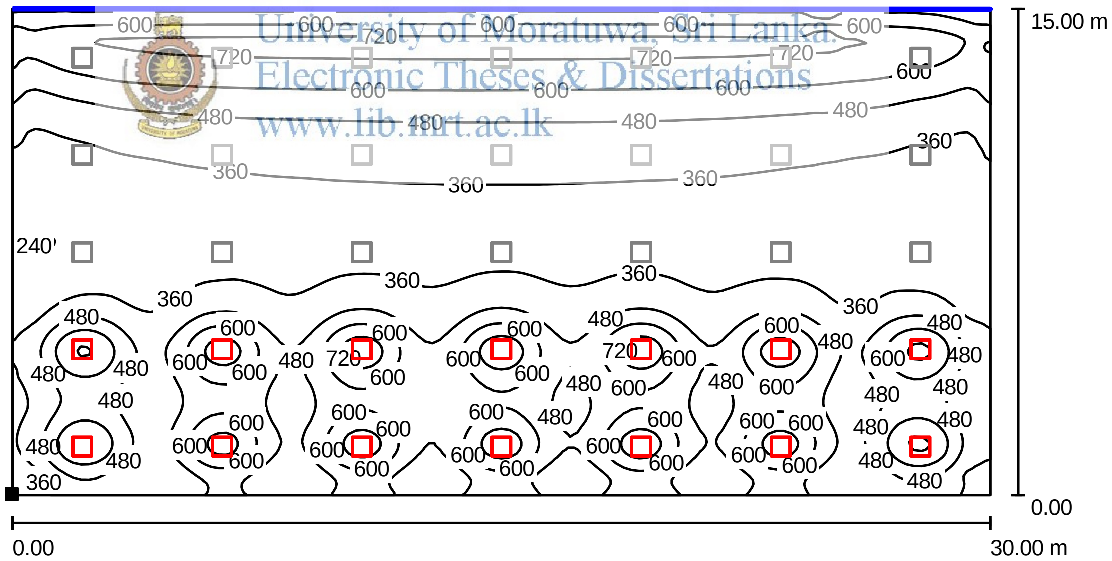

Figure A.16: Luminaire arrangement and illumination level W/W ratio at 55%

Scale 1 : 215

Daylight parameters:

Location: Sri Jaywardanapura, Longitude: 80.13°, Latitude: 6.10°, North deviation: 245.0°

Date: 21.12.2011, Time:17:00:00 (+5 hours difference to GMT)

Reference sky type: Clear sky

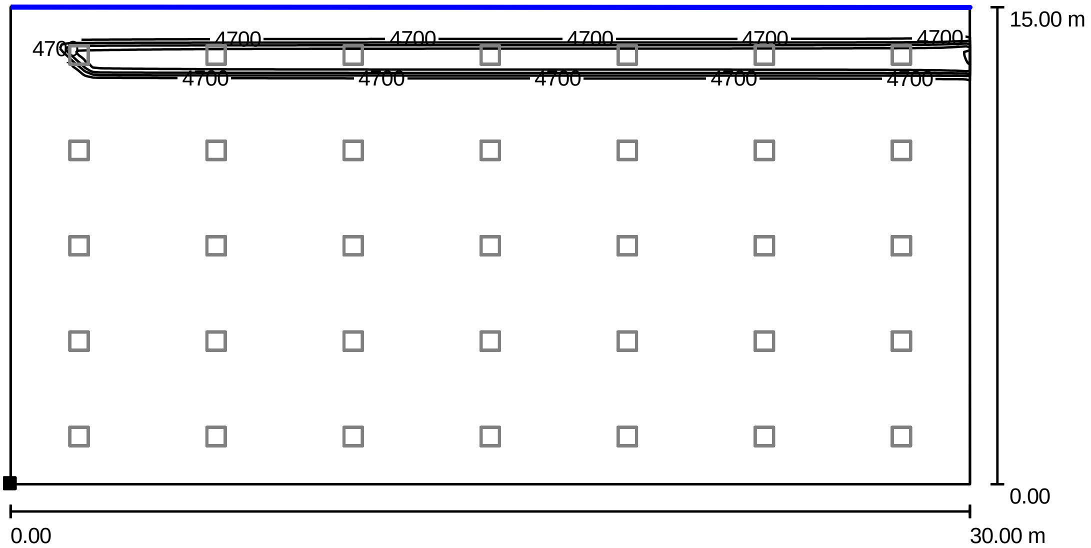

Figure A.17: Luminaire arrangement and illumination level W/W ratio at 35%

Scale 1 : 215

Daylight parameters:

Location: Sri Jaywardanapura, Longitude: 80.13°, Latitude: 6.10°, North deviation: 245.0°

Date: 21.06.2011, Time:09:00:00 (+5 hours difference to GMT)

Reference sky type: Clear sky

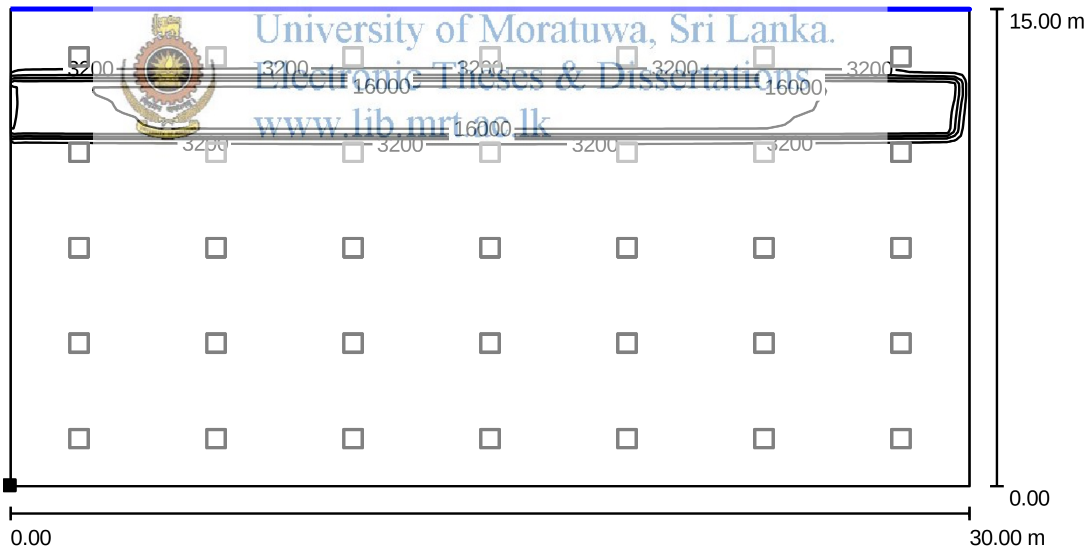

Figure A.18: Luminaire arrangement and illumination level W/W ratio at 35%

Scale 1 : 215

Daylight parameters:

Location: Sri Jaywardanapura, Longitude: 80.13°, Latitude: 6.10°, North deviation: 245.0°

Date: 21.12.2011, Time:09:00:00 (+5 hours difference to GMT)

Reference sky type: Clear sky

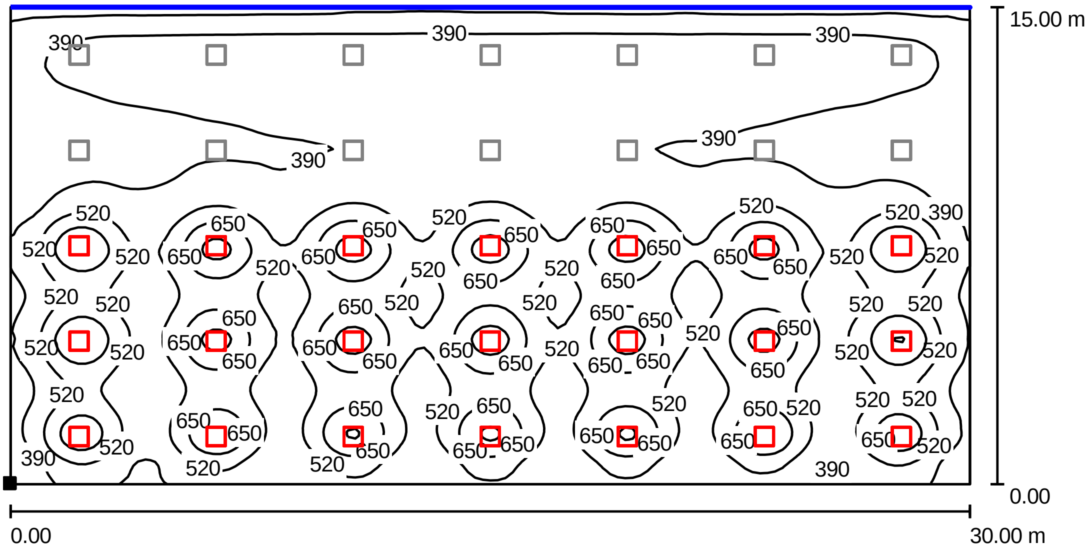

Figure A.19: Luminaire arrangement and illumination level W/W ratio at 35%

Scale 1 : 215

Daylight parameters:
Location: Sri Jaywardanapura, Longitude: 80.13°, Latitude: 6.10°, North deviation: 245.0°
Date: 21.06.2011, Time:17:00:00 (+5 hours difference to GMT)
Reference sky type: Clear sky

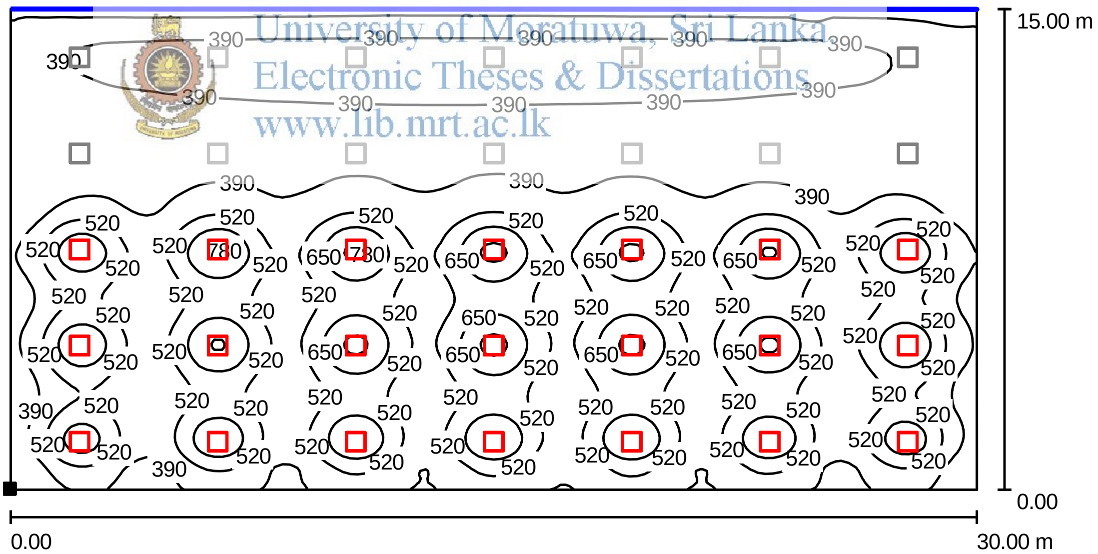

Figure A.20: Luminaire arrangement and illumination level W/W ratio at 35%

Scale 1 : 215

Daylight parameters:
Location: Sri Jaywardanapura, Longitude: 80.13°, Latitude: 6.10°, North deviation: 245.0°
Date: 21.12.2011, Time:17:00:00 (+5 hours difference to GMT)
Reference sky type: Clear sky

Appendix B: Cooling Load Temperature Difference for Calculating Load from Flat roof

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Table 5 Cooling Load Temperature Differences for Calculating Cooling Load from Flat Roofs

