Energy Problems in the Logistics of Japanese Antarctic Research Expedition from 1956 to 1984

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南極地域観測（1956–1984）設営におけるエネルギー問題

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要旨: 昭和基地のエネルギー源としてのディーゼル発電装置は，第1次観測(1956年) の 20kVA 2台に始まり，基地の拡大に伴い 45kVA, 65kVA, 110kVA, 125kVA を経て，1984年にはついに 200kVA 3台設置 (内1台は1985年設置) の規模に達し，越冬隊員も11名から35名に増加した．第1次の基地開設当時より発電用ディーゼルエンジンのトータルエネルギーシステム，すなわちエンジンの冷却水の熱量および排気熱量の回収を行い，基地燃料の節約に寄与している．これらの廃熱により，冬季は雪または氷を解かして飲料水および雑用水を作り，さらにそれを廃熱で温めて温水を作り，水道，風呂および暖房に利用してきた．

1984年に完成した新発電棟では，エンジン冷却水廃熱の回収に主力が注がれ，これによって低温水タンクならびに高温水タンクの水を温める．高温水は冷水タンクの冷水とともに水道配管されて，新発電棟の2階に設けられたウエットエリアに供給され，一方約100m離れた食堂ならびに娯楽室の温水暖房にも利用されている．低温水タンクの低温水は熱交換器を介して戸外に設けた 100kl および 130kl の貯水槽の保温ならびに冬季の融雪造水に利用される．排気熱の回収のためには，戸外にヒートパイプ方式のガス－空気熱交換器を設けて発電棟への取り入れ空気を予熱しているが，実測によると回収熱量は排気保有熱量の約3.9%に過ぎず，今後の改良を必要とする．

一方，みずほ基地においても，1971年以来 16kVA または 12kVA ディーゼル発電機の冷却水廃熱のみを利用して，融雪造水ならびに温水を作り，風呂および雪面下の2室の暖房をこれのみで賄っている．

極地における風力エネルギーの利用は，目下研究と試作を繰り返しているが，大型のものは基地の雑用熱源として，小型のものは無人基地の電源として，その完成が望まれている．

Abstract: This paper gives a review on the development of logistics for the Japanese Antarctic Research Expedition (JARE) from 1956 (JARE-1) to 1984 (JARE-25), especially on the energy problems of Syowa and Mizuho Stations.

Diesel-electric generators as the energy source of Syowa Station were developed from two sets of 20 kVA in 1956 to three sets of 200 kVA after 1984 (one of which will be set in 1985), and the number of wintering members increased from 11 (1956) to 35 (1984). A total energy system for a diesel engine, *i.e.* the recovering of coolant energy and exhaust-gas energy, has been fully developed saving much fuel at Syowa Station. The waste heat thus recovered has been used to melt ice or snow for producing water in winter and to produce hot water for bath and room heating throughout the year. In the new power house built in 1984 (JARE-25), a total energy system was also adopted; cold and hot water

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was produced through the coolant energy, and the exhaust-gas energy was used to warm the cold fresh air taken from outdoors, by employing a heat-pipe type heat-exchanger.

At Mizuho Station, the coolant energy of a 16-kVA or 12-kVA diesel-electric generator has been used to produce cold and hot water for bath and room heating. Some notes on the experiences in utilizing wind energy in Antarctica are added.

1. Development of Japanese Antarctic Stations and Power Generation

The Japanese Antarctic Research Expedition (JARE) established Syowa Station on 29 January 1957 (JARE-1) and Mizuho Station on 21 July 1970 (JARE-11). The development of power generation at these stations from JARE-1 through JARE-25 (1983/85) is shown in Table 1 with relevant data. The energy source facilities of Syowa Station began with two sets of 20-kVA diesel-electric generators and increased to two sets of 45-kVA (1966, JARE-7), 65-kVA (1968, JARE-9) and 110-kVA (1978, JARE-19). One of the two sets of 110-kVA generator was replaced by 125-kVA in 1979 (JARE-20) and the energy source facilities reached two sets of 200-kVA in 1984 (JARE-25) and another set of 200-kVA is planned to be brought in 1985 by JARE-26 (1984/86).

One of these two or three sets of diesel-electric generators has been continuously operated supplying all power necessary for the station. The remaining one is ready for the emergency use as well as for the replacement for the running set during its regular inspection.

The reasons for adoption of diesel-electric generators are as follows:

(1) Light diesel oil, the fuel for diesel engines, is relatively safe from fire hazard.

(2) Light diesel oil is suited for the transport in the tropics because of low vapor pressure.

(3) Fuel consumption rate of diesel engines is low, and the cost of fuel is low.

(4) In the early period of expedition, diesel engines of the same type were used for oversnow vehicles, so that common repair parts were available.

(5) Starting of diesel engines is easy even at −40°C.

(6) Exhaust-gas temperature of diesel engines is about 270 to 400°C, being lower than that of spark-ignition engines.

