

EVALUATION OF ENERGY PERFORMANCE USING DOE-2 ENERGY SIMULATION PROGRAM IN SINGAPORE

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ABSTRACT

Recently, due to worldwide energy cost rising significantly, there has been an essential need to minimize the energy consumption. This global warning address many countries including Singapore realizing the important of energy efficiency in industries and buildings. This paper deals with analyzing the energy consumption of an 11-storey commercial building in Singapore using DOE-2 Energy Simulation Program. A study is made on the benefits derived from modifying the building envelope, space system setting, air-conditioning plant, and lighting. This encompasses a description of its quantitative impact on cooling load, energy consumption and energy saving achieved as compared with the original building. Following this, a life cycle costing is done to determine the economic benefits attained from this modification. This study shows that some alternative solutions can be achieved using energy simulation program to conserve the energy consumption.

Keywords: energy simulation, modified building system, energy saving

INTRODUCTION

The prospect of global warming threatening human habitations and energy cost rising significantly have made many countries including Singapore more conscious and aware of the energy conservation. Commercial high-rise building is one of the greatest users of energy consumption in the form of energy for cooling, lighting, and various modern electrical equipments. World Energy Outlook, 1996, noted that the oil prices are predicted to rise from US\$ 17 per barrel in year 2000 to US\$ 25 by year 2005. In fact, it has been reached to US\$34-35 per barrel recently. The gas and liquefied natural gas (LNG) price will also rise roughly in line with the oil price. Accordingly, due to many newly and rapid industrialized countries grow, the electricity consumption is expected to increase at average annual rates of 6.5 % from 1993 to 2000 and 5.3% from 2000 to 2010. Total electric power generation in the Asia region is expected to increase from 1683.9 terawatt hours (TWh) in 1993 to 2960.8 TWh in 2000 and 5542.8 TWh in 2010. These rates are much higher than global averages, which are expected to be 2.4% and 3.1% in respective periods. The total annual cost of electricity for building in ASEAN (45 billion kWh) is about US\$ 4 billion. This is likely to increase significantly over time.

The investigations are concern to reveal a considerable potential for cost-effective conservation in industries and commercial buildings throughout ASEAN [3].

Realizing the need for energy conservation, the Singapore government has legislated building regulations and Code of Practice for new and existing commercial buildings. There are many alternative ways to enhance the efficiency of energy consumption such as building envelope modification, efficient space system settings, higher efficiency plant, and lighting modification, which are the main focus in this paper. The DOE-2 Energy Simulation Program then is very useful tool to study the total energy consumption of the existing building.

BUILDING DESCRIPTION

The building is 11-storey located at Cecil Street in Central Business District Area. It has a typical rectangular floor area of 1388 m² with 2 AHU per floor, providing effective air-conditioned area of 1220 m² and 168 m² core areas without air-conditioning. The first story is used as banking hall and 2nd to 4th floors are used as car parks, which are naturally ventilated. From 5th story onwards are being used as offices (Figure 1)

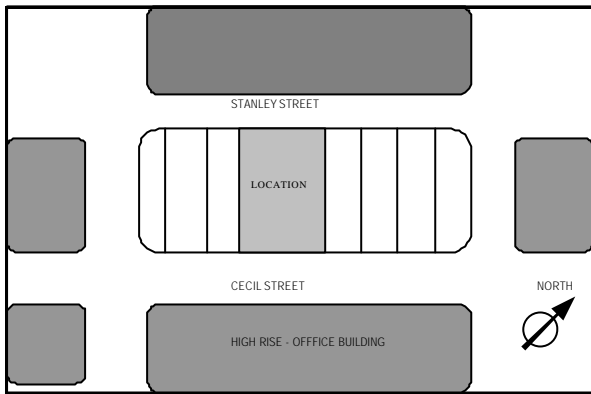


Figure 1. Site location of existing building

tons) and 1 unit small chiller (capacity 50 tons) as running system. The 2 units cooling tower (300 tons) and 1 unit small cooling tower (100 tons) are also utilized in the plant (Figure 2 and 3).

