【論文】

Assessment of Distributed Energy Adoption in Commercial Buildings

Part 2 Optimization Results for Prototypical Buildings

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業務用建物における分散型エネルギーに関する評価研究

その２ 種類別業務用建物における最適化結果

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Abstract

The previou paper described preliminary analysis on CHP investment climate in the U.S. and Japan. DER technologies, energy prices, and incentive measures were investigated. This paper intends to explore methods of choosing economically optimal DER, expanding on prior studies at the Berkeley Lab using the DER design optimization program, the Distributed Energy Resources Customer Adoption Model (DER-CAM). DER-CAM finds the optimal combination of installed equipment given prevailing utility tariffs and fuel prices, site electrical and thermal loads (including absorption cooling), and a menu of available equipment. It provides a global optimization, albeit idealized, that shows how site useful energy loads can be served at minimum cost. Five prototype Japanese commercial buildings are examined and DER-CAM is applied to select the economically optimal DER system for each. Based on the optimization results, energy and emission reductions are evaluated. Significant decreases in fuel consumption, carbon emissions, and energy costs were seen in the DER-CAM results. Savings were most noticeable in the prototype sports facility, followed by the hospital, hotel, and office building. Results show that DER with combined heat and power equipment is a promising efficiency and carbon mitigation strategy, but that precise system design is necessary.

Keywords: distributed energy resources, combined heat and power, building energy efficiency, commercial buildings, optimization, absorption cooling

1. Introduction

The previous paper (Zhou,2006) described the preliminary research on DER investment climate in Japan and the comparison to that in the US. As results, 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; In addition, database on building characteristic and load shape profile in prototypical buildings has been reviewed for future energy research.

This paper explores the optimization results of an analysis of the potential for DER and CHP utilization in Japan. 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 the Distributed Energy Resources Customer Adoption Model (DER-CAM), an analysis was conducted of economically optimal DER investments for different prototype buildings in the Tokyo climatic zone of Japan.

2. Methodology

DER-CAM optimizations were executed using the U.S. technology data, assuming a 1/3 subsidy across the board to all the technologies considered. Technology costs in

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Japan are effectively similar to those in the U.S. based on discussion in previous paper. The average efficiency of the Japanese macrogrid was assumed to be 36.6%. and CO2 emissions were assumed to be 0.66 kg/kWh, equivalent to elemental carbon emissions of 0.18 kg/kWh ; that is, all displaced macrogrid generation is assumed to be from fossil power plants.

In the results, whole system efficiency is the percentage of fuel energy used by the DER system applied to an end use as either electricity or heat. In the U.S., FERC has an alternative definition of efficiency defined as:

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

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

・ Do-Nothing: No DER investments are allowed. This scenario provides the baseline annual energy cost, consumption, and emissions prior to DER investment.

・ DER: DER investment in electricity generation only, i.e. no CHP allowed.

・ DER with CHP: DER investment in any of the electricity generation and heat recovery and utilization devices available.

CHP shifts the balance of utility purchases, reducing utility electricity purchases but significantly increasing natural gas requirements. Recovered heat from the equipment can be used to offset natural gas used for heating and/or electricity used for cooling. Examples of office and hospital buildings are shown below.

3. Results

The five prototype buildings considered are: office building, hospital, hotel, retail, and sports facility.

3.1 Office Building

Even for office buildings, which have low capacity factors, on-site generation may be economic because of high on-peak electricity prices and demand charges, combined with the discounted CHP natural gas rates. Table 1 shows example 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 is selected, resulting in decreased electricity purchases and increased natural gas purchases. Total annual energy costs (including capital and maintenance costs) are reduced by about 4.7% ($15,000). 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. Fig. 1 and Fig. 2 show the January weekday natural gas loads and how they are met by the CHP system. The peak load is about 1200 kW at 8 am, 600 kW being met by recovered heat. Fig. 3 and 4 show the electricity loads on July day. The peak electricity load is 569 kW, 300 kW of which is met by DER. The peak cooling electricity load is reduced 177 kW by absorption cooling, and the net electricity purchase from the macrogrid is reduced to 198 kW.

