LBNL-56359

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The Potential for Distributed Generation in Japanese Prototype Buildings: A DER-CAM Analysis of Policy, Tariff Design, Building Energy Use, and Technology Development (English Version)

(この報告書の日本語版は「LBNL-56359 Japanese」で閲覧できる）

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Environmental Energy Technologies Division

October 2004

http://eetd.lbl.gov/ea/EMS/EMS_pubs.html

This work was supported by the Office of the Assistant Secretary of Energy for Energy Efficiency and Renewable Energy, Office of Planning, Budget and Analysis of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098, and the Japan Kyushu Industrial Technology Center.

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Preface

This effort represents a first application of methods and tools developed to chart a path that can lead us to a robust distributed power system. While these tools have been crafted in the U.S., the paradigm shift that is reinventing power systems is global, and with this effort the first step is taken towards applying skills developed here internationally.

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Acronyms and Abbreviations

ANRE	Agency for Natural Resources and Energy
ABSHX	DER with heat recovery for heating and absorption cooling
ACH	Air Changes per Hour
AMeDAS	Japan Automated Meteorological Data Acquisition System
BECS	a HVAC simulation program in Japan
CEC	California Energy Commission
CERL	US Army Corps of Engineers Construction Engineering Research Lab
CERTS	Consortium for Electric Reliability Technology Solutions
CHP	Combined Heat and Power
CPUC	California Public Utilities Commission
DER	Distributed Energy Resources
DER-CAM	Distributed Energy Resources Customer Adoption Model
DOD	US Department of Defense
DG	Distributed Generation
Disco	distribution company
DOE	U.S.Department of Energy
DOE-2	building energy simulation model developed at Berkeley Lab
EPA	U.S.Environmental Protection Agency
FC	fuel cell
FERC	Federal Energy Regulatory Committee
GT	gas turbine
HASP	HVAC simulation program in Japan
HX	DER with heat recovery for heating
HVAC	Heating, Ventilation and Air Conditioning
LBNL	Lawrence Berkeley National Laboratory
LIPA	Long Island Power Authority
METI	the Ministry of Economy, Trade and Industry, Japan
MT	microturbine
NEGA	Japan Engine Generator Association
NG	gas engine
NYPSC	New York State the Public Service Commission
NYSERDA	New York State Energy Research and Development Authority
O&M	operation and maintenance
PG&E	Pacific Gas and Electric
PV	photovoltaic
PURPA	Public Utilities Regulatory Policies Act
QFs	qualifying facilities
SBC	system benefits charge
SC	Shading Coefficient
SCAQMD	South Coast Air Quality Management District
SCE	Southern California Edison
SDG&E	San Diego Gas and Electric
SDREO	San Diego Regional Energy Office
SMASH	HVAC simulation program in Japan
SoCalGas	Southern California Gas Company

Acknowledgments

The authors would like to particularly thank Joe Huang (LBNL) for his contribution to several important aspects of the modeling for this project. We would also like to thank Kazunari Shiraki (Osaka Gas Co.) and Atsushi Sakakura (Tokyo Gas Co.) for providing useful data, and Jennifer L. Edwards, Owen Bailey, and Peter Chan for their advice and editing that helped shape many of the concepts presented here.

The authors would also like to thank the Japan Kyushu Industrial Technology Center for its support of this work. Also, the prior and ongoing development of the methods and tools used in this study has been supported by the U.S. Department of Energy(DOE) and the California Energy Commission. Assistance from DOE has come from both the Distributed Energy Program and the office of Electric Transmission and Distribution.

Finally, the following Berkeley Lab researchers have contributed to DER research at Berkeley Lab in the past: Afzal Siddiqui, Michael Stadler, and Kristina Hamachi LaCommare.

Executive Summary

The August 2003 blackout of the northeastern U.S. and CANADA caused great economic losses and inconvenience to New York City and other affected areas. The blackout was a warning to the rest of the world that the ability of conventional power systems to meet growing electricity demand is questionable. Failure of large power systems can lead to serious emergencies. Introduction of on-site generation, renewable energy such as solar and wind power and the effective utilization of exhaust heat is needed, to meet the growing energy demands of the residential and commercial sectors.

Additional benefit can be achieved by integrating these distributed technologies into distributed energy resource (DER) systems. This work demonstrates a method for choosing and designing economically optimal DER systems.

An additional purpose of this research is to establish a database of energy tariffs, DER technology cost and performance characteristics, and building energy consumption for Japan. This research builds on prior DER studies at the Ernest Orlando Lawrence Berkeley National Laboratory (LBNL) and with their associates in the Consortium for Electric Reliability Technology Solutions (CERTS) and operation, including the development of the microgrid concept, and the DER selection optimization program, the Distributed Energy Resources Customer Adoption Model (DER-CAM). DER-CAM is a tool designed to find the optimal combination of installed equipment and an idealized operating schedule to minimize a site's energy bills, given performance and cost data on available DER technologies, utility tariffs, and site electrical and thermal loads over a test period, usually an historic year. Since hourly electric and thermal energy data are rarely available, they are typically developed by building simulation for each of six end use loads used to model the building: electric-only loads, space heating, space cooling, refrigeration, water heating, and natural-gas-only loads. DER-CAM provides a global optimization, albeit idealized, that shows how the necessary useful energy loads can be provided for at minimum cost by selection and operation of on-site generation, heat recovery, cooling, and efficiency improvements.

This study examines five prototype commercial buildings and uses DER-CAM to select the economically optimal DER system for each. The five building types are office, hospital, hotel, retail, and sports facility. Each building type was considered for both 5,000 and 10,000 square meter floor sizes. The energy consumption of these building types is based on building energy simulation and published literature. Based on the optimization results, energy conservation and the emissions reduction were also evaluated. Furthermore, a comparison study between Japan and the U.S. has been conducted covering the policy, technology and the utility tariffs effects on DER systems installations.

This study begins with an examination of existing DER research. Building energy loads were then generated through simulation (DOE-2) and scaled to match available load data in the literature. Energy tariffs in Japan and the U.S. were then compared: electricity prices did not differ significantly, while commercial gas prices in Japan are much higher than in the U.S. For smaller DER systems, the installation costs in Japan are more than twice those in the U.S., but this difference becomes smaller with larger systems. In Japan, DER systems are eligible for a

1/3 rebate of installation costs, while subsidies in the U.S. vary significantly by region and application.

For 10,000 m^2 buildings, significant decreases in fuel consumption, carbon emissions, and energy costs were seen in the economically optimal results. This was most noticeable in the sports facility, followed the hospital and hotel. This research demonstrates that office buildings can benefit from CHP, in contrast to popular opinion. For hospitals and sports facilities, the use of waste heat is particularly effective for water and space heating. For the other building types, waste heat is most effectively used for both heating and cooling.

The same examination was done for the 5,000 m^2 buildings. Although CHP installation capacity is smaller and the payback periods are longer, economic, fuel efficiency, and environmental benefits are still seen. While these benefits remain even when subsidies are removed, the increased installation costs lead to lower levels of installation capacity and thus benefit.

1. Background and Purpose

Energy consumption in Japan has been following a consistent rising trend, except for periods during the two oil crises. From 1990 to 2000 energy consumption by the residential/commercial sector increased 26.4%[1], reflecting changes in lifestyle and desire for comfort (METI, 2004; ANRE, 2004). In Japan, a country that depends on imports for most of its primary energy supply, on-site distributed energy systems, including combined heat and power (CHP) systems and renewables, such as photovoltaics and wind turbines have grown more important and are widely expected to spread to increase the efficiency of energy consumption and to address global environmental problems. Additional benefit may be gained from distributed systems through clusters of DER and loads in the same geographic area.

The Ministry of Economy, Trade and Industry (METI) is laying down a new Long-Term Energy Supply and Demand Outlook to 2030 and an interim report was released in June 2004. The Japanese government suggests more decentralized energy systems, and the new outlook includes a distributed generation development scenario where in the share of self generation in total electricity supply exceeds 20% in 2030 (METI, 2004).

While economics is a key to the implementation of DER, an economic optimization design tool based on technology information and current tariffs and policy has not yet been developed in Japan. This research conducts a survey of the potential for DER utilization and the installation of renewable energy in Japan. As part of this research, a database of DER technologies, Japanese energy tariffs, and prototypical building energy loads has been developed and can be used for energy conservation research.

The Distributed Energy Resources Customer Adoption Model (DER-CAM), developed by the Lawrence Berkeley National Laboratory (LBNL) of the United States is an optimization tool for DER technology selection. DER-CAM minimizes the annual energy cost of a given customer, including DER investment costs, based on input data consisting of DER technology cost and performance, electricity and natural gas tariffs, and end-use energy loads such as space heating, cooling, hot water, and electricity only. DER-CAM reports the optimal technology selection and operation schedule to meet the end-use loads of the customer.

Using DER-CAM, an investigation was conducted of economically optimal DER investments for different prototype buildings in Japan. The potential for DER in Japan and the resulting energy savings and environmental effects has been determined. Additionally, a comparison of the DER investment climate in Japan to that in the United States has been conducted.

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[1] *Trend of energy consumption in residential and commercial sector*, The Ministry of Economy, Trade and Industry (METI), http://www.enecho.meti.go.jp/english/energy/index.html
and Energy and Resources Today, Agency for Natural Resources and Energy (ANRE), http://www.meti.go.jp/report/downloadfiles/g01011gj.pdf

2. Distributed Energy Resources Customer Adoption Model

There are several DER assessment software programs available in the United States, including Washington State University Energy Program's Heatmap, and LBNL's DER-CAM. Heatmap assess the performance and economics of predetermined regional energy systems, including DER. The user specifies the DER capacity and operation schedule, pipe sizes in the CHP network, and end-use loads. Heatmap reports the total system cost, system performance statistics and environmental effects. The optimal technology for different scale buildings cannot be found automatically.

In Japan, much research on energy conservation and the environmental effects of DER has been conducted, relatively little on the economics of DER; however in many cases, DER economics will determine its potential, The assessment program CASCADE (Computer Aided Simulation for Cogeneration Assessment Design), developed by the Air Condition and Sanitation Institute of Japan has load data for five prototype buildings including: hotel, hospital, office, sports facility and factory. It can also assess total energy consumption, environmental effects, and economics of CHP. However, CASCADE has several weaknesses:

- It is only available as mainframe software.
- The data is averaged over all of Japan; i.e. it does not consider regional and climate differences.
- The load data is averaged, and thus does not consider load variation between days, such as between weekdays and weekend days.
- DER economics are not considered.

Yamaguchi Yoheh has conducted both energy saving and economic analyses for DER systems used by two office buildings and places in between the two (Yamaguchi, 2003). Okuda Hidenobu of Tokyo University has characterized the performance of the P15-07 micro gas turbine and determined economically optimized operation strategies for P15-07 CHP systems. Other DER technologies were not considered (Okuda, 2002).

Japan has several assessment tools for CHP installation but none address the economically optimal technology choice or system design. In the United States, however, there are several economic assessment tools for DER. DER-CAM is a tool for determining economically optimal DER investments for a specific site. DER-CAM determines the appropriate technology combination and operation schedule. Figure 1 shows this graphically.

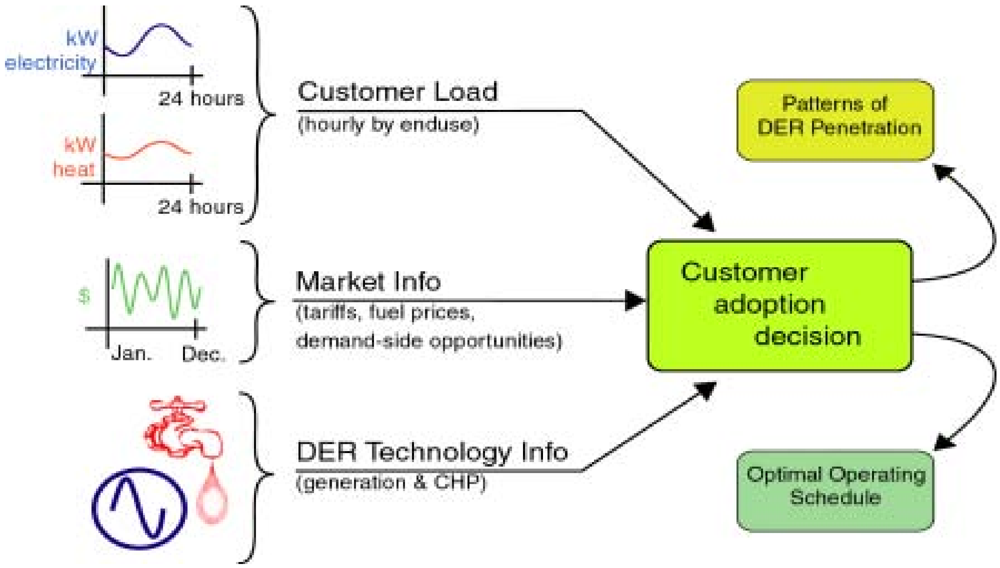

Figure 1: DER-CAM Schematic

This research uses DER-CAM to examine the potential for DER in Japan. A comparison to the climate for DER adoption in the United States is also made.

3. Method

3.1 DER-CAM

Figure 2 is a flow chart illustrating the structure of DER-CAM. DER-CAM requires the detailed structures and rates of electricity and natural gas tariffs; hourly end-use load data for each building type; and DER technology cost and performance data. DER-CAM, in turn, determines the economically optimal DER installation and operation schedule, as well as system performance statistics. This chapter describes the development of DER-CAM input data suitable to prototype Japanese buildings.

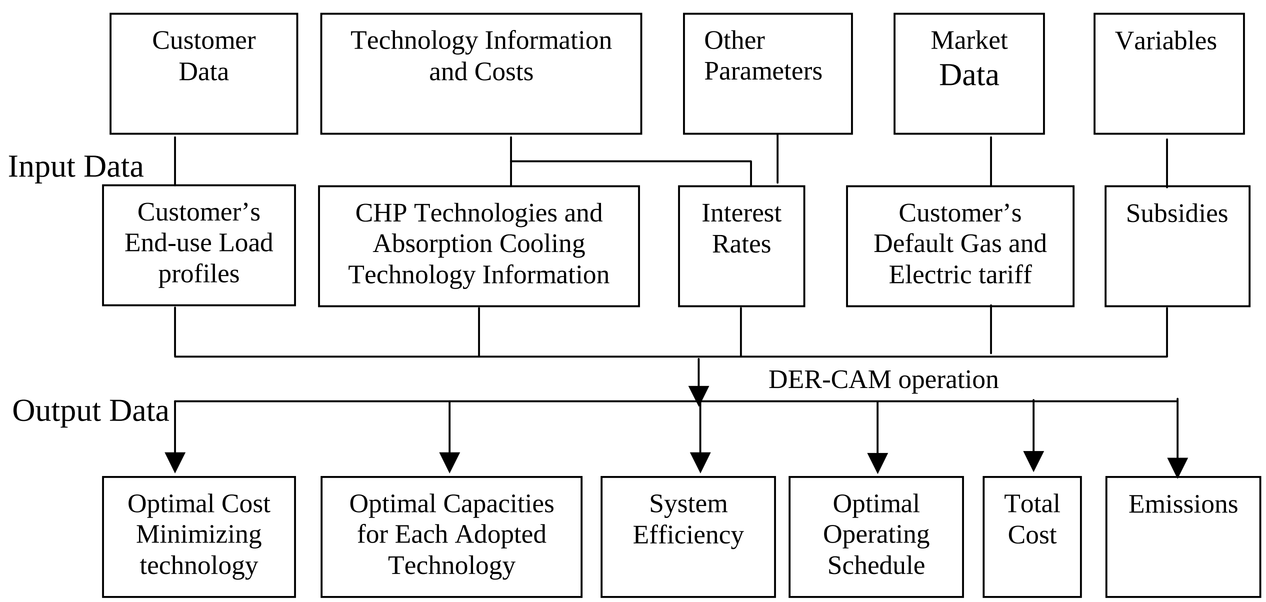

Figure 2: DER-CAM Flow Chart

Utility tariffs for commercial buildings were collected from various Japanese utilities. Financial details such as grants and taxes concerning DER installation were also obtained. DER technology data was collected from manufacturers and distributors. This data includes rated capacity, efficiency, turnkey capital cost, and operation and maintenance costs.

3.2 Estimation of Hourly Energy Consumption

3.2.1 Existing Estimates

Detailed knowledge of energy end-use loads is important for selecting an appropriate DER system. In Japan, when designing CHP systems, estimates of energy consumption intensities of various building types are typically obtained from the Natural Gas Cogeneration Plan/ Design Manual 2002 (Kashiwagi, 2002). This manual reports annual energy consumption and proportion of consumption by month and hour. Hourly loads can be estimated from this data. However this is average data for all of Japan; neither regional characteristics nor variations in load patterns by day type are considered.

Energy consumption data of various building types in the Kyushu area was collected for the Comprehensive Research on the Utilization of Un-utilized Energy in Building and Urban Scale in Kyushu Area (Nishida, 1997). From this report, building energy consumption for buildings in Kyushu is known in great detail, although load data is not differentiated by day type, and this data is no longer current.

Several building energy simulation programs have been developed in Japan. These include:

- SMASH: developed for residential building thermal simulation by the Housing and Building Energy Conservation Organization of Japan.
- BECS: developed for calculating and simulating air conditioning equipment under Energy Conservation Law by The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan
- HASP: developed for non-residential building by The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan

Building energy simulation programs for other building types in Japan are not widely available.

Current, detailed load data and simulation tools for Japanese buildings of various type and in various regions is lacking. However, in the United States, the building energy simulation program, DOE-2, developed by the Department of Energy, is used in a variety of commercial packages to model various building types and determine hourly building energy loads. Heatmap incorporates DOE-2 to estimate building energy loads. DER-CAM analyses are often preceded by the use of DOE-2 to obtain end-use energy load data. In this research, a version of DOE-2 suitable to Kyushu area office buildings was developed and used to simulate office building loads. These results were checked against available energy consumption data for generalized Japanese office buildings and Kyushu office buildings.

3.2.2 Building Loads from DOE-2 Simulation

In Japan, *An Introduction to Calculations for HVAC Dynamic Thermal Load* (Matso, 1980) is widely used for building simulation. Typical office building structure, material, and HVAC operation schedule are determined based on the guidance of this book and *Optimized HVAC Operation Considering Building Thermal Storage and Analysis of the Effect on Energy Consumption* (Nagai, 2001)

Table 1 shows the office building condition used for the simulation and for the climate data for Tokyo from the AMeDAS database is used.

Table 1 Description of Simulated Office Building

Building description	
Type :office Floors :5 aspect_ratio: 0.6 (36m*60m) wall_height: 2.6m perim_width 6m Glass ratio 0.45 Area : 10800m^2	
Construction and Shell Characteristics	
Exterior Floors : preformed mineral board, air-space, 130 mm conc.,stacco,Asphalt tile Interior Floors : preformed mineral board, air-space, 130 mm conc.,stacco,Asphalt tile Exterior walls : tile,stacco,concrete,stacco,gyp-board thickness =(8 mm,25 mm,120 mm, 20 mm, 3 mm) Interior walls : gyp-board,stacco,concrete,stacco,gyp-board thickness =(3 mm, 15 mm, 100 mm,15 mm, 3 mm) Roof : Asphalt tile,stacco, 130 mm conc.,air-space,preformed mineral board Windows : Absorbtion Glass 8mm, window_R 0.92 U = 6.18 W/m^{2}K , SC= 0.92	
Space Conditions	
No. of People	6.7m^2/person (0.15 persons /m^2)
People Schedule	1.00 working hrs, 0.1otherwise Weekend 0.90 and 0.05
Lighting Use Intensity (W/m^2)	20
Lighting Schedule	0.90 working hrs, 0.30 otherwise. Weekend 0.90 and 0.20
Equipment Use Intensity (W/m^2)	10(0.92 W/ft^2)
Equipment Schedule	1.00 working hrs, 0.17 otherwise. Weekend 0.17 and 0.17
Infiltration	0.3 ACH working hours
HVAC System and Control	
HVAC System Type	Variable-Air Volume with Economizer
Heating Temperature	22 ºC
Heating Schedule	All Year Workdays 8 am – 7 pm Weekends 8 am – 1 pm
Cooling Temperature	26 ºC
Cooling Schedule	All Year Workdays 8 am – 7 pm Weekends 8 am – 1 pm
Fan Schedule	On during working hours
Outside air / person	25 m^3/h (14.7ft^3/min/person)
Service Equipment	
Elevator Intensity	14 kW
Elevator Schedule	1.00 working hrs, 0.17 otherwise
Service Hot Water Intensity	11.6 L/min (0.00152 * 7650 m^2) / 0*
Service Hot Water Schedule	1.00 working hrs, 0 otherwise

Reference: Matsuo, 1985; Nagai, 2001; and US. DOE-2 Manual, 2000

Figure 3 to Figure 6 show the July Tokyo office building simulation results of the electricity, space heating, hot water heating, and space cooling loads. Each shows peak weekday, typical weekday, and weekend loads. The cooling load is expressed as the electricity required to perform the cooling.

