4-3. Sea Water Pumped-Storage Power Plant

4-3-1. Special features of pumped-storage power plant

In the case that nuclear and large thermal stations are used as base loads, power demand may drop below the generated base load on weekends and at certain times of day. Energy storage systems will be necessary to permit these stations to continue operating at maximum efficiency. There are several new technologies to improve electricity supply, such as pumped-storage power plants and large battery systems.

The pumped-storage power plant has the following advantages.

- Water pumped up by off-peak demand electricity is used as a source of generation. Therefore, power shifting and/or leveling between off-peak and peak electricity will be carried out.
- Pumped-storage power plants have the most favorable technologies to store a large quantity of energy.
- The quick start/stop operation of the turbine can enable a quick response to a sudden load change.
- Good quality electricity will be supplied by the availability of automatic frequency control.

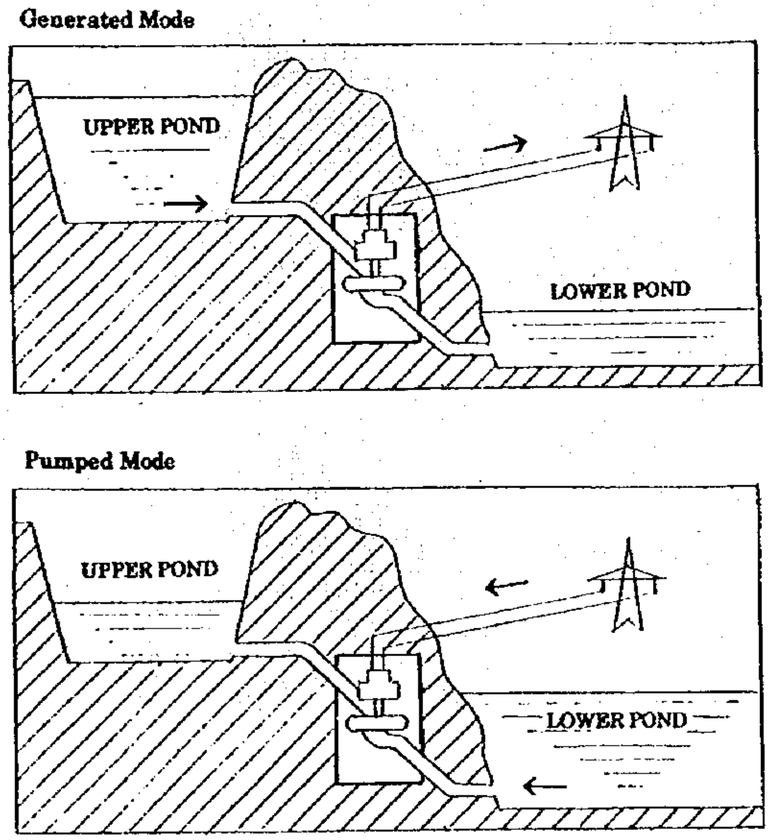


Figure 4-3-1 Concept of Pumped-storage Power Plant

In Oman, there is a variation between off-peak and peak power demand because of an increase in the use of air conditioning systems in the summer time. It may be possible to mitigate the increase of peak power demand by using this technology. It is impossible to use fresh water for the pumped-storage plant because of the lack of constant river flow in Oman; however, an investigation will be carried out on the possibilities of installing a sea water pumped-storage plant.

The sea water pumped-storage plant has the advantage of eliminating the lower reservoir. However, special considerations will be required for the selection of materials which are compatible with sea water, the countermeasures to cope with permeation and pollution caused by the sea water from the upper pond, and the environmental impacts. In Okinawa Prefecture of Japan, a 30MW demonstration plant with entrustment by the Ministry of International Trade and Industry will be completed in 1999, and will carry out test operations for 5 years after the completion.

Figure 4-3-2 Sea Water Pumped Storage Power Station
(30MW, Okinawa, Japan)

4-3-2. Site selection for the sea water pumped- storage power plant

(1) Conditions of a suitable site

The following three conditions are essential for the construction of economical pumped-storage power plant.

①Place

The following factors will be considered for the selection.
Where,
L : Horizontal length of waterway from intake to tailrace
H : Difference of elevation between the sea and the upper pond
From experience, a promising site is where the L/H is 4 to 6 and H is 400m or more.

②Geology

Locations with the following characteristics are not suitable for the construction site.
Excess folds and large faults
Sandy and/or gravely area
Environmentally important

③Transmission and capacity

From the viewpoint of economic efficiency, it is desirable that the pumped-storage power plant be close to the load center, as well as near to transmission lines which have the capacity needed for sending and receiving power. A location near the load center saves the construction cost of transmission line and decreases line loss.

(2)Study by topographic map

A topographic map of a scale of 1:20,000 is used for the study, however, there are no suitable sites which satisfy the above three conditions. A site of upper pond with an approximate height of 280m is observed 3km from the Qantab beach (See Figure 4-3-3).

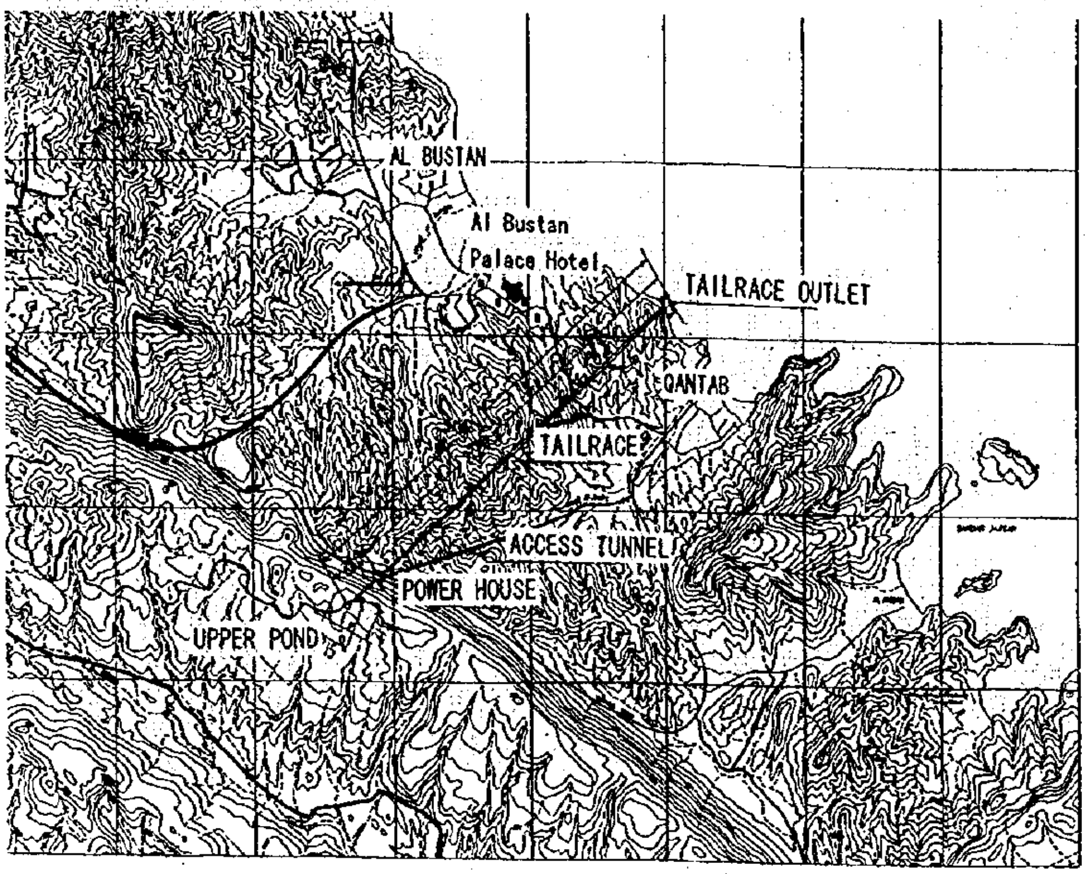


Figure 4-3-3 Potential Location of Pumped-storage Power Plant

(3) Geological analysis

The following issues are observed by the study of geological map of 1:100,000 scale (See Annex:4-3-a). The upper pond area mainly consists of dolomite and limestone. The areas around the tailrace tunnel, the underground power station and penstock mainly of harzburgite, and very complicated folds and large faults are found. Therefore, there may occur some difficulties for the construction of the underground structures.

(4) Site reconnaissance

The following results are confirmed by the site reconnaissance.

Upper pond

It is confirmed that the selected area in the topographic map study is suitable for the construction of the upper pond. A 33kV transmission line is located near the site and electricity for construction use is available. An unpaved access road to the site will be available after repairs are made.

Tailrace outlet

Sand and gravel are deposited around the Qantab area. To avoid excessive corrosion by sand, it is recommended to shift the tailrace outlet to the Al Bustan side.

Underground powerhouse and access tunnel

The existing road along Wadi Al Jirahy will be repaired and a new extended access road will be constructed.

Geology

The area of the tailrace tunnel and the underground power station consist of igneous rock and sedimentary rock. Very complicated folds and large faults are confirmed.

132kV transmission line and a suitable site for the pumped-storage power plant

The Muscat line and Wadi Jizzi line are 132kV transmission lines. These two lines will be connected in the future. The Muscat line is available for a 100MW pumped-storage power plant, considering the line capacity at present.

(5) Tidal fluctuation

The turbine center will be determined by the minimum sea level. The tidal levels of the Muscat area are as follows, from a report by of Maritime Safety Agency of Japan (Volume 2, The Pacific Ocean and Indian Ocean, 1994).

Sp. R : 2.7m
Np. R : 2.3m
M.S.L : 1.85m

The maximum tidal fluctuation is presumed to be less than 2m.

Note :
Sp. R(Spring Rise : Mean height of high water above datum level at spring time
Np.R (Neap Rise) : Mean height of high water above datum level at neat time
M.S.L : Mean sea level

4-3-3. Problems confirmed by site reconnaissance

(1)Distance from seashore to upper pond

The distance from the seashore to the upper pond is approx. 3km, and there are the following problems.

①L/H calculated by the formula stated in item 4-3-2 (2) is 3,000/280 = 10.7, and this site is not recommended as an economic site. The tailrace tunnel is long, and the civil cost is high.
②The hydraulic loss will be increased by the long tailrace tunnel , and the gross efficiency of the pumped-storage power plant will decrease.
③The following problems will occur as a result of the 3km long tailrace tunnel.
- Water separation phenomena will occur at load shedding. A surge tank will be necessary.
- The draft head is high compared with a normal pumped-storage power plant.

Therefore, the hydraulic model test is required before the detail design.

(2)Geology

The tailrace tunnel and the underground power station are in an area of very complicated folds and large faults. Detail surveys, including the boring etc., will be required before the detail design can be completed.

(3)132kV transmission line and site

The Muscat line is available for only a 100MW pumped-storage power plant, considering the line capacity. Therefore, a suitable site is limited at present.

(4) Environmental issues

For the environmental issues, the approval of environmental assessments at each stage shall be obtained according to the regulations of the Ministry of Regional Municipalities and Environment. The biggest problem is predicted to be the impact on the marine environment. The area of the tailrace outlet is rich with corral reefs and is a very beautiful environmental conservation area. It is also one of the centers of sightseeing and marine sports in Oman. Furthermore, Al Bustan Hotel is located at about 1km far from the tailrace outlet.

Following also are essential items. ･

- Impacts on and/or pollution of the sea coast caused by the intake and discharge of sea water through the operation of pump-turbine
- Impacts on and/or pollution caused by the leakage of sea water, and dispersion due to wind from the upper pond
- The dumping ground for the rock and gravel, due to the excavation of the underground powerhouse, tailrace tunnel, penstock, access tunnel and others locations.
- The influences caused by the excavation and the transportation of the rock, sand etc.

4-3-4. Outline of pumped-storage power plant

(1) Capacity

By the survey of the power demand and the system in Oman, the capacity of pumped-storage power plant is determined to be 100,000kW, and the operating time is 3 hours.

(2) Upper pond

- Effective storage capacity: 0.49 x $10^6 m^3$
- High water level: 285m
- Low water level: 265m

(3) Penstock

- Mean inside diameter : 3.0m
- Mean velocity : 6.2m/s

(4)Tailrace tunnel

- Mean inside diameter : 3.6m
- Mean velocity : 4.3m/s

(5)Specification of equipment

①Unit : 1

②Pump-turbine

• Specifications of turbine

	Maximum effective head	Mean effective head	Minimum effective head
Output (kW)	103,000	103,000	93,300
Head (m)	269	260	247
Discharge(m^3/s)	42.1	43.8	42
Speed (rpm)	428.5	428.5	428.5

• Specifications of pump

Output (kW)	97,800	101,900	108,100
Head (m)	295	289	277
Discharge(m^3/s)	30.9	33.0	36.7
Speed (rpm)	428.5	428.5	428.5

• Runaway speed : 640 rpm
• Runner diameter : 3,250mm
• Draft head : −40m

③Generator-motor

	Generator specification	Motor specification	Driving motor specification
Output (kVA)	112,000	112,000	8,000
Power factor	0.9	1.0	1.0
Voltage (kV)	13.8	13.8	6.6
Speed (rpm)	428.5	428.5	500
Frequency(Hz)	50	50	50

④Pump starting method

There are several starting methods, such as the motor damper starting method, the synchronous starting method, the direct-coupled motor starting method and thyristor starting method. The direct-coupled motor starting method is recommended after considering the number of units, the capacity and the stability of the transmission line.

(6) Gross efficiency of the pumped storage plant

Gross efficiency of the pumped-storage plant is calculated by considering the efficiency of the equipment, hydraulic loss and transmission line loss.

Table 4-3-1 Gross Efficiency of the Pumped-Storage Power Plant

Pumping operation	Efficiency	Generating operation	Efficiency
Pump	0.916	Turbine	0.924
Motor	0.973	Generator	0.971
Main transformer	0.99	Main transformer	0.99
House use	0.97	House use	0.97
Hydraulic loss	0.93	Hydraulic loss	0.93
Transmission loss	0.997	Transmission loss	0.997
Total efficiency of pumping	0.7935	Total efficiency of generating	0.7988

Gross efficiency of the pumped storage plant = Total efficiency of pumping
x Total efficiency of generating
=0.7935 x 0.7988 = 0.6338
=63%

This gross efficiency is lower 10% than 70% of a conventional pumped-storage plant due to the long tailrace tunnel.

(7) Special conditions for the sea water pumped-storage plant

Many considerations are required to plan the sea water pumped-storage power plant, compared to the conventional pumped-storage power plant.
The main items are as follows.

①Environmental issues are essential (Refer to item 4-3-3-(4)).
②The upper pond is of a fill dam type, and an ethylene propylene monomer rubber sheet will be adopted for the lining of the upper pond.
③If damage to the rubber sheet occurs, a sea water leakage will be detected by a sea water sensor and pressure gauges. Leaked water will be recharged to the upper pond by the pump.
④Special materials and/or protection will be adopted for the structures and parts that contact sea water.
⑤The enclosed type cooling system for the pump-turbine, the generator-motor and the main transformer will be adopted, and the heat exchanger of pure water/sea water will be used to discharge the heat of equipment.

4-3-5. Cost estimate and economic analysis

(1)The premise of cost estimate and economic analysis

A sea water pumped-storage plant in Okinawa will be completed in 1999. Test operations will be carried out for 5 years after the completion, in order to survey the various problems resulting from sea water. The collected data and experiences will be reflected in the specifications and the cost.
The reasonable cost will not be fixed at this stage. Therefore, the following premise will be applied.

- Cost will be estimated based on the most economical construction period and the technical specifications.
- Normal geological conditions and procedures will be applied.

・The costs of land, compensations, taxes are not included.

(2)Cost estimate

The construction cost is estimated as follows.

	Unit: RO
①Preparatory work (5% of Civil works)	2,758,000
②Environmental mitigation cost (5% of Civil works)	2,758,000
③Civil works	55,150,000
・Upper pond, intake and excavation of penstock	
・Powerhouse(including the foundation of equipment)	
・Tailrace tunnel, surge tank and tailrace outlet	
・Foundation of substation	
・Access tunnel	
④Hydraulic equipment (Penstock, gates, screen, etc.)	4,390,000
⑤Electro-mechanical equipment	23,310,000
⑥132kV transmission line	1,234,000
Sub-total	89,600,000
⑦Administration costs and engineering costs(15% of Sub-total)	13,440,000
⑧Contingency (10% of Sub-total)	8,960,000
Grand total	112,000,000

The environmental mitigation cost is estimated to be 5% of civil works.

(3) Financial analysis

①Indices of financial analysis

Financial analysis is measured on the basis of the NPV (Net Present Value), based on the quantification of benefits derived from the project, and the costs to build and run the plant. In this case, the cost and the benefits are calculated as follows;-

Cost = Construction cost of the pumped storage plant + replacement cost + operation & maintenance cost + pumping energy cost

Benefit = Construction cost of the alternative gas turbine plant + replacement cost + operation & maintenance cost + fuel cost

②Alternative gas turbine plant to be compared

a.The installed capacity of the alternative gas turbine plant will be calculated by the following formula.

Pg = Pp x kW adjusting factor x (1−H4)/(1-T4)

In the above equations;

Pg: Installed capacity of the alternative gas turbine plant

Pp: Output of the pumped storage plant

kW adjustment factor = (1−H1)x(1−H2)x(1−H3)/(1−T1)x(1−T2)x(1−T3)

H 1, T 1 : Rate of station use (%) of the pumped storage plant or the gas turbine plant

H 2, T 2 : Outage rate (%) of the pumped storage plant or the gas turbine plant

H 3, T 3 : Scheduled outage rate (%) of the pumped storage plant or the gas turbine plant

H4 : Rate of transmission loss from the pumped storage plant to the power center

T4 : Rate of transmission loss from the alternative gas turbine plant to the power center

b.Calculation of the kW adjustment factor will be as follows;

Table 4-3-2 Adjustment factor

Items	Pumped storage plant	Gas turbine plant
Rate of station use (%)	0.3	1.7(*)
Outage rate(%)	0.5	0.07(*)
Scheduled outage rate (%)	4.0	9.95(*)
Rate of transmission loss(%)	0.3	0

(*): based on the Rusail power plant in 1997

kW adjustment factor = (1−H1)x(1−H2)x(1−H3)／(1−T1)x(1−T2)x(1−T3)
= (1−0.003)x(1−0.005)x(1-0.04)／(1−0.017)
x (1−0.0007)x (1-0.0995)
=0.9523／0.8845 = 1.0766

c.Calculation of the capacity of the alternative gas turbine plant (Pg)

Pg = Pp x kW adjusting factor x (1-H4)x (1-T4)
= 100,000kW x 1.0766x (1-0.003)= 107,340kW

d.Construction cost of the alternative gas turbine plant

Construction cost = 107,340kW x Unit cost of alternative gas turbine

The unit cost of gas turbine is assumed from the recent tender data.

Construction cost of the alternative gas turbine plant
= 107,340kW x160RO／kW=17,200,000 RO

③Other data necessary for financial analysis

a. Fuel cost of the gas turbine plant for one year's operation of 100 days and 3 hours per day

Unit fuel cost = 6.979 RO／MWH (based on the Rusail power plant in 1997)
Total fuel cost for one year of operation
= 6.979 RO／MWH x 107.34MW／h x 100 days x 3 hours／day
= 225,000 RO

b. Pumping energy cost for one year of operation, 100 days and 3 hours per day
Unit pumping energy cost = Electricity cost of the gas turbine plan at Rusail／Gross efficiency of the pumped storage plant
= 10.163／0.63= 16.13 RO／MWH

c. Total pumping energy cost for one year of operation
= 16.13 RO／MWH x 100 MW／h x 100 days x 3 hours／day
= 484,000 RO

d. Operation & maintenance cost(%) for the construction cost

Table 4-3-3 Operation and maintenance cost

Item	Pumped storage plant	Gas turbine power plant
Operation & maintenance cost(%)	3.0	3.0

Concerning sea-water pumped-storage power plant, the complete overhaul for the pump- turbine, the generator-motor and the inlet valve etc will be carried out in every 8 years, and necessary replacements including the runner and the parts to contact sea-water etc will be carried out (3,048,000RO).

e. Life year

Hydraulic equipment and electro-mechanical equipment	25 years
Transmission line	60 years
Civil structures	50 years

(5) Conclusions

As shown in Table 4-3-4, NPV is negative and the value of B/C is only 0.169. There are no advantages to construct the pumped-storage power plant in Oman. (See Annex 3-3-o)

Table 4-3-4 Comparison of NPV

Unit: 1000RO

Cost (NPV) (Sea water pumped-storage plant)	Benefit (NPV) (Gas turbine plant)	NPV (B-C)	B/C
141,761	23,929	-117,832	0.169

The main reasons for this result are as follows:

①The cost of pumped-storage power plant will be generally compared with nuclear power plants or large steam turbine plants. However, low price gas turbine plants were adopted for comparison in this case.
②There is not a suitable place to construct the plant.
③The tailrace tunnel is long, and the civil cost is high.
④The fuel cost is low.
⑤Special materials and/or protection will be required for the equipment and structures that contact sea water, therefore the cost is high.

4-4. Battery Energy Storage

4-4-1. Battery Energy Storage System and Basic Configuration

The battery energy storage system stores electric power and supplies it when necessary. The following are considered its main functions.

(1)Daily load leveling
(2)Alternative spinning reserve of conventional power supply facilities.

In Oman, load leveling(1) is not attractive, for power generation costs are not expensive and there is no big difference between peak and off-peak time. On the other hand, the efficiency of gas turbines is low, because they are operated at partial loads to secure reserve capacity. This margin is a spinning reserve. From this, it seems possible to improve operating efficiency and increase gas turbine output if an alternative spinning reserve of battery energy storage is applied. In addition, this system is effective in voltage recovery for the Oman power system. From this point of view, the battery energy storage system is studied in this chapter.

Batteries are charged by direct current, and they discharge direct current. When batteries are used as an electric energy storage system, and the system is interconnected with a power system, direct current is converted into alternating current for use. The basic configuration of the battery energy storage system is shown in Figure. 4-4-1.

Interconnection uses a two-way power conversion device. A.C. power is converted into D.C. power to charge batteries. D.C. power stored in the batteries is converted into A.C. power and discharged into the power system. Thus, the configuration is relatively simple. Depending on the kind of batteries in use, the components of the system, such as battery modules and power conversion devices, can be packed in separate cubicles. This has merits such that transportation of the system from the manufacturing plant is easy, and that outdoor type cubicles can be installed without using a building.

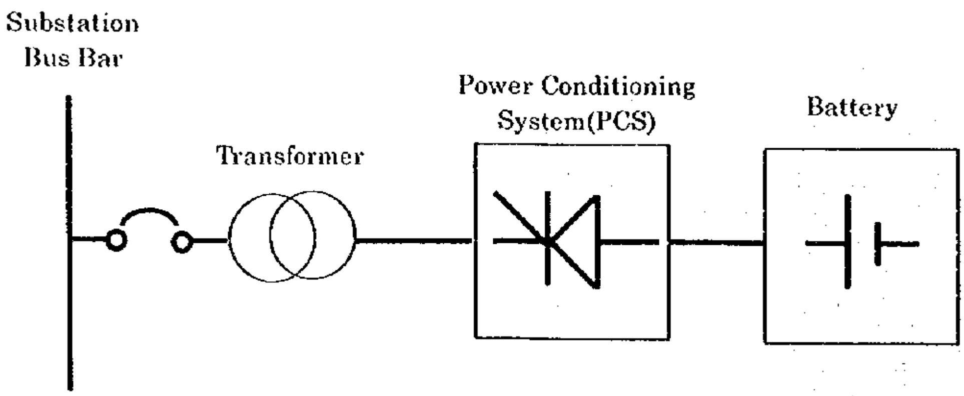


Figure 4-4-1　Outline of System Configuration

4-4-2. Examples of Battery Energy Storage Systems

Major examples of electric energy storage systems that were operated or investigated up to the present are summarized in Table 4-4-1. Of these systems, the system of Puerto Rico provides a spinning reserve of about 400 MW if the 2,300 MW power system fails. This is intended to avoid low load operation of existing plants, raise the operating efficiency and economize fuel expenses. This approach is also applicable to the power system of Oman. The system may be introduced to improve the operating efficiency of gas turbines.