Roof No	Description of Construction	Mass, kg/m²	U-value, W/m²·°C	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	of Maximum CLTD	Minimum CLTD	Maximum CLTD	Difference CLTD
	Without Suspended Ceiling																														
1	Steel sheet with 25.4-mm (or 50.8-mm) insulation	34 (39)	1.209 (0.704)	0	−1	−2	−2	−3	−2	3	11	19	27	34	40	43	44	43	39	33	25	17	10	7	5	3	1	14	−3	44	[illegible]
2	25.4-mm wood with 25.4-mm insulation	39	0.965	3	2	0	−1	−2	−2	−1	2	8	15	22	29	35	39	41	41	39	35	29	21	15	11	8	5	16	−2	41	[illegible]
3	101.6-mm l.w concrete	88	1.209	5	3	1	0	−1	−2	−2	1	5	11	18	25	31	36	39	40	40	37	32	25	19	14	10	7	16	−2	40	[illegible]
4	50.8-mm h.w. concrete with 25.4-mm (or 50.8-mm) insulation	142	1.170 (0.693)	7	5	3	2	0	−1	0	2	6	11	17	23	28	33	36	37	37	34	30	25	20	16	12	10	16	−1	37	[illegible]
5	25.4-mm wood with 50.8-mm insulation	44	0.619	2	0	−2	−3	−4	−4	−4	−2	3	9	15	22	27	32	35	36	35	32	27	20	14	10	6	3	16	−4	36	[illegible]
6	152.4-mm l.w. concrete	117	0.897	12	10	7	5	3	2	1	0	2	4	8	13	18	24	29	33	35	36	35	32	28	24	19	16	18	0	36	[illegible]
7	63.5-mm wood with 25.4-mm insulation	63	0.738	16	13	11	9	7	6	4	3	4	5	8	11	15	19	23	27	29	31	31	30	27	25	22	19	19	3	31	[illegible]
8	203.2-mm l.w. concrete	151	0.715	20	17	14	12	10	8	6	5	4	4	5	7	11	14	18	22	25	28	30	30	29	27	25	22	20	4	30	[illegible]
9	101.6-mm h.w. concrete with 25.4-mm (or 50.8-mm) insulation	254 (254)	1.136 (0.681)	14	12	10	8	7	5	4	4	6	8	11	15	18	22	25	28	29	30	29	27	24	21	19	16	18	4	30	[illegible]
10	63.5-mm wood with 50.8-mm insulation	63	0.528	18	15	13	11	9	8	6	5	5	5	7	10	13	17	21	24	27	28	29	29	27	25	23	20	19	5	29	[illegible]
11	Roof terrace system	366	0.602	19	17	15	14	12	11	9	8	7	8	8	10	12	15	18	20	22	24	25	26	25	24	22	21	20	7	26	[illegible]
12	152.4-mm h.w. concrete with 25.4-mm (or 50.8-mm) insulation	366 (366)	(1.090) (0.664)	18	16	14	12	11	10	9	8	8	9	10	12	15	17	20	22	24	25	25	25	24	22	20	19	19	8	25	[illegible]
13	101.6-mm wood with 25.4-mm (or 50.8-mm) insulation	83 (88)	0.602 (0.443)	21	20	18	17	15	14	13	11	10	9	9	9	10	12	14	16	18	20	22	23	24	24	23	22	22	9	24	[illegible]
	With Suspended Ceiling																														
1	Steel Sheet with 25.4-mm (or 50.8-mm) insulation	44 (49)	0.761 (0.522)	1	0	−1	−2	−3	−3	0	5	13	20	28	35	40	43	43	41	37	31	23	15	10	7	5	3	15	−3	43	[illegible]
2	25.4-mm wood with 25.4-mm insulation	49	0.653	11	8	6	5	3	2	1	2	4	7	12	17	22	27	31	33	35	34	32	28	24	20	17	14	17	1	35	[illegible]
3	101.6-mm l.w. concrete	97	0.761	10	8	6	4	2	1	0	0	2	6	10	16	21	27	31	34	35	36	34	30	26	21	17	13	17	0	36	[illegible]
4	50.8-mm h.w. concrete with 25.4-mm insulation	146	0.744	16	14	13	11	10	8	7	7	8	9	11	14	17	19	22	24	25	26	26	25	23	21	20	18	18	7	26	[illegible]
5	25.4-mm wood with 50.8-mm insulation	49	0.471	14	11	9	7	5	4	3	3	4	6	10	14	18	23	27	30	31	32	31	29	26	22	19	16	18	3	32	[illegible]
6	152.4-mm l.w. concrete	127	0.619	18	15	13	11	9	7	6	4	4	4	6	9	12	16	20	24	27	29	30	30	28	26	23	20	20	4	30	[illegible]
7	63.5-mm wood with 25.4-mm insulation	73	0.545	19	18	16	14	13	12	10	9	8	8	9	10	12	14	17	19	21	23	24	25	24	23	22	21	20	8	25	[illegible]
8	203.2-mm l.w. concrete	161	0.528	22	20	18	16	15	13	11	10	9	8	8	8	9	11	14	16	19	21	23	25	25	25	24	23	20	8	25	[illegible]
9	101.6-mm h.w. concrete with 25.4-mm (or 50.8-mm) insulation	259 (264)	0.727 (0.511)	17	16	15	14	13	13	12	11	11	11	12	13	15	16	18	19	20	21	21	21	21	20	19	18	19	11	21	[illegible]
10	63.5-mm wood with 50.8-mm insulation	73	0.409	19	18	17	16	14	13	12	11	10	10	10	11	12	14	16	18	19	21	22	23	23	22	22	21	21	10	23	[illegible]
11	Roof terrace system	376	0.466	17	16	16	15	15	14	13	13	13	12	12	13	13	14	15	16	16	17	18	18	19	18	18	18	21	12	19	[illegible]
12	152.4-mm h.w. concrete with 25.4-mm (or 50.8-mm) insulation	376 (376)	0.710 0.499	16	16	15	15	14	13	13	12	12	12	12	13	14	15	16	17	18	18	19	19	19	18	18	18	20	12	19	[illegible]
13	101.6-mm wood with 25.4-mm (or 50.8-mm) insulation	93 (97)	0.465 (0.363)	20	19	19	18	17	16	15	14	14	13	12	12	12	12	13	14	15	16	18	19	20	20	20	20	23	12	20	[illegible]

(1) *Direct Application of Table 5 Without Adjustments:*
Values in Table 5 were calculated using the following conditions:

- Dark flat surface roof ("dark" for solar radiation absorption)
- Indoor temperature of 25.5°C
- Outdoor maximum temperature of 35°C with outdoor mean temperature of 29.4°C and an outdoor daily range of 11.6°C
- Solar radiation typical of 40 deg North latitude on July 21
- Outside surface resistance. $R_o = 0.059$ m²·°C/W
- Without and with suspended ceiling, but no attic fans or return air ducts in suspended ceiling space
- Inside surface resistance, $R_i = 0.121$ m²·°C/W

(2) *Adjustments to Table 5 Values:*

The following equation makes adjustments for deviations of design and solar conditions from those listed in (1) above.

$$CLTD_{corr} = [(CLTD + LM) \cdot K + (25.5 - T_R) + (T_o - 29.4)] \cdot f$$

where CLTD is from this table

(a) LM is latitude-month correction from Table 9 for a horizontal surface.

(b) K is a color adjustment factor and is applied after first making month-latitude adjustments. Credit should not be taken for a light-colored roof except where permanence of light color is established by experience, as in rural areas or where there is little smoke.

$K = 1.0$ if dark colored or light in an industrial area
$K = 0.5$ if permanently light-colored (rural area)

(c) $(25.5 - T_R)$ is indoor design temperature correction.

(d) $(T_o - 29.4)$ is outdoor design temperature correction, where T_o is the average outside temperature on design day.

(e) f is a factor for attic fan and or ducts above ceiling and is applied after all other adjustments have been made.

$f = 1.0$ no attic or ducts
$f = 0.75$ positive ventilation

Values in Table 5 were calculated without and with a suspended ceiling, but made no allowances for positive ventilation or return ducts thru the space. If ceiling is insulated and a fan is used between ceiling and roof, CLTD may be reduced by 25% ($f = 0.75$). Use of the suspended ceiling space for a return air plenum or with return air ducts should be analyzed separately.

(3) *Roof Constructions Not Listed in Table:*

The *U*-Values listed are to be used only as guides. The actual value of *U* as obtained from tables such as Tables 3 and 4, Chapter 23, or as calculated for the actual roof construction should be used.

Appendix C: Cooling Load Temperature Difference for Calculating Cooling Load from Sunlit Walls

Table 7 Cooling Load Temperature Differences for Calculating Cooling Load from Sunlit Walls

North Latitude Wall Facing	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	Hr of Maximum CLTD	Minimum CLTD	Maximum CLTD	Difference CLTD
Group A Walls																												
N	8	8	8	7	7	7	7	6	6	6	6	6	6	6	6	6	6	6	7	7	7	7	8	8	2	6	8	2
NE	11	11	10	10	10	9	9	9	8	8	8	9	9	9	9	10	10	10	11	11	11	11	11	11	22	8	11	3
E	14	13	13	13	12	12	11	11	10	10	10	11	11	12	12	13	13	13	14	14	14	14	14	14	22	10	14	4
SE	13	13	13	12	12	11	11	10	10	10	10	10	10	11	11	12	12	13	13	13	13	13	13	13	22	10	13	3
S	11	11	11	11	10	10	9	9	9	8	8	8	8	8	8	8	9	9	10	10	11	11	11	11	23	8	11	3
SW	14	14	14	14	13	13	12	12	11	11	10	10	10	9	9	10	10	10	11	12	13	13	14	14	24	9	14	5
W	15	15	15	14	14	14	13	13	12	12	11	11	10	10	10	10	10	11	11	12	13	14	14	15	1	10	15	5
NW	12	12	11	11	11	11	10	10	10	9	9	8	8	8	8	8	8	8	9	9	10	11	11	11	1	8	12	4
Group B Walls																												
N	8	8	8	7	7	6	6	6	5	5	5	5	5	5	5	6	6	7	7	8	8	8	8	8	24	5	8	3
NE	11	10	10	9	9	8	7	7	7	7	8	8	9	9	10	10	11	11	11	12	12	12	11	11	21	7	12	5
E	13	13	12	11	10	10	9	8	8	9	9	10	12	13	13	14	14	15	15	15	15	15	14	14	20	8	15	7
SE	13	12	12	11	10	10	9	8	8	8	8	9	10	11	12	13	14	14	14	14	14	14	14	14	21	8	14	6
S	12	11	11	10	9	9	8	7	7	6	6	6	6	7	8	9	10	11	11	12	12	12	12	12	23	6	12	6
SW	15	15	14	13	13	12	11	10	9	9	8	8	7	7	8	9	10	11	13	14	15	15	16	16	24	7	16	9
W	16	16	15	14	14	13	12	11	10	9	9	8	8	8	8	8	9	11	12	14	15	16	16	17	24	8	17	9
NW	13	12	12	11	11	10	9	9	8	7	7	7	6	6	7	7	8	8	9	11	12	13	13	13	24	6	13	7
Group C Walls																												
N	9	8	7	7	6	5	5	4	4	4	4	4	5	5	6	6	7	8	9	9	9	10	9	9	22	4	10	6
NE	10	10	9	8	7	6	6	6	6	7	8	10	10	11	12	12	12	13	13	13	13	12	12	11	20	6	13	7
E	13	12	11	10	9	8	7	7	8	9	11	13	14	15	16	16	17	17	16	16	16	15	14	13	18	7	17	10
SE	13	12	11	10	9	8	7	6	7	7	9	10	12	14	15	16	16	16	16	16	16	15	14	13	19	6	16	10
S	12	11	10	9	8	7	6	6	5	5	5	5	6	8	9	11	12	13	14	14	14	14	13	12	20	5	14	9
SW	16	15	14	12	11	10	9	8	7	7	6	6	6	7	8	10	12	14	16	18	18	18	18	17	22	6	18	12
W	17	16	15	14	12	11	10	9	8	7	7	7	7	7	8	9	11	13	16	18	19	20	19	18	22	7	20	13
NW	14	13	12	11	10	9	8	7	6	6	5	5	6	6	6	7	9	10	12	14	15	15	15	15	22	5	15	10
Group D Walls																												
N	8	7	7	6	5	4	3	3	3	3	4	4	5	6	6	7	8	9	10	11	11	10	10	9	21	3	11	8
NE	9	8	7	6	5	5	4	4	6	8	10	11	12	13	13	13	14	14	14	13	13	12	11	10	19	4	14	10
E	11	10	8	7	6	5	5	5	7	10	13	15	17	18	18	18	18	18	17	17	16	15	13	12	16	5	18	13
SE	11	10	9	7	6	5	5	5	5	7	10	12	14	16	17	18	18	18	17	17	16	15	14	12	17	5	18	13
S	11	10	8	7	6	5	4	4	3	3	4	5	7	9	11	13	15	16	16	16	15	14	13	12	19	3	16	13
SW	15	14	12	10	9	8	6	5	5	4	4	5	5	7	9	12	15	18	20	21	21	20	19	17	21	4	21	17
W	17	15	13	12	10	9	7	6	5	5	5	5	6	6	8	10	13	17	20	22	23	22	21	19	21	5	23	18
NW	14	12	11	9	8	7	6	5	4	4	4	4	5	6	7	8	10	12	15	17	18	17	16	15	22	4	18	14
Group E Walls																												
N	7	6	5	4	3	2	2	2	3	3	4	5	6	7	8	10	10	11	12	12	11	10	9	8	20	2	12	10
NE	7	6	5	4	3	2	3	6	8	11	13	15	15	14	14	15	15	14	14	13	12	11	9	8	16	2	15	13
E	8	7	6	5	4	3	3	6	10	15	18	20	21	21	20	19	18	18	17	15	14	12	11	9	13	3	21	18
SE	8	7	6	5	4	3	3	4	7	10	14	17	19	20	20	20	19	18	17	16	14	13	11	10	15	3	20	17
S	8	7	6	5	4	3	2	2	2	3	5	7	10	14	16	18	19	18	17	16	14	13	11	10	17	2	19	17
SW	12	10	8	7	6	4	4	3	3	3	4	5	7	10	14	18	21	24	25	24	22	19	17	14	19	3	25	22
W	14	12	10	8	6	5	4	3	3	4	4	5	6	8	11	15	20	24	27	27	25	22	19	16	20	3	27	24
NW	11	9	8	6	5	4	3	3	3	3	4	5	6	7	9	11	14	18	21	21	20	18	15	13	20	3	21	18
Group F Walls																												
N	5	4	3	2	1	1	1	2	3	4	5	6	8	9	11	12	12	13	13	13	11	9	7	6	19	1	13	12
NE	5	4	3	2	1	1	3	8	13	16	17	16	16	15	15	15	15	14	13	12	10	9	7	6	11	1	17	16
E	5	4	3	2	2	1	4	9	16	21	24	25	24	22	20	19	18	17	15	13	11	10	8	7	12	1	25	24
SE	5	4	3	2	2	1	2	6	10	15	20	23	24	23	22	20	19	17	16	14	12	10	8	7	13	1	24	23
S	5	4	3	2	2	1	1	1	2	4	7	11	15	19	21	22	21	19	17	15	12	10	8	7	16	1	22	21
SW	8	6	5	4	3	2	1	1	2	3	4	6	10	14	20	24	28	30	29	25	20	16	13	10	18	1	30	29
W	9	7	5	4	3	2	2	2	2	3	4	6	8	11	16	22	27	32	33	30	24	19	15	12	19	2	33	31
NW	8	6	4	3	2	2	1	1	2	3	4	6	7	9	12	15	19	24	26	24	20	16	12	10	19	1	26	25
Group G Walls																												
N	2	1	0	0	0	1	4	5	5	7	8	10	12	13	13	14	14	15	12	8	6	5	4	3	18	0	15	15
NE	2	1	1	0	0	5	15	20	22	20	16	15	15	15	15	15	14	12	10	8	6	5	4	3	9	0	22	22
E	2	1	1	0	0	6	17	26	30	31	28	22	19	17	17	16	15	13	11	8	7	5	4	3	10	0	31	31
SE	2	1	1	0	0	3	10	18	24	27	28	27	23	20	18	16	15	13	11	8	7	6	4	3	11	0	28	28
S	2	1	1	0	0	0	1	3	7	12	17	22	25	26	24	21	17	14	11	8	7	5	4	3	14	0	26	26
SW	3	2	2	1	0	0	1	3	4	6	9	14	21	28	33	35	34	29	20	13	10	7	6	4	16	0	35	35
W	4	3	2	1	1	1	1	3	5	6	8	10	15	23	31	37	40	37	27	16	11	8	6	5	17	1	40	39
NW	3	2	1	1	0	0	1	3	4	6	8	10	12	15	20	26	31	31	23	14	10	7	5	4	18	0	31	31

(Solar Time, h)

(1) *Direct Application of Table 7 Without Adjustments:*
Values in the Table were calculated using the following conditions for walls as outlined for the roof CLTD table, Table 5. These values may be used for normal air-conditioning estimates usually without correction (except as noted below) when the load is calculated for the hottest weather.
For totally shaded walls use the North orientation values.

(2) *Adjustments to Table Values:*
The following equation makes adjustments for conditions other than those listed in Note (1).

$$CLTD_{corr} = (CLTD + LM) \cdot K + (25.5 - T_R) + (T_o - 29.4)$$

where CLTD is from Table 7 at the wall orientation.

(a) LM is latitude-month correction from Table 9.