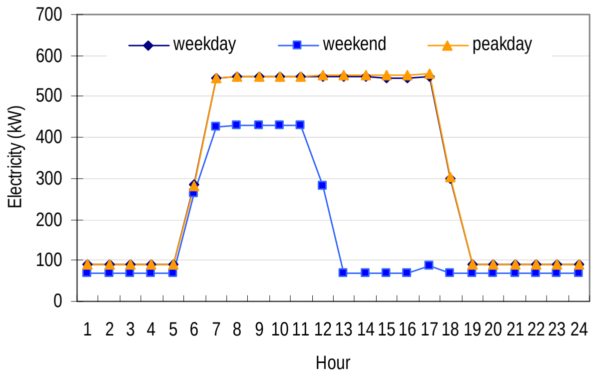

Figure 3: Office July Electricity Load from DOE-2 Simulation

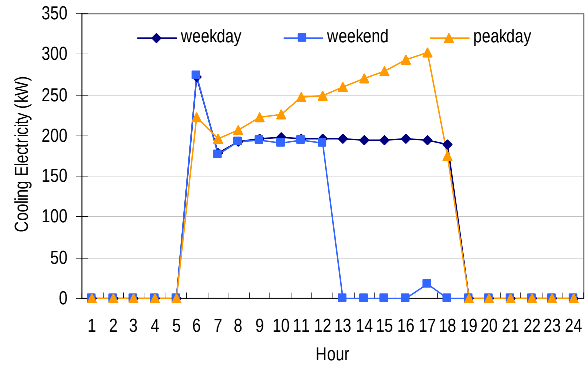

Figure 4: Office July Cooling Electricity Load from DOE-2 Simulation

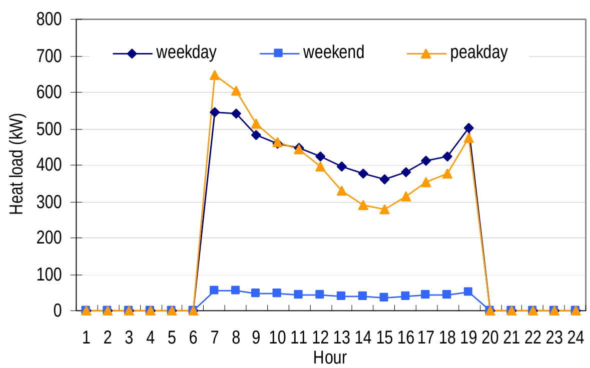

Figure 5: Office January Space Heating Load from DOE-2 Simulation

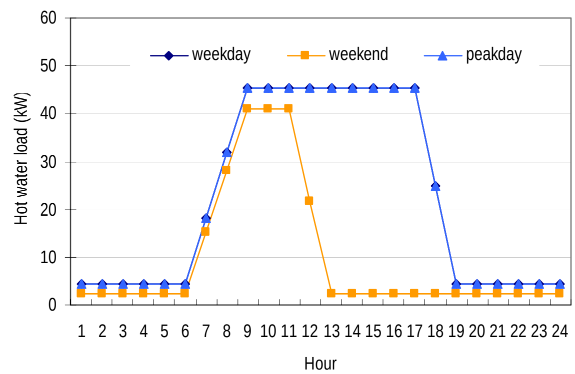

Figure 6: Office January Hot Water Load from DOE-2 Simulation

July non-cooling electricity use increases rapidly as the workday begins and is approximately 550 kW during the daytime. On Saturdays, there is a half-day of work with electricity consumption of approximately 430 kW. Sundays are not represented here. July cooling electricity loads are approximately 200 kW for both weekdays and weekends with a peak load of approximately 300 kW at 5 P.M. The space heating load in January weekdays typically ranges from 360 – 540 kW and the peak load is 650 kW. On Saturdays, the range is from 36-54 kW. The hot water load is small, around 45 kW.

3.2.3 Comparison of Three Load Data Sources

Figure 7 through Figure 9 show hourly electricity-only load data for a 10,000 m^2 office building in Kyushu area. Figure 7 is the result of a DOE-2 simulation using Fukuoka climate, Figure 8 shows an estimate from the Kyushu Area Energy Consumption Intensities (Nishida, 1997), and Figure 9 load data derived from energy consumption data in *Natural Gas Cogeneration Plan/ Design Manual 2002* (Kashiwagi, 2002). Below each are represented as Kyushu and Japan intensities respectively.

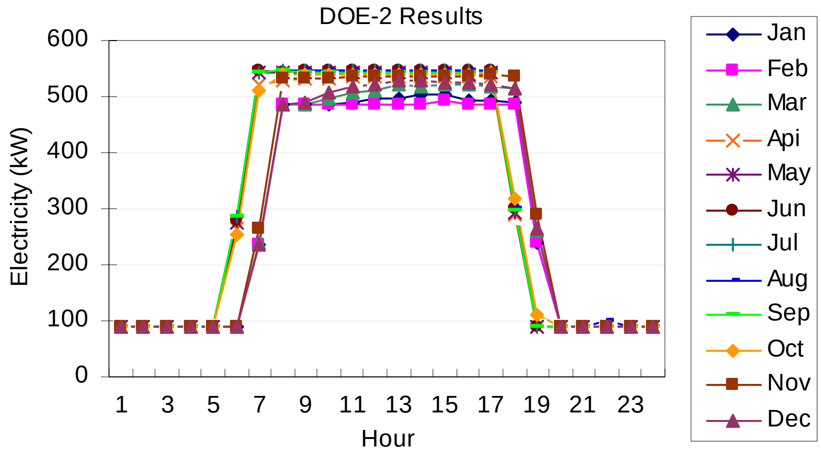

Figure 7: Electricity Only Loads from DOE-2 Simulation

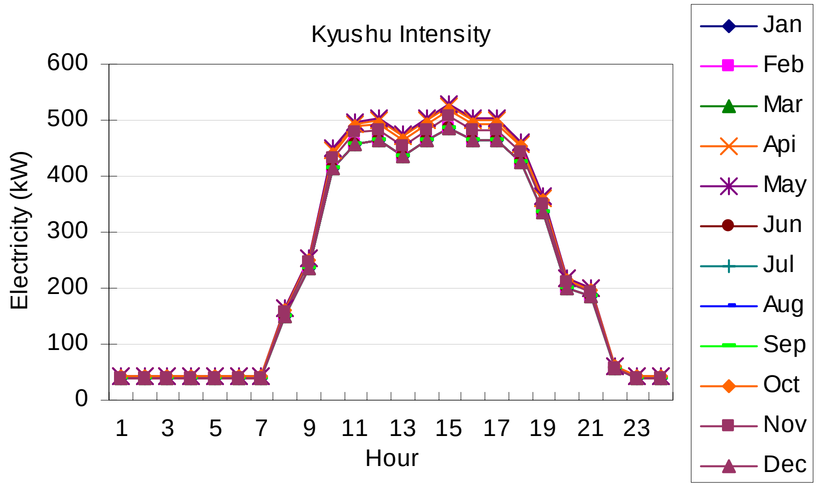

Figure 8: Electricity Only Loads from Kyushu Intensity (1997)

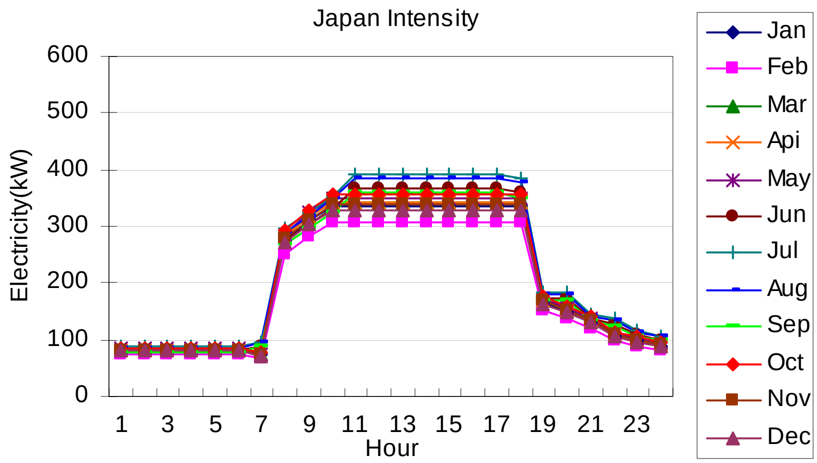

Figure 9: Electricity Only Loads from Japan Intensity (2002)

Non-cooling electricity loads from DOE-2 and Kyushu intensity (1997) have a flat daytime profile with a daytime load of approximately 500 kW year round. Day-time electricity loads from Japan intensity (2002) are also flat, but are approximately 150 kW smaller.

The cooling electricity loads are shown in Figure 10 through Figure 12. From the data of Kyushu intensity (1997), loads are 150 kW during the summer and 30 kW during the fall and spring. The data from Japan intensity (2002) is higher with this: 150 – 200 kW during the summer and 50 – 70 kW during fall and spring. From DOE-2, summer loads are approximately 200 kW. Both the shape and magnitudes of the load profiles vary significantly among the three sources.

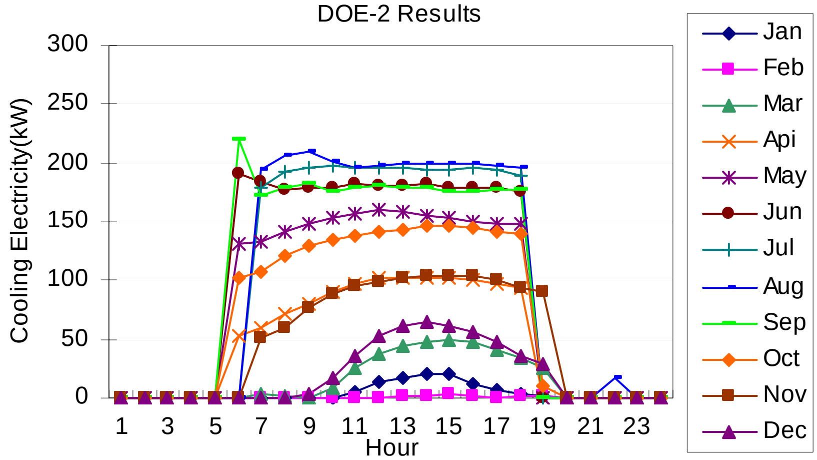

Figure 10: Cooling Electricity Load from DOE-2

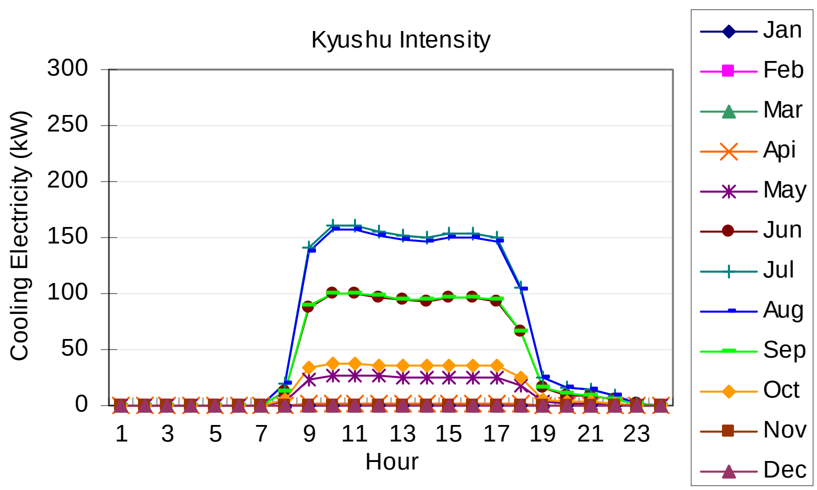

Figure 11: **Cooling Electricity Load from Kyushu Intensity (1997)**

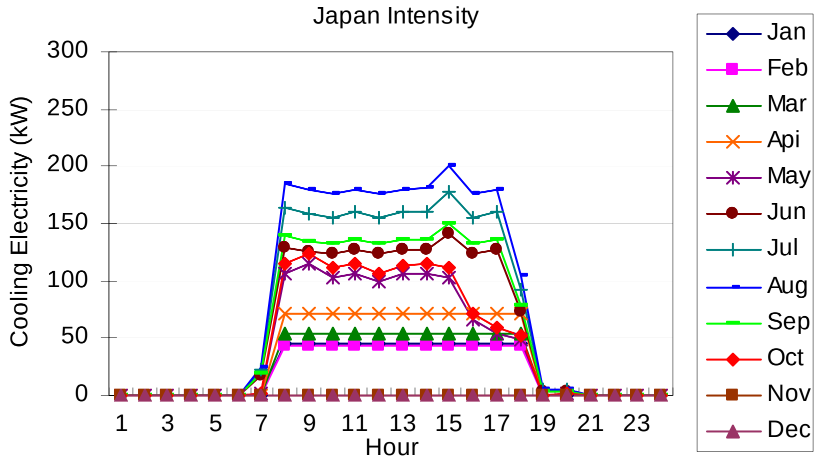

Figure 12: Cooling Electricity Load from Japan Intensity (2002)

The space heating and hot water loads are shown in Figure 13 through Figure 18. For space heating, the Kyushu intensity (1997) and Japan intensity (2002) show similar patterns while the DOE-2 data is higher. The loads are approximately 500-600 kW with a peak load of 974 kW. The Kyushu intensity (1997) has a peak load of 700 kW at 8 A.M. The DOE-2 data has loads varying from 400 to 600 kW during the workday.

For hot water loads, DOE-2 data shows a flat profile during the day which is 20 to 30 kW higher than the other two data sources. The Japan intensity (2002) data has the lowest values, with a peak load at 12 P.M., but the Kyushu intensity (1997) has a peak load at the beginning of the workday.

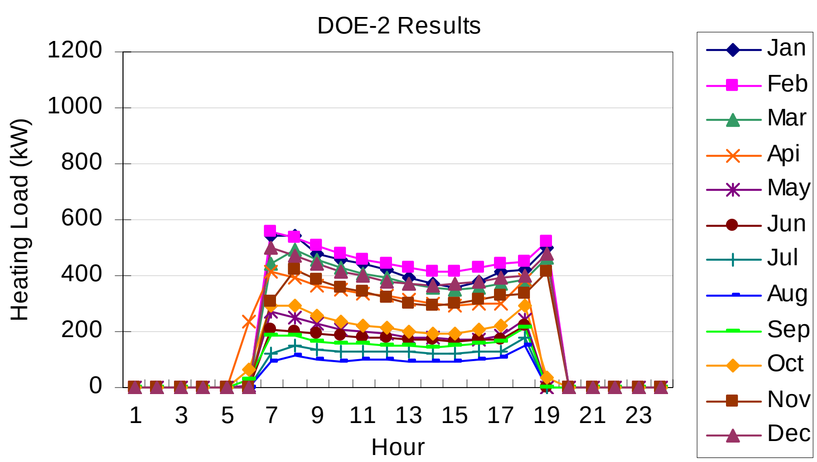

Figure 13: Heating Load from DOE-2

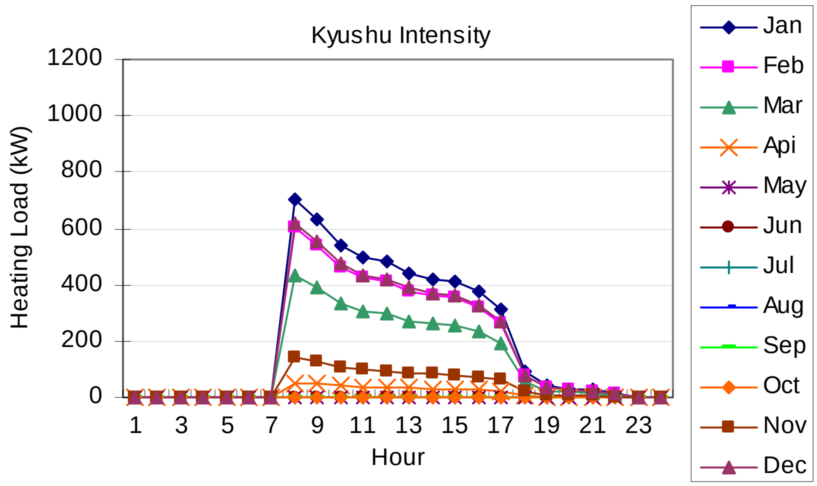

Figure 14: Heating load from Kyushu Intensity (1997)

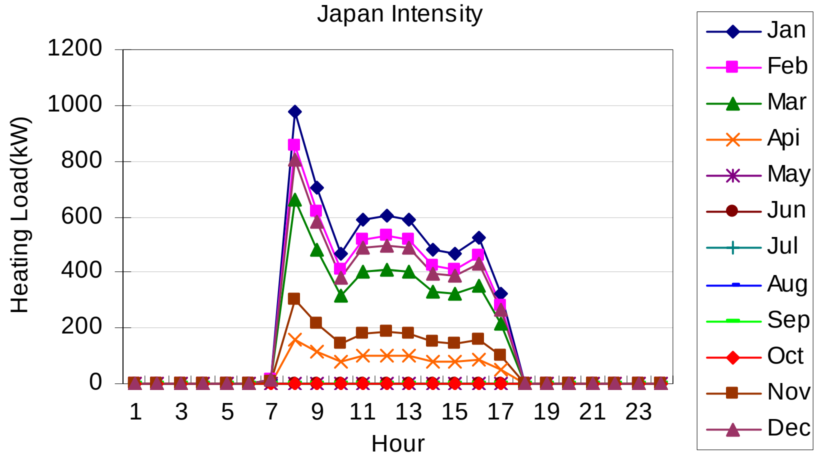

Figure 15: Heating Load from Japan Intensity (2002)

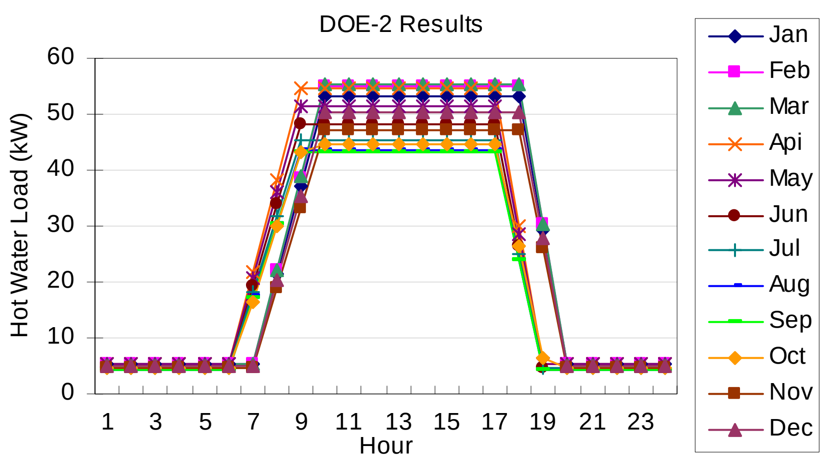

Figure 16: Hot Water Load from DOE-2

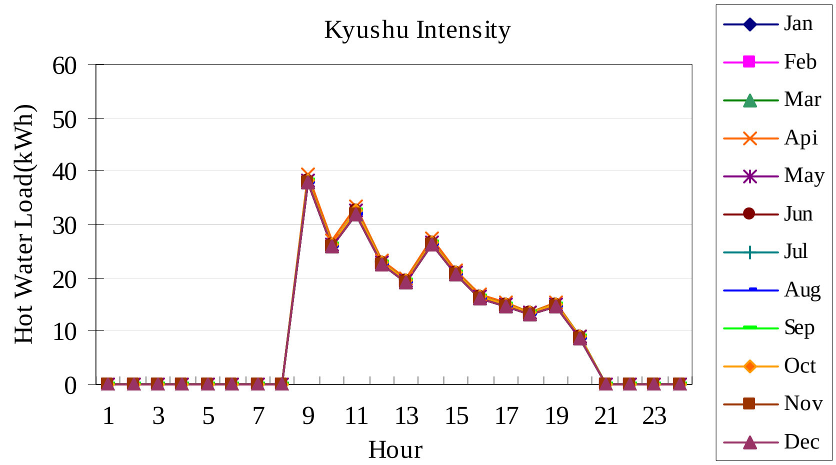

Figure 17: Hot Water Load from Kyushu Intensity (1997)

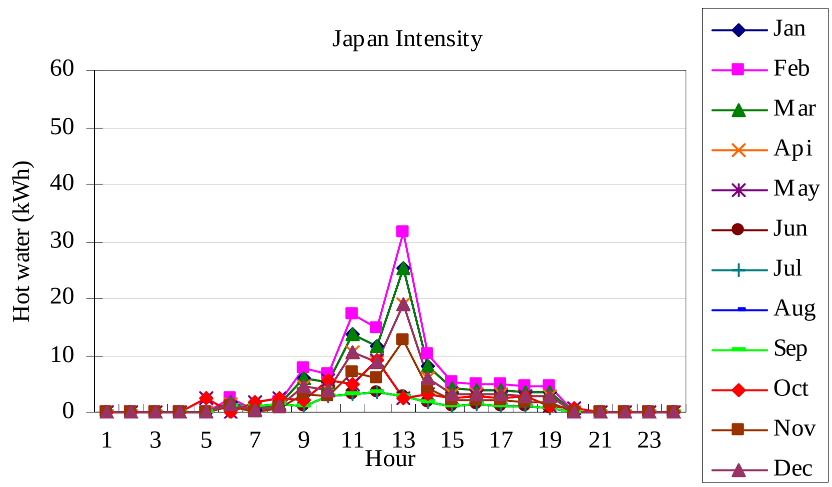

Figure 18: Hot Water Load from Japan Intensity (2002)

Discrepancies in the data sources shown above suggest that additional information is needed to accurately determine the energy load profiles of actual buildings. For this research, the most conservative (smallest) estimates of loads were used for all enduses so that economic savings would not be overstated. DOE-2 was used to model office buildings only because building data required for DOE-2 models was not available for the other building types considered here. Data from Japan intensity (2002) is commonly used for DER planning and design. It is derived from actual buildings throughout Japan and although not differentiated by climate it was used for this research.

