# Assessment of drastic peak demand reduction by gas cooling in Japan

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## Keywords

peak demand, gas cooling, $CO_2$ reduction, load diversity factor, gas fired absorption chiller-heater (GACH), part load efficiency, gas engine heat-pump (GHP), air-source heat pump (ASHP), cooling load diversity factor (CLDF), building peak electricity density (BPED), building electricity load factor (BELF), grid peak electricity density (GPED)

## Abstract

Electricity peak demand reduction by gas cooling has been successfully implemented for 40 years in Japan and more than ten million RT(refrigeration ton) (3.5 million kW) gas cooling was introduced by the end of FY 2002. This big amount of gas cooling contributes not only to reduce electricity peak demand but also to conserve energy, to reduce $CO_2$, CFCs, first and running cost.

In this paper, we first evaluated the contribution of gas cooling for peak demand reduction. In the first place, we surveyed peak electricity demand which were either air-conditioned by electricity or gas and showed the effect of gas cooling on buildings peak demand reduction in summer. Peak demand reduction for electric grid was also estimated by taking cooling load diversity factor (CLDF) into consideration and finally the rate of reduction was assessed.

Secondly, we evaluated the contribution of gas cooling to energy conservation for many types of buildings by developing a customized software PEACS to estimate annual energy consumption of various kinds of air-conditioning systems. Owing to continuous technical developments of gas cooling, it showed the advantage over alternative systems in many cases. $CO_2$ reduction was estimated by the difference of aforementioned annual energy consumption.

Thirdly, we carried out the economic comparison among various kinds of air-conditioning systems and showed the cost-effectiveness of gas cooling.

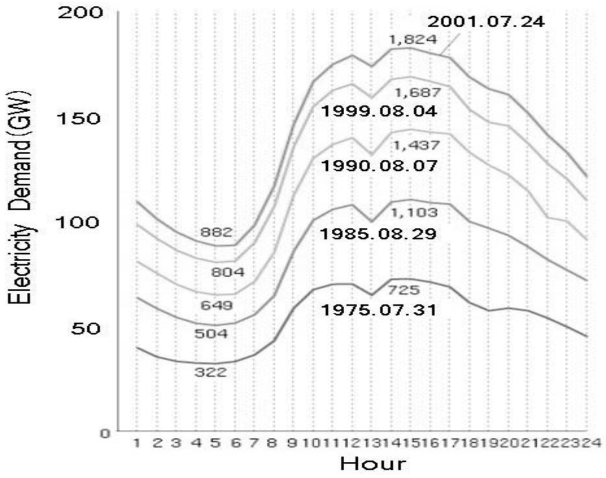
The result of these analyses suggests that gas cooling is a good solution for many other countries who are suffering electricity shortage in kW as well as kWh.

## Introduction

In many industrialized countries, air-conditioning has been becoming popular because of heat island phenomenon in densely populated cities, improvement of standard of living, increase of office automation devices and buildings floor area. In Japan, air-conditioning technology has been introduced about fifty years ago and began to be popularized in 1940's causing high peak electricity demand in summer. Peak electricity demand in summer gave birth to more investment in power plant, the decrease of load factor of electricity, the decrease of overall thermal and economical efficiency. On the other hand, gas utilities suffered low gas send out in summer and load factor of city gas has been declining.

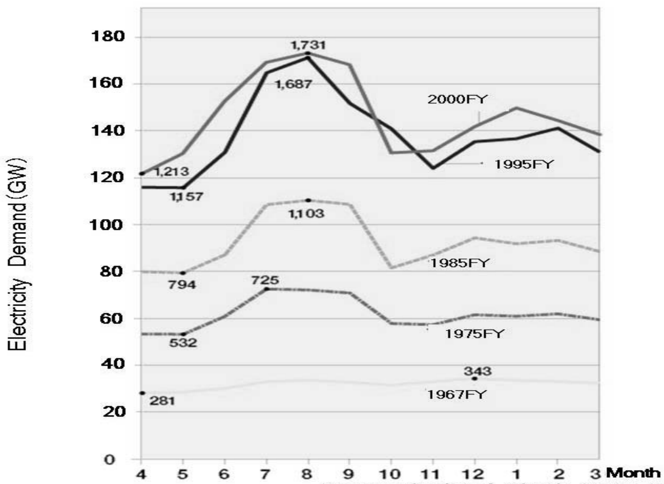
In order to rectify these situation, Japanese government introduced a policy to stimulate gas cooling in 1976 and the cooling capacity reached as much as 10 million RT (refrigeration ton) (3.5 million kW) and accounted for 21 percent of nationwide cooling capacity by the end of FY 2002 owing to government incentives, research and development of gas-fired air conditioners and appropriate tariff schemes.

In this paper, we analyzed the contribution of gas cooling to reduce electricity peak demand for buildings and grids,




*Source :Federation of Electric Power Companies of Japan*

***Figure 1.*** *Daily Electricity Load Pattern.*




*Source: Federation of Electric Power Companies of Japan*

***Figure 2.*** *Monthly Electricity Load Pattern.*

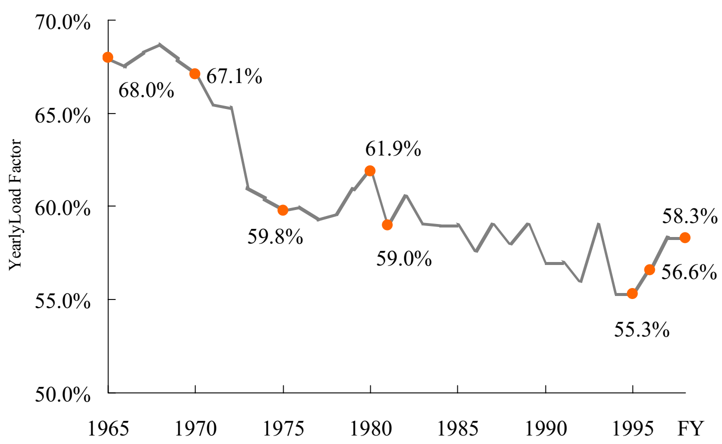



***Figure 3.*** *Trend of Electricity Load Factor.*

primary energy consumption, environmental load, initial cost and running cost quantitatively.

The results of these analyses suggest that gas cooling is a good solution for electricity load levelling as well as energy conservation, mitigation of global warming and cost reduction and it is applicable to other countries where air-conditioning is expected to be popularized in the future.

## Air-conditioning and Electricity Demand

In Japan cooling demand has recently increased remarkably especially in non-residential buildings because of increase of office automaton devices, aspiration of amenity, heat island phenomenon, increase of buildings' floor area and so on. According to FEPC (Federation of Electric Power Companies), one degree temperature rise in summer is equal to 4.7 GW increase in electricity demand for cooling load.