BASIC CASE SIMULATION

The analysis of building including the system design, operation and maintenance (O&M) procedures, and interview with the building management had been conducted in this study. The subsequent results are then compared with existing power and utility board (PUB). Finally, it is proposed some alternative modification to reach the more efficient energy consumption (Figure 4 and 5).



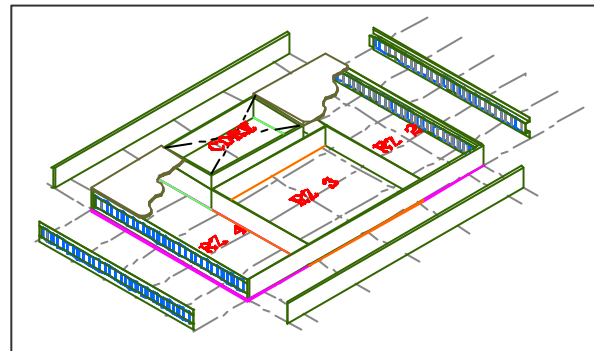
(1)



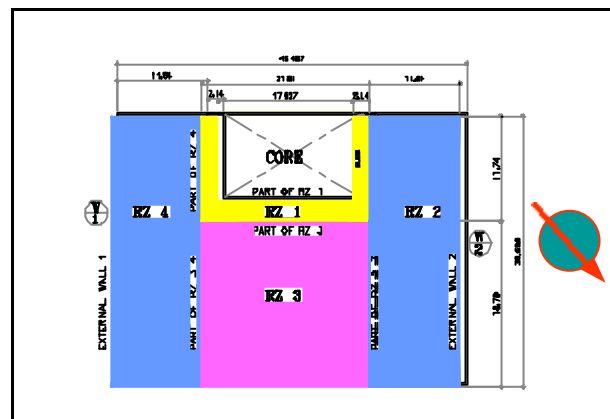
(2)

Figure 2 and 3. The 2 unit main cooling tower (300 tons), 1 unit small cooling tower (100 tons) and 2 unit main chiller (225 tons).

Common specifications for building are the front façade of 150 mm reinforced concrete wall with aluminum cladding, 1.7 m high, 6 mm thick glass window, and the rear façade of reinforced concrete wall with plaster paint finishing, 1.7 m high, 600 mm set back glass window. The building was 20 years old and had upgraded the air conditioning system eight years ago. The system of air conditioning used in this building is VAV with 2 units main chiller (capacity 225



(4)



(5)

Figure 4 and 5. The 3-D typical floor plan and the defined zoning plan.

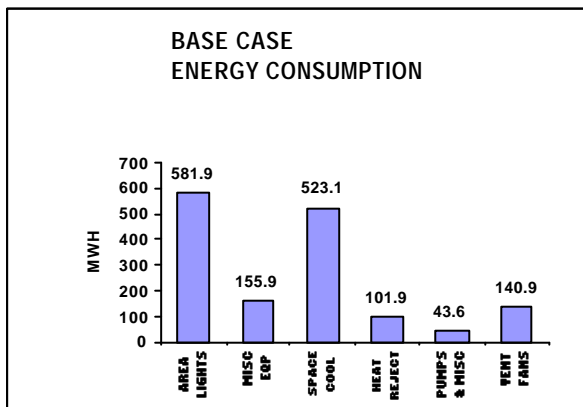
According to PUB, the estimated energy consumption for base case of the building are:

1. The occupancy rate from December to March 1998/1999 is 80% with 105.000 kWh/hour.
2. The estimation for fully occupied is 100% with 131.250 kWh/month or 1575 MWH/year, and 167 kWh/m²/year for 9420 m².

