Energy Efficiency Improvement Considerations at the Design Stage: The Case of Supermarkets

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Abstract

Supermarkets are large energy consumers, with high specific energy consumption than a majority of other commercial buildings. The main energy users are space cooling, lighting and the cold chain. This study was conducted as an initiative to demonstrate cost-effective, replicable ways to achieve significant electrical energy savings in supermarket buildings.

The largest consumer of a Supermarket is the HVAC system, with about 50% of the total energy consumption. Of the total demand, the cold chain accounts for about 20% and lighting for about 15% while other equipment use about 15%. The Arpico Super Center, Kegalle, project was selected as a model to maximise energy efficiency measures to save electricity. A saving of 22% of energy was achieved through efficiency improvements and a further 23% was self-generated from a roof mount solar power plant.

An inverter type air conditioning system, automated fresh air control system with CO₂ monitoring sensors, LED lamps, lighting controls (timer switch, light sensor, occupancy sensor), parabolic reflectors, skylights, variable frequency drives (VFD), power factor correction, energy efficient sewerage treatment plant, maximum use of gravity in water transportation and planned preventive maintenance are some of the energy efficiency improvement techniques implemented to achieve the study objectives.

Almost all of the Arpico supercenter roofs are operating as solar power plants and more than 3 MWp installations completed by 2019, including 260 kWp of this project.

Introduction

The outcomes of energy efficiency improvements of Arpico Supercenter projects were appreciated by the government and non-government organizations. Achievement of '**Outstanding Energy Manager of the Year**' in Sri Lanka National Energy Efficiency Awards 2016, by Sri Lanka Sustainable Energy Authority, encouraged

to lead and drive the organization for further energy efficiency improvements, conservation and management. As a result, Arpico Kegalle Supercenter was awarded the prestigious '**Platinum Rating**' under the new building category of the GREEN^{SL}® rating system for building environment at the Green Building Awards Ceremony 2018.

This paper is prepared with the intention of sharing knowledge and experience on energy efficiency improvements for the benefit of society. The simple and realistic energy savings and payback period estimates developed in this paper can be used as evidence to secure funds approved for similar projects. The pre and post-implementation energy consumptions can be logged to assess the true viability of investments.

Electricity demand in commercial office buildings is substantially different to the demand in supermarkets although both have the same marginal needs in HVAC (24 °C to 26 °C) and interior lighting (450 lux to 650 lux). Supermarkets have long working hours, higher occupancies and special equipment such as cold chain and hot kitchen equipment. Furthermore, supermarkets have seasonal peaks during festivals, as observed from the load profiles. Another important difference is that during the peak time of the day (6.30 pm to 10.30 pm), shopping malls have a higher demand whereas an office building has a negligible demand at that time.

Supermarkets present many opportunities for improvement of energy efficiency. Analysis of existing buildings generally indicate substantial potential to optimize the energy demand and use energy in more efficient ways. In other words, builds designs and operations can be more sustainable than the present buildings.

Solar PV Installation

Most of the supermarkets have a large roof space. Therefore, solar PV can be effectively installed. Solar PV installation will generate renewable energy to reduce the demand on the main grid

and reduce the grid electricity cost of supermarkets. It will encourage and recognize increasing levels of self-supply through renewable technologies to reduce environmental impacts associated with fossil fuel energy use.

The average annual electricity generation calculation is given below.

Annual global horizontal irradiation in Kegalle is 1800 kWh/year.m² [1].

Considering solar irradiation as 1000 W/m²;
Monthly yield of a 1 kW system at Kegalle
(Horizontal) = $1800/12$
= 150 kWh/kWp

Consider 20% losses for inclination, direction and unpredictable factors, and another 20% for rain and cloud effects.

Monthly yield of a 1 kW system at Kegalle
= $80\% \times 80\% \times 150 \text{ kWh/kWp}$
= * 96 kWh/kWp

Total system capacity : 260 kWp

Estimated monthly energy saving by solar system(avg) : $260 \text{ kWp} \times 96 \text{ kWh/kWp}$
: 26,960 kWh

*Monthly yield of 1 kWp may differ according to the location and we have obtained a monthly average above 120 kWh/kWp in western and southern coastal locations.