(b) K is a color adjustment factor and is applied after first making month-latitude adjustments
K = 1.0 if dark colored or light in an industrial area
K = 0.83 if permanently medium-colored (rural area)
K = 0.65 if permanently light-colored (rural area)
Credit should not be taken for a light-colored roof except where permanence of light color is established by experience, as in rural areas or where th is little smoke.

Appendix D: Cooling Load Temperature Differences for conduction through Glass

Table 10 Cooling Load Temperature Differences for Conduction through Glass

Solar Time, h	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200
CLTD °C	1	0	−1	−1	−1	−1	−1	0	1	2	4	5

Solar Time, h	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400
CLTD °C	7	7	8	8	7	7	6	4	3	2	2	1

Corrections: The values in the table were calculated for an inside temperature of 25.5°C and an outdoor maximum temperature of 35°C with an outdoor daily range of 11.6°C. The table remains approximately correct for other outdoor maximums 33.8-38.8°C and other outdoor daily ranges 8.9-18.9°C, provided the outdoor daily average temperature remains approximately 29.4°C. If the room air temperature is different from 25.5°C and/or the outdoor daily average temperature is different from 29.4°C, the following rules apply: (a) For room air temperature less than 25.5°C, add the difference between 25.5°C and room air temperature; if greater than 25.5°C, subtract the difference. (b) For outdoor daily average temperature less than 29.4°C, subtract the difference between 29.4°C and the daily average temperature; if greater than 29.4°C, add the difference.

Using the basic equations of Chapter 27, a computer program was generated to calculate the SHGFs for the double-strength sheet glass. The SHGFs—calculated for different latitudes (0°N to 64°N), months (January through December), orientations (seventeen) and daylight hours—were used as the "heat gain" input for calculating cooling load factors, employing appropriate room transfer functions (from Methodology and Equations for Hour-by-Hour Load Calculations, below). However, this implied the introduction of two new, interdependent variables into the calculations—(1) type of interior construction in the space: light, medium or heavy and (2) presence or absence of an interior shading device for the glass—with the consequent increase in the number of variables.

To simplify the data, a *normalized* profile of the SHGFs was obtained by dividing the SHGFs for a particular month by the maximum SHGF in that month. A comparison of the normalized profiles obtained for *different* months indicated great similarity among SHGFs in the warmest months of the year (May through September). These summer season SHGFs were then compared to those of other latitudes and orientations. As a result, a set of factors for one latitude and one month—40°N latitude and July—was considered *representative* of all latitudes and months of hottest weather (May through September). These representative values were used as the input for calculating cooling load factors.

For calculation, the cooling load from solar radiation must be analyzed in one of two cases: (1) presence of interior shading or (2) absence of interior shading. In converting heat gain to cooling load, the time lag, caused by the radiant solar energy entering the space, is variable; for example, it differs when energy is absorbed by interior draperies or Venetian blinds, it differs from when it is absorbed by the floor. Interior shading devices cause the cooling load to track the solar heat gain profile more closely, while the case without the interior shading spreads the load out. Rudoy[36] has shown that the lightweight construction of interior shading changes the cooling load profile less, but reduces the energy by virtue of a lower SC. The time lag difference in converting heat gain to cooling load appears in the cooling load factors used to multiply the solar heat gains.

Cooling load caused by solar radiation through fenestration is calculated by:

$$q = \text{Area} \cdot \text{Shading Coefficient} \cdot \text{Maximum Solar Heat Gain} \cdot \text{Cooling Load Factor} \quad (12)$$

The *area* is the net glass area of the fenestration. The *maximum solar heat gain* is obtained for the appropriate latitude, month and surface orientation (Table 11). The *shading coefficient*, for combination of the fenestration and shading device, can be obtained from Tables 28 and 34 to 36, Chapter 27. The CLF values for three common room thermal characteristics are in Tables 12 and 13 of this chapter.

Total Load through Fenestration

The total load through fenestration is the sum of the from to conduction heat gain [Eq. (9)] and the load from solar heat gain [Eq. (12)].

Example 4: Determine the cooling load caused by glass on the south and west walls of a building at 1200, 1400 and 1600 hours in Aug. The building is located at 32°N latitude with outside design conditions of 32°C dry-bulb temperature and a 11°C daily range. The inside design dry-bulb temperature is 25°C. Assume the room construction is of medium weight. The south glass is the insulating glass (6.35 mm air space) with an area of 9.29 m² with no interior shading. The west glass is 5.56 mm single grey-tinted glass with an area of 9.29 m² and with light-colored Venetian blinds.

Solution: Data required for the calculations are as follows:

	U W/m²·K (Chapter 27, Table 13)	SC (Chapter 27)	Maximum SHG (Table 11)
S. Glass	3.46	0.82 (Table 29, Chapter 27)	350
W. Glass	4.60	0.53 (Table 35, Chapter 27)	619

The conduction heat gain component of the cooling is calculated by:

$$q = UA\,(\text{CLTD})$$

Time	CLTD (Table 10)	CLTD Corrected	S. Glass *UA* (CLTD) W	W. Glass *UA* (CLTD) W
1200	5	2.2	71	94
1400	7	4.2	135	179
1600	8	5.2	167	222

The correction factor applied to the above values was −2.8°C, computed from the notes of Table 10. The CLTDs are rounded off and the solar heat gain component of the cooling load is calculated by:

$$q = A\,(\text{SC})(\text{SHG})(\text{CLF})$$

	S. Glass		W. Glass	
Time	CLF (Table 12)	*A* SC SHG CLF W	CLF Table 13	*A* SC SHG CLF W
1200	0.52	1386	0.17	578
1400	0.58	1546	0.53	1803
1600	0.47	1253	0.82	2789

The total cooling load from heat gain through the glass is therefore:

Time	S. Glass W	W. Glass W
1200	1457	672
1400	1681	1982
1600	1420	3011

Appendix E: Maximum Solar Heat Gain Factor, W/m2 for Sunlit Glass, North Latitudes

Table 11 Maximum Solar Heat Gain Factor, W/m² for Sunlit Glass, North Latitudes

0 Deg

	N	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SWW	S	HOR
Jan.	107	107	278	558	738	801	741	574	372	934
Feb.	114	123	416	647	773	779	663	445	211	965
Mar.	120	274	536	704	764	704	536	274	120	956
Apr.	224	423	609	707	697	581	372	120	117	896
May	357	517	640	688	634	486	252	117	117	836
June	407	546	650	669	603	441	208	117	117	805
July	363	517	634	672	615	470	243	120	120	820
Aug.	237	423	590	681	669	552	353	123	120	871
Sep.	126	265	514	672	729	672	514	265	126	924
Oct.	117	126	407	628	745	751	637	426	208	943
Nov.	110	110	278	552	726	789	726	565	369	924
Dec.	107	107	224	517	713	798	757	618	435	909

20 Deg

	N	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	91	91	151	435	634	767	798	735	675	732
Feb.	98	98	278	546	713	770	751	634	549	830
Mar.	107	155	416	631	748	745	650	480	363	896
Apr.	120	290	524	672	719	656	498	287	183	905
May	148	388	581	685	685	581	391	170	133	893
June	186	426	596	681	663	546	341	142	133	880
July	151	391	574	672	669	565	375	167	136	877
Aug.	126	287	511	650	694	631	480	278	180	883
Sep.	114	145	401	603	710	710	628	467	360	868
Oct.	101	101	274	527	685	745	729	618	536	814
Nov.	91	91	151	429	622	754	786	722	666	726
Dec.	85	85	110	385	590	751	801	760	713	685

4 Deg

	N	NNE/ NNW	NE NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	104	104	249	536	722	795	514	609	445	902
Feb.	110	110	388	628	764	782	678	480	278	550
Mar.	120	243	514	691	764	716	558	303	136	953
Apr.	174	394	596	704	704	599	398	136	120	905
May	293	486	631	694	650	508	281	120	120	858
June	347	517	637	678	618	464	230	120	120	830
July	303	486	622	678	631	492	268	123	120	842
Aug.	186	391	581	678	675	571	379	133	126	880
Sep.	123	237	492	659	729	681	536	293	139	924
Oct.	114	114	379	609	738	754	653	467	271	928
Nov.	107	107	249	530	713	782	732	599	439	896
Dec.	104	104	196	495	697	789	764	650	505	874

24 Deg

	N	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	85	85	129	404	599	757	798	760	716	675
Feb.	95	95	252	521	694	770	767	672	606	786
Mar.	107	142	391	615	738	748	675	530	432	868
Apr.	117	278	502	659	719	669	533	338	237	893
May	136	369	562	675	688	599	416	211	145	890
June	174	401	581	675	669	565	369	174	136	880
July	142	366	555	663	672	584	407	205	145	877
Aug.	120	274	492	640	694	644	511	325	227	874
Sep.	110	133	375	584	700	710	650	514	423	839
Oct.	98	98	249	502	666	748	741	653	590	770
Nov.	85	85	133	398	590	745	786	748	707	672
Dec.	82	82	91	353	568	738	779	779	748	628

8 Deg

	N	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	101	101	224	514	707	789	764	640	511	868
Feb.	107	107	360	609	754	782	691	521	347	928
Mar.	117	211	492	678	760	726	581	347	174	947
Apr.	139	360	581	697	710	615	423	167	123	912
May	233	461	625	694	659	527	306	123	120	874
June	284	489	631	685	631	445	259	123	123	849
July	243	457	615	678	644	511	294	126	123	858
Aug.	148	369	565	675	681	587	404	161	129	890
Sep	120	208	470	647	726	691	555	338	177	915
Oct.	110	110	353	590	729	754	666	505	341	909
Nov.	104	104	224	508	694	773	735	631	505	861
Dec.	98	98	174	470	678	776	779	678	565	836

28 Deg

	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE SSW	S	HOR
Jan.	79	79	110	369	577	741	792	779	751	618
Feb.	91	91	227	495	672	770	776	707	653	738
Mar.	104	129	366	596	729	748	697	574	495	836
Apr.	114	265	476	647	719	681	562	391	297	877
May	126	363	543	666	691	615	454	262	183	883
June	161	394	562	666	672	581	404	707	155	877
July	129	360	536	656	678	599	442	252	180	870
Aug.	120	262	470	628	694	653	543	379	287	858
Sep.	107	120	350	565	691	713	672	558	486	808
Oct.	95	95	224	476	644	745	751	685	637	722
Nov.	82	82	110	363	571	732	779	767	741	615
Dec.	75	76	76	312	543	716	782	792	776	565

12 Deg

	N	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	98	98	199	489	685	776	779	669	574	827
Feb.	107	107	331	587	741	782	713	558	420	902
Mar.	114	183	467	663	757	735	599	391	230	937
Apr.	126	341	562	691	716	631	448	202	126	915
May	189	439	612	694	669	546	334	126	126	883
June	237	470	625	685	644	508	284	126	126	864
July	199	439	603	678	653	530	322	129	129	868
Aug.	133	344	549	669	688	603	426	196	448	890
Sep.	117	180	448	634	722	700	574	382	230	905
Oct.	107	107	325	568	716	751	691	543	410	883
Nov.	101	101	199	483	675	760	767	659	565	820
Dec.	95	95	148	445	653	764	792	704	622	789

32 Deg

	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
June	76	76	91	331	552	722	786	789	776	555
Feb.	85	85	205	470	647	764	782	732	697	685
Mar.	101	117	338	577	716	748	716	615	555	795
Apr.	114	252	461	631	716	691	590	445	363	855
May	120	350	536	656	694	628	489	312	233	874
June	139	385	555	656	675	596	439	262	189	871
July	126	350	527	643	678	612	473	303	227	861
Aug.	117	249	445	615	691	663	571	429	350	836
Sep.	104	110	325	546	678	716	688	596	540	770
Oct.	88	88	199	451	615	738	754	710	678	672
Nov.	76	76	91	325	546	710	773	776	767	552
Dec.	69	69	69	265	511	688	776	795	795	498

16 Deg

	N	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	95	95	174	464	663	770	792	704	628	782
Feb.	104	104	303	568	729	779	735	593	486	868
Mar.	110	167	441	647	745	741	622	435	293	918
Apr.	123	312	543	681	716	644	473	243	142	912
May	164	416	596	688	678	565	363	142	129	890
June	208	448	612	685	653	527	312	129	129	874
July	174	416	590	675	663	549	350	139	133	874
Aug.	129	316	530	659	691	644	451	233	145	890
Sep.	114	158	423	618	716	707	603	423	293	890
Oct.	104	104	300	549	704	748	710	577	473	852
Nov.	95	95	174	457	650	760	779	694	618	776
Dec.	91	91	129	416	625	760	801	735	669	738

36 Deg

	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE SSW	S	HOR
Jan.	69	69	76	284	524	691	779	795	795	489
Feb.	82	82	180	439	615	754	782	754	732	628
Mar.	95	104	312	555	704	751	732	650	606	751
Apr.	110	240	454	618	710	697	618	492	426	827
May	120	338	530	644	694	644	521	366	293	858
June	148	372	552	647	678	612	473	312	243	861
July	123	338	521	634	681	628	508	357	284	846
Aug.	114	237	435	599	688	669	596	476	413	811
Sep.	98	98	300	527	663	719	704	631	590	726
Oct.	85	85	177	420	590	726	754	729	710	615
Nov.	69	69	76	274	514	678	767	782	782	486
Dec.	63	63	63	218	476	644	760	798	801	429

Values of *U* can be obtained from Chapter 23. Temperature t_b may have any value over a considerable range according to conditions in the adjacent space. The temperature in a kitchen or boiler room may be as much as 8 to 25°C above the outdoor air temperature. It is recommended that actual temperatures in adjoining spaces be measured wherever practicable; where nothing is known except that the adjacent space is of conventional construction and contains no heat sources,- $t_b - t_i$ should be considered the difference between the outdoor air and conditioned-space design dry- bulb temperatures *minus* 2.8°C. In some cases, the air temperature in the adjacent space will always correspond to the outdoor air temperature.

For floors directly in contact with the ground, or over an underground basement that is neither ventilated nor warmed, heat transfer may be neglected for cooling load estimates.