Figure 1 and Figure 2 show the daily and monthly pattern of electricity demand and it is clear that the peak load occurs at 2 or 3 pm in July or August and it increases year by year.

Owing to this peak load caused by cooling demand, annual electricity load factor is decreasing year by year as shown in Figure 3. Here, annual electricity load factor represents the rate of power plants operation and is defined as average electricity load divided by maximum electricity load. Higher load factor means more constant operation of power plants. Table 1 shows the comparison of annual load factor among industrialized countries and it is seen that Japanese figure is the lowest .This is probably Japanese archipelago is situated in monsoon area and her climatic condition is more cooling oriented than that in western countries. In summer, power utilities are obliged to operate low efficiency thermal power plants fuelled by oil to meet peak demand and this causes lower thermal efficiency and higher emission from the power plants. According to Japanese government report, one percent improvement of annual load factor is equal to 140 Billion yen (1 Billion Euro) monetary gain.

Figure 4 shows the comparison of daily load pattern of gas and electricity and it is evident that gas and electricity utilities are complementary. Judging from these data, it is beneficial for both gas and electric utilities to convert cooling load from motor driven air-conditioners to gas fired air-conditioners. Figure 5 shows the effect of gas cooling peak cut schematically. Even though gas air-conditioner consumes small amount of auxiliary electricity power, major energy is shouldered by gas energy.

## Gas Cooling Technologies and Its Dramatic Technical Improvement

In order to popularize gas cooling, Japanese government subsidized a lot of technical researches and developments and variety of gas cooling devices have been put into market. Figure 6 shows various gas cooling systems in accordance with the sizes and types of buildings. Gas cooling systems mainly consists of gas fired absorption chiller-heaters (GACH) and gas engine driven heat pumps (GHP). Figure 7 shows the installed capacity of gas cooling and the share of gas cooling .As of the end of FY 2002, gas cooling capacity exceeded 10 million RT (refrigeration ton) and ac-

**Table 1. Comparison of Electric Load Factor among Major Countries**

Unit [%]

| France | U. S. A. | U. K. | Old W. G. | Japan |
|---|---|---|---|---|
| 67.9 | 61.0 | 65.4 | 71.8 | 56.6 |

*Source: METI (Ministry of Economy Trade and Industry)*

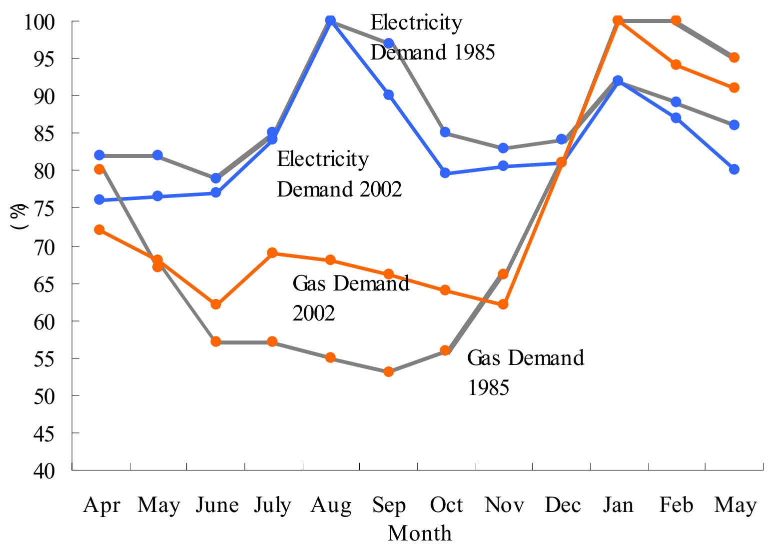



***Figure 4.*** *Comparison between Gas and Electricity Load Pattern.*

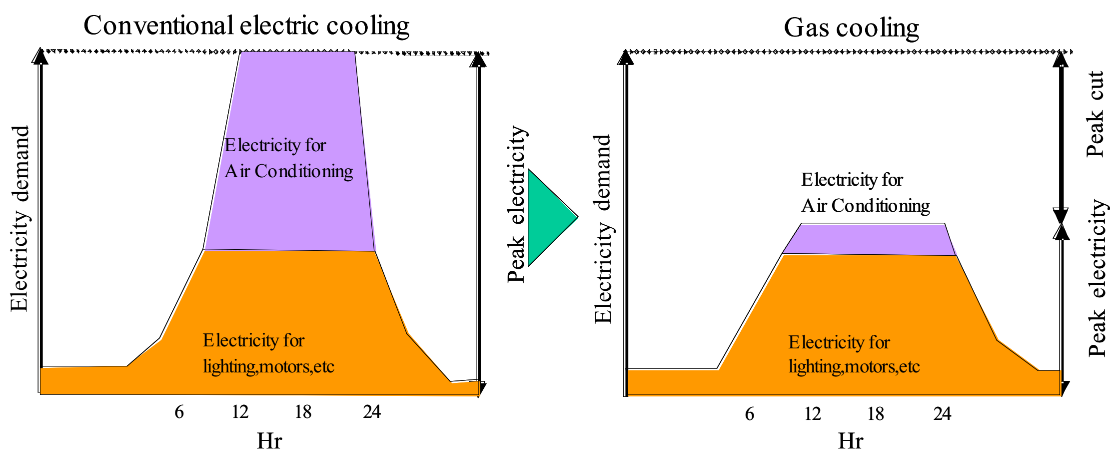



***Figure 5.*** *Illustration of Electricity Demand Peak Cut Contribution by Gas Cooling.*

count for 21 percent of total nationwide cooling capacity. (Japan Gas Association)

Figure 8 shows the improvement of GACH in terms of gas consumption, electricity consumption, volume, foot print and weight compared to the original machine. It has been downsized to about 30% of original model and this contributed to ease of installation, machine room space reduction and first cost reduction. Figure 9 shows the dramatic improvement of GACH' COP (coefficient of performance) and the present model is two times thermally efficient than original model. Triple stage model has been developed under the auspice of government and is going to be launched in 2005. As the original chiller uses thermal input once, it is called single stage and COP is as low as 0.7. In triple stage chiller, thermal input is used three times and higher COP is expected, but higher technical barriers have to be broken. It is interesting that an absorption chiller was originally invented in 1777 by E.G.Nairne, French and was commercialized in 1945 in USA and was improved and sophisticated in Japan.