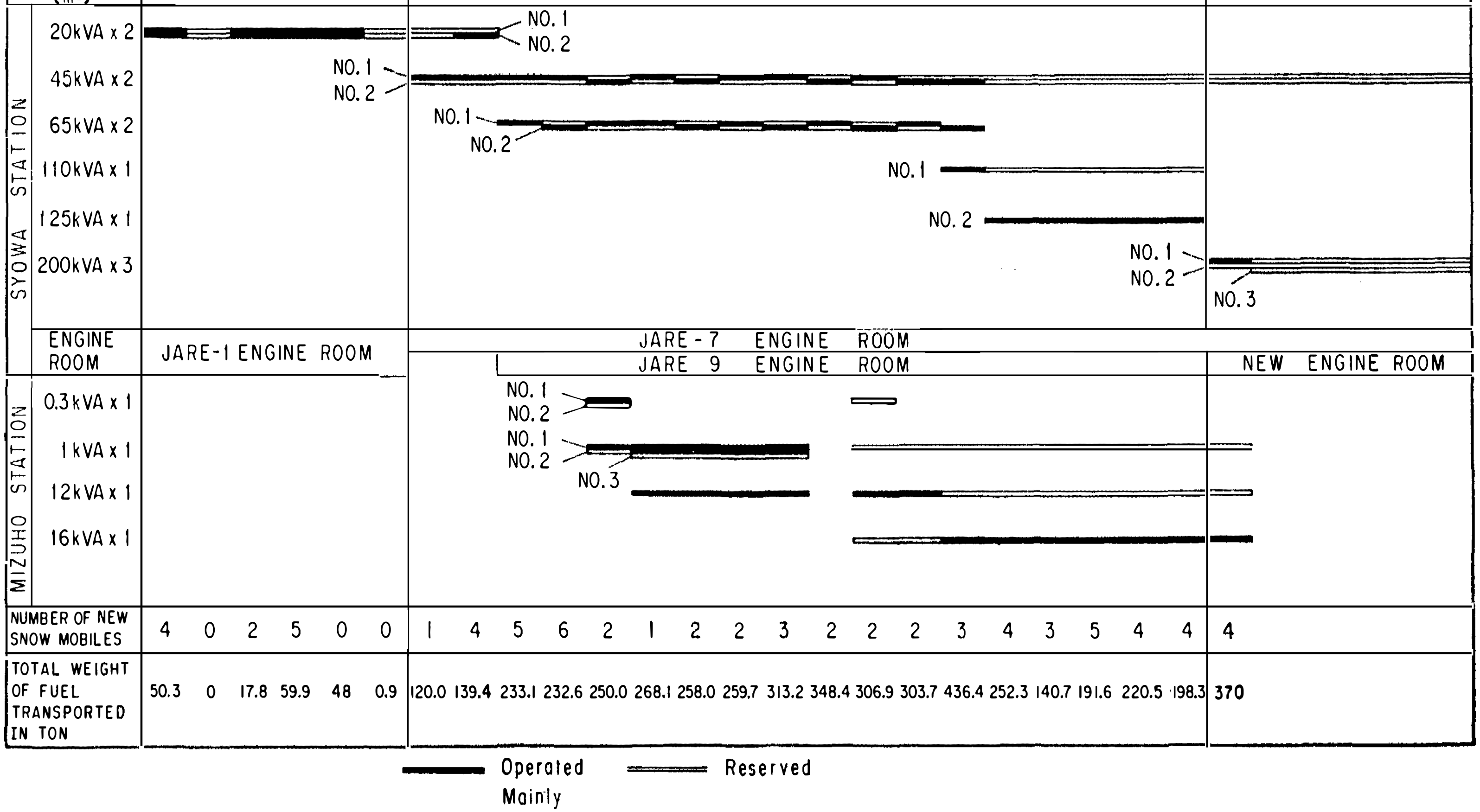
From JARE-15 (1973/75) through JARE-24 (1982/84), about 240 to 300 t of fuel were shipped to Syowa Station every year, which account for about 50 to 60% of the total cargo (500 t) of the icebreaker FUJI. In JARE-25 (1983/85), a new icebreaker SHIRASE made her first voyage to Antarctica. Its cargo capacity was increased to 1 000 t, and 400 k*l* (340 t) of light diesel oil was tarnsported to Syowa by her barge.

2. Total Energy System for Recovering the Waste Heat of Diesel Engines

At Syowa Station, systems for recovering coolant and exhaust-gas energy were installed and used effectively from 1957 (JARE-1) to the present; the recovered energy

Table 1. Development of diesel-electric generators at Syowa and Mizuho Stations with relevant data of Japanese Antarctic Research Expedition.

JARE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1856/58	1957/58	1958/60	1959/61	1960/62	1961/62	1965/67	1966/68	1967/69	1968/70	1969/71	1970/72	1971/73	1972/74	1973/75	1974/76	1975/77	1976/78	1977/79	1978/80	1979/81	1980/82	1981/83	1982/84	1983/85	1984/86				
ICE BREAKER	SOYA						FUJI																		SHIRASE					
WINTERING MEMBERS	11	0	14	15	16	0	18	24	28	28	30	29	30	30	30	30	29	30	30	30	33	34	34	35	35					
TOTAL AREA OF LABORATORIES (m²)	134.6	134.6	144.3	177.8	177.8	177.8	690.8	1275.5	1819.3	2189.9	2640	2706.5	2873.5	3068.1	3168.9	3240.9	3268.7	3369.5	3478.0	3478.0	3801.2	3894.8	3894.8	4359.1	4359.1					
ENGINE ROOM	JARE-1 ENGINE ROOM						JARE-7 ENGINE ROOM; JARE 9 ENGINE ROOM																		NEW ENGINE ROOM					
NUMBER OF NEW SNOW MOBILES	4	0	2	5	0	0	1	4	5	6	2	1	2	2	3	2	2	2	3	4	3	5	4	4	4					
TOTAL WEIGHT OF FUEL TRANSPORTED IN TON	50.3	0	17.8	59.9	48	0.9	120.0	139.4	233.1	232.6	250.0	268.1	258.0	259.7	313.2	348.4	306.9	303.7	436.4	252.3	140.7	191.6	220.5	198.3	370					



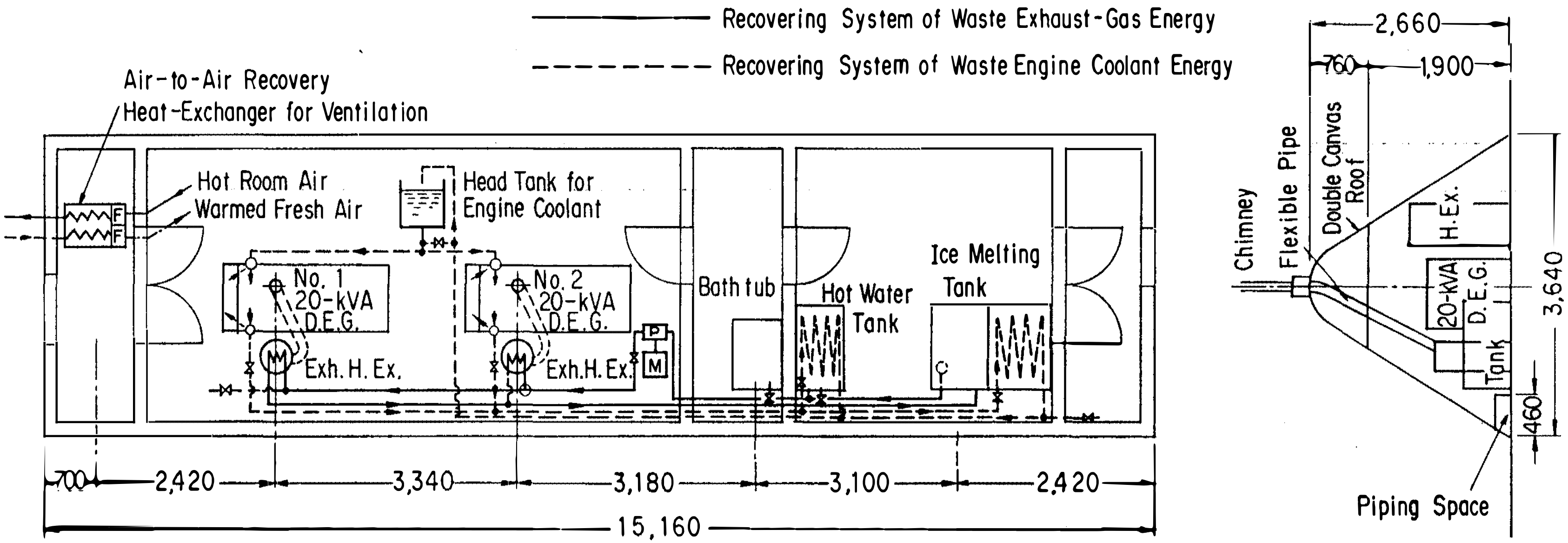


Fig. 1. Waste heat recovery system and 20-kVA diesel-electric generators in JARE-1 engine room (1956–62).