Table 13 Cooling Load Factors for Glass without Interior Shading, North Latitudes

Fenestration Facing	Room Construction	Solar Time, h																							
		0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400
N (Shaded)	L	0.17	0.14	0.11	0.09	0.08	0.33	0.42	0.48	0.56	0.63	0.71	0.76	0.80	0.82	0.82	0.79	0.75	0.84	0.61	0.48	0.38	0.31	0.25	0.20
	M	0.23	0.20	0.18	0.16	0.14	0.34	0.41	0.46	0.53	0.59	0.65	0.70	0.73	0.75	0.76	0.74	0.75	0.79	0.61	0.50	0.42	0.36	0.31	0.27
	H	0.25	0.23	0.21	0.20	0.19	0.38	0.45	0.49	0.55	0.60	0.65	0.69	0.72	0.72	0.72	0.70	0.70	0.75	0.57	0.46	0.39	0.34	0.31	0.28
NNE	L	0.06	0.05	0.04	0.03	0.03	0.26	0.43	0.47	0.44	0.41	0.40	0.39	0.39	0.38	0.36	0.33	0.30	0.26	0.20	0.16	0.13	0.10	0.08	0.07
	M	0.09	0.08	0.07	0.06	0.06	0.24	0.38	0.42	0.39	0.37	0.37	0.36	0.36	0.36	0.34	0.33	0.30	0.27	0.22	0.18	0.16	0.14	0.12	0.10
	H	0.11	0.10	0.09	0.09	0.08	0.26	0.39	0.42	0.39	0.36	0.35	0.34	0.34	0.33	0.32	0.31	0.28	0.25	0.21	0.18	0.16	0.14	0.13	0.12
NE	L	0.04	0.04	0.03	0.02	0.02	0.23	0.41	0.51	0.51	0.45	0.39	0.36	0.33	0.31	0.28	0.26	0.23	0.19	0.15	0.12	0.10	0.08	0.06	0.05
	M	0.07	0.06	0.06	0.05	0.04	0.21	0.36	0.44	0.45	0.40	0.36	0.33	0.31	0.30	0.28	0.26	0.23	0.21	0.17	0.15	0.13	0.11	0.09	0.08
	H	0.09	0.08	0.08	0.07	0.07	0.23	0.37	0.44	0.44	0.39	0.34	0.31	0.29	0.27	0.26	0.24	0.22	0.20	0.17	0.14	0.13	0.12	0.11	0.10
ENE	L	0.04	0.03	0.03	0.02	0.02	0.21	0.40	0.52	0.57	0.53	0.45	0.39	0.34	0.31	0.28	0.25	0.22	0.18	0.14	0.12	0.09	0.08	0.06	0.05
	M	0.07	0.06	0.05	0.05	0.04	0.20	0.35	0.45	0.49	0.47	0.41	0.36	0.33	0.30	0.28	0.26	0.23	0.20	0.17	0.14	0.12	0.11	0.09	0.08
	H	0.09	0.09	0.08	0.07	0.07	0.22	0.36	0.46	0.49	0.45	0.38	0.33	0.30	0.27	0.25	0.23	0.21	0.19	0.16	0.14	0.13	0.12	0.11	0.10
E	L	0.04	0.03	0.03	0.02	0.02	0.19	0.37	0.51	0.57	0.57	0.50	0.42	0.37	0.32	0.29	0.25	0.22	0.19	0.15	0.12	0.10	0.08	0.06	0.05
	M	0.07	0.06	0.06	0.05	0.05	0.18	0.33	0.44	0.50	0.51	0.46	0.39	0.35	0.31	0.29	0.26	0.23	0.21	0.17	0.15	0.13	0.11	0.10	0.08
	H	0.09	0.09	0.08	0.08	0.07	0.20	0.34	0.45	0.49	0.49	0.43	0.36	0.32	0.29	0.26	0.24	0.22	0.19	0.17	0.15	0.13	0.12	0.11	0.10
ESE	L	0.05	0.04	0.03	0.03	0.02	0.17	0.34	0.49	0.58	0.61	0.57	0.48	0.41	0.36	0.32	0.28	0.24	0.20	0.16	0.13	0.10	0.09	0.07	0.06
	M	0.08	0.07	0.06	0.05	0.05	0.16	0.31	0.43	0.51	0.54	0.51	0.44	0.39	0.35	0.32	0.29	0.26	0.22	0.19	0.16	0.14	0.12	0.11	0.09
	H	0.10	0.09	0.09	0.08	0.08	0.19	0.32	0.43	0.50	0.52	0.49	0.41	0.36	0.32	0.29	0.26	0.24	0.21	0.18	0.16	0.14	0.13	0.12	0.11
SE	L	0.05	0.04	0.04	0.03	0.03	0.13	0.28	0.43	0.55	0.62	0.63	0.57	0.48	0.42	0.37	0.33	0.28	0.24	0.19	0.15	0.12	0.10	0.08	0.07
	M	0.09	0.08	0.07	0.06	0.05	0.14	0.26	0.38	0.48	0.54	0.56	0.51	0.45	0.40	0.36	0.33	0.29	0.25	0.21	0.18	0.16	0.14	0.12	0.10
	H	0.11	0.10	0.10	0.09	0.08	0.17	0.28	0.40	0.49	0.53	0.53	0.48	0.41	0.36	0.33	0.30	0.27	0.24	0.20	0.18	0.16	0.14	0.13	0.12
SSE	L	0.07	0.05	0.04	0.04	0.03	0.06	0.15	0.29	0.43	0.55	0.63	0.64	0.60	0.52	0.45	0.40	0.35	0.29	0.23	0.18	0.15	0.12	0.10	0.08
	M	0.11	0.09	0.08	0.07	0.06	0.08	0.16	0.26	0.38	0.48	0.55	0.57	0.54	0.48	0.43	0.39	0.35	0.30	0.25	0.21	0.18	0.16	0.14	0.12
	H	0.12	0.11	0.11	0.10	0.09	0.12	0.19	0.29	0.40	0.49	0.54	0.55	0.51	0.44	0.39	0.35	0.31	0.27	0.23	0.20	0.18	0.16	0.15	0.13
S	L	0.08	0.07	0.05	0.04	0.04	0.06	0.09	0.14	0.22	0.34	0.48	0.59	0.65	0.65	0.59	0.50	0.43	0.36	0.28	0.22	0.18	0.15	0.12	0.10
	M	0.12	0.11	0.09	0.08	0.07	0.08	0.11	0.14	0.21	0.31	0.42	0.52	0.57	0.58	0.53	0.47	0.41	0.36	0.29	0.25	0.21	0.18	0.16	0.14
	H	0.13	0.12	0.12	0.11	0.10	0.11	0.14	0.17	0.24	0.33	0.43	0.51	0.56	0.55	0.50	0.43	0.37	0.32	0.26	0.22	0.20	0.18	0.16	0.15
SSW	L	0.10	0.08	0.07	0.06	0.05	0.06	0.09	0.11	0.15	0.19	0.27	0.39	0.52	0.62	0.67	0.65	0.58	0.46	0.36	0.28	0.23	0.19	0.15	0.12
	M	0.14	0.12	0.11	0.09	0.08	0.09	0.11	0.13	0.15	0.18	0.25	0.35	0.46	0.55	0.59	0.59	0.53	0.44	0.35	0.30	0.25	0.22	0.19	0.16
	H	0.15	0.14	0.13	0.12	0.11	0.12	0.14	0.16	0.18	0.21	0.27	0.37	0.46	0.53	0.57	0.55	0.49	0.40	0.32	0.26	0.23	0.20	0.18	0.16
SW	L	0.12	0.10	0.08	0.06	0.05	0.06	0.08	0.10	0.12	0.14	0.16	0.24	0.36	0.49	0.60	0.66	0.66	0.58	0.43	0.33	0.27	0.22	0.18	0.14
	M	0.15	0.14	0.12	0.10	0.09	0.09	0.10	0.12	0.13	0.15	0.17	0.23	0.33	0.44	0.53	0.58	0.59	0.53	0.41	0.33	0.28	0.24	0.21	0.18
	H	0.15	0.14	0.13	0.12	0.11	0.12	0.13	0.14	0.16	0.17	0.19	0.25	0.34	0.44	0.52	0.56	0.56	0.49	0.37	0.30	0.25	0.21	0.19	0.17
WSW	L	0.12	0.10	0.08	0.07	0.05	0.06	0.07	0.09	0.10	0.12	0.13	0.17	0.26	0.40	0.52	0.62	0.66	0.61	0.44	0.34	0.27	0.22	0.18	0.15
	M	0.15	0.13	0.12	0.10	0.09	0.09	0.10	0.11	0.12	0.13	0.14	0.17	0.24	0.35	0.46	0.54	0.58	0.55	0.42	0.34	0.28	0.24	0.21	0.18
	H	0.15	0.14	0.13	0.12	0.11	0.11	0.12	0.13	0.14	0.15	0.16	0.19	0.26	0.36	0.46	0.53	0.56	0.51	0.38	0.30	0.25	0.21	0.19	0.17
W	L	0.12	0.10	0.08	0.06	0.05	0.06	0.07	0.08	0.10	0.11	0.12	0.14	0.20	0.32	0.45	0.57	0.64	0.61	0.44	0.34	0.27	0.22	0.18	0.14
	M	0.15	0.13	0.11	0.10	0.09	0.09	0.09	0.10	0.11	0.12	0.13	0.14	0.19	0.29	0.40	0.50	0.56	0.55	0.41	0.33	0.27	0.23	0.20	0.17
	H	0.14	0.13	0.12	0.11	0.10	0.11	0.12	0.13	0.14	0.14	0.15	0.16	0.21	0.30	0.40	0.49	0.54	0.52	0.38	0.30	0.24	0.21	0.18	0.16
WNW	L	0.12	0.10	0.08	0.06	0.05	0.06	0.07	0.09	0.10	0.12	0.13	0.15	0.17	0.26	0.40	0.53	0.63	0.62	0.44	0.34	0.27	0.22	0.18	0.14
	M	0.15	0.13	0.11	0.10	0.09	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.17	0.24	0.35	0.47	0.55	0.55	0.41	0.33	0.27	0.23	0.20	0.17
	H	0.14	0.13	0.12	0.11	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.25	0.36	0.46	0.53	0.52	0.38	0.30	0.24	0.20	0.18	0.16
NW	L	0.11	0.09	0.08	0.06	0.05	0.06	0.08	0.10	0.12	0.14	0.16	0.17	0.19	0.23	0.33	0.47	0.59	0.60	0.42	0.33	0.26	0.21	0.17	0.14
	M	0.14	0.12	0.11	0.09	0.08	0.09	0.10	0.11	0.13	0.14	0.16	0.17	0.18	0.21	0.30	0.42	0.51	0.54	0.39	0.32	0.26	0.22	0.19	0.16
	H	0.14	0.12	0.11	0.10	0.10	0.10	0.12	0.13	0.15	0.16	0.18	0.18	0.19	0.22	0.30	0.41	0.50	0.51	0.36	0.29	0.23	0.20	0.17	0.15
NNW	L	0.12	0.09	0.08	0.06	0.05	0.07	0.11	0.14	0.18	0.22	0.25	0.27	0.29	0.30	0.33	0.44	0.57	0.62	0.44	0.33	0.26	0.21	0.17	0.14
	M	0.15	0.13	0.11	0.10	0.09	0.10	0.12	0.15	0.18	0.21	0.23	0.26	0.27	0.28	0.31	0.39	0.51	0.56	0.41	0.33	0.27	0.23	0.20	0.17
	H	0.14	0.13	0.12	0.11	0.10	0.12	0.15	0.17	0.20	0.23	0.25	0.26	0.28	0.28	0.31	0.38	0.49	0.53	0.38	0.30	0.25	0.21	0.18	0.16
HOR	L	0.11	0.09	0.07	0.06	0.05	0.07	0.14	0.24	0.36	0.48	0.58	0.66	0.72	0.74	0.73	0.67	0.59	0.47	0.37	0.29	0.24	0.19	0.16	0.13
	M	0.16	0.14	0.12	0.11	0.09	0.11	0.16	0.24	0.33	0.43	0.52	0.59	0.64	0.67	0.66	0.62	0.56	0.47	0.38	0.32	0.28	0.24	0.21	0.18
	H	0.17	0.16	0.15	0.14	0.13	0.15	0.20	0.28	0.36	0.45	0.52	0.59	0.62	0.64	0.62	0.58	0.51	0.42	0.35	0.29	0.26	0.23	0.21	0.19

L = Light construction: frame exterior wall, 50.8 mm concrete floor slab, approximately 146 kg of material/m^2 of floor area.
M = Medium construction: 101.6 mm concrete exterior wall, 101.6 mm concrete floor slab, approximately 341 kg of building material/m^2 of floor area.
H = Heavy construction: 152.4 mm concrete exterior wall, 152.4 mm concrete floor slab, approximately 635 kg of building materials/m^2 of floor area.

Appendix G: Cooling Load Factors for Glass with Interior Shading, North Latitudes

Table 14 Cooling Load Factors for Glass with Interior Shading, North Latitudes (All Room Constructions)

Fenes-tration Facing	Solar Time, h 0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400
N	0.08	0.07	0.06	0.06	0.07	0.73	0.66	0.65	0.73	0.80	0.86	0.89	0.89	0.86	0.82	0.75	0.78	0.91	0.24	0.18	0.15	0.13	0.11	0.10
NNE	0.03	0.03	0.02	0.02	0.03	0.64	0.77	0.62	0.42	0.37	0.37	0.37	0.36	0.35	0.32	0.28	0.23	0.17	0.08	0.07	0.06	0.05	0.04	0.04
NE	0.03	0.02	0.02	0.02	0.02	0.56	0.76	0.74	0.58	0.37	0.29	0.27	0.26	0.24	0.22	0.20	0.16	0.12	0.06	0.05	0.04	0.04	0.03	0.03
ENE	0.03	0.02	0.02	0.02	0.02	0.52	0.76	0.80	0.71	0.52	0.31	0.26	0.24	0.22	0.20	0.18	0.15	0.11	0.06	0.05	0.04	0.04	0.03	0.03
E	0.03	0.02	0.02	0.02	0.02	0.47	0.72	0.80	0.76	0.62	0.41	0.27	0.24	0.22	0.20	0.17	0.14	0.11	0.06	0.05	0.05	0.04	0.03	0.03
ESE	0.03	0.03	0.02	0.02	0.02	0.41	0.67	0.79	0.80	0.72	0.54	0.34	0.27	0.24	0.21	0.19	0.15	0.12	0.07	0.06	0.05	0.04	0.04	0.03
SE	0.03	0.03	0.02	0.02	0.02	0.30	0.57	0.74	0.81	0.79	0.68	0.49	0.33	0.28	0.25	0.22	0.18	0.13	0.08	0.07	0.06	0.05	0.04	0.04
SSE	0.04	0.03	0.03	0.03	0.02	0.12	0.31	0.54	0.72	0.81	0.81	0.71	0.54	0.38	0.32	0.27	0.22	0.16	0.09	0.08	0.07	0.06	0.05	0.04
S	0.04	0.04	0.03	0.03	0.03	0.09	0.16	0.23	0.38	0.58	0.75	0.83	0.80	0.68	0.50	0.35	0.27	0.19	0.11	0.09	0.08	0.07	0.06	0.05
SSW	0.05	0.04	0.04	0.03	0.03	0.09	0.14	0.18	0.22	0.27	0.43	0.63	0.78	0.84	0.80	0.66	0.46	0.25	0.13	0.11	0.09	0.08	0.07	0.06
SW	0.05	0.05	0.04	0.04	0.03	0.07	0.11	0.14	0.16	0.19	0.22	0.38	0.59	0.75	0.83	0.81	0.69	0.45	0.16	0.12	0.10	0.09	0.07	0.06
WSW	0.05	0.05	0.04	0.04	0.03	0.07	0.10	0.12	0.14	0.16	0.17	0.23	0.44	0.64	0.78	0.84	0.78	0.55	0.16	0.12	0.10	0.09	0.07	0.06
• W	0.05	0.05	0.04	0.04	0.03	0.06	0.09	0.11	0.13	0.15	0.16	0.17	0.31	0.53	0.72	0.82	0.81	0.61	0.16	0.12	0.10	0.08	0.07	0.06
WNW	0.05	0.05	0.04	0.03	0.03	0.07	0.10	0.12	0.14	0.16	0.17	0.18	0.22	0.43	0.65	0.80	0.84	0.66	0.16	0.12	0.10	0.08	0.07	0.06
NW	0.05	0.04	0.04	0.03	0.03	0.07	0.11	0.14	0.17	0.19	0.20	0.21	0.22	0.30	0.52	0.73	0.82	0.69	0.16	0.12	0.10	0.08	0.07	0.06
NNW	0.05	0.05	0.04	0.03	0.03	0.11	0.17	0.22	0.26	0.30	0.32	0.33	0.34	0.34	0.39	0.61	0.82	0.76	0.17	0.12	0.10	0.08	0.07	0.06
HOR.	0.06	0.05	0.04	0.04	0.03	0.12	0.27	0.44	0.59	0.72	0.81	0.85	0.85	0.81	0.71	0.58	0.42	0.25	0.14	0.12	0.10	0.08	0.07	0.06

CALCULATING SPACE COOLING LOAD FROM HEAT SOURCES WITHIN THE CONDITIONED SPACE

Lighting

An accurate estimate of the space cooling load imposed by lighting, often the major space load component, is essential in air-conditioning system design. Calculation of this load component is not straightforward; the rate of heat gain to the air caused by lights can be quite different from the power supplied to the lights.

