Energy Saving by means of Effective Usage of Heat Pumps

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Abstract

Huge amount of fossil fuel is consumed by human activities. Air conditioning systems also require large amount of energy resources, mainly fossil fuels in their running time. But there are many kind of energy resources besides fossil fuels, such as wind power, solar energy, various wasted heat and so on. If we can use such so-called unused energy, we can achieve great energy savings.

In this paper, the authors show the effect of the effective usage of heat pumps in order to utilize the unused energies. In such study, it is essential that total amount of energy usage in air-conditioning systems and total amount of heat usage in buildings are measured. In case of district heating and cooling plants, we can easily obtain such data. Therefore, DHC plants are analyzed here.

1. Introduction

With the Third Conference of Parties to the United Nations Convention on Climate Change (COP3), held in December 1977, as a momentum, greater pressure, in Japan, is brought to bear on all sectors of the economy to achieve further energy conservation. HVAC systems' energy consumption data in real buildings are needed to identify what kinds of energy-saving options would be actually workable. Since energy and heat consumption measurements in individual buildings are hard to obtain, however, even data on the efficiency of heat-source systems are yet to be made available in district heating and cooling(DHC) systems.

A study has been conducted lately to derive plant COP from primary energy input and heat sales in DHC plants in Tokyo area. This paper reports on the results of this survey.

2. Method of survey

A total of 22 DHC plants in Tokyo area were surveyed. Thermal storage tanks are set in all plants. Three plants are utilizing so-called low-temperature unused energy such as riverwater, sewage and ground water as heat sinks of heat pumps, two are utilizing high-temperature unused energy sources, such as factory or process waste heat.

The authors obtained annual and monthly heat sales and the inputs of energy, including electricity, town gas, fuel oil and kerosene, at the plants during a period from fiscal 1992 to fiscal 1997. Plant COP values were calculated by converting energy inputs into primary energy quantities as shown in Figure 1. The survey excluded high- and low-temperature unused energy sources from primary energy sources considered.

3. Survey results

Primary energy inputs into the plant and calories sold are used in the survey. Thus the plant COP is defined as an indicator that includes power for lighting and auxiliary machinery used in the plants and heat losses from thermal storage tanks and district piping, among others. Electricity is converted into primary energy as 1 kWh = 2,450 kcal.

3.1. Annual heat sales and plant COP

Figure 2 shows the relationship between annual heat sales and the plant COP in fiscal 1997. The plant COP ranges from 0.55 to 1.3. The greater annual heat sales, the higher the plant COP tends to get. This appears to be because the plants with smaller calories sold carry smaller loads than planned and, as a result, become excessively large heat-source facilities that involve relatively large carrier power and heat losses and hence are poor in operating efficiency. In general, the plant COP takes a higher value with those plants that use low-temperature unused energy sources like riverwater as heat sinks.

3.2. Annual heat sales and CO_2 emission

Figure 2 shows changes in CO_2 emission intensity per kWh of electricity generated in full day, indicating the average of hourly emission intensities on 365 days of the year. As shown in the graphs, the emission intensities per kWh of gross and net electricity productions in the time period from 10:00 to around 20:00 remained almost constant and were higher than in the nighttime. The lowest emission intensities were recorded at around 5:00 hour. Following the startup of pumped-storage hydroelectric power plants at about 8:00, the difference between gross and net power productions in emission intensity per kWh began to widen from that time to 11:00. According to the data, the environmental load intensity of net electricity production was 98.4 g-C/kWh in the daytime, compared with 76.7 g-C/kWh in the nighttime and 91.1 g-C/kWh on the daily average.[1]

CO_2 emission intensity in carbon equivalent per Gcal of heat sold, derived on the basis of data in fiscal 1997, is shown in Figure 4. For fuel oil A, kerosene and town gas, CO_2 emission intensities rely on 0.074, 0.074 and 0.057 (kg-C/Mcal), respectively, as noted in literature .[2]

CO_2 emission intensity ranges from 30 to 75 g-C/Mcal. Gaps in CO_2 emission intensity among energy sources are wider than those gained in terms of primary energy consumption per annual heat sales(plant COP). This suggests that primary en-