3.2 Hospital

Table 2 shows results for the hospital building: the Do-Nothing total energy bill is $332,920. No equipment was selected for DER without heat recovery so there are no changes. 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. Annual fuel cost are reduced by 40%. Fig. 5 and Fig. 6 show the natural gas loads for January and how the load is met from CHP. The peak load is 1252 kW, of which 438 kW is met by the CHP system. Fig. 7 and Fig. 8 show the electricity loads in July and how the CHP system meets these loads. The electricity load peaks at 10 A.M. at 461 kW, of which 300 kW is met by DER. Also, 44 kW of the peak cooling electricity load (161 kW) is offset by absorption cooling, reducing the net macrogrid electricity purchase to only 128 kW.

3.3. Comparative Results for all Buildings

Table 3 shows the installed capacity and natural gas used for the optimal CHP solutions for all prototype buildings. For office, hospital and hotel buildings, 300 kW gas engines with both heating and cooling equipment were selected. Cooling was provided by utilizing recovered heat in an absorption chiller. A larger size (1000 kW) gas engine with both heating and cooling equipment was selected for the Retail building. This may be attributable to its higher peak load. With more self generation and cooling offset by heat recovery, the high demand charge can be avoided. For the sports facility, because the cooling requirement is low, two 300 kW gas engines with only heat recovery were selected. The capacity factor is high in the hotel and hospital buildings, which are generally considered to be favorable CHP sites. The capacity factor is lowest in the retail building, in part because the selection of larger equipment to avoid the high on-peak electricity price and demand charge.

The natural gas purchased in the optimal case for all buildings shown in the table illustrates that the natural gas are most used for DER, except for sports facility where a lot of the heating requirement in the winter is directly met by natural gas due to the subsidized gas tariff for CHP installation. The effect of incentive tariffs on decision-making could be a topic for future work.

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Table 1 Office Building DER-CAM Results

Case	Installed Capacity	Installed Technology	Installation Cost	Electricity Purchased	Natural Gas (k$)		Energy Cost	Total Cost	Energy Cost Reduction	Overall Cost Reduction	Pay Back Years
	kW		k$	k$	For DER	Gas only	k$	k$	%	%	a
Do-Noth.	0	0	0	275.3	0	42.1	317.4	317.4			
DER	300	NG--0030 0	36.4	125.2	112	28.8	266	302.5	-16.2%	-4.7%	6.1
DER with CHP	300	NG-ABSH X-00300	58.5	83.8	129.4	6.7	219.9	278.4	-30.7	-12.3%	4.7

Table 2 Hospital Building DER-CAM Results

Case	Installed Capacity	Installed Technology	Installation Cost	Electricity Purchased	Natural Gas (k$)		Energy Cost	Total Cost	Energy Cost Reduction	Overall Cost Reduction	Pay Back Year
	kW		k$	k$	For DER	Gas only	k$	k$	%	%	a
Do-Noth.	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-ARSH X--00300	62.9	18.6	163	18	199.7	262.6	-40.01%	-21.1%	3.4

Table 3 Installed Capacity and Natural Gas Used for the Optimal CHP Solutions

	Office	Hospital	Hotel	Retail	Sports facility
installed technology	NG-ABSHX --00300	NG-ABSHX --00300	NG-ABSHX --00300	NG-ABSHX --01000	2 unit of NG--HX--00300
installed capacity (kW)	300	300	300	1000	600
capacity factor	49%	62%	72%	27%	56%
NG purchased for CHP (k$)	129.4	163	189.1	212.3	294.3
NG purchased for other use (k$)	6.7	18	9.5	3.4	277.1