Moreover, a battery system for spinning reserve is expected to have low construction costs per kW. It is designed in such a way that the discharge time is short, in other words, the capacity of batteries (kWh) is small, but a certain level of output (kW) is provided. Among the systems in the table, Chino and Puerto Rico plants are operating practically. The system in Berlin was also operated practically, but battery life has expired. Since then, the system has been used for new battery test operations. All of the examples in Japan are under research or demonstration tests(TEPCO,NGK), and their construction costs are too expensive for an economic estimation.

Table 4-4-1 System Examples of Battery Energy Storage System

Name	Capacity	Battery Type	Schedule	Objective For This Study
SCE Chino SS (USA)	10MW/40MWh Load Levering	Lead Acid	1988 Test Start 1991 Operation Start	Installation at Primary Substation
BEWAG(Berlin) (Germany)	17MW/14.4MWh Frequency Control, Spinning Reserve	Lead Acid	1987 Operation Start 1992 Disuse	
Puerto Rico (USA)	20MW/14.1MWh Frequency Control, Spinning Reserve	Lead Acid	1992 Construction Start 1995 Commissioning Test Finish	
NEDO (Japan)	1MW/4MWh	Lead Acid	1986 Operation Start 1993 End of Operation	Research
Research (Japan)	30kW	Lead Acid	Under Researching	Research
TEPCO, NGK (Japan)	6MW(2MWx3) 48MWh	Sodium-Sulfur	1997 Operation Start	Installation at Distribution Substation

Name	Construction Cost (US$/kW)	Site Area (m²)	Others
SCE Chino SS (USA)		4645	DC:2000V
BEWAG(Berlin) (Germany)	833 (23 MDM) · Battery : 30% · PCS : 30% · Computer : 10% · Building etc. : 30%		Connection : 30kV DC:1200V AC: Step Up Transformer (1.4/30kV)
Puerto Rico (USA)	1000 (20M$) · Battery : 25% · PCS : 28% · Computer : 7% · Building etc. : 40%	Total : 1368 Battery : 864 (2 layer) PCS : 216 Others : 288	Connection : 13.2kV DC: 2000V AC: Step Up Transformer Battery Life : 10years Plant Life : 30years
NEDO (Japan)	9333 · Battery : 58% · PCS : 33% · Building : 9%	Total : 797 Battery : 240	Connection : 6.6kV DC: 1095V
Research (Japan)	2333 · Battery : 70%(4h)		
TEPCO, NGK (Japan)	12500	600 (20mx30m)	Connection : 6.6kV DC: 922V AC: 440V/6.6kV Battery Life: 15years

-Exchange Rate: 120Y/US$, 0.381RO/US$

-PCS: Power Conditioning System

4-4-3. Cost Estimate and Economic Analysis

(1) Rough Assessment of Merits of Installing Battery Energy Storage System in Oman

①Substitution of reserve power

The battery energy storage system can be substituted for the spinning reserve power of gas turbines, the generating efficiency of gas turbines can be improved and, as a result, fuel cost will be saved. The fuel saving of the Muscat system in case of using batteries was calculated as follows by the computer program (Refer to Chapter 9), which shows the most economical operations.

Power Supply	Fuel Cost per day
Economical operation with a spinning reserve by gas turbine (94MW) (1) a.1-8-1997 b.1-5-1997	 103,598 RO/d 68,039 RO/d
Economical operation with a spinning reserve by battery (100MW) (2) a.1-8-1997 b.1-5-1997	 98,540 RO/d 64,706 RO/d
Fuel saving [(1)-(2)] a.1-8-1997 b.1-5-1997 Average	 5,058 RO/d 3,333 RO/d 4,196 RO/d→1.5 M RO/y

Consequently, the spinning reserve by battery energy storage will save fuel costs by 1.5 million RO in a year. The concepts of improving gas turbine load factors are shown in Figure 4-4-2.

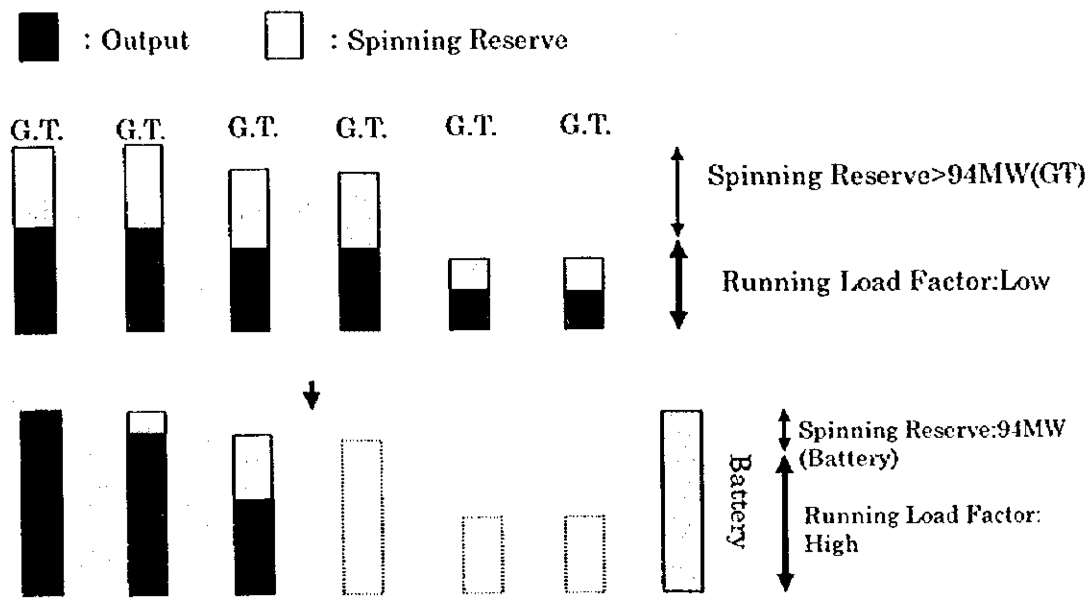


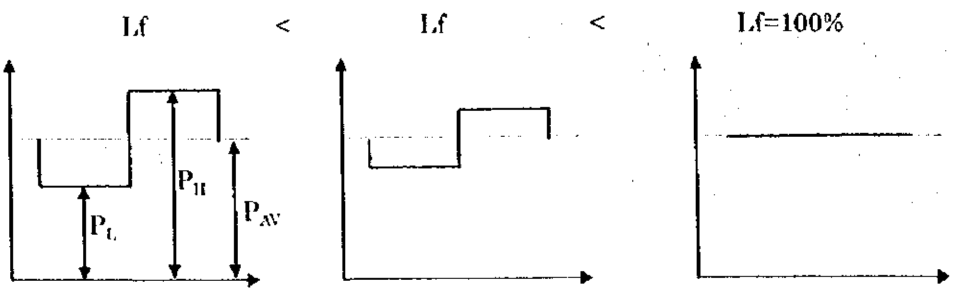
Fig.4-4-2 Concept of Using Battery as Spinning Reserve

②Voltage stabilization

It is possible to install a battery energy storage system at a substation where a large voltage drop takes place. The system is used as a source of reactive power to improve the voltage stability.

③Load leveling

Improvement in gas turbine load factors through load leveling reduces fuel expenses due to improvement in generating efficiencies.



Lf(Load Factor)= P_{AV}/P_H
RLf(Running Load Factor)= P_{AV}/P_{100}(P_{100}:Rated Output)

Figure 4-4-3 Load Leveling Model

- On the basis of the simple model shown above (Figure 4-4-3), the running load factors of gas turbines and load factors representing load fluctuations are changed. Consider the corresponding change in generating efficiency.

- When the running load factor is 50 % (average output) and the load factor is improved from 55 % to 70 %, the generating efficiency of gas turbines will improve by a relative value of 25%. (See Annex 4-2-a)

  (Additive explanation)
  Assumption: load factor 55 %; maximum output 90%, minimum output 10%
  Generating efficiency = [0.97(at 90%)+0.33(at 10%)]/2=0.65
  Assumption: load factor 70 %; maximum output 70%, minimum output 30%
  Generating efficiency = [0.93(at 70%)+0.33(at 30%)]/2=0.80
  Improvement of generating efficiency: (0.80-0.65)/0.65=0.23≒25%

- In other words, one point improvement in load factor (@ running load factor: 50 %) is expected to improve the generating efficiency by a relative value of 1.7% (25%/(70-55)%). With regard to the fuel expenses of the Muscat system, annual fuel expenses are 24 million RO. Hence, one point improvement in load factor will reduce fuel expenses by about 0.41 million RO.

- The Muscat system, with a load of about 1,000 MW at peak time, will have 100MW for four hours with an annual operating ratio of 1/3 if a battery energy storage system is operated. Its improvement in load factor is about one point, on the basis of the above-mentioned model.
  (Peak output cutting ratio: 100,000 kW/1 million kW × 4 hour/12 hour × 1/3 [annual operating ratio] ≒ about 1 %.) When charge and discharge efficiencies of the batteries, about 70 %, are taken into consideration, the merit will be reduced further.

- In Oman, power sources are inexpensive gas turbines. The generating costs at the peak and at the bottom do not differ much. This discourages a big investment for daily load leveling. The same conclusion was drawn for the pumped storage plant. Battery energy storage system is not competitive as a means of daily load leveling, with the storage duration of 4 to 8 hours, because the price per unit output (RO/kW) is too high.

④Deferral of construction of transmission lines

Construction of transmission lines from a power station to substations can be postponed, and costs can be reduced.

- As for the Muscat system, the distance between the power sources and the substations are as short as about 10 km, and the costs of expansion of transmission lines are relatively low. Hence the merit of this deferral of construction of transmission lines is small.

⑤Reducing losses of transmission lines and transformers

By installation of a Battery Energy Storage system on the secondary side of a substation, peak power is reduced and the loss also decreases.

- On the basis of the examination mentioned above, it seems advantageous to avoid measures aiming at load leveling. This reduction of losses is also omitted from consideration.

The above results are outlined in Table 4-4-2.

Table 4-4-2 Battery Storage Assessment

Studying items	Summary	Assessment
a. Improving operation efficiency of gas turbine, and fuel conservation by using as spinning reserve.	• Saving about 10 order of million US$ a year by relative value of 20% increasing of operation efficiency.	• Most promising.
b. Stabilization of Voltage.	• Installation, at the low voltage point, is effective.	• Promising.
c. Improving operation efficiency of gas turbine, and fuel conservation by load leveling.	• Saving about 1 million US$ a year by 1% up of load factor on Muscat power system. • Maximum 1% increase of load factor.	• Less effective, and severe operation for battery system.
d. Deferral of transmission line construction.	• Less effective, because of short transmission line between PS and SS.	• Less effective.
e. Loss reduction on transmission line and transformer.	• Peak load, save through transmission line or transformer, reduction effect is limited.	• Less effective.

(2) Financial Evaluation

①Conditions assumed in calculation and assessment

The conditions assumed in cost calculation and financial assessment, such as construction costs of Battery Energy Storage system and gas turbine, maintenance cost (rate) and interest rate, are indicated in a summary form (Table 4-4-3).These values are determined by referring with the above-mentioned examples of systems.

Table 4-4-3 Basic Conditions for Calculation and Assessment.

Items	Value
Discount Rate	0.08
Exchange Rate	130¥/US$, RO 0.388/US$
Construction Cost	
・ Gas Turbine	160 RO/kW
・ Battery Energy Storage System	366 RO/kW
Battery (life 10 years)	110 RO/kW
Auxiliary equipment (life 30 years)	256 RO/kW
Operation and Maintenance Cost Rate	
・ Gas Turbine	3 %
・ Battery Energy Storage System	1 %
Calculation period	1998 to 2018

②Assessment

As a result of the examination mentioned in (1) above, it is most effective in Oman to use Battery Energy Storage systems as a substitute of reserve power.

First, we assume the construction of battery storage systems of 100 MW, being equivalent to the maximum capacity of largest gas turbine, during the period from 1998 to 2018 as shown in Table 4-4-4.

The fuel saving effect with the installation of 100 MW of batteries is assumed to be 1.5 million RO/year. Furthermore, one gas turbine construction can be avoided as the merit. As shown in Table 4-4-5, the investment for a battery energy storage system is not effective now and installation of this system is not reasonable. (See Annex 3-3-p)

Table 4-4-4 Case Study of Battery Development

Year	Case Study (MW)	
	Gen.	BES
1998	- 94	100
After 1999		
Until 2018		
Total	- 94	100

Table 4-4-5 Comparison of Cost and Merit

Items		Present Value: ($RO10^6$)
Plan with Battery System	Avoid of gas turbine	17.9
	Construction of Battery System etc.	-45.6
	Fuel saving	14.7
NPV		-13.0

4-4-4. Conceptual Design Focused on Muscat System

(1) Installation sites

Battery Energy Storage systems are suited to dispersed installation in substations. It is better to install battery storage systems in major substations as shown in Figure 4-4-4. A total of100 MW battery storage systems are locally installed 20 MW each. In this way, a large space is not required. The storage systems are also expected to work as reactive power sources for voltage compensation and voltage stability.

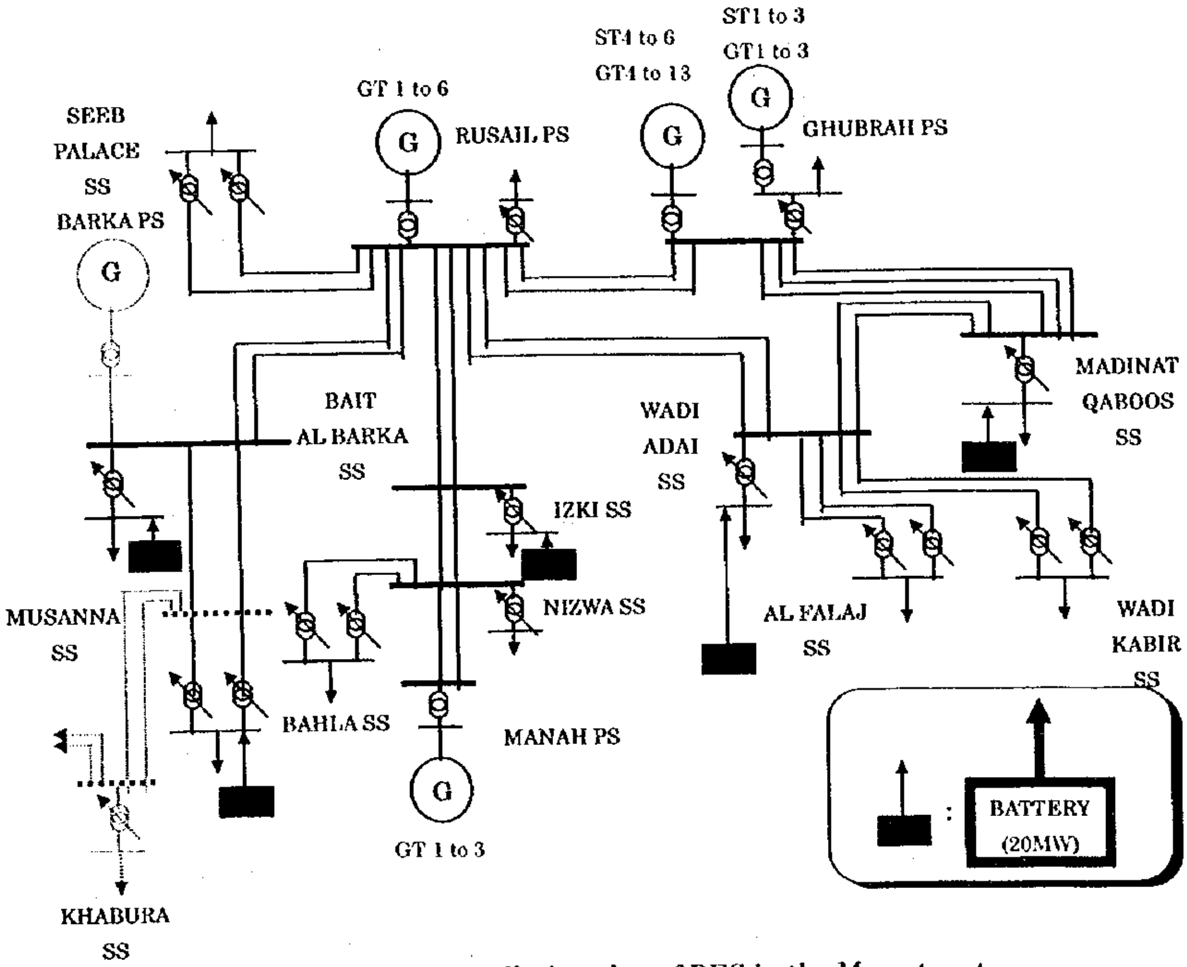


Figure 4-4-4 Installation plan of BES in the Muscat system.

(2) Example of Installation of a Battery Energy Storage system at a substation

The example of Puerto Rico was used as a model. The configuration of a battery storage system when it is installed in Madinat Quaboos substation is shown in Figure.4-4-5. According to the actual records at the peak load in August 1997, the load flowing from the 132kV bus to the 33 kV bus is about 140 MW. Then 20 MW of batteries can bear 14 % of the load, equivalent to 3 feeders of 33 kV (20 feeders). When a battery electric energy storage system is to be installed on a 33 kV bus of a primary substation, its required capacity is 23 MV. On the other hand, when a battery electric energy storage system is to be installed on a 11 kV bus of a distribution substation, its required capacity is 2.8 MW.

The space required for a battery storage system is about 1,500 m^2 in the case of Puerto Rico, and an equivalent land space is available next to Madinat Quaboos substation. On the basis of our findings from the field survey, spaces for battery storage systems are judged to pose no problems to any substations.

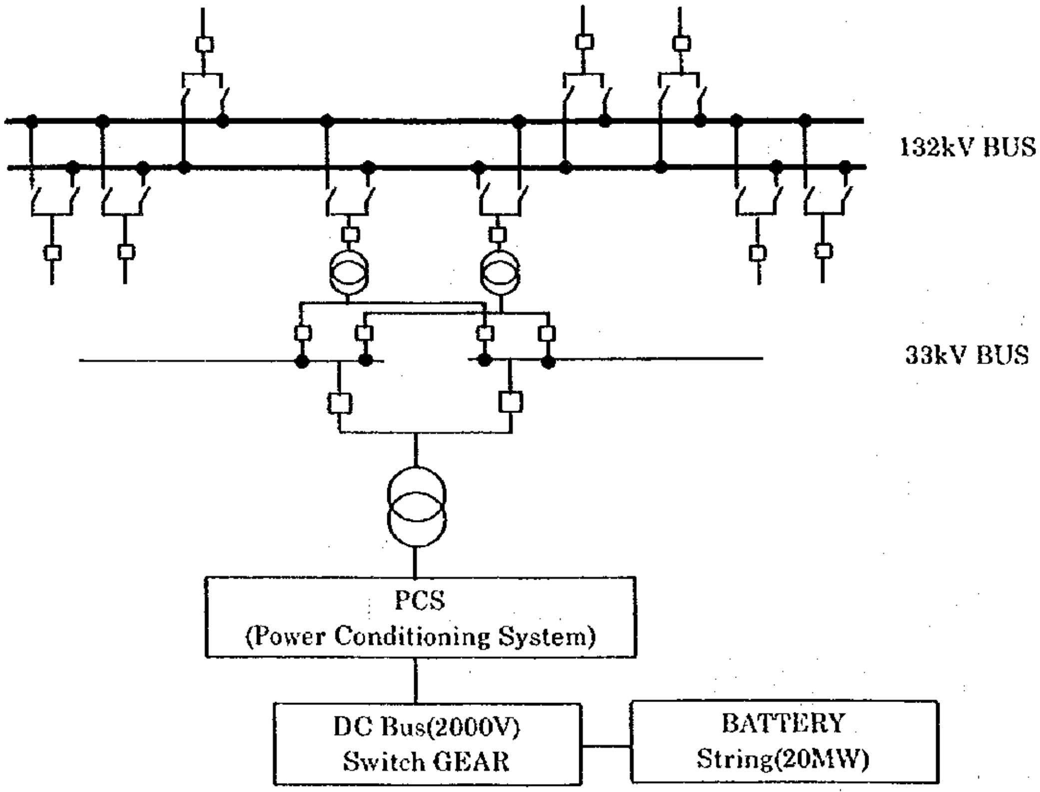


Figure 4-4-5 Installation Example (Madinat Qaboos SS)

4-4-5. Use of Battery Energy Storage System for Voltage Stabilization

In this case, the use of the battery energy storage system is almost the same as a stability condenser in the electric power system. The battery energy storage system is able to be substituted for some parts of stability condenser and, at the same time, has role of emergency power supply source while load is large. Here, the study result of keeping voltage is shown in Table 4-4-6 and Figure 4-4-6.

Table 4-4-6 Voltage Keeping by Battery System

SS, PS	No Measure	Measure	Battery(MVA)	SC(MVA)	Total
RUSAIL	0.952	0.977			
RUSAIL G	1.02	1.02			
WADI ADAI	0.917	0.955			
BARKA	0.909	0.968	20	20	40
SEEB 1	0.925	0.952			
GHUBRAH	0.953	0.974			
GHUB 13G	1.005	1.005			
MADINAT	0.937	0.964			
AL FALAJ 1	0.915	0.954	20	40	60
WADI KABIR	0.907	0.953	20	50	70
MUSANNAH 1	0.848	0.956	20	50	70
IZKI	0.953	0.969			
NIZWA	0.955	0.969			
MANAH	0.963	0.975			
MANAH G	1.025	1.025			
BAHLA 1	0.945	0.959			
KHABURA	1.008	1.008			

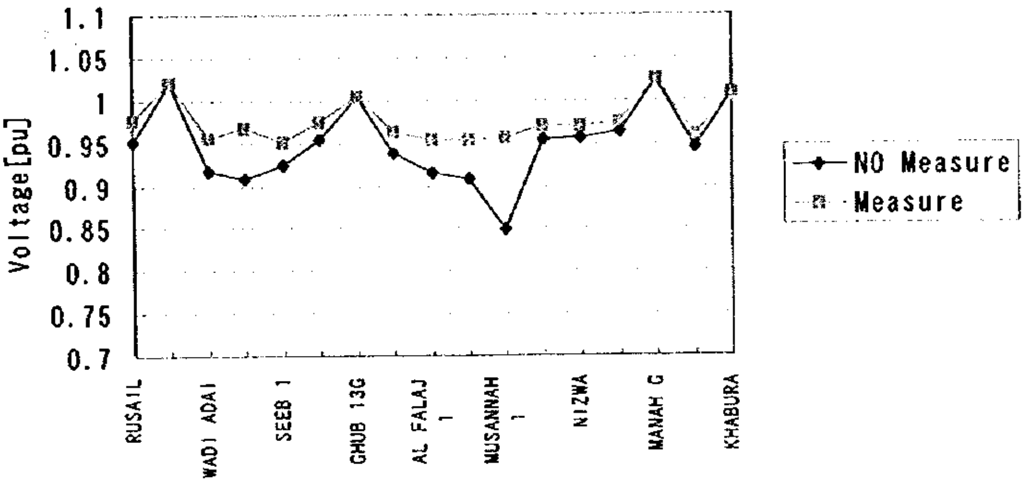


Figure 4-4-6 Effectiveness of voltage keeping

4-4-6. Proposal for the Master Plan

Considering the above result, a plan on Battery Energy Storage is proposed as follows.

Some problems against the installation:

- No merit can be expected at present, even though fuel savings are expected, to use BES as an alternative spinning reserve of gas turbines.
- Little installation results exist and reliability, concerning battery life, is not confirmed.

