CONTENTS

1. Summary of Energy Conservation Effect

1.1 Summary of energy conservation effect at ECCJ Factory — Fuji

Utility	Apparatus	Energy conservation measure	Present		Improvement effect		Invested amount	Recovering years
			Consumption	Cost	Reduction	Cost		
			t,MWh/y	$/y	t,MWh/y	$/y	$	y
Fuel oil (price) $200/t	Boiler 10 t/h	Optimization of air ratio	3,152.1	630,420	82.0	16,391	0	0.0
		Intensification of heat insulation	3,070.1	614,029	43.9	8,774	12,216	1.6
		Air heater	3,026.3	605,255	121.1	24,210	40,000	1.9
		Economizer	2,905.2	581,045	72.6	14,526	70,000	6.9
		After improvement	2,832.6	566,519	319.5	63,901	122,216	2.2
	Boiler 5 t/h	Optimization of air ratio	2,841.8	568,368	99.5	19,893	0	0.0
		Intensification of heat insulation	2,742.4	548,475	43.8	8,754	7,147	0.9
		Air heater	2,698.6	539,721	145.7	29,145	30,000	1.1
		Economizer	2,552.9	510,576	130.2	26,039	60,000	2.7
		After improvement	2,422.7	484,537	419.2	83,831	97,147	1.3
	Industrial furnace	Optimization of air ratio	441.5	88,294	109.5	21,895	32,000	1.7
		Intensification of heat insulation (50 mm)	332.0	66,399	48.0	9,605	23,800	3.0
		Recuperator	284.0	56,794	83.9	16,775	50,000	3.7
		After improvement	200.1	40,019	241.4	48,275	105,800	2.6
	Dyeing machine	Waste water recovery	567.0	113,400	305.8	61,167	74,000	1.4
		Condasate recovery	261.0	52,200	63.0	12,600	19,200	1.7
		Heat insulation	198.0	39,600	10.7	2,138	10,890	7.5
		After improvement	187.3	37,462	316.5	63,306	84,890	1.5
	Drying machine	Humidity control (40 → 44)	594.7	118,938	33.0	6,608	2,500	0.4
		Waste heat (gas) recovery	472.9	94,580	121.8	24,360	2,500	0.1
		Condasate recovery	439.8	87,960	108.0	21,600	37,000	2.0
		After improvement	331.8	66,360	141.0	28,208	39,500	1.6
	Total of fuel oil reduction effect		6,435.4	1,287,082	1,404.6	280,914	447,053	1.8
	Consumption after improvement and reduction rate		5,030.8	1,006,169	21.8	%		

Electricity	Blower	Motor exchange (75 → 37)	257.8	51,810	104.2	20,936	55,500	3.2
(price)		Damper → Rotating speed control	153.6	30,874				
$201/MWh	Pump	Motor exchange (22 → 11)	105.3	21,158	37.7	7,569	25,431	4.3
			67.6	13,589				
	Compressor	Improvement of operation method	375.0	75,375	89.7	18,036	15,000	0.9
		Cooling of introduced air	285.3	57,339	15.1	3,039	5,000	1.9
		After improvement	270.2	54,300	104.8	21,075	20,000	1.0
	Illumination	Illumination classification	288.0	57,888	156.0	31,356	49,500	1.8
			132.0	26,532				
	Transformer	Adjusting the number of operating transformers	623.4	125,295	3.2	645	0	0.0
		Improvement of power factor (installation of capacitor)	620.2	124,650		19,112	5,000	0.3
		After improvement	620.2	124,650	3.2	19,757	5,000	0.3
	Total of electricity reduction effect		1,026.0	206,231	405.9	100,692	155,431	1.8
	Consumption after improvement and reduction rate		620.2	105,538	39.6	48.8	%	
Common	Energy management system		-	-	-	-	80,280	-
	(when the installation of measuring instruments is not necessary)		-	-	-	-	180,780	-
Total of equipment energy cost reduction effect			(Before improvement)	1,493,313	-	420,910	704,184	1.9
Cost after improvement and reduction rate			(After improvement)	1,072,403	-	28.2	%	
Investment including energy management system			(Before improvement)	1,493,313	-	420,910	784,464	2.2
(including measuring instruments cost)			(After improvement)	1,072,403	-	420,910	884,964	2.5

1.2 Summary of energy conservation effect at ECCJ Factory — Sakura

Utility	Apparatus	Energy conservation measure	Present		Improvement effect		Invested amount	Recovering years year		
			Consumptio t,MWh/y	Cost $/y	Reduction t,MWh/y	Cost $/y	$	Interest rate % 10	Interest rate % 5	Interest rate % 3
Fuel oil (price) $100/t	Boiler 10 t/h	Optimization of air ratio	3,152.1	315,210	82.0	8,195	0	0.0	0.0	0.0
		Intensification of heat insulation	3,070.1	307,015	43.9	4,387	12,216	3.4	3.1	3.0
		Air heater	3,026.3	302,628	121.1	12,105	40,000	4.2	3.7	3.5
		Economizer	2,905.2	290,522	72.6	7,263	70,000	34.8	13.5	11.5
		After improvement	2,832.6	283,259	319.5	31,951	122,216	5.1	4.4	4.1
	Boiler 5 t/h	Optimization of air ratio	2,841.8	284,184	99.5	9,947	0	0.0	0.0	0.0
		Intensification of heat insulation	2,742.4	274,238	43.8	4,377	7,147	1.9	1.7	1.7
		Air heater	2,698.6	269,861	145.7	14,572	30,000	2.4	2.2	2.2
		Economizer	2,552.9	255,288	130.2	13,020	60,000	6.5	5.4	5.0
		After improvement	2,422.7	242,268	419.2	41,916	97,147	2.8	2.5	2.4
	Industrial furnace	Optimization of air ratio	441.5	44,147	109.5	10,948	32,000	3.6	3.2	3.1
		Intensification of heat insulation (50 mm)	332.0	33,200	48.0	4,803	23,800	7.2	5.8	5.4
		Recuperator	284.0	28,397	83.9	8,387	50,000	9.5	7.3	6.7
		After improvement	200.1	20,010	241.4	24,138	105,800	6.1	5.1	4.8
	Dyeing machine	Waste water recovery	567.0	56,700	305.8	30,584	74,000	2.9	2.6	2.5
		Condasate recovery	261.2	26,116	63.0	6,300	10,890	Not recov-erable	1.9	1.8
		Heat insulation	189.4	18,940	10.7	1,070	19,200	#NUM!	46.6	26.1
		After improvement	325.6	32,563	241.4	24,138	104,090	5.9	5.0	4.7
	Drying machine	Humidity control (40 → 44)	594.7	59,469	33.0	3,304	2,500	0.8	0.8	0.8
		Waste heat (gas) recovery	561.7	56,165	121.8	12,180	2,500	0.2	0.2	0.2
		Condasate recovery	439.8	43,980	108.0	10,800	37,000	4.4	3.9	3.7
		After improvement	353.3	35,332	241.4	24,138	42,000	2.0	1.9	1.8
	Total of fuel oil reduction effect		6,435.4	643,541	1,098.7	109,874	381,363	4.5	3.9	3.7
	Consumption after improvement and reduction rate		5,336.7	533,667	17.1	%				

Electricity (price) $95/MWh	Blower	Motor exchange (75 → 37)	257.8	24,487	104.2	9,895	55,500	8.6	6.7	6.2
		Damper → Rotating speed control	153.6	14,592						
	Pump	Motor exchange (22 → 11)	105.3	10,000	37.7	3,577	25,431	13.0	9.0	8.1
			67.6	6,423						
	Compressor	Improvement of operation method	375.0	35,625	89.7	8,524	15,000	2.0	1.9	1.8
		Cooling of introduced air	285.3	27,101	15.1	1,436	5,000	4.5	3.9	3.7
		After improvement	270.2	25,664	104.8	9,961	20,000	2.4	2.2	2.1
	Illumination	Illumination classification	288.0	27,360	156.0	14,820	49,500	4.3	3.7	3.6
			132.0	12,540						
	Transformer	Adjusting the number of operating transformers	623.4	59,219	3.2	305	0	0.0	0.0	0.0
		Improvement of power factor (installation of capacitor)	620.2	58,914		9,556	5,000	0.6	0.5	0.5
		After improvement	620.2	58,914	3.2	9,861	5,000	0.5	0.5	0.5
	Total of electricity reduction effect		1,026.0	97,472	405.9	48,114	155,431	4.1	3.6	3.4
	Consumption after improvement and reduction rate		620.2	49,358	39.6	49.4	%			
Common	Energy management system		-	-	-	-	80,280	-	-	-
	(when the installation of measuring instruments is not necessary)		-	-	-	-	180,780	-	-	-
Total of equipment energy cost reduction effect			(Before improvement)	741,013	-	208,223	704,184	4.3	3.8	3.6
Cost after improvement and reduction rate			(After improvement)	532,791	-	28.1	%			
Investment including energy management system			(Before improvement)	741,013	-	208,223	784,464	5.0	4.3	4.1
(including measuring instruments cost)			(After improvement)	532,791	-	208,223	884,964	5.8	4.9	4.6

2. Organization and Investment for Energy Conservation

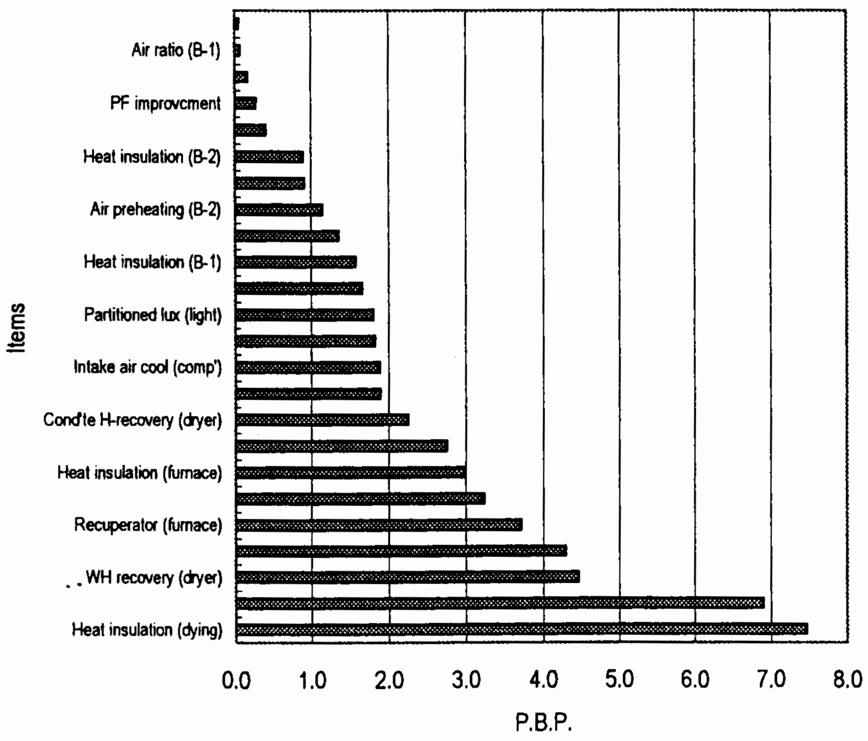
2.1 Energy conservation investment plan (Case for high energy cost: Fuji)

(Arranged in P.B.P. order)