Table 4 Prototype Building System Efficiency Improvement

	Office	Hospital	Hotel	Retail	Sports facility
Macrogrid Electrical Efficiency			36.6%		
Natural Gas Combustion Efficiency			80%		
Do-Nothing System Efficiency	42.1%	49.5%	48.3%	41.2%	64.1%
DER without CHP Efficiency	31.0%	n/a	27.5%	34.0%	27.5%
DER with CHP System Efficiency	75.0%	74.1%	78.0%	69.4%	73.6%
DER with CHP System Efficiency (FERC)	53.0%	52.5%	54.5%	51.7%	52.3%
DER with CHP Whole System (DER & Util.) Efficiency	63.1%	72.2%	75%	69.4%	76.6%
Efficiency improvement (percentage points)	21.0	22.7	26.7	28.2	14.5

Fig. 9 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 the 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 usage reduction; all peak loads can be economically met by self-generated power and waste heat recovery from CHP. The effect on air conditioning loads of heat recovery is seen in all of the buildings except the sports facility, for which heat recovery for cooling is not economic.

CHP also shifts the amounts and sources of carbon emissions. Fig.10 shows the carbon emissions reductions. CHP installation reduces these emissions for all prototype buildings. This reduction is most significant for the hotel (34% reduction) and retail building (34% reduction), followed by the hospital (32% reduction). Furthermore, CHP shifts the amounts and sources of annual energy costs. Fig.11 shows the economics of the CHP installations. For the sports facility, costs are reduced by 32%, followed by the hotel (23%) and the hospital (21%).