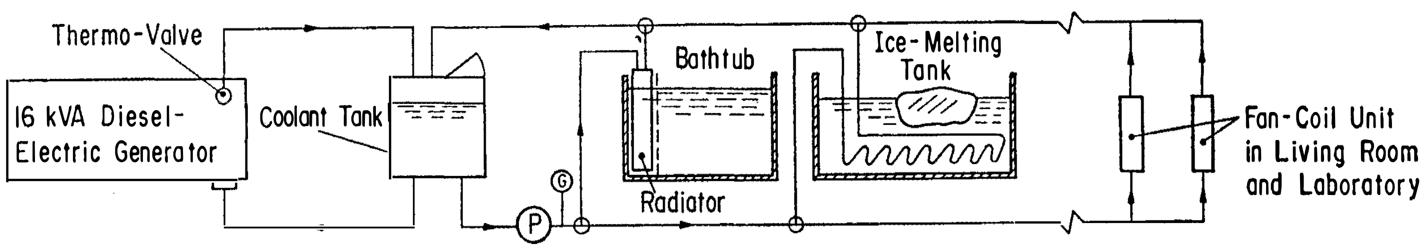


Fig. 2. Coolant heat recovery system in a trench engine room of Mizuho Station prepared for JARE-17 (1975/77).

was used for the water supply in winter and part of the room-heating, thus saving about 50 k*l* of fuel every year (AWANO *et al.*, 1982).

At Mizuho Station, which is 270 km inland from Syowa Station, a system for recovering jacket coolant energy of a 16-kVA or 12-kVA diesel-electric generator has been used for producing cold and hot water for the use in bath since 1971 (JARE-12), and the hot water has also been used for room heating from 1977 (JARE-18) to the present.

2. 1. Recovery of coolant energy

(a) Coolant energy of a diesel engine accounts for about 29 to 30% of the heat released from the fuel.

(b) Energy recovery is very easy by using an ordinary shell- and tube-type heat exchanger.

(c) The coolant energy may be used for making cold water by melting ice or snow, making hot water of 50 to 80°C, and room heating by utilizing the hot water and fan-coil units.

(d) Remarks: 1) Coolant temperature of the engine should not be lowered excessively by recovering heat because it occasionally causes incomplete combustion; 2) An external load should be put in parallel to the engine radiator. With a light external load, an automatic valve regulated by the coolant temperature opens and leads a part of the coolant to the engine radiator so that the coolant temperature will not exceed its allowable maximum value; 3) A 50% ethylene glycol solution should be used instead of water as coolant to prevent freezing.

2. 2. Recovery of exhaust-gas energy

(a) Exhaust-gas energy of diesel engine is about 30 to 35% of the heat released from the supplied fuel.

(b) The design of heat exchanger for recovering exhaust-gas energy is very difficult for the following reasons: 1) Acid corrosion of metals is very severe when the steam contained in the exhaust-gas condenses on the surface of the metalic wall cooled by cold water flowing along the other side of the wall; 2) Impinging of hot exhaust gas occasionally causes some cracks on the shell surfaces due to thermal stress: 3) Soot adhering to a heating surface decreases the overall heat transfer from hot gas to cold water through the wall. As an example, the heat recovery efficiency decreased from 73 to 40% after three weeks.

(c) Protection against acid corrosion: 1) Minimum temperature of the exhaust gas at the outlet of heat exchangers should be kept above 100 to 150°C; 2) Water temperature led to the exhaust-gas heat exchanger should not be too low, because the condensation of steam contained in the exhaust-gas is promoted. It is more preferable to heat again the warm water preheated by engine coolant than to heat directly the extremly cold water such as melted ice water.

(d) A new type exhaust-gas heat exchanger, which was developed by one of the authors AWANO has been used successfully since several years ago. This heat exchanger is composed of a stainless-steel cylindrical shell with water jackets and an aluminium finned cylindrical core cooled internally by water. In this heat exchanger, temperature of fins is kept sufficiently high so that the condensation of steam may be prevented (AWANO *et al.*, 1982).

(e) The exhaust-gas heat exchanger may be used for making hot water, which can be used for bath and for room heating, and for making cold water by melting snow or ice.

(f) In the new engine room built in 1984 (JARE-25), a heat-pipe type gas-to-air heat exchanger was first adopted to heat the intake air to the engine room by the hot exhaust gas. But the experimental results on heat recovery were not sufficient as shown in Table 2.