However, some advantages are also expected:

- A battery energy storage system has functions for voltage stabilization as well as emergency power supply source.
- A battery energy storage system is suited to dispersed installation in substations. Furthermore, investment can also be dispersed.
- In the future, improvement of system reliability and cost reductions are expected.

Given all these points, it is proposed to continue studying BES and to install 20MW or 10MW system every year up to the total capacity of 100MW(corresponding to the maximum capacity of gas turbine in Oman) in late years as shown in Table 4-4-7. Here, the construction cost is estimated 70%(256 RO/kW) of the value used in Table 4-4-3, considering cost reduction in the future.

Table 4-4-7 Cost/Merit Calculation

	Period											
Year	1998	...	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
Battery(MW)			10	10	10	10	10	10	20	20		100
G.T.(MW)			-91									

Unit: million RO

Battery Storage System Costs (including M & O)	-7.8
Investment saving of Gas Turbine	6.4
Fuel Saving	1.5
NPV	0.1

Chapter 5

Measures on Demand Side

5. Measures on Demand Side

5-1. Outline of Demand Side Management

5-1-1. Demand Side Management and Its Significance

In Oman, with the electricity demand increase for air conditioning, the electric power systems are experiencing large load fluctuations. This naturally hinders the stable supply of electricity. The deteriorating load factors also make effective operations of power supply facilities difficult. Moreover, with the increasing restraints of environmental issues in the world, it is getting more and more difficult, in some countries, to find suitable sites for power sources and construct power facilities. Oman is not completely free of such conditions. Under such circumstances, increasing attention has been given to the demand side management (DSM). This is a new method of coping with electric power system problems to achieve coordination between suppliers and customers.

In the DSM, electricity suppliers, or government authorities, foster the initiatives of electricity customers to change their patterns of electricity usage to achieve a higher efficiency of electricity supply. Also, environmental considerations are important. For example, emissions of NOx and SOx can be reduced by energy conservation or energy shifting. This is the ultimate objective of DSM. Its concept is shown in Figure 5-1-1.

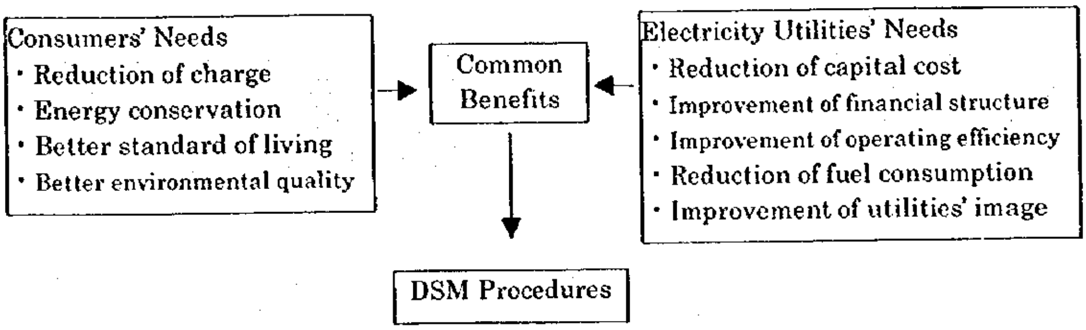


Figure 5-1-1 Concept of DSM

The main measures of DSM include:

- Load management
- Energy conservation
- Public relations activities to promote DSM.

These measures are expected to have the following effects:

- Investment in electric power facilities is reduced, and the electricity charges are lowered.(load leveling, energy conservation)
- Efficiency of operation of power facilities is improved to reduce costs and lower the electricity charges. (load leveling)
- Energy conservation and improvement in the image of the electricity company. (energy conservation)

General effects of these measures are shown in Figure 5-1-2. Load leveling aims to cut down the peak load and/or push up the off-peak load to achieve more efficient operations of power supply facilities with improved load factors, which leads to lower costs. Energy conservation aims to reduce the overall power load to eventually restrain the peak load on the power supply facilities and to reduce inevitable operations at lower efficiencies. This is also effective for coping with global environmental issues and is a timely measure.

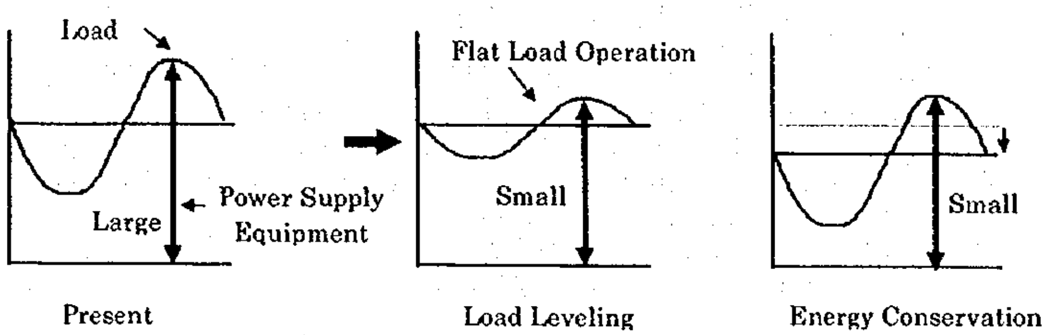


Figure 5-1-2 Concept of DSM Procedures and Effect.

Load management and energy conservation are fundamental ideas. There are many approaches, technical and economical, for actual implementation of DSM. Specific techniques used in DSM are summarized in Table 5-1-1.

Table 5-1-1 DSM and Related Technologies

Installation Place Category		Power Station	Substation	Demand Side (● : Hardware, ◆ : Software)
Load Leveling	Peak Shaving			•Solar Cell •Co-generation •Gas Air Conditioner •Direct Load Control ◆Tariff Structure
	Peak Shift	•Pumped Storage •SMES (＊1) •CAES (＊2)	•Battery •SMES •Flywheel	•Battery •Ice Thermal Storage Air Conditioner ◆Tariff Structure
	Bottom Up			•Electric Water Heater (off-peak time) etc. •Electric Vehicle (charging at off-peak) ◆Tariff Structure
	Others			◆Load Management Contract
Energy Conservation		•High Efficiency Gas Turbine		•High Efficiency Appliances •Thermal insulation •Innovative architectural design ◆Subsidy for Energy Conservation ◆People's awareness
Public Relations				◆Study and Advice for DSM

(*1)Superconducting Magnetic Energy Storage.
(*2)Compressed Air Energy Storage.

5-1-2. Electric Power Systems in Oman and Outline of DSM Measures

(1) Outline of Electric Power Systems and Concept of DSM

On the basis of the findings in Oman and other data, the relationship between the outline of electric power systems in Oman and the present survey may be summarized as shown in Figure 5-1-3. Shadowed items are DSM measures. Of these technologies, some technologies that are considered to be very advantageous to Oman should be examined fully, then efforts should be made to implement them.

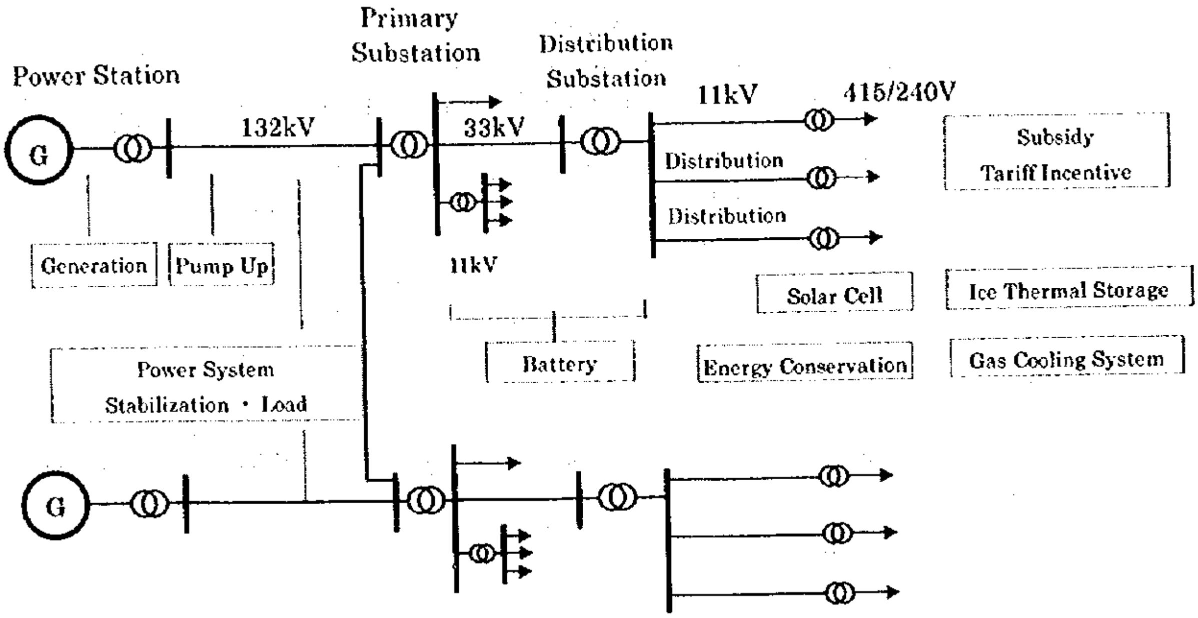


Figure 5-1-3 Power System and DSM Technologies.

(2) Load Management Method

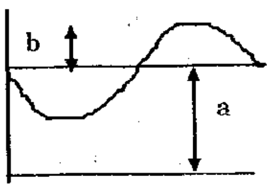
①Diversity of peak load and load leveling

Available data were surveyed to examine load fluctuations of the Muscat power system at primary substations and at distribution substations. The results are shown in Table 5-1-2. (See Annex 5-1-a through 5-1-f, which are based on the actual data at substations) In the load curves of main transmission lines and 33kV bus, two peaks are observed, as described in Chapter 2. In the load curves of 33 kV and 11kV feeders, the timings when peak loads are observed are different. This difference is large at the end of load. Therefore, the peak-shift at this end may not be effective because that does not necessarily contribute to overall load leveling.

The fluctuation(9MVA) of an 11 kV feeder multiplied by the average number (10) of feeders connected to the 11 kV bus is greater than the fluctuation of the 11 kV bus (2.8 MVA). Hence, there is a diversity of peak times for maximum demands among respective 11 kV feeders. Accordingly, at the far end of the load, peak cutting with fuel switching (including solar cells as long as they are cost effective) rather than peak shifting seems to be more effective. Here, it is assumed that battery energy storage systems are installed in substations and used for load leveling. Load fluctuations at the respective levels of substations and feeders are shown.

Table 5-1-2 Load Fluctuations in Oman

Items	Average Load(a)	Fluctuation(b)
Primary SS 33kV Bus (132/33kV Trans. Load)	132 MVA	23 MVA
Distribution SS 11kV Bus (33kVFeederLoad)	8.0 MW	2.8 MW
Distribution 11kV Feeder (Load)	3.2 MVA	0.9 MVA



Calculation method

- Primary SS 33kV Bus (Annex 5-1-b)
  Average Load: Average load for one day at Madinat Quaboos SS.
  Fluctuation: Maximum value of fluctuation from the average.
- Distribution SS 11kV Bus(Annex 5-1-c,d)
  Average Load: Average load of 6 feeders(33kV) in Annex 5-1-c,d.
  Fluctuation: Average of 6 feeders' maximum values of fluctuation.
- Distribution 11kV Feeder(Annex 5-1-e,f)
  Average Load: Average load of 3 feeders(11kV) in Annex 5-1-e,f.
  Fluctuation: Average of 3 feeders' maximum values of fluctuation.

②Technologies for load management

Many technologies have been developed in countries where load management has become an urgent issue. Japan is one of these countries which has been striving to improve the electric load curve. The technologies that are considered to be very effective in terms of load management are ice thermal storage (peak shifting) and natural gas cooling (fuel switching). The applicability of these technologies are discussed in the following chapters.

(3) Energy Conservation

In Oman, new types of electrical appliances are now on the market, and energy efficient air conditioners seem to be becoming popular. Therefore, it seems better to foster energy conservation more aggressively. With regard to the thermal insulation of buildings, some countermeasures, like double layers of vinyl sheets on the roof of complex buildings, are observed. It is obvious that there is a consciousness toward energy conservation among people. However, there are no strict measure to enforce the thermal insulation of buildings.

Accordingly, we recommend to consider the energy conservation policies and measures, as follows, which are implemented in Japan for the sake of energy conservation in Oman. (Japan Energy Conservation Handbook 1997, The Japan Energy Conservation Center)

Scheme of energy conservation policies in Japan

①Industrial sector

- Rationalization of energy use : Establishment and announcement of guidelines
- Major energy consumers: Designation of Factory (nomination of energy managers etc.)
- Small energy consumers : Audit and guidance of energy conservation etc.
- Incentive for energy conservation equipment investment: finance and taxation by Energy Conservation Assistance Law

②Residential and commercial sector

- Buildings : Establishment and announcement of guidelines for building owners
- Aid for energy conservation equipment investment for buildings : finance and taxation by Energy Conservation Assistance Law
- Residential and commercial use apparatuses : Establishment and announcement of guidelines for specific apparatuses
- Aid the dissemination in residential and commercial use apparatuses

③Transportation sector

- Automobiles : Establishment and announcement of guidelines for specific apparatuses energy efficiencies : Information for energy saving use
- Mass transportation means : The measures for improvement and expanded utilization

④Technology development

- R & D of energy conservation : Aid based on Energy Conservation Assistance Law
  : New Sunshine Project
  : NEDO (New Energy and Industrial Technology Development Organization)

<u>The Energy Conservation Center, Japan</u>

This center is established to achieve the above energy conservation measures, whose activities include, guidance and advice for measures, designation of energy managers, audit and guidance, information, publicity, international cooperation etc.

<u>Guidelines of buildings for rationalization of energy use</u>

①Hotels, hospitals or clinics, commodity merchandising stores, business offices and schools

With regards to the following measures, owners of five kinds of buildings as above shall make thermal loss or consumption energy lower than the standard value decided in the regulation.

a. Prevention of heat loss through external walls, windows, etc. of building

b. Efficient use of energy concerning air conditioners, mechanical ventilating equipment except air conditioners, lighting facilities, hot water supply systems and elevators.

②Residence

The owners of a residence(from a single house to an apartment house) shall make the values of heat loss coefficient and coefficient of solar radiation received lower than the regulated values. These regulated values are decided for every 6 region blocks in Japan.

<u>Activities of Oman Energy Conservation Center (to be established)</u>

a. Planning on promotion of energy conservation
- Promotion of energy conservation apparatus
- Data analysis on cooling load, efficiency of air conditioners, etc.
- Promotion of architectural measures for energy conservation

b. Financial assistance
- Assistance for investment in energy conservation
  (by subsidy, low interest loan or tax incentive)
- Giving reward for individuals and companies who take an initiative

c. Public relations and education
- Promotion of publicity on energy conservation
- Examination of existing facilities and provision of recommendations
- Human resource development

5-2. Gas Cooling System

5-2-1. Basic Concept on Introducing Gas Cooling System

(1)Study Objective

The objective of the study, from the view point of the Demand Side Management, on introducing natural gas cooling system in the urban areas in Oman is as follows :

- Significant reduction of utility power consumption on the demand side
- Energy conservation by utilizing natural gas directly for air-conditioning

All the cooling systems in the Muscat area are currently using electricity which is generated by using natural gas. Accordingly, the direct utilization of natural gas for cooling system will bring about substantial benefits from the viewpoint of energy conservation.

(2) Buildings considered for gas cooling system introduction

The objective buildings investigated for introducing gas cooling system are:

- Government building (Ministry of Civil Services ; Ministry of Electricity and Water)
- Hospital and Hotel (Royal Hospital ; Al Falaj Hotel)
- Commercial Complex (Al Araimi Complex)
- House (large-size villa)

Among these buildings, the most suitable type of buildings for introducing gas cooling system is hotel and hospital, which have been studied intensively by performing conceptual design. According to the results of those case studies, introducing gas cooling system to such buildings would be beneficial in Oman to users as well as utilities.

(3) Features of Gas Cooling System

The gas cooling system has been rapidly spreading in Japan as an effective means of reducing peak power demand in the summer. It is applied mostly to mid- or large-size buildings. The total amount of gas cooling system capacity reached more than 250 million RT(refrigeration ton) in 1996.

<u>Principle of Cooling System</u>

There are two types for generating chilled water for cooling; one is refrigerant compression which is generally used by electricity cooling system, and the other is refrigerant absorption which is mainly applied to gas cooling system. The compression type principally removes heat from circulating chilled water by inflating compressed refrigerant such as freon. This type has four main cycling processes; Evaporation, Compression, Condensation and Expansion.

The gas cooling system are classified into two categories; absorption type and gas-engine heat-pump type(GHP). The GHP has the same operating principle as the compression type. The former is mainly applied to comparably large-scale buildings, while the latter is applied to small-scale buildings. The absorption type has four basic cycling processes; Evaporation, Absorption, Re-generation(or re-concentration) and Condensation; in which water is used as refrigerant and harmless Lithium-Bromide (LiBr) solution is used as absorbent. (See Figure 5-2-1)

The fundamental principle in this cycle is as follows;

① Refrigerant water, when vaporized in the evaporator vessel vacuumed to the extent of 6.5mmHg, removes the latent heat from the circulating chilled water inside the tube in the vessel and keep its temperature in 5℃.
② LiBr solution absorbs the vaporized water inside the vessel in order to keep the vessel continuously in vacuum.
③ Diluted LiBr solution which has absorbed refrigerant water vapor is heated by gas burning or steam heat in order to separate the solution into water vapor and concentrated LiBr solution.
④ The separated water vapor is condensed in the condenser and re-used for the evaporator as refrigerant, while concentrated LiBr solution is also re-used as absorbent in the absorber.

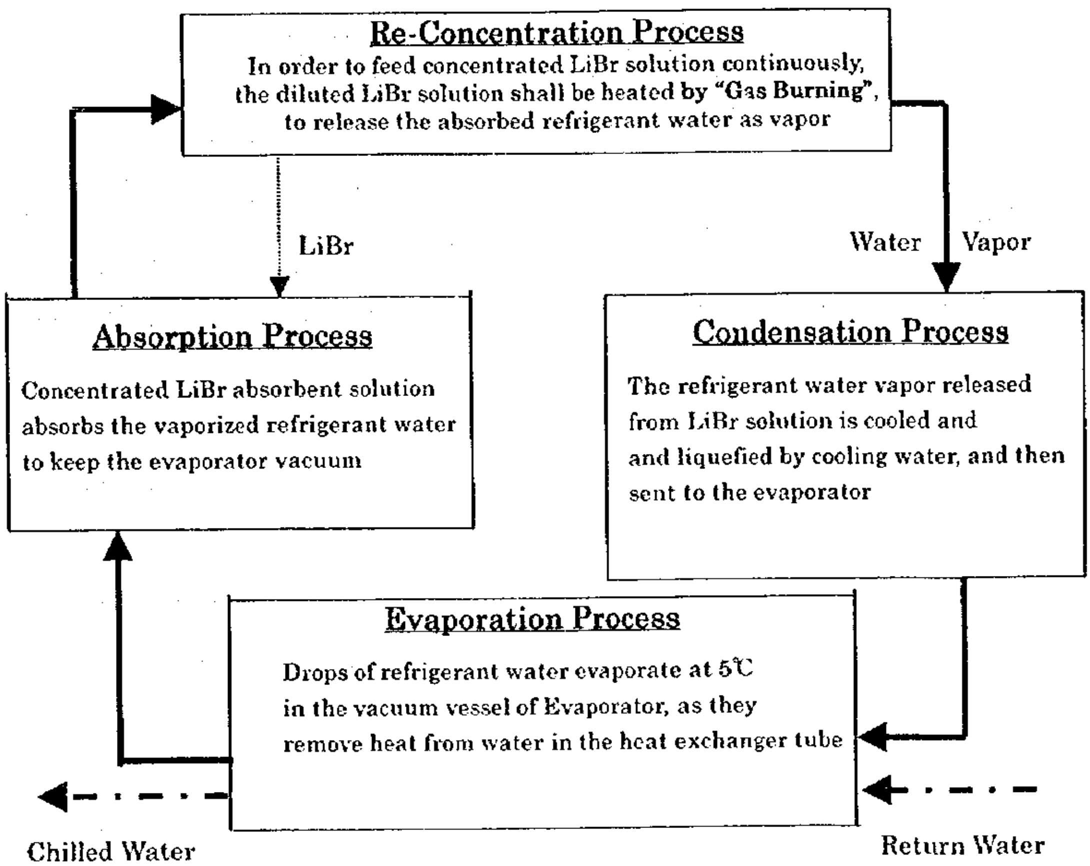


Figure 5-2-1 Operating Principle of Gas Absorption Chiller

Application

As shown in Table 5-2-1, gas absorption type systems (Steam Absorption Chiller system, and Direct Gas-fired Absorption Chiller system) are mainly applied to large scale buildings from the viewpoint of higher efficiency and economies of scale. Furthermore, to large scale hospitals and/or hotels which require heat energy such as steam for laundry, hot water for shower and fire for kitchen other than cooled air, a Gas Co-Generation System is often applicable from the viewpoint of energy conservation and economy, that is to say the effective utilization of waste heat. Unit RT in the table indicates a range of cooling capacity needed for each type of building.

Table 5-2-1 Type and Capacity of Gas Cooling System

Type	Capacity	Building(m^2)	--3,000	--10,000	--50,000	--100,000
GHP	10-50 RT	Small Office, Shop				
Multi-GHP	10-100 RT	Buildings with multi-tenants				
Gas Absorption	100 – 3,000 RT	Large-scale Buildings				
Co-Generation with Gas Turbine, Engine, Absorption Chiller	300 – 5,000 RT	Hospitals, Hotels, Large-scale Buildings, District Cooling				

Efficient Gas Absorption Chillers (with double effect cooling cycle) are mainly manufactured by Japanese companies such as Kawaju-Reinetu, Sanyo, Mitsubishi Heavy Industries, Hitachi, Ebara, Daikin and Yazaki. A typical line-up of chillers are in the capacity of 100, 150, 200, 300, 400, 500, 1000, 1500, 2000 and 3000RT.

Conceptual Diagram for Introducing Gas Cooling System to Existing Buildings

Conceptual diagram for the case of replacing existing electric cooling system with a gas cooling system (steam absorption chiller system) is shown in Figure 5-2-2.

Steam Absorption Chiller System with a Gas-fired Boiler

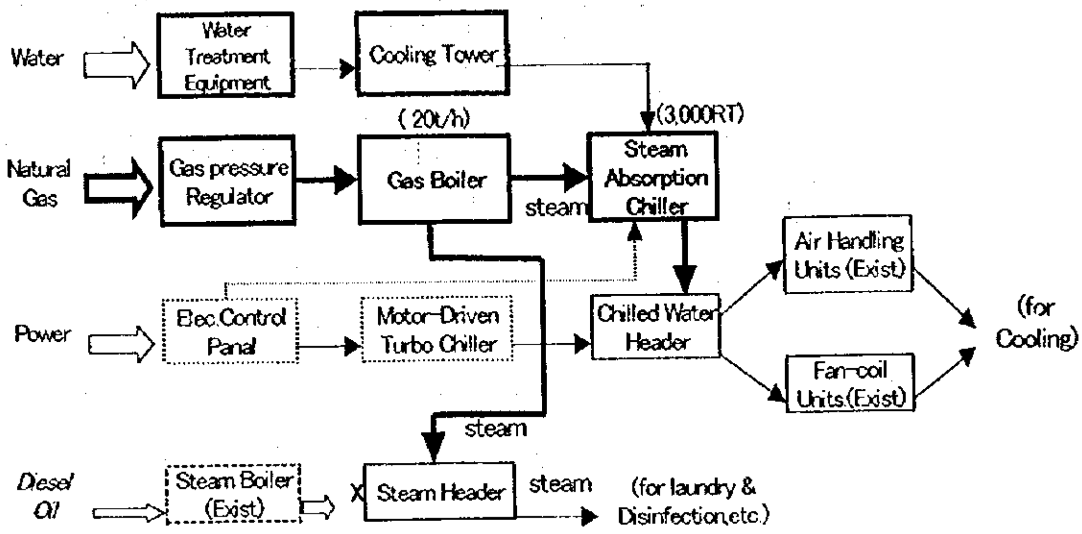


Figure 5-2-2 Gas cooling system with gas-boilers and steam absorption chillers

Dark boxes in the above show facilities to be added for converting to gas cooling system, and white boxes mean facilities to be re-used in the new system. White boxes with dotted lines are facilities to be removed.