3.2.4 Selection of Building Size

The five prototype buildings considered in this study are:

- office building
- hospital
- hotel
- retail
- sports facility

Table 2 and Figure 19 show the average distribution of construction floor area distribution for various building types in Japan. This data is from The Ministry of Construction's (present Ministry of Land, Infrastructure and Transport) "*Construction Data and Statistics Annual Report*". Most office buildings are below 5,000 m^2 but there are many above 10,000 m^2 and under 2,000 m^2. The results of a survey of Kyushu area buildings is shown in Table 3 and Figure 20 (Nishida,1997). Most sports facilities in this survey are between 3,000 and 5,000 m^2. Most hotels are larger than 10,000 m^2, and most hospitals are smaller than 7,500 m^2, but there are also many buildings over 20,000 m^2. There are similar numbers of commercial buildings from 5,000 to 10,000 m^2 and over 10,000 m^2. Research has shown that buildings are smaller in Kyushu than in other areas. The appropriate building scale to consider for DER is discussed below.

Table 2: Distribution of Average Construction Floor Area by Building Type in Japan (%)

	< 2,000 m^2	2,000 – 4,999 m^2	5,000 – 9,999 m^2	> 10,000 m^2
Office	55.4	14.9	11.1	18.6
Retail	39.3	15.4	13.6	31.7
Restaurant	39.3	24.1	18.9	17.7
Hotel	39.3	15.4	13.6	31.7
Hospital	23.7	26.8	26.7	22.8
school	33.5	27.5	30.3	8.7
others	39.3	24.1	18.9	17.7

Table 3: Kyushu Only Distribution of Average Floor Area by Building Type

	Number of Buildings	Average Floor Area (m^2)	Average Stories
Office	367	9,039	8.5
Commercial Building	133	11,658	5.4
Hospital	68	8,737	5.2
Hotel	50	11,970	11
Educational Facility	68	6,175	5.1
Cultural Facility	45	6,680	5.1
Sports Facility	34	5,096	2.9
Average		8,853	6.9

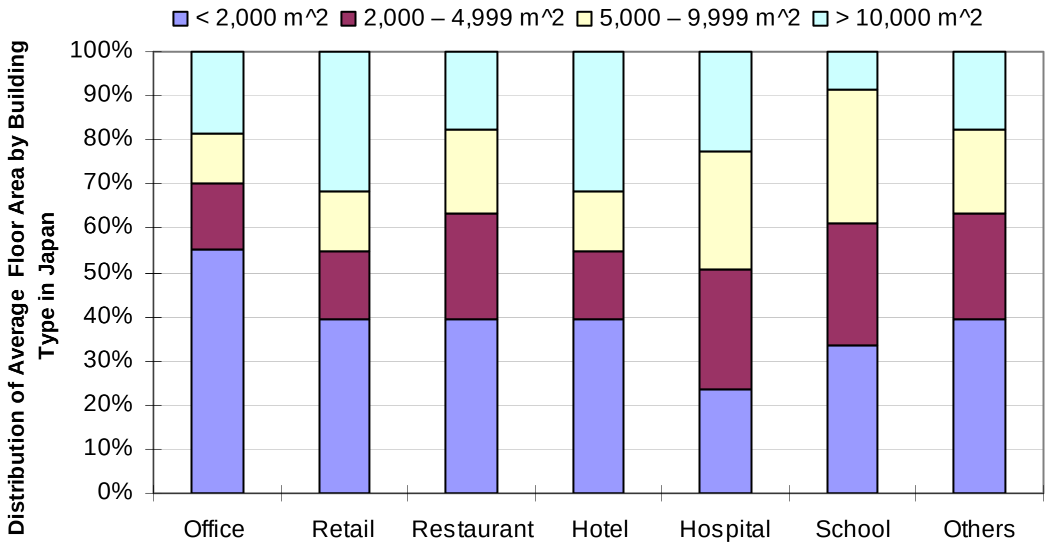

Figure 19: Distribution of Average Construction Floor Area by Building Type

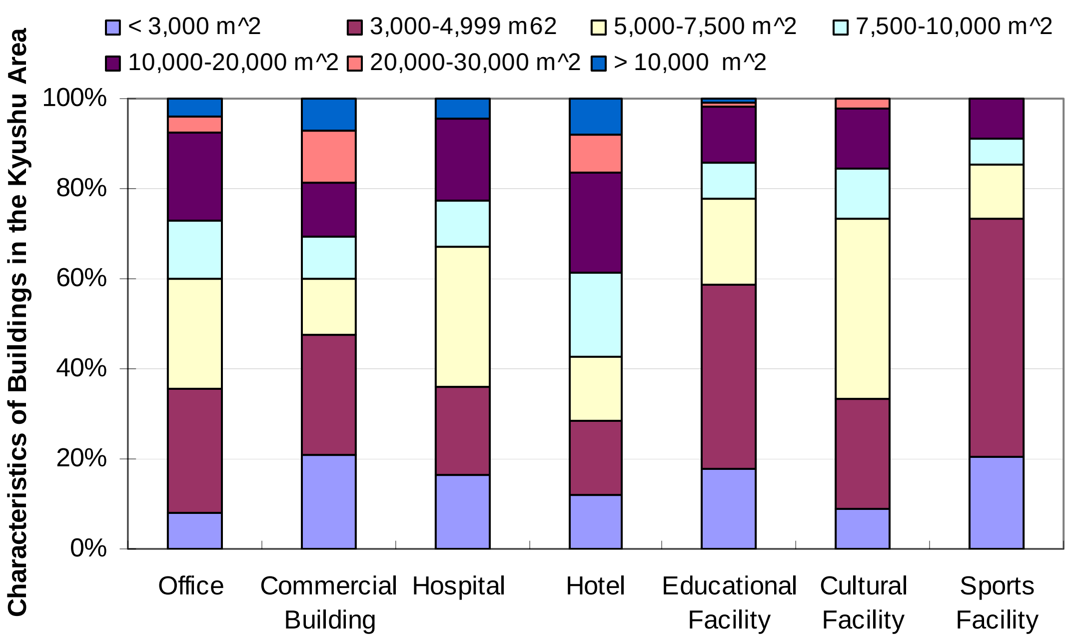

Figure 20: Characteristics of Buildings in the Kyushu Area

3.3 Comparison of Utility Tariffs in Japan and the U.S.

Utility electricity and gas tariffs are key factors determining the economic benefit of the CHP installation. In Japan, major electricity companies include Tokyo Electric Power Co,.INC, Kansai Electric Power Co,.INC and Kyushu Electric Power Co,.INC. Figure 21shows a map of electricity company service territories in Japan. Tokyo Gas, Osaka Gas, and Saibu Gas are the major natural gas companies. Unlike the U.S., tariff structures and rates do not vary much from utility to utility.

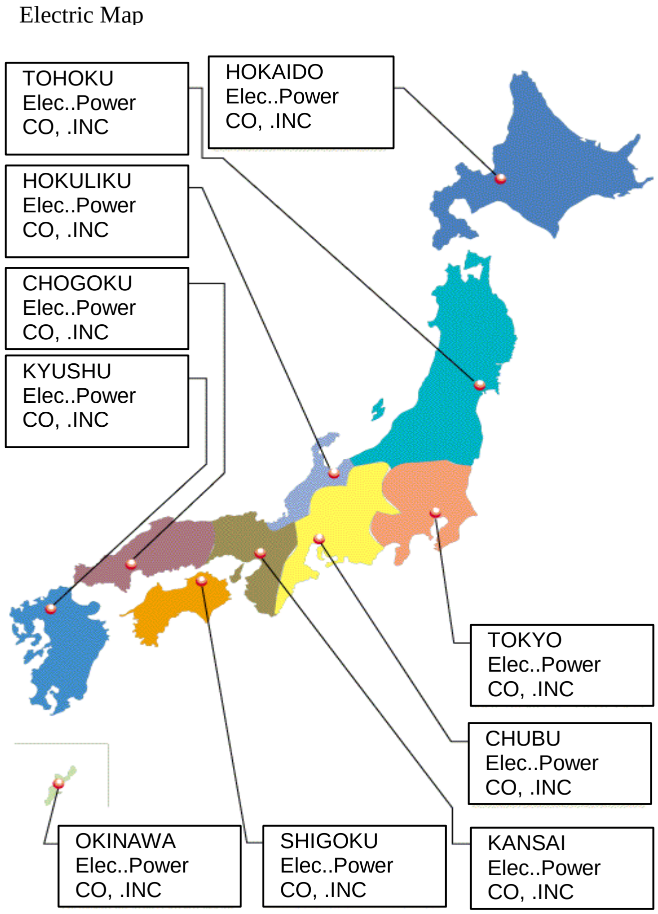

Figure 21: Japanese Electric Utility Service Territories

A comparison of Japan and U.S. energy rates was completed using Tokyo Electric Power Co,.INC and Kyushu Electric Power Co,.INC for Japanese electricity, and Tokyo Gas and Saibu Gas for Japanese natural gas. Bailey, 2003 reports a range of U.S. rates. Table 4 shows the electricity tariffs of several facilities in the U.S., and Table 8 shows equivalent tariffs for Tokyo Electricity and Kyushu Electricity. The exchange rate used was that of October, 2003: US$1 = 120 ¥.

Table 4: Electricity Tariffs at Several Facilities in the U.S.

	Facility Location	A&P Hauppauge, NY	Guaranteed Savings Bank Fresno, CA	Orchid Resort Mauna Lani, HI	Pharmingen Torrey Pines, CA	San Bernardino USPS Redlands, CA	Wyoming County Community Hospital Warsaw, NY
Electricity Rate Structure	Summer months	June- Aug	May- Oct	flat rate	May-Sept	June- Sept	May- Sept
	Summer On Peak hours	11h-18h	11h-18h	flat rate	11h-18h	12h-18h	07h-21h
	Summer Mid Peak hours	06h-11h, 18h-22h	06h-11h, 18h-22h	flat rate	06h-11h, 18h-22h	08h-12h, 18h-23h	21h-22h
	Summer Off Peak hours	00h-06h, 22h-24h	00h-06h, 22h-24h	flat rate	00h-06h, 22h-24h	00h-08h, 23h-24h	00h-07h, 22h-24h
	Winter months	Jan-May, Sept-Dec	Jan- Apr, Nov- Dec	flat rate	Jan- Apr, Oct- Dec	Jan- May, Oct- Dec	Jan- Apr, Oct- Dec
	Winter On Peak hours	17h-20h	17h-20h	flat rate	17h-20h	08h-09h	07h-21h
	Winter Mid Peak hours	06h-17h, 20h-22h	06h-17h, 20h-22h	flat rate	06h-17h, 20h-22h	09h-21h	21h-22h
	Winter Off Peak hours	00h-06h, 22h-24h	00h-06h, 22h-24h	flat rate	00h-06h, 22h-24h	00h-08h, 21h-24h	00h-07h, 22h-24h
Energy Price ($/kWh)	Summer On Peak	0.09	0.16	0.16	0.15	0.20	0.07
	Summer Mid Peak	0.09	0.16	0.16	0.11	0.11	0.07
	Summer Off Peak	0.09	0.16	0.16	0.09	0.09	0.04
	Winter On Peak	0.08	0.11	0.16	0.15	0.12	0.07
	Winter Mid Peak	0.08	0.11	0.16	0.10	0.12	0.07
	Winter Off Peak	0.08	0.11	0.16	0.08	0.09	0.04
Power Price (Demand Charge) ($/kW peak monthly usage during certain hours)	Summer On Peak	11.39	7.37	0.00	7.84	19.75	8.54
	Summer Mid Peak	0.00	0.00	0.00	0.00	2.97	0.00
	Summer Off Peak	0.00	0.00	0.00	0.00	0.00	0.00
	Winter On Peak	11.10	1.82	0.00	0.00	0.00	8.54
	Winter Mid Peak	0.00	0.00	0.00	7.48	0.00	0.00
	Winter Off Peak	0.00	0.00	0.00	0.00	0.00	0.00
Coincident Demand Charge ($/kW at the utility system peak)	Summer On Peak	0.00	0.00	0.00	20.38	0.00	0.00
	Summer Mid Peak	0.00	0.00	0.00	20.38	0.00	0.00
	Summer Off Peak	0.00	0.00	0.00	20.38	0.00	0.00
	Winter On Peak	0.00	0.00	0.00	6.44	0.00	0.00
	Winter Mid Peak	0.00	0.00	0.00	6.44	0.00	0.00
	Winter Off Peak	0.00	0.00	0.00	6.44	0.00	0.00
Peak Power Charge ($/kW peak monthly usage at any time)		0.00	0.00	12.10	0.00	7.26	0.00
Standby Charge ($/kW DER Capacity)		?	2.17	11.40	0.00	6.60	0.00
Facility Charge ($/month)		21.56	75.00	375.00	43.50	299.00	16.00

Table 5: Electricity Tariffs in Several Facilities in Two Japanese Utilities

		Comercial Tariff of KYUSHU Elec.Co,.INC				Comercial Tariff of TOKYO Elec.Co,.INC			
		Commercial Electricity*	Commercial Electricity II	Commercial Electricity with Peak Hour	Commercial Electricity with Peak Hour II	Commercial Electricity	Commercial Electricity II	Commercial Electricity with Peak Hour	Commercial Electricity with Peak Hour II
Electricity Rates Structure	Summer months	July- September				July- September			
	Summer On Peak hours	13h-16h				13h-16h			
	Summer Mid Peak hours	8h-13h, 16h-22h				8h-13h, 16h-22h			
	Summer Off Peak hours	00h-08h, 22h-24h				00h-08h, 22h-24h			
	Winter months	January-June, September-December				January-June, September-December			
	Winter On Peak hours	13h-16h				13h-16h			
	Winter Mid Peak hours	8h-13h, 16h-22h				8h-13h, 16h-22h			
	Winter Off Peak hours	00h-08h, 22h-24h				00h-08h, 22h-24h			
Energy Price ($/kWh)	Summer On Peak	0.12	0.08	0.18	0.11	0.10	0.09	0.13	0.12
	Summer Mid Peak	0.12	0.08	0.15	0.09	0.10	0.09	0.12	0.11
	Summer Off Peak	0.12	0.08	0.04	0.04	0.10	0.09	0.05	0.05
	Winter On Peak	0.11	0.07	0.18	0.11	0.09	0.08	0.13	0.12
	Winter Mid Peak	0.11	0.07	0.14	0.08	0.09	0.08	0.11	0.93
	Winter Off Peak	0.11	0.07	0.04	0.04	0.09	0.08	0.05	0.05
Power Price (Demand Charge) ($/kW peak monthly usage during certain hours)	Summer	10.00	18.58	10.00	18.58	13.00	15.50	13.00	15.50
	Winter	10.00	18.58	10.00	18.58	13.00	15.50	13.00	15.50

*Commercial Electricity: Mainly for office buildings
Commercial Electricity II: Mainly for resturants and supermakets
Commercial Electricity with Peak Hour: Mainly for hospitals and hotels
Commercial Electricity with Peak Hour II : Mainly for 24h resturants and supermakets

Electricity rates vary by season and by time of day, but in both countries, there are three main components to each monthly bill.

- Fixed monthly charge ($)
- Demand charge: proportional to maximum power consumption during the month ($/kW)
- Energy charge: proportional to the amount of energy consumed ($/kWh)

Table 9 shows the gas tariffs of six different U.S. facilities. Table 7 shows CHP rates and seasonal rates for Saibu Gas and Tokyo Gas. For a general facility without CHP installation, if monthly consumption for any month is less than 75% of the maximum consumption for any month, the General Rate is applied. Otherwise, the less expensive seasonal rate will be applied. Accurately comparing the cost of natural gas in Japan and the United States is difficult because of the complex Japan gas tariff structure. However, costs in Japan are roughly two to three times higher than in the U.S. Even the cogeneration rate, which is much lower than other rates, is still higher than rates in the United States.

Table 6: Gas Tariffs at Several U.S. Facilities

	A&P Hauppauge, NY	Guaranteed Savings Bank Fresno, CA	Orchid Resort* Mauna Lani, HI	Pharmingen Torrey Pines, CA	San Bernardino USPS Redlands, CA	Wyoming County Community Hospital Warsaw, NY
month	cost ($/kJ)	cost ($/kJ)	cost ($/kJ)	cost ($/kJ)	cost ($/kJ)	cost ($/kJ)
January	8.29E-06	8.76E-06	9.94E-06	5.26E-06	6.27E-06	4.19E-06
February	7.85E-06	8.33E-06	9.94E-06	4.99E-06	5.30E-06	4.19E-06
March	8.17E-06	8.07E-06	9.94E-06	5.14E-06	5.28E-06	4.19E-06
April	8.40E-06	7.10E-06	9.94E-06	4.40E-06	5.40E-06	4.19E-06
May	8.50E-06	6.85E-06	9.94E-06	4.94E-06	6.09E-06	4.19E-06
June	8.71E-06	5.84E-06	9.94E-06	4.71E-06	5.64E-06	4.19E-06
July	8.46E-06	6.47E-06	9.94E-06	4.82E-06	4.19E-06	4.19E-06
August	7.80E-06	5.75E-06	9.94E-06	5.28E-06	3.91E-06	4.19E-06
September	7.27E-06	5.55E-06	9.94E-06	5.39E-06	4.19E-06	4.19E-06
October	6.69E-06	6.10E-06	9.94E-06	5.31E-06	3.73E-06	4.19E-06
November	8.14E-06	6.77E-06	9.94E-06	5.60E-06	4.06E-06	4.19E-06
December	7.81E-06	7.56E-06	9.94E-06	5.99E-06	5.94E-06	4.19E-06

Table 7: Gas Tariffs at Several Facilities in two Japanese Utilities

	Comercial Gas Tariff of SAIBU Gas CO.				Comercial Gas Tariff of SAIBU Gas CO.								
	CHP System Program				CHP System Program				Commercial Seasonal Program			General F	
month	Flow Rate ($/kJ)	Maxmum Demand Season Charge ($/kJ)	Energy Charge ($/kJ)	Demand Charge ($/mon)	Flow Rate ($/kJ)	Maxmum Demand Season Charge ($/kJ)	Energy Charge ($/kJ)	Demand Charge ($/mon)	Flow Rate ($/kJ)	Energy Charge ($/kJ)	Demand Charge ($/mon)	Energy Charge ($/kJ)	Demand Charge ($/mon)
January	1.72E-04	2.28E-07	9.62E-06	2.50E+02	2.15E-04	2.28E-07	8.50E-06	1.79E+02	2.15E-04	1.38E-05	1.42E+02	1.93E-05	8.01E+01
February	1.72E-04	2.28E-07	9.62E-06	2.50E+02	2.15E-04	2.28E-07	8.50E-06	1.79E+02	2.15E-04	1.38E-05	1.42E+02	1.93E-05	8.01E+01
March	1.72E-04	2.28E-07	9.62E-06	2.50E+02	2.15E-04	2.28E-07	8.50E-06	1.79E+02	2.15E-04	1.38E-05	1.42E+02	1.93E-05	8.01E+01
April	1.72E-04	2.28E-07	9.62E-06	2.50E+02	2.15E-04	2.28E-07	8.58E-06	1.79E+02	2.15E-04	1.17E-05	1.42E+02	1.99E-05	8.01E+01
May	1.72E-04	2.28E-07	9.62E-06	2.50E+02	2.15E-04	2.28E-07	8.58E-06	1.79E+02	2.15E-04	1.17E-05	1.42E+02	1.99E-05	8.01E+01
June	1.72E-04	2.28E-07	9.62E-06	2.50E+02	2.15E-04	2.28E-07	8.58E-06	1.79E+02	2.15E-04	1.17E-05	1.42E+02	1.99E-05	8.01E+01
July	1.72E-04	2.28E-07	9.62E-06	2.50E+02	2.15E-04	2.28E-07	8.68E-06	1.79E+02	2.15E-04	1.18E-05	1.42E+02	1.98E-05	8.01E+01
August	1.72E-04	2.28E-07	9.62E-06	2.50E+02	2.15E-04	2.28E-07	8.68E-06	1.79E+02	2.15E-04	1.18E-05	1.42E+02	1.98E-05	8.01E+01
September	1.72E-04	2.28E-07	9.62E-06	2.50E+02	2.15E-04	2.28E-07	8.68E-06	1.79E+02	2.15E-04	1.18E-05	1.42E+02	1.98E-05	8.01E+01
October	1.72E-04	2.28E-07	9.62E-06	2.50E+02	2.15E-04	2.28E-07	8.59E-06	1.79E+02	2.15E-04	1.17E-05	1.42E+02	1.97E-05	8.01E+01
November	1.72E-04	2.28E-07	9.62E-06	2.50E+02	2.15E-04	2.28E-07	8.59E-06	1.79E+02	2.15E-04	1.17E-05	1.42E+02	1.97E-05	8.01E+01
December	1.72E-04	2.28E-07	9.62E-06	2.50E+02	2.15E-04	2.28E-07	8.59E-06	1.79E+02	2.15E-04	1.38E-05	1.42E+02	1.93E-05	8.01E+01

Note: Flow rate (contracted maximum amount,depond on the equipment rating)
Maxmum Demand Season (total gas concumption from Dec-Mar)

The structure of natural gas tariffs in DER-CAM is different than that of Tokyo Gas, so rates had to be approximated. The monthly maximum demand charge was estimated and added to the energy charge. The flow rate charge depends on capacity of the equipment. It was converted into $/kW and input as a standby charge[2].