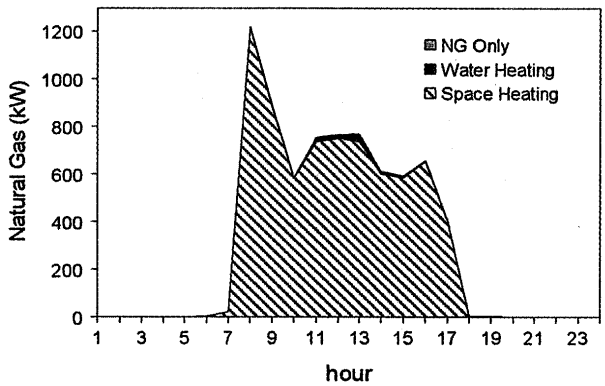

Fig. 1. Office Building Jan Natural Gas Use

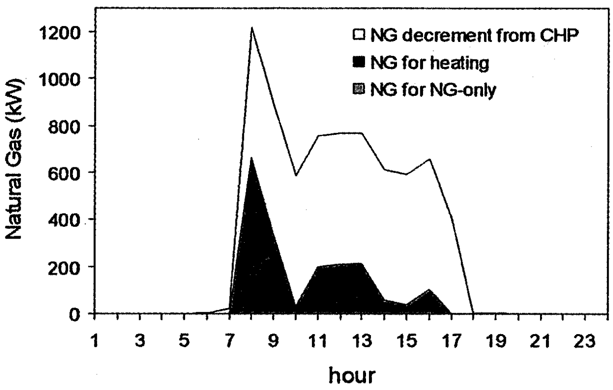

Fig. 2. Office Building Jan Natural Gas Load Provision with CHP

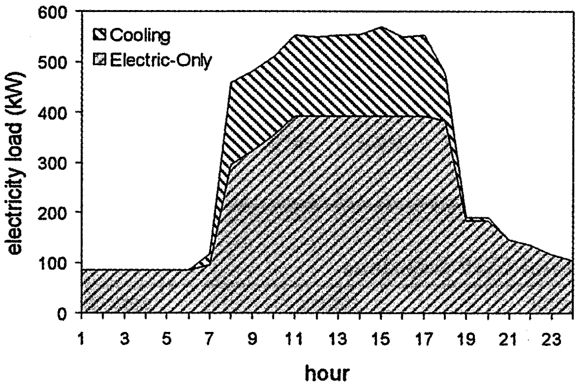

Fig. 3. Office Building Jul Electricity Use

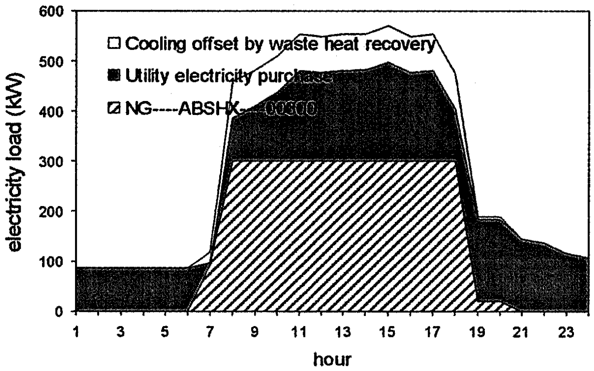

Fig. 4. Office Building Jul Electricity Load Provision with CHP

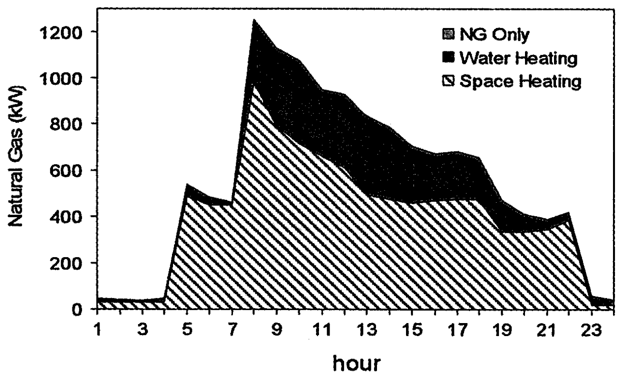

Fig. 5. Hospital Jan Natural Gas Use

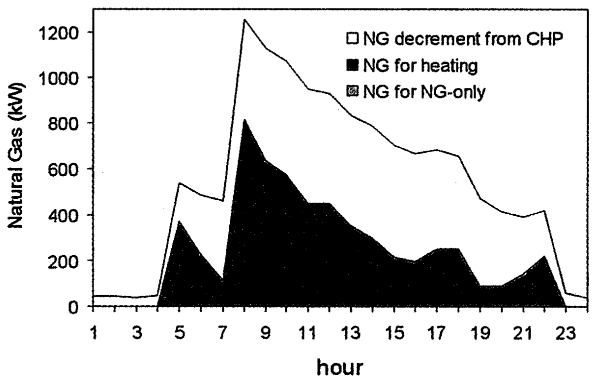

Fig. 6. Hospital Jan Natural Gas Load Provision with CHP

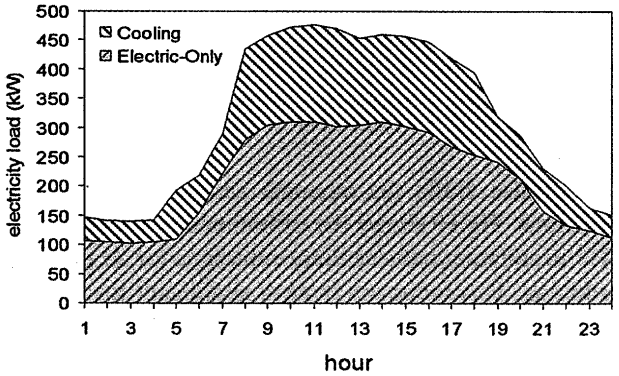

Fig.7. Hospital Jul Electricity Use

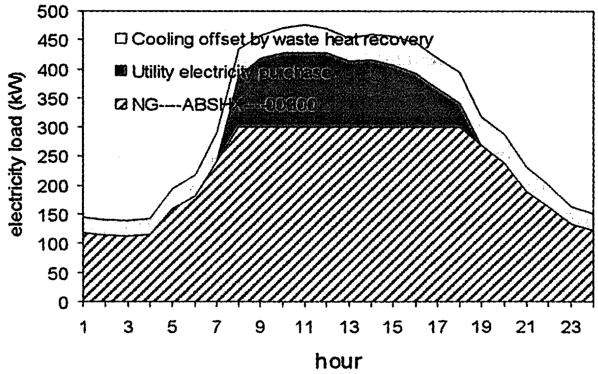

Fig. 8. Hospital July Electricity Load Provision with CHP

followed by the sports facility (3.3 years) and the hospital (3.4 years).

Table 4 states the system efficiency for the three scenarios (Do-Nothing, DER without CHP, and DER with CHP). The assumed macrogrid efficiency is used to calculate purchased electricity efficiency, Natural Gas combustion efficiency is used to calculate the gas direct use efficiency. The reported efficiency represents an overall efficiency of electricity generation and gas combustion of the DER system. This efficiency will be used if there is no electricity purchase from the grid. DER with CHP Whole System efficiency is the efficiency including both DER efficiency and the purchased electricity efficiency.

The entire system efficiency has been improved in all prototype buildings. The efficiency improvement is most significant for retail buildings (28.2 percentage point improvement), followed by the hotel (26.7) and the hospital (22.7). In all cases, the efficiency for DER without CHP is even lower than macrogrid efficiency demonstrating the importance of CHP for making DER competitive and effective for carbon mitigation.