Features of Gas Cooling System

Primary features of Gas Cooling System are:

a. Capability of reducing power consumption especially in the summer.

b. Cheaper running cost compared with conventional electric cooling system due to energy saving effect (note) ;

(Note) Only 20% of the primary energy of natural gas is available as electricity at end-user.

c. Stable operation with less noise and less vibration compared with electric system

d. Only once a year periodical maintenance

e. Less impact on the environment; smaller emission of SOx, NOx, CO_2, and harmless absorbent (LiBr)

As promotional measures for the gas cooling system, special gas tariff system, low interest loan scheme and tax incentive scheme have been introduced in Japan.

The above described are the advantages of gas cooling system in comparison with an electric cooling system, however, its disadvantages are;

a. Water is required for the cooling process.

b. Equipment is relatively large in size and, hence, initial cost is higher

c. A smaller package type gas cooling unit for household is still under development.

In Table 5-2-2, the estimated running costs and capital costs of gas cooling system in Oman are presented. For reference, the costs of electric cooling system are also indicated.

Table 5-2-2 Unit Cost Comparison for cooling between Gas and Electricity in Oman

		Running Cost (Bz/RT.h)	Capital Cost (Bz/RT.h)	Total Cost (Bz/RT.h)
Large Scale Buildings	Electricity	30	8	38
	Gas Cooling			
	[Co-Gene]	11	13	24
	[Steam-Abs.]	16	9	25
	[Gas-fired]	16	9	25
Small Scale Buildings	Electricity	30	10	40
	Gas Cooling			
	[Steam-Abs.]	16	13	28
	[GHP]	16	20	36

(Note 1) Energy price: Electricity ; Large Scale Building; 30 Baiza/kWh: Small Scale Building; 20Baiza/kWh Gas; 19.7 Baiza/m^3 (8,700 kcal/m^3).
(Note 2) Capital cost of electric cooling equipment is assumed to be cheaper than that of gas cooling by 10 to 20%. The duration of depreciation is assumed 5 years.

The unit cost (Bz/RT.h) of gas cooling system can be evaluated as two thirds of the cost of electricity cooling for large scale buildings, and three quarters for small scale buildings. Accordingly, introducing gas cooling system would bring about substantial economic advantages in Oman, where the electricity demand for air-conditioning is extremely large.

(4)Benefits of Gas Co-generation System

Gas Co-generation System is a system by which electricity and heat can be produced on site. Gas co-generation system is the most efficient energy saving system especially for hospitals, hotels or large scale commercial complexes, where they consume a lot of electricity, cooling heat, hot water and steam for multi-purpose energy utilization.

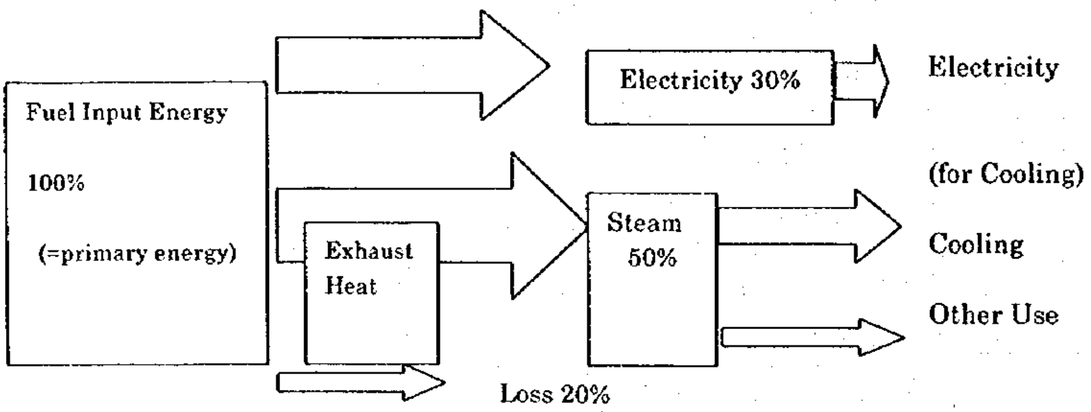


Figure 5-2-3 Effective Energy Utilization by Co-Generation

In this system, electricity is generated by a gas engine or a gas turbine, and simultaneously <u>the exhaust heat (often wasted at power stations) is recovered and effectively utilized for cooling, steam and hot water supply</u>. Thus the total energy utilization efficiency would reach up to 70-80% of the primary energy input. (See Figure 5-2-3) In contrast, the utility power only has the efficiency of less than 35%, at most. Gas co-generation, therefore, can attain substantial energy conservation and lower running cost. In addition, this co-generation system can contribute to the environmental protection, by reducing total SOx, NOx, and CO_2 emissions, because of the less fuel consumption as well as the use of clean natural gas. At the same time, the public utilities can benefit from a co-generation system, because the lower peak load will defer new plant development and also improve the plant factor of existing power plants.

5-2-2. Analysis

(1)Collected Information/ Data

①Meteorological Data

Monthly average temperature and humidity in the Muscat area through the year 1996 is shown in Figure 5-2-4 below. Monthly maximum/minimum temperature and humidity as well as the hourly fluctuation of temperature and humidity in a typical hottest and coolest day of 1996 are also indicated in Annex 5-2-a "General weather conditions at Muscat in Oman".

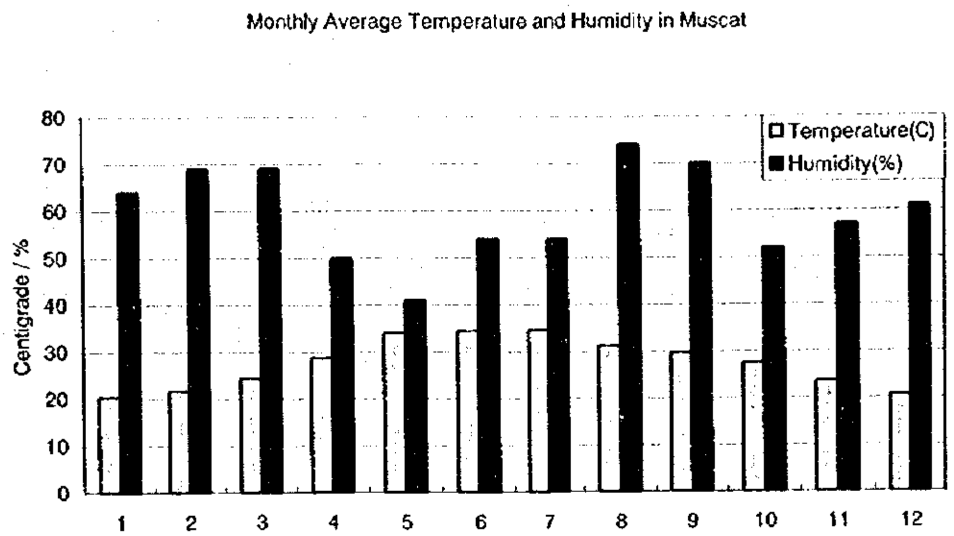


Figure 5-2-4 Meteorological Condition in Muscat, Oman

As shown in Figure 5-2-4, the meteorological conditions in the Muscat area are particularly severe in the mid-summer, from May to August, when monthly average temperature rises up to 35℃ and the maximum temperature reaches as high as 48℃. On the other hand, average humidity is comparably low during the period, which means water will easily evaporate. Water temperature will rise along with the atmospheric temperature, and it is estimated to reach up to 35℃, which may cause some technological problems for the condensation process of gas cooling system. But the atmospheric humidity in the high temperature season of May to July is comparably low except August and September, which indicates that the severe conditions would be eased.

Water Supply

The water supply for the cooling process shall be considered in terms of temperature and supply capacity. Comparably low humidity in the summer may mitigate the problem of high water temperature for the cooling process. It would be possible to resolve the issue technologically. As to the water supply capacity, water from the Ghubrah Desalination Plant, the Eastern Well-field in Wadi Aday, the Western Well-field in Seeb & Al Khuwair and some storage can easily meet the additional demand for water, as shown in Table 5-2-3.

Table 5-2-3 Water Production /Consumption and Capacity in Muscat Area(1997)

Water Production / Consumption (unit: Gallon)			
	Production	Monthly Average Consumption	Daily Average Consumption
Total	12,320,988,680	12,305,937,980	(33,714,898)
Maximum Consumption -Peak-day (26/5/'97)			42,942,220
Minimum Consumption (1/1/'97)			31,086,580
Water Supply Capacity (unit: Gallon /day)			
Desalination Plant			34,000,000
Easter Well-field			4,500,000
Western Well-field			4,500,000
Total			43,000,000 +Storage

Architectural/Equipment data and cooling load of objective buildings

Investigation results of the selected 5 objective buildings are summarized in Table 5-2-4 "Features of the objective buildings for Cooling System", in which contains the architectural data, brief comments on the cooling equipment and its capacity, and the estimated maximum unit cooling load. Data of Maximum Cooling Load per unit space(kcal/m².hr) are calculated or estimated on the basis of actual cooling area space and the current operation data (operation period, power consumption). Diesel oil consumption for steam boilers or hot water boilers and LPG consumption for kitchens are added in this table, for the study on energy conservation.

Table 5-2-4 Features of the objective buildings for Cooling System

Name of Building	Ministry of Civil Services (MCS)	Ministry of Electricity & Water (MEW)	Royal Hospital	Al Falaj Hotel	Al Araimi complex	Residential Villa
For Use	office	Office	Hospital	Hotel	Commercial shop	Residential house
Total Stories	6	3	4	8	3	2
Structure	reinforced concrete	Reinforced concrete	Reinforced concrete	Reinforced concrete	Steel frame dome	Concrete
Total Floor Area (m^2)	11,200	7,710	55,692	9,244	15,000	250-450
Average height between stories	3.5m	3.5m	3.0m	3.0m	Center part; from base to top is a stairwell	3.0m
Total capacity of the existing cooling system (RT)	(150RTx3+1 for comp) 450 RT	(50RTx12) 600 RT	(Accommodation area; 1,580RT) 3,240 RT	740 RT	560 RT	10-30RT
Type of cooling equipment	Elec. Compressor Chiller/AH (Flotronic)	Elec. Compressor Chiller/AH (Carrier)	Elec. Compressor Chiller/AH ( )	Elec. Compressor CHW/FCU (Carrier)	Elec. Compressor Chiller/AH (Lennox)	Package type A/C
CHW lvg/ent Temperature	7.0°C/12°C		7.0°C/12°C	8.0°C/12°C (measured)		
Setting Temp/Humid	Avr. 22-24°C/50%		Avr. 24°C/50%	Variable as control		
Design/Install Co.	Majan Eng./Bahwan Eng.	/Bahwan Eng.	Winpey.	Bahwan Eng. Co.		Bahwan, etc.
Power consumption (kwh/month)	(8h/d, 5d/w); comp(24/d, 7d/w)	(8h/d, 5d/w)	(24h/d, 7d/w)	(24h/d, 7d/w)	(11.5h/d, 6.5d/w)	(24h/d, 7d/w)
—Summer	210,750	296,360	3,852,580	529,410	364,000	
—Winter	89,850	65,490	1,686,290	243,140	224,000	
Power Consumption for cooling (kwh/month)						
—summer			2,725,720	(estimated) 409,410		
—winter			944,620	(estimated) 123,140		
Maximum Heat Load by Capacity (kcal/m^2hr)	121.5		176	242	113	150-200
Actual Heat Load estimated (kcal/m^2hr)			150	120		
Diesel Oil Consumption (kl/month) For equipment	—	—	(6.3tx(1+1) steam boiler) 50 for Laundry,Csst, Incinerator	(1.4t steam boiler) 12.4 for Laundry, Sauna	—	
LPG Consumption (kg) For equipment	—	—	4.1 kl =2,500 for Kitchen, residential	3,000 for kitchen	—	

Ministry of Civil Services :
This building is comparably new, and has about 12,000 m^2 of the total floor area, equipped with the capacity of 150RT x 3= 450RT of electric chillers which operates from 5:00 a.m. to 9:00 p.m. except on holidays. The estimated maximum cooling load is approximately 120 kcal/m^2.hr, which is considered to be 30% larger than the average cooling load for the office in Japan, but is understandable considering the different meteorological conditions.

Royal Hospital :
This is a large scale hospital, which has about 65,000 m^2 of total floor area, and additionally has a large-scale accommodation buildings for the staff adjacent to the hospital. The capacity of the cooling system is as big as 3,240RT for the hospital (capacity for the accommodation buildings is 1,580RT) , which operates 24 hours a day, and the total power consumption is at 4 million kWh per month (including lightning) in the summer. This hospital also consumes a lot of energy by the form of steam, hot-water for laundry, disinfecting and shower, and for cooking. Monthly power consumption of Royal Hospital is shown in Figure 5-2-5. The data for power consumption for cooling is the estimated, because no separate meter is equipped.

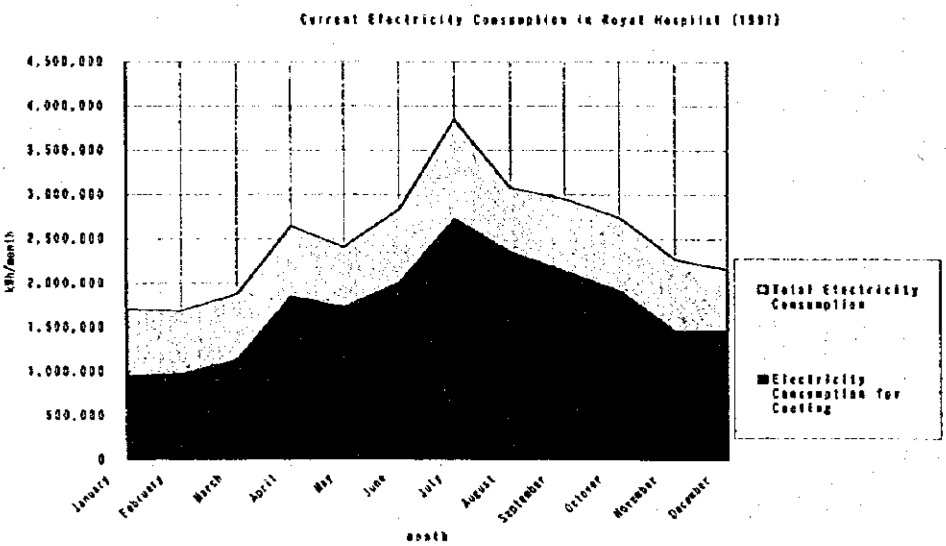


Figure 5-2-5 Power Consumption at Royal Hospital

Al Falaj Hotel :
The cooling equipment of this hotel has the capacity of 40RT x 4 x 2 (old) and 30RT x 7 x 2 (new), and has the total capacity of 740RT. However, the necessary capacity of the equipment is estimated about 300RT, because the availability of facility is 60%--70% even in the middle summer and in addition the actual efficiency of facility is estimated too much worse according to the calculated COP(Coefficient of Performance) of about 2.0. This cooling system operates 24 hours per day. The hotel consumes a lot of electricity for cooling, diesel oil for boilers and LPG for kitchen. The estimated maximum heat load for cooling is 242 kcal/m^2.hr, which is considered to be a little too large, but it is calculated

from the excess capacity of 740 RT including the capacity of dome type big hall for the event, so that the actual cooling load of the hotel section may be considered to be about a half of this figure. Monthly power consumption of Al Falaj Hotel is given in Figure 5-2-6. The data for power consumption for cooling is the estimated, because no separate meter is equipped.

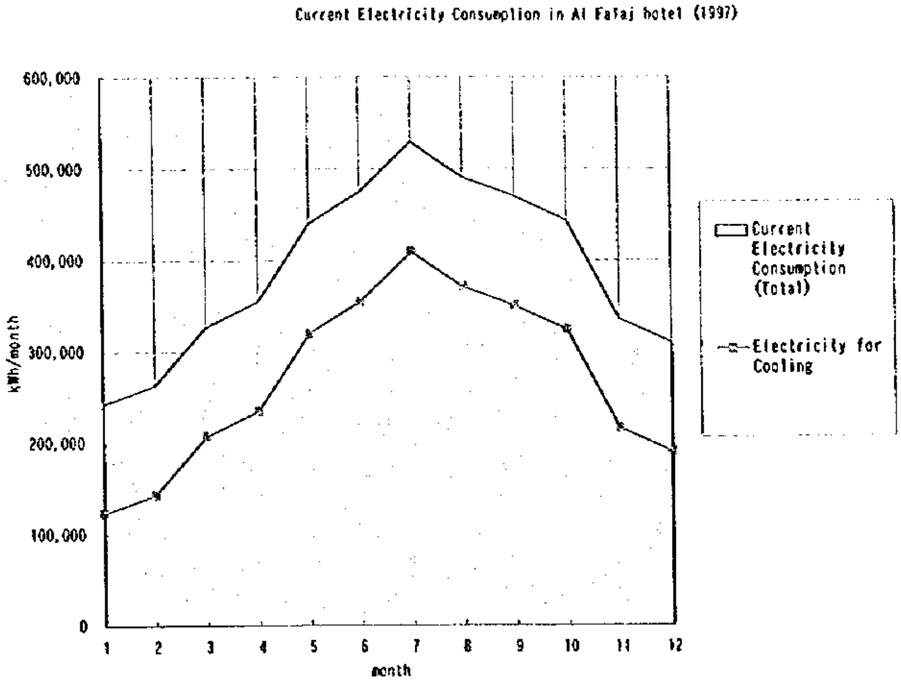


Figure 5-2-6 Power Consumption in Al Falaj Hotel

Al Araimi Complex:
This is a dome type building which requires a large spherical cooling. The cooling equipment is separately installed on the roof. Each tenant has its own cooling (package type). The main roof is covered with a cloth tent type for lighting but has some measures to dissipate heat by convection. The cooling equipment operates only during the business hours. The complex consumes a lot of electricity for cooling and lightning but does not use other energy such as heater for cooking. Adjacent to the building, there are many similar commercial buildings, so that the applicability of district cooling system might be studied.

Villa :
The investigated villa (under construction) is a large scale gorgeous house which is equipped with 22 units of fan-coils for cooling with an electricity capacity of 114 kW. The cooling heat load capacity of the villa is 10—20RT, which is equivalent to the capacity of a small scale commercial building in Japan. A gas cooling system by GHP or by package type absorption chiller, will be applicable.

②Natural Gas Supply
Continuous natural gas supply is a fundamental prerequisite for introducing gas cooling system. Information on the current natural gas supply situation and the plan for

natural gas distribution system, if any, was obtained from the Ministry of Oil & Gas (MOG) and the following facts were revealed:

There is neither natural gas distribution network to supply gas to buildings in the capital area at present, nor any official plan for its construction. A feasibility study conducted by British Gas Co. for constructing city gas distribution networks in the Muscat area concluded that there is no financial viability. But this study did not consider gas cooling.

The existing natural gas transmission pipelines (high pressure ; 75—19bar) shown in Annex 5-2-c, are installed from the Yibal gas field to the Ghubrah, Rusail and Wadi Jizzi power stations. The natural gas production in Oman is about 7.3 billion m^3 (1996), half of which is used for re-injection and own use at the well-site, and 2.5 billion m^3 of which is utilized for gas supply to the power plants and other governmental facilities.

This natural gas contains 85% of methane, and its heat value is 8,700 kcal/ m^3. Natural gas proven reserve of the Yibal gas field is estimated about 500 billion m^3, which is considered not enough to supply for the next 20 yeas, so that the plan of constructing complementary pipelines from the Saih Rawl gas field (located in the middle part of Oman) is currently underway. The pipelines from this gas field to the Sur LNG export terminal (under construction) is also under construction. The current natural gas price to the power plants is 1.5 US$/MMBTU (approximately 0.05$=¥6.5/$Nm^3$). For reference, the current electricity price is 10-30 Bz/kWh, which corresponds to approximately 7.6 – 22.8 US$/MMBTU and is equivalent to 10 times of natural gas price of the same heat value.

5-2-3. Introduction of Gas Cooling System

(1)Natural Gas Supply

Although there is no natural gas distribution network in the Muscat area at present, an assumption is made that "a natural gas distribution network in Muscat area will be constructed in near future", to continue the study for introducing gas cooling system as a DSM technology. Hotels and hospitals, to which introducing gas cooling system is deemed to be most effective, have been studied intensively by designing some appropriate gas cooling systems.

Among the objective buildings, the ministry buildings and the Royal Hospital are located less than 1 km away from the high pressure natural gas pipeline(19-25 Bar; 20"), which is running to the Ghubrah power station (See Annex 5-2-b), so that the implementation of designing and feasibility studies on those buildings have been conducted with an assumption that MOG would invest in constructing PRT (Pressure Regulating Terminal) of the high pressure pipeline, and the Royal Hospital would bear the cost of constructing a spur pipeline from the tapping point.

(2)Results of Study

The optimal gas cooling systems are designed and studied in particular for the Royal Hospital and the Al Falaj Hotel to which the introduction of gas cooling system is deemed to be most effective. Introducing a co-generation system fueled by natural gas to a large scale facility like the Royal Hospital would lead to substantial energy conservation and eventually cost effectiveness.

① Royal Hospital

・ Existing Facilities of Royal Hospital

Royal Hospital is a 4 story large scale general hospital with a floor area of 55,692 m^2. The current capacity of its cooling system is 270RT x 12 units = 3,240RT equipped with electric turbo chillers in the ward and additional 1,580RT equipped with small package type electric chillers for the adjacent staff accommodation complex which has 600 rooms. In the ward, 12 units of chillers are in full operation in the middle summer with an electric current value of 480 A, while in the winter only 5 units of chillers are in operation with an electric current value of 250 A. The temperature of the chilled water is 7℃ for send out and 12℃ for return. The control system for the cooling system is the mixture of constant flow and variable flow type controlled by chilled water pressure, which does not always correspond to the cooling heat demand. The improvement by changing it into a demand tracking system by detecting the temperature of return chilled water is suggested. The maintenance work is being performed by a UK firm, Winpey.

The unit heat load in full operation is calculated as about 150 Kcal / m^2hr, which is 1.5 times larger than that in Japan. Power consumption in the hospital in the mid summer rises up to 3.9 million kWh per month, 2.8 million kWh of which is used for the cooling system. The power consumption decreases to 1.7 million kWh per month in the winter. The electricity charge per month in the mid summer reaches 120,000 RO (average unit price is 30Bz/kWh).

The Royal Hospital consumes diesel oil for producing steam by boilers (6.3t x 2units) for laundry and disinfecting. Diesel oil is also used for incineration, and the total consumption of diesel oil amounts 145.6 kl in 3 months, which is equivalent to 10% of electric energy consumption in the hospital. The fuel charge of diesel oil is about 4,000 RO (unit price ; 81.6Bz/ lt.) per month. LPG is primarily used in the kitchen for cooking, and its consumption is 3,200 gallon(12.1kl) per 3 months, with a payment of about 310 RO (unit price ; 292Bz/Gallon) per month. About 3,000 gallons per month of LPG is also consumed in the staff accommodation.