[2] *Standby charges* are charges proportional to the electrical capacity of the installed DER system. Utilities assert that this is the cost of providing access to additional utility electrical capacity for use during DER outages.

In this report, commercial electricity and natural gas rates in Tokyo were used as the representative Japanese rates.

3.4 DER Technology Information in Japan and the U.S.

Table 8 shows United States DER technology data collected by Firestone (2004). It is itemized by natural gas engine (GE), gas turbine (GT), microturbine (MT), fuel cell (FC), and photovoltaic (PV). All equipment (besides PV) can be purchased for electricity generation only, and with heat recovery for heating (HX), or with heat recovery for heating and absorption cooling (ABSHX). Numbers at the end of each name in Table 8 refer to the rated capacity of the equipment. Data includes capacity, lifetime (in years), turnkey capital costs, maintenance costs, heat rate, and electrical efficiency.

Table 8: DER Technology Information for the U.S.

Technology	Name	Capacity kW	Lifetime a	Capital Cost $/kW	Fixed Annual Cost $/kW	Variable Annual Cost $/kW	Heat Rate kJ/kWh	HHV Efficiency %
Fuel Cell	FC--00200	200	10	5005	0	0.029	10000	36.00%
Gas Turbine	GT--01000	1000	20	1403	0	0.0096	16438	21.90%
	GT--05000	5000	20	779	0	0.0059	13284	27.10%
	GT--10000	10000	20	716	0	0.0055	12414	29.00%
	GT--25000	25000	20	659	0	0.0049	10496	34.30%
	GT--40000	40000	20	592	0	0.0042	9730	37.00%
Microturbine	MT--00028	28	10	2263	0	0.015	15929	22.60%
	MT--00060	60	10	1828	0	0.015	14400	25.00%
	MT--00067	67	10	1708	0	0.015	14286	25.20%
	MT--00076	76	10	1713	0	0.015	14876	24.20%
	MT--00100	100	10	1576	0	0.015	13846	26.00%
Natual Gas Reciprocating Engine	NG--00030	30	20	1044	0	0.02	13080	27.52%
	NG--00060	60	20	991	0	0.018	12528	28.74%
	NG--00075	75	20	974	0	0.017	12360	29.13%
	NG--00100	100	20	1030	0	0.018	12000	30.00%
	NG--00300	300	20	790	0	0.013	11613	31.00%
	NG--01000	1000	20	720	0	0.009	10588	34.00%
	NG--03000	3000	20	710	0	0.009	10286	35.00%
	NG--05000	5000	20	695	0	0.008	9730	37.00%
Photovoltaic	PV--00010	10	30	8740	12	0	0	100.00%
	PV--00025	25	30	8140	12	0	0	100.00%
	PV--00050	50	30	7940	12	0	0	100.00%
	PV--00100	100	30	7840	12	0	0	100.00%
Fuel Cell with Heat Recovery for Heating	FC--HX--00200	200	10	5200	0	0.029	10000	36.00%
Gas Turbine with Heat Recovery for Heating	GT--HX--01000	1000	20	1910	0	0.0096	16438	21.90%
	GT--HX--05000	5000	20	1024	0	0.0059	13284	27.10%
	GT--HX--10000	10000	20	928	0	0.0055	12414	29.00%
	GT--HX--25000	25000	20	800	0	0.0049	10496	34.30%
	GT--HX--40000	40000	20	702	0	0.0042	9730	37.00%
Microturbine with Heat Recovery for Heating	MT--HX--00028	28	10	2636	0	0.015	15929	22.60%
	MT--HX--00060	60	10	2082	0	0.015	14400	25.00%
	MT--HX--00067	67	10	1926	0	0.015	14286	25.20%
	MT--HX--00076	76	10	1932	0	0.015	14876	24.20%
	MT--HX--00100	100	10	1769	0	0.015	13846	26.00%
Gas Engine Heat Recovery for Heating	NG--HX--00030	30	20	1442	0	0.02	13080	27.52%
	NG--HX--00060	60	20	1362	0	0.018	12528	28.74%
	NG--HX--00075	75	20	1336	0	0.017	12360	29.13%
	NG--HX--00100	100	20	1350	0	0.018	12000	30.00%
	NG--HX--00300	300	20	1160	0	0.013	11613	31.00%
	NG--HX--01000	1000	20	945	0	0.009	10588	34.00%
	NG--HX--03000	3000	20	935	0	0.009	10286	35.00%
	NG--HX--05000	5000	20	890	0	0.008	9730	37.00%
Fuel Cell with Heating and Cooling	FC--ABSHX--00200	200	10	5366	9.69	0.029	10000	36.00%
Gas Turbine with Heating and Cooling	GT--ABSHX--01000	1000	20	2137	10.37	0.0096	16438	21.90%
	GT--ABSHX--05000	5000	20	1149	4.03	0.0059	13284	27.10%
	GT--ABSHX--10000	10000	20	1025	2.76	0.0055	12414	29.00%
	GT--ABSHX--25000	25000	20	859	2.12	0.0049	10496	34.30%
	GT--ABSHX--40000	40000	20	746	1.88	0.0042	9730	37.00%
Microturbine with Heating and Cooling	MT--ABSHX--00028	28	10	3046	23.49	0.015	15929	22.60%
	MT--ABSHX--00060	60	10	2420	19.5	0.015	14400	25.00%
	MT--ABSHX--00067	67	10	2201	15.87	0.015	14286	25.20%
	MT--ABSHX--00076	76	10	2225	16.92	0.015	14876	24.20%
	MT--ABSHX--00100	100	10	2015	14.27	0.015	13846	26.00%
Gas Engine with Heating and Cooling	NG--ABSHX--00030	30	20	2029	22.56	0.02	13080	27.52%
	NG--ABSHX--00060	60	20	1851	18.93	0.018	12528	28.74%
	NG--ABSHX--00075	75	20	1796	17.84	0.017	12360	29.13%
	NG--ABSHX--00100	100	20	1774	16.51	0.018	12000	30.00%
	NG--ABSHX--00300	300	20	1465	12.08	0.013	11613	31.00%
	NG--ABSHX--01000	1000	20	1117	6.97	0.009	10588	34.00%
	NG--ABSHX--03000	3000	20	1038	4.37	0.009	10286	35.00%
	NG--ABSHX--05000	5000	20	967	3.45	0.008	9730	37.00%

Note: cost for maintenance and operating

For this study, data was collected on Japanese DER equipment (Table 9). Figure 22 compares DER turnkey costs in Japan and the U.S. There is little difference in the range 3,000 kW to 5,000 kW. At higher capacities Japanese prices are lower, while at the lower capacities, Japanese prices are significantly higher.

Table 9: Japanese DER Technology Information (Only With Waste Heat Recovery)

	Technology	Capacity (kW)	Lifetime (a)	CapCost ($/kW)	Maintenance Cost ($/kW)	Power Generation Efficiency (%)	Total Efficiency (%)	Heat Recovery Efficiency (%)	Annual Operation Hour(h)
Average	Gas Engine	10	15	3333.33	0.02	26	82.5	56.5	4000
		210	15	2083.33	0.03	32.6	86.8	54.2	4000
		610	15	1666.67	0.02	40.8	75	34.2	4000
		815	15	1500.00	0.02	40.8	74	33.2	4000
		2383	15	1083.33	0.02	41.1	74.8	33.7	4000
	Gas Turbine	3770	15	916.67	0.01	27.5	72.1	44.6	7000
Company MITSUYI	Gas Turbine CHP	3370	15	1186.94	0.01			47.8	
		4420	15	980.39	0.01			51.4	
		5300	15	864.78	0.01			50.9	
		7260	15	757.58	0.01			47.5	
		9090	15	687.57	0.01			48.7	
		10310	15	646.62	0.01			49.4	
		1090	15	1529.05	0.01			46.2	
		1270	15	1377.95	0.01			30.4	

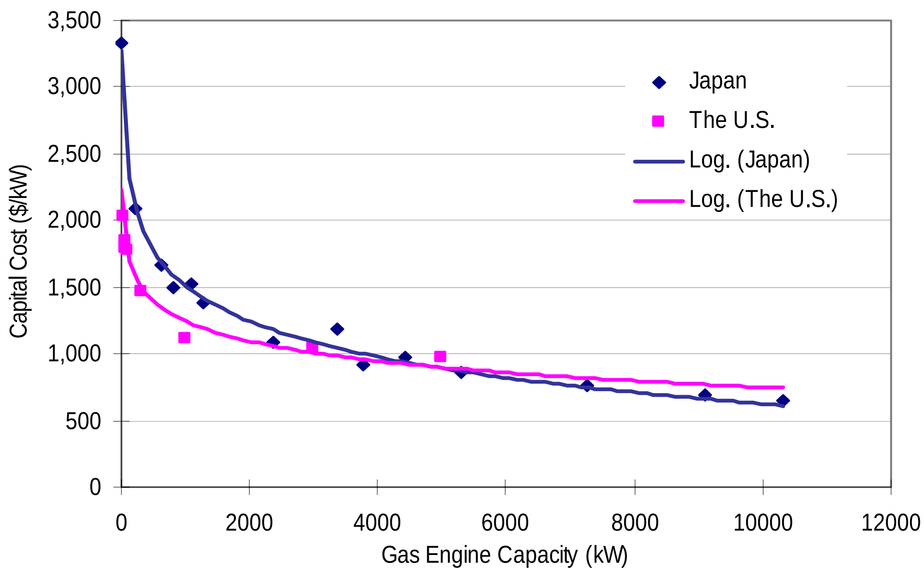

Figure 22: Comparison of turnkey CHP costs in Japan and the U.S.

Because CHP subsidies of 1/3 of turnkey costs are available throughout Japan, making DER costs become similar to those in the United States. U.S. technology information was used. A sensitivity analysis was also done without the Japanese subsidy, for which the United States costs were multiplied by 1.5.

3.5 Incentives for DER Installation

3.5.1 The U.S. DER Incentives

There is no single incentive for DER installation in the U.S., rather it varies by state and region, and can include rebates and low-interest loans. Historically under federal law and Federal Energy Regulatory Committee (FERC) regulations, individual states determine incentives for qualifying facilities (QFs) which includes larger (>~1 MW) CHP plants in their state. Small scale CHP is entirely under state and local jurisdiction on incentives may include rebates on DER project costs, energy tariff reductions, or utility purchase of excess electricity. Determining which incentives were available to each site proved difficult. In the work by Bailey (2003), organizations contacted included FERC, the New York State Public Service Commission (NYPSC), the Long Island Power Authority (LIPA), KeySpan, the California Energy Commission (CEC), the California Public Utilities Commission (CPUC), Pacific Gas and Electric (PG&E), Southern California Edison (SCE), San Diego Gas and Electric (SDG&E), and various energy consultants.

Clearly, presentation of any comprehensive picture of U.S. DER incentives is not possible here, so that example programs one from California, one from New York and one federal are described.

3.5.1.1 CPUC

As part of California Assembly Bill 970, the CPUC introduced a statewide self-generation incentive program in September 2000. It provides financial incentives to customers that install new qualifying self-generation equipment to provide all or a portion of their electricity needs. Funding of $125 million annually statewide provided is for self-generation up to 1 MW. The program is administered by PG&E, SCE, SoCalGas and the San Diego Regional Energy Office (SDREO, serving SDG&E customers).

Eligible technologies include MTs, FCs, PVs, small GTs, wind turbines, and internal combustion engines that meet the following criteria:

- At least 5% of the power system's total energy output is in the form of useful thermal energy.
- Where useful thermal energy results from power production, the useful annual electrical output plus one-half the annual useful thermal energy output equals not less than 42.5% of any natural gas and oil energy input.
- In the case of microturbines, small gas turbines, and internal combustion engines, the following power quality and reliability requirements must be met:
    - The self-generating facility must be designed to operate at a power factor between 0.95 power factor loading and 0.90 power factor leading.

- Sites with greater than 200 kW generating capability must coordinate maintenance schedules with the local utility, and in general, can only schedule maintenance from October to March, or only during off peak or weekend hours between April and September.

Funding from this program is available as a secondary source after other sources have been fully tapped. The CPUC funding limits are decreased by the amount of alternate funding. In other words, the limits set out by the CPUC represent a cap to funding available to qualifying sites in California. It is assumed, therefore, that the test sites located in California that indicated they are applying for or have received CPUC self-generation funding are qualifying facilities, and will receive funding up to the limits set by the CPUC in this program（Table 10）.

Table 10: CPUC DER Incentives

Incentive Category	Incentive Offered	Maximum % of Project	Minimum System Size	Maximum System Size*	Eligible Technologies
Level 1	$4500 / kW	50%	30 kW	1.5 MW	PVs, FCs operating on renewable fuel, and wind turbines
Level 2	$2500 / kW	40%	None	1.5 MW	FCs operating on non-renewable fuel and utilizing sufficient waste heat recovery
Level 3	$1000 / kW	30%	None	1.5 MW	MTs, small GTs, internal combustion engines, using sufficient waste heat recovery and meeting reliability criteria
* Maximum system size 1.5 MW, but rebate funding only available up to a 1 MW cap					

3.5.1.2 New York State Funding for Energy Efficiency and DER

In New York State, the NYPSC has implemented a system benefits charge (SBC) applied to all electric rates to provide a fund for the purposes of increasing energy efficiency and providing public goods programs. The program has been expanded to include transmission and distribution issues due to the increasing difficulty of providing energy services to “load pockets.” 75% if funds collected by the SBC are distributed to the New York State Energy Research and Development Authority (NYSERDA), and the remainder goes electric utilities for their own programs. NYSERDA’s programs are called “Energy$mart” and include low interest loans, and targeted energy efficiency programs for schools, agriculture, homes, communities, and pollution control and monitoring for air water and solid waste emissions.

NYSERDA offers funding for projects that demonstrate the use of DER technologies in industrial, commercial, municipal, and institutional organizations. NYSERDA’s DER programs provide approximately $12 million annually statewide for 2002 through 2006 (Table 11).

Table 11: NYSERDA's DER program

Funding Allocation	**2001**	**2002-2006**	**Total**
Distributed Generation Combined Heat and Power	$8,637,233	$58,445,839	$67,083,072

3.5.1.3 Climate Change Fuel Cell program

The DOD's Climate Change Fuel Cell program was initiated in 1995 and provides up to $1,000/kW for fuel cell installations with a capacity of at least 3 kW. The fund is administered through the US Army Corps of Engineers Construction Engineering Research Lab (CERL). The funding level for fiscal year 2002 was expected to be $3 million.

Table 12 shows several incentives that apply to different sites as shown above. Although overall numbers cannot be cited, many sites still can receive incentives.

3.5.2 Incentives in Japan

	Installed Technology	Project Cost	Grants Received	Grants Rate
A&P	60 kW Capstone microturbine,CHP for space heating &desiccant dehumidification	$145,000	$95,000	66%
USPS Absorption Cooling		$680,000	$0 (project not porsued) ($204,000 potential)	30%
Guarantee Savings Building	3 x 200 kW Phosphoric Acid Fuel Cells, CHP,350 kW (100ton) adsorption chiller	$4,353,375	SELFGEN, CPUC benefits through PG&E $1.5 million DODCCFC Grant $600,000,loan for $2.6 million from UTC	48%
AA Dairy	Digester biogas system converted 130kW diesel engine	$363,000 $61,000 without digester system	EPA Ag Star $24,000,local Soil Conservation District $120,000	40%
East Bay Municipal Utility District	10 x 60 kW Capstone microturbines,150 ton absorption chiller and CHP	$3,900,000(total funding) $184,522 for absorption chiller and heat exchanger	$855,000 rebate, and $1.9 million low interest loan	22%
Wyoming County Community Hospital	560 kW natural gas engine with CHP and absorption cooling	$1,013,690	NYSERD A funded 50% of $25,000 feasibility study	
Byron Bergen (upstate NY school)	8 different engines. 7diesel, 1natural gas, 2absorption chillers, onsite natural gas well andtwo boilers.1450 kW total Grid independent	$3 million	$2,760,000 State rebates for capital projects atschools.Taxpayer direct cost was $240,000	92%

Table 13 shows interest rates as low as 1.65% for CHP installation. Table 15 shows details of available subsidies. In general, 1/3 of the installation cost will be subsidized.

Table 12: Grants for DG in Selected Site in the U.S.

	Installed Technology	Project Cost	Grants Received	Grants Rate
A&P	60 kW Capstone microturbine,CHP for space heating &desiccant dehumidification	$145,000	$95,000	66%
USPS Absorption Cooling		$680,000	$0 (project not porsued) ($204,000 potential)	30%
Guarantee Savings Building	3 x 200 kW Phosphoric Acid Fuel Cells, CHP,350 kW (100ton) adsorption chiller	$4,353,375	SELFGEN, CPUC benefits through PG&E $1.5 million DODCCFC Grant $600,000,loan for $2.6 million from UTC	48%
AA Dairy	Digester biogas system converted 130kW diesel engine	$363,000 $61,000 without digester system	EPA Ag Star $24,000,local Soil Conservation District $120,000	40%
East Bay Municipal Utility District	10 x 60 kW Capstone microturbines,150 ton absorption chiller and CHP	$3,900,000(total funding) $184,522 for absorption chiller and heat exchanger	$855,000 rebate, and $1.9 million low interest loan	22%
Wyoming County Community Hospital	560 kW natural gas engine with CHP and absorption cooling	$1,013,690	NYSERD A funded 50% of $25,000 feasibility study	
Byron Bergen (upstate NY school)	8 different engines. 7diesel, 1natural gas, 2absorption chillers, onsite natural gas well andtwo boilers.1450 kW total Grid independent	$3 million	$2,760,000 State rebates for capital projects atschools.Taxpayer direct cost was $240,000	92%

Table 13 Financial Loan for CHP Installation in Japan

Program Name	Objective	Content
New Energy Installation Promotion	equipment over 100kW, efficiency greater than 60% FC	Interest rate 1.65% Subsidy 40% of investment
Energy Conservation Promotion	equipment over 50 kW, efficiency greater than 60%, CHP (any type of fuel)	Interest rate 1.65% Subsidy 50% of investment
New Power Generation/Distribution Enterprises	Electricity generation, transmission, distribution enterprise	Interest rate 1.55 - 1.65% Subsidy 50% of investment

Table 14: Subsidy for CHP in Japan

Policy	Objective	Content
The New Energy and Industrial Technology Development Organization (NEDO) : Rational Energy Utilization Enterprise Support Project	Office building ESCO project and using Natural Gas with CHP installation project, must be conducted by private enterprise	Subsidy: no more than 1/3 of cost, up to 500 million ¥ (5 million dollars)
Minister of Economy, Trade and Industry (METI): New Energy Enterprise Support Project	High efficiency natural gas CHP system, Natural gas co-gen utilization energy supply equipment	Subsidy: no more than 1/3 of cost, bond covered up to 90%
NEDO: Local New Energy Installation Promotion Enterprise	Local govt. (public) organization: project conducted by local public org. and high efficiency CHP system, Natural gas CHP utilization energy supply equipment	Subsidy: no more than 1/2 of cost
NEDO: Local Energy Conservation Promotion Enterprise	Local govt .(public) organization:: high effectiveness demonstration, energy conservation promotion measure	Subsidy: no more than 1/2 of cost
NEDO: Global Warming Prevention Support Enterprise	New energy equipment and energy conservation equipment and the combination – installation of multiple equipment such as new energy equipment and energy conservation equipment	Subsidy: no more than 1/2 of cost
METI: Disaster Response Oil Supply Facility Promotion	Gasoline station generator more than 10 kW Internal combustion power generator	Subsidy: 1/5 of the capital cost (installation and equip) , up to 500 million ¥ (5 million dollars)
LP (Liquefied Petroleum Gas Promotion Center) (this is an organization): Petroleum gas energy utilization system installation enterprise (the company that installs these systems)	Civic (non-industrial) sector: office building/facility used for civic sector or office, gas turbine, gas engine, single unit with more than 250 kW. FCs over 100 kW.	Subsidy: for GT, NG, ½ of the expenses up to 60 million ¥ (600K dollars), Fuel Cell ½ up to 52 million ¥ (520K dollars)
Petroleum Industry Activation Center: Advanced Petroleum Gas Energy Utilization System Enterprise	Single unit over 500 kW total unit over 1000 kW for non-industrial use (petroleum cogeneration equipment)	½ of capital cost up to 400 million ¥ (4 million dollars)
Ministry of Land, Infrastructure and Transport: Ecological Housing District (neighborhood) Model Enterprise	Housing area- must have more than 50 households qualify the guidelines of an ecological housing district, have cogeneration system	1/3 of the facility infrastructure expense
Local Goverment (Ministry of Health, Labour and Welfare): Emergency medical security disaster infrastructure/establishment for hospital to ensure emergency medical care during disasters	Disaster medical center, local disaster medical center that use independent energy system (like self generator).	national or local govt subsidizes 1/3 of the capital cost up to 1 facility: 178 million ¥ (1.8 million dollars)

4. Results

This chapter presents results of the DER-CAM optimizations. As described in Section 3.2, the five prototype buildings considered are office building, hospital, hotel, retail and sports facility. All buildings were considered in 5,000 m^2 and 10,000 m^2 floor area sizes. Customer end use load data is from Kashiwagi (2002). For all DER-CAM scenarios, a real interest rate of 5% is used. In many cases, sites would be eligible for loans with lower interest rates.