CHP installation benefits all the prototype buildings considered, but hospitals, hotels, and sports facilities appear to have the most potential benefit. Although not as great as for the other building types, even office buildings, which are traditionally not considered DER candidates, can also reap benefit.

4. Conclusions

This study examined five prototype commercial buildings in the Tokyo climate zone of Japan. DER-CAM was used to select the economically optimal DER system for each. Decreases in fuel consumption, carbon emissions, and energy costs were seen in the economically optimal results. Benefits were most noticeable for the sports facility, followed the hospital and the hotel. Further, this research suggests that even office buildings can possibly benefit from CHP. In contrast to popular opinion, the low capacity factors of office building installations can be compensated for because cooling can be such an economically valuable use for waste heat, displacing costly on-peak electricity, lowering demand charges, and downsizing necessary on-site generating capacity. Reciprocating engines are generators of choice in each case, and they are clearly the strongly incumbent technology. Absorption cooling is chosen in all buildings except the sports facility, underscoring its economic importance. While much more detailed analysis would be necessary to determine the viability of DER for any specific building, the potential payoff seems promising. Also, careful equipment selection and design will be required to achieve reasonable system performance. The results here provide a useful starting point for such an analysis of individual sites. Additionally, DER-CAM can be used for wider assessments of potential DER market penetration and the consequent possible efficiency and environmental benefits.

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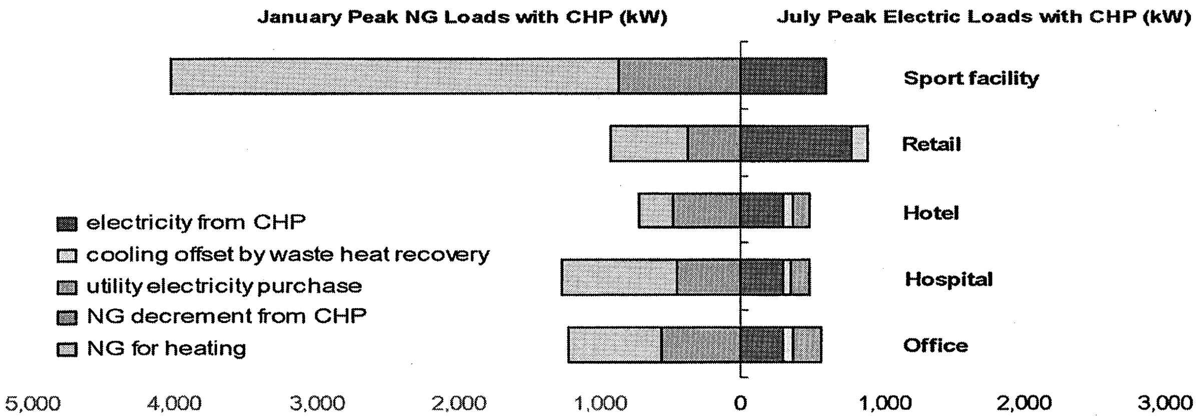