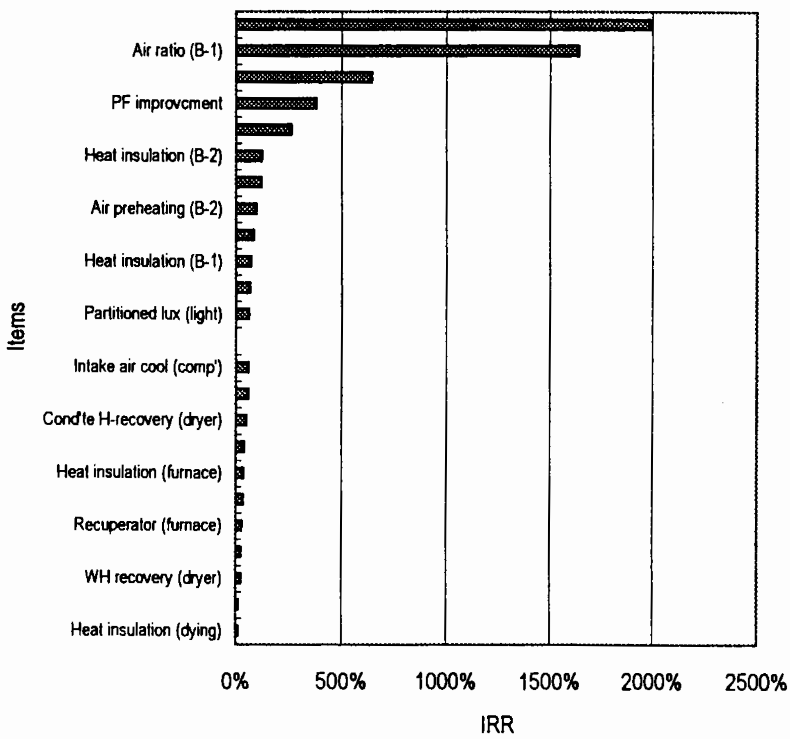
Item	Enecost saving	Investment	P.B.P	IRR
Air ratio (B-2)	19,893	1,000	0.053	1989%
Air ratio (B-1)	16,391	1,000	0.064	1639%
Unit reduction (Tr)	645	100	0.164	645%
PF improvcment	19,112	5,000	0.278	382%
Humidity control (dryer)	6,608	2,500	0.405	264%
Heat insulation (B-2)	8,754	7,147	0.894	122%
Operation improve (comp')	18,036	15,000	0.911	120%
Air preheating (B-2)	29,145	30,000	1.140	97%
HWH-recovery (dying)	61,167	74,000	1.353	82%
Heat insulation (B-1)	8,774	12,216	1.573	71%
Air ratio (furnace)	21,895	32,000	1.658	67%
Partitioned lux (light)	31,356	49,500	1.803	62%
Cond'te H-recovery (dying)	12,019	19,200	1.826	0%
Intake air cool (comp')	3,039	5,000	1.886	59%
Air preheating (B-1)	24,210	40,000	1.895	59%
Cond'te H-recovery (dryer)	19,187	37,000	2.248	50%
Economizer (B-2)	26,039	60,000	2.748	41%
Heat insulation (furnace)	9,605	23,800	2.987	37%
Moter replace (blowers)	20,936	55,500	3.232	34%
Recuperator (furnace)	16,775	50,000	3.713	29%
Motor replace (pumps)	7,569	25,431	4.296	25%
WH recovery (dryer)	23,091	80,000	4.463	24%
Economizer (B-1)	14,526	70,000	6.899	13%
Heat insulation (dying)	2138.4	10,890	7.469	11%

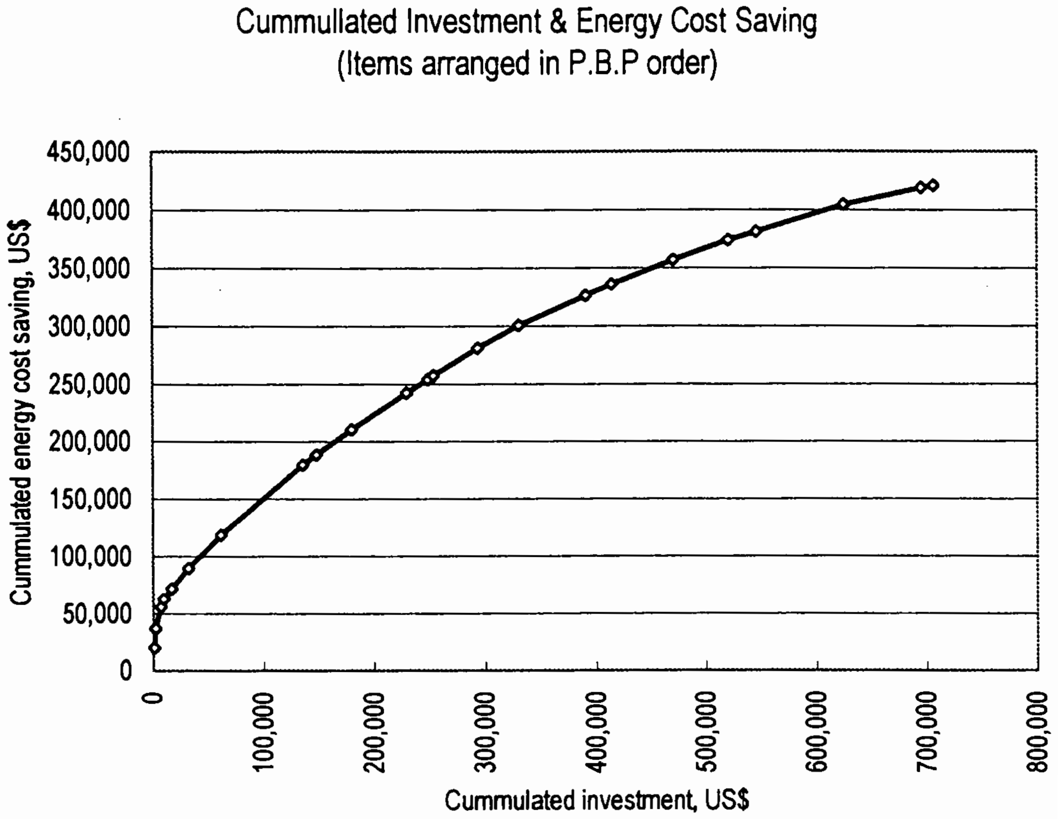
* Although the adjustment of the boiler air ratio and the control of the number of transformers in operation are not included in the investment items, investment values are shown above for purposes of software (Microsoft Excel) operations.

P.B.P. of Improvements



IRR of Improvements




Cummullated Investment & Energy Cost Saving
(Items arranged in P.B.P order)
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400,000
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300,000
250,000
200,000
150,000
100,000
50,000
0
Cummulated energy cost saving, US$
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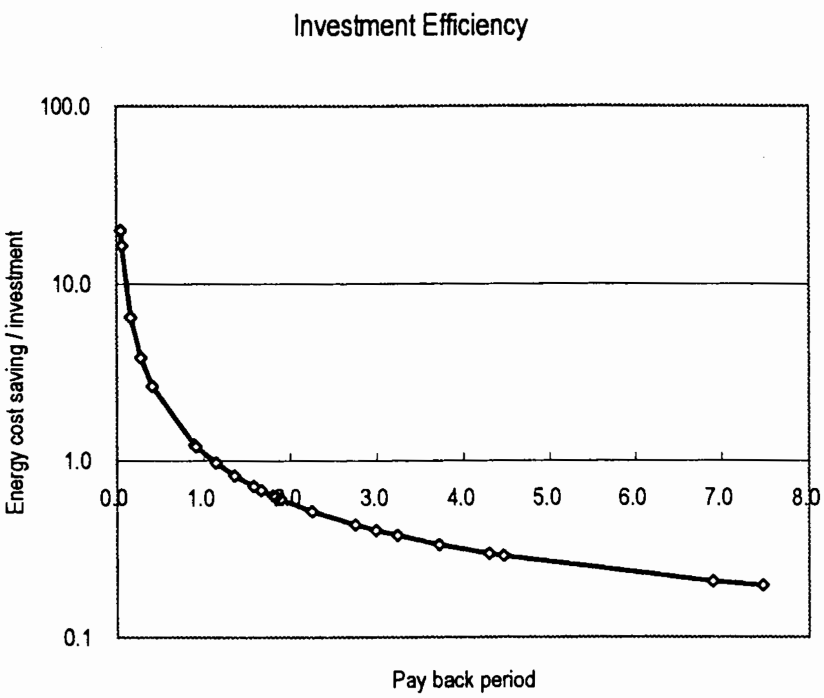
700,000
800,000
Cummulated investment, US$


Investment Efficiency
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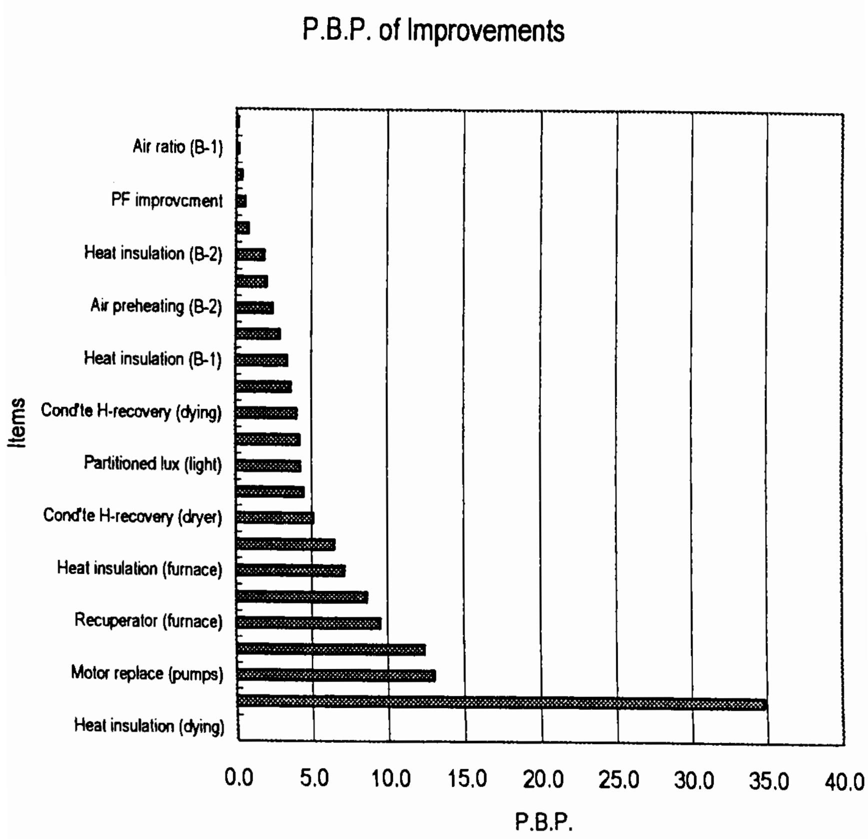
10.0
1.0
0.1
Energy cost saving / investment
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
Pay back period

2.2 Energy conservation investment plan (Case for low energy cost: Sakura)

(Arranged in P.B.P. order)

Item	Enecost saving	Investment	P.B.P	IRR
Air ratio (B-2)	9,947	1,000	0.106	995%
Air ratio (B-1)	8,195	1,000	0.129	820%
Unit reduction (Tr)	305	100	0.350	305%
PF improvcment	9,033	5,000	0.597	181%
Humidity control (dryer)	3,304	2,500	0.826	132%
Heat insulation (B-2)	4,377	7,147	1.870	60%
Operation improve (comp')	8,524	15,000	2.031	55%
Air preheating (B-2)	14,572	30,000	2.418	46%
HWH-recovery (dying)	30,584	74,000	2.906	38%
Heat insulation (B-1)	4,387	12,216	3.424	32%
Air ratio (furnace)	10,948	32,000	3.628	30%
Cond'te H-recovery (dying)	6,009	19,200	4.039	0%
Air preheating (B-1)	12,105	40,000	4.209	25%
Partitioned lux (light)	14,820	49,500	4.265	25%
Intake air cool (comp')	1,436	5,000	4.489	23%
Cond'te H-recovery (dryer)	9,594	37,000	5.112	20%
Economizer (B-2)	13,020	60,000	6.481	14%
Heat insulation (furnace)	4,803	23,800	7.180	12%
Moter replace (blowers)	9,895	55,500	8.635	9%
Recuperator (furnace)	8,387	50,000	9.513	7%
WH recovery (dryer)	11,545	80,000	12.388	3%
Motor replace (pumps)	3,577	25,431	13.020	3%
Economizer (B-1)	7,263	70,000	34.809	-4%

* Although the adjustment of the boiler air ratio and the control of the number of transformers in operation are not included in the investment items, investment values are shown above for purposes of software (Microsoft Excel) operations.