For all building types and sizes, separate DER-CAM optimizations were done using subsidized and non-subsidized DER capital costs. Commercial electricity and natural gas rates in Tokyo were used as the representative Japanese rates. The average efficiency of the Japanese macrogrid was assumed to be 36.6%[3]. CO_2 emissions were assumed to be 0.66 kg/kWh (fossil fuels, only)[4]. This is equivalent to carbon emissions of 0.18 kg/kWh.

In the results *whole system efficiency* is the percentage of energy from fuel used by the DER system that is applied to an end use in the form of electricity or heat. In the United States, the Federal Energy Regulatory Commission (FERC) uses an alternative definition of efficiency, herein referred to as the *FERC efficiency*, which is defined as:

$$\text{FERC Efficiency} = \frac{[\text{Electrical Energy Produced}] + \frac{1}{2}[\text{Recovered Heat Utilized}]}{[\text{HHU of Fuel Consumed}]} \times 100\%$$

4.1 10,000 m^2 Buildings

For each building type modeled, three DER-CAM scenarios were considered:

- ***Do-Nothing:*** No DER investments are considered. This scenario provides the annual energy cost, consumption, and emissions prior to DER investment.
- ***DER:*** DER investment in electricity generation only, no CHP.
- ***DER with CHP:*** DER investment in any of the electricity generation and heat recovery and utilization devices mentioned in Chapter 3.4

The results of these studies are described below.

4.1.1 Office Building

Table 15 shows the DER-CAM results for the office building. The Do-Nothing total energy bill is $317,400. In the DER without heat recovery scenario, a 300 kW natural gas engine was selected, resulting in decreased electricity purchase and increased natural gas purchase. Total annual fuel costs (electricity and natural gas) are reduced by 16.2% and the total annual energy costs (including the capital and maintenance costs) are reduced by 4.7% ($15,000). The payback period is 6 years.

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[3] According to Nippon Engine Generator Association (NEGA), http://www.nega.or.jp/

[4] Based on the assumption of Japan Ministry of Environment, http://www.env.go.jp/council/06earth/r062-01/index.html.

For the DER with CHP scenario, the 300 kW natural gas engine with heat recovery for heating and absorption cooling was chosen. Compared with the Do-Nothing case, the total annual energy bill savings are 12.3% ($40,000) with a payback period of 4.7 years. Total annual fuel costs are reduced by 30.3%. CHP installation has sufficient economic benefit.

Table 15: Office Building DER-CAM Results

			Annual Cost								
Case	Installed Capacity	Installed Technology	Installation Cost	Electricity Purchased	Gas		Energy Cost	Total Cost	Energy Cost Reduction	Overall Cost Reduction	Pay Back Year
	kW		k$	k$	For DER (k$)	Gas only (k$)	k$	k$	%	%	a
Do-Nothing	0	0	0	275.3	0	42.1	317.4	317.4			
DER	300	NG--00300	36.4	125.2	112	28.8	266	302.5	-16.2%	-4.7%	6.1
DER with CHP	300	NG-ARSHX--00300	58.5	83.8	129.4	6.7	219.9	278.4	-30.7	-12.3%	4.7

Figure 23 and Figure 24 show how the CHP system meets electricity loads in January. The daytime electricity load is a constant 380 kW, 300 kW of which is met by DER. The remainder (80kW) is met by electricity purchase. Figure 25 and Figure 26 show the electricity loads in the summer (July). The electricity load is 569 kW, 300 kW of which is met by DER. The peak cooling electricity load (177 kW) is offset by absorption cooling, and the electricity purchase from the macrogrid is reduced to 198 kW.

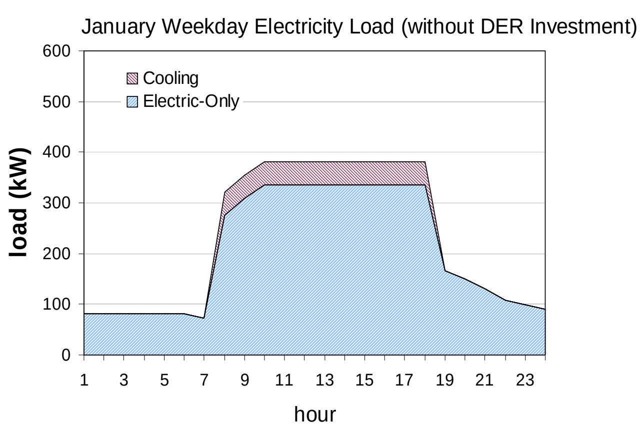

Figure 23: Office Building January Electricity Loads

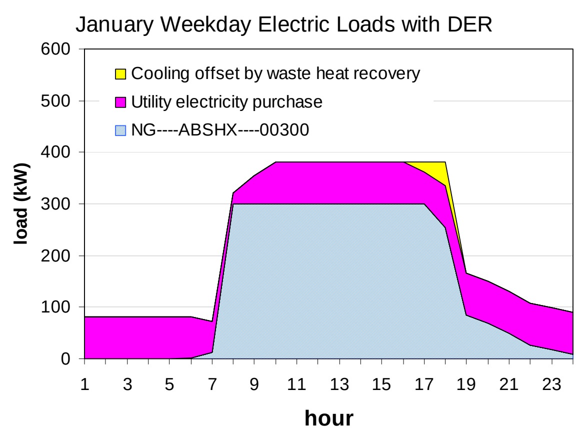

Figure 24: Office Building January Electricity Provisions with CHP System

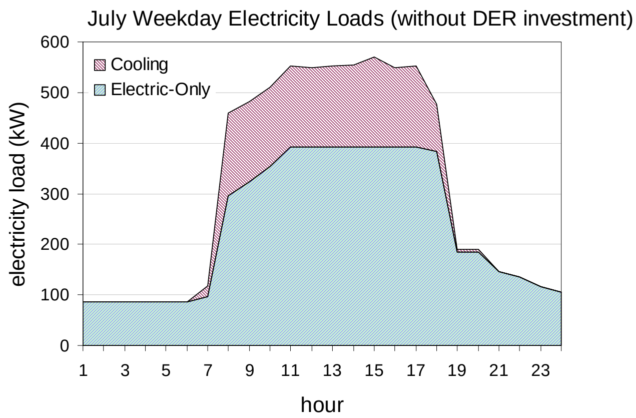

Figure 25: **Office Building July Electricity Loads**

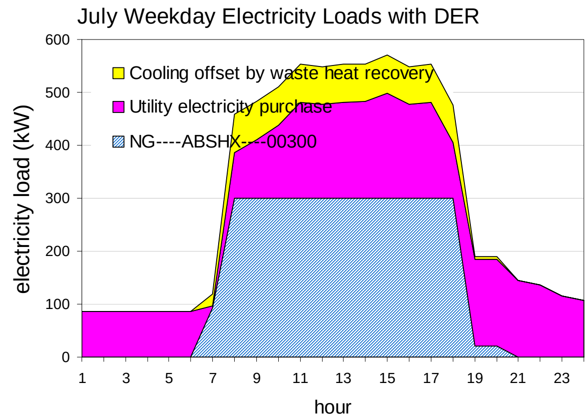

Figure 26: **Office Building July Electricity Provision with CHP**

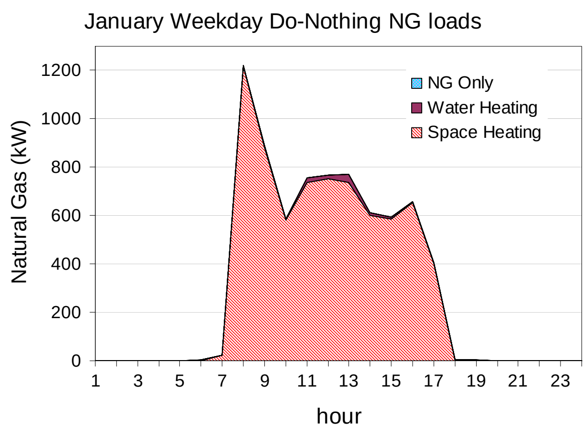

Figure 27: Office Building January Natural Gas Loads

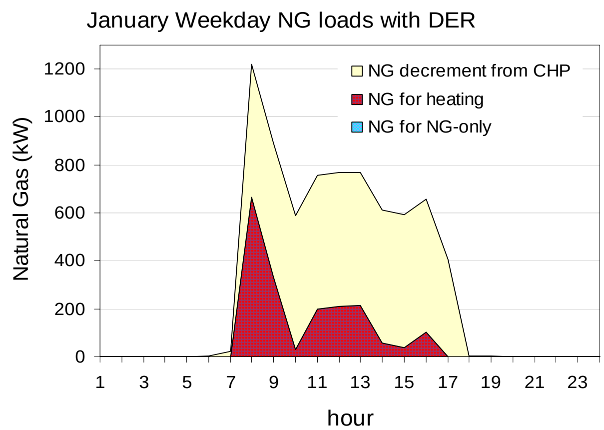

Figure 28: Office Building January Natural Gas Load Provisions with CHP

In addition, Figure 25 and Figure 26 show the January weekday natural gas loads and how they are met by the CHP system.

Furthermore, fuel consumption and carbon emissions resulting from the three scenarios were analyzed (Figure 29, Figure 30, and Table 16). Fuel consumption for DER without CHP is increased by 8% and carbon emissions are reduced 6.5%. For the DER with CHP case, fuel consumption is reduced by 8% and carbon emissions are reduced by 22.7%.

Table 17 states the system efficiency for the three scenarios. In the Do-Nothing scenario, the total efficiency is 42.1%. For DER without CHP, the system efficiency is 31%, even lower than macrogrid efficiency. For DER with CHP, system efficiency reaches 63.1%. DER without CHP does not seem to be appropriate for office building

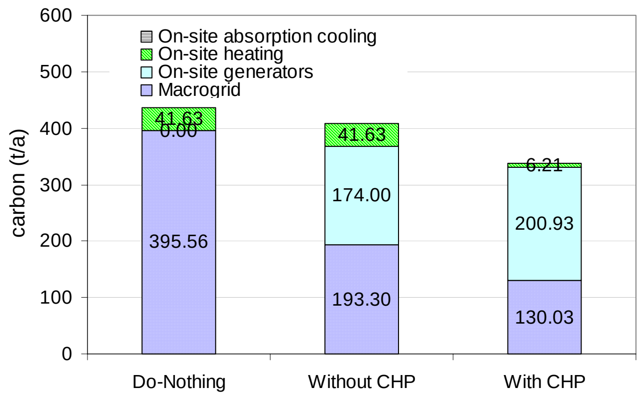

Figure 29: **Office Building Annual Carbon Emissions for the Three DER-CAM Scenarios**

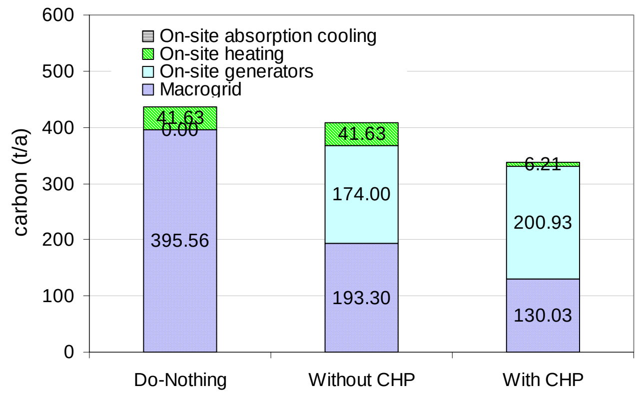

Figure 30: **Office Building Annual Fuel Consumption for the Three DER-CAM Scenarios**

Table 16: **Office Building Annual Carbon Emissions and Fuel Consumption**

Case	Fuel Consumption (TJ/a)	Reduction from Do-Nothing case	Carbon Emission (t/a)	Reduction from Do-Nothing case
Do-Nothing	24.8		437	
DER	26.7	8%	409	-6.5%
DER with CHP	22.7	-8.2%	338	-22.7%

Table 17: **Office Building System Efficiency**

Macrogrid Electrical Efficiency	36.6%
Natural Gas to Heat Efficiency	80%
Do-Nothing System Efficiency	42.1%
DER Electrical Efficiency	31%
DER with CHP System Efficiency	75%
DER with CHP System Efficiency (FERC)	53%
Whole System (DER & Util.) Efficiency	63.1%

4.1.2 Hospital

Table 18 shows the results for the hospital: for the Do-Nothing scenario, the total cost is $332,920. For DER without CHP, no equipment was selected: there is no change in cost or efficiency from the Do-Nothing case. For DER with CHP, a 300 kW natural gas engine with heat recovery for heating and absorption cooling was chosen. Compared with the Do-Nothing case, the total annual energy savings are 21.1% ($70,310) with a payback period of 3.4 years. The annual fuel costs are reduced by 40%. Figure 32 shows the January electricity loads and how the CHP system meets these loads. The winter (January) daytime electricity load is 270 kW, all of which is met by DER. Figure 33 and Figure 34 show the electricity loads in summer (July). The electricity load at 10 A.M. is 311 kW; 300 kW is met by DER and 44 kW of the peak cooling electricity load (161 kW) is offset by absorption cooling, reducing the macrogrid electricity purchase to only 128 kW. Figure 35 and Figure 36 show the gas load the natural gas loads for winter (January) – the peak load is 1252 kW, of which 438 kW is met by the CHP system.

Fuel consumption and carbon emissions were analyzed Figure 37, Figure 38, and Table 19), Fuel consumption for DER with CHP is reduced by 16.6% and carbon emissions are reduced by 32.4%.

Table 20 shows the system efficiencies. In the Do-Nothing scenario, the total efficiency is 49.5%. For the DER with CHP scenario, the CHP system efficiency is 74.1% and the total system efficiency (including electricity purchase) is 72.2%.

Table 18: Hospital Building DER-CAM Results

Annual Cost											
Case	Installed Capacity	Installed Technology	Installation Cost	Electricity Purchased	Gas		Energy Cost	Total Cost	Energy Cost Reduction	Overall Cost Reduction	Pay Back Year
	kW		k$	k$	For DER (k$)	Gas only (k$)	k$	k$	%	%	a
Do-Nothing	0	0	0	229.9	0	103.1	332.9	332.9			
DER	0	0	0	229.9	0	103.1	332.9	332.9			
DER with CHP	300	NG-ARSHX--00300	62.9	18.6	163	18	199.7	262.6	-40.01%	-21.1%	3.4

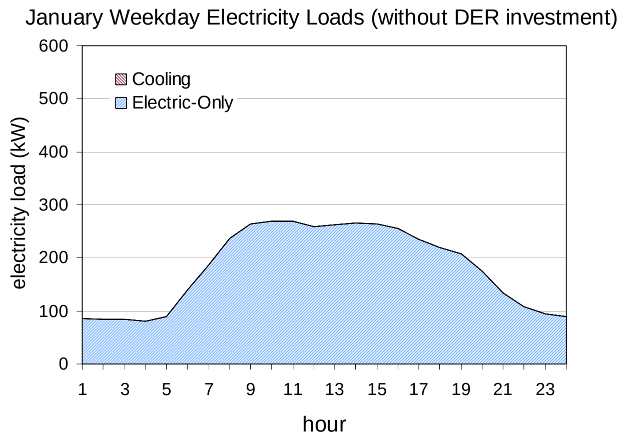

Figure 31: Hospital January Electricity Load

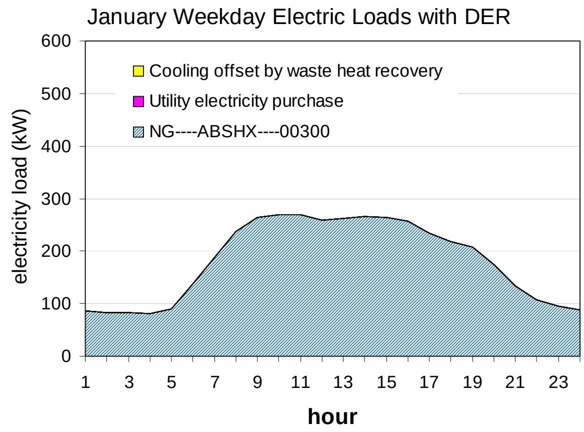

Figure 32: Hospital January Electricity Load Provision with CHP

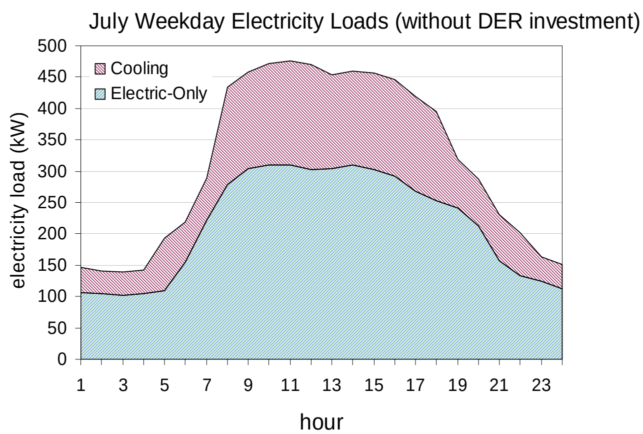

Figure 33: Hospital July Electricity Load

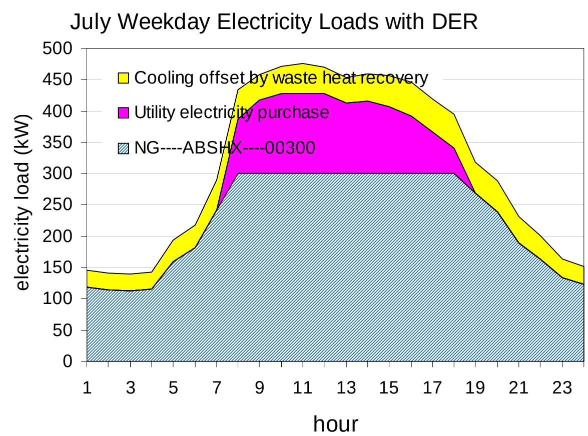

Figure 34: Hospital July Electricity Load Provision with CHP

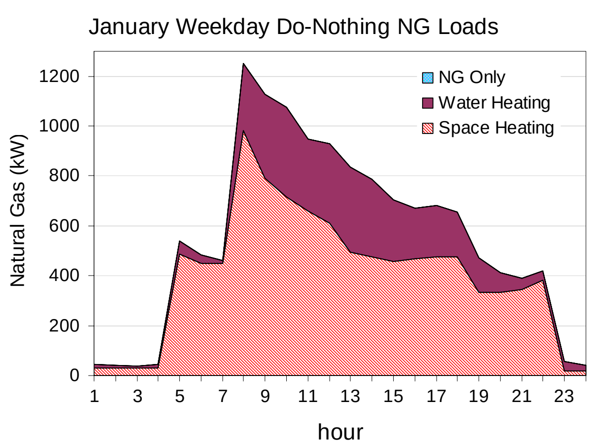

Figure 35: Hospital January Natural Gas Load

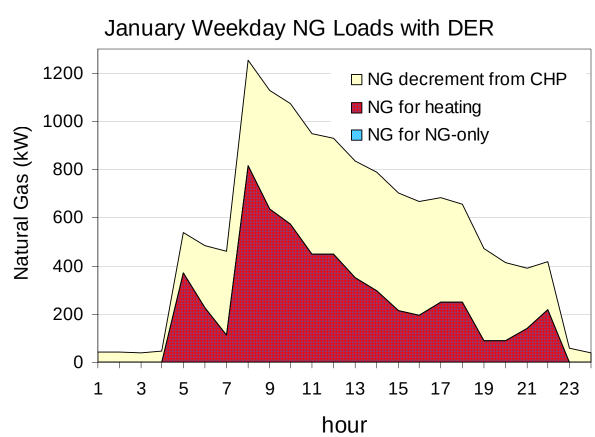

Figure 36: Hospital January Natural Gas Load Provision with CHP

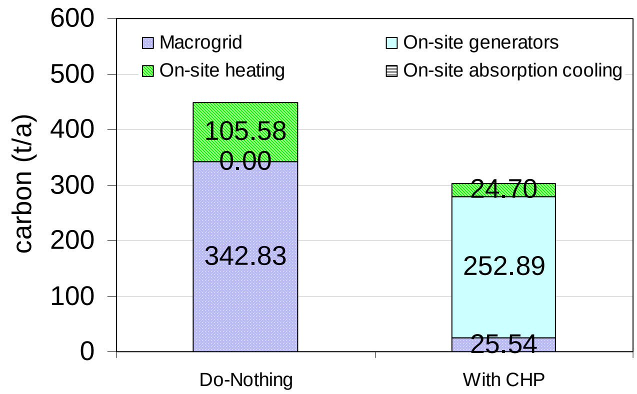

Figure 37: **Hospital Annual Carbon Emissions**

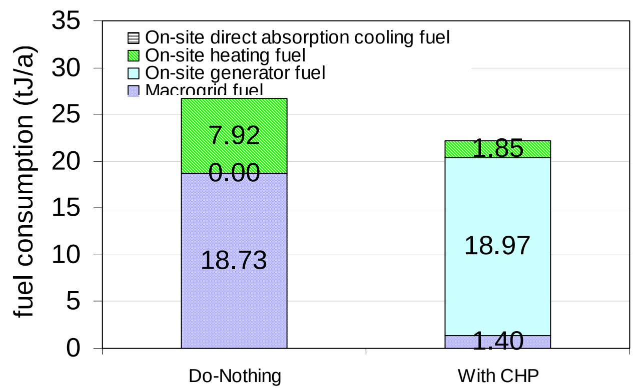

Figure 38: **Hospital Annual Fuel Consumption**

Table 19: **Hospital Annual Carbon Emissions and Fuel Consumption**

Case	Fuel Consumption (TJ/a)	Reduction from Do-Nothing case	Carbon Emission (t/a)	Reduction from Do-Nothing case
Do-Nothing	26.7		448	
DER				
CHP	22.2	-16.6%	303	-32.4%