After completion of projects, it is very important to monitor the performance. With the modern technology, all the reputed inverter manufactures have provided online monitoring facility to analyze the performance on daily, monthly and yearly basis.

Figure 1: A Sample of Daily & Monthly Yield Obtained by Online Monitoring Portal

The largest energy consumer of the supermarket is the air conditioning system. Air-conditioning systems used in the supermarket will account for about 50 percent of the total electricity consumption. However, they are essential for buildings in hot and humid climates, where air-conditioning is used to provide a comfortable internal environment for customers so that they will enjoy, purchase and spend more time in supermarket. Therefore, proper selection/ design of AC system is an important task in energy optimization of a supermarket.

The selection of a suitable air conditioning system depends on:

1. Capacity, performance (COP) and partial load requirements (for inverter application)
2. Initial and running costs
3. Required system reliability and flexibility
4. Maintainability and costs
5. Architectural constraints

The relative importance of the above factors will vary from project to project. We have introduced water cooled inverter package AC units for this project.

Fresh Air Supply System

Supermarkets are with high footprint and thus the infiltration rates are very high. Therefore, it is advisable to measure the CO₂ level and only required fresh air quantity must be induced to the retail floor. This is done by CO₂ sensors with motorised dampers.

Heat recovery wheel is a further improvement of technology available today. The ventilation system is designed to meet the minimum requirement of ASHRAE 62.1-2004.

Efficient Lighting System

An efficient lighting system should satisfy the visual performance needs and quality needs of the supermarket with minimum energy consumption. Lighting system of supermarkets or any other buildings should be designed effectively to use more natural light. Natural light will normally provide the best color rendering properties. To minimize heat entering the building with natural light, canopy shades, low e glasses or solar reflective films can be used. We have ensured that adequate light is provided according to the operational requirements of the supermarket. The lighting was designed to

minimize the wastage of light and pollution. The colour temperature should be selected to meet the operational requirements.

When selecting a large quantity of lights for supermarkets, it is recommended to set the minimum efficacy level to the supplier. Once receiving the order, a sample is tested and verified from a reputed institution. The average efficacy of the tested sample lamps for this project was 113 lm/W.

Simple monthly energy saving calculation of LED lamp vs fluorescent lamp is given below;

Number of lamps at used for the project : 800
 Power requirement of fluorescent lamps : 42 W x 800 (including ballast loss)
 : 33.6 kW
 Estimated energy consumption by fluorescent lamps : 33.6 kW x 14 h x 30 days
 : 14,112 kWh/month
 Power requirement of LED lamps : 18 W x 800 : 14.4 kW
 Estimated energy consumption by LED lamps : 14.4 kW x 14h x 30 days : 6,048 kWh/month
 Estimated Monthly Energy saving by LED lamps : 14,112 – 6,048 kWh/month : 8,064 kWh/month

Parabolic Reflectors:

Linear lamps are the most commonly used lamps for general lighting in supermarkets of Sri Lanka. Various types of reflectors are used to improve the optical efficiency of luminaires used in linear lamps.

Most standard reflectors used in luminaires of linear lamps have reflectivity of about 70 to 80%. However, reflectors made of special material can improve the reflective effectiveness. These reflector materials have a mirror-like finish, that allows better redirection of light rays. Some of the special reflector materials are anodized specular aluminium, having a total reflectivity of 85 to 90%, and vacuumed posited specula silver applied on a polyester surface, having a total reflectivity of 91 to 95%.

Simple monthly energy saving calculation of more efficient parabolic reflector application is given below:

Assuming 14 hours/day of artificial lighting will operate and 10% of additional lighting is reflected and utilized by highly efficient parabolic reflectors.

Total power of lamps : 18W x 800
 : 14.4 kW

Estimated monthly energy saving by parabolic reflectors : 14.4 kW x 14h x 30 days x 10%
 : 605 kWh/month

Lighting Controls

Apart from lamp efficacy, the effective use of lamp is also very important. Provided switching facility as per the operational requirement, lamps synchronized with the skylight system, automatically controlled the less occupied common places with occupancy sensors and time-based controllers for the external car park and main signage board have improved the lighting system efficiency.