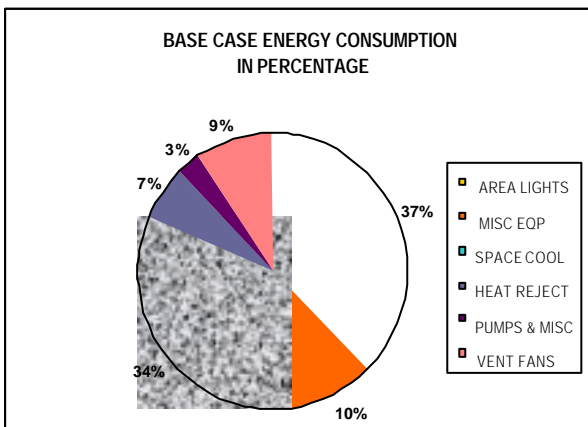
Table 1 shows the detailed specification of material for existing building.

Element	Position	Description
WALL	Front façade	150 mm thickness reinforced concrete wall, aluminum cladding, 6 mm thickness glass window, height 1.7 m
	Rear façade	150 mm thickness reinforced concrete wall, plaster, 6 mm thickness glass window with 600 mm set back.
	Internal	150 mm thickness reinforced concrete wall with plaster
	Partition	12 mm gypsum board
ROOF		150 mm thickness light weight concrete flat roof with water proofing membrane
FLOOR		150 mm thickness reinforced concrete slab
WINDOW		6 mm single glazing, shading devices only at rear façade

This result is compared with base case DOE2 result, as seen in Table 2. The features of each part of building consuming energy can be seen in Figure 6 and 7.



(6)



(7)

Figure 6 and 7. The detailed Base Case Energy Consumption and Base Case Energy Consumption in Percentage.

Table 2. Comparison between PUB Result and Base Case DOE2 Result

PUB Result	Base Case DOE2 Result
1575 MWH	1547.4 MWH
167 kWh/m ² /year	164.3 kWh/m ² /year

MODIFICATION USING DOE2 SIMULATION PROGRAM

The building energy simulation software DOE2.1 E is used to study the effect on annual energy consumption of the building by changing some possible parameters. The U.S. Department of Energy's DOE-2.1 E is a program designed to explore the energy behavior of proposed and existing buildings, and their associated heating, ventilation, and air conditioning (HVAC) systems [5]. The energy simulation is a complex calculation as following; the general procedures can be followed as below [3]:

1. Obtain the building characteristic, such as building material, component size, external surface from building plan and specification.
2. Determine building location, orientation and external shading.
3. Determine the appropriate weather data and select outdoor design conditions.
4. Obtain heat sources within the conditioned space. It would be contributed by lighting, occupants, internal equipments, and other appliance and process.
5. Finally, calculate the space-cooling load at design conditions.

BUILDING ENVELOPE MODIFICATION

Some materials of building envelope were replaced with other special material known as smarter material to cut down heat entering the building in view of energy and cost savings, as following:

1. The 6 mm acrylic/polycarb glazing (U value = 5.48 W/m²°K) is replaced with double-glazing argon space (U value = 2.87 W/m²°K).
2. The roof insulation IPI-35, 2 inches thickness is replaced with IN-46, 3 inches insulation. Gravel RG-02, 1 inch is also added on the insulation.
3. The window glazing at front is set back by 600 mm.

The energy result after replacing with the materials above are:

1. The space cooling energy consumption reduced by 16.2 MWH, which is 3.1% reduction as compared to the base case.
2. The heat rejected in cooling tower decreased resulting in lowered annual energy consumption for Heat Reject by 5.3 MWH, which is 5.2 % reduction compared to base case "Heat Reject".
3. The pumps and miscellaneous equipment energy consumption decreased by 2.5 MWH, which is 5.7% reduction compared to the base case.
4. The vent fans energy consumption lowered to 136.7 MWH, which is 3 % reduction compared to base case.

The complete result can be seen in Figure 8.