・ Designing Study on Gas Cooling System

A large amount of energy is consumed in the Royal Hospital in the form of electricity (for cooling) , diesel oil (for steam) and LPG (for kitchen). The amount of electricity consumption differs by season due to the fluctuation of cooling demand, while the heat consumption does not change throughout a year. Hourly consumption of electricity through a day does not so much fluctuate even in the summer. For a building having such a characteristic of energy consumption, a gas cooling system may be the most appropriate system from the viewpoint of energy conservation and economic advantage. Furthermore, introducing a co-generation system has been studied and found to achieve the energy efficiency of more than 70%. As an alternative, a gas cooling system with steam absorption chillers and gas boilers and a gas cooling system with gas direct-fired absorption chillers have been also studied mainly for cooling purpose. These systems are also found to be worth investing with less investment. Schematic diagrams of these three types of systems are shown in Figure 5-2-7,8 and 9.

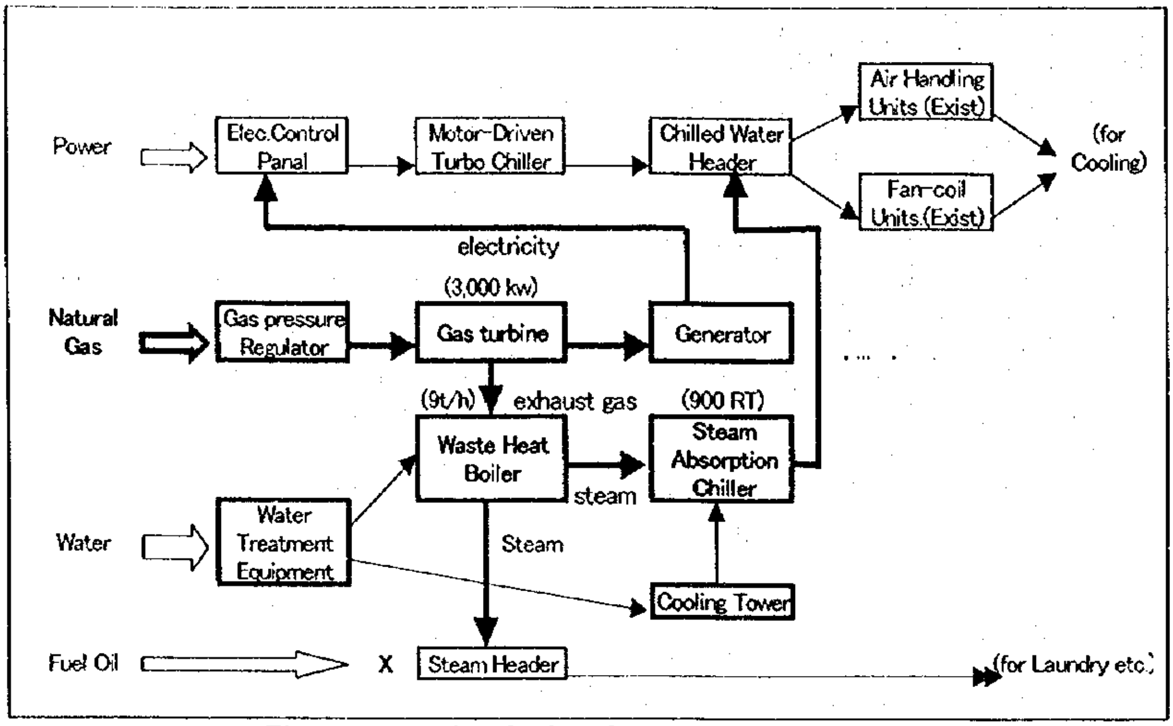


Figure 5-2-7 Gas Cooling System by Co-generation

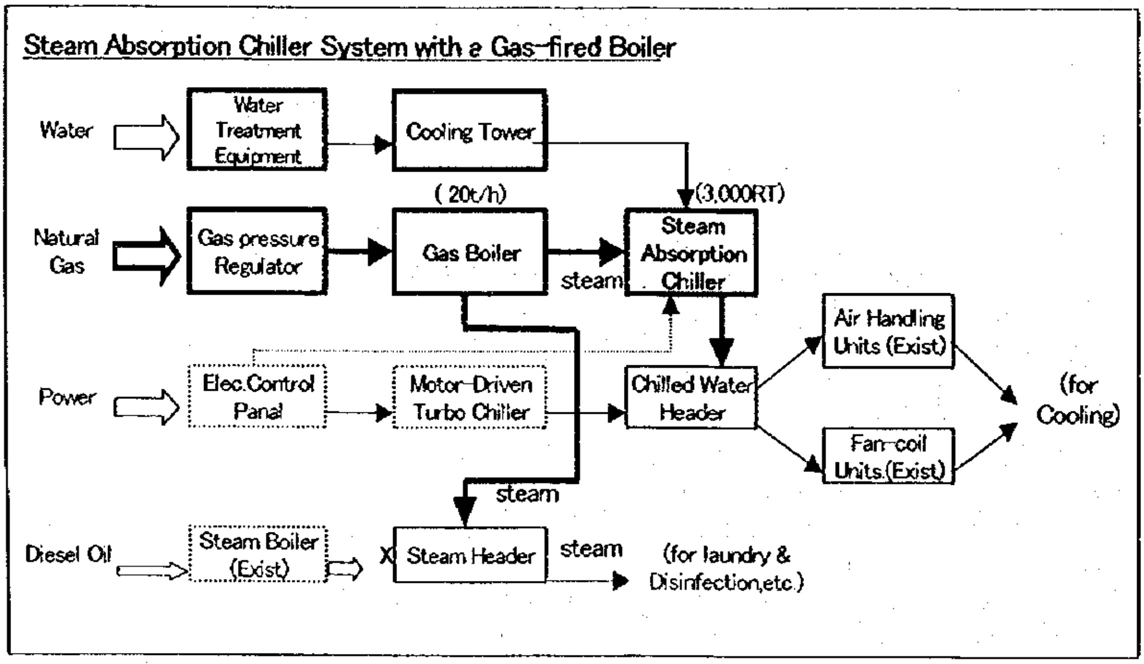


Figure 5-2-8 Gas Cooling System with Gas Boilers and Steam Absorption Chillers

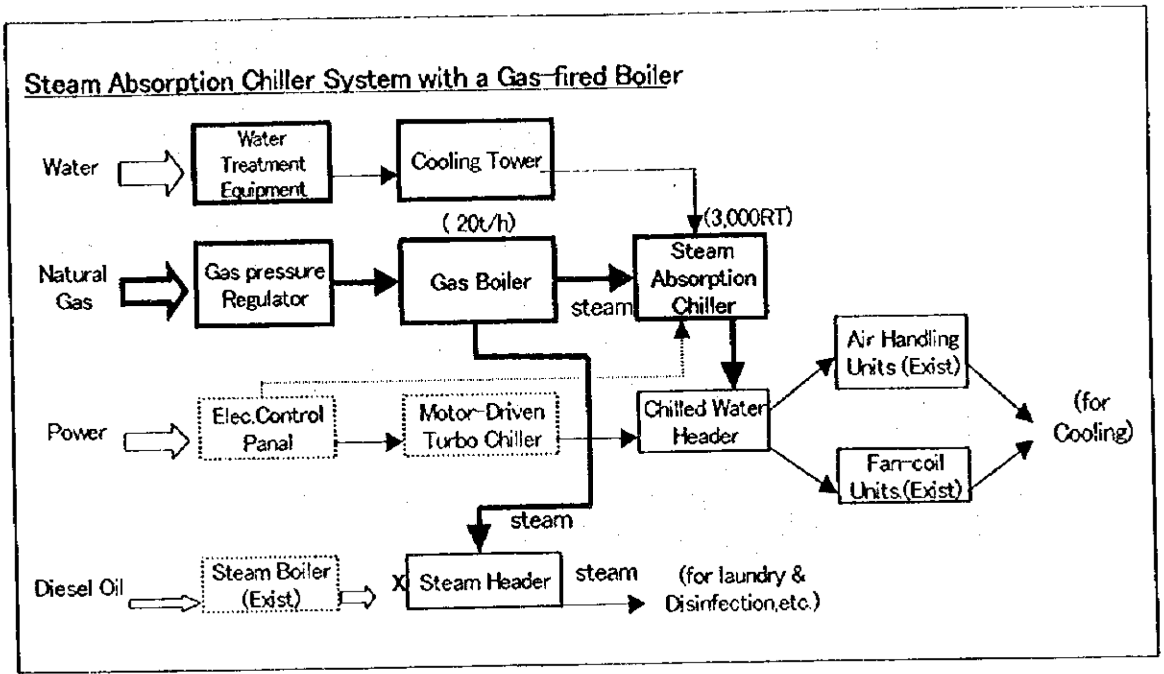


Figure 5-2-9 Gas Cooling System with Direct-fired Gas Absorption Chillers

As a result of the comparative study, the Gas Cooling System by Co-generation has been selected as the optimal system. Among the three systems, Its financial benefit is the highest. (See Table 5-2-7) Also, the connected utility power can provide a backup function especially in the case of emergency eliminating the need for emergency power source. For these reasons, it is recommended to introduce a co-generation system fueled by natural gas, by adding equipment such as gas turbine and generators, waste heat boilers and steam absorption chillers indicated in Table 5-2-5. The overall configuration is shown in Annex 5-2-d.

Table 5-2-5 Basic Equipment to be added for Recommended Co-generation system

Equipment	Unit	Spec./Capacity	Note
1. Gas Turbine	2	1,500kw/unit heat rate=3,400kcal/kwh	430 RO/kW with control system
2. Electric Generator	2	1,500kw/unit	
3. Waste Heat Boiler	3	3 t/h /unit	
4. Steam Absorption Chiller	1	900 RT	200 RO/RT
5. Cooling Tower for Chiller	1	Corresponding to 4.	
6. Steam Header	1		Included in 3.
7. Dedicated Gas Pipeline	1km	2000m 150mm ϕ	30 RO/m tap & regulator ; 2000RO
8. Others			Additional piping etc.

The expected reduction of utility power consumption by introducing the co-generation system is given in Figure 5-2-10.

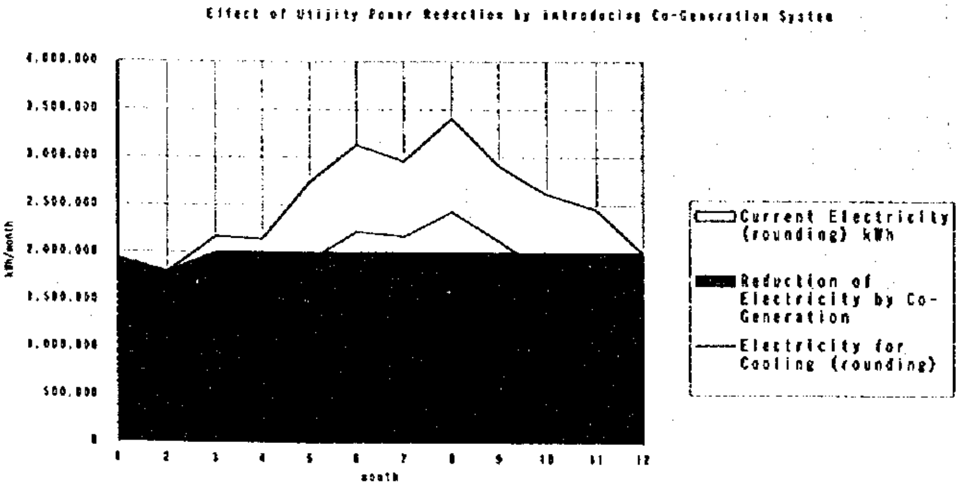


Figure 5-2-10 Power Reduction by Introducing Co-Generation system

Evaluation on Financial Feasibility

The estimated investment cost for constructing the Co-generation System in the Royal Hospital and the running costs are indicated in Table 5-2-6. (Note: It is assumed that the cost of constructing the PRT station (maybe 1.5 to 1.9 million RO) is borne by MOG) The NPV of this investment over the 15 year period is a big sum of 2.3 million RO and the payback period is within 5 years, mainly due to the substantial reduction of the electricity cost. (See Table 5-2-7 and Annex 3-3-q)

Table 5-2-6

Rough Cost Estimation on the Recommended Co-Generation system for Royal Hospital Investment

Construction of the Natural Gas supply pipeline to Royal Hospital

(Assuming 2km of 150mm diameter pipeline from the tapping point to R.H.)

2,000m x @30RO/m = 60,000 RO

Tapping & Regulator ; 2,000 RO Total ; 62,000 RO

Equipment ; Gas Turbines, Generator, Waste Heat Boiler & Control system;

3,000 kW x @430 RO/kW = 1,300,000 RO

Equipment ; Steam Absorption Chillers (1.000RT)

1,000RT x @200 RO/RT = 200,000 RO

Civil Engineering & Piping ; 20% of above total

1562 RO x .2 = 300,000 RO

Reinforcement of water supply facilities, if needed.

All Total = 1,860,000 RO(4.9 million $)

Running Cost increased and reduced in comparison with current system

Utility Electric Power consumption reduced (-)

[(current 2,520,000 kWh /month) x 0.03 RO/ kWh = 75,600 RO/month]

Reduction by Co-generation & Absorption chiller ;

2,000,000 kWh /month x 0.03 RO/ kWh = 60,000 RO/month

NG consumption (+)

3,000 kWh x 0.0057 RO/kWh = 17 RO/h

17 RO/h x 24 x 30d = 12,240 RO/month

Water consumed for cooling tower (+)

7,350 t/month x 0.8 RO/t (0.003 RO/gallon) = 5,880 RO/month

Diesel Oil(-) ; Current 50 kl/month x @ 0.08164RO/Gallon = 4,000 RO/month

Maintenance Cost (+)

3 % of Investment = 1,860,000RO x 0.03 = 55,800 RO/year = 4,650 RO /month

Total reduced ; 60,000 - 12,240 – 5,880 + 4,000 – 4,650 = 41,230 RO /month

Cost Recovery

Details of Financial Projection are shown in "Cash Flow Analysis".

Table 5-2-7 shows the comparison of the cost effectiveness among the three types of gas cooling systems applicable to the Royal Hospital.

Table 5-2-7 Cost Effectiveness of Gas Cooling System for Royal Hospital

Current Annual Energy Consumption and Cost at Royal Hospital

	Consumption	Cost
Utility Power	30 million kWh /year	907,000 RO /year
Diesel Oil	1,100 kl /year	90,000 RO /year

Recommended

		Co-Generation system	Steam Absorption Chiller system	Gas-fired Absorption Chiller system	Current Electric Cooling System
1	Main Equipment to be installed	Gas Turbine & Generator: 1,500KW x 2 Steam Abs. Chiller: 900RT	Gas Boiler: 20t/hr Steam Abs. Chiller: 3,000RT	Gas-fired Abs. Chiller:3,000 RT	
2	Additional Investment (RO)	1,860,000	1,212,000	1,174,000	0
3	Effect on Energy Saving	Best	Better	Good	
4	Effect on Environment	Biggest	Biggest	Bigger	
5	Effect on: Reducing Power Station Capacity (RO)	(3,000kw) 480,000	(2,500kw) 400,000	(2,480kw) 397,000	
6	Increment of Power Consumption(RO/y)	-720,000	-568,080	-568,080	[907,154]
7	Increment of NG Consumption (RO/y)	+146,880	+167,400	+126,960	0
8	Increment of Water Consumption (RO/y)	+70,560	+169,320	+169,320	[695]
9	Increment of Fuel Oil Consumption (RO/y)	-48,000	-48,000	0	[90,982]
10	Additional Maintenance Cost(RO/y)	+55,800	+36,000	+35,220	0
11	Increment of Total Running Cost (RO/y)	-494,760	-243,360	-236,580	[1,000,000]
12	NPV	+2,374,888	+871,035	+851,001	
13	Pay Back Period	4 years	5 years	5 years	

②Al Falaj Hotel

Introducing a gas cooling system to Al Falaj Hotel is not feasible due to the lack of gas pipeline network. The following discussions are based on the assumption that a gas pipeline network has already been developed.

・ Energy Facilities of Al Falaj Hotel

Like the Royal Hospital, the Al Falaj Hotel has a substantial amount of cooling load as shown in Table 5-2-4, and the operation time is also long. Simultaneously it also consumes the heat energy for laundry, shower and cooking. Although the existing cooling equipment in the Al Falaj Hotel is 740RT, the maximum capacity of the cooling equipment needed for this hotel would only be 300RT(or 375 kW).

- Gas cooling system to Al Falaj Hotel

Although the maximum cooling capacity for Al Falaj Hotel would be 300RT, introducing a gas cooling system would bring about a substantial advantage in cost saving. The scale of cooling capacity for this hotel is much smaller than that of the Royal Hospital and the available space is limited. Therefore, a "Gas Cooling system with Gas Boilers and Steam Absorption Chillers" (See Figure 5-2-8), or a "Gas Heat Pump system" is recommended as an appropriate option. In case of GHP system, 24 sets of 45kW GHPs, which operates for cooling, but not for generating steam, would be necessary. The additional equipment needed for a gas cooling system with gas boilers and gas absorption chillers is listed in Table 5-2-8.

Table 5-2-8 Equipment to be installed for Gas Cooling System at Al Falaj Hotel

Equipment	Unit	Spec./Capacity	Note
1. Gas Boiler	1	3 t/h /unit	
2. Steam Absorption Chiller	1	300 RT	200 RO/RT
3. Cooling Tower for Chiller	1	Corresponding to 2.	
4. Steam Header	1		Included into 1.
5. Dedicated Gas Pipeline	0.5km	50mm φ	20 RO/m tap & regulator ; 2000RO
6. Others			Additional piping etc.

The configuration of the proposed gas cooling system is shown in Annex 5-2-e. Reduction of power consumption by introducing a Gas Cooling System with gas boilers and steam absorption chillers is given by the dark part in Figure 5-2-11.

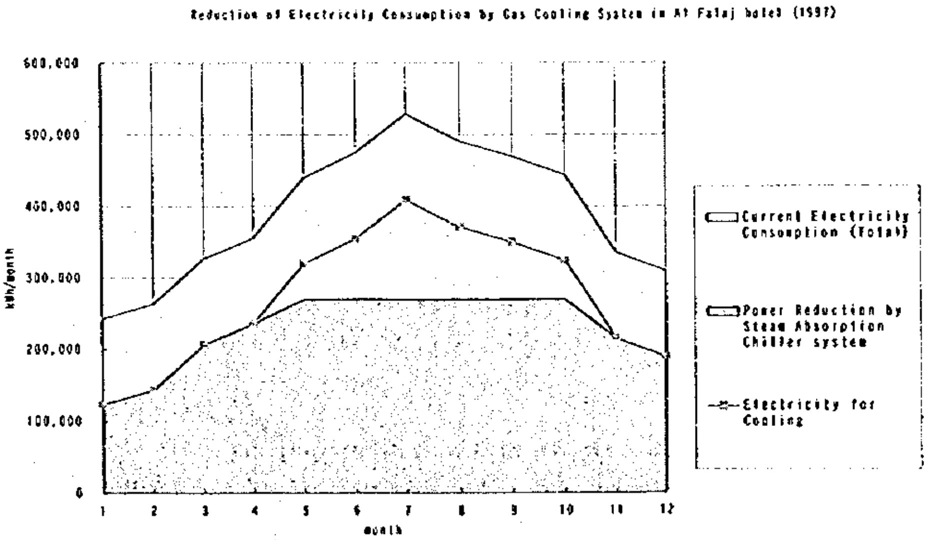


Figure 5-2-11 Power Reduction by Introducing Gas Steam Absorption Chiller

- Financial Feasibility of the proposed system

The estimated investment cost for constructing a Gas Cooling System with gas boilers and a gas absorption chillers, and the running costs in the Al Falaj Hotel are indicated in Table 5-2-9. The way of evaluating the financial feasibility is the same as the case of the Royal Hospital. The NPV of this investment over the 15 year period is positive (195,554RO) and the payback period is within 4 years, mainly due to the substantial reduction of the utility power cost and diesel oil cost. (See Table 5-2-10 and Annex 3-3-r)

Table 5-2-9 (Case-Study(AF1)); Gas Steam Absorption Chiller
Rough Cost Estimation on the Recommended Gas Cooling System for Al Falaj Hotel

Investment
Construction of the NG supply pipeline to A.F.H.
(Assuming 0.5 km of 100mm diameter pipeline from the tapping point to A.F.H.)
500m x @20RO/m = 10,000 RO
Tapping & Regulator ; 2,000 RO Total ; 12,000 RO
Equipment ; Gas Boiler (new)
3 t/h x @9,000 RO/t = 27,000 RO
Equipment ; Steam Absorption Chillers (250RT)
300RT x @300 RO/RT = 90,000 RO
Civil Engineering & Piping ; 20% of above total
129,000 RO x 0.2 = 25,800 RO
Reinforcement of water supply facilities, if needed. : (10,000 RO)
All Total = 164,800 RO($434 thousand)

Running Cost increased and reduced in comparison with current system
Utility Electric Power consumption reduced (-)
[(current average 270,000 kWh/month) x 0.0204 RO/kWh = 5,510 RO/month]
Reduction by Gas Steam Absorption chiller system;
(270,000 – 48kw*24*30*51%) kWh/month x 0.0204 RO/kWh = 5,150 RO/month
(Average for A/C – need for Abs. chillers)
NG consumption (+)
205 m^3/h x 0.0197 RO/ m^3 = 4.0 RO/h
4.0 RO/h x 24 x 30d x 51%(annual average Operation Load)= 1,470 RO/month
Water consumed for cooling tower (+)
3 t/h x 24 x 30 x 51% x 0.8 RO/t (0.003 RO/Gallon) = 880 RO/month
Diesel Oil(-) ; Current 12.4 kl/month x @ 0.0904RO/ltr = 1,120 RO/month
Maintenance Cost (+)
3 % of Investment = 164,800RO x 0.03 = 4,940 RO/year = 410 RO /month
Total reduced ; 5,150 – 1,470 – 880 + 1,120 – 410 = 3,510 RO /month

Cost Recovery
Details of Financial Projection are shown in "Cash Flow Analysis".

The following Table 5-2-10 shows the comparison of cost effectiveness between the two types of gas cooling systems applicable to the Al Falaj Hotel. The investment cost for the GHP system is higher than the Steam Absorption system. Accordingly, a Gas Cooling System with Gas Boilers and Gas Absorption Chillers shall be recommended.

Table 5-2-10 Comparison of Gas Cooling systems applicable for Al Falaj Hotel

		Recommended Steam Absorption Chiller system by fueling NG	NG fueled GHP Chiller system (Int'l price)	Currently Existing Electric Cooling System
1	Main Equipment to be installed	Gas Boiler: 3t/h & Steam Abs. Chiller: 300RT	Gas Heat Pump Chiller: 300RT (45kw * 24)	
2	Additional Investment (RO)	164,800	258,270	0
3	Effect on Energy Saving	Best	Better	
4	Effect on Environment	Biggest	Biggest	
5	Effect on: Reducing Power Station Capacity (RO)	(300kw) 48,000	(300kw) 48,000	
6	Increment of Power Consumption(RO/y)	-61,800	-63,840	[66,120]
7	Increment of NG Consumption (RO/y)	+17,640	+13,040	0
8	Increment of Water Consumption (RO/y)	+10,560	+0	[10,200]
9	Increment of Fuel Oil Consumption (RO/y)	-13,440	-0	[13,440]
10	Additional Maintenance Cost(RO/y)	+4,940	+7,750	0
11	Increment of Total Running Cost (RO/y)	-42,100	-43,050	[89,760]
12	NPV	+195,554	+110,216	
13	Pay Back Period	4 years	6 years	

③District Cooling System to Commercial Complex Region

The cooling equipment of Commercial Complex (e.g. Al Araimi Complex) operates only during business hours. Though it consumes a lot of electricity for cooling and lightning, it does not use other energy such as steam, hot-water or fire. But there are several (6 or 7) commercial buildings concentrated in the same area, so that the applicability of district cooling system with a capacity of 3,360RT, which indicates 6 times capacity of Al Araimi Complex (560RT), may be worth studying. However, those existing commercial complex buildings are having different features or conditions from hotels and/or hospitals:

- They have no or little heat demand other than cooling at the moment;
- Cooling operation is limited during business hours;
- Their location is far from the natural gas transmission pipeline;
- District cooling system requires outdoor pipelines for sending chilled water to each complex, which may further require an additional cost for piping and insulation.
- Evaluation on the economic feasibility is deemed not so promising. The running cost reduction may be not enough to recover the investment cost in a short period, because of the short time operation and little demand for utilizing the waste heat.