Timer Switch

Simple timers were used to switch on and off the lighting circuits at predetermined times based on occupancy schedules. Also, the main signage lights (about 18 W, 100 lamps) were set to on and off for a pre-defined duration. Provision for manual override was incorporated into the controls so that occupants can extend the operating hours of lighting circuits based on individual requirements. Lighting control systems can consist of simple timers that have 24-hour clocks to switch on and off lighting daily at preset times or more sophisticated timers that can be used to program lighting schedules for a year or more, where holidays and other special requirements can be programmed in advance.

Often lighting operating schedules can also be programmed into building automation systems to control the operating hours of lighting. Simple monthly energy saving calculation for timer switch application is given below;

External lighting system of the Kegalle supercentre consists of 100 lamps each of 18W for the main signboard and 30 lamps each of 150W in car park lamps.

Assuming 1hr wastage of switching ON and OFF by the operators every day;

Total power of external lamps : 6.3 kW
 (18W x 100 + 150W x 30)

Estimated monthly energy saving by timers
: 180 kWh/month

Light Sensors

Exterior and interior areas of buildings, which are exposed to natural light, can have light sensors to switch off or provide dim artificial lighting when sufficient natural light is available. Artificial lighting system can be synchronized with skylight system by incorporating light sensors effectively.

Simple monthly energy saving calculation for lighting sensor application is given below;

Assuming average switching off of artificial lighting of 4 hours per day by the use of natural light near the façade glasses,

Total power of lamps : 18W x 100
: 1.8 kW

Estimated monthly energy saving by light sensors : 1.8 kW x 4 h x 30 days
: 216 kWh/month

Occupancy Sensors

Occupancy sensors can be used to switch on lamps when a space is occupied and switch off the lamps after a pre-set time delay when the space is not occupied. Typical applications for occupancy sensors in supermarkets are in toilets, car parks, staff lunchrooms, restrooms, storage areas and common corridors. The three basic technologies used in occupancy sensing devices are infrared, ultrasonic and microwave.

Simple monthly energy saving calculation for occupancy sensor application is given below:

Assuming artificial lighting could be switched off 8 hours per day.

Total power of lamps : 18W x 30
: 540 W

Estimated monthly energy saving by light sensors : 540 W x 8 h x 30 days
: 129 kWh/month

Skylights

Skylights for supermarkets must be selected carefully by considering the light input versus heat gain. Therefore, it is not recommended to install on the roof of air-conditioned space (retail area) without a comprehensive study. It is very important to synchronize with the lighting

system by using a light sensor to achieve uniform illuminance.

Calculation of skylight (in an air-conditioned space);

As per the datasheet obtain by Bristolite [2], solar heat gain coefficient (SHGC) of the skylight is 0.5, U factor 0.6 Btu/hr.ft².F, visible light transmission 0.49,

Dimension of skylight : 1.2 x 1.2 m

For a perpendicular surface at sea level, bright sunlight provides lighting of approximately 93 lm/W [3]. The irradiation of the sun is about 1050 W/m².

Thus, luminance of direct sunlight

: 93 lm/W x 1050 W/m²
: 98,000 lm/m²

Visible light transmitted to the building by skylight (98,000 lm/m² x 0.49 x 1.2 m x 1.2m)
: 69,149 lm

As per the lamp performance test report numbered 17/LT/LED 413 issued by the NERD Centre, light output of a 18 W 1.2 m T8 LED lamp is 1978 lm.

Numbers of lamps that can be shut down during day-time (69,149 lm/1978 lm) : 35

Rated power of the lamp : 18 W

Lighting power saving with skylight : 629W (35 x 18 W)

Average sun hours : 5.5 h/ Day

Lighting energy saving with a skylight/ month
: 103.8 kWh/ month (a)

Heat load to the AC by skylight:

Heat gain by Skylight : 124.75 kWh/month (SHGC x 1.2 m x 1.2 m x 1050 W/m² x 5.5 h 30 days)

COP of the AC System : 3.5

Monthly power requirement to absorb the heat gain from skylight : 35.6 kWh/ month (b)

Therefore, net energy saving by skylight per month per skylight (a - b) : 89.1 kWh/ month

Low e Glasses

Façade glasses of supermarkets are important to display the identity and to get natural light. But the amount of heat gain should be minimized to

reduce the impact on AC demand. Low e glasses are installed at this project to increase the energy efficiency.