Some of the energy emanating from lights is in the form of radiation that only affects the air after it has been absorbed by walls, floors and furniture, and has warmed them to a temperature higher than the air temperature. This absorbed energy, stored by the structure, contributes to the space cooling load after a time lag, and is present after the lights are switched off. The time lag effect (Fig. 2) should be taken into account when calculating the cooling load, since the actual load is lower than the instantaneous heat gain and the peak load may be affected significantly.

Generally, the instantaneous rate of heat gain from electric lighting in watts can be calculated from:

$$q = \text{total light wattage} \cdot \text{use factor} \cdot \text{special allowance factor} \quad (14)$$

The rate of heat gain can be expressed in units of Btu/h by multiplying Eq.(14) by 3.413. The *total light wattage* is obtained from the ratings of all fixtures installed for general illumination or special use. The *use factor* is the ratio of the wattage in use, for the conditions under which the load estimate is being made, to the total installed wattage. For commercial applications such as stores, the use factor is generally unity. The *special allowance factor* is introduced for fluorescent fixtures and fixtures requiring more energy than their rated wattage. For fluorescent fixtures, the special allowance factor accounts for ballast losses, which can be as high as 2.19 for 32-W single lamp high-output fixtures on 277 V. Rapid-start, 40-W lamp fixture allowance factors vary from a low of 1.18 for two lamps on 277 V to a high of 1.30 for one lamp on 118 V. For other industrial fixtures, such as sodium lamp fixtures, special allowance factors may vary from 1.04 to 1.37, depending on the manufacturer.

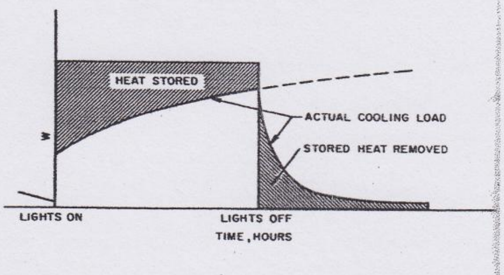

Fig. 2 Thermal Storage Effect in Cooling Load from Ligh

Appendix H: Shading Coefficients for Single Glass with Indoor Shading by Venetian Blinds or Roller Shades

Table 35 Shading Coefficients for Single Glass with Indoor Shading by Venetian Blinds or Roller Shades

	Nominal Thickness[a] in.	Solar Trans.[b]	Type of Shading: Venetian Blinds		Roller Shade: Opaque		Roller Shade: Translucent
			Medium	Light	Dark	White	Light
Clear	2.5 to 6	0.87 to 0.80					
Clear	6 to 12	0.80 to 0.71					
Clear Pattern	3 to 12	0.87 to 0.79	0.64	0.55	0.59	0.25	0.39
Heat-Absorbing Pattern	3	—					
Tinted	5 to 5.5	0.74, 0.71					
Heat-Absorbing[d]	5 to 6	0.46					
Heat-Absorbing Pattern	5 to 6	—	0.57	0.53	0.45	0.30	0.36
Tinted	3 to 5.5	0.59, 0.45					
Heat-Absorbing or Pattern	—	0.44 to 0.30	0.54	0.52	0.40	0.28	0.32
Heat-Absorbing[d]	10	0.34					
Heat-Absorbing or Pattern	—	0.29 to 0.15 0.24	0.42	0.40	0.36	0.28	0.31
Reflective Coated Glass S.C.[c] = 0.30			0.25	0.23			
0.40			0.33	0.29			
0.50			0.42	0.38			
0.60			0.50	0.44			

[a] Refer to manufacturer's literature for values.
[b] For vertical blinds with opaque white and beige louvers in the tightly closed position, SC is 0.25 and 0.29 when used with glass of 0.71 to 0.80 transmittance.
[c] SC for glass with no shading device.
[d] Refers to gray, bronze, and green tinted heat-absorbing glass.

Table 36 Shading Coefficients for Insulating Glass[a] with Indoor Shading by Venetian Blinds or Roller Shades

Type of Glass	Nominal Thickness, Each Light	Solar Trans.[b] Outer Pane	Solar Trans.[b] Inner Pane	Venetian Blinds[c] Medium	Venetian Blinds[c] Light	Roller Shade Opaque Dark	Roller Shade Opaque White	Roller Shade Translucent Light
Clear Out	2.5, 3 mm	0.87	0.87					
Clear In				0.57	0.51	0.60	0.25	0.37
Clear Out								
Clear In	6 mm	0.80	0.80					
Heat-Absorbing[d] Out Clear In	6 mm	0.46	0.80	0.39	0.36	0.40	0.22	0.30
Reflective Coated Glass SC[e] = 0.20				0.19	0.18			
0.30				0.27	0.26			
0.40				0.34	0.33			

[a] Refers to factory-fabricated units with 5, 6 or 13 mm air space, or to prime windows plus storm windows.
[b] Refer to manufacturer's literature for exact values.
[c] For vertical blinds with opaque white or beige louvers, tightly closed, SC is approximately the same as for opaque white roller shades.
[d] Refers to bronze, or green tinted, heat-absorbing glass.
[e] SC for glass with no shading device.

Table 37 Shading Coefficients for Double Glazing with Between-Glass Shading

Type of Glass	Nominal Each Pane	Solar Trans.[a] Outer Pane	Solar Trans.[a] Inner Pane	Description of Air Space	Venetian Blinds Light	Venetian Blinds Medium	Louvered Sun Screen
Clear Out, Clear In	2.5, 3 mm	0.87	0.87	Shade in contact with glass or shade separated from glass by air space.	0.33	0.36	0.43
Clear Out, Clear In	6 mm	0.80	0.80	Shade in contact with glass-voids filled with plastic.	—	—	0.49
Heat-Abs.[b] Out, Clear In				Shade in contact with glass or shade separated from glass by air space.	0.28	0.30	0.37
	6 mm	0.46	0.80	Shade in contact with glass-voids filled with plastic.	—	—	0.41

[a] Refer to manufacturer's literature for exact values.
[b] Refers to grey, bronze and green tinted heat-absorbing glass.

Appendix I: Cooling Load Factors When Lights Area on for 8 Hours

Table 17A Cooling Load Factors When Lights Are on for 8 Hours

"a" Coef-ficients	"b" Class-ification	Number of hours after lights are turned on																							
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
0.45	A	0.02	0.46	0.57	0.65	0.72	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.24	0.19	0.15	0.12	0.10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	B	0.07	0.51	0.56	0.61	0.65	0.68	0.71	0.74	0.77	0.34	0.31	0.28	0.25	0.22	0.20	0.18	0.16	0.15	0.13	0.12	0.11	0.10	0.09	0.
	C	0.11	0.55	0.58	0.60	0.63	0.65	0.67	0.69	0.71	0.28	0.26	0.25	0.23	0.22	0.20	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.
	D	0.14	0.58	0.60	0.61	0.62	0.63	0.64	0.65	0.66	0.22	0.22	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.17	0.16	0.16	0.16	0.15	0.
0.55	A	0.01	0.56	0.65	0.72	0.77	0.82	0.85	0.88	0.90	0.37	0.30	0.24	0.19	0.16	0.13	0.10	0.08	0.07	0.05	0.04	0.03	0.03	0.02	0.
	B	0.06	0.60	0.64	0.68	0.71	0.74	0.76	0.79	0.81	0.28	0.25	0.23	0.20	0.18	0.16	0.15	0.13	0.12	0.11	0.10	0.09	0.08	0.07	0.
	C	0.09	0.63	0.66	0.68	0.70	0.71	0.73	0.75	0.76	0.23	0.21	0.20	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.11	0.10	0.
	D	0.11	0.66	0.67	0.68	0.69	0.70	0.71	0.72	0.72	0.18	0.18	0.17	0.17	0.16	0.16	0.15	0.15	0.14	0.14	0.13	0.13	0.13	0.12	0.
0.65	A	0.01	0.66	0.73	0.78	0.82	0.86	0.88	0.91	0.93	0.29	0.23	0.19	0.15	0.12	0.10	0.08	0.06	0.05	0.04	0.03	0.03	0.02	0.02	0.
	B	0.04	0.69	0.72	0.75	0.77	0.80	0.82	0.84	0.85	0.22	0.19	0.18	0.16	0.14	0.13	0.12	0.10	0.09	0.08	0.08	0.07	0.06	0.06	0.
	C	0.07	0.72	0.73	0.75	0.76	0.78	0.79	0.80	0.82	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.11	0.10	0.10	0.09	0.08	0.08	0.
	D	0.09	0.73	0.74	0.75	0.76	0.77	0.77	0.78	0.79	0.14	0.14	0.13	0.13	0.13	0.12	0.12	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.
0.75	A	0.01	0.76	0.80	0.84	0.87	0.90	0.92	0.93	0.95	0.21	0.17	0.13	0.11	0.09	0.07	0.06	0.05	0.04	0.03	0.02	0.02	0.02	0.01	0.
	B	0.03	0.78	0.80	0.82	0.84	0.85	0.87	0.88	0.89	0.15	0.14	0.13	0.11	0.10	0.09	0.08	0.07	0.07	0.06	0.05	0.05	0.04	0.04	0.
	C	0.05	0.80	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.13	0.12	0.11	0.10	0.10	0.09	0.09	0.08	0.08	0.07	0.07	0.06	0.06	0.06	0.
	D	0.06	0.81	0.82	0.82	0.83	0.83	0.84	0.84	0.85	0.10	0.10	0.10	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.

Table 17B Cooling Load Factors When Lights Are on for 10 Hours

"a" Coef-ficients	"b" Class-ification	Number of hours after lights are turned on																							
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
0.45	A	0.03	0.47	0.58	0.66	0.73	0.78	0.82	0.86	0.88	0.91	0.93	0.49	0.39	0.32	0.26	0.21	0.17	0.13	0.11	0.09	0.07	0.06	0.05	0.
	B	0.10	0.54	0.59	0.63	0.66	0.70	0.73	0.76	0.78	0.80	0.82	0.39	0.35	0.32	0.28	0.26	0.23	0.21	0.19	0.17	0.15	0.14	0.12	0.
	C	0.15	0.59	0.61	0.64	0.66	0.68	0.70	0.72	0.73	0.75	0.76	0.33	0.31	0.29	0.27	0.26	0.24	0.23	0.21	0.20	0.19	0.18	0.17	0.
	D	0.18	0.62	0.63	0.64	0.66	0.67	0.68	0.69	0.69	0.70	0.71	0.27	0.26	0.26	0.25	0.24	0.23	0.23	0.22	0.21	0.21	0.20	0.19	0.
0.55	A	0.02	0.57	0.65	0.72	0.78	0.82	0.85	0.88	0.91	0.92	0.94	0.40	0.32	0.26	0.21	0.17	0.14	0.11	0.09	0.07	0.06	0.05	0.04	0.
	B	0.08	0.62	0.66	0.69	0.73	0.75	0.78	0.80	0.82	0.84	0.85	0.32	0.29	0.26	0.23	0.21	0.19	0.17	0.15	0.14	0.12	0.11	0.10	0.
	C	0.12	0.66	0.68	0.70	0.72	0.74	0.75	0.77	0.78	0.79	0.81	0.27	0.25	0.24	0.22	0.21	0.20	0.19	0.17	0.16	0.15	0.14	0.14	0.
	D	0.15	0.69	0.70	0.71	0.72	0.73	0.73	0.74	0.75	0.76	0.76	0.22	0.22	0.21	0.20	0.20	0.19	0.18	0.18	0.17	0.17	0.16	0.16	0.
0.65	A	0.02	0.66	0.73	0.78	0.83	0.86	0.89	0.91	0.93	0.94	0.95	0.31	0.25	0.20	0.16	0.13	0.11	0.08	0.07	0.05	0.04	0.04	0.03	0.
	B	0.06	0.71	0.74	0.76	0.79	0.81	0.83	0.84	0.86	0.87	0.89	0.25	0.22	0.20	0.18	0.16	0.15	0.13	0.12	0.11	0.10	0.09	0.08	0.
	C	0.09	0.74	0.75	0.77	0.78	0.80	0.81	0.82	0.83	0.84	0.85	0.21	0.20	0.18	0.17	0.16	0.15	0.14	0.14	0.13	0.12	0.11	0.11	0.
	D	0.11	0.76	0.77	0.77	0.78	0.79	0.79	0.80	0.81	0.81	0.82	0.17	0.17	0.16	0.16	0.15	0.15	0.14	0.14	0.14	0.13	0.13	0.12	0.
0.75	A	0.01	0.76	0.81	0.84	0.88	0.90	0.92	0.93	0.95	0.96	0.97	0.22	0.18	0.14	0.12	0.09	0.08	0.06	0.05	0.04	0.03	0.03	0.02	0.
	B	0.04	0.79	0.81	0.83	0.85	0.86	0.88	0.89	0.90	0.91	0.92	0.18	0.16	0.14	0.13	0.12	0.10	0.09	0.08	0.08	0.07	0.06	0.06	0.
	C	0.07	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.89	0.15	0.14	0.13	0.12	0.12	0.11	0.10	0.10	0.09	0.09	0.08	0.08	0.
	D	0.08	0.83	0.83	0.84	0.84	0.85	0.85	0.86	0.86	0.87	0.87	0.12	0.12	0.12	0.11	0.11	0.11	0.10	0.10	0.10	0.09	0.09	0.09	0.