The development targets of triple stage GACH are a) COP is higher than 1.6 in terms of higher heat value, b) volume is smaller than 1.2 times of conventional model c) more than 20 percent reduction of gas consumption when applied to cogeneration heat recovery system. The first cost of chiller is thought to be proportional to its volume and the triple

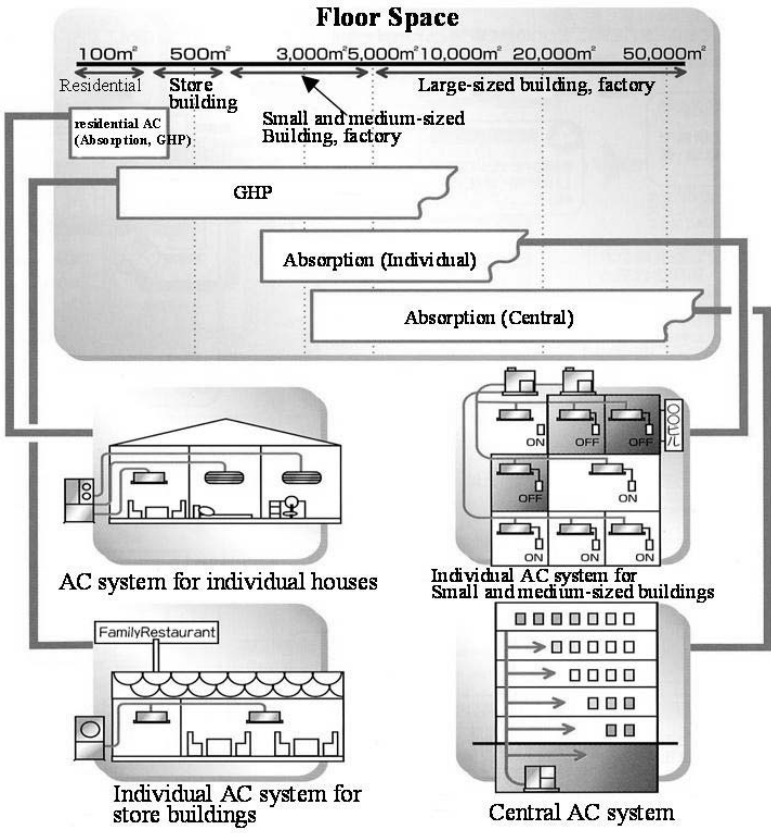



***Figure 6.*** *Various Types of Gas Air-conditioning Systems.*

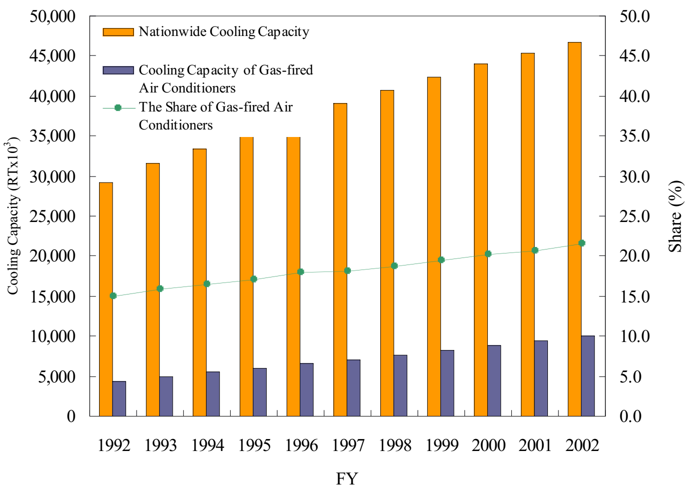



***Figure 7.*** *Trend of Gas Cooling Installed Capacity and Share.*

effect model is expected to cost within 120% of the present model. Figure 10 shows the prototype of the newly developed triple stage model and its COP proved to be 1.5.

GHP was invented in Japan and commercialized in 1987 and Figure 11 shows its principle. Instead of a electric motor, a gas engine is used to drive a compressor. The COP of GHP has been also improved dramatically and new GHP whose COP is as high as 1.5 is going to be launched in 2007. All these researches and developments help gas cooling to popularize and penetrate in Japan.

## Evaluation of Gas Cooling Contribution to Peak Electricity Demand Reduction

### METHODOLOGY

Introduction of gas cooling to buildings contributes to reduce peak electricity demand in two ways. Firstly, it decreases building peak electricity demand and improve electricity load factor. And the effect can easily be estimated by measuring the peak electricity demand and annual electricity consumption of gas cooled buildings and electricity cooled buildings respectively and comparing the both results.

Secondly, introduction of gas cooling to buildings contributes to reduce grid peak electricity demand. This assessment is a little complicated than the previous one because each building's maximum cooling load usually does not happen at the same time in summer. Each building has different geometric orientation, different usage, different occupancy rate and cooling peak hour of each buildings will not coincide. So we introduce the concept of load diversity factor to represent the coincidence of many buildings' cooling load and define cooling load diversity factor (CLDF). We surveyed operating cooling capacity of each gas cooled buildings on peak electricity day and summation of this operating cooling capacity divided by aforementioned summation of maximum cooling load wad defined as CLDF.

These two processes to assess gas cooling contribution are schematically illustrated in Figure 12.

## ELECTRIC PEAK CUT EFFECT OF GAS COOLING FOR INDIVIDUAL BUILDING

### Building Peak Electricity Density (BPED)

94 office buildings cooled either by gas or electricity in Tokyo, Osaka and Nagoya were selected to survey maximum electricity demand in summer. Both systems consist of central and individual air-conditioning system. Because there are varieties of floor area in sampled buildings, we introduced the concept of building peak electricity density (BPED) to normalize the data. BPED is defined by building's peak electricity demand (kW) divided by cooling capacity (kW (th)) and the index is independent from building size or cooling capacity. Collected data was statistically processed and Figure 13 shows the relationship between BPED and floor area and Table 2 shows the breakdown of the data.

These data reveals the following results.

- BPED of gas cooled building is smaller than that of electricity cooled building both in central and individual system.
- In case of electricity cooled building, individual system's BPED is higher than that of central system. On the contrary, in case of gas cooled building, individual system's BPED is smaller than that of central system.
- The difference of BPED between individual gas and electricity cooled building is 0.256 [kW/kW (th)] and 0.355 [kW/kW (th)] for central system respectively.
- The difference of BPED between overall individual gas and electricity cooled building is 0.295[kW/kW (th)].

### Building Electric Load Factor (BELF)

Load factor is an index to show the degree of energy load pattern flatness or load levelling and an important factor for both energy suppliers and customers. Low load factor means low operation of suppliers' facility and low economical efficiency leads to higher energy cost. From the view point of customers, low load factor means higher flat rate of energy cost because energy cost usually consists of fixed charge and proportional charge and flat rate is inversely proportional to load factor. It is evident that load factor for flat load pattern is equal to one.