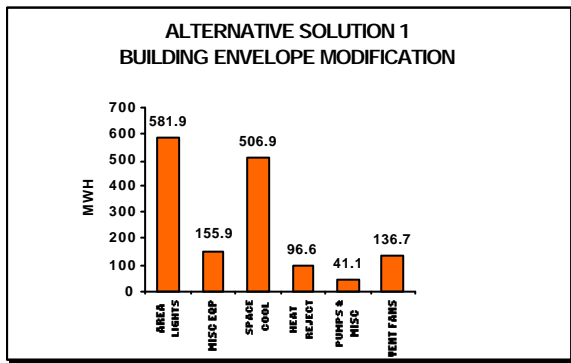


Figure 8. The Result of Building Envelope Modification.

SPACE SYSTEM SETTINGS MODIFICATION

Similar with the first modification, the space system settings of the building can be modified according to the standard. There some available of them that possible to be changed, such as the increasing of space temperature from 21°C to 24.4°C, the off coil temperature is increased to 18.3 °C from 16.1 °C, and the chilled water supply temperature is increased from 6.1°C to 8.9°C (Table 3).

The advantages of space system settings modification can be seen below:

1. The space cooling annual energy consumption is reduced by 12.5 MWH, which is 2.4% reduction as compared to the base case.

2. The heat reject is decreased by 2.4 MWH, which is 5.5% reduction compared to the base case.

Table 3. The Space System Settings Modification

System Adjustment	Base Case	Modification
Space thermostat set point	21°C=70°F	24.4°C=76°F
Off coil temperature	16.1°C=61°F	18.3°C=65°F
Min. supply temperature	6.1°C=43°F	8.9°C=48°F

3. The pumps and miscellaneous annual energy consumption is reduced by 1 MWH, which is 2.3% reduction compared to the base case.
4. There is a significant reduction in vent fan annual energy consumption, which is decreased by 34.9 MWH (24.8% reduction compared to the base case).
5. Overall reduction in annual energy consumption by changing space system settings is resulting in net savings by S\$ 6,950.

Figure 9 shows the results of the modification:

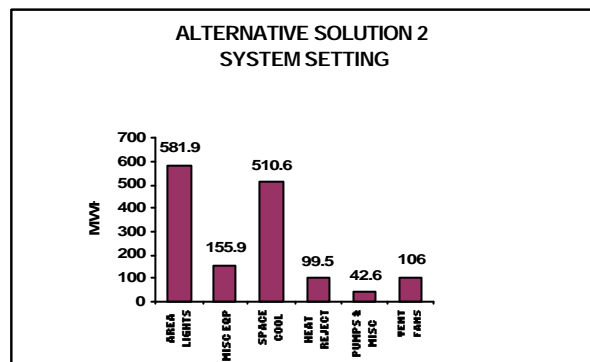


Figure 9. The Space System Settings Modification

AIR CONDITIONER (AC) PLANT MODIFICATION

The other alternative can be made from modification of air conditioner plant. There are some plant modification on annual energy consumption were studied, such as increasing coefficient of performance of chillers to 5.0 and reducing the outdoor air demand from 7.6 l/s per person to 4.7 l/s per person (Table 4).

Table 4. The AC Plant Modification

AC Plant	Base Case	Modification
Coefficient of performance	4.0	5.0 (new chiller)
Outdoor air demand	7 l/s person = 14.8 cf/m	4.7 l/s person = 19 cf/m

The plant modification has the following advantages on the annual energy consumption (Figure 10):

1. The space cooling annual energy consumption is decreased by 137.8 MWH, which is 27.6% reduction compared to base case.
2. The heat reject annual energy consumption is reduced by 2.3 MWH, which is 0.9% reduction compared to the base case.
3. The overall reduction in annual energy consumption by plant system modification will result in net savings of S\$ 19,285 per year.