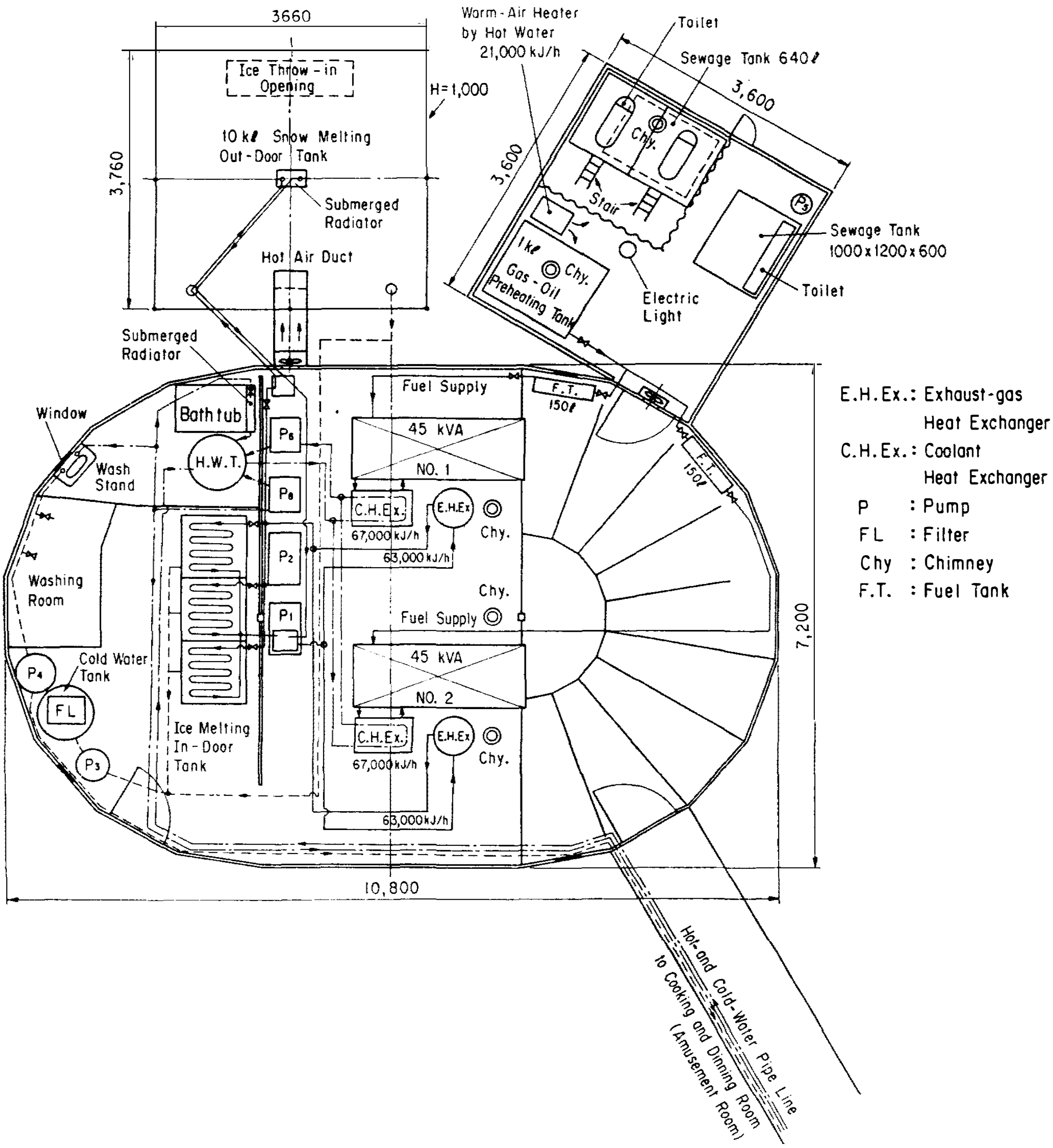


Fig. 3. Waste heat recovery system for 45-kVA diesel-electric generators in JARE-7 engine room (1965/79).

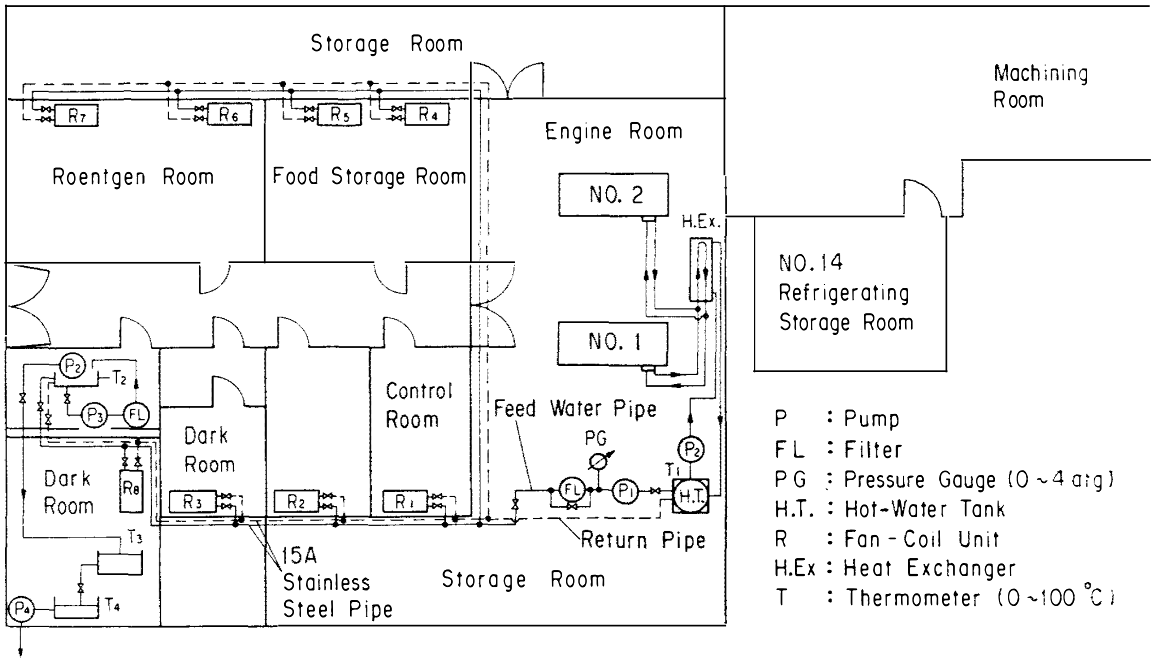


Fig. 4. JARE-9 engine room containing two 65-kVA diesel-electric generators, which were replaced by a 110- and 125-kVA in 1978/79 (JARE-19/20).

Table 2. Data on the heat balance of a 200-kVA diesel-electric generator at Syowa Station (27 June 1984 by TAKEUCHI*).*

Fuel consumption	34.6 l/h	
Heat supplied	117.0×10^4 kJ/h	100.0(%)
Effective output	35.0×10^4 kJ/h (96.0 kW)	29.9
*Cooling loss	35.4×10^4 kJ/h	30.2
**Exhaust-gas energy at the exit of a turbo-charger	41.2×10^4 kJ/h	35.2
Other losses	5.4×10^4 kJ/h	4.7
*Recovery of cooling loss	35.4×10^4 kJ/h	100.0(%)
Heating of ice-melting tank	21.8×10^4 kJ/h	61.5
Radiation from a radiator to air	10.9×10^4 kJ/h	30.8
Heating of recirculating hot water	2.7×10^4 kJ/h	7.7
**Exhaust-gas energy	41.2×10^4 kJ/h	100.0(%)
Heating of outdoor air	1.6×10^4 kJ/h	3.7
Rediation from duct in the engine room	7.5×10^4 kJ/h	18.2

Remarks 1) Outdoor air temperature −14.1°C.
Exit air temperature of a heat-pipe type air heater 46.0°C.
Flow rate of air at the exit of air heater 4 m^3/min.
2) Air flow aspirated by a turbo-charger 0.32 m^3/s.
Room air temperature 25.0°C.
Temperature of exhausted gas from the turbo-charger 320°C.
3) Recovery of coolant energy is nearly perfect, but the recovery of exhaust-gas energy is unsatisfactory and more improvement are desired.