Solar factor (SF) of the low e glass is 63% and this is about 17% more efficient than normal glasses.

Heat gain saving by Low e glasses in east direction:

$(0.17 \times 25 \text{ m} \times 7 \text{ m} \times 1050 \text{ w/m}^2 \times 2.5 \text{ h} \times 0.80 \text{ shading} \times 30 \text{ days})$: 1,875 kWh/month
: 533 TR/month

Efficiency of AC system: 0.95 kW/TR

Monthly AC bill saving : 506 kWh/month
(533 TR/month $\times$ 0.95 kW/TR)

Variable Frequency Drives (VFD)

Frequency (Hz) is directly related to the motor speed (rpm). In other words, the faster the frequency, the faster the RPM. If any application does not require an electric motor to run at full speed, the VFD can be used to ramp down the frequency and voltage to meet the requirements of the electric motor load. As the motor speed requirements change, the VFD can simply turn up or down the motor speed requirement. Variable frequency drives provide the following advantages:

- Energy saving
- Low motor starting current
- Reduction of thermal and mechanical stresses on motors and belts during starts
- Simple installation
- High power factor
- Lower maximum demand

This supercenter is air conditioned with water-cooled inverter-type package AC system. The project has installed VFD for the cooling tower fan motor to control fan speed according to the wet bulb temperature.

Selection of an Energy Efficient Sewerage Treatment Plant

The wastewater and sewer water disposal of supermarket is a crucial problem. The best way to get rid of this issue is to install sewerage treatment plant (STP). The black and greywater can be treated to meet the Central Environment Authority (CEA) specifications of surface discharge water. The discharge water should be treated to the CEA requirement and the Environmental Protection License (EPL) has to be obtained. Subsequently, the discharge water should be tested and the EPL renewed every year.

There are many technologies of water treatment processes are available in the market to achieve the CEA requirements. We must select the most energy efficient and cost-effective technology.

The schematic diagram of the treatment process used in the supercenter project is shown below.

Figure 2: Schematic Diagram of Treatment Process

The capacity of the system is 10,000 liters per day. The power consumption of this system is about 0.375 kW. Power requirement of conventional Aerobic System : 1.5 kW
Estimated energy requirement of aerobic system per month : 1.5 kW $\times$ 20h $\times$ 30d
: 900 kWh/month

Power requirement of Ozone system : 0.375 kW

Estimated energy requirement of Ozone system per month : 0.375 kW $\times$ 20h $\times$ 30d
: 225 kWh/month

Estimated monthly energy saving by STP system : 900 – 225 kWh/month
: 675 kWh/month

Use of Gravity Pressure

All the possible measures should be taken to reduce the energy requirement for water pumping. For potable water, the day tank should be elevated at a higher level to maximize the use of gravity pressure. This will eliminate the requirement for booster pumps.

The black/grey water treatment plant was designed to feed the garden landscape drip irrigation system with gravity pressure

Planned Preventive Maintenance (PPM)

Planned preventive maintenance is predetermined work performed to a schedule with the aim of preventing sudden failure of

equipment components. Preventive maintenance helps to protect assets, prolong the useful life of equipment and increase the energy efficiency of the operation. PPM will improve system reliability and decrease the cost of replacement while decreasing system downtime and reducing energy cost.

Air Conditioning System Maintenance

Investing more efficient systems only will not provide the expected output. A proper maintenance is very important for the efficiency. For example, the evaporator and condenser tubes of chillers provide the surface for heat transfer between the refrigerant and chilled water or condenser water, respectively. If there is scaling or fouling on the tube surfaces, the resistance to heat transfer increases. This results in a higher temperature difference driving the heat transfer process, which leads to lower chiller efficiency. Condenser tubes are more prone to fouling since the circulating water is open to the outside (at the cooling towers) and therefore need to be cleaned regularly.

Scale and fouling in condensers are normally controlled by:

- a. Water treatment systems to inhibit scaling and fouling
- b. Blowdown, where water is regularly drained from the bottom of the cooling tower basin and topped up with clean water
- c. Tube cleaning, where the insides of tubes are cleaned periodically by brushing

The effectiveness of water treatment systems in controlling scaling depends on the treatment program employed. In chemical treatment programs the alkalinity of the water, which increases the tendency for scaling, is controlled by increasing its acidity. However, increase in acidity leads to increased corrosion and, therefore, chemical treatment programs are used more for controlling scaling than eliminating it. Blowdown and tube cleaning too are measures that are carried out periodically but cannot eliminate scaling and fouling. This can result in chiller efficiency varying with time.