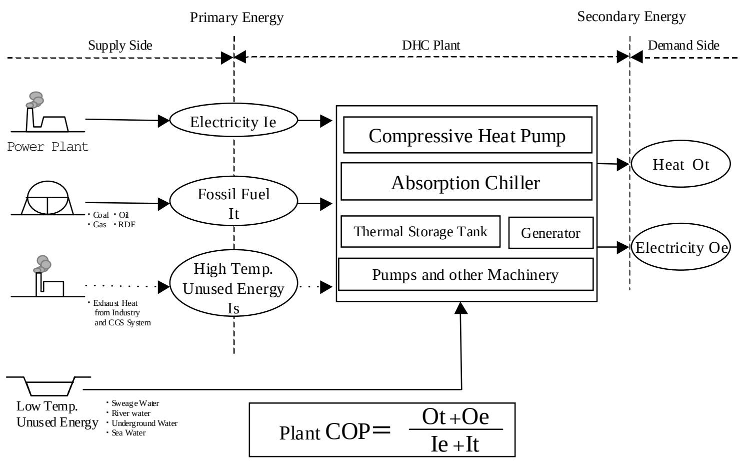

Figure 1. Concept of plant COP

ergy consumption rate does not necessarily link with CO_2 emissions. As a response to COP3, a primary energy-based approach toward energy conservation is now under consideration. However, another indicator may be necessary if CO_2 emissions are actually reduced.

Basically, CO_2 emission intensity is in proportion to the inverse number of the plant COP shown in Figure 2. Yet it is affected by how much electric energy has been successfully shifted from daytime to nighttime - namely, what capacity of thermal storage tank is held and how effectively it has been used for desired purposes. When composite heat sources are in use, the result is also dependent on CO_2 emission intensity of fuels used other than electric power.

The plant C, fueled by process or factory waste heat, for example, outperforms the plant C using waste heat from buildings significantly in terms of COP but makes no substantial difference in terms of CO_2 emissions. This is because while the plant C is using fuel oil, the plant B fires LNG. It is also ascribable to the fact that the plant C has a thermal storage tank with an insufficient capacity so that sufficient electricity cannot be transferred from daytime to nighttime.

A look at the composite heat source system reveals that reductions in environmental loads such as CO_2 emission intensity are not necessarily in agreement with economical plant operation.

3.3. Changes in plant COP over time

Figure 5 summarizes the relationship between plant COP levels and calories sold during a period from fiscal 1992 through fiscal 1997. A fewer plots are allotted to those plants which went into service during this period.

Many plants experience an improvement of plant COP as heat sales increase. This seems to be because: 1) operators become accustomed to the plant; 2) losses from thermal tanks and piping decrease relatively; and 3) the plant operates at capacity closer to design capacity.

The plant A using sewage as a heat source showed an improvement of plant COP, despite a decrease in calories sold, during a period from fiscal 1994 through fiscal 1996. One of the contributing elements is a change in the balance between cold and hot water supply. Yet it may be attributable in a greater measure to the above factor 2). The efficiency of thermal storage air-conditioning systems appears

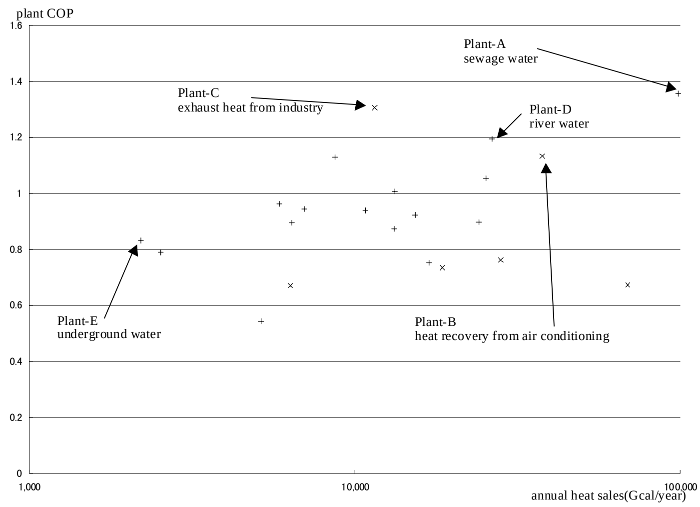

Fig.2 Relation between Plant COP and Annual Heat Sales(1997)

to be affected by operation and control methods.

In the plant B using waste heat collected from buildings, the COP is found to be improving as heat sales increase. This is largely owing to the fact that both plant and building operators have been operating facilities in best possible conditions.

For the plant C using factory or process waste heat, the plant COP was kept within the range from 1.1 to 1.2 over the past six years. No correlationship with loads was observed. The COP of this plant appears to be significantly influenced by factory operating conditions.