We defined building electric load factor (BELF) as annual electricity consumption (kWh) divided by [peak electricity demand (kW)*24h*365days] and the result is shown in Figure 14 and Table 2. These data reveals the following results.

- BELF of gas cooled building is higher than that of electricity cooled building for either central or individual system.
- In case of electricity cooled building, BELF of central system is higher than individual system whereas individual system is higher than central system in case of gas cooled building.
- The difference of BELF between gas and electricity central system is 8.7 point and 11.1 point for individual system respectively and the difference of BELF between overall gas and electricity cooled building is 9.6 point.

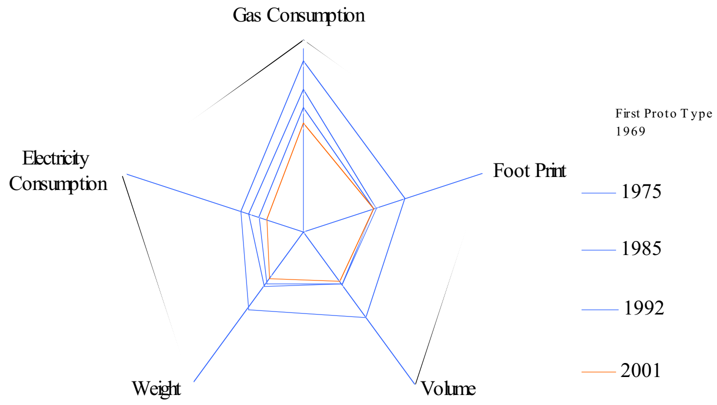



***Figure 8.*** *Historical Improvement of GACH Performance.*

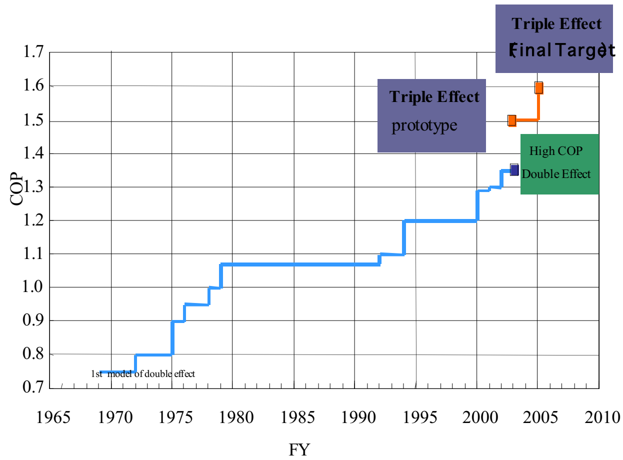



***Figure 9.*** *Historical Improvement of GACH'COP.*

***Figure 10.*** *Prototype of Triple Stage GACH.*

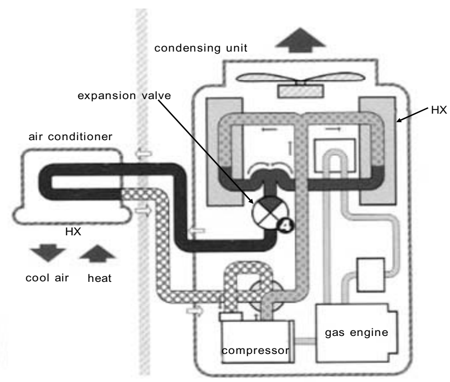



***Figure 11.*** *The Principle of GHP.*

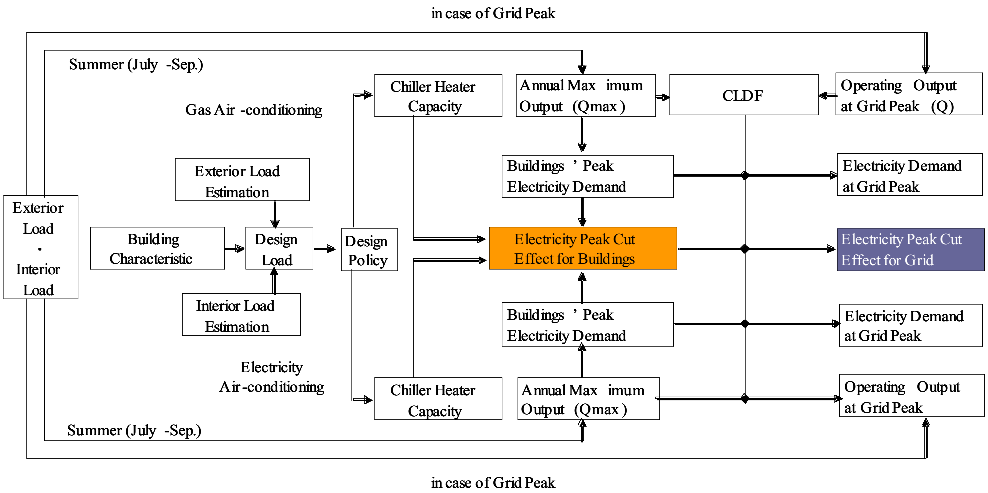



***Figure12.*** *Assessment of Electricity Peak Cut Effect for Buildings and Grids.*

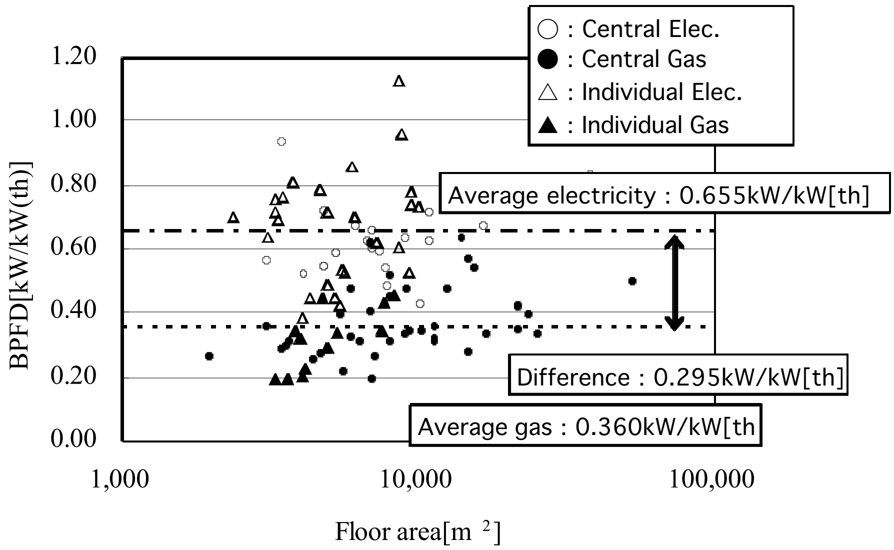



***Figure 13.*** *Relationship between BPED and floor area.*

## ELECTRICITY PEAK CUT EFFECT OF GAS COOLING FOR GRID

### Cooling Load Diversity Factor (CLDF)

94 sample buildings were situated in Kanto area whose main city is Tokyo and in Kansai area whose main city is Osaka. According to the utilities' reports, peak electricity loads occurred from 14:00 to 15:00 on 3 (Friday) of July, 1998 in Kanto area, and occurred from 14:00 to 15:00 on 4 (Tuesday) of August, 1998 in Kansai area. At this peak hour, the operating cooling output Q was estimated from gas flow rate to GACH on the assumption that cooling output Q was proportional to gas input. We obtained gas flow rate to GACH from customers' data. Maximum cooling output $Q_{max}$ was estimated from the maximum gas flow rate to GACH from July to September on the same assumption. We again obtained gas flow rate to GACH from customers' data.