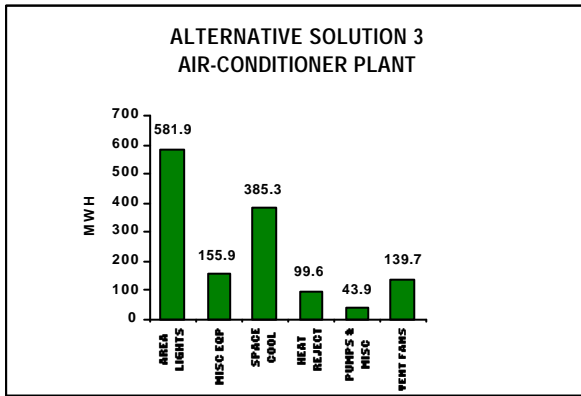


Figure 10. The Air Conditioner Plant Modification

LIGHTING MODIFICATION

The effect of the following lighting modification on the annual energy consumption was also studied (Table 5):

1. The using of a better efficacy lamp 75 lumen/W from 60 lumen/W
2. The reducing of lighting load to 13.5 W/m² from 20.4 W/m²
3. The using of day light to 6 m perimeter zone adjacent to windows.

Table 5. The Lighting Modification

Lighting	Base Case	Modification
Lighting Load	20.4 W/m ²	13.5 W/m ²
Calculation for 12 m ² typical workstation	245 Watt Efficacy = 60 lumen/W (fluorescent lamp) ≈ 14.700 lumen (total) ≈ 1225 lux (illuminance)	160 Watt Efficacy = 75 lumen/W (energy efficient PLC lamp) ≈ 12.000 lumen (total) ≈ 1000 lux (illuminance)
Daylight	Not consider the daylight	Consider the daylight fenestration to the area near window (6 meter perimeter zone) during working hours

The light modification produced the following advantages on the annual energy consumption (Figure 11):

1. The area light annual energy consumption is reduced by 195.2 MWH (33.5% reduction compared to the base case).
2. The space cooling is lowered by 53.9 MWH (10.3% reduction compared to the base case).
3. The heat reject is reduced by 13.8 MWH (13.5% reduction compared to the base case).
4. The pump and miscellaneous is reduced by 6.2 MWH (2.3% reduction compared to the base case).
5. The vent fans is lowered by 18.8 MWH (13.3% reduction compared to the base case).
6. The overall reduction in annual energy consumption by lighting modification will result in net saving of S\$ 39,352 per year.