Accordingly, the applicability of district cooling system to the existing commercial complex area may not be so promising. For the same reason, introducing gas cooling system to each existing complex independently will be less applicable. Nevertheless, if a large scale commercial complex is to be newly constructed and the city gas supply network becomes available, a district cooling system would be worth studying. The utilization of natural gas for other facilities such as restaurants would make the district cooling competitive.

④Gas Cooling System to Governmental Buildings

Government buildings, such as MCS and MEW, are located considerably near(within 1 km) to the Ghubrah power station, so that the construction of gas spur pipelines is easy. However, the features of these buildings are:

- Operation time for cooling is relatively short;
- No heat demand other than cooling;

Although the reduction of power consumption can be expected by introducing gas cooling system, the economic feasibility is not so promising. In general, short time operation and little demand for utilizing the waste heat would make it difficult to recover the investment cost in a short period by the running cost reduction. Accordingly, introducing gas cooling system alone to the existing buildings is not recommendable, because it is difficult to offset higher modification cost in a short period, due to the short operation hours.

Nevertheless, if a governmental building is to be newly constructed or modified together with its cooling equipment in future and a city gas supply network become available at that time, gas cooling system might be feasible, because the total unit cost (both capital and running unit cost) will be competitive at that time.

⑤Gas Cooling System to large houses

As far as we have investigated, the heat load capacity for cooling in large or middle scale villas in Oman is 10 to 30RT, which may be ten times larger than that in Japan. Such a size of gas cooling chillers have already been developed and used in Japan. To such villas, GHP type gas cooling system, which is widely applied to middle/small scale buildings in Japan, or recently developed package-type gas cooling system will be recommendable.

Apart from the gas cooling system, energy conservation from architectural viewpoint should be considered. Unit heat load of villas, as shown in Table 5-2-4, reaches as big as 150 - 200Kcal / m^2hr and the cooling floor area per person is also large. Architectural conservation measures, for example, heat insulation and shielding from sunshine, will greatly contribute to reducing the building's heat load and result in energy saving.

<u>Recommendations on introducing Gas Cooling System</u>

Oman is endowed with affluent natural gas which is considered to be more advantageous for the environmental improvement. (Table 5-2-11) However, there is no natural gas distribution network at present in the Muscat area, so that the realization of introducing gas cooling system is facing a difficult situation.

Natural gas, among other fossil fuels, is easy to be utilized by the high-efficient combustion devices, and has a feature of less emission of SOx, NOx, CO_2 while burning. Consequently, the utilization of natural gas, especially for civilian use, greatly contributes to energy conservation and environment protection.

Table 5-2-11 Comparison of Pollutant Emission among Fossil Fuels

(Coal=100)

	Natural Gas	Petroleum	Coal
SOx	0	68	100
NOx	29	71	100
CO_2	57	83	100

(IEA "Natural Gas Prospect to 2010" 1986)

Accordingly, the early development of natural gas distribution network is strongly desired. This is just the basic requirement for the wide spread of gas cooling system and the key issue for the government of Oman. The proposal of introducing co-generation system to the Royal Hospital as a demonstration plant should be seriously considered. The plant will trigger the dissemination of gas cooling system around this area. In parallel with this project, it is required again to study and discuss on the construction of natural gas distribution network for the civilian use in the Muscat area. In the long run, the investigations on new buildings, hotels, hospitals and so on, which are deemed suitable for gas cooling system or gas district cooling system, shall be implemented.

5-3. Ice Thermal Storage Air Cooling System

5-3-1. Operations of Ice Thermal Air Cooling System

(1) Features of Ice thermal storage air cooling system

Ice thermal storage system is one of the countermeasures for shifting and/or leveling power demand. In this system, a chiller is operated to make ice using special discounted electricity rates, and the cooling source of air cooling (hereinafter, it is called A/C) at peak demand hour is discharged from the latent heat of ice and sensible heat of water. The features of ice thermal storage air cooling system are as follows (See Figure 5-3-1).

- On the supply side, the investment for the construction of power station, transmission and distribution line will be deferred by the load leveling and peak cut operation.
- On the demand side, the investment will be offset by special discounted rates of electricity, and also the capacity of chillers and power receiving facilities such as transformers will be decreased.

The operation method is indicated in Figure 5-3-2 Operational drawing of Ice Thermal Air Cooling System.

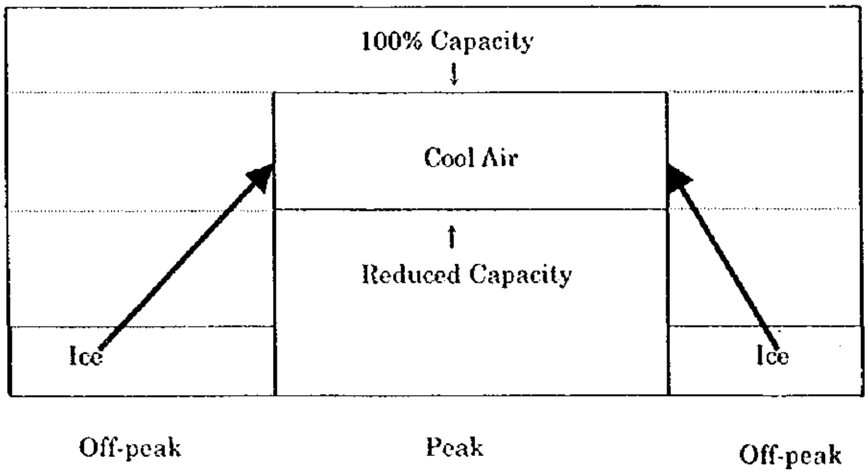


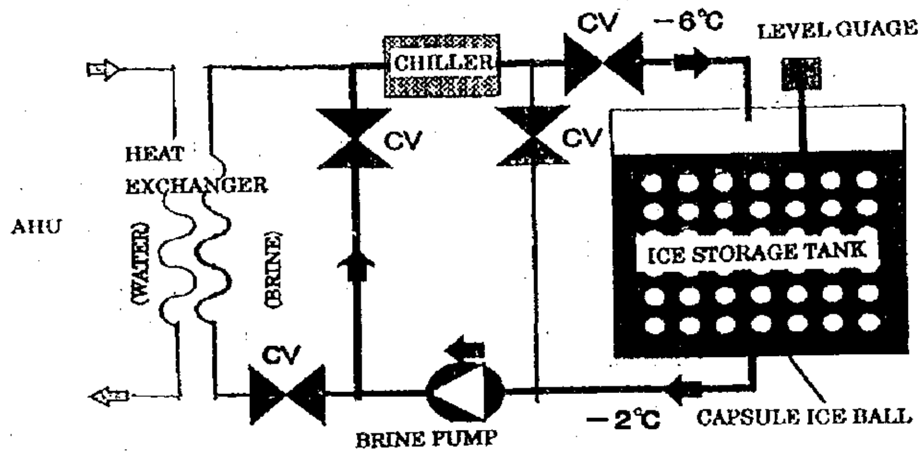
Figure 5-3-1 Concept of Ice Thermal Air Cooling System

(2) Comparison between ice thermal storage system and chilled water storage system

There is another thermal system, chilled water storage system, which stores chilled water of 7℃ in order to use the sensible heat of water. However, in this system, a large storage tank is required for using only sensible heat. Recently, ice thermal storage system has become more popular owing to the advancement of ice-making technologies.

The storage tank capacity of ice thermal storage system will be reduced to approximately 15% of that of chilled water storage system in case of ice packing factor is 50% as shown Table 5-3-1. An advantage of chilled water storage system is that the water storage tank can be commonly used as a fire extinguisher tank.

ICE STORAGE OPERATION



THERMAL DISCHARGE OPERATION

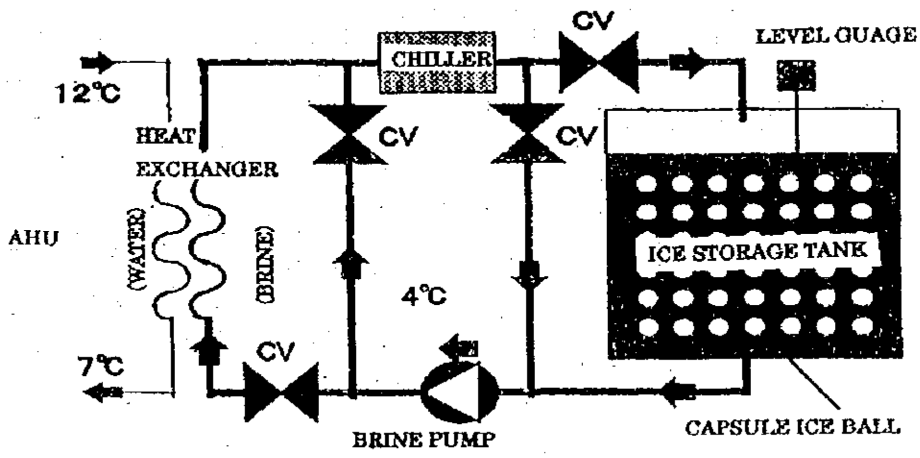


Figure 5-3-2 Operational Drawing of Ice Thermal Air Cooling System

Table 5-3-1 Comparison of Stored Energy and Tank Capacity between Ice Thermal Storage System and Chilled Water Storage System

	Available water sensible heat		Latent heat of ice (Mcal/m³)*	Total (Mcal/m³)	Ratio of tank (%)
	Temperature (℃)	Stored heat (Mcal/m³)			
Ice thermal system	0-15	15	40	55	14.5
Chilled water system	7-15	8	0	8	100

* : Ice packing factor of 50 %

(3) Comparison of operation of ice thermal storage system and conventional A/C system

In case of conventional A/C system, the operation is very simple to control the number of the chillers by the demand of cooling load. However, in case of ice thermal storage system, there are the following operations (See Figure 5-3-3).

<u>Ice storage operation</u>

Operation to store ice using off-peak electricity

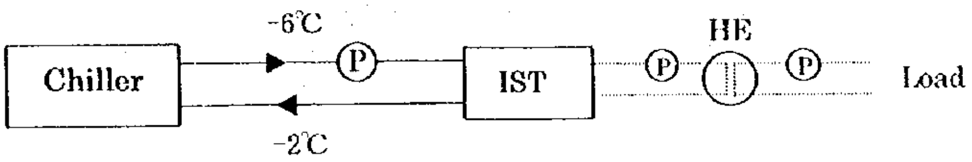
<u>Ice discharge operation</u>

Cooling energy of peak demand is taken from stored ice thermal energy to reduce the electricity of peak demand hour.

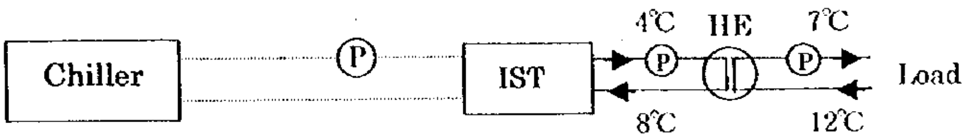
<u>Follow-up operation (Chiller plus ice discharge operation)</u>

If cooling energy is insufficient by the discharge of ice thermal energy, the chillers will be operated to compensate the insufficient capacity. The chillers will be operated as conventional A/C chiller.

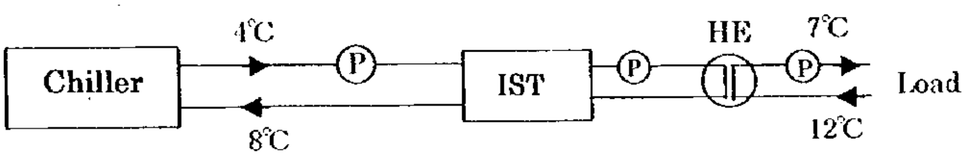
As mentioned above, ice thermal storage system can be operated as several operations by considering the cooling loads and hours, and it is the advantages of this system.



(a) Ice Storage Operation



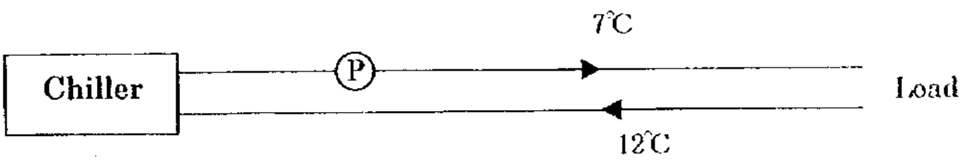
(b) Ice Discharge Operation



(c) Follow-up Operation(Chiller plus Ice Discharge Operation)

1. Concept for Operation of Thermal Storage System

Note:
The temperatures mentioned above will be fixed by actual designs.



2. Concept for Operation of Conventional A/C System

Figure 5-3-3 Comparison of Operation of Ice Thermal Storage System and Conventional A/C System

5-3-2. Investigation for Application of Ice Thermal Storage System

(1)Maximum outdoor air temperature and humidity of Muscat area

The maximum outdoor air temperature and humidity in June 5th 1996 is shown in Annex:5-2-a, and the maximum temperature is 46.9℃ and the minimum temperature is 34.5℃ respectively.

(2)Variation of power demand

The maximum power demand of the Muscat area in 1997 was August 2 as shown in Table 5-3-2, and load curve is shown Figure 5-3-4. The features of this load curve are as follows:

Two peaks occurred in the afternoon and at midnight.

The ratio of off-peak to peak was 67.5%.

Table 5-3-2 Power Demand (August 2nd 1997)

Unit: MW

Hour	1	2	3	4	5	6	7	8	9	10	11	12
MW	964	924	912	892	*841*	*738*	*730*	*763*	*803*	*819*	*836*	888

Hour	13	14	15	16	17	18	19	20	21	22	23	24
MW	961	1042	1080	1024	883	*782*	*801*	893	976	1039	1058	1037

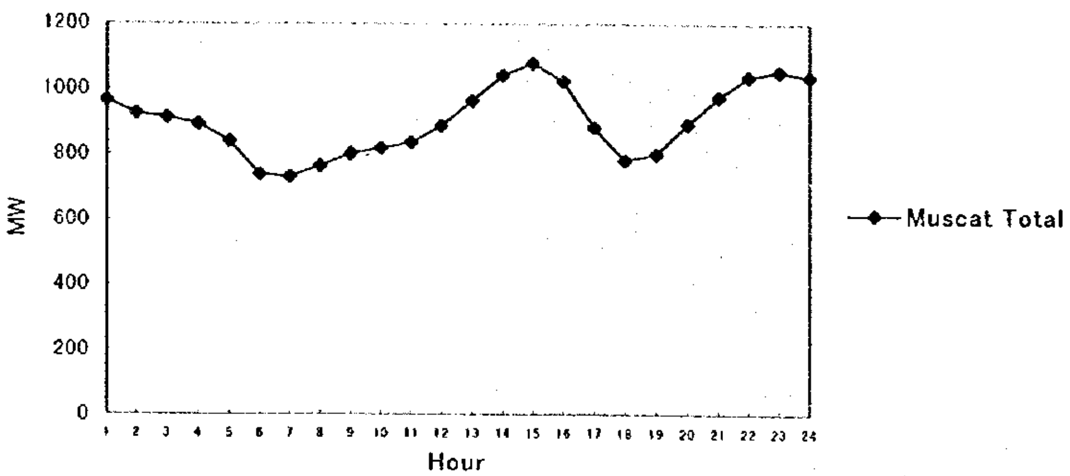


Figure 5-3-4 Load Curve of Maximum Demand in the Muscat Area (August 2nd 1997)

(3) Relationship between A/C operation and peak, off-peak power demand

The operation of A/C of the Royal Hospital, MCS (Ministry of Civil Services), MEW (Ministry of Water and Electricity), the Al Falaj Hotel and the Al Araimi Complex are summarized in Table 5-3-3. The relationship between A/C operation and power demand is clearly indicated by adding the peak and off-peak hours stated in item 5-3-2, (2) Variation of power demand.

Table 5-3-3 A/C operation and Peak, Off-peak Demand Hour

X : A/C operation hours
○ : Peak demand is presumed more than 1,000MW.
● : Off-peak demand is presumed less than 850MW.

Time	Royal Hospital	MCS	MEW	Al Falaj Hotel	Al Araimi Complex	Residential House	Peak and Off-peak Hour
1	X			X		X	
2	X			X		X	
3	X			X		X	
4	X			X		X	
5	X	X		X		X	●
6	X	X		X		X	●
7	X	X	X	X	7 : 30X	X	●
8	X	X	X	X	X	X	●
9	X	X	X	X	X	X	●
10	X	X	X	X	X	X	●
11	X	X	X	X	X	X	●
12	X	X	X	X	X	X	
13	X	X	X	X		X	
14	X	X	X	X		X	○
15	X	X	X	X		X	○
16	X	X		X	X	X	○
17	X	X		X	X	X	
18	X	X		X	X	X	●
19	X	X		X	X	X	●
20	X	X		X	X	X	
21	X			X	X	X	
22	X			X		X	○
23	X			X		X	○
24	X			X		X	○

The relationship of A/C operation hour of each facility and peak demand hour in summer is as follows.

<u>Royal Hospital</u>
A/C is 24 hour's operation and related to two peaks.

<u>MCS</u>
A/C is operated from 5am to 9pm and related to peak in the afternoon.

<u>MEW</u>
A/C operates up to 3pm and is related to peak in the afternoon slightly.

<u>Al Fajaj Hotel</u>
A/C is 24 hour's operation and related to two peaks.

<u>Al Araimi Complex</u>
A/C is operated from 7:30am to 1pm, and 4pm to 10pm respectively corresponding the

business hours. Therefore, A/C is not related to peak demand except one hour of 4pm in the afternoon.

Residential house
A/C is 24 hour's operation and related to two peaks.

(4)Power consumption of each month in 1997

The power consumption of each month may be accurate due to the difference in the date of meter reading. The monthly power consumption and ratio of each month are summarized in Table 5-3-4.

Table 5-3-4 Power Consumption of each month in 1997

Unit: kWH

	Royal Hospital		MCS		MEW		Al Fajaj Hotel	
	kWH	%	kWH	%	kWH	%	kWH	%
Jan.	1,706,530	44	89,850	43	65,490	22	243,140	46
Feb.	1,686,290	44	99,870	47	101,740	34	263,240	50
Mar.	1,876,830	49	152,200	72	106,090	36	327,450	62
Apr.	2,650,660	69	103,450	49	121,720	41	355,390	67
May	2,411,810	63	150,920	72	205,310	69	439,950	83
June	2,834,080	74	210,750	100	296,360	100	474,760	90
July	3,852,580	100	165,900	79	228,710	77	529,410	100
Aug.	3,079,290	80	155,560	74	216,160	73	491,180	93
Sep.	2,955,300	77	174,010	82	218,420	74	470,100	89
Oct.	2,746,780	71			*	*	444,120	84
Nov.	2,273,900	59	116,850	55	291,730	98	335,780	63
Dec.	2,164,180	56			108,650	37	309,800	59
Total	30,238,236				1,960,380		4,684,320	

Note: 100% shows the month of maximum power consumption in 1997
Meter reading of October at MEW is included in November.

(5)Variation of daily load current

Variations of daily load current of Bank of Dhohar Al Omani Al Fransi, Muscat Security Market and Al Falaj Hotel are shown in Table 5-3-5.

Measuring current point of Bank of Dhohar Al Omani Al Fransi and Muscat Security Market is the current of transformers, and the minimum current is about 30% of maximum current in spite of small lighting capacity. That says comparable large cooling load is required in the midnight. In case of Al Falaj Hotel, the current of chillers is measured to indicate the cooling load.

Table 5-3-5 Variation of daily load current

Objects	Bank of Dohar Al Omani Al Fransi		Muscat Securities Market		Al Falal Hotel (Old Block)			
Day	June 9,1998		June 9,1998		June 13, 1998			
Measured point	Trans. Receiving current		Trans. Receiving current		Chiller current		Outdoor temp.	Humidity
Unit	A	%	A	%	A	%	℃	%
Hour 1					66	64	33	43
2	190	33	488	49	33	32	30	39
3					32	31	30	37
4	181	31	512	52	32	31	33	34
5					32	31	35	37
6	184	32	536	54	66	64	33	34
7	504	87	732	74	67	65	35	37
8	528	91	825	84	67	65	35	
9					100	97	36	
10	565	98	873	88	102	99	38	
11	577	100	979	99	102	99	39	43
12	560	97	987	100	70	68	41	42
13					102	99	40	48
14	427	74	918	93	102	99	40	50
15					103	100	40	47
16	533	92	821	83	102	99	38	49
17					102	99	37	50
18	521	90	668	68	102	99	37	
19			715	72	69	67	36	
20	357	62	691	70	73	71	35	28
21					67	65	35	36
22	190	33	516	52	69	67	35	45
23					70	68	35	57
24	190	33	348	35	68	66	35	52

Note: 100% shows the maximum current.

5-3-3. Outdoor Air Temperature and Technical Issues for Ice Thermal Storage System

In case of high outdoor air temperature as stated item 5-3-2-(1), the following technical issues will take place.

(1)Chiller

The brine outlet temperature from the chiller will be set approximately at minus 6 degree centigrade for ice-making operation, and the efficiency of chiller is lower than conventional operation. As a result, the power consumption will increase. Therefore, ice making should be done during the period when the outdoor air temperature is low.

(2)Ice storage tank

Ice storage tank will gradually lose the stored energy due to the high outdoor air temperature. The actual energy loss is reported as 5% in Japan. More strict heat protection will be required in Oman, and the investment cost will increase.

5-3-4. Operation Mode of Ice Thermal Storage System and Incentives to the Demand Side

The supply side can give incentives to the demand side which contributes to load leveling and/or power cut operation. Before the discussion of incentives, the operation modes of ice thermal storage system will be studied.

(1)Operation mode of ice thermal discharge

There are several operation modes of ice thermal discharge.

①Load leveling operation

As illustrated in Figure .5-3-5, stored ice thermal energy discharges to all the operating hours, and load leveling will be possible to every stage, and the maximum capacity of chiller can be reduced. This operation is advantageous for the supply side and the demand side.

②Peak cut operation

As illustrated in Figure .5-3-6, stored ice thermal energy discharges to the peak demand hour to reduce the peak of electricity. In this operation, the maximum capacity of chiller can't be reduced, however, the peak demand can be reduced drastically contributing to the supply side.

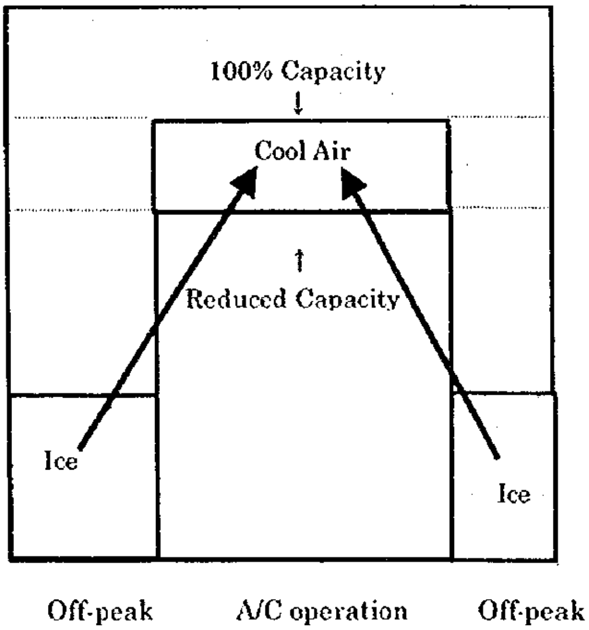


Figure 5-3-5 Load Leveling Operation

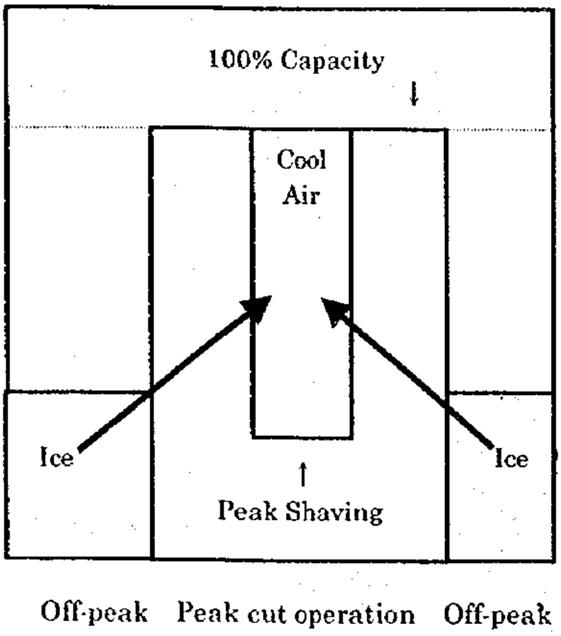


Figure 5-3-6 Peak Cut Operation

③Combined operation of load leveling and peak cut

As illustrated in Figure 5-3-7, if ice making hours are long enough and large ice storage tank are available, the combined operation with the both merits can be carried out. This operation is advantageous for the supply side as well as the demand side.