P.B.P. of Improvements
Air ratio (B-1)
PF improvcment
Heat insulation (B-2)
Air preheating (B-2)
Heat insulation (B-1)
Cond'te H-recovery (dying)
Partitioned lux (light)
Cond'te H-recovery (dryer)
Heat insulation (furnace)
Recuperator (furnace)
Motor replace (pumps)
Heat insulation (dying)
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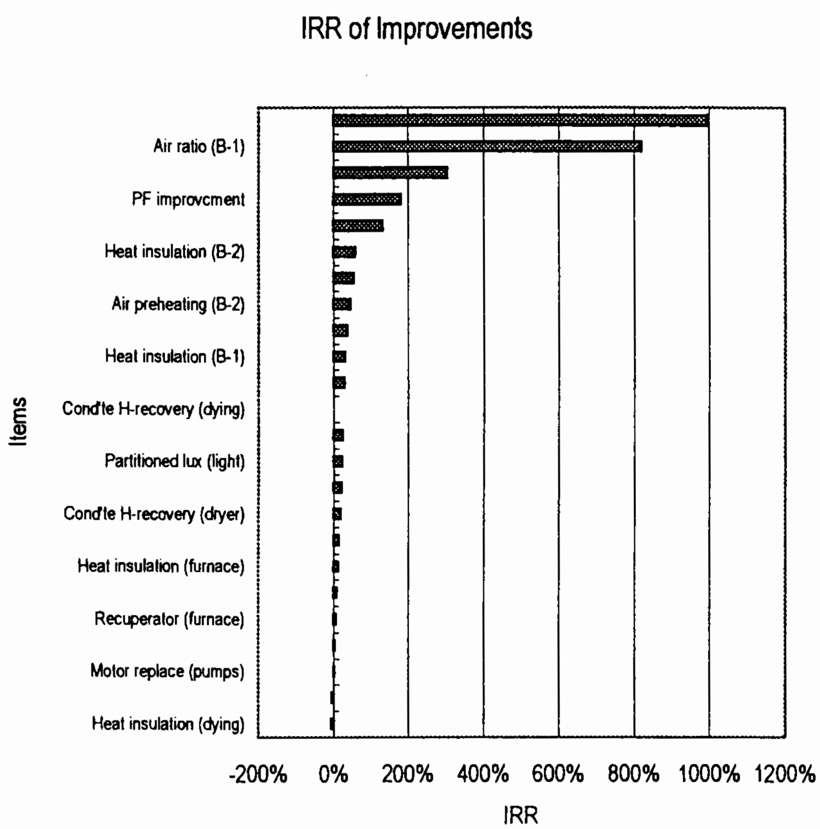
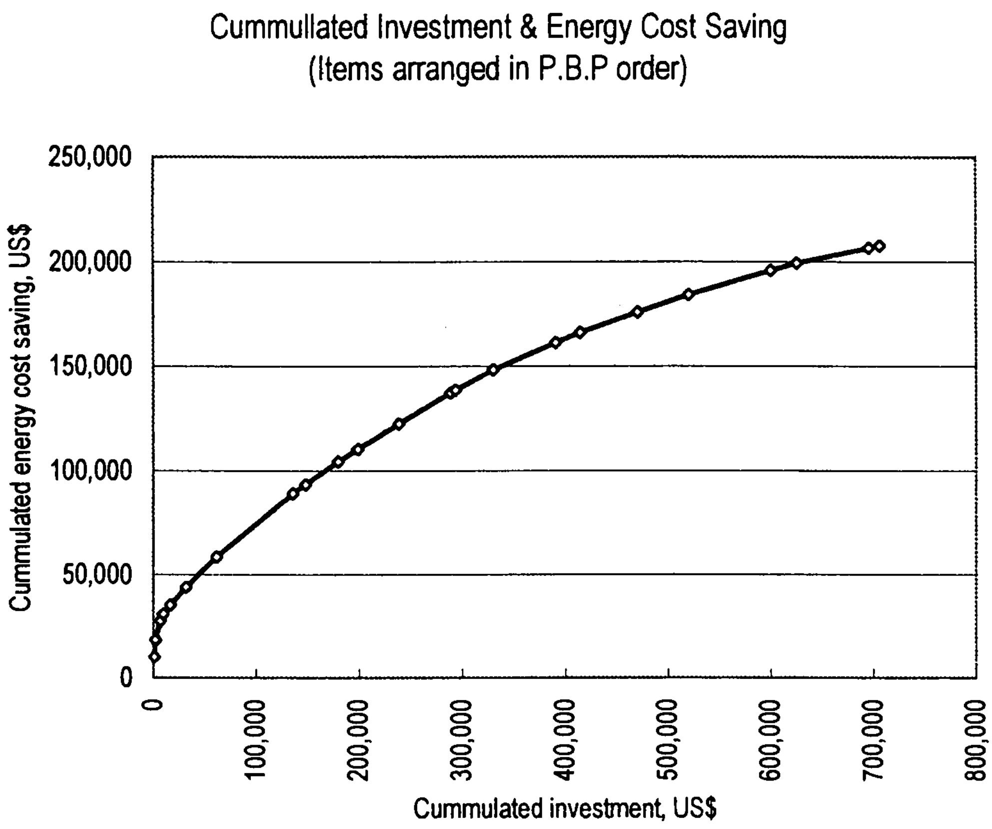
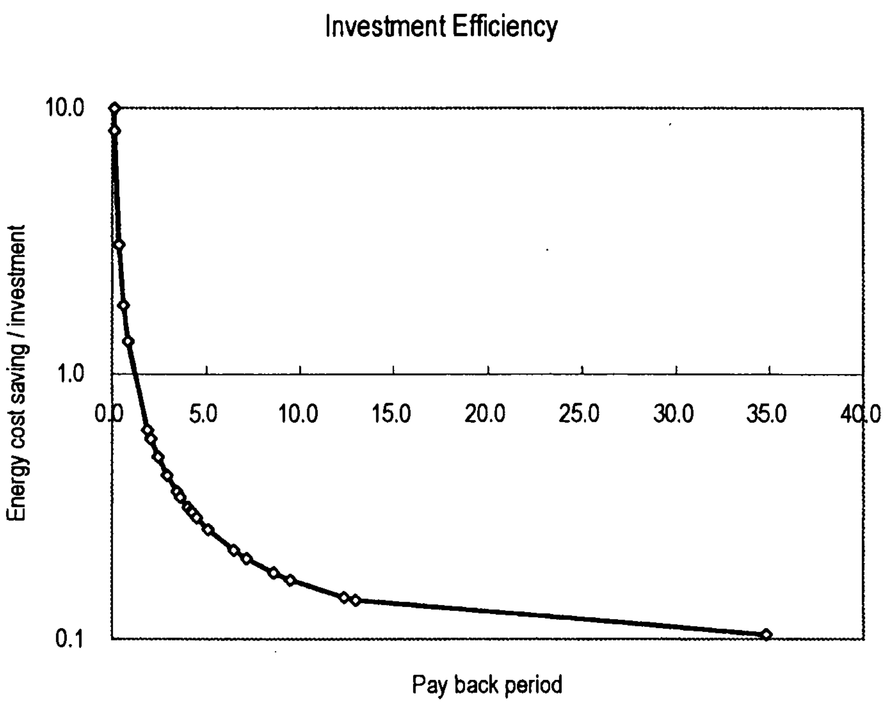
20.0
25.0
30.0
35.0
40.0
P.B.P.


IRR of Improvements
Air ratio (B-1)
PF improvcment
Heat insulation (B-2)
Air preheating (B-2)
Heat insulation (B-1)
Cond'te H-recovery (dying)
Partitioned lux (light)
Cond'te H-recovery (dryer)
Heat insulation (furnace)
Recuperator (furnace)
Motor replace (pumps)
Heat insulation (dying)
Items
-200%
0%
200%
400%
600%
800%
1000%
1200%
IRR


Cummullated Investment & Energy Cost Saving
(Items arranged in P.B.P order)
250,000
200,000
150,000
100,000
50,000
0
Cummulated energy cost saving, US$
0
100,000
200,000
300,000
400,000
500,000
600,000
700,000
800,000
Cummulated investment, US$


Investment Efficiency
10.0
1.0
0.1
Energy cost saving / investment
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
Pay back period

2.3 Establishment of energy conservation promotion organizations

1. Factory energy conservation committee
   Held monthly, the committee is chaired by the director of the factory and made up of departmental representatives, appointed on a one department one member basis.
   The secretariat is headed by a section chief at the Technology Department, and includes a member of the Energy Department.
2. Formation of small action groups in manufacturing division
   Employees are encouraged to form small workplace groups consisting of five to six members according to their specialties and voluntarily engage in energy conservation activities.

3. No.1 Boiler

3.1 Summary

(1) Present problems

Apparatus		Problem		Improving measure
Boiler, 10 t/h	1	The O_2 concentration of exhaust gas is as high as 8%, and the exhaust gas volume is large.	1	Optimize the air ratio.
	2	The heat insulator is as thin as 50 mm, and the body radiation heat loss is large.	2	Intensify the heat insulation.
	3	Exhaust gas temperature is as high as 270°C, and the exhaust gas heat is not recovered.	3 4	Introduce an air heater. Introduce an economizer.

(2) Effect of energy conservation

No.	Improvement item	Production and energy consumption (Calorific value) 42,119 KJ/kg				Energy cost				Energy cost reduction rate	Invested amount	Recovering years
		Unit	Before improvement	After improvement	Effect	Unit price	Before improvement	After improvement	Effect			
						$/t-fuel	$/y	$/y	$/y	%	$	year
Production		t/y	44,520									
1	Optimization of air ratio	t/y	3,152.1	3,070.1	82.0	200	630,420	614,029	16,391	2.6	0	0.0
		MJ/t	2,982.3	2,904.4	77.9	100	315,210	307,015	8,195	2.6		0.0
2	Intensification of heat insulation	t/y	3,070.1	3,026.3	43.9	200	614,029	605,255	8,774	1.4	12,216	1.6
		MJ/t	2,904.4	2,862.9	41.5	100	307,015	302,628	4,387	1.4		3.4
3	Installation of air heater	t/y	3,026.3	2,905.2	121.1	200	605,255	581,045	24,210	4.0	40,000	1.9
		MJ/t	2,862.9	2,748.6	114.3	100	302,628	290,522	12,105	4.0		4.2
4	Installation of economizer	t/y	2,905.2	2,832.6	72.6	200	581,045	566,519	14,526	2.5	70,000	6.9
		MJ/t	2,748.6	2,680.0	68.6	100	290,522	283,259	7,263	2.5		34.8
	Total	t/y	3,152.1	2,832.6	319.5	200	630,420	566,519	63,901	10.1	122,216	2.2
		MJ/t	2,982.3	2,680.0	302.3	100	315,210	283,259	31,951	10.1		5.1

3.2 Method of energy conservation

(1) Decreasing the O_2 concentration of exhaust gas

Present O_2 concentration of exhaust gas: 8%

Heat loss by exhaust gas: $L_l = G \cdot c_g (t_g - t_o)$ KJ/kg (fuel) ....(1)

- G: Quantity of exhaust gas (Nm^3/kg)
- c_g: Mean specific heat of exhaust gas 1.381 KJ/Nm^3·°C
- t_g: Exhaust gas temperature (°C)
- t_o: Atmospheric temperature (°C)

Here; $G = G_o + G_w + (m - 1) A_o$ ....(2)

- G_o: Theoretical quantity of dry exhaust gas (Nm^3/kg)
- G_w: Quantity of vapor generated by combustion, and quantity of vapor by evaporation of moisture in fuel (Nm^3/kg)
- m : Air ratio
- A_o: Theoretical quantity of combustion air (Nm^3/kg)

$A_o = 11.09$ ....(3)

$G_o + G_w = 11.82$ ....(4)

$m = \frac{21}{21 - O_2(\%)} = \frac{21}{21 - 8} = 1.62$ ....(5)

Therefore,

$$G = 11.82 + (1.62 - 1) \times 11.09 = 18.70 \quad (Nm^3/kg)$$

Heat loss by exhaust gas: $L_l = 18.70 \times 1.382 \times (270 - 33) = 6125$ (KJ/kg)

The rate of heat loss by exhaust gas to fuel input heat is

$$R_l = \frac{6125}{42119} \times 100 = 14.5\%$$

(Improvement method)

Improve combustion to decrease the O_2 concentration of exhaust gas to 5%

$$m = \frac{21}{21 - 5} = 1.31$$

$$G = 11.82 + (1.31 - 1) \times 11.09 = 15.26 \quad (Nm^3/kg)$$

$$L_l = 15.26 \times 1.382 \times (270 - 33) = 4995 \quad (KJ/kg)$$

$$R_l = \frac{4995}{42119} \times 100 = 11.9\%$$

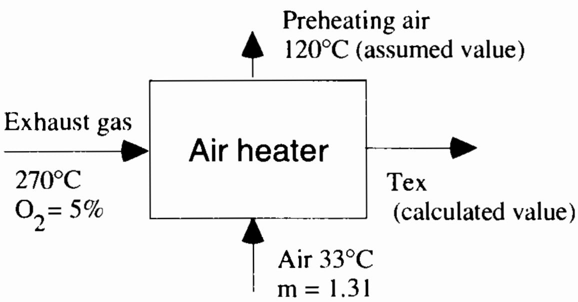
By decreasing the O_2 concentration of exhaust gas from 8% to 5%,

$$14.5 - 11.9 = 2.6\%$$

It is possible to raise the boiler efficiency by approx. 2.6%.