CLDF is derived from summation of individual chiller's operating output Q divided by summation of individual chiller's maximum output. $Q_{max.}$ Table 3 shows the procedure to obtain CLDF in Kanto Area and overall value is 0.854.

$\Sigma Q_0$ : summation of chiller nominal capacity
$\Sigma Q_{max}$ : summation of annual maximum output
$\Sigma Q$ :summation of operating output at electricity peak hour
CLDF :cooling load diversity factor ($\Sigma Q/\Sigma Q_{max}$)

## GRID PEAK ELECTRICITY DENSITY REDUCTION (GPED)

As BPLD is defined as building's peak electricity demand (kW) divided by building's cooling load [kW(th)], grid peak electricity density (GPED) is defined as grid peak electricity load (kW) divided by buildings' cooling load[kW(th)].

Then GPED reduction can be calculated by the following equation.

GPED reduction by gas cooling [kW/kW(th)] = BPED[kW/kW(th)]*CLDF

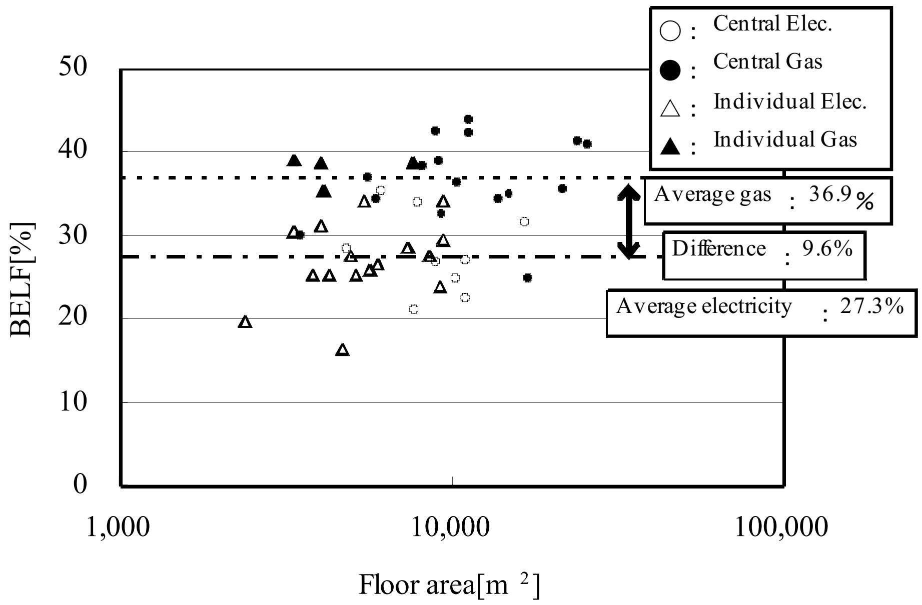



***Figure 14.*** *Relationship between BELF and Building Floor Area.*

**Table 2. BPED, BELF and their Differences between Gas and Electricity Cooled Building.**

| Air-conditioning System | | BPED[kW/kW(th)] | BELF(%) |
|---|---|---|---|
| Central System | Electricity A.C. | 0.628 | 27.9 |
| | Gas A.C. | 0.372 | 36.6 |
| | Difference | 0.256 | 8.7 |
| Individual System | Electricity A.C. | 0.674 | 27.0 |
| | Gas A.C. | 0.319 | 38.1 |
| | Difference | 0.355 | 11.1 |
| Total | Electricity A.C. | 0.655 | 27.3 |
| | Gas A.C. | 0.360 | 36.9 |
| | Difference | 0.295 | 9.6 |

**Table 3. Assessment of CLDF in Kanto Area.**

| Floor Area ($m^2$) | No. of Buildings | $\Sigma Q_0$ (kW) | $\Sigma Q_{max}$(kW) | $\Sigma Q$(kW) | CLDF(%) |
|---|---|---|---|---|---|
| ~3000 | 20 | 1 336 | 1 186 | 847 | 71.4 |
| 3000~10000 | 7 | 4 435 | 4 013 | 3 446 | 85.9 |
| 10000~ | 3 | 6 054 | 5 823 | 5 116 | 87.9 |
| Total | 30 | 11 826 | 11 022 | 9 409 | 85.4 |

As BPED difference is 0.295[kW/kW(th)] from Table 2 and CLDF is 0.854 from Table 3, GPED reduction by gas cooling is 0.295[kW/kW(th)]*0.854 = 0.252[kW/kW(th)]. In other words, the grid peak electricity density is reduced by 0.252 kW per building unit cooling capacity (kW(th)) owing to the introduction of gas cooling.

### GRID PEAK ELECTRICITY LOAD REDUCTION

Grid peak electricity load reduction by gas cooling (kW) can be calculated by the following equation.

Grid peak electricity load reduction (kW) = (GPED reduction [kW/kW(th)])*(Gas cooling capacity [kW(th)])

As GPED is obtained in the previous section and gas cooling capacity for office buildings in Kanto area is 3 011 MW(th) as is shown in Table 5, grid peak electricity load reduction by gas cooling (kW) is 0.252[kW/kW(th)]*3 011(MW) = 758 MW for TEPCO (Tokyo Electric Power Company). In other words, 758 MW was shouldered by gas cooling in Kanto area at peak hour in summer.

### GRID PEAK ELECTRICITY LOAD REDUCTION RATE

Grid peak electricity load reduction rate (%) can be calculated by the following equation.