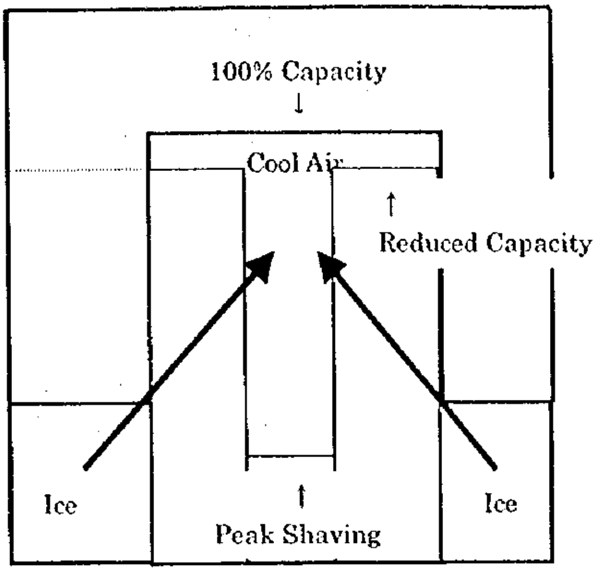


Figure 5-3-7 Combined Operation of Load Leveling and Peak Cut Operation

(2)Incentives to the demand side

The ice thermal storage system is more expensive than the conventional A/C system due to the additional equipment such as ice storage tanks, brine solution, brine circulating pumps, heat exchangers and others. Therefore, suitable incentives to the demand side are essential to promote it. The following measures will be generally considered.

①The construction of new generating station can be deferred by the load leveling and/or peak cut operation of ice thermal storage system. The investment of demand side can be partially offset by a grant method which is to be established as a reward for reducing new investments.
②Time of use (TOU) tariff, especially special discount rate for off-peak time
③Subsidized interest and tax incentive system

Among the above three items, ① grant method and ② TOU tariff seem to be reasonable and applicable measures to promote the ice thermal storage system. Cost estimate and economic analysis will be studied for above two cases.

5-3-5. Proposed System for Each Building/Facility

(1)Fundamental concept for the proposal

The Royal Hospital, MCS, the Al Falaj Hotel, the Al Araimi Complex and residential houses were investigated, and each building/facility has special conditions for the application of ice thermal storage system. Therefore, the following conditions will be considered before making a proposal for each building/facility.

- A/C is 24 hour's operation, special ideas for ice-making will be required.(Royal Hospital, Al Falaj Hotel)
- A/C is 24 hour's operation, no time to make ice. (Residential houses)
- The facility was completed recently, and the additional investment should be avoided.(MCS)
- Converting to ice thermal storage system is difficult due to the characteristics of

existing facility. (Royal Hospital)

- A/C operation mode is little related to system peak load. (MEW, Al Araimi Complex)

MEW was the candidate to survey at first, however, MCS which has recent data was selected. Furthermore, there has been no chance to survey the actual cooling load during the hottest summer season. The cooling demand for each hour will be presumed to be equal.
Proposals for each facility are as follows, which will be also applicable for the new buildings of similar size and function.

Royal Hospital
A/C operates 24 hours. The Royal Hospital has 12 sets of 270 RT chiller, among which one set is standby. Actual operating current of 12 sets in the hottest season is 485A in spite of rated current of 564A. This system has about 15% allowance, and two sets of chiller can be converted to ice thermal storage chillers.

MCS
A/C operation is from 5am to 9pm, all the chillers can be converted to ice-making system.

Al Falaj Hotel
A/C operates 24 hours. Two A/C systems of old block (2stes of 160 RT) and new block (2sets of 210 RT) are installed in this hotel, and each block operates independently. The connection of both systems is difficult for the long distance between the two blocks. It is difficult to convert one of the two sets to ice making chiller in case of such independent system. However, a new hotel of same capacity can be designed as one system, and the some allowance will be considered. In that case, one set (160 RT) of old block can be converted to ice-making chiller.

Al Araimi Complex
A/C is operated from 7:30am to 1pm, and 4pm to 10pm considering the shopping hours respectively. Therefore, A/C is not related to peak demand except one hour of 4pm in the afternoon. Moreover, the A/C system for the dome is concentrated type, and each tenant has independent A/C system. Further study is meaningless.

Residential Houses
A/C operates 24 hours and has no chance to make ice. If it is forced to make ice, a larger capacity of chiller and/or or independent ice-making chiller is required, and it is meaningless from economic and technical viewpoint.

Specifications of ice thermal storage system, operation mode and power consumption
The outline of the Royal Hospital, MCS and the Al Falaj Hotel are indicated Table 5-3-5 and Table 5-3-14, and the operation mode and power consumption are shown in related documents.

5-3-6. Cost Estimate and Economic Analysis

(1)Methods of cost estimate and economic analysis

Cost estimate and economic analysis will be carried out for following two cases.

Case 1 Grant method for reduced peak electricity by peak cut operation

Case 2 TOU tariff for load leveling operation

(2)Case 1 Grant method for reduced peak electricity by peak cut operation

Conditions to be applied

- Ice making hours of 4.5 hours at off-peak time
- Ice discharging hours of 3 hours at peak time

Grant for reduced peak electricity by peak cut operation to be based on the unit construction cost of gas turbine.

- Present electricity rate

①Specifications of ice thermal storage system, operation mode and power consumption

Table 5-3-6 Specifications of Ice Thermal Storage System for each Facility at Peak Cut Operation

	Royal Hospital	MCS	Al Falaj Hotel
Existing Facility (Chiller)	12 x 270 RT	3 x 150 RT	2 x 210 RT 2 x 160 RT
Chillers converted to ice thermal system	2 x 270 RT	3 x 150 RT	1 x 160 RT
Ice storage tank capacity (m^3)	120	100	35
Ice making hours(h)	4.5	4.5	4.5
Ice discharge hours(h)	3 (from 2pm to 5pm)	3 (from 2pm to 5pm)	3 (from 2pm to 5pm)
Reduced peak electricity by peak cut operation(kW)	740	614	215
Reference Operation mode • Power consumption	Annex:5−3−a Annex:5−3−b		

②Parameters of economic analysis

Economic analysis is based on the NPV (Net Present Value) method, which compares the benefits derived from the facility and the associated costs over a long period of time. In this case, the cost and benefit are as follows:

Cost = Investment of ice thermal storage system - Grant for reduced peak electricity + Operation & maintenance cost + Power consumption of ice making + Power consumption of brine circulating pump for ice thermal discharge

Benefit = Investment of conventional A/C system + Operation & maintenance cost + Power consumption of conventional A/C system

The following assumptions will apply.

- Grant for reduced peak electricity will be based on the unit construction cost of gas turbine by recent tender (160RO/kW).
- The costs of energy generating parts (chiller, ice storage tank, heat exchanger) between ice thermal storage system and the conventional A/C system are compared, but the cost of air handling units, control system and piping from the

energy generating parts are not considered because of same specifications for both systems.

- Life year is 15 years.
- Taxes are not included.
- Peak period of 100Days

③Royal Hospital(Case 1)

a. Investment

Investment costs for equipment, installation and testing are estimated as follows.

Table 5-3-7 Comparison of Investment for Royal Hospital (Peak Cut Operation)

Unit: RO

	Ice thermal system(A)	Conventional A/C system(B)	Difference (A-B)
Equipment	260,000	167,000	93,000
Chiller			
Tanks, brine			
Pumps, heat exchanger			
Piping, insulation			
Power & control panel			
Installation, testing	50,000	27,000	23,000
Total	310,000	194,000	116,000

b. Operation & maintenance

Operation & maintenance cost is estimated as 0.8% of ice thermal storage system and 1.0% of conventional A/C system for the investment cost respectively.

c. Electricity cost

Electricity of Cost side = {(Power consumption of ice-making (4.5h) + Power consumption of brine circulating pump for ice thermal discharge(3h))} x 100days x 0.03 RO/kWh
= { 700kW/h x 4.5h + 40kW/h x 3h} x 100 x 0.03 RO/kWh
= 9,810 RO

Electricity of Benefit side = Power consumption of conventional A/C operation (3h) x 100 days x 0.03 RO/kWh
= 780kW/h x 3h x 100 x 0.03 RO/kWh
= 7,020 RO

d. Grant for reduced peak electricity (included in Cost side)

Grant = Reduced peak electricity (Power consumption of conventional A/C operation-Power consumption of brine circulating pump) x unit construction cost of
gas turbine
= (780−40)kW x 160 RO/kW
= 118,400RO

The summary of above calculation and basic data for calculation of NPV are shown in Table 5-3-8.

Table 5-3-8 Summary of Costs and Benefits for Royal Hospital (Peak Cut Operation)

Unit : RO

	Cost Side (Ice Thermal storage system)					Benefit Side (Conventional A/C system)			
Year	Investment	O&M	Electricity	Grant(-)	Total	Investment	O&M	Electricity	Total
0	310,000			-118,400	191,600	194,000			194,000
1		2,480	9,810		12,290		1,940	7,020	8,960
2		2,480	9,810		12,290		1,940	7,020	8,960
3		2,480	9,810		12,290		1,940	7,020	8,960
4		2,480	9,810		12,290		1,940	7,020	8,960
5		2,480	9,810		12,290		1,940	7,020	8,960
6		2,480	9,810		12,290		1,940	7,020	8,960
7		2,480	9,810		12,290		1,940	7,020	8,960
8		2,480	9,810		12,290		1,940	7,020	8,960
9		2,480	9,810		12,290		1,940	7,020	8,960
10		2,480	9,810		12,290		1,940	7,020	8,960
11		2,480	9,810		12,290		1,940	7,020	8,960
12		2,480	9,810		12,290		1,940	7,020	8,960
13		2,480	9,810		12,290		1,940	7,020	8,960
14		2,480	9,810		12,290		1,940	7,020	8,960
15		2,480	9,810		12,290		1,940	7,020	8,960
Total	310,000	37,200	147,150	-118,400	375,950	194,000	29,100	105,300	328,400

e. Evaluation

As shown in Table 5-3-9, NPV is negative and the value of B/C is 0.912. Even with the grant, there is no economic advantage in choosing ice thermal storage system.

Table 5-3-9 Calculation of NPV for Royal Hospital (Peak Cut Operation)

Unit : RO

	Cost Side (Ice Thermal storage system)	Benefit Side (Conventional A/C system)	NPV (B−C)	B/C
Present Value	296,796	270,693	−26,103	0.912

④MCS (Case 1)

a. Results of Calculation

The same calculation is carried out. Only the first year cost is shown for reference.

Table 5-3-10 Summary of Cost Side and Benefit Side for First Year in MCS

Unit : RO

	Cost Side (Ice Thermal storage system)					Benefit Side (Conventional A/C system)			
Year	Investment	O&M	Electricity	Grant(-)	Total	Investment	O&M	Electricity	Total
0	267,000			-98,240	168,760	170,000			170,000
1		2,320	8,424		10,744		1,700	5,850	7,550

b. Evaluation

As shown in Table 5-3-11, NPV is negative and the value of B/C is 0.900, which means there is no advantages to adopt ice thermal storage system.

Table 5-3-11 Calculation of NPV for MCS (Peak Cut Operation)

Unit : RO

	Cost Side (Ice Thermal storage system)	Benefit Side (Conventional A/C system)	NPV (B−C)	B/C
Present Value	260,723	234,624	−26,099	0.900

⑤Al Falaj Hotel (Case 1)

a. Result of Calculation

The same calculation is carried out. Only the first year cost is shown for reference.

Table 5-3-12 Summary of Cost Side and Benefit Side for First Year in Al Falaj Hotel

Unit : RO

	Cost Side (Ice Thermal storage system)					Benefit Side (Conventional A/C system)			
Year	Investment	O&M	Electricity	Grant(-)	Total	Investment	O&M	Electricity	Total
0	107,000			-34,400	72,600	69,000			69,000
1		856	1,890		2,746		690	1,380	2,070

b. Evaluation

As shown in Table 5-3-13, NPV is negative and the value of B/C is 0.902 which means there is no advantages to adopt ice thermal storage system.

Table 5-3-13 Calculation of NPV for Al Falaj Hotel (Peak Cut Operation)

Unit : RO

	Cost Side (Ice Thermal storage system)	Benefit Side (Conventional A/C system)	NPV (B−C)	B/C
Present Value	96,104	86,718	−9,386	0.902

(3)Case 2 TOU tariff for load leveling operation

①Conditions to be applied

- No grant for reduced peak electricity by load leveling operation
- TOU tariff to be applied
  Royal Hospital and MCS: 30Bz/kWh at day time and 10Bz/kWh at other period
  Al Falaj Hotel: 20Bz/kWh at day time and 10Bz/kWh at other period
- TOU period of 180days
- Ice making hours of 8 hours (except MCS of 4.5 hours) at off-peak time
- Ice discharging hours of 10 hours at day time
- Chiller capacity to be reduced by ice discharge operation.

Other conditions are same as Case 1.

②Specifications of ice thermal storage system, operation mode and power consumption

Table 5-3-14 Specifications of Ice Thermal Storage System for each Facility at Load Leveling Operation

	Royal Hospital	MCS	Al Falaj Hotel
Existing Facility (Chiller)	12 x 270 RT	3 x 150 RT	2 x 210 RT 2 x 160 RT
Chillers converted to ice thermal system	2 x 270 RT	3 x 150 RT	1 x 160 RT
Capacity of new chillers	2 x 190 RT	2 x 125 RT	1 x 105 RT
Ice storage tank capacity (m^3)	150	90	40
Ice making hours(h)	8	4.5	8
Ice discharge hours(h)	10	10	10
Reduced peak electricity by load leveling operation	270	140	70
Reference Operation mode ・ Power consumption	Annex:5－3－c Annex:5－3－d		

③Parameters of economic analysis

Economic analysis is based on the NPV (Net Present Value) method, which compares the benefits derived from the facility and the associated costs over a long period of time. In this case, the cost and benefit are as follows:

Cost = Investment of ice thermal storage system + Operation & maintenance cost + Power consumption of ice making + Power consumption of brine circulating pump for ice thermal discharge + power consumption of follow-up operation

Benefit = Investment of conventional A/C system + Operation & maintenance cost + Power consumption of conventional A/C system

④Royal Hospital(Case 2)

a. Investment

Investment costs for equipment, installation and testing are estimated as follows.

Table 5-3-15 Comparison of Investment at Royal Hospital (Load Leveling Operation)

Unit: RO

	Ice thermal system (A)	Conventional A/C system (B)	Difference (A-B)
Equipment	228,000	167,000	61,000
Chiller			
Tanks, brine			
Pumps, heat exchanger			
Piping, insulation			
Power & control panel			
Installation, testing	46,000	27,000	19,000
Total	274,000	194,000	80,000

b. Electricity cost

Electricity of Cost side = {Power consumption of ice-making(8h)x0.01RO/kWh + {Power consumption of brine circulating pump for ice thermal discharge (10h))+Power consumption of follow-up operation(10h)} x 0.03 RO] x180days
480kWhx10h} x0.03RO/kWh }x 180days
= 34,740 RO

Electricity of Benefit side = Power consumption of conventional A/C operation (10h) x 180 days x 0.03 RO/kWh
= 780kW/h x 10h x 180 x 0.03 RO/kWh
= 42,120 RO

The summary of above calculation and basic data for calculation of NPV is indicated in Table 5-3-16.

Table 5-3-16 Summary of Costs and Benefits for Royal Hospital(Load Leveling Operation)

Unit : RO

	Cost Side (Ice Thermal storage system)				Benefit Side (Conventional A/C system)			
Year	Investment	O&M	Electricity	Total	Investment	O&M	Electricity	Total
0	274,000			274,000	194,000			194,000
1		2,190	34,740	36,930		1,940	42,120	44,060
2		2,190	34,740	36,930		1,940	42,120	44,060
3		2,190	34,740	36,930		1,940	42,120	44,060
4		2,190	34,740	36,930		1,940	42,120	44,060
5		2,190	34,740	36,930		1,940	42,120	44,060
6		2,190	34,740	36,930		1,940	42,120	44,060
7		2,190	34,740	36,930		1,940	42,120	44,060
8		2,190	34,740	36,930		1,940	42,120	44,060
9		2,190	34,740	36,930		1,940	42,120	44,060
10		2,190	34,740	36,930		1,940	42,120	44,060
11		2,190	34,740	36,930		1,940	42,120	44,060
12		2,190	34,740	36,930		1,940	42,120	44,060
13		2,190	34,740	36,930		1,940	42,120	44,060
14		2,190	34,740	36,930		1,940	42,120	44,060
15		2,190	34,740	36,930		1,940	42,120	44,060
Total	274,000	32,850	521,100	827,950	194,000	29,100	631,800	854,900

c. Evaluation

As shown in Table 5-3-17, NPV is negative and the value of B/C is 0.968 and there is no economic advantage in choosing ice thermal storage system.

Table 5-3-17 Calculation of NPV for Royal Hospital (Load Leveling Operation)

Unit : RO

	Cost Side (Ice Thermal storage system)	Benefit Side (Conventional A/C system)	NPV (B−C)	B/C
Present Value	590,102	571,131	−18,971	0.968

⑤MCS (Case 2)

a. Results of Calculation

The same calculation is carried out. Only the first year cost is shown for reference.

Table 5-3-18 Summary of Cost Side and Benefit Side for First Year in MCS

Unit : RO

	Cost Side (Ice Thermal storage system)				Benefit Side (Conventional A/C system)			
Year	Investment	O&M	Electricity	Total	Investment	O&M	Electricity	Total
0	234,000			234,000	170,000			170,000
1		1,870	31,590	33,460		1,700	35,100	36,800

b. Evaluation

As shown in Table 5-3-19, NPV is negative and the value of B/C is 0.932, which means there is no advantages to adopt ice thermal storage system.

Table 5-3-19 Calculation of NPV for MCS (Load Leveling Operation)

Unit : RO

	Cost Side (Ice Thermal storage system)	Benefit Side (Conventional A/C system)	NPV (B−C)	B/C
Present Value	520,400	484,989	−35,411	0.932

⑥Al Falaj Hotel (Case 2)

a. Result of Calculation

The same calculation is carried out. Only the first year cost is shown for reference.

Table 5-3-20 Summary of Cost Side and Benefit Side for First Year in Al Falaj Hotel

Unit : RO

	Cost Side (Ice Thermal storage system)				Benefit Side (Conventional A/C system)			
Year	Investment	O&M	Electricity	Total	Investment	O&M	Electricity	Total
0	95,000			95,000	69,000			69,000
1		760	7,690	8,450		690	8,280	8,970

b. Evaluation

As shown in Table 5-3-21, NPV is negative and the value of B/C is 0.871 which means there is no advantages to adopt ice thermal storage system.

Table 5-3-21 Calculation of NPV for Al Falaj Hotel (Load Leveling Operation)

Unit : RO

	Cost Side (Ice Thermal storage system)	Benefit Side (Conventional A/C system)	NPV (B−C)	B/C
Present Value	167,328	145,779	−21,549	0.871

5-3-7. Conclusion

The economic analysis was carried out for two cases, one is of grant method for reduced peak electricity by peak cut operation (Case 1), and the other is TOU tariff for load leveling operation (Case 2). The values of B/C for both cases are less than 1.0, and the ice thermal storage system is still not economical compared with the conventional A/C system. However, the value of B/C for case 2 is close to 1.0, therefore, the ice thermal storage system may be realized if the suitable measures to be taken.

Case 1—Grant method for reduced peak demand by peak cut operation

	Royal Hospital	MCS	Al Falaj Hotel
B/C	0.912	0.900	0.902

Case 2—TOU tariff for load leveling operation

	Royal Hospital	MCS	Al Falaj Hotel
B/C	0.968	0.932	0.87

Note: Applicable TOU tariff
Royal Hospital and MCS: 30Bz/kWh at day time and 10Bz/kWh at other period
Al Falaj Hotel: 20Bz/kWh at day time and 10Bz/kWh at other period

The main reasons why ice thermal storage system are not economical are as follows.

(1)The ratio of peak and off-peak demand is approximately 68%, which is not so big compared with about 45% in Japan. Load curve is so complicated;- there are two peak demands and two off-peak demands every day, and ice making hours are so limited.

(2)The unit construction cost of gas turbine of 160 RO/kW is low compared with nuclear and large thermal power stations, therefore, the amount of the grant is not sufficient for offsetting the additional cost of ice thermal storage system.

(3)The value of B/C for Al Falaj Hotel at TOU tariff for load leveling operation is lower than other cases because of their electricity tariff is 20Bz/kWh.

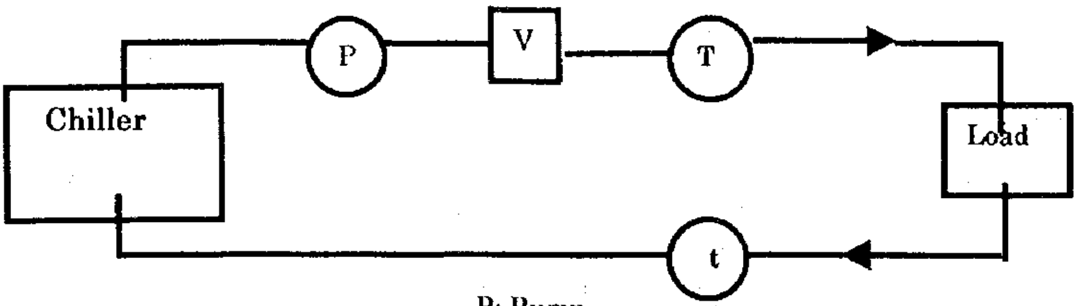
5-3-8. Future Measures for A/C System and Energy Saving Policy

As stated in item 5-3-2 (5) Variation of daily load current, approximate 30% of peak current remains in the midnight for A/C system. In order to design an accurate A/C system and to establish the energy saving policy, it is recommendable to measure the thermal load capacities for one of governmental buildings, commercial buildings, hotels or hospitals and private houses for several years. With these data, more concrete discussions would become possible. The concept of measurement is illustrated in Figure 5-3-8 and thermal load capacity will be calculated by the following formula.

$$Q = K \times V \times (t-T)$$

Where,

Q: Thermal capacity
K: Factor
V: Quantity of chilled water
t: Outlet temperature of chilled water
T: Inlet temperature of chilled water



P: Pump
V: Quantity of chilled water (m^3/h)
T: Inlet temperature (℃)
t: Outlet temperature (℃)

Figure 5-3-8 Concept of measurement for thermal capacity

5-4. Photovoltaic Power Generation

5-4-1. Solar Energy

(1) Maximum Available Energy

Solar energy is a clean, natural and renewable energy, and, of course, it is effective in saving energy resources. It is also said to be friendly to the environment. In recent years, with the growing concern over global environmental issues, solar energy is attracting a lot of attention. Energy radiated by the sun onto the earth is about 1kW per square meters. This energy can be converted by Photovoltaic (PV) generation (generation with solar cells) into electric energy of 0.1 kW per square meters. This relationship is shown in Figure 5-4-1. PV generator is used world wide in many applications, from niche markets in developed countries to primary village power in developing countries where grid connection is too expensive.