(2) Installing the air heater

Normally the improvement of boiler efficiency by heat collection of an air heater is 3%–6%. Suppose the following data are obtaind by installing an air heater;



$$15.26 \times 1.382 \times (270 - Tex)$$
$$= 11.09 \times 1.31 \times 1.3 \times (120 - 33)$$

$$Tex = 190°C$$

The heating value of heat reovered by air heater is

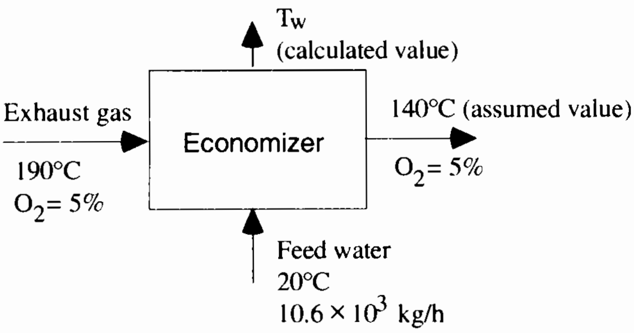
$$11.09 \times 1.31 \times 1.3 \times (120 - 33) = 1694 \text{ KJ/kg (fuel)}$$

The energy conservation efficiency by air heater is

$$\frac{1694}{42119} \times 100 = 4.0\%$$

(3) Installing the economizer

Normally the rise of boiler efficiency by heat collection of an economizer is 3%–5% more or less. Suppose the following data are obtaind by installing an economizer;



$$10.6 \times 10^3 \times 4.187 \times (T_w - 20)$$
$$= 15.26 \times 750.5 \times (1 - 0.026)$$
$$\times (1 - 0.040) \times 1.382 \times (190 - 140)$$

$$T_w = 36.7°C$$

(Exhaust gas after passing the economizer is assumed to be 140°C as the temperature without generating condensed water.)

The heating value of heat collected by economizer is

$$10.6\times 10^3 \times 4.187 \times (36.7 - 20) = 741.1 \times 10^3 \text{ KJ/h}$$

The energy conservation efficiency by economizer is

$$\frac{741.1 \times 10^3}{750.5 \times (1 - 0.026) \times (1 - 0.040) \times 42119} \times 100 = 2.5\%$$

From (1), (2) and (3), the boiler efficiency of a case all the above-mentioned energy conservation measures are applied is

Efficiency of boiler itself	80.0%
Improvement of combustion	2.6
Air heater	4.0
Economizer	2.5
Efficiency of energy conservation boiler	89.1%

(4) Others

a: Raise the feed water temperature by collecting heat from blow water
Increase of efficiency by approx. 1.5%

b: As the boiler surface temperature 150°C is too high, reduce heat loss from the surface by applying insulator.

c: For fuel, eliminate soot blow by changing it to another with better quality such as gas.

d: The blow ratio 10% is for a once-through boiler and is too high, so drop it to 5% or so, if possible. (dependent on the quality of feed water)

3.3 Recovery of initial cost

• Air heater

Fuel saving by heat recovery of the air heater is,
supposing A heavy oil is $0.2/kg,

$$750.5 \times (1 - 0.026) \times 4200 \times 0.040 \times 0.2 = \$24{,}561/\text{year}$$

Supposing the air heater costs $400,000.
Payback period at 10% interest

$$\frac{\log\left(\frac{P}{P - Ii}\right)}{\log(1 + i)} = \frac{\log\left(\frac{24{,}561}{24{,}561 - 40{,}000 \times 0.1}\right)}{\log(1 + 0.1)} = 1.9$$

P: "Profit" (energy savings)

I: Investment

i: Interest rate (10%)

The initial cost can be recovered in 1.9 years.

• Economizer

Fuel saving by heat recovery of the economizer is

$$750.5 \times (1 - 0.026) \times (1 - 0.040) \times 4200 \times 0.025 \times 0.2 = \$14,737/\text{year}$$

Supposing the economizer costs $70,000.

$$\frac{\log\left(\dfrac{14,737}{14,737 - 70,000 \times 0.1}\right)}{\log(1 + 0.1)} = 6.8$$

The initial cost can be recovered in 6.8 years.

	Energy conservation efficiency (%)	Initial cost ($)	Fuel saving ($/year)	Period for initial cost recovery (year)
Improvement of combustion	2.6	0	16,391/year	0.0
Air heater	4.0	40,000	24,561/year	1.9
Economizer	2.5	70,000	14,737/year	6.8

Effect of improved heat insulation is not included in the above table.

4. No.2 Boiler

4.1 Summary

(1) Present problems

Apparatus		Problem		Improving measure
Boiler, 5 t/h	1	The O_2 concentration of exhaust gas is as high as 8%, and the exhaust gas volume is large.	1	Optimize the air ratio.
	2	The heat insulator is as thin as 50 mm, and the body radiation heat loss is large .	2	Intensify the heat insulation.
	3	The exhaust gas temperature is as high as 350°C, and the exhaust gas heat is not recovered.	3	Introduce an air heater.
			4	Introduce an economizer.

(2) Effect of energy conservation

No.	Improvement item	Production and energy consumption (Calorific value) 10,060 kcal/kg				Energy cost				Energy cost reduction rate	Invested amount	Recovering years
						Unit price	Before improvement	After improvement	Effect			
		Unit	Before improvement	After improvement	Effect	$/t·fuel	$/y	$/y	$/y	%	$	year
Production		t/y	37,440									
1	Optimization of air ratio	t/y	2,841.8	2,742.4	99.5	200	568,368	548,475	19,893	3.5	0	0.0
		MJ/t	3,197.0	3,085.3	111.7	100	284,184	274,238	9,947	3.5		0.0
2	Intensification of heat insulation	t/y	2,742.4	2,698.6	43.8	200	548,475	539,721	8,754	1.6	7,147	0.9
		MJ/t	3,085.3	3,035.8	49.5	100	274,238	269,861	4,377	1.6		1.9
3	Installation of air heater	t/y	2,698.6	2,552.9	145.7	200	539,721	510,576	29,145	5.4	30,000	1.1
		MJ/t	3,035.8	2,872.1	163.7	100	269,861	255,288	14,572	5.4		2.4
4	Installation of economizer	t/y	2,552.9	2,422.7	130.2	200	510,576	484,537	26,039	5.1	60,000	2.7
		MJ/t	2,872.1	2,725.6	146.5	100	255,288	242,268	13,020	5.1		6.5
	Total	t/y	2,841.8	2,422.7	419.2	200	568,368	484,537	83,831	14.7	97,147	1.3
		MJ/t	3,197.0	2,725.6	471.4	100	284,184	242,268	41,916	14.7		2.8

4.2 Method of energy conservation

(1) Decreasing the O_2 concentration of exhaust gas

Present O_2 concentration of exhaust gas: 8%

Heat loss by exhaust gas: $L_l = G \cdot c_g\ (t_g - t_o)$ KJ/kg (fuel) .... (1)

- G: Quantity of exhaust gas (Nm^3/kg)
- c_g: Mean specific heat of exhaust gas 1.382 $KJ/Nm^3 \cdot °C$
- t_g: Exhaust gas temperature (°C)
- t_o: Atmospheric temperature (°C)

Here; $G = G_o + G_w + (m - 1)\ A_o$ .... (2)

- G_o: Theoretical quantity of dry exhaust gas (Nm^3/kg)
- G_w: Quantity of vapor generated by combustion, and quantity of vapor by evaporation of moisture in fuel (Nm^3/kg)
- m : Air ratio
- A_o: Theoretical quantity of combustion air (Nm^3/kg)

$A_o = 11.09$ .... (3)

$G_o + G_w = 11.82$ .... (4)

$m = \frac{21}{21 - O_2(\%)} = \frac{21}{21 - 8} = 1.62$ .... (5)

Therefore,

$$G = 11.82 + (1.62 - 1) \times 11.09 = 18.70 \quad (Nm^3/kg)$$

Heat loss by exhaust gas: $L_l = 18.70 \times 1.382 \times (350 - 33) = 8189$ (KJ/kg)

The rate of heat loss by exhaust gas to fuel input heat is

$$R_l = \frac{8189}{42119} \times 100 = 19.4\%$$

(Improvement method)

Improve combustion to decrease the O_2 concentration of exhaust gas to 5%

$$m = \frac{21}{21 - 5} = 1.31$$

$$G = 11.82 + (1.31 - 1) \times 11.09 = 15.26 \quad (Nm^3/kg)$$

$$L_l = 15.26 \times 1.382 \times (350 - 33) = 6682 \quad (KJ/kg)$$

$$R_l = \frac{6682}{42119} \times 100 = 15.9\%$$

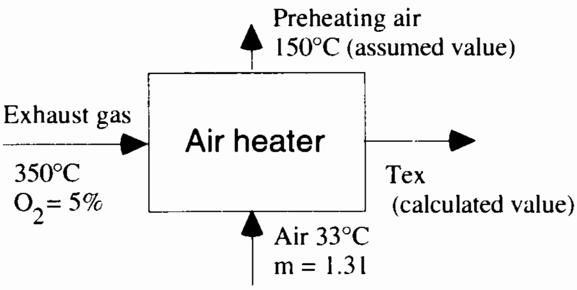
By decreasing the O_2 concentration of exhaust gas from 8% to 5%,

$$19.4 - 15.9 = 3.5\%$$

It is possible to raise the boiler efficiency by approx. 3.5%.

(2) Installing the air heater

Normally the rise of boiler efficiency by heat collection of an air heater is 3%–6%. Suppose the following data are obtaind by installing an air heater;



$$15.26 \times 1.382 \times (350 - Tex)$$
$$= 11.09 \times 1.31 \times 1.3 \times (150 - 33)$$

$$Tex = 242°C$$

The heating value of heat collected by air heater is

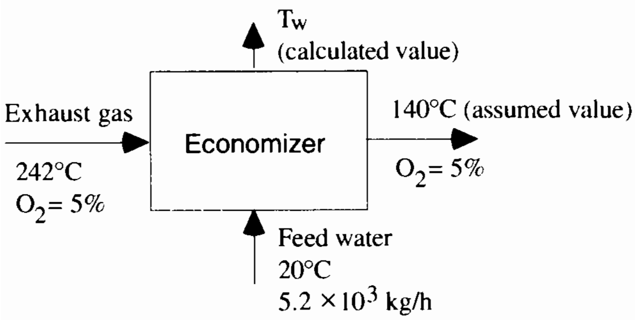
$$11.09 \times 1.31 \times 1.3 \times (150 - 33) = 2277 \text{ KJ/kg(fuel)}$$

The energy conservation efficiency by air heater is

$$\frac{2277}{42119} \times 100 = 5.4\%$$

(3) Installing the economizer

Normally the rise of boiler efficiency by heat collection of an economizer is 3%–5% more or less. Suppose the following data are obtaind by installing an economizer ;



$$5.2 \times 10^3 \times 4.187 \times (T_w - 20)$$
$$= 15.26 \times 394.7 \times (1 - 0.035)$$
$$\times (1 - 0.054) \times 1.382 \times (242 - 140)$$

$$T_w = 55.6°C$$

(Exhaust gas after passing the economizer is assumed to be 140°C as the temperature without generating condensed water.)

The heating value of heat collected by economizer is

$$5.2 \times 10^3 \times 1.0 \times (55.6 - 20) = 775.0 \times 10^3 \text{ KJ/h}$$

The energy conservation efficiency by economizer is

$$\frac{775.0 \times 10^3}{394.7 \times (1 - 0.035) \times (1 - 0.054) \times 42119} \times 100 = 5.1\%$$

From (1), (2) and (3), the boiler efficiency of a case all the above-mentioned energy conservation measures are applied is

Efficiency of boiler itself	74.5%
Improvement of combustion	3.5
Air heater	5.4
Economizer	5.1
Efficiency of energy conservation boiler	88.5%

(4) Others

a: Raise the feed water temperature by collecting heat from blow water

Increase of efficiency by approx. 1.5%

b: As the boiler surface temperature 150°C is too high, reduce heat loss from the surface by applying insulator.

c: For fuel, eliminate soot blow by changing it to another with better quality such as gas.

d: The blow ratio 10% is for a once-through boiler and is too high, so drop it to 5% or so, if possible. (dependent on the quality of feed water)

4.3 Recovery of initial cost

• Air heater

Fuel saving by heat recovery of the air heater is,

supposing A heavy oil is $0.1/kg,

$$394.7 \times (1 - 0.035) \times 7200 \times 0.054 \times 0.1 = \$14{,}809/\text{year}$$

Supposing the air heater costs $30,000

$$\frac{\log\left(\dfrac{14{,}809}{14{,}809 - 30{,}000 \times 0.1}\right)}{\log(1 + 0.1)} = 2.4$$

The initial cost can be recovered in 2.4 year.