Fig. 9. Peak Load Shifts

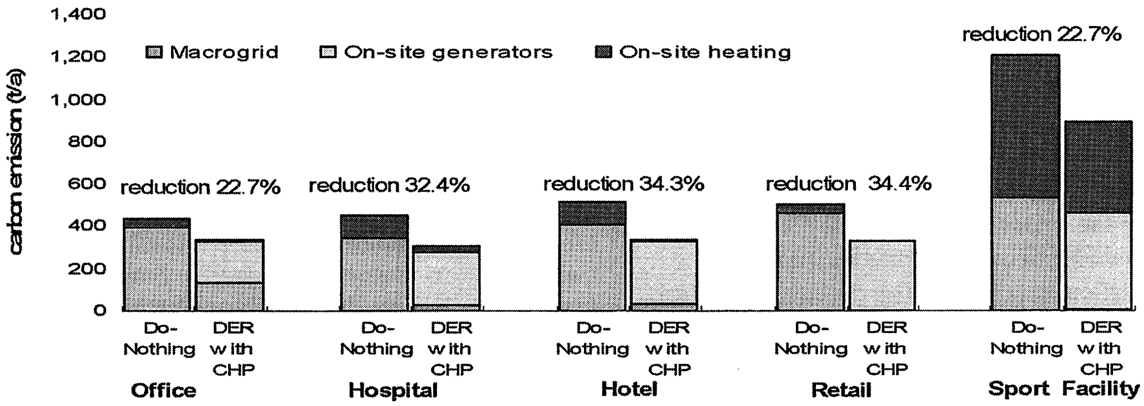

Fig. 10. Carbon Emission Reductions

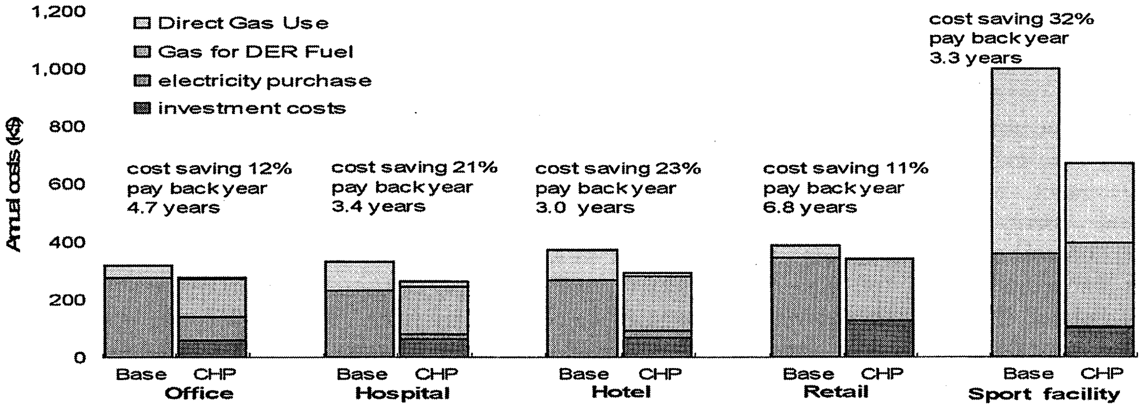

Fig. 11. Energy Bill Savings

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