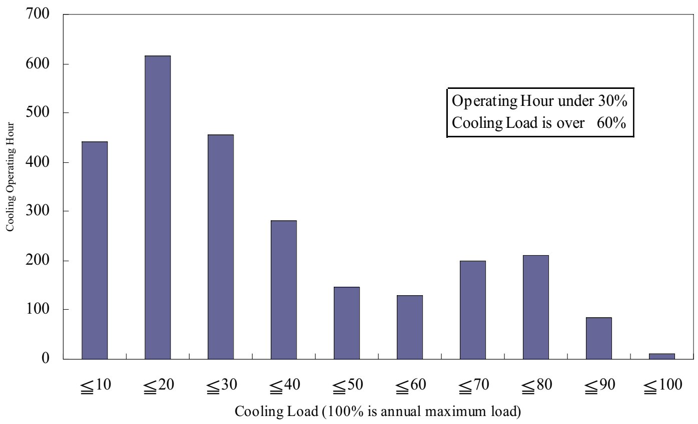
Grid peak electricity load reduction rate (%) = (Peak electricity load reduction (kW)) / (Maximum electric load without gas cooling (kW))

In FY 1998, maximum demand of TEPCO in summer was 59 200 MW as is shown in Table 4. If gas cooling was not introduced in Kanto area, peak demand for TEPCO would be 59 958 MW (= 59 200 MW+758 MW). Then, peak cut rate by gas cooling is 758/59 958*100 = 1.3(%).

The same calculation was carried out for Kansai area and the following is the summary for both areas.

- Electricity peak load reduction rate by office buildings' gas cooling in Kanto and Kansai is 1.3% and 2.0% respectively.
- Electricity peak load reduction rate by office buildings' gas cooling in all Japan is estimated to be 1.1% when the electricity peak load reduction rate for office buildings in Kanto is applied. (cf. Table 4 and Table 6)

Peak Load Reduction Rate =
(0.252*7,059) / (168,320+0.252*7,059) = 0.0105 ⇒ 1.1(%)




*Source: TEPCO (Tokyo Electric Power Company)*

***Figure 15.*** *Histogram of Cooling Load of Typical Office Building in Tokyo.*

- Electricity peak load reduction rate by all kinds of buildings' gas cooling in Kanto area is estimated to be 5.0 % when the electricity peak load reduction rate for office buildings in Kanto is applied. (cf. Table 4 and Table 5)

Peak Load Reduction Rate =
(0.252*12 448) / (59 200+0.252*12 448) = 0.0503 ⇒ 5.0(%)

- Electricity peak load reduction rate by all kinds of buildings' gas cooling in all Japan is estimated to be 3.9% when the electricity peak load reduction rate for office buildings in Kanto is applied. (cf. Table 4 and Table 5)

Peak Load Reduction Rate =
(0.252*26 759) / (168 320+0.252*26 759) = 0.0385 ⇒ 3.9(%)

## Primary Energy Consumption and Environmental Load of Gas Cooling

Owing to the climatic condition, the cooling load varies hourly, daily and monthly. Figure 15 shows the histogram of cooling load of a typical office building in Tokyo. This shows that operating hours under 30 percent of maximum cooling load is more than 60 percents of total operating hours.On the other hand, part load thermal efficiency of chillers varies according to the types of chillers and cooling load as illustrated in Figure 16. As GACH consists solely of heat exchanger, part load efficiency is higher than rated efficiency because actual heat exchanger service area surpasses designed service area at part load. On the contrary, part load efficiency of electric chillers deteriorates because of compressors mechanical loss. Although GHP also consists of reciprocating compressor, engine revolution (rpm) is controlled in proportion to cooling load and compressor mechanical loss is compensated.

In addition, it is well known that the COP of air source heat pump (ASHP) is dependent on outside temperature.

**Table 4. Maximum Electricity Demand and Sales in FY 1998.**

| | Max.Demand (MW) | Sales(GWh) |
|---|---|---|
| Ten Utilities | 168 320 | 880 286 |
| TEPCO | 59 200 | 292 390 |
| KEPCO | 32 160 | 152 572 |

TEPCO: Tokyo Electric Power Co.
KEPCO: Kansai Electric Power Co.

**Table 5. Installed Capacity of Gas Cooling for all types of Building at the end of FY 1998.**

Unit [MW(th)]

| | GACH | GHP | Total |
|---|---|---|---|
| All Japan | 22 630 | 4 248 | 26 759 |
| Kanto Area | 10 500 | 1 948 | 12 488 |
| Kinki Area | 6 667 | 1 301 | 7 969 |

**Table 6. Installed Capacity of Gas Cooling for Office Building at the end of FY 1998.**

Unit [MW(th)]

| | GACH | GHP | Total |
|---|---|---|---|
| All Japan | 6 110 | 949 | 7 059 |
| Kanto Area | 2 573 | 438 | 3 011 |
| Kinki Area | 2 127 | 336 | 2 462 |

These facts suggest that computer simulation is necessary to estimate primary energy consumption of chillers and heaters accurately and software called PEACS (Performance Evaluation of Air-conditioning System) was developed in order to estimate and compare various air-conditioning systems. Table 7 shows PEACS's main function and characteristic.

Three typical air-conditioning systems, GACH, ASHP and combination of motor driven centrifugal chiller and boiler (CC+BO) were simulated by PEACS. The performance of each system is shown in Table 8. Table 9. shows three types of COP in terms of primary energy, that is a) COP is constant, b) COP is corrected by part load, c) COP is corrected by part load and outside temperature. This result reveals the importance of considering part load efficiency and the effect of outdoor temperature on heat pump performance. Figure 17. shows the comparison of primary energy consumption of each systems.

$CO_2$ emission of chillers and heaters is calculated by their thermal efficiency and types of fuels and the result is shown

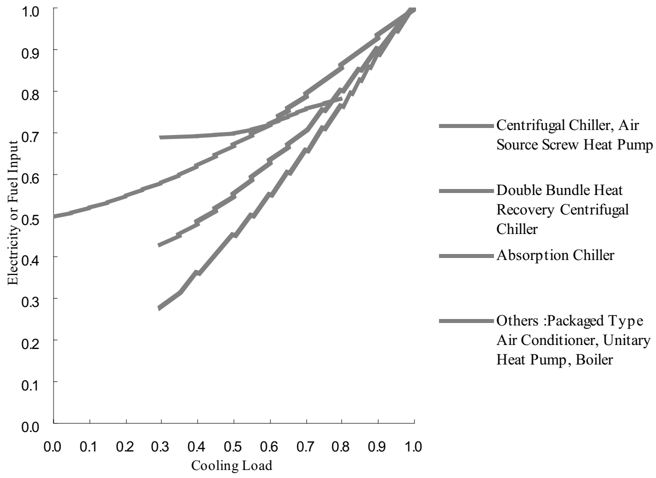
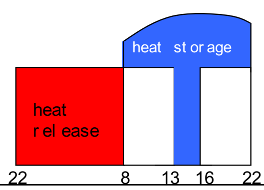
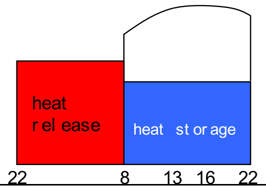
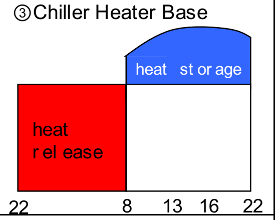