• Economizer

Fuel saving by heat recovery of the economizer is

$$394.7 \times (1 - 0.035) \times (1 - 0.054) \times 7200 \times 0.051 \times 0.1 = \$13,230/\text{year}$$

Supposing the economizer costs $60,000

$$\frac{\log\left(\dfrac{13,230}{13,230 - 60,000 \times 0.1}\right)}{\log(1 + 0.1)} = 6.3$$

The initial cost can be recovered in 6.3 year.

	Energy conservation efficiency (%)	Initial cost ($)	Fuel saving ($/year)	Period for initial cost recovery (year)
Improvement of combustion	3.5	0	9,947/year	0.0
Air heater	5.4	30,000	14,809/year	2.4
Economizer	5.1	60,000	13,230/year	6.3

Effect of improved heat insulation is not included in the above table.

5. Dyeing Machine

5-1 Steam consumption

(at dyeing water temperature of 20°C and ambient air temperature of 33°C)

(1) Steam conditions

Steam pressure	P	=0.7Mpa		
Enthalpy of dry saturated steam	h''	=2.762.1	kj/kg	
Enthalpy of saturated water	h'	=716.0	kj/kg	
Dryness fraction	X	=0.98		
Enthalpy of wet saturated steam	h	=2.721.1	kj/kg	h=h'+X(h''-h')
Latent heat	r	=2.005.1	kj/kg	

(2) Required heat (per dyeing machine per operation cycle)

- Heat for heating tanks:
  - dyeing 1.560 kg× (95-20) ×0.460 kj/kg·K=53.875 kj
- Heat for heating products
  - dyeing 85 kg× (95-20) ×1.80 kj/kg·K=11.474 kj
- Heat for heating liquids
  - dyeing 1.300×(95-20)×4.186kj/kg·K=408.135 kj
- Heat dissipation ql (cylindrical surface area 9.33m^2 vertical surface area 2.74m^2)

Heating up to dyeing temp. (cylindrical) dissipation at (90+33)°C/2=61.5°C: 808kj/m^{2}h
808 × 9.33×60/60 = 7.538kj
(vertical) dissipation at (90+33)°C/2=61.5°C: 875kj/m^{2}h
875×2.74×60/60 = 2.397kj

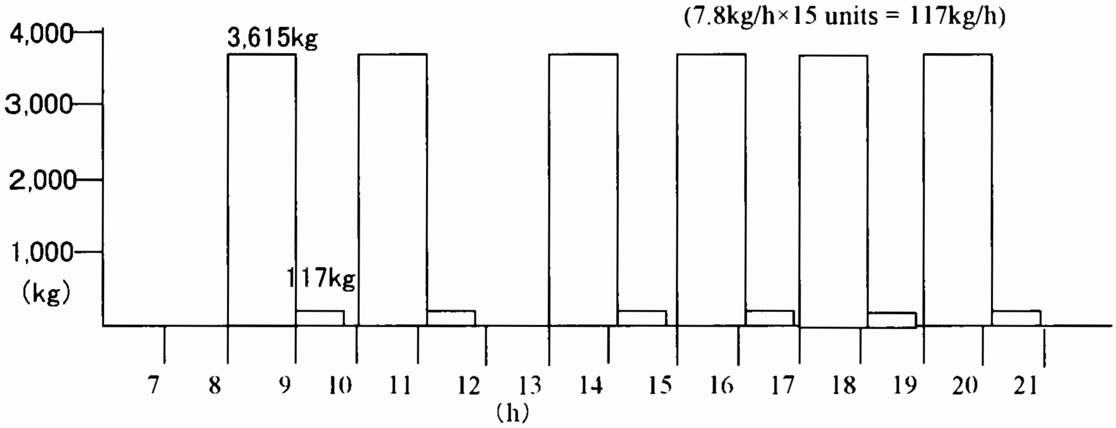
Dyeing (cylindrical) dissipation at 90°C: 1.900kj/m^{2}h
1.900×9.33×40/60 = 11.816kj
(vertical) dissipation at 90°C: 2.055kj/m^{2}h
2.055×2.74×40/60 = 3.753kj

◆ Total dissipation = 7.538+2.397+11.816+3.753=25.506kj/cycle

	Heat for dyeing kj/cycle		Heat kj		Steam kg	
			heating	dyeing	heating	dyeing
Heating tanks	53.875		53.875	0	26.9	
Heating products	11.471		11.471	0	5.7	
Heating liquids	408.135		408.135	0	203.5	
Dissipation	25.506		9.935	15.570	4.9	7.8
Condensate heat	157.316		152.384	4.933		
	656.185				241.0	7.8

Steam consumotion = Required heat/Latent heat of vaporization
Latent heat of vaporization = 2.005.1kj/kg
Condensate heat = Steam consumption× (716.0-83.7)

- Load curve ··· steam consumption (kg) for 15 units (241.0kg/h×15 units = 3.615kg/h)
(7.8kg/h×15 units = 117kg/h)



Load curve

(3) Heat input qs = heat/cycle·unit

(a) Heat carried in by steam Unit potential heat in supplied water at 20℃ = 83.7 kj
qs = 248.8kg×(2.721.1-83.7)kj=656.185 kj/cycle

(4) Heat output

(a) Heat taken away by warm effluent qw

	Dyeing
Water volume l	1.300
Effluent temp. ℃	95

Effluent from dyeing qW = 1.300×(95-20)×4.186kj/kg·K=408.135 kj/cycle

(b) Heat taken away by nylon fabric qn

Fabric weight: 85kg specific heat C: 1.80 kj/kg fabric temp.: 95℃

qn = 85(95-20)×1.80 = 11.475 kj/cycle

(c) Heat dissipation ql (cylindrical surface area: 9.33 m^2; vertical surface area: 2.74 m^2)

Heating up to dyeing temp. (cylindrical) dissipation at (90+33)℃/2 = 61.5℃: 808 kj/m^2h
808×9.33=7.538 kj/cycle
(vertical) dissipation at (90+33)℃/2 = 61.5℃: 875 kj/m^2h
875×2.74=2.397 kj/cycle

Dyeing (cylindrical) dissipation at 90℃=1.900 kj/m^2h
1.900×9.33×40/60=11.816 kj/cycle
(vertical) dissipation at 90℃=2.055 kj/m^2h
2.055×2.74×40/60=3.753 kj/cycle

◆Total for dyeing ql1 = 7.538+2.397+11.816+3.753=25.506 kj/cycle

(d) Heat carried by condensate qc

qc = 248.8kg/cycle×(716.0-83.7)=157.316 kj/cycle

(e) Other loss qL

qL = Heat input – Heat output (qw + qn + ql + qc)
= 656.185-(408.135+3.060+25.506+157.316) = 62.168kj/cycle

Heat input	kj/cycle	%	Heat input	kj/cycle	%
Steam consumption	656.185	100	-	656.185	100
			Heat taken by effluent	408.135	62.2
			Heat taken by product	3.060	0.5
			Heat dissipated	25.506	3.9
			Heat taken by condensate	157.316	24.0
			Other heat loss	62.168	9.4

5-2 Improvement

(1) Improvement measures

①Heat recovery from warm effluent…heat recovered via heat exchanger and used for dyeing (heat exchange efficiency 85%)

②Heat recovery from condensate…recycled for boiler

③Heat insulation…reduction in heat loss, and safety (preventing burns)

④Lower liquor ratio…dyeing water circulartion pump, and lower feed rate (liquor ratio 1:15-1:12)

(2) Claculations

Assumptions for calculation

・Production: 85kg×6cycle/day = 510 kg/day・unit 510×300days=153,000kg/year・unit
・Heat of steam: 248.8kg/cycle・steam 248.8×(2,721.1-83.7) kj/kg・steam=656,185 kj/cycle
・Heat generation per unit oil = 42,111kj/kg. Boiler efficiency = 80%
・Oil consiumption: 656,185kj/(42,111kj/kg×0.8) = 19.5kg/cycle
19.5×6cycle/day = 117kg/day・unit

		cycle/unit	6cycle/day・unit	15 units/day
Production	kg	85	510	7,650
Heat of steam	kj	656,185	3,937,110	59,056,650
Oil consumption	kg	19.5	117	1,755
Oil per unit production	kg・oil/kg	0.229	-	-

①Warm effluent heat recovery

・Heat carried by effluent: 408,135 kj/cycle・unit recovered by heat exchanger, exchanger efficiency 85%
・Heat recoverd (cycle・unit)
408,135 kj×0.85=346,915 kj/cycle
・Steam recovered (cycle・unit)
= 346,915/(2721.1-83.7) = 131.5kg/cycle
・Energy and cost saved (G: kg・oil/year, X: $/year)
HL: 42,111 kj/kg、boiler efficiency: 80.0% (No.1 unit). oil@: high $0.2/kg, (low $0.1/kg)

G = 346,915/(42,111×0.8) = 10.30kg・oil/cycle
・Recovery per year = 10.30×6×15×300 = 278,100kg・oil/year
・Cost saved per year
X1 = 278,100kg×$0.2/kg = $55,620/year. X2 = 278,100kg×$0.1/kg = $2,781/year

・Payback period (n years)
・Investment
Heat exchanger: $40,000, pipes: $10,000, pumps & tanks: $24,000, total = $74,000
・n

$$n = \frac{\mathrm{Log}\left(\dfrac{P}{P-L*\ 1}\right)}{\mathrm{Log}\ (1+I)}$$

P = effect ($)
L = investment ($)
I = interest 10%

n = log(55,620/(55,620-74,000×0.1))/log(1+0.1)   log(1+0.1)=0.0414
n = log1.1525/log(1+0.2) = 1.5 years (3.0 years)

② Condensate recovery

Condensate is recovered after waste liquid recovery. Its effect is estimated from reduction in steam consumption

・Reduction in seam consumption
(Heat input = heat input before recovery - recovered heat =656,185 - 346,915 = 309,270 kj/cycle)

Heat input	kj/cycle	%
Heat of steam	656.185	100
Heat recoverd	-346.915	
Total	309.270	

* Recovery of effluent leads to decreased heat input.

= 309.270/(2.721.1-83.7) = 117.3kg/cycle

Enthalpy of steam = 2.721.1kj/kg
Enthalpy of water = 83.7kj/kg

- Condensate recovery = 117.3*(716.0-83.7) = 74.169kj/cycle
- Recovered steam = 74.169/(2.721.1-83.7)=28.1kg/cycle
- Effect of condensate rtecovery 74.169kj/cycle・unit
- Energy and cost saved (G: kg・oil/year. X: $/year)
  HL: 42.111 kj/kg、boiler efficiency: 80.0% (No.1 unit). oil@: high $0.2/kg. (low $0.1/kg)

  G = 74.169/(42.111×0.8) = 2.20kg・oil/cycle
- Recovery per year = 2.20×6×15×300 = 59.400kg・oil/year
- Cost saved per year
  X1 = 59.400×0.2 = $11.880/year. X2 = 59.400×0.1 = $5.940/year

- Payback period (n years)
  - Investment
    Pipes: $7.200. tanks: $7.000. pumps: $5.000. total = $19.200
  - n

$$n = \frac{\text{Log}\left(\dfrac{P}{P-L*1}\right)}{\text{Log}\ (1 + I)}$$

P = effect ($)
L = investment ($)
1 = interest 10%

n = log(11.880/(11.880-19.200×0.1))/log(1+0.1) log(1+0.1) =0.0414
n = log1.2024/log(1+0.2) = 1.9 years (3.9 years)

③ Heat insulation

Heat insulation for surface of deying machine

Heat-insulated area: cylindrical surface area 9.33 m^2 vertical surface area 2.74 m^2
Heat insulator: polyethylene t = 15 mm
heat conductivity λ = 0.146W/m・K emissivity ε = 0.35

- Heat dissipation beforc anf after insulation kj/unit・cycle

	not insulated	insulated	effect
dyeing process	25.506	5.624	19.881

- Effect of heat insulation 25.506-5.624 = 19.881 kj/cycle・unit
- Improvement in heat consumption
  19.881/(2.721.1-83.7)=7.54kg/cycle

Enthalpy of steam = 2.721.1kj/kg
Enthalpy of water = 83.7kj/kg

- Energy and cost saved (G: kg・oil/year. X: $/year)
  HL: 42.111 kj/kg、boiler efficiency: 80.0% (No.1 unit). oil@: high $0.2/kg. (low $0.1/kg)

  G = 19.881/(42.111×0.8) = 0.59kg・oil/cycle
- Recovery per year = 0.59×6×15×300 = 15.930kg・oil/year
- Cost saved per year
  X1 = 15.930×0.2 = $3.186/year. X2 = 15.930×0.1 = $1.590/year

・Payback period (n years)

・Investment

Heat insulation: $60/m^2×12.1×15=$10.890

・ n

$$n = \frac{\mathrm{Log}\left(\dfrac{P}{P-L*1}\right)}{\mathrm{Log}\ (1+I)}$$

P = effect ($)
L = investment ($)
I = interest 10%

n = log(3.186/(3.186-10.890*0.1))/log(1+0.1)   log(1+0.1)=0.0414
n = log1.5193/log(1+0.2) = 4.4 yeras (8.8 years)

④ Lower liquor ratio

Dyeing water circulartion pumps are installed to perform showering of dyeing liquid. Liquid feed rate is reduced from 1.300L to 900L.. Water temp. is measured at outlet of heat exchanger.