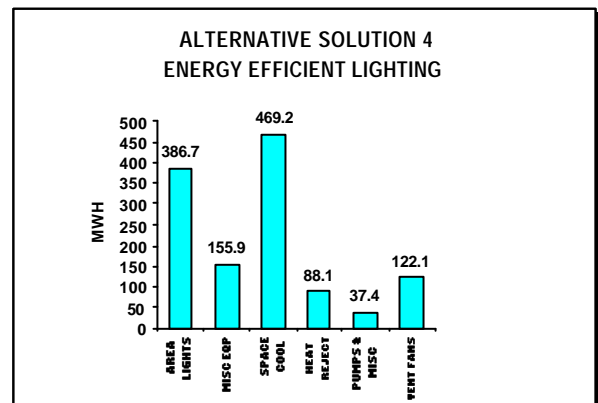


Figure 11. The Lighting Modification

CONCLUSION

1. From the results, it can be seen that by replacing the lighting system with higher efficacy lamps and effective use of daylight, S\$ 39,325 per year can be saved as energy conservation. The modifications are highly recommended for implementation in the existing building. The changes can be done without affecting the normal operations of the building.
2. Improving the COP of the chiller from 4.0 to 5.0 and reducing the fresh air from 7 l/s per person to 4.7 l/s per person resulted in annual saving of S\$ 9,825. The COP of chiller was calculated based on the running amps of the chiller. It is evident that the following suggestions can be made to improve the value:
 - a. Cleaning the cardeuser shell to improve the heat exchange
 - b. Brushing the cleaning system. A system of automatic cleaning of cardeuser tubes at regular intervals of once or twice per day is available to maintain the COP of the chiller.
 - c. Replacing of chiller can be considered if the above options do not produce significant improvement. Recently, chillers with COP in the range of 6.5 to 7.0 are available hence resulting in substantial annual energy saving.
3. The reduction of fresh air from designed 7 l/s per person to 4.7 l/s per person is not recommended. In fact, ASHRAE Standard 62 recommended 10 l/s per person to achieve a proper indoor environment. The fresh air openings/dampers shall be checked to ensure that the desired fresh air is introduced in the air-conditioned space.
4. Modifying the space temperature to 24.4°C from 21°C is highly recommended. The set point for space temperature, off-coil temperature and chilled water supply temperature shall be easily changed with the build-in control system. If the present control system does not have the provisions to change the set points, the control system of the building shall be upgraded to incorporate the set point changes by replacing the cooling coils and incorporate LF/HCV coils.
5. The building envelope modification has shown the least energy saving potential. However a window set back at the rear of building can reduce the solar heat gain due to solar radiation by shielding it.
6. The total site energy of 164.3 KWH/m² per year is an efficient feature of 8 year building. However it is possibly enhanced to a further potential energy consumption reduction by incorporating the strategies mentioned above, which may reduce the total site energy to less than 150 KWH/m² per year.