Table 17C Cooling Load Factors When Lights Are on for 12 Hours

"a" Coef-ficients	"b" Class-ification	Number of hours after lights are turned on																							
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
0.45	A	0.05	0.49	0.59	0.67	0.73	0.78	0.83	0.86	0.89	0.91	0.93	0.94	0.95	0.51	0.41	0.33	0.27	0.22	0.17	0.14	0.11	0.09	0.07	0
	B	0.13	0.57	0.61	0.65	0.69	0.72	0.75	0.77	0.79	0.82	0.83	0.85	0.87	0.43	0.39	0.35	0.31	0.28	0.25	0.23	0.21	0.18	0.17	0
	C	[illegible]	[illegible]	0.65	0.67	0.69	0.71	0.73	0.74	0.76	0.77	0.79	0.80	0.81	0.37	0.35	0.33	0.31	0.29	0.27	0.26	0.24	0.23	0.21	0
	D	0.22	0.66	0.67	0.68	0.69	0.70	0.71	0.72	0.73	0.74	0.74	0.75	0.76	0.32	0.31	0.30	0.29	0.28	0.27	0.26	0.26	0.25	0.24	0
0.55	A	0.04	0.58	0.66	0.73	0.78	0.82	0.86	0.89	0.91	0.93	0.94	0.95	0.96	0.42	0.34	0.27	0.22	0.18	0.14	0.11	0.09	0.07	0.06	0
	B	0.11	0.65	0.68	0.72	0.74	0.77	0.79	0.81	0.83	0.85	0.86	0.88	0.89	0.35	0.32	0.28	0.26	0.23	0.21	0.19	0.17	0.15	0.14	0
	C	0.15	0.69	0.71	0.73	0.75	0.76	0.78	0.79	0.80	0.81	0.83	0.84	0.85	0.30	0.29	0.27	0.25	0.24	0.22	0.21	0.20	0.19	0.17	0
	D	0.18	0.72	0.73	0.74	0.75	0.76	0.76	0.77	0.78	0.78	0.79	0.80	0.80	0.26	0.25	0.24	0.24	0.23	0.22	0.22	0.21	0.20	0.20	0
0.65	A	0.03	0.67	0.74	0.79	0.83	0.86	0.89	0.91	0.93	0.94	0.95	0.96	0.97	0.33	0.26	0.21	0.17	0.14	0.11	0.09	0.07	0.06	0.05	0
	B	0.09	0.73	0.75	0.78	0.80	0.82	0.84	0.85	0.87	0.88	0.89	0.90	0.91	0.27	0.25	0.22	0.20	0.18	0.16	0.15	0.13	0.12	0.11	0
	C	0.12	0.76	0.78	0.79	0.80	0.81	0.83	0.84	0.85	0.86	0.86	0.87	0.88	0.24	0.22	0.21	0.20	0.19	0.17	0.16	0.15	0.14	0.14	0
	D	0.14	0.79	0.79	0.80	0.80	0.81	0.82	0.82	0.83	0.83	0.84	0.84	0.85	0.20	0.20	0.19	0.18	0.18	0.17	0.17	0.16	0.16	0.15	0
0.75	A	0.02	0.77	0.81	0.85	0.88	0.90	0.92	0.94	0.95	0.96	0.97	0.97	0.98	0.23	0.19	0.15	0.12	0.10	0.08	0.06	0.05	0.04	0.03	0
	B	0.06	0.81	0.82	0.84	0.86	0.87	0.88	0.90	0.91	0.92	0.92	0.93	0.94	0.19	0.18	0.16	0.14	0.13	0.12	0.10	0.09	0.08	0.08	0
	C	0.09	0.83	0.84	0.85	0.86	0.87	0.88	0.88	0.89	0.90	0.90	0.91	0.91	0.17	0.16	0.15	0.14	0.13	0.12	0.12	0.11	0.10	0.10	0
	D	0.10	0.85	0.85	0.86	0.86	0.86	0.87	0.87	0.88	0.88	0.88	0.89	0.89	0.14	0.14	0.14	0.13	0.13	0.12	0.12	0.12	0.11	0.11	0

Table 17D Cooling Load Factors When Lights Are on for 14 Hours

"a" Coef-ficients	"b" Class-ification	Number of hours after lights are turned on																						
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
0.45	A	0.07	0.51	0.61	0.68	0.74	0.79	0.83	0.87	0.89	0.91	0.93	0.94	0.95	0.96	0.97	0.53	0.42	0.34	0.27	0.22	0.18	0.14	0.12
	B	0.18	0.61	0.65	0.68	0.72	0.74	0.77	0.79	0.81	0.83	0.85	0.86	0.88	0.89	0.90	0.46	0.41	0.37	0.34	0.30	0.27	0.24	0.22
	C	0.24	0.67	0.69	0.71	0.73	0.74	0.76	0.77	0.79	0.80	0.81	0.82	0.83	0.84	0.85	0.41	0.39	0.36	0.34	0.32	0.30	0.28	0.27
	D	0.26	0.71	0.72	0.72	0.73	0.74	0.75	0.76	0.77	0.78	0.78	0.79	0.80	0.80	0.80	0.36	0.35	0.34	0.33	0.32	0.31	0.30	0.29
0.55	A	0.06	0.69	0.68	0.74	0.79	0.83	0.86	0.89	0.91	0.93	0.94	0.95	0.96	0.97	0.98	0.43	0.35	0.28	0.22	0.18	0.15	0.12	0.09
	B	0.15	0.68	0.71	0.74	0.77	0.79	0.81	0.83	0.85	0.86	0.88	0.89	0.90	0.91	0.92	0.38	0.34	0.31	0.27	0.25	0.22	0.20	0.18
	C	0.19	0.73	0.75	0.76	0.78	0.79	0.80	0.81	0.83	0.84	0.85	0.86	0.86	0.87	0.88	0.34	0.32	0.30	0.28	0.26	0.25	0.23	0.22
	D	0.22	0.76	0.77	0.77	0.78	0.79	0.79	0.80	0.81	0.81	0.82	0.82	0.83	0.83	0.84	0.29	0.28	0.28	0.27	0.26	0.25	0.24	0.24
0.65	A	0.05	0.69	0.75	0.80	0.84	0.87	0.89	0.92	0.93	0.95	0.96	0.96	0.97	0.98	0.98	0.34	0.27	0.22	0.17	0.14	0.11	0.09	0.07
	B	0.11	0.75	0.78	0.80	0.82	0.64	0.85	0.87	0.88	0.89	0.90	0.91	0.92	0.93	0.94	0.29	0.26	0.24	0.21	0.19	0.17	0.16	0.14
	C	0.15	0.79	0.80	0.82	0.83	0.84	0.85	0.86	0.86	0.87	0.88	0.89	0.89	0.90	0.91	0.26	0.25	0.23	0.22	0.20	0.19	0.18	0.17
	D	0.17	0.81	0.82	0.82	0.83	0.83	0.84	0.84	0.85	0.85	0.86	0.86	0.87	0.87	0.87	0.23	0.22	0.21	0.21	0.20	0.20	0.19	0.18
0.75	A	0.03	0.78	0.82	0.86	0.88	0.91	0.92	0.94	0.95	0.96	0.97	0.97	0.98	0.98	0.99	0.24	0.19	0.16	0.12	0.10	0.08	0.07	0.05
	B	0.08	0.82	0.84	0.86	0.87	0.88	0.90	0.91	0.92	0.92	0.93	0.94	0.94	0.95	0.96	0.21	0.19	0.17	0.15	0.14	0.12	0.11	0.10
	C	0.11	0.85	0.86	0.87	0.88	0.88	0.89	0.90	0.90	0.91	0.91	0.92	0.92	0.93	0.93	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12
	D	0.12	0.87	0.87	0.87	0.88	0.88	0.89	0.89	0.89	0.90	0.90	0.90	0.90	0.91	0.91	0.16	0.16	0.15	0.15	0.14	0.14	0.14	0.13

Appendix J: Rates of Heat Gain from Occupant of Conditioned Spaces and Sensible Heat Cooling Load Factors for People

Table 17E Cooling Load Factors When Lights Are on for 16 Hours

Coef-nts	"b" Classification	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
		Number of hours after lights are turned on																							
	A	0.12	0.54	0.63	0.70	0.76	0.81	0.85	0.88	0.90	0.92	0.94	0.95	0.96	0.97	0.97	0.98	0.98	0.54	0.43	0.35	0.28	0.23	0.18	0.15
	B	0.23	0.66	0.69	0.72	0.75	0.78	0.80	0.82	0.84	0.85	0.87	0.88	0.89	0.90	0.91	0.92	0.93	0.49	0.44	0.39	0.35	0.32	0.29	0.26
.45	C	0.29	0.72	0.74	0.75	0.77	0.78	0.80	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.88	0.89	0.45	0.42	0.39	0.37	0.35	0.33	0.31
	D	0.31	0.75	0.76	0.77	0.77	0.78	0.79	0.79	0.80	0.81	0.81	0.82	0.82	0.83	0.83	0.84	0.84	0.40	0.39	0.37	0.36	0.35	0.34	0.33
	A	0.10	0.63	0.70	0.76	0.81	0.84	0.87	0.90	0.92	0.93	0.95	0.96	0.97	0.97	0.98	0.98	0.99	0.44	0.35	0.28	0.23	0.18	0.15	0.12
	B	0.19	0.72	0.75	0.77	0.80	0.82	0.84	0.85	0.87	0.88	0.89	0.90	0.91	0.92	0.93	0.94	0.94	0.40	0.36	0.32	0.29	0.26	0.24	0.21
.55	C	0.24	0.77	0.79	0.80	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.88	0.89	0.90	0.90	0.91	0.37	0.34	0.32	0.30	0.29	0.27	0.25
	D	0.26	0.80	0.80	0.81	0.82	0.82	0.83	0.83	0.84	0.84	0.85	0.85	0.86	0.86	0.86	0.87	0.87	0.33	0.32	0.31	0.30	0.29	0.28	0.27
	A	0.07	0.71	0.77	0.81	0.85	0.88	0.90	0.92	0.94	0.95	0.96	0.97	0.97	0.98	0.98	0.99	0.99	0.34	0.27	0.22	0.18	0.14	0.12	0.09
	B	0.15	0.78	0.81	0.82	0.84	0.86	0.87	0.88	0.90	0.91	0.92	0.92	0.93	0.94	0.94	0.95	0.96	0.31	0.28	0.25	0.23	0.20	0.18	0.16
.65	C	0.18	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.89	0.90	0.90	0.91	0.92	0.92	0.93	0.93	0.28	0.27	0.25	0.24	0.22	0.21	0.20
	D	0.20	0.84	0.85	0.85	0.86	0.86	0.87	0.87	0.87	0.88	0.88	0.88	0.89	0.89	0.89	0.90	0.90	0.25	0.25	0.24	0.23	0.22	0.22	0.21
	A	0.05	0.79	0.83	0.87	0.89	0.91	0.93	0.94	0.95	0.96	0.97	0.98	0.98	0.98	0.99	0.99	0.99	0.24	0.20	0.16	0.13	0.10	0.08	0.07
	B	0.11	0.85	0.86	0.87	0.89	0.90	0.91	0.92	0.93	0.93	0.94	0.95	0.95	0.96	0.96	0.96	0.97	0.22	0.20	0.18	0.16	0.15	0.13	0.12
.75	C	0.13	0.87	0.88	0.89	0.89	0.90	0.91	0.91	0.92	0.92	0.93	0.93	0.94	0.94	0.94	0.95	0.95	0.20	0.19	0.18	0.17	0.16	0.15	0.14
	D	0.14	0.89	0.89	0.89	0.90	0.90	0.90	0.91	0.91	0.91	0.91	0.92	0.92	0.92	0.92	0.93	0.93	0.18	0.18	0.17	0.17	0.16	0.16	0.15

Table 18 Rates of Heat Gain from Occupants of Conditioned Spaces[a]

egree of Activity	Typical Application	Total Heat Adults, Male Watts	Total Heat Adjusted[b] Watts	Sensible Heat Watts	Latent Heat Watts
eated at rest	Theater, movie	115	100	60	40
eated, very light work writing	Offices, hotels, apts	140	120	65	55
eated, eating	Restaurant[c]	150	170[c]	75	95
eated, light work, typing	Offices, hotels, apts	185	150	75	75
tanding, light work or walking slowly	Retail Store, bank	235	185	90	95
ight bench work	Factory	255	230	100	130
/alking, 1.3 m/s, light machine work	Factory	305	305	100	205
owling[d]	Bowling alley	350	280	100	180
Ioderate dancing	Dance hall	400	375	120	255
Ieavy work, heavy machine work, lifting	Factory	470	470	165	300
Ieavy work, athletics	Gymnasium	585	525	185	340

[a]Note; Tabulated values are based on 25.5°C room dry-bulb temperature. For 26.6°C room dry-bulb, the total heat remains the same, but the sensible heat value should be decreased by approximately 8% and the latent heat values increased accordingly.

[b]Adjusted total heat gain is based on normal percentage of men, women, and children for the application listed, with the postulate that the gain from an adult female is 85% of that for an adult male, and that the gain from a child is 75% of that for an adult male.

[c]Adjusted total heat value for eating in a restaurant, includes 17.6 W for food per individual (8.8 W sensible and 8.8 W latent).

[d]For bowling figure one person per alley actually bowling, and all others as sitting 117 W or standing and walking slowly 231 W.

lso refer to Tables 4 and 7, Chapter 8.
ll values rounded to nearest 5 watts.