Table 20: **Hospital System Efficiencies**

Macrogrid Electrical Efficiency	36.6%
Natural Gas to Heat Efficiency	80%
Do-Nothing System Efficiency	49.5%
DER Electrical Efficiency	
DER with CHP System Efficiency	74.1%
DER with CHP System Efficiency (FERC)	52.5%
Whole System (DER & Util.) Efficiency	72.2%

4.1.3 Hotel

Table 21 shows the results for the hotel. For the Do-Nothing scenario, the total annual energy bill is $ 374,580. For DER without CHP, a 30 kW natural gas engine was selected; electricity purchase decreases, gas consumption increases, and the total annual fuel costs are reduced by 10%. The total annual energy savings (including the cost of capital and maintenance) are 9 ($33,470). The payback period is less than 1 year, because of the small capacity of the DER selected. Most energy is purchased from the macrogrid. The impact of DG without CHP is limited.

Table 21: Hotel DER-CAM Results

Case	Installed Capacity	Installed Technology	Installation Cost	Electricity Purchased	Gas		Energy Cost	Total Cost	Energy Cost Reduction	Overall Cost Reduction	Pay Back Year
			Annual Cost								
	kW		k$	k$	For DER (k$)	Gas only (k$)	k$	k$	%	%	a
Do-Nothing	0	0	0	268.9	0	105.7	374.6	374.6			
DER	30	NG--0030	3.5	260.8	4.2	72.5	337.5	341.0	-9.9%	-9%	0.8
DER with CHP	300	NG-ARSHX--00300	66.3	24.9	189.1	9.5	223.5	289.8	-40.3%	-22.6%	3.0

For the DER with CHP scenario, a 300 kW natural gas engine with heat recovery for heating and absorption cooling was chosen. Compared with the Do-Nothing scenario, the total annual energy savings are 21.6% ($84,760) with a payback period of 3 years. The total annual fuel costs are reduced by 40.3%. Figure 39 and Figure 40 show how the CHP system meets electricity load. In the winter (January) the day time peak electricity load is 278 kW at 12 P.M. The entire load is met by the CHP system. Figure 41 and Figure 42 shows the case in the summer. The peak electricity load is 321 kW at 2 P.M. 300 kW of this is met by the CHP system and 72 kW of the 174 kW peak cooling load is offset by absorption cooling, and the electricity purchase from the macrogrid is reduced to 123 kW.

Figure 43 and Figure 44 show the gas load. 480 kW of the peak winter load is met by the CHP system and 179 kW are provided by natural gas purchase. Fuel consumption and carbon emissions of CHP system were analyzed (Figure 45, Figure 46, and Table 22). No difference is seen in the DER without CHP scenario. Fuel consumption for DER with CHP is reduced by 18.7% and carbon emissions are reduced by 34.3%.

Table 23 shows the system efficiency. For the Do- nothing scenario, the total efficiency is 48.3%. For the DER without CHP scenario, the total system efficiency (including macrogrid electricity purchase) is 27.5%. For the DER with CHP scenario, the CHP system efficiency is 78% and the total system efficiency (including macrogrid electricity purchase) is 75%. The total system efficiency using the FERC definition is 54.5%.

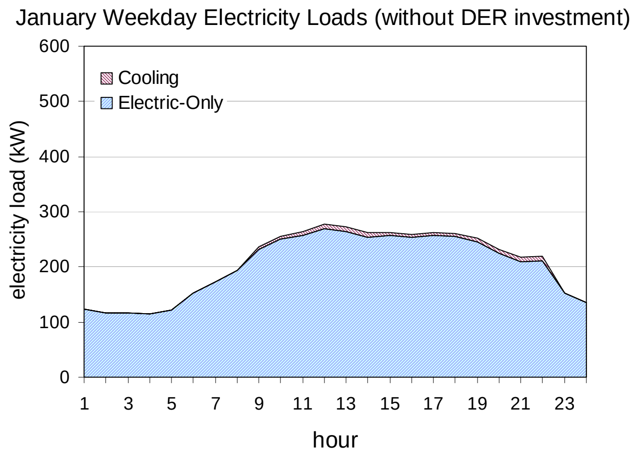

Figure 39: **Hotel January Electricity Loads**

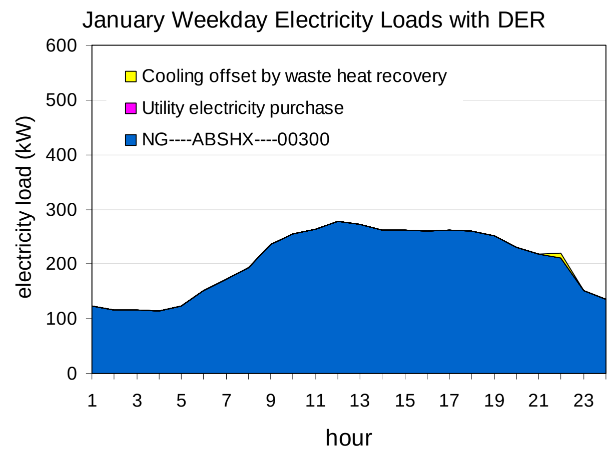

Figure 40: Hotel January Electricity Load Provision

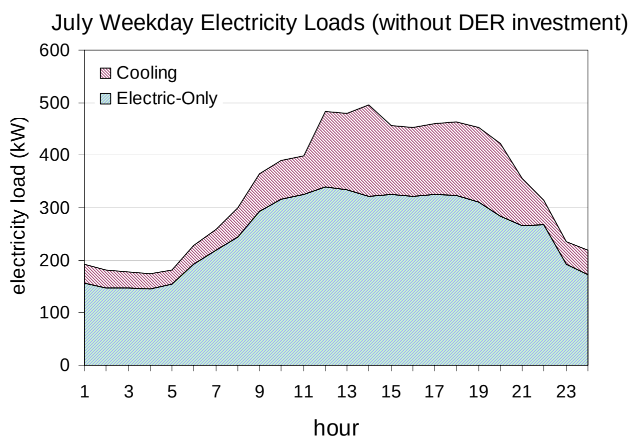

Figure 41: **Hotel July Electricity Loads**

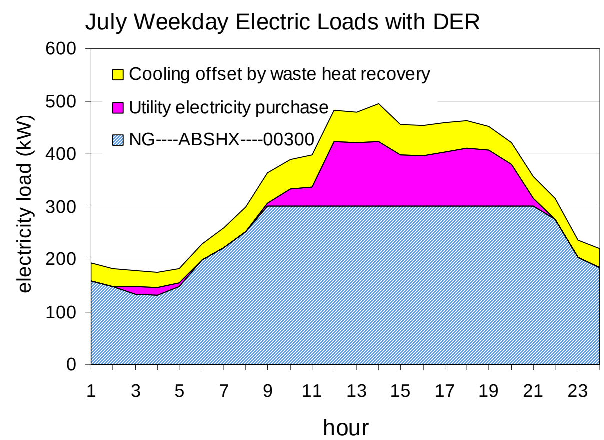

Figure 42: Hotel July Electricity Load Provision with CHP

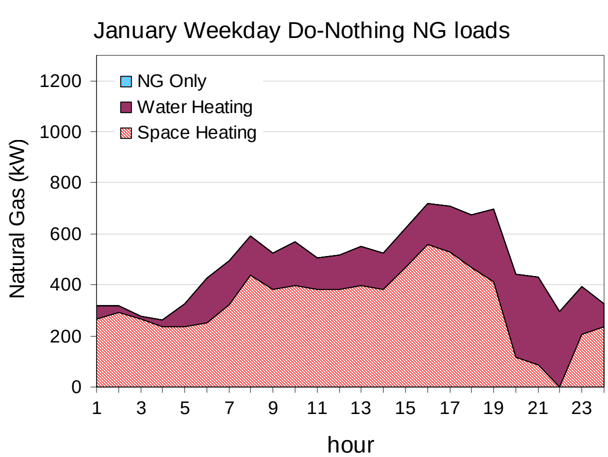

Figure 43: **Hotel January Natural Gas Loads**

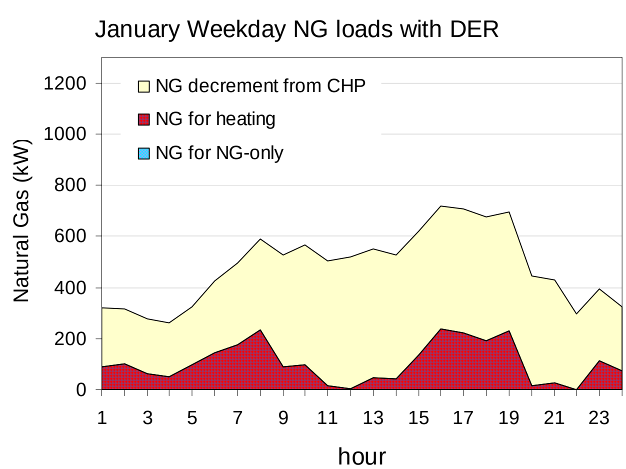

Figure 44: Hotel January Natural Gas Load Provisions with CHP

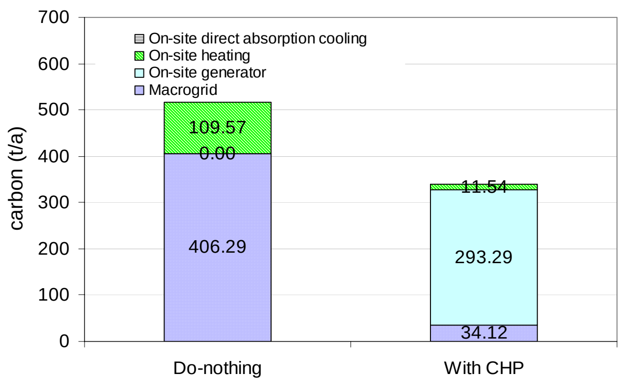

Figure 45: **Hotel Annual Carbon Emissions**

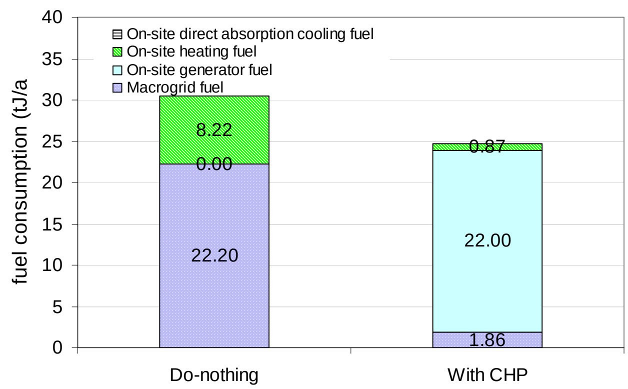

Figure 46: Hotel Annual Fuel Consumption

Table 22: Hotel Annual Carbon Emissions and Fuel Consumption

Case	Fuel Consumption (TJ/a)	Reduction from Do-Nothing case	Carbon Emission (t/a)	Reduction from Do-Nothing case
Do-Nothing	30.4		516	
DER	30.5	0	516	0
DER with CHP	24.7	-18.7%	339	-34.3%

Table 23: Hotel System Efficiencies

Macrogrid Electrical Efficiency	36.6%
Natural Gas to Heat Efficiency	80%
Do-Nothing System Efficiency	48.3%
DER Electrical Efficiency	27.5%
DER with CHP System Efficiency	78%
DER with CHP System Efficiency (FERC)	54.5%
Whole System (DER & Util.) Efficiency	75%

4.1.4 Retail

Table 24 shows the results for the retail building: For the Do-Nothing scenario, the total cost is $386,590. For the DER without CHP scenario, a 1,000 kW natural gas engine is selected; annual fuel costs are reduced by 32% and the total annual energy cost (including capital and maintenance costs) are reduced by 8.6%($33,410). The payback period is less than 6 year.

For DER with CHP, a 1,000 kW natural gas engine with heat recovery for heating and absorption cooling was chosen. Relative to the Do-Nothing scenario, the savings are 11.4% ($44,000) with a payback period of 7 years. The total annual fuel costs are reduced by 44.2%.

Figure 47 and Figure 48 show the January electricity loads and how the CHP system meets these loads. The winter (January) daytime peak electricity load is 471 kW at 2 P.M., all of which is met by the CHP system. Figure 49 and Figure 50 show this for the summer (July). The summer peak electricity load is 639 kW at 2 P.M., all of which is met by the CHP system. 118 kW of the 253 kW peak cooling electricity load is offset by absorption cooling. No electricity is purchased from the grid.

Figure 51 and Figure 52 show the natural gas load. The winter (January) peak natural gas load is 920 kW at 9 A.M., of which 380 kW is met by the CHP system. During the daytime, natural gas loads, which range from 335kW to 591 kW, are almost all met by the CHP system.

Fuel consumption and carbon emissions were analyzed (Figure 53, Figure 54, and Table 25). For the DER system without CHP, fuel consumption is reduced by 7% and the carbon emissions by 19.9%. For the DER system with CHP, fuel consumption is reduced by 12.5% and carbon emission by 34.4%.

Table 26 shows the system efficiencies. For the Do-Nothing case, the total efficiency is 41.2%. For DER without CHP, the total system efficiency (including electricity purchase) is 34%. For DER with CHP, the system efficiency is 69.4% and the total system efficiency (including electricity purchase) is 69.4%. Total FERC system efficiency is 51.7 .

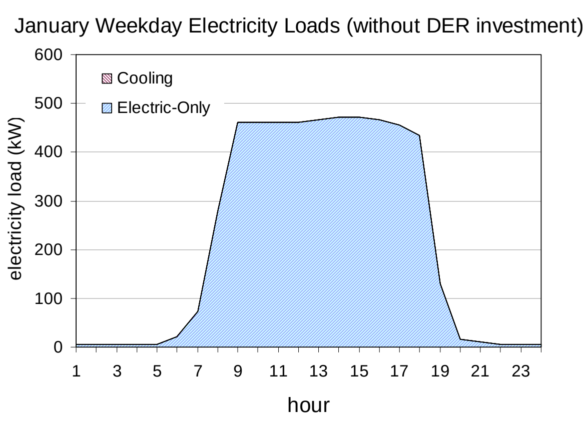

Figure 47: Retail January Weekday Electricity Loads

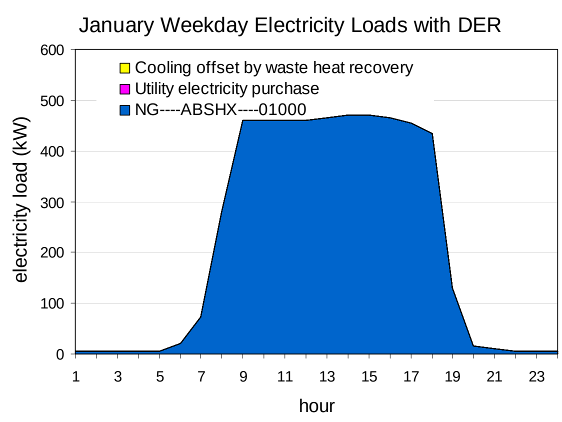

Figure 48: Retail January Weekday Electricity Load Provision

Table 24: Retail DER-CAM Results

					Annual Cost						
Case	Installed Capacity	Installed Technology	Installation Cost	Electricity Purchased	Gas		Energy Cost	Total Cost	Energy Cost Reduction	Overall Cost Reduction	Pay Back Year
	kW		k$	k$	For DER (k$)	Gas only (k$)	k$	k$	%	%	a
Do-Nothing	0	0	0	347.1	0	39.5	386.6	386.6			
DER	1000	NG--01000	90.3	0	235.3	27.6	262.9	353.2	-32%	-8.6%	5.8
DER with CHP	1000	NG-ARSHX--01000	126.7	0	212.3	3.4	215.7	342.6	-44.2%	-11.4%	6.8