***Figure 16.*** *Part Load Efficiency of Various Types of Chillers.*

**Table 7. Main Function and Characteristics of PEACS.**

| | | | |
|---|---|---|---|
| System | ①GACH ②ASHP ③CC+BO ④Water Storage System(ASHP) ⑤Ice Storage System(ASHP) | | |
| Operation Pattern of Storage System (cooling mode) | ①Peak Cut   | ②Heat Rejection Base   | ③Chiller Heater Base   |
| Part Load Correction | ● taking COP change by load into consideration<br>● possible to use actual performance data | | |
| Outside Air Temperature Correction | ● possible to red outside wetbulb temperature<br>● possible to correct chiller's performance based on dry bulb and wetbulb temperature | | |
| Building Thermal Load | ● to calculate building cooling and heating load by annual load intensity, monthly load pattern and hourly load pattern<br>● possible to input peak load intensity and peak day hourly load pattern for selectin chiller heater capacity<br>● two pipe system is assumed | | |
| Auxiliary Power | ● to calculate chiller heater auxiliary power, pump power(cooling water pump, chilled water primary and secondary pump, storage air pump), fan power(cooling tower, air conditioner, ventilation)<br>● possible to select constant and variable mode of chilled and heating water pump and cooling water pump<br>● to consider auxiliary power decrease at part load operation | | |
| Piping System of Storage System | ● possible to select open type or closed type water storage system | | |

GACH: Gas Absorption Chiller Heater

ASHP: Air Source Heat Pump

CC+BO: Combination of Centrifugal Chiller and Boiler

**Table 8. Typical Air-conditioning System's Performance.**

| | | GACH | ASHP | CC+BO |
|---|---|---|---|---|
| Cooling | Rated Capacity(kW) | 1 125 | 1 064 | 1 125 |
| | COP | 1.00 | 2.99 | 4.5 |
| Heating | Rated Capacity(kW) | 941 | 1 273 | 605 |
| | COP | 0.85 | 3.85 | 0.80 |

**Table 9. Typical Air-conditioning System's COP in terms of Primary Energy.**

| System | | GACH | ASHP | CC+BO |
|---|---|---|---|---|
| Cooling | COP Constant | 0.96 | 1.05 | 1.58 |
| | Part Load Correction | 0.90 | 0.63 | 1.24 |
| | Outside Temp. & Part Load Correction | 0.99 | 0.70 | 1.35 |
| Heating | COP Constant | 0.80 | 1.35 | 0.78 |
| | Part Load Correction | 0.78 | 0.40 | 0.77 |
| | Outside Temp. & Part Load Correction | - | 0.41 | - |
| Annual | COP Constant | 0.90 | 1.13 | 1.20 |
| | Part Load Correction | 0.86 | 0.54 | 1.04 |
| | Outside Temp. & Part Load Correction | 0.92 | 0.57 | 1.10 |

**Table 10. Annual $CO_2$ Emission from Typical Air-conditioning System.**

| System | Electricity Consumption (MWh) | Gas Consumption ($m^3$) | $CO_2$ Emission ($t\text{-}CO_2$) | Ratio |
|---|---|---|---|---|
| GACH | 600 | 89 824 | 603 | 100 |
| ASHP | 1 153 | - | 753 | 125 |
| CC+BO | 748 | 33 913 | 568 | 94 |

Natural Gas $CO_2$ Emission Rate : 2 354 kg-$CO_2$/$m^3$

Electricity $CO_2$ Emission Rate : 0.653 kg-$CO_2$/kWh (Average Thermal Power Plant)

in Table 10. GACH is thought to be one of the most environmentally friendly chiller-heaters.

## Economic Characteristics of Gas Cooling

The types of air-conditioning is usually decided by architectural offices and building owners and one of the most important element is the initial cost and running cost of air-conditioning.

In order to penetrate gas cooling, Japanese government prepares several incentives and some of them are shown in Table 11. In addition, major gas utilities offer tariff schemes to stimulate gas cooling. Owing to these public and private incentives, gas cooling usually has advantages over alternatives and Figure 18 shows an example of economic comparison among major air-conditioning systems. In this comparison, fixed cost stands for depreciation of air-conditioning systems first cost and is calculated under the assumption that interest rate is 3% and service life of air-conditioning systems is 15 years. Proportional cost includes gas, electricity, water and sewage charge and maintenance cost. In addition to these economic characteristics, ease of operation, space factor of machine rooms, environmental friendliness, peak electricity demand reduction and gas supply reliability are major components to contribute the popularization of gas cooling.

## Conclusion

More than ten million RT (refrigeration ton) (3.5 million kW) gas cooling was introduced by the end of FY2002 in Japan. In this paper, we analysed the contribution of gas cooling to many areas such as peak electricity demand reduction, energy conservation, $CO_2$ reduction, and cost reduction quantitatively.

We first evaluated the contribution of gas cooling to reduce peak demand in two ways. In terms of individual building's load levelling, gas cooling reduced peak electricity load by 0.295 kW per unit cooling capacity [kW(th)] and increased electricity load factor by 9.6 point. If this index is applied to a typical office building whose floor are is 10 000 $m^2$ situated in Tokyo, peak reduction is estimated as high as 350 kW. From the view point of grid's load levelling, nationwide peak electricity was expected to be reduced by 3.9% by the introduction of gas cooling or 6.7 GW peak demand was reduced. In other words, 6 power plants capacity was replaced by gas cooling. Judging from these results, utilities' and customers' thermal and economical efficiency has been remarkably improved by the massive introduction of gas cooling.