Stand-alone PV system can be used for water pumping, cathodic protection, telecommunications, lighting and small appliances. Utilities are also using PV in many applications, including large centralized generation. For Demand Side Management (DSM) , PV has particular value because it produces power for the grid at the time of the utilities peak demand.

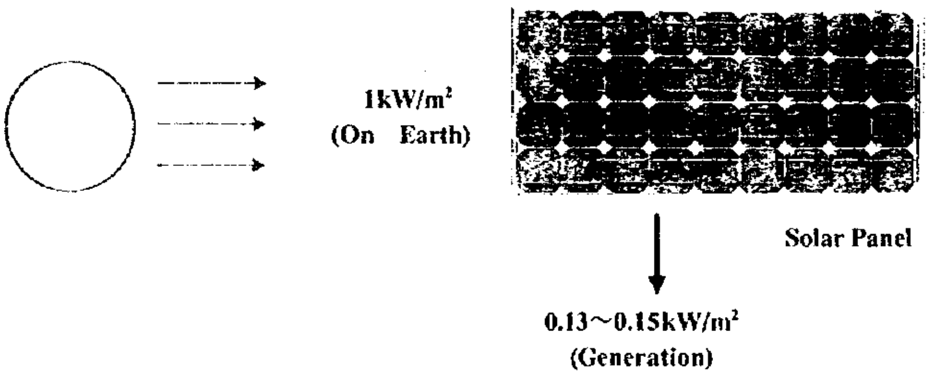


Figure 5-4-1 Solar Energy

This energy is abundant and will be attractive to Oman where land space is large relative to the population. Given the fact that the present maximum electricity demand in Oman is 1,000 MW, we can meet this demand by using solar cells of the which total area is 10 million square meters (10 square kilometers). These solar cells cover an area of about 3.2 km× 3.2 km.

(2) Available Energy

The available energy discussed above is the maximum energy to be generated by solar cells. There are, of course, cloudy or rainy days and no sunshine at night. According to solar panel manufacturers' data, shown in Table 5-4-1, the plant factor of a photovoltaic system is about 13 % in Japan.

Table 5-4-1 Basic data of Solar Power System

Capacity(kW) (1)	1.33	2.04	3.06	4.08	5.35	2.57	3.19	4.32
Standard Installation Area (m^2)	12	17	26	34	45	21.4	26.7	35.6
Yearly Generation Energy (kWh/year)(2)	1543	2365	3552	4736	6210	2986	3705	5020
Plant Factor ((2)/[(1)x8760])	0.13							

5-4-2. Configuration of Photovoltaic System

(1) Interconnected Type to Commercial System

A normal configuration of a photovoltaic system of this interconnected type is shown in Figure 5-4-2. DC power is generated by solar cells and supplied to an inverter. The DC power is converted into AC power so that it can be used for household loads or connected to commercial power grids. A battery system may be connected, as an option, to the DC circuit. The power can be stored in this battery system so that the surplus power of solar generation can be used more effectively.

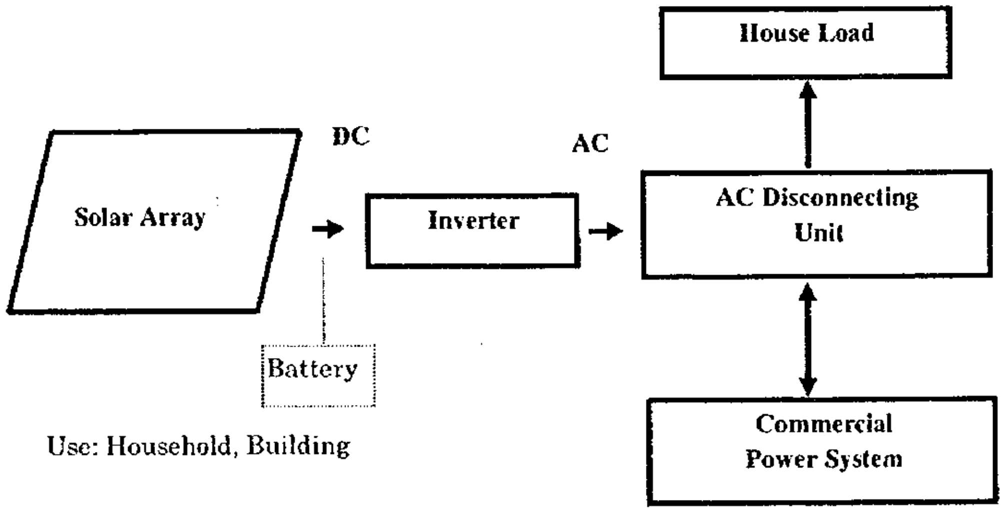


Figure 5-4-2 Configuration of Interconnected Type to Commercial System

In case of grid connection, surplus electricity during the daytime can be sold to the utilities and, in return, necessary electricity is purchased from the utilities during the night time. This mechanism is shown in Figure 5-4-3. From the view point of DSM, photovoltaic generation is effective as a means of peak demand shaving, because the system's peak hours coincide with the peak time of solar power generation.

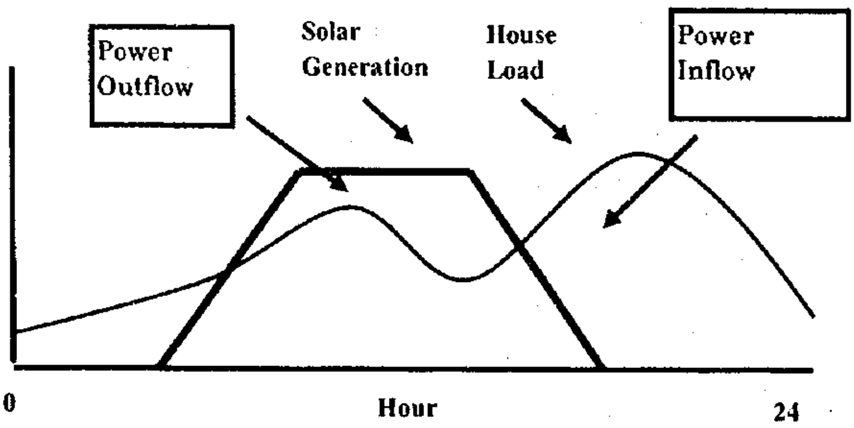


Figure 5-4-3 Solar Generation and Load

(2) Stand-alone Type

This type is separated from the commercial power system and electric power supplied to the load is only from the solar system. The battery system is necessary to supply constant power during poor weather or at night.

There are two types of DC and AC, as shown in Figure 5-4-4 and 5-4-5, in this stand-alone type.

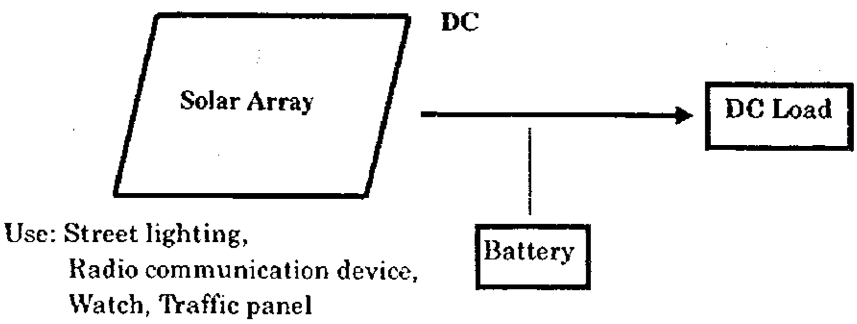


Figure 5-4-4 Configuration of DC Stand-alone Type

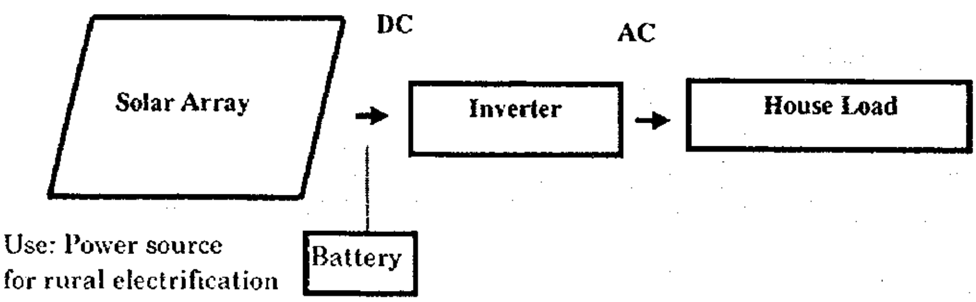


Figure 5-4-5 Configuration of AC Stand-alone Type

5-4-3. Economy of Photovoltaic System

(1) Conditions Assumed

The following conditions are assumed in the economic evaluation of a photovoltaic system.

①Life : Twenty years(from 1998 to 2018)

Method: A solar system is assumed to be built in 1998, and the benefits/costs of net present value during this period were compared.

- Social discount rate: 8%
- Construction cost: 2,980 RO/kW (current actual cost including inverter in Japan) or less
- Maintenance costs: 1 % of construction costs.
- Plant factor: 19 % (43% higher than 13% in Japan)

(Explanation)

Sunshine in Japan; 13.62 MJ/m^2/d (at Hiroshima, corresponding to plant factor 13%)

Sunshine in Oman; 19.43 MJ/m^2/d (Average of 7 places data)

13%×19.43/13.62=19%

(Sunshine data: NEDO report)

- Benefit: Real electricity tariff 10 or 30 Bz/kWh etc.

Benefit=Tariff (Bz/kWh) ×Solar generation (kWh/year)

Solar generation (kWh/year) =System output (kW) ×Plant factor×8,760(hrs/year)

②Electricity tariff

10 or 30 Bz/kWh: minimum or maximum level for house hold or government use.

(Reference) Merit by Reduction of CO_2 release

The release value of some fuels is shown in Table 5-4-2. From this table, a reduction of 0.162 kg-C/kWh([0.178-0.016] kg-C/kWh) is possible by substituting photovoltaic energy for natural gas. This monetary value of reduction will be determined in the market and, therefore, it is not clear now. But it is estimated to be a few dollars or a few tens of dollars per 1 ton of carbon release reduction, which is negligible as a benefit of photovoltaic.

Table 5-4-2 Unit Release Value of C in Generation Equipment Life Cycle

Fuel of power generation	CO_2 Release quantity (kg-C/kWh)
LNG Thermal	0.178
Oil Thermal	0.200
Coal Thermal	0.270
Nuclear	0.0057
Photovoltaic	0.016

(2) Financial Analysis

The results of calculation are shown in Table 5-4-3 and Figure 5-4-6.

- Investments can not be recovered from the merits of tariff at the present levels of system costs, 2,980 RO/kW, in Japan.
- With the level, in the near future, of system costs at 596 to 894 RO/kW, the

investment can be expected to be recovered from more than 30 Bz/kWh of most expensive tariff at present.

Table 5-4-3 Construction Cost and Economical Estimation of PV system.

100 kW, 20 years, NPV

Const. Cost (RO/kW)	Cost (10^3 RO)	Benefit(10^3 RO)		B/C	
		10Bz/kWh	30Bz/kWh	10Bz/kWh	30Bz/kWh
298	32.7	16.8	49	0.51	1.50
596	65.5	16.8	49	0.26	0.75
894	98.2	16.8	49	0.17	0.50
1192	130.9	16.8	49	0.13	0.37
1490	163.7	16.8	49	0.10	0.30
1788	196.4	16.8	49	0.09	0.25
2086	229.1	16.8	49	0.07	0.21
2384	261.8	16.8	49	0.06	0.19
2682	294.6	16.8	49	0.06	0.17
2980	327.3	16.8	49	0.05	0.15

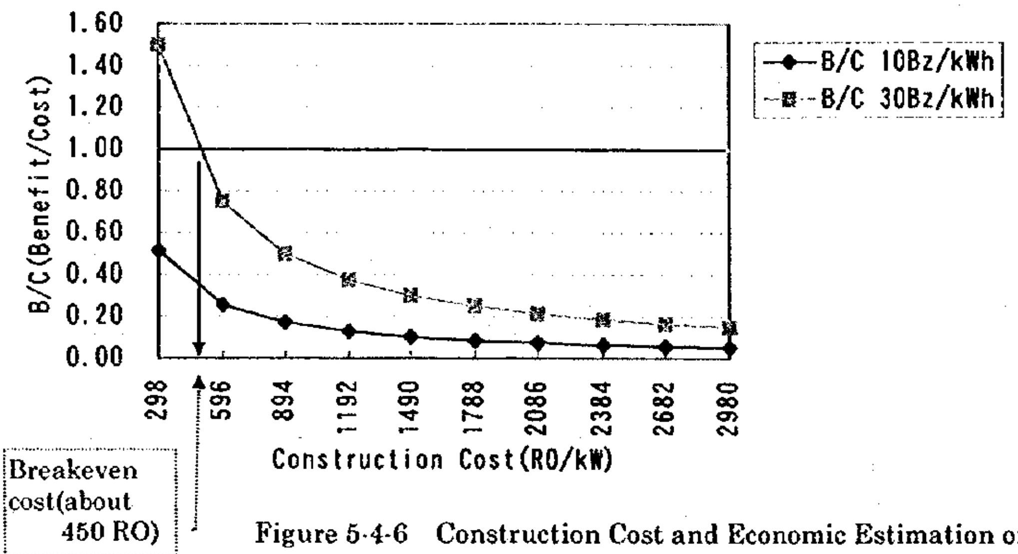


Figure 5-4-6 Construction Cost and Economic Estimation of Photovoltaic System

Therefore, much subsidy will be necessary to introduce the photovoltaic system from the view point of environment problems. For example, in the case of 30 Bz/kWh, the break even cost is about 450 RO/kW from Table 5-4-3. At the present level of system costs 2,980 RO/kW in Japan, about 85% (2,530 RO/kW) of subsidy is needed.

5-4-4. Photovoltaic Application in Oman

From the previous study, it is clear that introducing a photovoltaic system with the present construction costs and the merits of tariff in Oman will be difficult. In other words, it is difficult to install the system in the city or town electrified by the present power system. Therefore, we consider the case that it is expensive to supply electricity. For example, this is the case to electrify the local district far from the present power system. Long distribution line necessary, in comparison with its load, to supply electricity and the real supply costs (Bz/kWh) will be much more expensive.

From here, we compare the supply costs for both the photovoltaic generation and the long distribution line construction. Use of supply costs is useful for comparing installations with different life times.

(1) Generation costs of photovoltaic generation system

Table 5-4-4 and Figure 5-4-7 show the calculation result based on the condition in the Term 5-4-3(1).

Table 5-4-4 Construction Cost and Generation Cost.

Construction Cost (RO/kW)	Generation Cost (Bz/kWh)	Generation Cost (Incl. Battery.:+20%) (Bz/kWh)
298	19.7	23.6
596	39.4	47.3
894	59.1	70.9
1192	78.8	94.5
1490	98.5	118.2
1788	118.2	141.8
2086	137.9	165.4
2384	157.6	189.1
2682	177.3	212.7
2980	196.9	236.3

Generation Cost = Construction Cost*(crf+M&O Rate)/(8760*Plant Fact.)

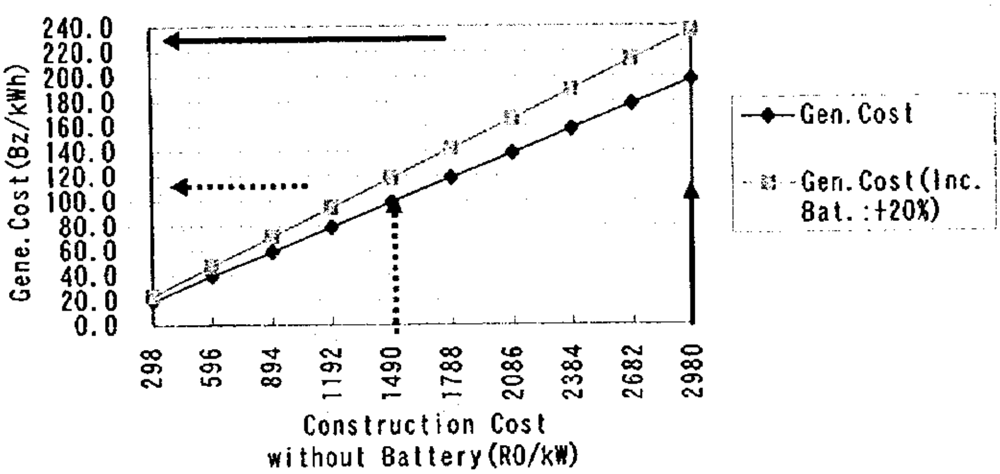


Figure 5-4-7 Generating Cost of Photovoltaic System

With regard to the stand-alone type with battery for rural electrification, its construction cost is more expensive, by 20%, than the one without battery. From Figure 5-4-6, it is clear that the photovoltaic system will be reasonable only when the supply cost is about 10 times(240 Bz/kWh) the present tariff level.

(2) Electricity supply costs by distribution line

The additive cost by construction of distribution depends on the line's length(km) and load(kWh) which connects to the line. Therefore, the result in Table 5-4-5 and Figure 5-4-7 were obtained based on the assumptions as follows:

- Distribution construction cost: 6,000 RO/km at 11kV (Asset assessment in Oman)
- Load scale: 6,000 kWh/Demand/year (One half of average household in Oman)
- Connections : 20, 40, 200

Here, the 20 connections corresponds to less than 1 % of the distribution feeder load in the city. (In city, peak feeder load; 2,000 to 4.000 kW and load factor; 70% gives 12 to 25 GWh/year consumption.)

Table 5-4-5 Supply Cost by Distribution Line

(Bz/kWh)

L(km)	Demand Number 20	Number 40	Number 200		
				Construction Cost	6000 RO/km
				Crf (40y,8%)	0.084
10	42	21	4.2	Load/Demand	6000 kWh/y/Demand
20	84	42	8.4		
30	126	63	12.6		
40	168	84	16.8		
50	210	105	21		
60	252	126	25.2		

Distribution Cost(Bz/kWh)=Const.Cost*L*crf/(Load/Demand)/Demand Number*1000

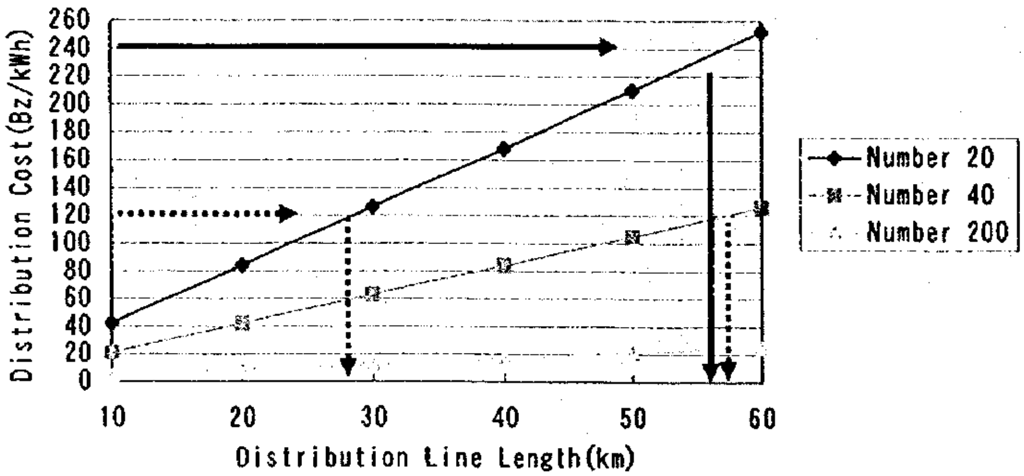


Figure 5-4-8 Supply Cost by Distribution Line

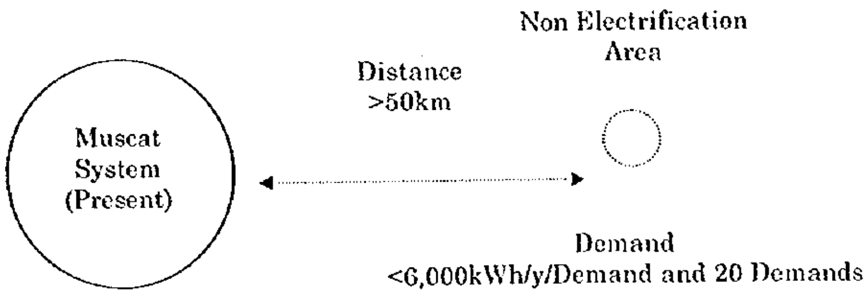
From Figure 5-4-7, generation cost of about 200 Bz/kWh(based on present construction cost level) is equal to the supply cost of 20 connections(0.12 GWh/year) and 50 km of distribution line. In the future, if the construction costs of photovoltaic system are reduced by 50 %, it will be reasonable in the case of 20 connections and even 30 km of distribution line or in the case of 40 connections and 50 km line.

(3) Example of Photovoltaic Generation System

In Oman, about 20% of the country's area is not yet electrified. Then, it might be possible to introduce a photovoltaic system to such an area. From the previous analysis, in the case of more than 50 km of distribution line and 0.12 GWh/year (6,000 kWh/Demand/year×20 connections), the photovoltaic system will be reasonable. In this case, an AC type of stand-alone (Figure 5-4-5) is useful and its capacity is calculated about 5kW as follows considering the battery charge-discharge efficiency of 0.7;

- 6,000(kWh/Demand/year)/8760(hrs)/0.19(plant factor)/0.7=5.1 kW≒5kW.

This system scale is similar to that widely used in Japan. (See Figure 5-4-9 and Table 5-4-6)



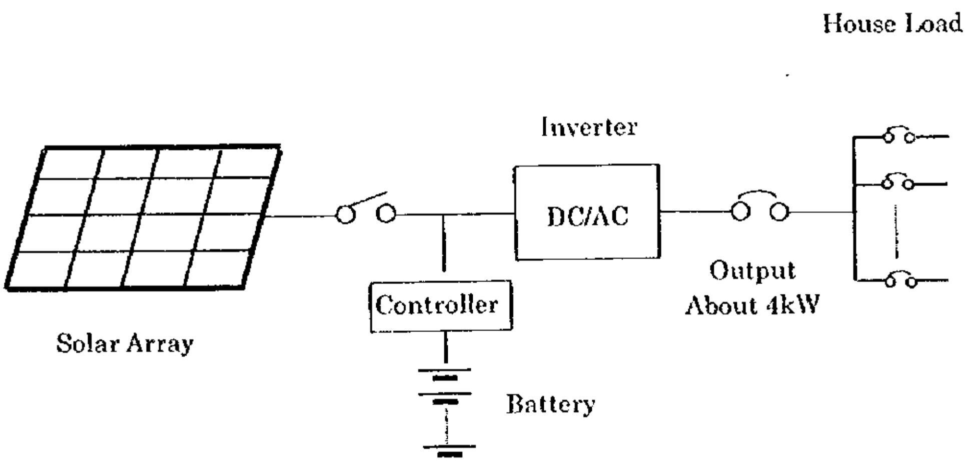


Figure 5-4-9 Example of System Configuration

Table 5-4-6 Example of Specifications in Japan

(Interconnection type without battery)

Item	Explanation
Solar Equipment	Module Maximum Output: 85 W Module Number: 56 Array Maximum Output: 4.76 kW Area: About 37 m^2 ($0.66m^2 \times 56$)
Inverter (with Protection Devices)	Rated Output: 4.5 kW
Installation of Solar Equipment	On the roof of existing house.

Construction cost: 15,000 RO, One third is supplied as subsidy.