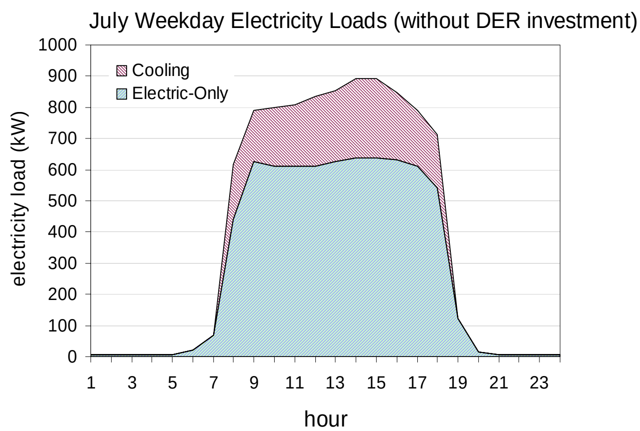

Figure 49: Retail July Weekday Electricity Loads

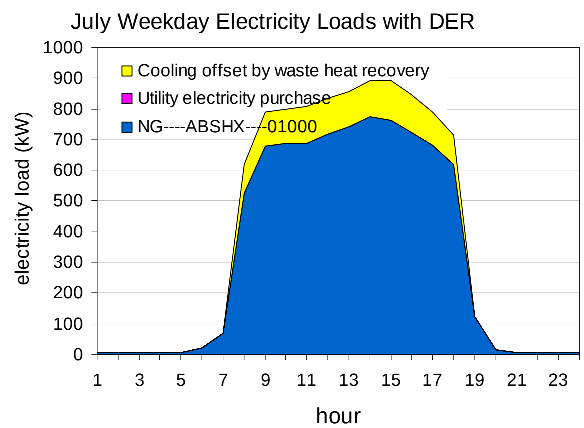

Figure 50: Retail July Weekday Electricity Load Provision with CHP

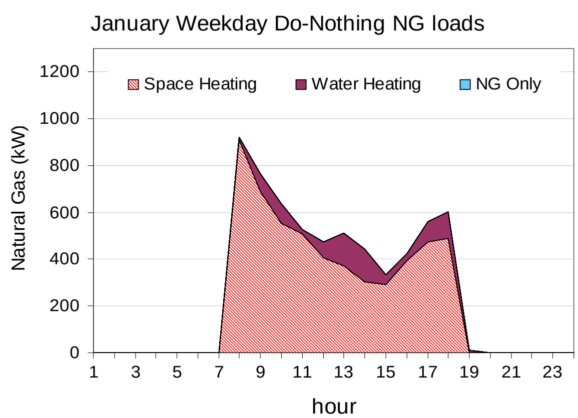

Figure 51: Retail January Weekday Natural Gas Loads

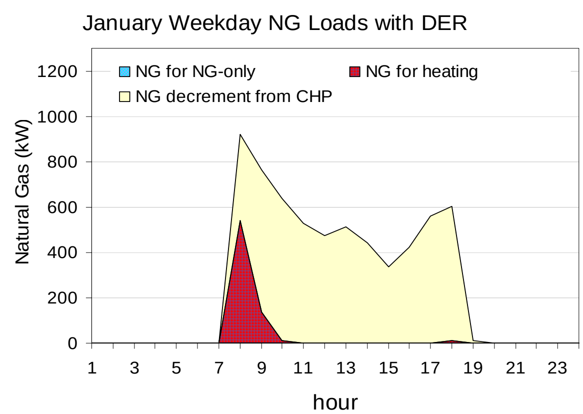

Figure 52: Retail January Weekday Natural Gas Load Provision with CHP

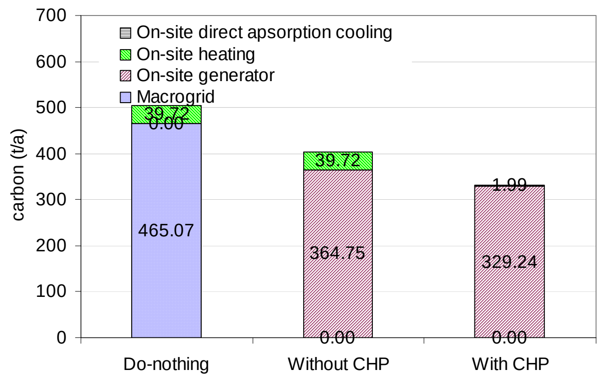

Figure 53: **Retail Annual Carbon Emissions**

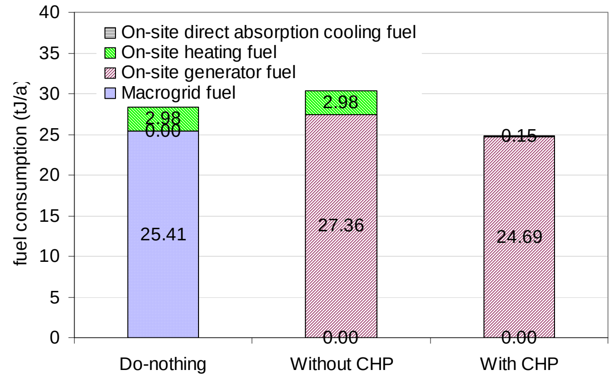

Figure 54: **Retail Annual Fuel Consumption**

Table 25: **Retail Annual Carbon Emissions and Fuel Consumption**

Case	Fuel Consumption (TJ/a)	Reduction from Do-Nothing case	Carbon Emission (t/a)	Reduction from Do-Nothing case
Do-Nothing	28.4		505	
DER	30.3	-7%	404	-19.9%
DER with CHP	24.8	-12.5%	339.1	-34.4%

Table 26: **Retail System Efficiencies**

Macrogrid Electrical Efficiency	36.6%
Natural Gas to Heat Efficiency	80%
Do-Nothing System Efficiency	41.2%
DER Electrical Efficiency	34%
DER with CHP System Efficiency	69.4%
DER with CHP System Efficiency (FERC)	51.7%
Whole System (DER & Util.) Efficiency	69.4%

4.1.5 Sports Facility

Sports facility includes pool, tennis court, gym etc...Table 27 shows the DER-CAM results for the sports facility. For the Do-Nothing scenario, the total cost is $ 988,140. For DG without CHP a 30 kW natural gas engine was selected; annual fuel costs are reduced by 20.89% and total annual energy costs (including the capital and maintenance costs) are reduced by 20.6% ($205,200). The payback period is less than 3 months.

For the DER with CHP scenario, two 300 kW natural gas engines with heat recovery for heating were selected. Compared with the Do-Nothing case, the total annual energy savings are 32.5% ($324,300) with a payback period of 3.5 years. The total annual fuel costs are reduced by 42.5%.

Figure 55 and Figure 56 show the winter (January) electricity loads and how the CHP system meets them. The peak winter electricity load is 500 kW at 2 P.M., all of which is met by CHP. Figure 57 and Figure 58 show this data for the summer. The peak electricity load is 594kW at 8 P.M., all of which is met by the CHP system. No electricity is purchased from the macrogrid.

Figure 59 and Figure 60 show the winter (January) natural gas loads and how the CHP system meets them. The winter peak load is 4020 kW at 9 P.M., of which 860 kW is met by the CHP system.

Carbon emissions and fuel consumption were analyzed (Figure 61, Figure 62, and Table 28). For the DER without CHP scenario, there is little difference from the Do-Nothing scenario because the installed generator is small. For the DER with CHP scenario, fuel consumption is reduced by 16.4% and carbon emissions by 26.3%.

Table 29 shows the system efficiency. In the Do-Nothing scenario, the total efficiency is 64.1%. For the DER without CHP scenario, the total DER system efficiency (including electricity purchase) is 27.5%. For the DER with CHP scenario, the CHP system efficiency is 73.6% and the total system efficiency (including electricity purchase) is 76%. Total FERC system efficiency is 52.3 .

Table 27: Sports Facility DER-CAM Results

Annual Cost											
Case	Installed Capacity	Installed Technology	Installation Cost	Electricity Purchased	Gas		Energy Cost	Total Cost	Energy Cost Reduction	Overall Cost Reduction	Pay Back Year
	kW		K$	K$	For DER (k$)	Gas only (k$)	k$	k$	%	%	a
Do-Nothing	0	0	0	359.8	0	638.4	998.1	998.1			
DER	30	NG--0030	3.3	352.6	3.0	434	789.6	793	-20.9%	-20.6%	0.2
DER with CHP	600	2 unit NG-ARSHX--00300	99.8	2.6	294.3	277.1	574.1	693.9	-42.5%	-32.5%	3.3

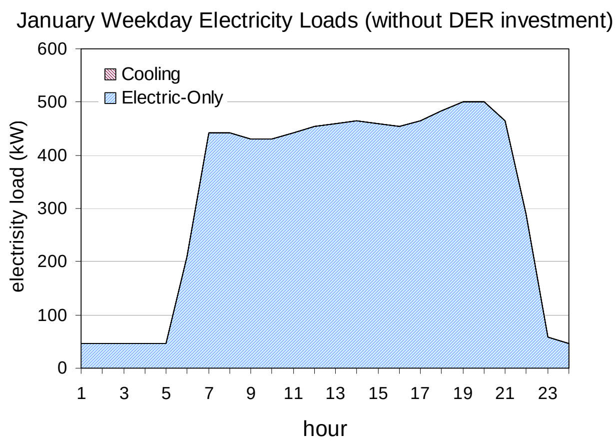

Figure 55: Sports Facility January Electricity Loads

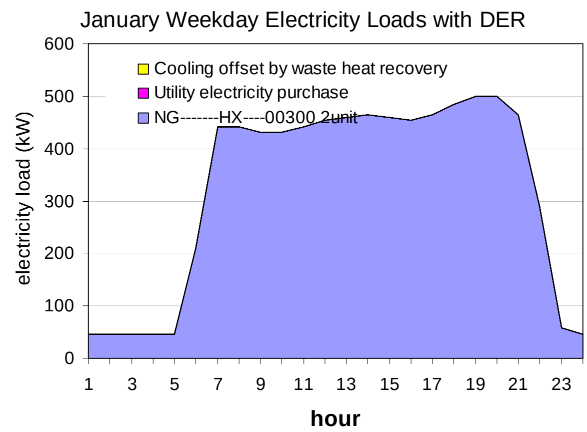

Figure 56: Sports Facility January Electricity Load Provision with CHP

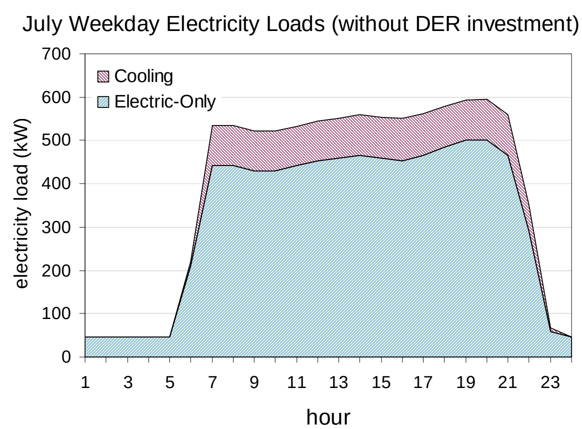

Figure 57: Sports Facility July Electricity Loads

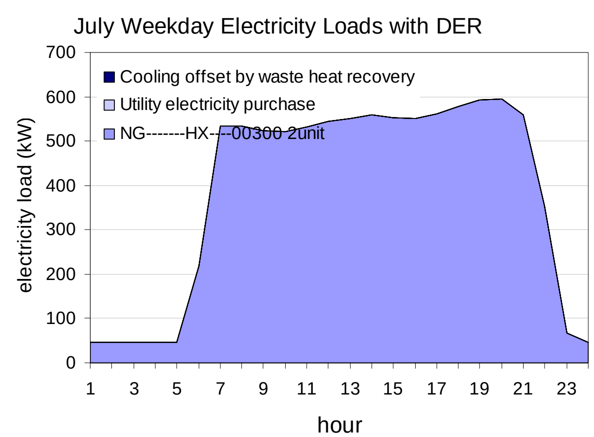

Figure 58: Sports Facility July Electricity Load Provision with CHP

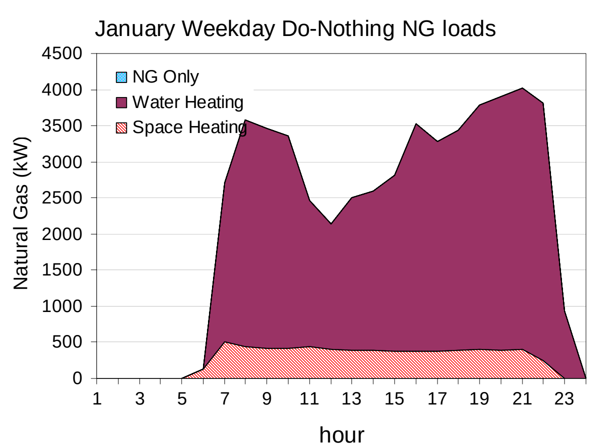

Figure 59: Sports Facility January Natural Gas Loads

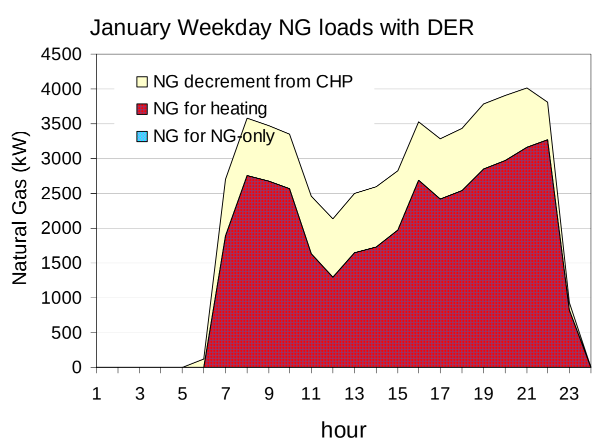

Figure 60: Sports Facility January Natural Gas Load Provision with CHP

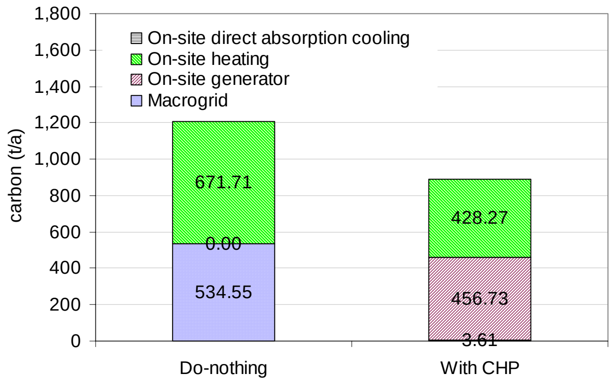

Figure 61: **Sports Facility Annual Carbon Emissions**

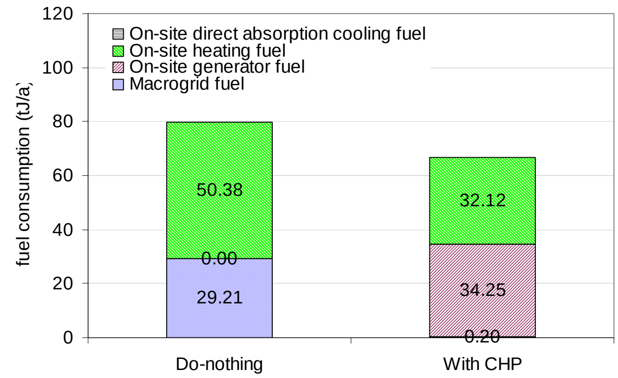

Figure 62: Sports Facility Annual Fuel Consumption

Table 28: **Sports Facility Annual Carbon Emissions and Fuel Consumption**

Case	Fuel Consumption (TJ/a)	Reduction from Do-Nothing case	Carbon Emission (t/a)	Reduction from Do-Nothing case
Do-Nothing	79.6		1206	
DER	79.7	0	1206	0
DER with CHP	66.6	-16.4%	889	-26.3%

Table 29: **Sports Facility System Efficiencies**

Macrogrid Electrical Efficiency	36.6%
Natural Gas to Heat Efficiency	80%
Do-Nothing System Efficiency	64.1%
DER Electrical Efficiency	27.5%
DER with CHP System Efficiency	73.6%
DER with CHP System Efficiency (FERC)	52.3%
Whole System (DER & Util.) Efficiency	76.6%

4.1.6 Conclusions for 10,000 m^2 Buildings

CHP shifts the balance of utility purchase of electricity and natural gas in several ways. Operating generation equipment reduces utility electricity purchase and increases natural gas purchase. Recovered heat from the equipment can be used to offset natural gas used for heating and/or electricity used for cooling. Figure 63 shows the peak load shift effect of CHP in the prototype buildings in both winter and summer. In the winter, the heating peak load of the sports facility is most significant, followed by hospital and office buildings. The biggest peak load reduction is seen in the sports facility (900 kWh), followed by the office building (550 kWh).

In the summer, the retail building shows the biggest utility electricity reduction; all peak loads can be economically met by the generated power and waste heat recovery from CHP. The effect of air conditioning by heat recovery is seen in all of the building except the sports facility. Heat recovery for cooling is not economic for the sports facility.

CHP also shifts the amounts and sources of carbon emissions. Figure 64 shows the carbon emissions reductions. CHP installation reduces these emissions for all of the prototype buildings. This reduction is most significant for the hospital (61.4% reduction), followed by hotel (34% reduction) and retail building (34% reduction).

Furthermore, CHP shifts the amounts and sources of annual energy costs. Figure 65 shows the economics of CHP installation. For the sports facility, costs are reduced by 32%, followed by hotel (23% reduction) and hospital (21% reduction). The hotel has the shortest payback period (3.0 years), followed by sports facility (3.3 years) and hospital (3.4 years).

CHP installation benefits the entire prototype buildings considered. Hospitals, hotels, and sports facilities have the potential for benefiting the most. Although benefits are not as great as for other building types, office buildings – which are traditionally not considered DER candidates – can also benefit.

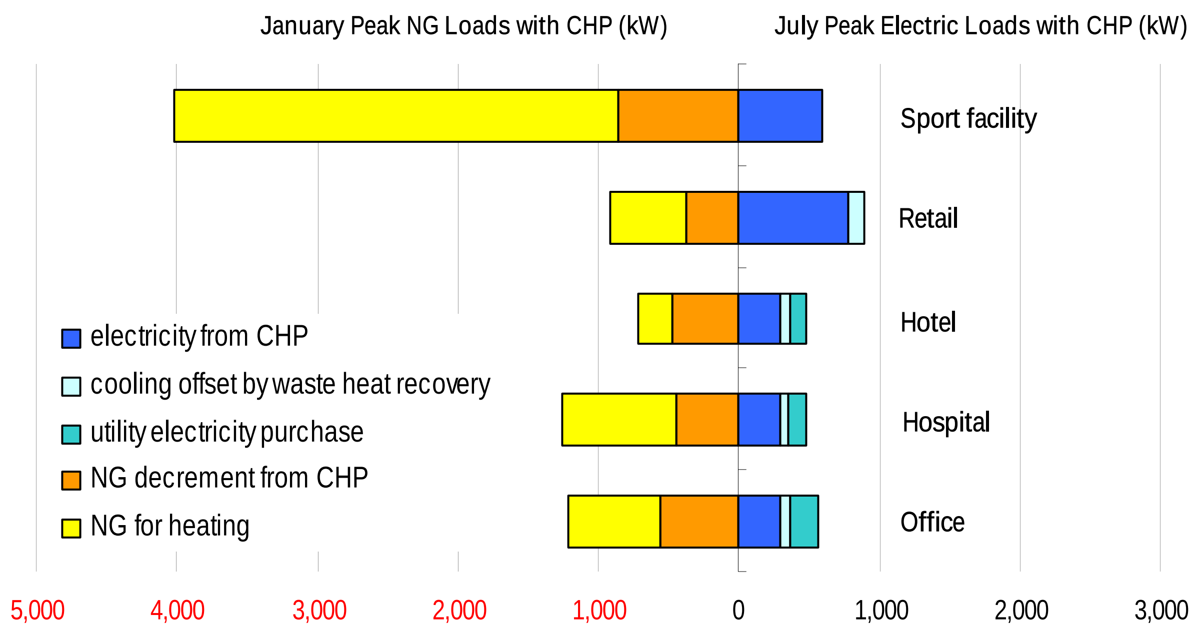

Figure 63: The Peak Load Shift Effect of Prototype Building

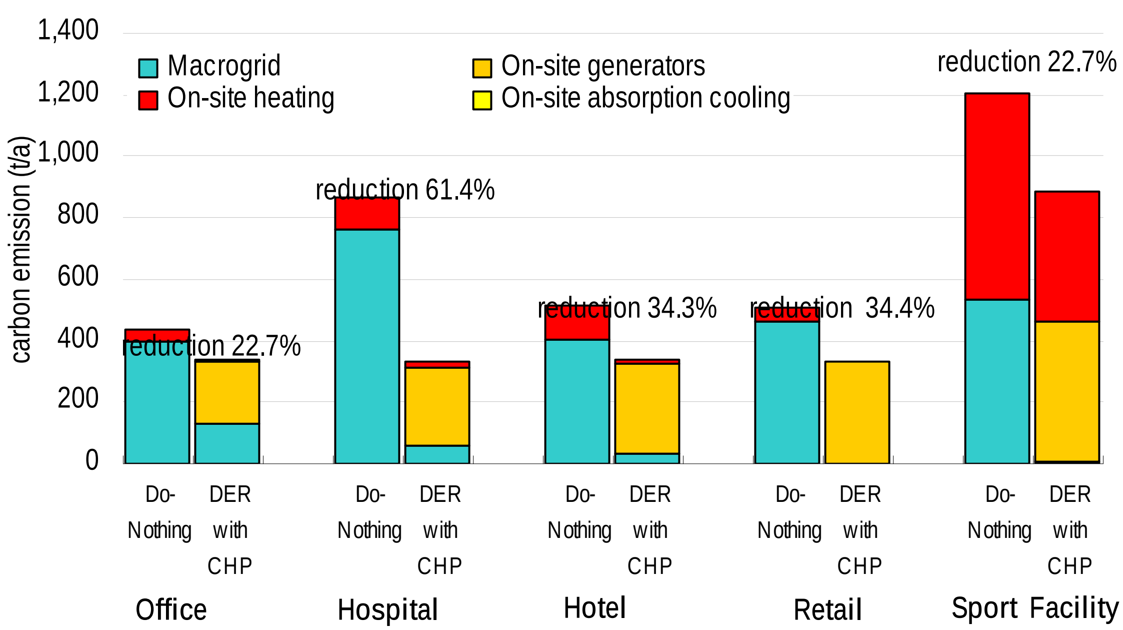

Figure 64 :The Effect of Prototype Building Carbon Emission Reduction

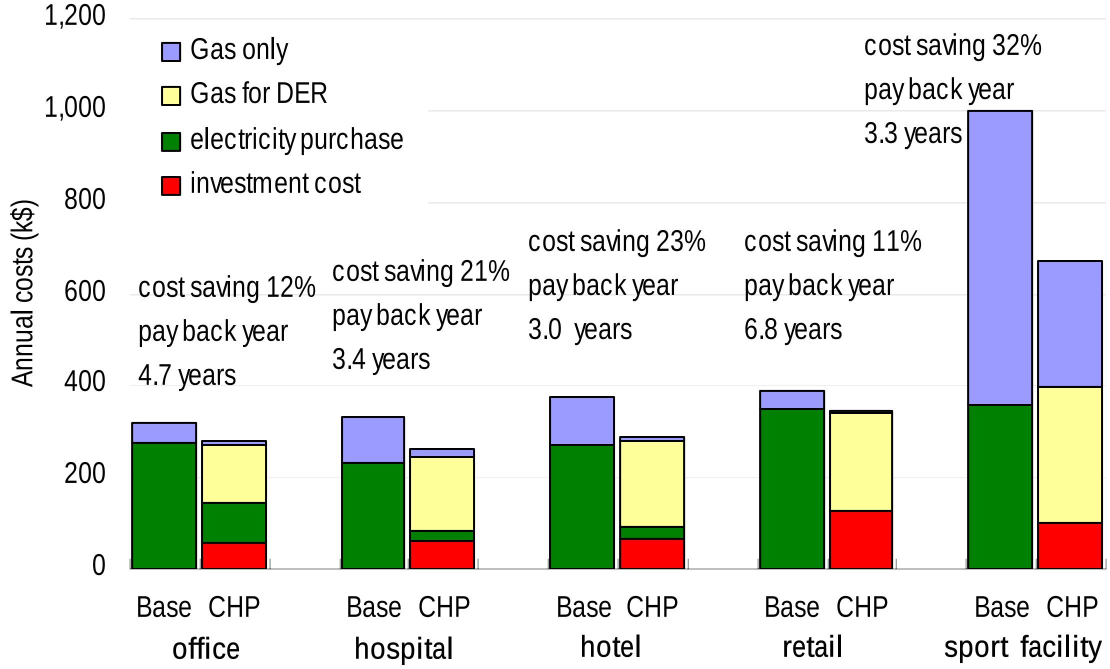

Figure 65: The Economic Effect of Prototype Building

4.2 5,000 m^2 Buildings

All the above results are for 10,000 m^2 buildings, but smaller buildings are also common. In this section, 5,000 m^2 buildings of the same types were also evaluated to clarify the DER potential for smaller buildings. Loads are calculated from the building energy intensity, and Table 30 shows results. The hotel was the only building type to select DER in the DER without CHP scenario.