Table 19 Sensible Heat Cooling Load Factors for People

Total Hours in Space	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	Hours after Each Entry Into Space																							
2	0.49	0.58	0.17	0.13	0.10	0.08	0.07	0.06	0.05	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
4	0.49	0.59	0.66	0.71	0.27	0.21	0.16	0.14	0.11	0.10	0.08	0.07	0.06	0.06	0.05	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.01
6	0.50	0.60	0.67	0.72	0.76	0.79	0.34	0.26	0.21	0.18	0.15	0.13	0.11	0.10	0.08	0.07	0.06	0.06	0.05	0.04	0.04	0.03	0.03	0.03
8	0.51	0.61	0.67	0.72	0.76	0.80	0.82	0.84	0.38	0.30	0.25	0.21	0.18	0.15	0.13	0.12	0.10	0.09	0.08	0.07	0.06	0.05	0.05	0.04
10	0.53	0.62	0.69	0.74	0.77	0.80	0.83	0.85	0.87	0.89	0.42	0.34	0.28	0.23	0.20	0.17	0.15	0.13	0.11	0.10	0.09	0.08	0.07	0.06
12	0.55	0.64	0.70	0.75	0.79	0.81	0.84	0.86	0.88	0.89	0.91	0.92	0.45	0.36	0.30	0.25	0.21	0.19	0.16	0.14	0.12	0.11	0.09	0.08
14	0.58	0.66	0.72	0.77	0.80	0.83	0.85	0.87	0.89	0.90	0.91	0.92	0.93	0.94	0.47	0.38	0.31	0.26	0.23	0.20	0.17	0.15	0.13	0.11
16	0.62	0.70	0.75	0.79	0.82	0.85	0.87	0.88	0.90	0.91	0.92	0.93	0.94	0.95	0.95	0.96	0.49	0.39	0.33	0.28	0.24	0.20	0.18	0.16
18	0.66	0.74	0.79	0.82	0.85	0.87	0.89	0.90	0.92	0.93	0.94	0.94	0.95	0.96	0.96	0.97	0.97	0.97	0.50	0.40	0.33	0.28	0.24	0.28

Appendix K: Overall Coefficient of Heat Transmission(U-Factor) of Windows, Shading Patio Doors and Skylights for User in Peak Load Determination and Mechanical Equipment Sizing only and not in Any Analysis of Annual Energy Usage, W/m2·0C

Table 13 Overall Coefficients of Heat Transmission (*U*-Factor) of Windows, Sliding Patio Doors, and Skylights for Use in Peak Load Determination and Mechanical Equipment Sizing Only and Not in Any Analysis of Annual Energy Usage, $W/m^2 \cdot °C$

Part A. Exterior[a] Vertical Panels

	No Storm Sash				Glass Outdoor Storm Sash 1-in. Air Space[b] Added to Described Product			
	No Shade		Indoor Shade		No Shade		Indoor Shade	
	Winter*	Summer**	Winter*	Summer**	Winter*	Summer**	Winter*	Summer**
Flat Glass[c]								
Single Glass, Clear	6.2	5.9	4.7	4.6	2.3	2.8	2.5	2.8
Single Glass, Low Emittance Coating[d]								
e = 0.60	5.8	5.7	4.3	4.5	2.7	3.4	2.2	3.1
e = 0.40	5.2	5.1	3.9	4.0	2.5	3.4	2.1	3.1
e = 0.20	4.5	4.3	3.3	3.1	2.3	2.8	1.9	2.6
Insulating Glass, Double[e]								
5 mm air space[f]	3.5	3.7	3.0	3.3	2.1	2.3	1.7	2.1
6 mm air space[f]	3.3	3.5	2.7	3.1	2.0	2.2	1.6	2.0
13 mm air space[g]	2.8	3.2	2.4	3.0	1.8	2.2	1.4	2.1
13 mm air space low emittance coating[h]								
e = 0.60	2.4	3.0	2.2	2.8	2.3	2.3	1.4	2.1
e = 0.40	2.2	2.7	2.0	2.4	1.5	2.2	1.3	2.0
e = 0.20	1.8	2.2	1.7	2.0	1.4	1.9	1.1	1.7
Insulating Glass, Triple[e]								
6 mm air space[f]	2.2	2.5	1.8	2.3	1.5	1.8	1.3	1.7
13 mm air space[i]	1.8	2.2	1.5	2.0	1.3	1.8	1.1	1.7

	Glass Indoor Storm Sash 25 mm Air Space[b] Added to Described Product				Acrylic Indoor Storm Sash 25 mm Air Space[b] Added to Described Product			
	No Shade		Indoor Shade		No Shade		Indoor Shade	
	Winter*	Summer**	Winter*	Summer**	Winter*	Summer**	Winter*	Summer**
Flat Glass[c]								
Single Glass, Clear	2.8	2.8	2.5	2.8	2.7	2.7	2.4	2.7
Single Glass, Low Emittance Coating[d]								
e = 0.60	2.7	2.8	2.2	2.6	2.6	2.8	2.2	2.6
e = 0.40	2.4	2.6	2.0	2.3	2.3	2.6	2.0	2.3
e = 0.20	2.1	2.0	1.8	1.7	2.0	2.0	1.8	1.7
Insulating Glass, Double[e]								
5 mm air space[f]	2.1	2.3	1.7	2.0	2.0	2.2	1.6	2.0
6 mm air space[f]	2.0	2.2	1.6	2.0	1.9	2.2	1.5	1.9
13 mm air space[g]	1.8	2.2	1.4	2.0	1.7	2.1	1.4	1.9
13 mm air space, Low emittance coating[h]								
e = 0.60	1.7	2.1	1.4	1.9	1.6	2.0	1.3	1.8
e = 0.40	1.5	1.9	1.3	1.7	1.5	1.8	1.3	1.6
e = 0.20	1.4	1.6	1.1	1.5	1.4	1.6	1.1	1.4
Insulating Glass, Triple[e]								
6 mm air space[f]	1.5	1.8	1.3	1.7	1.5	1.8	1.3	1.7
13 mm air space[i]	1.3	1.7	1.1	1.6	1.3	1.7	1.0	1.6

Part B. Exterior[a] Horizontal Panels (Skylights)

Description	Winter[j]	Summer[k]
Flat Glass[g]		
Single Glass	7.0	4.7
Insulating Glass; Double[e]		
5 mm air space[f]	4.0	3.2
6 mm air space[f]	3.7	3.1
13 mm air space[g]	3.4	2.8
13 mm air space, low emittance coating[h]		
e = 0.60	3.2	2.6
e = 0.40	3.0	2.4
e = 0.20	2.7	2.0
Plastic Domes[l]		
Single Walled	6.5	4.5
Double Walled	4.0	2.6

Passive Solar Gain

Energy analysis of a fenestration product should include the value of passive solar gain in winter through the product. As described in Chapter 57, 1982 APPLICATIONS VOLUME, the magnitude of this energy gain depends on a number of variables such as latitude and orientation. In many cases, passive solar gain enables properly designed and used fenestration products to allow more energy into the building over the course of a heating season than they lose, making them energy contributing rather than energy consuming. Care must be taken to control excessive solar gain during the cooling season.

Overall Coefficient of Heat Transfer

In the absence of sunlight, heat flows through fenestration by thermal conduction. When the outdoor temperature, t_o, is

Appendix L: Glass Performance Data

GLASS PERFORMANCE DATA 24mm IG Unit (6mm-12mm gap-6mm)

Insulated Glass Unit Comparisons with PPG Glass 6mm-12mm-6mm

Glass Configuration	Visible Light			Solar Energy					U-Values - W/m² · °K			LSG
6mm-12mm Gap -6mm	LT%	LR% Ext.	LR% Int.	R%	T%	SF EN410	SHGC	SC	Win-NFRC air/argon**	Sum - NFRC air/argon**	EN 673 air/argon**	
Uncoated												
STARPHIRE + STARPHIRE	84	15	15	14	84	0.81	0.82	0.94	2.70 / 2.55	2.84 / 2.71	2.8 / 2.7	1.02
Clear + Clear	79	15	15	12	61	0.71	0.70	0.81	2.70 / 2.55	2.84 / 2.71	2.8 / 2.7	1.13
SOLEXIA + Clear	69	13	15	8	39	0.50	0.49	0.57	2.70 / 2.55	2.84 / 2.71	2.8 / 2.7	1.41
ATLANTICA + Clear	60	11	14	7	28	0.41	0.40	0.47	2.70 / 2.55	2.84 / 2.71	2.8 / 2.7	1.50
AZURIA + Clear	61	11	14	7	28	0.41	0.39	0.45	2.70 / 2.55	2.84 / 2.71	2.8 / 2.7	1.56
CARIBIA + Clear	60	11	14	7	28	0.40	0.39	0.45	2.70 / 2.55	2.84 / 2.71	2.8 / 2.7	1.54
PACIFICA + Clear	38	7	13	6	23	0.35	0.36	0.41	2.70 / 2.55	2.84 / 2.71	2.8 / 2.7	1.06
SOLARBLUE + Clear	50	9	13	7	37	0.49	0.49	0.56	2.70 / 2.55	2.84 / 2.71	2.8 / 2.7	1.02
SOLARBRONZE + Clear	47	8	13	7	39	0.49	0.51	0.59	2.70 / 2.55	2.84 / 2.71	2.8 / 2.7	0.92
SOLARGRAY + Clear	40	7	13	7	33	0.44	0.45	0.53	2.70 / 2.55	2.84 / 2.71	2.8 / 2.7	0.89
OPTIGRAY 23 + Clear	21	5	12	5	15	0.27	0.29	0.34	2.70 / 2.55	2.84 / 2.71	2.8 / 2.7	0.72
GRAYLITE + Clear	12	5	12	5	19	0.30	0.34	0.39	2.70 / 2.55	2.84 / 2.71	2.8 / 2.7	0.35
Coated												
SUNGATE 500 Low-E Glass												
SUNGATE 500 (2) + Clear	74	17	17	14	52	0.63	0.62	0.71	1.98 / 1.75	2.03 / 1.79	2.0 / 1.7	1.19
SOLEXIA + SUNGATE 500 (3) Clear	64	14	16	9	33	0.46	0.45	0.51	1.98 / 1.75	2.03 / 1.79	2.0 / 1.7	1.42
ATLANTICA + SUNGATE 500 (3) Clear	56	12	16	7	25	0.36	0.35	0.41	1.98 / 1.75	2.03 / 1.79	2.0 / 1.7	1.60
AZURIA + SUNGATE 500 (3) Clear	57	12	15	7	24	0.37	0.34	0.40	1.98 / 1.75	2.03 / 1.79	2.0 / 1.7	1.68
CARIBIA + SUNGATE 500 (3) Clear	56	12	15	7	24	0.36	0.34	0.40	1.98 / 1.75	2.03 / 1.79	2.0 / 1.7	1.65
PACIFICA + SUNGATE 500 (3) Clear	35	7	14	6	19	0.31	0.30	0.35	1.98 / 1.75	2.03 / 1.79	2.0 / 1.7	1.17
SOLARBLUE + SUNGATE 500 (3) Clear	46	10	15	9	32	0.44	0.44	0.51	1.98 / 1.75	2.03 / 1.79	2.0 / 1.7	1.05
SOLARBRONZE + SUNGATE 500 (3) Clear	44	9	15	9	33	0.45	0.46	0.53	1.98 / 1.75	2.03 / 1.79	2.0 / 1.7	0.96
SOLARGRAY + SUNGATE (3) Clear	37	8	15	8	28	0.40	0.40	0.47	1.98 / 1.75	2.03 / 1.79	2.0 / 1.7	0.93
OPTIGRAY 23 + SUNGATE 500 (3) Clear	19	6	14	6	13	0.23	0.24	0.28	1.98 / 1.75	2.03 / 1.79	2.0 / 1.7	0.79
GRAYLITE + SUNGATE 500 (3) Clear	11	5	14	6	16	0.26	0.28	0.33	1.98 / 1.75	2.03 / 1.79	2.0 / 1.7	0.39
SOLARBAN 60 Solar Control Low-E Glass												
SOLARBAN 60 (2) STARPHIRE + STARPHIRE	74	11	13	[illegible]	28	[illegible]	0.40	0.46	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.85
SOLARBAN 60 (2) Clear + Clear	70	11	12	29	33	0.42	0.38	0.44	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.84
SOLARBAN 60 (2) SOLEXIA + Clear	61	10	12	11	25	0.34	0.32	0.37	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.91
SOLARBAN 60 (2) ATLANTICA + Clear	53	9	10	[illegible]	20	0.29	[illegible]	0.32	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.96
SOLARBAN 60 (2) AZURIA + Clear	54	8	11	7	21	0.3	0.28	0.32	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.93
SOLARBAN 60 (2) CARIBIA + Clear	54	8	11	7	20	0.29	0.27	0.32	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	2.00
SOLARBAN 60 (2) PACIFICA + Clear	34	6	10	7	15	0.24	0.22	0.26	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.55
SOLARBAN 60 (2) SOLARBLUE + Clear	44	7	11	13	21	0.30	0.28	0.32	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.57
SOLARBAN 60 (2) SOLARBRONZE + Clear	42	7	11	16	20	0.28	0.27	0.31	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.56
SOLARBAN 60 (2) SOLARGRAY + Clear	35	6	11	12	17	0.26	0.25	0.28	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.40
SOLEXIA + SOLARBAN 60 (3) Clear	61	11	11	11	25	0.39	0.36	0.42	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.69
ATLANTICA + SOLARBAN 60 (3) Clear	53	9	10	7	20	0.33	0.31	0.35	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.71
AZURIA + SOLARBAN 60 (3) Clear	54	9	10	7	21	0.35	0.31	0.36	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.74
CARIBIA + SOLARBAN 60 (3) Clear	54	9	10	7	20	0.34	0.31	0.35	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.74
PACIFICA + SOLARBAN 60 (3) Clear	34	6	9	7	15	0.27	0.29	0.25	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.17
SOLARBLUE + SOLARBAN 60 (3) Clear	45	8	10	13	21	0.35	0.32	0.37	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.41
SOLARBRONZE + SOLARBAN 60 (3) Clear	42	7	10	17	20	0.33	0.31	0.36	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.35
SOLARGRAY + SOLARBAN 60 (3) Clear	35	7	10	13	17	0.30	0.28	0.33	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.25
OPTIGRAY 23 + SOLARBAN 60 (3) Clear	18	5	9	6	9	0.30	0.18	0.21	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.00
GRAYLITE + SOLARBAN 60 (3) Clear	11	5	9	10	7	0.17	0.18	0.2	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	0.61
SOLARBAN z50 Solar Control Low-E Glass												
SOLARBAN z50 (2) OPTIBLUE + Clear	51	8	11	23	26	0.34	0.32	0.36	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.59
SOLARBAN z50 (2) OPTIBLUE + OPTIBLUE	36	7	8	23	20	0.33	0.31	0.36	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.16
SOLEXIA + SOLARBAN z50 (3) OPTIBLUE	44	10	7	11	19	0.38	0.35	0.41	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.26
ATLANTICA + SOLARBAN z50 (3) OPTIBLUE	39	8	7	7	15	0.32	0.30	0.34	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.30
AZURIA + SOLARBAN z50 (3) OPTIBLUE	39	8	7	7	15	0.34	0.30	0.35	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.30
CARIBIA + SOLARBAN z50 (3) OPTIBLUE	39	8	7	7	15	0.33	0.30	0.35	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.30
PACIFICA + SOLARBAN z50 (3) OPTIBLUE	24	6	7	7	11	0.26	0.24	0.28	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.00
SOLARBLUE + SOLARBAN z50 (3) OPTIBLUE	32	7	7	13	16	0.34	0.32	0.36	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	1.00
SOLARBRONZE + SOLARBAN z50 (3) OPTIBLUE	30	7	7	16	15	0.32	0.31	0.35	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	0.97
SOLARGRAY + SOLARBAN z50 (3) OPTIBLUE	25	6	7	13	13	0.29	0.28	0.32	1.66 / 1.38	1.60 / 1.29	1.6 / 1.3	0.89