In the riverwater-using plant D, although there was no substantial change in calories sold, the plant COP declined to a slightly lower level than at the outset. A further study will have to be made to iden-

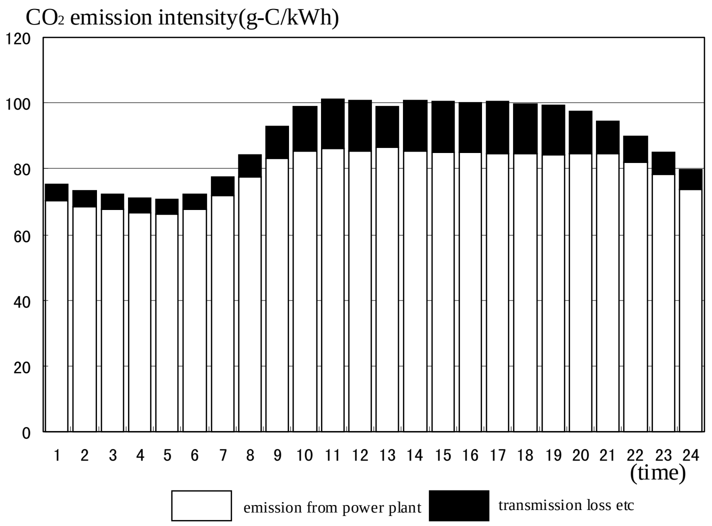

Fig.3 CO_2-Emission from Electricity(FY1997)

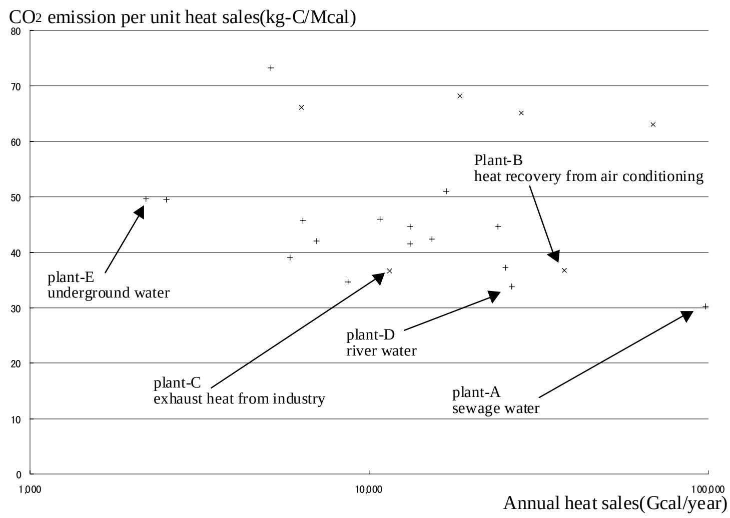

Fig.4 Relation between CO_2-emission from DHC Plant and Annual Heat Sales(FY1997)

tify whether this COP deterioration has been caused by a drop in the efficiency of heat-source equipment or by the effects of load characteristics on the demand side.

As for the ground water-based plant E, which has been in service since fiscal 1994, the plant COP remained lower than 0.6 as no loads were served in the initial year. In fiscal 1995, when calories sold began to increase, the COP exceeded 0.9. Since large buildings started receiving district heating and cooling service at the end of fiscal 1997, a followup survey will be conducted to inquire into how the COP of this plant will change in years ahead. Of low-temperature unused energy sources, ground water makes a highly suitable source of air conditioning. Yet a study will have to be made on the effects of the regulations on the pumping-up of ground water.

3.4. Monthly heat sales and plant COP

Figure 6 shows the relationship between monthly calories sold and monthly plant COP for the plants A, B and C. Of all facilities using low-temperature unused energy sources, the plant A shows the highest efficiency. The plant B is the most efficient facility that operates on low-temperature unused energy sources. The plant C is utilizing high-temperature unused energy.

At all of these plants, the plant COP stays almost constant when loads start to increase in summer, whereas the plant COP improves in winter when hot water loads increase. This tendency develops because all of these plants use double bundle refrigerators to take out cold and hot water and store it in thermal storage tanks so that heat can be supplied whenever necessary.

There is a difference observed in the plant COP in summer between the plants A and B. This may be due to the difference arising from whether low-temperature unused energy could be utilized as a heat sink. Considering the operating conditions of both plants, it may well be said that the two facilities are displaying almost the highest possible efficiency that thermal storage type district heating and cooling plants could attain in terms of performance and primary energy equivalent values for the present refrigerators.