Present 1.300L 53℃
Improved 900L (liquor ratio reduced from 1:15 to 1:12. Fabric weight 85kg/cycle.)

・Reduction in heating (1.300-900)×(95-53)×4.186=70.325kj/cycle
・Reduction in steam consumption 70.325/(2.721.1-221.9) = 2.93kg/cycle (53℃:221.9kj/kg)
・Energy and cost saved (G: kg・oil/year. X: $/year)
HL: 42.111 kj/kg, boiler efficiency: 80.0% (No.1 unit), oil@: high $0.2/kg. (low $0.1/kg)

G = 70.325/(42.111×0.8) =2.087kg・oil/cycle
・Recovery per year = 2.087×6×15×300 = 56.349kg・oil/year
・Cost saved per year
Reduction in steam heat :X1 = 56.349×0.2 = $11.270/year. X2 = 56.349×0.1 = $5.634/year
Reduction in water cost: Y1=(1.300-900)/1.000×6×15×300×$0.83/L = $8.964/year
(Water price $0.83 includes cost for waste water disposal.)
Cost saved per year = X1+W1 = 11.270+8.964 = $20.234/year
(When oil price is $0.1: 5.634+8.964 = $14.598/year)

・Payback period (n years)

・Investment

Pumps: $2.000. modification of rotating drum: $1.500 total = 3.500×15units = $52.500

$$n = \frac{\mathrm{Log}\left(\dfrac{P}{P-L*1}\right)}{\mathrm{Log}\ (1+I)}$$

P=effect ($)
L=investment ($)
I =interest 10%

n = log(20.234/(20.234-52.500×0.1))/log(1+0.1)   log(1+0.1)=0.0414
n = log1.3504/log(1+0.2)= 3.1 years
When oil price is $0.1.
n = log(14.598/(14.598-52.500×0.1))/log(1+0.1)
n = log1.5616/log(1+0.2)= 4.7 years

5-3 Investments in dyeing equipment improvement for energy conservation

No	Equipment	Improvement for energy conservation	Specification	Investment (US$)
5	Dyeing machine	1. Heat recovery via heat exchange from effluent		(total for 15 units)
		(1) heat exchanger	plate type heat exchanger K=16.800kJ/m^2・h・℃ number of plates 35 plates, 0.15m^2/plate	40.000
		(2) warm water feeding pump (VVVF control)	inverter and pump piping works	10.000
		(3) tank installtion	60m^3 × 2 units	24.000
			total	74.000
		2. Recovery of heat from copndensate *1 (1) piping works for heat recovery	40mm × 90m ¥80.000/m	(total for 15 units) 7.200
		(2) storage tanks	20m^3 tanks	7.000
		(3) feed water pump equipment (VVVF control)	inverter and pump	5.000
			total	19.200
		3. Heat insulation polyethylene insulator insulation area 12.1m^2	t=15mm λ=0.146 W/m・K ε=0.23 cost $60/m^2	($726/unit × 15 units) 10.890
			total	10.890
		4. Modification for lower loquor ratio (1) circulating pumps	inverter and pump	(total for 15 units) 2000×15=30.000
		(2) rotary drum modification	scrape-up blades	1500×15=22.500
			total	52.500
		*1) Recovered condensate heat is used for boiler water tank Not useful to decrease steam consumption in dyeing machiones		

5-4 List of effects

(1) Dyeing machine: 15 units

*for entry

Effects 1 (High Fuel Charge $0.2/kg)

No.	Measures	Current				Improvement effects										energy reduction rate	investment	payback	energy consumption after improvement
		production	steam	oil	unit	steam	oil	unit production (fabric)		unit energy cost (fabric)			energy cost						
			consumption	consumption	production	saved	saved	saved	after improvement	before improvement	saved	after improvement	before improvement	saved	after improvement			years	
		kg/Y	kg/Y	kg/Y·oil	kj/kg	kg/Y	kg/Y	kj/kg	kj/kg	$/kg	$/kg	$/kg	$/Y	$/Y	$/Y	%	$	Y	kg/Y·oil
Improv. 1	Heat from waste water	2,295,000	6,717,600	525,902	9,649.8	3,550,500	278,100	5,102.9	4,546.9	0.046	0.024	0.022	105,180	55,620	49,560	52.9	74,000	1.5	247,802
Improv. 2	Heat from condensate	2,295,000	3,167,100	247,802	*1	588,600	59,400	*1	*1	*1	*1	*1	49,560	11,880	37,680	24.0	19,200	1.9	*1
Improv. 3	Heat insulation	2,295,000	3,167,100	247,802	4,546.9	203,580	15,930	292.3	4,254.6	0.022	0.001	0.020	49,560	3,186	46,374	6.4	10,890	4.4	231,872
Improv. 4	Lower liquor ratio	2,295,000	2,963,520	231,872	4,254.6	39,555	56,430	1,035.4	3,219.2	0.020	0.005	0.015	46,374	11,286	35,088	24.3	52,500	*2 3.1	175,442
Assumptions for calculation		production kg	steam kg	heat of steam	HL·kj/kg	recovered steam kg	recovered oil			oil@									
Improv. 1	Heat from waste water	85	248.8	656185.1	42,111	131.5	10.30			0.2									
Improv. 2	Heat from condensate					21.8	2.20												
Improv. 3	Heat insulation					7.54	0.59												
Improv. 4	Lower liquor ratio					2.93	2.09												

*1): Recovered heat, which is fed to boiler water tanks, is not included in unit production calculations for dyeing machines.
*2): Effect of reducving water consumption is added.
*: Effects of existing measures are not included in calculations for new measures.

Effects 2 (Low Fuel Charge $0.1/kg)

No	Measures	Current				Improvement effects										energy reduction rate	investment	payback	energy consumption after improvement
		production	steam	oil	unit	steam	oil	unit production (fabric)		unit energy cost (fabric)			energy cost						
			consumption	consumption	production	saved	saved	saved	after improvement	before improvement	saved	after improvement	before improvement	saved	after improvement			years	
		kg/Y	kg/Y	kg/Y·oil	kj/kg	kg/Y	kg/Y	kj/kg	kj/kg	$/kg	$/kg	$/kg	$/Y	$/Y	$/Y	%	$	Y	kg/Y·oil
Improv. 1	Heat from waste water	2,295,000	6,717,600	525,902	9,649.8	3,550,500	278,100	5,102.9	4,546.9	0.023	0.012	0.011	52,590	27,810	24,780	52.9	74,000	3	247,802
Improv. 2	Heat from condensate	2,295,000	3,167,100	247,802	*1	588,600	59,400	*1	*1	*1	*1	*1	24,780	5,940	18,840	24.0	19,200	3.9	*1
Improv. 3	Heat insulation	2,295,000	3,167,100	247,802	4,546.9	203,580	15,930	292.3	4,254.6	0.011	0.001	0.010	24,780	1,593	23,187	6.4	10,890	8.8	231,872
Improv. 4	Lower liquor ratio	2,295,000	2,963,520	231,872	4,254.6	79,110	56,430	1,035.4	3,219.2	0.010	0.002	0.008	23,187	5,643	17,544	24.3	52,500	*2 4.7	175,442
Assumptions for calculation		production kg	steam kg	heat of steam	HL·kj/kg	recovered steam kg	recovered oil			oil@									
Improv. 1	Heat from waste water	85	248.8	656185.1	42,111	131.5	10.30			0.1									
Improv. 2	Heat from condensate					21.8	2.20												
Improv. 3	Heat insulation					7.54	0.59												
Improv. 4	Lower liquor ratio					2.93	2.09												

*1): Recovered heat, which is fed to boiler water tanks, is not included in unit production calculations for dyeing machines.
*2): Effect of reducving water consumption is added.
*: Effects of existing measures are not included in calculations for new measures.

6. SL Drying Machines

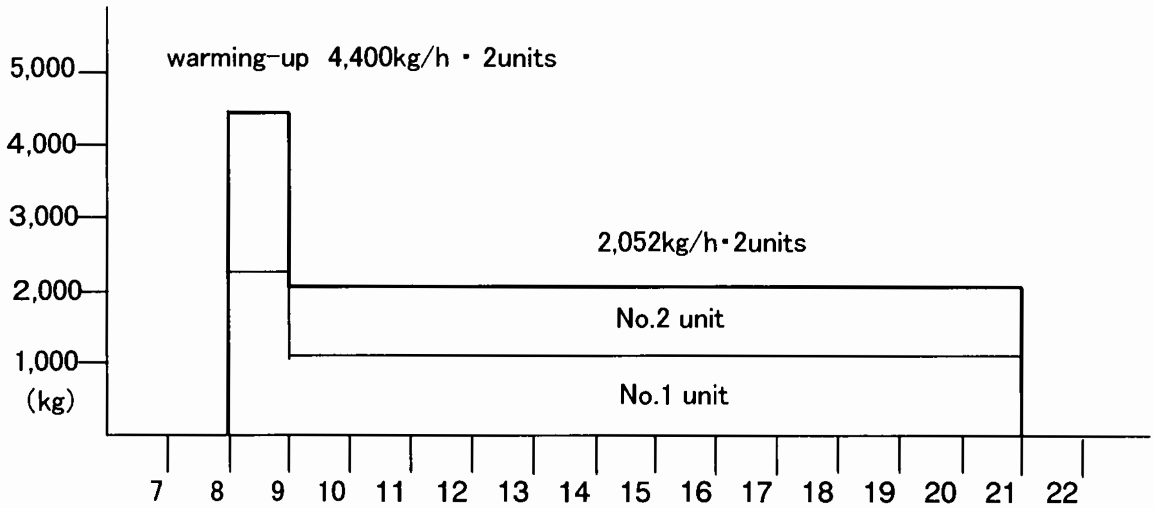
6-1 Heat balance (assuming an ambient air temperature of 33°C)

Reference temp. for heat balance calculation 0°C, warming-up not included.