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ATTACHMENT 1

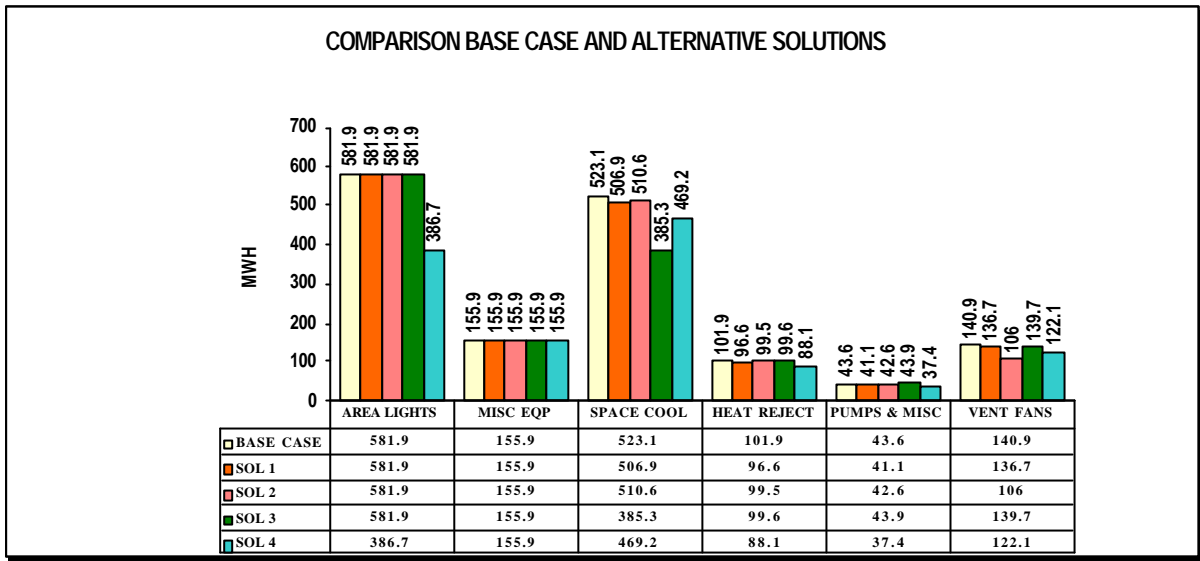


Figure 12. Comparison Base Case and Alternative Solutions

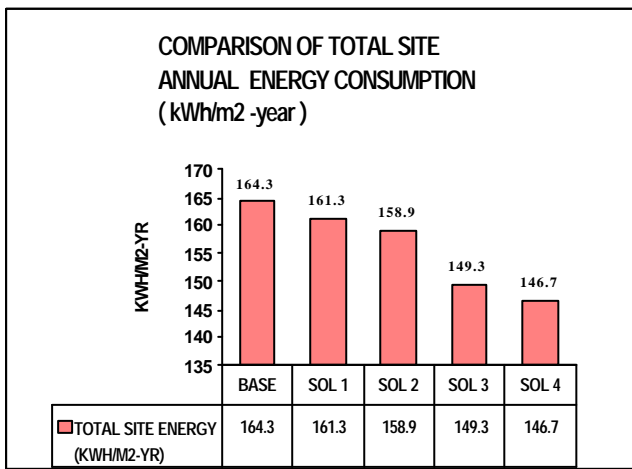
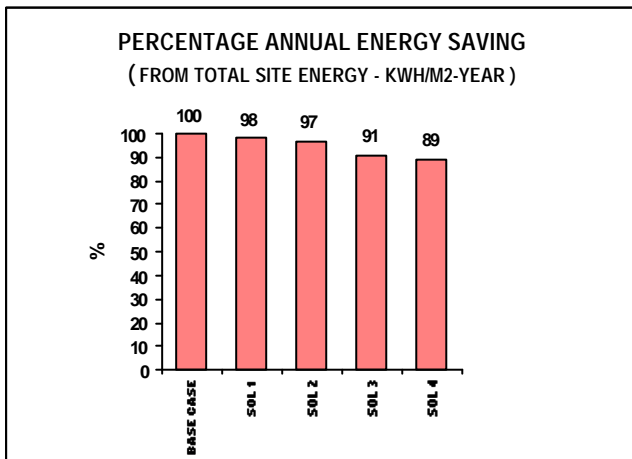


Figure 13. Comparison of Total Site Annual Energy Consumption in kWh/m2-year and in Percentage Annual Energy Saving

ATTACHMENT 2

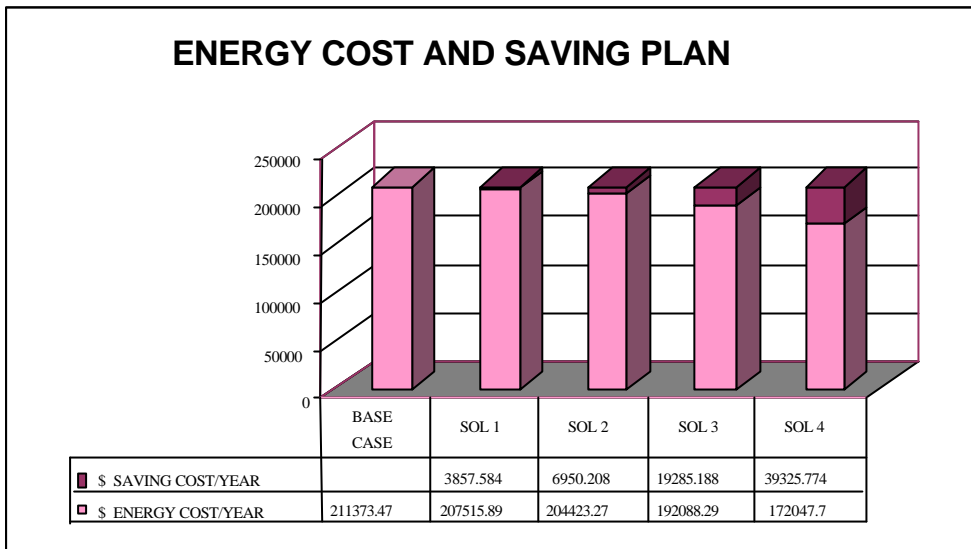


Figure 14. Energy Cost and Saving Plan