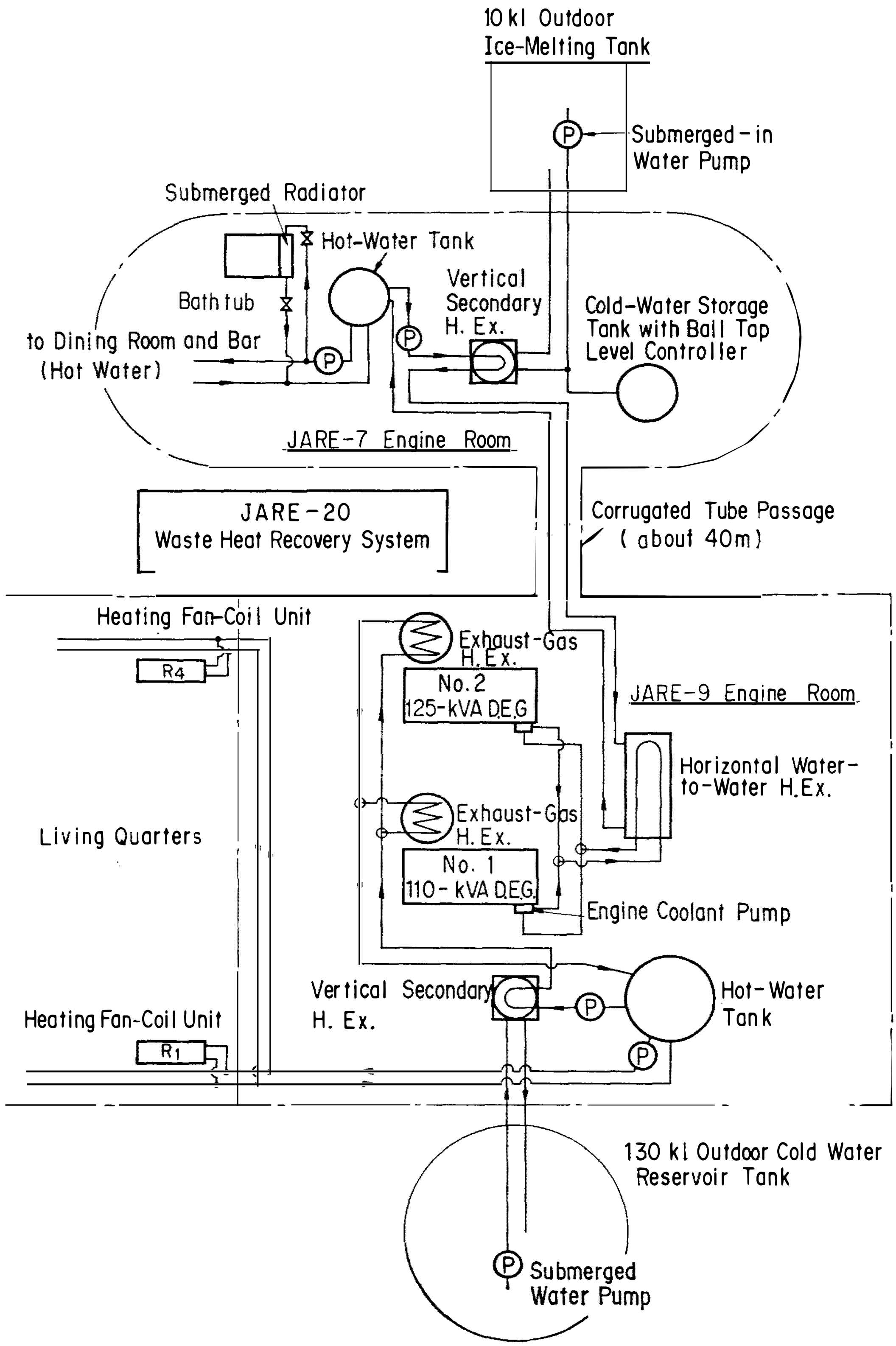


Fig. 5. Rearranged waste heat recovery system for 110- and 125-kVA diesel-electric generators in 1979/84 (JARE-20/24).

3. Water Making System

(a) At Syowa Station, the water in a pond called the First Dam has been used in summer. The water is supplied to the JARE-7 engine room (built by JARE-7) through the following route: First Dam–Aragane Dam–100-k*l* (130 k*l* afterward) outdoor tank–10-k*l* outdoor tank–water supply line in the JARE-7 engine room (TSUCHIYA, 1969; MATSUDA, 1971; OKAMOTO *et al.*, 1971; TAGA, 1972).

(b) In winter, a 2- to 5-kW electric heater is placed in the First Dam to prevent the bottom water from freezing. However, the pond is about 1-m deep and the ice developes to the bottom in early winter. A fire engine pump and hoses have been used to reduce the time necessary for the temporary pumping up and transporting of this water so as to prevent its freezing. The 130-k*l* outdoor tank, which was built to replace a 100-k*l* tank in 1982 (JARE-23), was kept at +6 to 14°C throughout the year by the heat recovered from the exhaust gas of diesel engines.

(c) The 10-k*l* outdoor tank, which was built in 1966 (JARE-8), has been used for melting snow or ice from April through November because the water in the First Dam becomes salty with the growth of ice cover and finally it becomes unsuitable for drinking. The 10-k*l* tank can be kept at +20 to 30°C throughout the year by the recovered exhaust-gas energy.

(d) A cold and hot water supply line was constructed in 1966 (JARE-7). It makes a closed loop that can circulate water continuously to prevent the cold water from freezing. A polyethylene pipe, 140 mm in diameter and 3.88 m in length accommodates a set of aluminium pipes of 32 mm in external diameter, which consists of two pipes employed for hot water and one or two pipes employed for cold water. The space around these aluminium pipes is filled with polyurethane foam. Of the two pipes employed for hot and cold water, one serves as a feeding pipe and the other as a return pipe.

The heat loss from the hot water pipes prevents the freezing of the cold water. These insulated piping units are successively connected to make a hot- and cold-water supply line of 160 m in its total length.

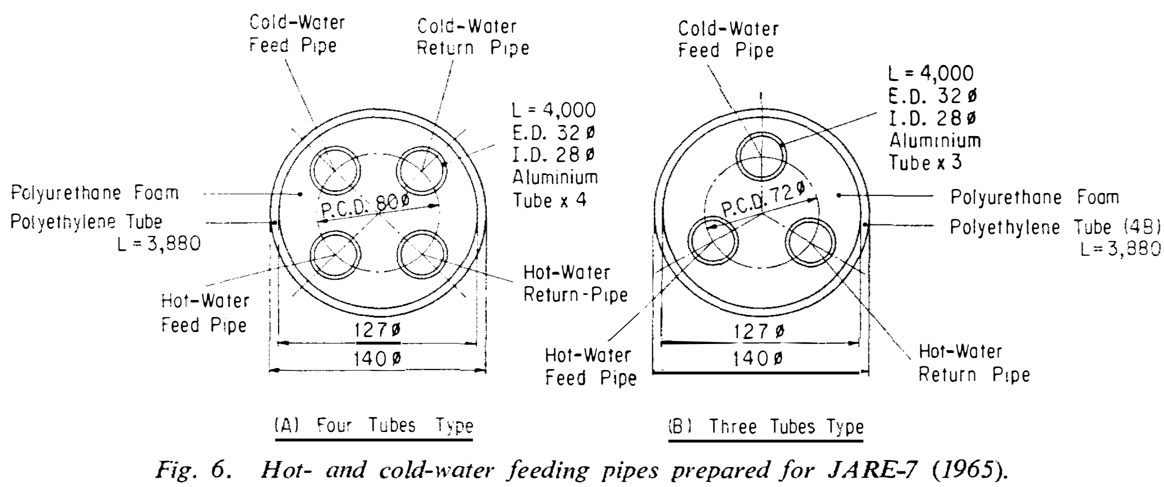


Fig. 6. Hot- and cold-water feeding pipes prepared for JARE-7 (1965).