The COP declines to a level lower than 0.5 in May with the plant C because factories are subjected to maintenance and high-temperature unused energy supplies are suspended. When high-temperature unused energy sources are utilized, actions taken in maintenance may have a substantial impact on the yearly efficiency of facilities. Because of its equip-

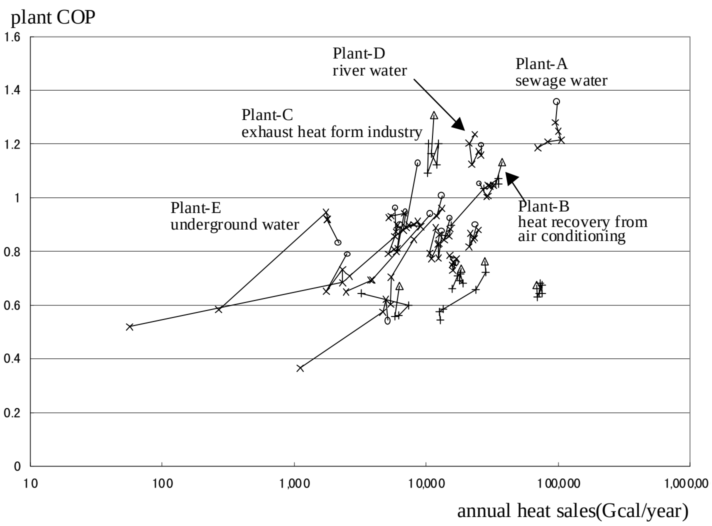

Fig.5 Relation between plant COP and annual heat sales(1992-1997)

ment makeup, this plant uses fuel oil to make up for the deficiency of high-temperature unused energy .

4. Conclusion

It is evident from the data that energy-saving capability increases by operating the double bundle refrigerator to collect cooling waste heat and generate heat.

The current primary energy concept is effective when the national energy consumption is to be calculated in oil equivalent. Yet it is open to question as a tool of assessing the energy-saving ability of individual DHC systems and buildings. The approach is not appropriate as an indicator for an energy conservation debate to achieve CO_2 emission reductions. Thus a new indicator should be provided for future efforts.

Many energy conservation arguments are based on theoretical values. If workable energy-saving policy measures are to be developed, data will be needed to show what will be the results of such possible measures. This is why the results of the survey we conducted recently are presented here. Diverse allegedly energy-saving systems are suggested. It is the responsibility of those who have suggested such systems to make public actual data to indicate what results have come out of the application of these systems.

References

[1] T.Kobayakawa and T. Tanaka, Hourly Environmental Load Intensities (2) in the Electric Utility Industry, *Proceedings of the Academic Lecture Meeting of the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan* (in Japanese), pp.1621-1624.

[2] the Global Environment Committee, Society of Heating, Air-Conditioning and Sanitary Engineers of Japan., *"For Structures and Facilities for Supporting Sustainable Society,"* Text of the Symposium on the Global Environment, July 1997, pp. 60

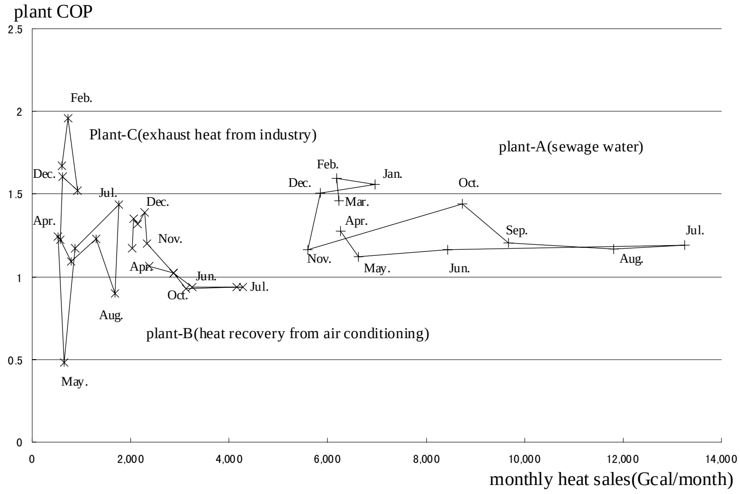

Fig.5 Relation between Plant COP and Monthly Heat Sales(1997)