Table 30: Economic Results for 5000 m^2 Prototype Buildings

Case	Installed Capacity	Installed Technology	Installation Cost	Annual Cost Electricity Purchased	Gas		Energy Cost	Total Cost	Energy Cost Reduction	Overall Cost Reduction	Pay Back Year
	kW		k$	k$	For DER (k$)	Gas only (k$)	k$	k$	%	%	a
Office											
Do-Nothing	0	0	0	137.6	0	21.1	158.7	158.7			
DER	0	0	0	-	-	-	-	-	-	-	-
DER with CHP	100	NG-ARSHX--00100	24	76.2	41	6.4	123.6	147.5	-22.1%	-7%	6
Hospital											
Do-Nothing	0	0	0	114.9	0	51.5	166.5	166.5			
DER	0	0	0	-	-	-	-	-	-	-	-
DER with CHP	100	NG--HX--00100	20.4	55.6	49.2	11.1	115.8	136.2	-30.4%	-18.2%	2.7
Hotel											
Do-Nothing	0	0	0	173.6	0	19.7	193.3	193.3			
DER	300	NG--00300	35.4	32.3	104.1	14.9	151.3	186.6	-21.7%	-3.4%	5.6
DER with CHP	300	NG-ARSHX--00300	55.7	9	107.4	3.28	119.7	175.4	-38.1%	-9.3%	6.3
Retail											
Do-Nothing	0	0	0	134.5	0	52.8	187.3	187.3			
DER	0	0	0	-	-	-	-	-	-	-	-
DER with CHP	130	1 unit NG-HX—0030 1 unit NG—ABSHX--00100	35.2	30	83.5	4.32	117.86	153.03	-37.1%	-18.3%	3.3
Sports facility											
Do-Nothing	0	0	0	179.9	0	319.2	499.1	499.1			
DER	0	0	0	-	-	-	-	-	-	-	-
DER with CHP	300	NG--HX--00300	49.88	1.3	147.2	139.7	288.1	338	-42.3%	-32.3%	1.6

In the DER with CHP scenario, for the office building, at 100 kW natural gas engine with heat recovery for heating and cooling was selected. The total annual energy cost (including capital and maintenance costs) is reduced by 7% from the do nothing scenario. The payback period is 6 years. Total annual fuel costs are reduced by 22.1%.

For the hospital, a 100 kW natural gas engine with heat recovery for heating was selected, reducing the total annual energy cost by 18.2 % from the Do-Nothing scenario, with a payback period of 2.7 years. Total annual fuel costs are reduced by 30.4%.

For the hotel, a 300 kW natural gas engine with heat recovery for heating and cooling is selected. Total annual energy costs are reduced by 9.3% and the payback period is 6.3 years. Total annual fuel costs are reduced by 38.1%.

For the retail building, a 100 kW natural gas engine with heat recovery for heating and cooling and a 30 kW natural gas engine with heat recovery only for heating are selected. The total annual energy costs are reduced by 18.3%. The payback period is 3.3 years. Total annual fuel costs are reduced by 37.1%.

For the sports facility, a 300 kW natural gas engine with heat recovery for heating is selected. Total annual energy costs are reduced by 32.3% and the payback period is 1.6 years. Total annual fuel costs are reduced by 42.3%.

Although the installation capacity is smaller than for 10,000 m^2 buildings, CHP installations for smaller scale buildings still have significant economic benefits (Figure 66 and Figure 67). Sports facilities have the highest economic potential for CHP installation, followed by hotels.

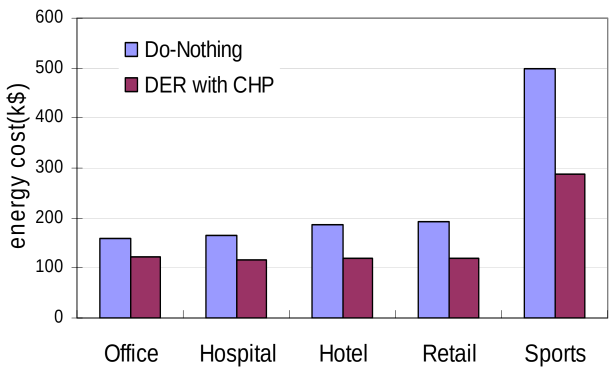

Figure 66: **5,000 m^2 Building Total Annual Fuel Costs**

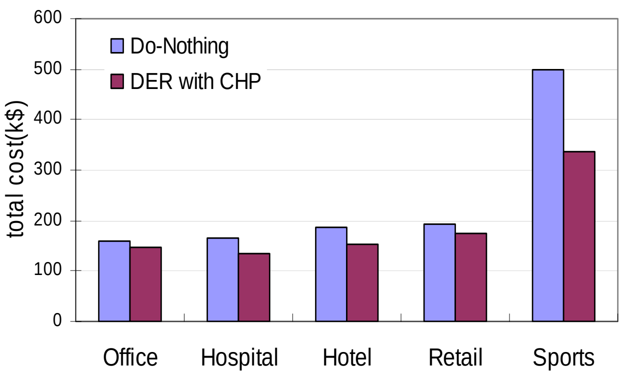

Figure 67: **5,000 m^2 Building Total Annual Energy Costs**

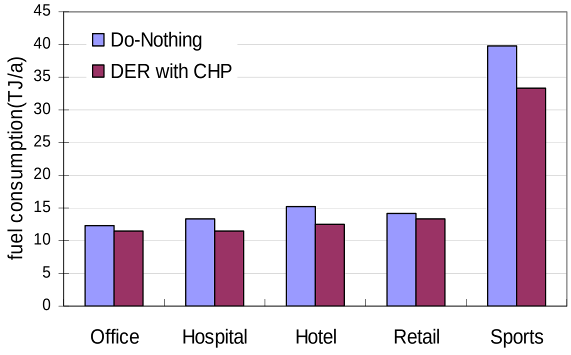

Figure 68 : 5,000 m² Building Fuel Consumption

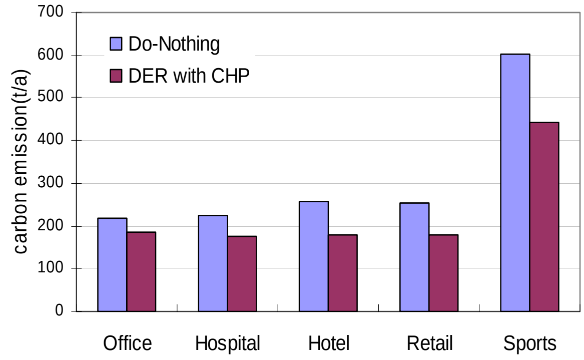

Figure 69: 5,000 m² Building Carbon Emissions

Figure 68 and Figure 69 show energy conservation and carbon emissions for the 5,000 m² buildings. For office buildings with CHP, fuel consumption is reduced by 6.5 % and carbon emissions by 15.2%. For the hospital, fuel consumption is reduced by 14.1% and carbon emissions by 21.6%. For the hotel, fuel consumption is reduced by 18.2% and carbon emissions by 30.9%. For the retail building, fuel consumption is reduced by 6.3% and carbon emissions by 28.5%. For the sports facilities, fuel consumption is reduced by 16.4% and carbon emissions by 26.3%. Sports facilities have the largest fuel and carbon reductions, followed by hotels.

As shown above, even for 5,000 m² buildings, CHP adoption can have an economic benefit and result in fuel savings and carbon emission reductions.

Table 31: **Fuel Consumption and Carbon Emissions for 5000 m² Buildings**

		Fuel Comsumption(TJ/a)	Reduction from Do-Nothing	Carbon Emission(t/a)	Reduction from Do-Nothing
Office	Do-Nothing	12.37		218.60	
	DER with CHP	11.56	-6.5%	185.39	-15.2%
Hospital	Do-Nothing	13.33		224.20	
	DER with CHP	11.45	-14.1%	175.82	-21.6%
Hotel	Do-Nothing	15.21		257.93	
	DER with CHP	12.44	-18.2%	178.12	-30.9%
Retail	Do-Nothing	14.20		252.39	
	DER with CHP	13.30	-6.3%	180.56	-28.5%
Sports	Do-Nothing	39.79		603.13	
	DER with CHP	33.29	-16.4%	444.31	-26.3%

4.3 10,000 M^2 Buildings with Unsubsidized Technology Costs

The analyses in Chapters 4 and 4.2 are based on the technology cost with the grants applied. The 10,000 m^2 buildings were also examined with no DER equipment subsidy. This was done by increasing the DER capital costs by 50%. Economic results are shown in Table 32, Figure 70, and Figure 71

Table 32: **The Economic Results For Unsubsidized Technology Costs**

Case	Installed Capacity	Installed Technology	Installation Cost	Annual Cost: Electricity Purchased	Annual Cost: Gas For DER	Annual Cost: Gas only	Energy Cost	Total Cost	Energy Cost Reduction	Overall Cost Reduction	Pay Back Year
	kW		K$	K$	(k$)	(k$)	k$	k$	%	%	Y
Office											
Do-Nothing	0	0	0	275.3	0	42.1	317.4	317.4			
DER	0	0	0	-	-	-	-	-	-	-	-
DER with CHP	300	NG-ABSHX--00300	76.2	83.8	129.4	6.7	219.9	296.1	-30.7%	-6.7%	7
Hospital											
Do-Nothing	0	0	0	229.85	0	103.1	332.9	332.9			
DER	0	0	0	-	-	-	-	-	-	-	-
DER with CHP	300	NG--HX--00300	62.4	62.1	135.9	17.9	215.9	278.3	-35.2%	-16.4%	4.5
Hotel											
Do-Nothing	0	0	0	268.9	0	105.7	374.6	374.6			
DER	0	0	0	-	-	-	-	-	-	-	-
DER with CHP	300	NG-ABSHX--00300	83.93	24.9	189.1	9.5	223.5	307.5	-40.3%	-17.9%	4.5
Retail											
Do-Nothing	0	0	0	268.9	0	105.7	374.6	374.6			
DER	0	0	0	-	-	-	-	-	-	-	-
DER with CHP	300	NG—ABSHX--00300	83.9	24.9	189.1	9.5	223.5	307.5	-40.3%	-17.9%	4.5
Sports facility											
Do-Nothing	0	0	0	359.8	0	638.7	998.1	998.1			
DER	0	0	0	-	-	-	-	-	-	-	-
DER with CHP	475	NG--HX—0075 NG--HX—00100 NG--HX—00300	114.2	29.8	277.1	278	584.9	699	-41.4%	-30%	2.1

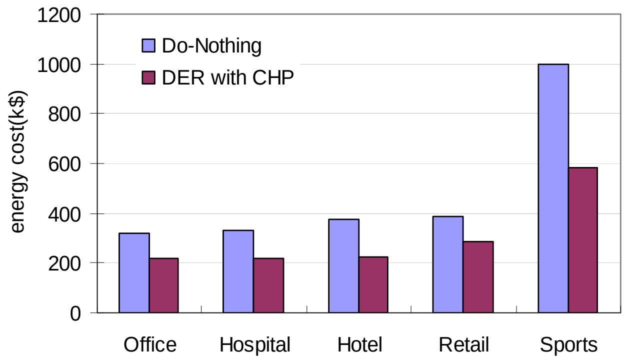

Figure 70: **Total Annual Fuel Costs with Unsubsidized DER Capital Costs**

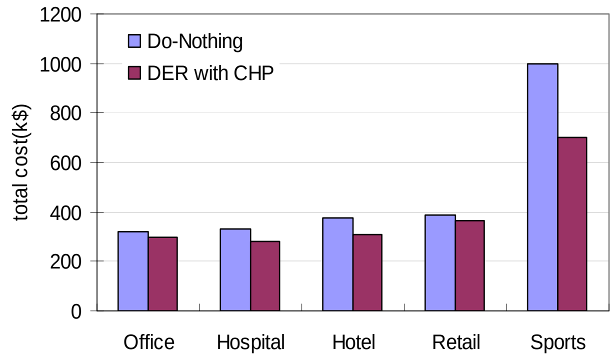

Figure 71: **Total Annual Energy Costs with Unsubsidized DER Capital Costs**

None of the prototype buildings invested in DER in the DER without CHP scenario. In the DER with CHP scenario, for the office building, a 300 kW natural gas engine with heat recovery for heating and cooling was selected. This reduces the total annual energy cost by 6.7%. The payback period is 7 years. Total annual fuel costs are reduced by 30.7%.

For the hospital, a 300 kW natural gas engine with heat recovery for heating was selected, resulting in a 16.4 % reduction in total annual energy costs and a payback period of 4.5 years. Total annual fuels costs are reduced by 35.2%.

For the hotel, a 300 kW natural gas engine with heat recovery for heating and cooling was selected, leading to a 17.9% reduction in total annual energy costs and a 4.5 year payback period. Total annual fuel costs are reduced by 40.3%.

For the retail building, a 300 kW natural gas engine with heat recovery for heating and cooling was selected, resulting in a 6.3% reduction in total annual energy costs and a 4.5 year payback period. Total annual fuel costs are reduced by 25.6%.

For the sports facility, three natural gas engines with heat recovery for heating are selected: 300 kW, 100 kW, and 75 kW. These investments lead to a 30% reduction in total annual energy costs and a 2.1 year payback period. Total annual fuel costs are reduced by 41.4%.

Figure 72, Figure 73, and Figure 33 show fuel consumption and carbon emissions. For office buildings with CHP installation fuel consumption is reduced by 8.2% and carbon emissions by 22.7%. For the hospital, fuel consumption is reduced by 13.7% and carbon emissions by 25.7%. For the hotel, fuel consumption is reduced by 18.7% and carbon emissions by 34.3%. For the retail building, fuel consumption is reduced by 7.6% and carbon emissions by 18.9%. For sports facilities, fuel consumption is reduced by 16.2% and carbon emissions by 25.3%. Sports facilities have the most significant effect, followed by hotels.

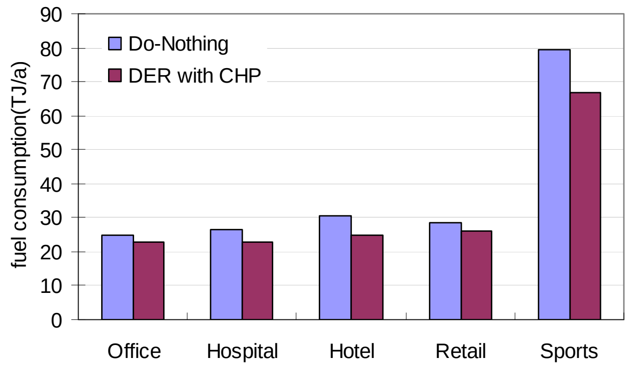

Figure 72: Total Annual Fuel Consumption with Unsubsidized DER Capital Costs

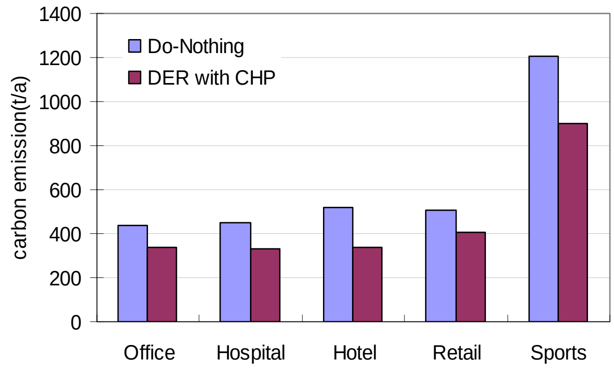

Figure 73: Total Annual Carbon Emissions With Unsubsidized DER Capital Costs

Table 33: **Total Annual Fuel Consumption and Carbon Emission for the 10,000 m^2 Buildings with Unsubsidized DER Capital Costs**

		Fuel Comsumption(TJ/a)	from Do-Nothing	Carbon Emission(t/a)	Reduction from Do-Nothing
	Do-Nothing	24.74		437.19	
Office	DER with CHP	22.71	-8.2%	338.14	-22.7%
	Do-Nothing	26.65		448.41	
Hospital	DER with CHP	23.01	-13.7%	333.23	-25.7%
	Do-Nothing	30.42		515.86	
Hotel	DER with CHP	24.73	-18.7%	338.94	-34.3%
	Do-Nothing	28.39		504.78	
Retail	DER with CHP	26.24	-7.6%	409.15	-18.9%
	Do-Nothing	79.59		1206.26	
Sports	DER with CHP	66.73	-16.2%	900.92	-25.3%

As shown above, even without subsidy, all prototype buildings can benefit significantly from CHP installation as fuel consumption and environmental load reduction effects.

Compared to the cases with DER subsidy, installed CHP systems are smaller, as are the resulting effects.

5. Conclusions

This research used DER-CAM to examine the potential for cogeneration in different Japanese prototype buildings.

Chapter 1 described the research background and purpose.

Chapter 2 described the related research regarding CHP assessment and details of DER-CAM.

Chapter3 described the DER-CAM structure and input data. For building energy consumption data, DOE2 was used for office building simulation and the results were compared with the load data used in Japan. Also, comparisons of fuel tariffs (electricity and natural gas) between Japan and the United States were made. Commercial electricity tariffs in the two countries are similar. However, the commercial natural gas tariffs in Japan are higher than in the United States.

Furthermore, differences in DG technology information between the two countries were discussed. In Japan, small-scale CHP installation costs are almost twice as much as in the United States, but this difference shrinks as CHP size increases. For large CHP system size, capital costs are lower in Japan than in the United States.

A comparison of DG subsidies in the two countries has also been made. In Japan, 1/3 of the capital costs of CHP systems is covered by subsidy. In the United States, subsidies vary by region. Subsidies range from 20% to 90%.

Chapter 4 presents results from the examination 10,000 m^2 office buildings, hotel, hospital, retail store and sports facility prototype buildings. Economically optimal DER investment for each was determined, and the resulting the annual energy cost savings, fuel savings, and carbon emissions reductions are quantified. The economic and environmental effect of CHP installation can be seen. Even though these studies conduct *cost* optimizations, fuel consumption and carbon emissions are noticeably reduced.

Sports facilities can benefit the most from CHP, followed by hospitals and hotels. Even for office buildings, which have not been considered in existing studies for CHP potential, CHP adoption potential is shown. For hospitals and sports facilities, using recovered heat for heating is effective. For the other buildings, using recovered heat for both heating and cooling is most effective.

Chapter 5 presents results from the examination of 5,000 m^2 buildings. DER installation capacity is smaller than for the 10,000 m^2 buildings, and payback periods are longer, but there are still economic, energy, and carbon emissions savings.

Chapter 6 presents results for the 10,000 m^2 buildings without DER equipment subsidy. Even without subsidy, economic, energy, and carbon emissions savings are seen, although the magnitudes of the reductions are decreased.

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