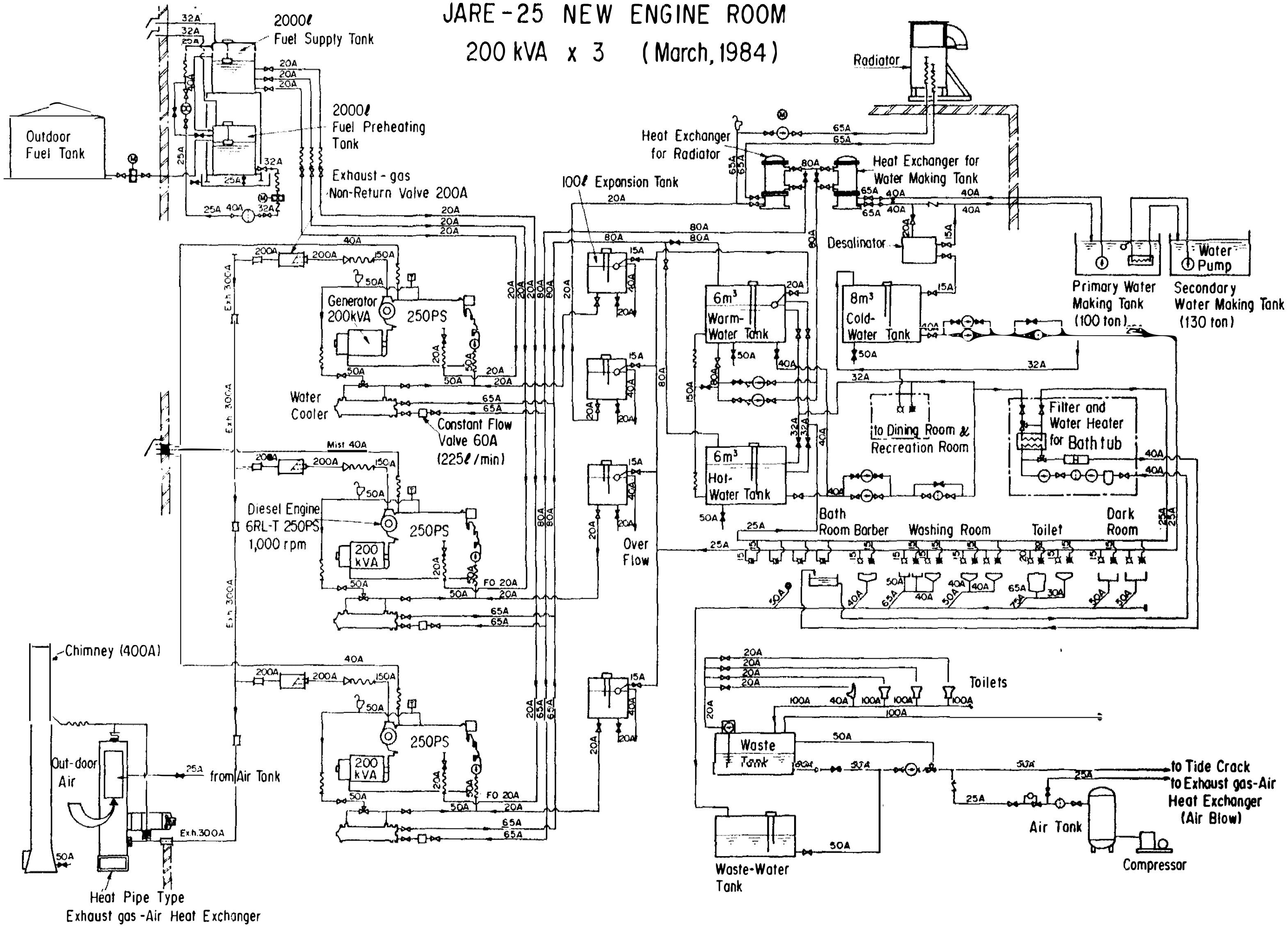


Fig. 7. Waste heat recovery system for 200-kVA diesel-electric generators in a new engine room built in 1984 (JARE-25).

(e) The water consumption at Syowa Station was as follows:

From 1957 (JARE-1) through 1961 (JARE-5)	14.5 to 21 *l*/day·person
From 1966 (JARE-7) through 1978 (JARE-20)	40 to 54 *l*/day·preson, except
1976 (JARE-17)	77 *l*/day·person.

(f) It is desired to increase the water supply up to 100 to 150 *l*/day·person. One of the methods to increase the water supply, especially in winter, is mechanical collection of snow or ice and automatic feeding into the ice-melting tank. Another method is the use of pond water or sea water throughout the year.

In 1984 (JARE-25) a desalination equipment using ion-exchange resin-films was prepared in the new engine room so that the water in the First Dam may be used till late summer. During the winter, the drifting snow is automatically collected into the outdoor 100-k*l* and 130-k*l* tanks.

Generally, a method of evaporating sea water to make pure water requires more energy than the ice- or snow-melting method.

(g) In the new engine room, a new water-making system is prepared as shown in Fig. 7. A horizontal shell- and tube-type heat exchanger is prepared for each of 200-kVA diesel-electric generators and recovers the engine coolant energy to hot water recirculating between the heat exchanger and a 6-k*l* hot-water tank set on the first floor. Another 6-k*l* warm-water tank is prepared besides the hot-water tank, in which the hot water is mixed with the cold water led from an 8-k*l* cold-water tank on the same floor through a desalinator. The warm water warms the ice- or snow-melting outdoor 100-k*l* and 130-k*l* tanks by the aid of a vertical shell- and tube-type heat exchanger and returns to the coolant heat exchanger. These two large outdoor ice-melting tanks can supply cold water at a rate of 5 t/day, which corresponds to 170 *l*/day·person in design.

Hot- and cold-water supply lines are led to a dark room, lavatories, a washing room, a barber shop and to a bathroom on the second floor.

The hot water is also used for heating a dining room and a recreation hut which are separated about 100 m from the new engine room.