Secondly, we evaluated the contribution of gas cooling to conserve energy for many types of buildings by developing customized software (PEACS) to estimate annual energy consumption of various kinds of chillers and air-source heat pumps taking into consideration of their inherent part load efficiency. Typical systems were simulated and the results

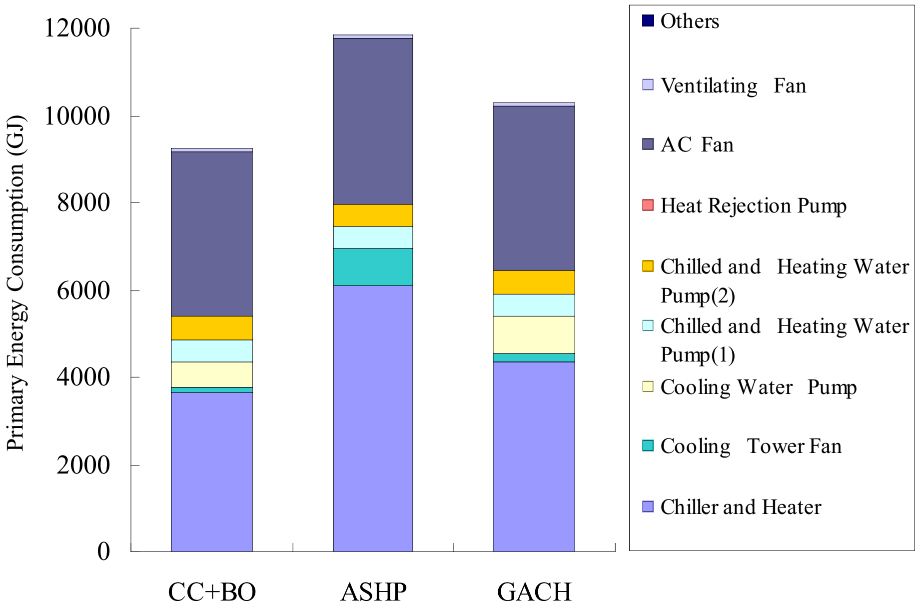



***Figure 17.*** *Annual Primary Energy Consumption.*

**Table 11. Government Incentives for Promoting Gas Cooling.**

| | | System | Technology | Comments |
|---|---|---|---|---|
| Tax Incentive | | Investment Promoting Taxation for Structural Reform on Energy Supply and Demand | ①GACH<br>(≧10RT, group controlled)<br>②Cogeneration<br>( Cogeneration , GHP etc.) | ①7% Tax Exemption of Purchasing Price<br>(applicable to enterprise with the capital of \10million or less, max 20% of the Corporation Tax) or 30% Special Redemption<br>②Standard Purchasing Price<br>GACH: 75%<br>Cogeneration /$NH_3$ Absorption Chiller: 100%<br>③Applying Period ('92.4.1-'02.3.31) |
| Low Interest Loan | DBJ | 【Energy Saving Promoting System】 | GACH<br>(non-petroleum gas only, 100RT min/50,000RT max excluding Direct and Indirect-fired Single Stage Chiller Heater) | ①Interest 2.10%<br>②Lending rate 40% max<br>③Lending period 15 years or less |
| | DBJ | 【Public Nuisance Prevention /Ozone Layer Conservaion System】 | Absorption Chiller<br>(no restriction on type of fuel and capacity) | ①Interest 2.10%<br>②Lending rate 40% max<br>③Lending period 10 years or less |
| | DBJ | 【Energy Saving Promoting System】 | GHP | ①Interest 2.25%<br>②Lending rate 40% max<br>③Lending period 10 years or less |
| | JASME | Oil Substitute Energy Fund | GACH<br>(non-petroleum gas only) | ①Interest ～Substitute Energy Fund<br>Substituting Rate 40%min 2.10%<br>20%min 2.10%(first 3years)<br>2.15%(4th year onward)<br>～Energy Saving Fund 2.10%<br>②Loan Limit 193,000EURO max<br>③Lending Period<br>～Substitute Energy Fund :15years or less (2years of defermen<br>～Energy Saving Fund :15years or less (2years of defermen |
| | JASME | Energy Saving Fund | Improved Dual Stage GACH (≧10RT) | |
| Subsidy | | Individual GACH Introducing and Promoting System for Existing Small and Medium Sized Building | Individual GACH for Existing Building 10.000m$^2$ or smaller | ①Grant of Subsidy for Introducing GACH<br>(1/3 of the rest deducting running cost merit from balance betwe GACH and Non-Storage Type Electric Cooling)<br>②Term of Deferment 3years ('98-'00)<br>③Subsidy 500,000EURO('00 budget) |

GACH: Gas-fired Chiller Heater
GHP: Gas-Engine Heat Pump
DBJ: Development Bank of Japan
JASME: Japan Finance Corporation for Small & Medium Enterprise

showed that GACH consumed less energy than conventional ASHP. $CO_2$ reduction was also estimated by using this result, thermal power plant efficiency and the type of fuel and the result showed that emission from GACH was less than conventional ASHP.

Thirdly, we carried out the economic comparison among various kinds of air-conditioning systems and showed the cost-effectiveness of GACH. As the economic comparison is heavily dependent on the prerequisite condition, it is difficult to generalize the result but it is fair to say that gas cool-

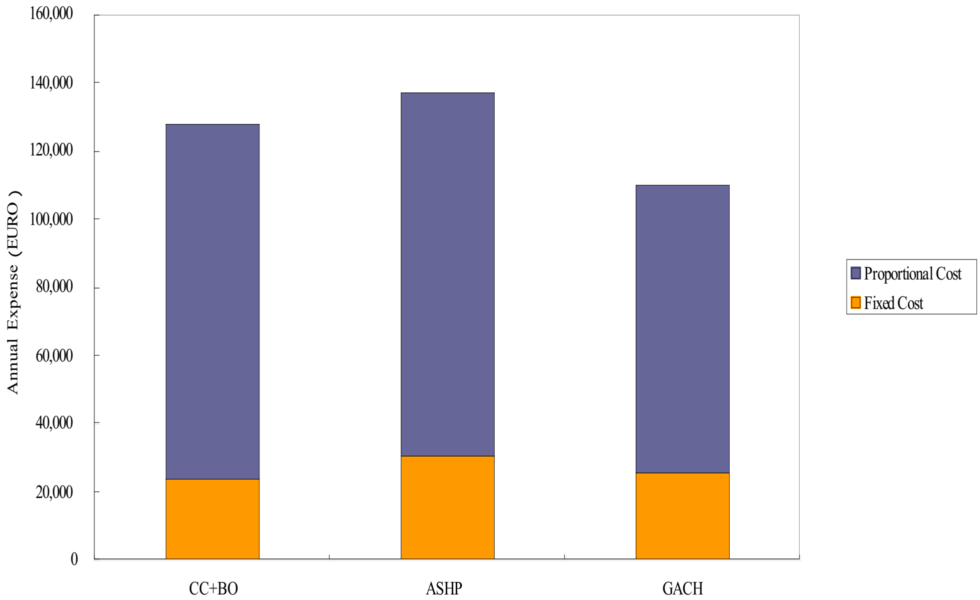



***Figure 18.*** *Economic Comparison of Typical Air-conditioning Systems.*

ing is one of the less expensive chiller-heaters at present in Japan.

The results of these analyses suggest that gas cooling is a good solution for electricity load levelling as well as energy conservation, mitigation of global warming and cost reduction and it is applicable to other countries where air-conditioning is expected to be popularized in the future.

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