When scale and fouling deposits collect on condenser tubes, the resistance to heat transfer across the tubes from the condensing refrigerant to the cooling water increases. This leads to an increase in the condensing temperature (and pressure) and causes the chiller efficiency to drop

since the compressor must compress the refrigerant vapor to a higher pressure. Over time, the thickness of the layer formed by scale and fouling increases, resulting in a gradual drop in chiller efficiency. Periodically, when tubes are cleaned by brushing, the efficiency returns to the normal rated value. Thereafter, the efficiency gradually drops again when scale and fouling build up on tube surfaces. This results in a kind of "saw tooth" pattern, where the length of the tooth denotes the time interval between cleanings while the height of the tooth indicates the maximum drop in chiller efficiency between cleanings.

Regular Maintenance of luminaires

Maintenance can also impact the optical efficiency of luminaries. The light available in the space or at the working plane can be reduced due to the accumulation of dirt, discoloring of lenses and reflectors, and ageing of lamps. Therefore, regular maintenance is required to maximize the lighting levels by cleaning dirty lamps and fixtures, replacing faded reflectors, lenses and lamps which are nearing the end of their useful life.

No/ Low Cost Energy Saving Measures

As the initial step of energy saving of any building, it is advisable to start with no/low-cost energy saving methods. This involves small investment on modifications and good practice in the workplace to control energy wastage. Few points of such measures are explained below.

Monitoring the power consumption pattern on daily basis and analyse to identify the reason for the sudden fluctuation. We can identify problems early when we have a monitoring system implemented in the SM building.

Most of the open display cases are switched on after SM operation hours. This will waste energy. The night curtains are installed by the manufacturer to close the display case after operating hours. These curtains should be closed during non-operational hours and need to monitor by the management.

Installation of strip curtains to cool room access will minimize the infiltration of hot air during loading and unloading.

Due to the high footfall of SM, the open duration of the entrance and exit doors are high. Using an air curtain will separate outdoor and indoor as a barrier and minimize the energy wastage.

Swing doors are inefficient in SM operation due to energy wastage and need of doorman to operate the door. Sensor operated auto door will save energy as well as manpower requirement.

Seasonal decoration with lighting is more popular in supermarket buildings. Using LED drop ceiling ornament lights to reduce the energy consumption than conventional lamps.

Summary and Comparison of Calculations

Monthly energy consumption without improvement and estimated energy saving are tabulated below.

Table 1: Energy savings without improvement

Energy Saving Technology Used	Monthly Energy Consumption Without Improvement (kWh)	Estimated Monthly Energy Saving (kWh)
Saving Achieved Through Energy Efficiency Inversions		
Water cooled packaged type inverter AC	43,092	8,620
LED lamps	14,112	8,064
Timer switches		180
Light sensors		216
Occupancy sensors		129
Parabolic reflectors		605
Low e glasses		506
Efficient STP	900	675
Planned Preventive Maintenance (Assumption)		300
Low/no cost energy saving measures (Assumption)		300
Cold Chain (35 kW, 60%, 24 hr)	15,120	
Other	15,000	
Total	88,224	19,595
Percentage of total energy saving	22%	
In house electricity generation		
Average monthly yield of 332 kWp solar plant		24,960
Total	88,224	24,960
Percentage of total energy generation	28%	
Monthly energy consumption after improvement (kWh)	43,669	

Table 2: Equipment level savings achieved

Load Description	Before Improvement kWh/month	After Improvement (Without Solar) kWh/month
AC	43,092	27,504
Lighting	14,112	4,918
Cold Chain	15,120	15120
Other	15,900	14625
Total	88,224	62,167

Figure 3: Comparison of energy savings (without solar energy)

The percentage of energy saving is about 22% and the percentage of solar energy is 28%. Therefore, total demand reduction to the main grid is about 50%. This is not limited only to supermarkets but could be extended to different applications with necessary studies and modifications.

References

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