Appendix M: Data for Cooling Load

DATA FOR COOLING LOAD

1. Thermal properties of building materials –Resistance (R)
   a. Roofing
      i. Asbestos –cement shingles — 0.037 $m^2.°C/W$
      ii. Asphalt shingles — 0.077 $m^2.°C/W$

   b. Masonry materials
      i. Concretes mortar — 1.39 m.°C/W per thickness
      ii. Concrete sand/stone aggregate — 0.76 m.°C/W per thickness
      iii. Brick common — 1.39 m.°C/W per thickness
      iv. Concrete block 3 cores 200 mm — 0.20 $m^2.°C/W$

   c. Plastering materials
      i. Cement plaster 9.5 mm — 0.014 $m^2.°C/W$
      ii. Gypsum plaster 12 mm — 0.056 $m^2.°C/W$

   d. Insulating materials
      i. Mineral fibre acoustic tile — 19.85 m.°C/W per thickness

   e. Finishing floor materials
      i. Carpet & fibrous pad — 0.37 $m^2.°C/W$
      ii. Tile ceramic — 0.009 $m^2.°C/W$

Table 1 Surface Conductances and Resistances for Air

Position of Surface	Direction of Heat Flow	Surface Emittance, ε: Non-reflective $\varepsilon = 0.90$ h_i	R	Reflective $\varepsilon = 0.20$ h_i	R	Reflective $\varepsilon = 0.05$ h_i	R
STILL AIR							
Horizontal	Upward	9.26	0.11	5.17	0.19	4.32	0.23
Sloping—45°	Upward	9.09	0.11	5.00	0.20	4.15	0.24
Vertical	Horizontal	8.29	0.12	4.20	0.24	3.35	0.30
Sloping—45°	Downward	7.50	0.13	3.41	0.29	2.56	0.39
Horizontal	Downward	6.13	0.16	2.10	0.48	1.25	0.80
MOVING AIR (Any position)		h_o	R				
Wind (for winter) 6.7 m/s (24 km/h)	Any	34.0	0.030	—	—	—	—
Wind (for summer) 3.4 m/s (12 km/h)	Any	22.7	0.044	—	—	—	—

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Data for Cooling Load (*continued*)

2. Overall coefficients of heat transmission (U-factor) of Windows
   a. Flat glass- single pane, clear — 5.9 W/ m^2°C No shade
   b. Flat glass- single pane, clear — 4.6 W/ m^2°C Indoor shade
   c. Insulating glass, 5 mm air space — 3.7 W/ m^2°C No shade
   d. Insulating glass, 5 mm air space — 3.3 W/ m^2°C Indoor shade

3. Heat output from occupancy

Table 1 Representative Rates at Which Heat and Moisture Are Given Off by Human Beings in Different States of Act

Degree of Activity		Total Heat, W		Sensible Heat, W	Latent Heat, W	% Sensible He Radian
		Adult Male	Adjusted, M/F[a]			Low V
Seated at theater	Theater, matinee	115	95	65	30	
Seated at theater, night	Theater, night	115	105	70	35	60
Seated, very light work	Offices, hotels, apartments	130	115	70	45	
Moderately active office work	Offices, hotels, apartments	140	130	75	55	
Standing, light work; walking	Department store; retail store	160	130	75	55	58
Walking, standing	Drug store, bank	160	145	75	70	
Sedentary work	Restaurant[c]	145	160	80	80	
Light bench work	Factory	235	220	80	140	
Moderate dancing	Dance hall	265	250	90	160	49
Walking 4.8 km/h; light machine work	Factory	295	295	110	185	
Bowling[d]	Bowling alley	440	425	170	255	
Heavy work	Factory	440	425	170	255	54
Heavy machine work; lifting	Factory	470	470	185	285	
Athletics	Gymnasium	585	525	210	315	

Appendix N: Minimum Ventilation Rates in Breathing Zone

TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values: Occupant Density (see Note 4)	Default Values: Combined Outdoor Air Rate (see Note 5)		Air Class
	cfm/person	L/s·person	cfm/ft²	L/s·m²		#/1000 ft² or #/100 m²	cfm/person	L/s·person	
Correctional Facilities									
Cell	5	2.5	0.12	0.6		25	10	4.9	2
Dayroom	5	2.5	0.06	0.3		30	7	3.5	1
Guard stations	5	2.5	0.06	0.3		15	9	4.5	1
Booking/waiting	7.5	3.8	0.06	0.3		50	9	4.4	2
Educational Facilities									
Daycare (through age 4)	10	5	0.18	0.9		25	17	8.6	2
Daycare sickroom	10	5	0.18	0.9		25	17	8.6	3
Classrooms (ages 5–8)	10	5	0.12	0.6		25	15	7.4	1
Classrooms (age 9 plus)	10	5	0.12	0.6		35	13	6.7	1
Lecture classroom	7.5	3.8	0.06	0.3		65	8	4.3	1
Lecture hall (fixed seats)	7.5	3.8	0.06	0.3		150	8	4.0	1
Art classroom	10	5	0.18	0.9		20	19	9.5	2
Science laboratories	10	5	0.18	0.9		25	17	8.6	2
University/college laboratories	10	5	0.18	0.9		25	17	8.6	2
Wood/metal shop	10	5	0.18	0.9		20	19	9.5	2
Computer lab	10	5	0.12	0.6		25	15	7.4	1
Media center	10	5	0.12	0.6	A	25	15	7.4	1
Music/theater/dance	10	5	0.06	0.3		35	12	5.9	1
Multi-use assembly	7.5	3.8	0.06	0.3		100	8	4.1	1
Food and Beverage Service									
Restaurant dining rooms	7.5	3.8	0.18	0.9		70	10	5.1	2
Cafeteria/fast-food dining	7.5	3.8	0.18	0.9		100	9	4.7	2
Bars, cocktail lounges	7.5	3.8	0.18	0.9		100	9	4.7	2
General									
Break rooms	5	2.5	0.06	0.3		25	10	5.1	1
Coffee stations	5	2.5	0.06	0.3		20	11	5.5	1
Conference/meeting	5	2.5	0.06	0.3		50	6	3.1	1
Corridors	–	–	0.06	0.3		–			1
Storage rooms	–	–	0.12	0.6	B	–			1
Hotels, Motels, Resorts, Dormitories									
Bedroom/living room	5	2.5	0.06	0.3		10	11	5.5	1
Barracks sleeping areas	5	2.5	0.06	0.3		20	8	4.0	1
Laundry rooms, central	5	2.5	0.12	0.6		10	17	8.5	2
Laundry rooms within dwelling units	5	2.5	0.12	0.6		10	17	8.5	1
Lobbies/prefunction	7.5	3.8	0.06	0.3		30	10	4.8	1
Multipurpose assembly	5	2.5	0.06	0.3		120	6	2.8	1

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Minimum Ventilation Rates in Breathing Zone (*continued*)

TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE *(continued)*
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values: Occupant Density (see Note 4)	Default Values: Combined Outdoor Air Rate (see Note 5)		Air Class
	cfm/person	L/s·person	cfm/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	cfm/person	L/s·person	
Office Buildings									
Office space	5	2.5	0.06	0.3		5	17	8.5	1
Reception areas	5	2.5	0.06	0.3		30	7	3.5	1
Telephone/data entry	5	2.5	0.06	0.3		60	6	3.0	1
Main entry lobbies	5	2.5	0.06	0.3		10	11	5.5	1
Miscellaneous Spaces									
Bank vaults/safe deposit	5	2.5	0.06	0.3		5	17	8.5	2
Computer (not printing)	5	2.5	0.06	0.3		4	20	10.0	1
Electrical equipment rooms	–	–	0.06	0.3	B	–			1
Elevator machine rooms	–	–	0.12	0.6	B	–			1
Pharmacy (prep. area)	5	2.5	0.18	0.9		10	23	11.5	2
Photo studios	5	2.5	0.12	0.6		10	17	8.5	1
Shipping/receiving	–	–	0.12	0.6	B	–			1
Telephone closets	–	–	0.00	0.0		–			1
Transportation waiting	7.5	3.8	0.06	0.3		100	8	4.1	1
Warehouses	–	–	0.06	0.3	B	–			2
Public Assembly Spaces									
Auditorium seating area	5	2.5	0.06	0.3		150	5	2.7	1
Places of religious worship	5	2.5	0.06	0.3		120	6	2.8	1
Courtrooms	5	2.5	0.06	0.3		70	6	2.9	1
Legislative chambers	5	2.5	0.06	0.3		50	6	3.1	1
Libraries	5	2.5	0.12	0.6		10	17	8.5	1
Lobbies	5	2.5	0.06	0.3		150	5	2.7	1
Museums (children's)	7.5	3.8	0.12	0.6		40	11	5.3	1
Museums/galleries	7.5	3.8	0.06	0.3		40	9	4.6	1
Residential									
Dwelling unit	5	2.5	0.06	0.3	F,G	F			1
Common corridors	–	–	0.06	0.3					1
Retail									
Sales (except as below)	7.5	3.8	0.12	0.6		15	16	7.8	2
Mall common areas	7.5	3.8	0.06	0.3		40	9	4.6	1
Barbershop	7.5	3.8	0.06	0.3		25	10	5.0	2
Beauty and nail salons	20	10	0.12	0.6		25	25	12.4	2
Pet shops (animal areas)	7.5	3.8	0.18	0.9		10	26	12.8	2
Supermarket	7.5	3.8	0.06	0.3		8	15	7.6	1
Coin-operated laundries	7.5	3.8	0.06	0.3		20	11	5.3	2

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Minimum Ventilation Rates in Breathing Zone (*continued*)

TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE *(continued)*
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values: Occupant Density (see Note 4)	Default Values: Combined Outdoor Air Rate (see Note 5)		Air Class
	cfm/person	L/s·person	cfm/ft²	L/s·m²		#/1000 ft² or #/100 m²	cfm/person	L/s·person	
Sports and Entertainment									
Sports arena (play area)	–	–	0.30	1.5	E	–			1
Gym, stadium (play area)	–	–	0.30	1.5		30			2
Spectator areas	7.5	3.8	0.06	0.3		150	8	4.0	1
Swimming (pool & deck)	–	–	0.48	2.4	C	–			2
Disco/dance floors	20	10	0.06	0.3		100	21	10.3	1
Health club/aerobics room	20	10	0.06	0.3		40	22	10.8	2
Health club/weight rooms	20	10	0.06	0.3		10	26	13.0	2
Bowling alley (seating)	10	5	0.12	0.6		40	13	6.5	1
Gambling casinos	7.5	3.8	0.18	0.9		120	9	4.6	1
Game arcades	7.5	3.8	0.18	0.9		20	17	8.3	1
Stages, studios	10	5	0.06	0.3	D	70	11	5.4	1

GENERAL NOTES FOR TABLE 6-1

1 **Related requirements:** The rates in this table are based on all other applicable requirements of this standard being met.
2 **Smoking:** This table applies to no-smoking areas. Rates for smoking-permitted spaces must be determined using other methods. See Section 6.2.9 for ventilation requirements in smoking areas.
3 **Air density:** Volumetric airflow rates are based on an air density of 0.075 lb_{da}/ft^3 (1.2 kg_{da}/m^3), which corresponds to dry air at a barometric pressure of 1 atm (101.3 kPa) and an air temperature of 70°F (21°C). Rates may be adjusted for actual density but such adjustment is not required for compliance with this standard.
4 **Default occupant density:** The default occupant density shall be used when actual occupant density is not known.
5 **Default combined outdoor air rate (per person):** This rate is based on the default occupant density.
6 **Unlisted occupancies:** If the occupancy category for a proposed space or zone is not listed, the requirements for the listed occupancy category that is most similar in terms of occupant density, activities and building construction shall be used.
7 **Health-care facilities:** Rates shall be determined in accordance with Appendix E.

ITEM-SPECIFIC NOTES FOR TABLE 6-1

A For high school and college libraries, use values shown for Public Assembly Spaces—Libraries.
B Rate may not be sufficient when stored materials include those having potentially harmful emissions.
C Rate does not allow for humidity control. Additional ventilation or dehumidification may be required to remove moisture.
D Rate does not include special exhaust for stage effects, e.g., dry ice vapors, smoke.
E When combustion equipment is intended to be used on the playing surface, additional dilution ventilation and/or source control shall be provided.
F Default occupancy for dwelling units shall be two persons for studio and one-bedroom units, with one additional person for each additional bedroom.
G Air from one residential dwelling shall not be recirculated or transferred to any other space outside of that dwelling.

6.2.7 Dynamic Reset. The system may be designed to reset the design *outdoor air intake flow* (V_{ot}) and/or space or zone airflow as operating conditions change. These conditions include but are not limited to:

1. Variations in occupancy or ventilation airflow in one or more individual zones for which ventilation airflow requirements will be reset.

   Note: Examples of measures for estimating such variations include: occupancy scheduled by time-of-day, a direct count of occupants, or an estimate of occupancy or ventilation rate per person using occupancy sensors such as those based on indoor CO_2 concentrations.
2. Variations in the efficiency with which outdoor air is distributed to the occupants under different ventilation system airflows and temperatures.
3. A higher fraction of outdoor air in the air supply due to intake of additional outdoor air for free cooling or exhaust air makeup.

6.2.8 Exhaust Ventilation. Exhaust airflow shall be provided in accordance with the requirements in Table 6-4. Exhaust makeup air may be any combination of outdoor air, recirculated air, and transfer air.

6.2.9 Ventilation in Smoking Areas. Smoking areas shall have more ventilation and/or air cleaning than comparable no-smoking areas. Specific ventilation rate requirements cannot be determined until cognizant authorities determine the concentration of smoke that achieves an acceptable level of risk. Air from smoking areas shall not be recirculated or transferred to no-smoking areas.

6.3 Indoor Air Quality (IAQ) Procedure. The Indoor Air Quality (IAQ) Procedure is a performance-based design approach in which the building and its ventilation system are designed to maintain the concentrations of specific contaminants at or below certain limits identified during the building design and to achieve the design target level of perceived indoor air quality acceptability by building occupants and/or