(1) Steam conditions

Steam pressure (gauge)	P	=0.5Mp		
Enthalpy of dry saturated steam	h"	=2,754.0	kj/kg	
Enthalpy of saturated water	h'	=666.8	kj/kg	
Dryness fraction	X	=0.98		
Enthalpy of wet saturated steam	h	=2,712.2	kj/kg	h=h'+X(h"-h')
Latent heat	r	=2,045.2	kj/kg	

(2) Steam consumption (per dyeing machine unit per operation cycle): 1,026 kg/h



Load curve (hours)

(3) Heat input kJ/h

①Steam consumption	q s=1,026kg/h×2,712 kJ/k	2,782,717
②Electricity-converted	q p=0,23kWh/kg×570kg/h×3,600 kJ/kWh	471,960
③Air-carried heat	q a=238Nm³/min×1.3kg/Nm³×60min×68.2 kJ/kg	1,266,064
④Fabric-carried heat	q f0=570kg/h×1.3 kJ/kg·℃×33℃	24,453
⑤Moisture in fabric	q w0=570kg/h×1.019×4.186 kJ/kg·℃×33℃	80,311
Total		4,625,505

(4) Heat output kJ/h

①Exhaust-carried heat	q e=238Nm³/min×1.3kg/Nm³×60min×184.1 kJ/kg	3,417,632
②Fabric-carried heat	q f1=570kg/h×1.3 kJ/kg·℃×70℃	51,870
③Moisture in fabric	q w1=570kg/h×0.045×4.186 kJ/kg·℃×70℃	7,523
④Condensate-carried	q c=1.8kg/kg×570kg/h×666.8 kJ/kg	684,136
⑤Dissipation	q l=top102m²×343 kJ/m²·h+vertical230m²×330+bottom102m²×305	141,996
⑥Other loss	q l= heart input - heat output	322,348
Total		4,625,505

6-2 Improvement

(1) Improvement measures

①Heat recovery from exhaust…・heat exchangers installed on air lines to recover exhaust heat
②Exhaust moisture control (VVVF control)…・inverters on exhaust fans for moisture (WB) control
③Heat recovery from condensate …recycled for boilers (closed circuit recovery)
④Heat insulation…study of effect of insulation and methods for recovery

(2) Claculations

Assumptions for calculation

・Production: 570kg・h・unit   570×12×2×300=4,104,000kg/year・fabric
(in service: 12hours/day, equipment: 2 units, yearly: 300 days/year)
・Steam (heat) volume: 1,026kg/h・unit   1,026×2,712.2 kJ/kg=2,782,717 kJ/h・unit
・Oil volume: 2,782,717kJ/(42,111kJ/kg×0.8)=82.6kg/h・unit 82.6×12h/day×2 units=1,982.42kg/day
1,982.42×300=594,725kg/year・oil
・Unit consumption: 594,720/4,104,000=0.145 kg・oil/kg・fabric   0.145×42,111=6,106 kJ/kg・fabric
・Conditions for air supply and exhaust (to specify conditions for improvement)

	current	heat exchanger	heat exchanger + VVVF
Exhaust DB℃	70	50	50
Exhaust WB℃	42	40	44
Enthalpy of exhaust kJ/kg	184.1	161.1	200.9
Unit steam consumption kg/kg・fabric	1.80	1.43	1.33
Exhaust flow rate Nm^3/min	238	238	157

①Heat recovery from exhaust…・heat exchangers installed on air lines to recover exhaust heat
Rotary-disk type sensible heat exchanger installed in dryer exhaust duct for heat exchange with fresh air
Unit consumption of steam decreased from 1.80 to 1.43 kg/kg

・Heat input kJ/h

①Steam consumption	q s=1.43kg/kg・fabric×570kg/h×2,712.2 kJ/kg	2,210,714
②Electricity-converted	q p=0,23kWh/kg×570kg/h×3,600 kJ/kWh	471,960
③Air-carried heat	q a=238Nm^3/min×1.3kg/Nm^3×60min×68.2 kJ/kg	1,266,064
④Fabric-carried heat	q f0=570kg/h×1.3 kJ/kg・℃×33℃	24,453
⑤Moisture in fabric	q w0=570kg/h×1.019×4.186 kJ/kg・℃×33℃	80,311
Total		4,053,502

・Heat output kJ/h

①Exhaust-carried heat	q e=238Nm^3/min×1.3kg/Nm^3×60min×161.1 kJ/kg	2,990,660
②Fabric-carried heat	q f1=570kg/h×1.3 kJ/kg・℃×70℃	51,870
③Moisture in fabric	q w1=570kg/h×0.045×4.186 kJ/kg・℃×70℃	7,523
④Condensate-carried	q c=1.43kg/kg×570kg/h×666.8 kJ/kg	543,508
⑤Dissipation	q I=top102m^2×343 kJ/m^2・h+vertical230m^2×330+bottom102m^2×305	141,996
⑥Other loss	q l= heart input - heat output	317,945
Total		4,053,502

・Effect of recovery

・Recovered heat: difference between before and after installation of heat exchanger
2,782,717-2,210,714=570,004 kJ/h

・Volume of steam recovered (kg・unit/h)
=570,004/(2712.2-83.7)=216.8kg/h

・Energy and cost saved (G: kg・oil/year, X: $/year)
HL: 42,111 kJ/kg, boiler efficiency: 80.0% (No.1 unit), oil@: high $0.2/kg, (low $0.1/kg)

G=570,004/(42,111×0.8)=16.92kg・oil/h
・Energy saved per year=16.92×2×12×300=121,824kg・oil/year
・Cost saved per year
X1=121,824×0.2=$24,364/year, X2=121,824×0.1=$12,182/year

・Payback period (n years)

・Investment

Installtion fo rotary-disk type heat exchanger $40,000/unit 2 units total=$80,000

・n

$$n = \frac{\mathrm{Log}\left(\dfrac{P}{P - L \times 1}\right)}{\mathrm{Log}\ (1 + I)}$$

P=effect ($)
L=investment ($)
I =interest 10%

n = log(24,364/(24,364-80,000×0.1))/log(1+0.1) log(1+0.1)=0.0414

n = log1.489/log(1+0.2) = 4.2 years (8.4years)

②Exhaust moisture control (VVVF control)...・inverters on exhaust fans for moisture (WB) control

VVVF control of exhaust fans to keep constant moisture in exhaust

Unit consumption of steam decreased from 1.43 to 1.33kg/kg

・Heat input kJ/h

①Steam consumption	q s=1.33kg/kg・fabric×570kg/h×2,712.2 kJ/kg	2,056,118
②Electricity-converted	q p=0,23kWh/kg×570kg/h×3,600 kJ/kWh	471,960
③Air-carried heat	q a=157Nm^3/min×1.3kg/Nm^3×60min×68.2 kJ/kg	835,177
④Fabric-carried heat	q f0=570kg/h×1.3 kJ/kg・℃×33℃	24,453
⑤Moisture in fabric	q w0=570kg/h×1.019×4.186 kJ/kg・℃×33℃	80,311
Total		3,468,019

・Heat output kJ/h

①Exhaust-carried heat	q e=157Nm^3/min×1.3kg/Nm^3×60min×200.9 kJ/kg	2,460,221
②Fabric-carried heat	q f1=570kg/h×1.3 kJ/kg・℃×70℃	51,870
③Moisture in fabric	q w1=570kg/h×0.045×4.186 kJ/kg・℃×70℃	7,523
④Condensate-carried	q c=1.33kg/kg×570kg/h×666.8 kJ/kg	505,501
⑤Dissipation	q l=top102m^2×343 kJ/m^2・h+vertical230m^2×330+bottom102m^2×305	141,996
⑥Other loss	q l= heart input - heat output	300,908
Total		3,468,019

・Effect of recovery

・Recovered heat: difference between before and after installation of VVVF control

2,210,714-2,056,118=154,596 kJ/h

・Volume of steam recovered (kg・unit/h)

=154,596/(2712.2-83.7)=58.81kg/h

・Energy and cost saved (G: kg・oil/year, X:$/year)

HL:42,111 kJ/kg, boiler efficiency:80.0% (No.1 unit), oil@:high $0.2/kg, (low $0.1/kg)

G=154,596/(42,111×0.8)=4.59kg・oil/h

・Energy saved per year =4.59×2×12×300=33,048kg・oil/Y

・Cost saved per year

X1=33,048×0.2=$6,609/Y, X2=33,048×0.1=$3,304/Y

・Payback period (n years)

・Investment

Exhaust flow rate controller (inverter + moisture controller) $2,500/unit 2 units total=$5,000

・n

$$n = \frac{\mathrm{Log}\left(\dfrac{P}{P - L \times 1}\right)}{\mathrm{Log}\ (1 + I)}$$

P=effect ($)
L=investment ($)
I =interest 10%

n = log(6,609/(6,609-5,000x0.1))/log(1+0.1)   log(1+0.1)=0.0414
n = log1.082/log(1+0.2) = 0.8 year (1.7 years)

③ Heat recovery from condensate

Condensate heat recovery is performed after implementation of exhaust heat recovery and exhaust moisture control. Its effect is estimated from decrease in steam consumption. Recovered heart is fed directly to boilers (closed circuit recovery).

・Heat output   kJ/h

①Exhaust-carried heat	q e=157Nm^3/minx1.3kg/Nm^{3}x60minx200.9 kJ/kg	2,460,221
②Fabric-carried heat	q f1=570kg/hx1.3 kJ/kg・℃x70℃	51,870
③Moisture in fabric	q w1=570kg/hx0.045x4.186 kJ/kg・℃x70℃	7,523
④Condensate-carried	q c=1.33kg/kgx570kg/hx666.8 kJ/kg	505,501
⑤Dissipation	q I=top102m^{2}x343 kJ/m^2・h+vertical230m^{2}x330+bottom102m^{2}x305	141,996
⑥Other loss	q l= heart input - heat output	300,908
Total		3,468,019

・Effect of heat recovery from condensate   505,501 kJ/h

・Volume of steam recovered (kg・unit/h)
=505,501/(2712.2-83.7)=192.31kg/h

・Energy and cost saved (G: kg・oil/year, X:$/year)
HL:42,111 kJ/kg, boiler efficiency:80.0% (No.1 unit), oil@:high $0.2/kg, (low $0.1/kg)

G=505,501/(42,111x0.8)=15.00kg・oil/cycle
・Energy saved per year =15.0x2x12x300=108,000kg・oil/year
・Cost saved per year
X1=108,000x0.2=$21,600/year,   X2=108,000x0.1=$10,800/year

・Payback period (n years)
・Investment

booster pump for direct recovery:	$20,000	
modification in water supply to boiler:	$5,000	total=$37,000
piping installtion	$12,000	

・n

$$n = \frac{\mathrm{Log}\left(\dfrac{P}{P - L \times 1}\right)}{\mathrm{Log}\ (1 + I)}$$

P=effect ($)
L=investment ($)
I =interest 10%

n = log(21,600/(21,600-37,000x0.1))/log(1+0.1)   log(1+0.1)=0.0414
n = log1.206/log(1+0.2)=2.0 years (3.9 years)

④Heat insulation

Addition of 40-50mm glass wool to existing 20mm does not largely increase current heat insulation. More than 10 years will be required for payback, and economic effect will be small.

6-3 Steam piping

6-3-1 Heat insulation of pipe

(1) Present condition

Pipe size	4" (OD=114 mm)	6" (OD=165 mm)
Surface area	0.358 m^2/m (=0.114*π)	0.518 m^2/m (=0.165*π)
Pipe length	130 m	100 m
Steam flow hour	24 h/d	14 h/d
Heat insulation	20 mm thickness of glass wool	20 mm thickness of glass wool
Insulated length	52 m (=130*40%)	40 m (=100*40%)
Radiation heat rate of insulated part	1,250 kJ/m^2 h = 447 kJ/m h (=1250*0.358)	1,250 kJ/m^2 h = 647 kJ/m h (=1250*0.518)
Radiation heat of insulated part	22,244 kJ/h (= 447 * 52)	25,880 kJ/h (= 647 * 40)
Not-insulated length	78 m (=130*60%)	60 m (=100*60%)
Radiation heat rate of not-insulated part	11,540 kJ/m^2 h = 4,131 kJ/m h (=11540*0.358)	11,540 kJ/m^2 h = 5,978 kJ/m h (=11540*0.518)
Radiation heat of not-insulated part	322,218 kJ/h (= 4131 * 78)	358,680 kJ/h (= 5978 * 60)

Total heat radiation loss: 729,022 kJ/h

(2) Improvement

Referring to Table 29 of Text No. 23 "Heat insulation technology for energy conservation", the thickness of economical heat insulation for 4" and 6" diameter pipe at this temperature is 50 mm, and so heat insulation cannot be said sufficient with the present 20 mm thickness glass wool.

Heat insulation of the pipe of 4"×130 m and 6"×100 m is renewed to 50mm thickness glass wool.