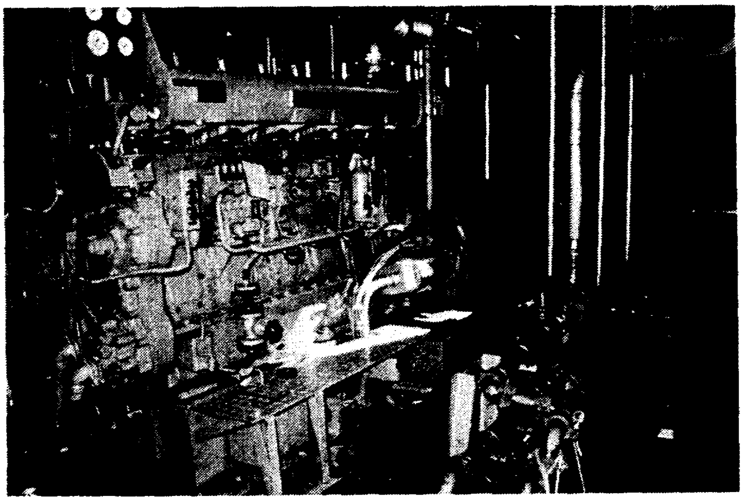


Fig. 8. Inside view of the new engine room and a 200-kVA diesel-electric generator with a shell- and tube-type horizontal heat exchanger for coolant heat recovery.

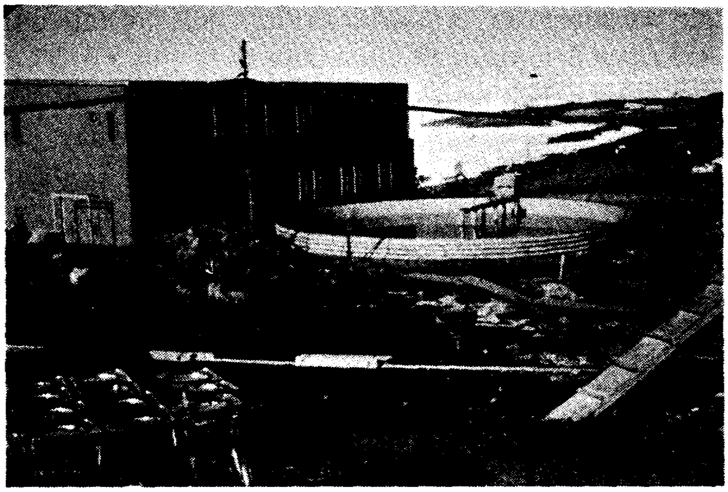


Fig. 9. Outdoor 100-kl water tank set near the new engine room.

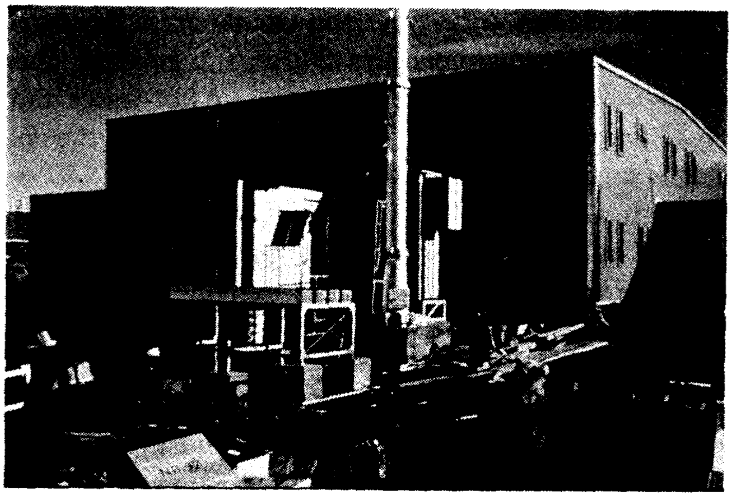


Fig. 10. A cold storage room and a heat-pipe type gas-to-air heat exchanger built on the side of the new engine room.

Table 3. Quality of water at Syowa Station in 1984.

Items		Water in 100-k*l* tank	Water of the new water supply line in new engine room	Water of the old water supply line in JARE-7 engine room
pH		6.35	6.43	6.72
Electric conductivity	(s/cm)	618	54	474
Cl	(mg/*l*)	329	18	205
Fe	(mg/*l*)	0.15	0.02	0.00
Colon bacilli			undetected	undetected
Various bacilli			undetected	undetected
Minerals	(mg/*l*)	152.2	4.2	100.5

Remarks 1) Cl ion removal ratio 95.2%.
2) Total ions removal ratio 91.2% (calculated from the decrease of electric conductivity).
3) Minerals removal ratic 97.2% by using a desalinator.

(h) A new water supply system in the new engine room replaced the old-water supply system on 10 March 1984. Actually, this new system has a capacity to feed water at a rate of about 2 876 *l*/day for 29 wintering members, which corresponds to 99.2 *l*/day·person. The water of the First Dam was first fed on 20 March 1984 to the new engine room, when the thickness of ice was 20 cm. The pond water was desalted completely. Water temperature of the 100-k*l* tank was 30°C, and that of 130-k*l* tank was 0 to +10°C. The properties of the water are shown in Table 3. Temperature of the hot-water tank was 52°C.

(i) The heat balance of the new system was measured by one of the authors, TAKEUCHI, as shown in Table 2. The measured cooling loss of a diesel engine is about 30.2% of total supplied energy, 61.5% of which is recovered and used effectively to melt ice, to make hot water and to protect the freezing of 100- and 130-k*l* tank.

4. Room Heating Systems

(a) From 1957 (JARE-1) to 1962 (JARE-5) pot-type warm air heating furnaces (heating capacity 41 860 kJ/h) were used to supply warm air to the living quarters and the laboratory. A mixture of recirculated air and fresh air was heated by the furnace and blown out through several nozzles which were opened on the wall of a closed-loop type air duct suspended from the ceiling (SPECIAL COMMITTEE ON ENGINEERING FOR JARE, 1959).

(b) After 1966 (JARE-7), a forced fuel atomizing furnace with a heating capacity of 104 650 kJ/h was placed in the vestibule of the living quarters (100 m^2) and the laboratory. It provided very comfortable air conditioning, but fuel consumption was increased, although room temperature was kept at +10 to 17°C. Fuel was also changed from light diesel oil to kerosene, about 60 k*l* of which was consumed every year (KOKURITSU KYOKUCHI KENKYÛJO, 1983).

(c) A hot-water heating system utilizing coolant energy of a diesel engine was first introduced to Syowa Station in 1967 (JARE-8) to warm a kitchen in the mess hall and this method was also applied to heat a recreation hut (40.3 m^2) near the JARE-7 engine room by the members of JARE-9. In 1968 (JARE-9), an engine control room, a living room, two dark rooms, a dispensary and a food storage room (area is 120 m^2 in total) in the JARE-9 engine room were also heated by eight fan-coil units, through which the hot water heated by the coolant of a 65 kVA diesel-electric generator was recirculated (Fig. 4). The use of these room-heating systems of the recreation hut and the rooms in the JARE-9 engine room has been continued to 1983 saving much quantity of fuel (AWANO *et al.*, 1982).

(d) Hot-water room heating at Syowa Station: 1) In the environment science laboratory built in 1974 (JARE-15), a hot-water room-heating system with a boiler was adopted, because the recirculation of air must be avoided in this laboratory; 2) For the rocket assembling and control room built in 1969 (JARE-10), a warm air heating system produced by hot water was adopted to warm rocket motor, in addition to the warming of room by ordinary oil furnace; 3) In the summer of 1978/79 and 1979/80 (JARE-20/21), a two-storied summer quarters with a floor area of 302.4 m^2 was built. In this building, a sufficient supply of hot water was necessary during the summer relief period, so the hot-water production and room-heating system with an oil-fired boiler was also adopted (KOKURITSU KYOKUCHI KENKYÛJO, 1983).

(e) Room heating at Mizuho Station: It was already described that the water at Mizuho Station was produced by the use of coolant energy of a diesel engine. A fire occurred in the engine room on 29 January 1975. After the re-opening of the Station in 1977 (JARE-18), the livnig and observation huts were heated with two fan-coil units using hot water produced by the coolant of a diesel engine. This heating system is effective to avoid fire hazard and carbon monoxide especially in a trench room.

(f) Remaining problems on room heating: 1) More saving of fuel; 2) Elimination on fire hazard; 3) Prevention of back flow of hot gas through chimneys during blizzard. Two methods have been adopted at Japanese stations; one is to install a blower in an intermediate part of chimney and the other is to use a slit type chimney; 4) Realization of district heating system.; 5) Houses near an engine room should be warmed by the waste heat of the diesel engine, while houses far from the engine room should be heated by electric power; 6) Utilization of wind energy must be realized.

5. Freezing and Cold Storage Room

(a) Freezing and cold storage rooms are necessary even in Antarctica.

(b) At Syowa Station, six storage rooms (total area 185.3 m^2) and three natural temperature storage room (total area 170 m^2) have been prepared for food storage (KOKURITSU KYOKUCHI KENKYÛJO, 1983).

(c) In 1973 (JARE-14), the air-cooled condenser employed so far in the refrigerator was replaced with a liquid-cooled condenser (TAKEUCHI *et al.*, 1974).

(d) Remaining problems on refrigerator: 1) Waste heat of the condenser should be recovered; 2) Adoption of an absorption type refrigerator, in which the waste heat of a diesel engine can be used as its driving power.

6. Sewerage System

(a) No sewerage system could be prepared for JARE-1 (1956/58) because the natural environment around the scientific station to be established was unknown. In 1966 (JARE-7), a lavatory and a sewerage tank were first prepared in the JARE-7 engine room (SATO, 1967).

(b) At present, six flush toilets similar to those in the aircraft have been prepared in three huts, the new engine room, the summer quarter and the Ionospheric Physics Laboratory. The sewage was dumped into tide cracks. Improvement of sewerage system at the Japanese station is necessary.

7. Fuel Storage

(a) At Syowa Station, the following reservoirs were prepared (KOKURITSU KYOKUCHI KENKYÛJO, 1983):

Steel tank	50 kl×2	100 kl
Steel tank	20 kl×3	60
Rubber bladders	10 kl×8	80
	25 kl×1	25
	38 kl×1	38
FRP tanks	20 kl×1	20
	56 kl×1	56
Drums	0.2 kl×145	29
	Total	408 kl

(b) The fuel supply lines from reservoir tanks to the engine rooms were completed.

(c) Total fuel consumption of Syowa and Mizuho Stations

Fuel	Average of 1968/79 (JARE-9/20)	1984 (JARE-25) (planned)
Light diesel oil	220 kl/year	330 kl/year
Kerosene	60 kl/year	60 kl/year
Gasoline	20–30 kl/year	30 kl/year
Total	300–310 kl/year	420 kl/year
Mean electric power	60 kW	90 kW

(d) The fuel consumption per a head is 8 to 11 kl/year.

(e) The consumption of light diesel oil at Mizuho Station is about 22 kl/year, and the mean electric power is 4.1 kW.

(f) The fuel saved by recovering waste heat of diesel engines is estimated as

Syowa Station	1980/84 (JARE-19/24)	about 50 kl/year
Mizuho Station	1979/84 (JARE-18/24)	about 3 kl/year.

8. Natural Energy in Antarctica

8.1. Wind energy

(a) The annual mean wind velocity at Syowa Station is 6.1 and 11 m/s at Mizuho Station. Wind energy is the most promising natural energy source in Antarctica.

(b) The wind energy will be available as a supplementary energy source of the station, for such uses as melting ice or snow and heating water of a pond. A medium type windmill is suitable for these purposes.

(c) The windmill should be able to withstand blizzards, and its rotational speed should be governed positively and accurately even under such conditions.

(d) The transportation of long blades and a high tower, the erection of the tower, and the reassembling of the blades will be difficult problems.

(e) Electrical output power of 2 to 20 kVA will be mostly available for these purposes.

(f) In JARE-1 (1956/57), a windmill with three polyester blades of 4.4 m in diameter and an 1-kW DC electric generator was prepared by Honda Giken Kogyo Co., Ltd. The windmill was tested in Japan and shipped to Antarctica as an emergency energy source, but unfortunately it was lost in the sea near Syowa Station before being tested (SPECIAL COMMITTEE ON ENGINEERING FOR JARE, 1959).

(g) The authors built a small windmill of down-wind type with a stator and an eddy-current electric brake named NU-102 in 1978 (JARE-19) and tested at Syowa Station in October 1978. It had multi-blades of 1.2 m in diameter. It could resist blizzards of 20 to 40 m/s and 2 to 4 kW output was obtained (AWANO, 1974; AWANO *et al.*, 1976, 1979).

(h) In 1982 in Japan, one of the authors AWANO succeeded to make hot water directly by using an eddy-current brake coupled to a three-blade windmill 15 m across.

(i) A two-blade windmill 3 m across was used as the electric source of the unmanned observation station by JARE-18 (1977). The output was 1.2 kW (AYUKAWA *et al.*, 1978).

(j) One kW windmill was used at Mizuho Station during 120 days in 1983 (JARE-23) as a supplementary energy source of room heating (MORITA *et al.*, 1983).

(k) Since 1977 small wind generators, 1 to 2 kW, have been used as the main electric source of unmanned observation stations in the inland. Further improvement is necessary to resist blizzards of 50 to 60 m/s.

(l) Two hydrogen gas explosions at the unmanned stations occurred by the overcharging of batteries. Perfect ventilation of the battery room is needed and some devices to avoid the overcharging should be given.

8.2. Solar energy

(a) Solar energy may be available in summer of Antarctica to make a small electric energy source by utilizing solar cells (NISHIBORI *et al.*, 1974).

(b) The solar-cell panel should withstand blizzards and should be protected from snow covering.

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