Pipe size	4" (OD=114 mm)	6" (OD=165 mm)
Pipe length	130 m	100 m
Heat insulation	50 mm thickness of glass wool	50 mm thickness of glass wool
Radiation heat rate of insulated part	56 W/m = 201 kJ/m h (=56*3.6)	74 W/m = 266 kJ/m h (=74*3.6)
Radiation heat of insulated part	26,130 kJ/h (= 201 * 130)	26,600 kJ/h (= 266 * 100)

1) Total heat radiation loss: 52,730 kJ/h

2) Effect of insulation improvement: 676,292 kJ/h (=729,022 – 52,730)

3) Steam recovery rate: 676,292 / (2712.2 – 83.7) = 257.3 kg/h

4) Energy and cost saved (G: kg-oil/year, X: $/year)

HL=42,111 kJ/kg, Boiler efficiency = 80.0% (No. 1 boiler),

Oil unit price: high $0.2/kg, low $0.1/kg

G = 676,292 / (42,111 × 0.8) × 14h = 281 kg-oil/day

Energy saved per year = 281 × 300 = 84,300 kg-oil/year

Cost saved per year

X1 = 84,300 × 0.2 = $16,860/year

X2 = 84,300 × 0.1 = $8,430/year

5) Payback period

Investment cost

- Insulation of 4" and 6" pipe: 1.2 × (12000 × 50^(–1.17) + 100) × 10 $/m^3

  = 1.2 (12000 × 0.0103 + 100) × 10

  = $2,681 /m^3

- Volume of heat insulation is given as (0.214^2 - 0.114^2) Xπ/4 × 130 m = 4.62 m^3 for 4"pipe and (0.265^2 – 0.165^2) Xπ/4 × 100 m = 5.36 m^3 for 6" pipe

- The overall heat insulation installation cost is as follows:

  2681 × 4.62 + 2681 × 5.36 = $26,756.-

Payback year: n

n = log(P / (P–L*I)) / log(1+I)

P = Saved cost ($), L=Investment ($), and I = Interest rate (10%)

Case X1:

n = log(16,860 / (16.860–26,756 × 0.1)) / log(1+0.1) = log1.189/log1.1 = 1.8 years

Case X2:

n = log(8,430 / (8,430–26,756 × 0.1)) / log(1+0.1) = log1.465/log1.1 = 3.9 years

6-3-2 Steam leakage

Steam leakages are found at steam traps and pipe flanges.

(1) Present condition

Pipe size	4" (OD=114 mm)	6" (OD=165 mm)
Steam flow hour	24 h/d	14 h/d
Steam trap with leakage	4-set	2-set
Steam leakage volume per trap	30 kg/h	30 kg/h
Steam leakage from traps	120 kg/h	60 kg/h
Pipe flange with leakage	10-set	0
Hole equivalent to leaked flange gap	1.5 mm diameter	–
Leaked volume of steam per flange	8 kg/h	
Steam leakage from flanges	80 kg/h	

Total heat leakage loss: 260 kg/h = 260 × (2712.2 – 83.7) = 683,280 kJ/h

(2) Improvement

Leaked steam traps are replaced with new ones and leaked flanges are repaired with tightening of bolts or change of gaskets.

1) Effect of stop of leakage: 260 kg-steam/h = 683,280 kJ/h

2) Energy and cost saved (G: kg-oil/year, X: $/year)

HL = 42,111 kJ/kg, Boiler efficiency = 80.0% (No. 1 boiler),

Oil unit price: high $0.2/kg, low $0.1/kg

G = 683,280 / (42,111 × 0.8) × 14h = 284 kg-oil/day

Energy saved per year = 284 × 300 = 84,200 kg-oil/year

Cost saved per year

X1 = 84,200 × 0.2 = $16,840/year

X2 = 84,200 × 0.1 = $8,420/year

3) Payback period

Investment cost

- Replacement of steam traps:

  Price of a steam trap: $170.- for float type

  Price of steam traps: 170 × 6 = $1020.-

- Repair of flanges: maintenance cost

Payback year: n

n = log(P / (P–L*I)) / log(1+I)

P=Saved cost ($), L=Investment ($), and I=Interest rate (10%)

Case X1:

n = log(16,840 / (16.840–1,020×0.1)) / log(1+0.1) = log1.006 / log1.1 = 0.1 years

Case X2:

n = log(8,420 / (8,420–1,020×0.1)) / log(1+0.1) = log1.465 / log1.1 = 0.1years

6-4 Investments in drying equipment improvement for energy conservation

No	Equipment	Improvement for energu conservation	Specification	Invesdtment (US$)	
6	Drying machine	1. Heat recovery from exhaust		(2 units)	
		(1) heat-exchanger	disk-type heat exchanger	40,000/unit	
					80,000
			total		80,000
		2. Control of moisture in exhaust		(2 units)	
		(1) VVVF equipment	2.2 kW inverter	2,000/unit	
					4,000
		(2) Moisture control	sensor	500/unit	
					1,000
			total		5,000
		3. Heat recovery from condensate *1		(2 units)	
		(1) booster pump for recovery	5.5 kW recovery pump		20,000
		(2) Modification in boiler water feeder	water level controller		5,000
		(3) Piping works for recovery	32mm×160m×$75/m		12,000
			total		37,000
		*1) Recovered condensate heat is used for boiler water tank Not useful for steam consumption in drying machiones			

6-5 List of effects

(1) Dryer: 2 units

*for entry

Effects 1 (High Fuel Charge $0.2/kg)

No. Measures	Current: production	Current: steam consumption	Current: oil consumption	Current: unit production	Improvement effect: steam saved	oil saved	unit production (fabric) saved	unit production (fabric) after improvement	unit energy cost (fabric) before improvement	unit energy cost (fabric) saved	unit energy cost (fabric) after improvement	energy cost before improvement	energy cost saved	energy cost after improvement	energy reduction rate	investment	payback years	energy consumption after improvement
	kg/Y	kg/Y	kg/Y·oil	kj/kg	kg/Y	kg/Y	kj/kg	kj/kg	$/kg	$/kg	$/kg	$/Y	$/Y	$/Y	%	$	Y	kg/Y·oil
Improv. 1 Recovery of waste heat	4,104,000	7,387,200	594,725	6,102	1,560,960	121,824	1,250.0	4,852.4	0.029	0.006	0.023	118,945	24,365	94,580	20.5	80,000	3.0	472,901
Improv. 2 Exhaust moist. control (VVVF)	4,104,000	5,826,240	472,901	4,852	423,432	33,048	339.1	4,513.3	0.023	0.002	0.021	94,580	6,610	87,971	7.0	19,200	0.8	439,853
Improv. 3 Condensate heat	4,104,000	5,402,808	439,853	*1	1,384,632	108,000	*1	*1	*1	*1	*1	87,971	21,600	66,371	24.6	37,000	2.0	*1
Improv. 4 Heat insulation																		
Assumprions for calculation	production kg	steam kg	heat of steam	HL·kj/kg	recovered steam kg	recovered oil			oil@									
Improv. 1 Recovery of waste heat	570	1,026	2,782,717	42,111	216.8	16.920			0.2									
Improv. 2 Exhaust moist. control (VVVF)					58.81	4.59												
Improv. 3 Condensate heat					192.3	15.0												
Improv. 4 Heat insulation																		

*1): Recovered heat, which is fed directly back to boiler water tanks, is not included in unit production calculations for dyeing machines.
*: Effects of existing measures are not included in calculations for new measures.

Effects 2 (Low Fuel Charge $0.1/kg)

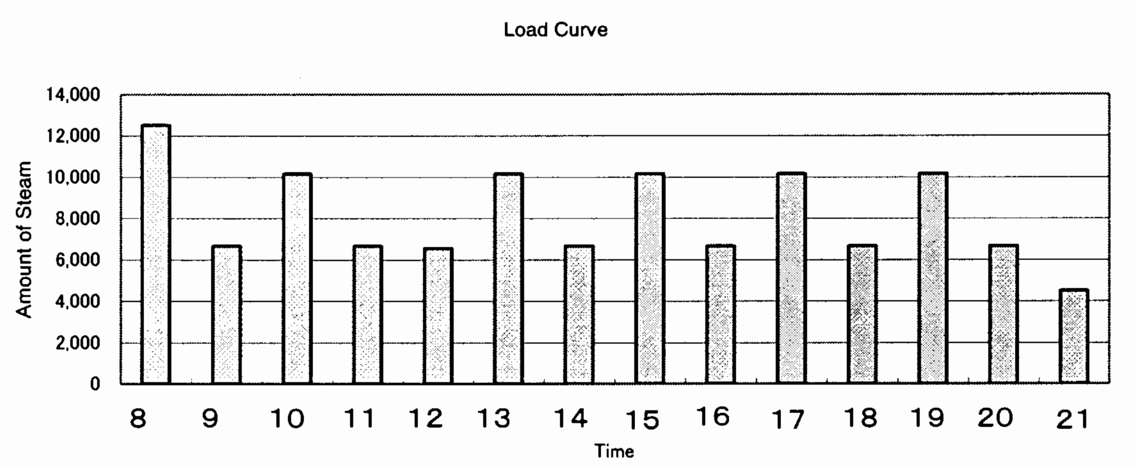
No. Measures	Current: production	Current: steam consumption	Current: oil consumption	Current: unit production	Improvement effect: steam saved	oil saved	unit production (fabric) saved	unit production (fabric) after improvement	unit energy cost (fabric) before improvement	unit energy cost (fabric) saved	unit energy cost (fabric) after improvement	energy cost before improvement	energy cost saved	energy cost after improvement	energy reduction rate	investment	payback years	energy consumption after improvement
	kg/Y	kg/Y	kg/Y·oil	kj/kg	kg/Y	kg/Y	kj/kg	kj/kg	$/kg	$/kg	$/kg	$/Y	$/Y	$/Y	%	$	Y	kg/Y·oil
Improv. 1 Recovery of waste heat	4,104,000	7,387,200	594,725	6,102	1,560,960	121,824	1,250.0	4,852.4	0.014	0.003	0.012	59,472	12,182	47,290	20.5	80,000	5.9	472,901
Improv. 2 Exhaust moist. control (VVVF)	4,104,000	5,826,240	472,901	4,852	423,432	33,048	339.1	4,513.3	0.012	0.001	0.011	47,290	3,305	43,985	7.0	19,200	1.7	439,853
Improv. 3 Condensate heat	4,104,000	5,402,808	439,853	*1	1,384,632	108,000	*1	*1	*1	*1	*1	43,985	10,800	33,185	24.6	37,000	3.9	*1
Improv. 4 Heat insulation																		
Assumprions for calculation	production kg	steam kg	Heat of steam	HL·kj/kg	recovered steam kg	recovered oil			oil@									
Improv. 1 Recovery of waste heat	570	1,026	2,782,717	42,111	216.8	16.920			0.1									
Improv. 2 Exhaust moist. control (VVVF)					58.81	4.59												
Improv. 3 Condensate heat					192.3	15.0												
Improv. 4 Heat insulation																		

*1): Recovered heat, which is fed directly back to boiler water tanks, is not included in unit production calculations for dyeing machines.
*: Effects of existing measures are not included in calculations for new measures.

6-6 Load curve of steam consumption

(1) Convensional load curve

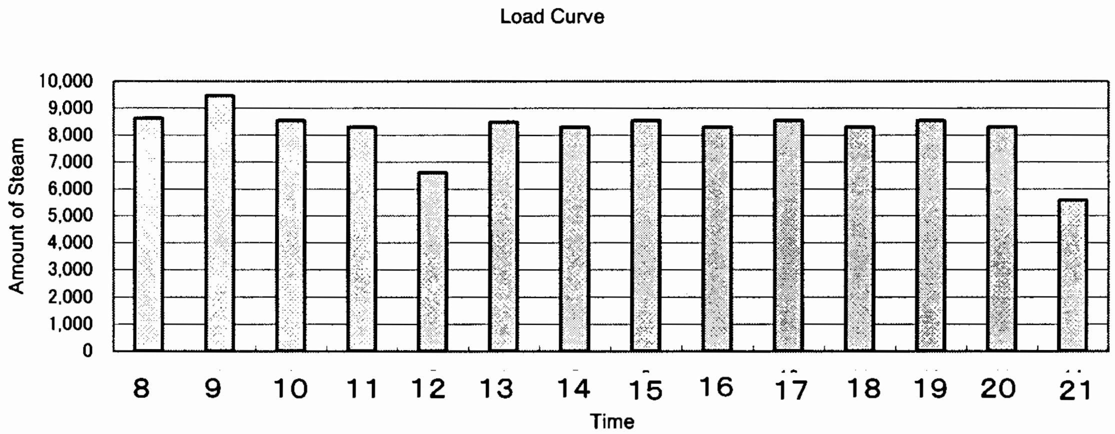
	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Drying machine ×15	3,615	117	3,615	117	0	3,615	117	3,615	117	3,615	117	3,615	117	
Drier 1	2,200	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	
Drier 2	2,200	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	
Base load	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
Utilities	500	500	500	500	500	500	500	500	500	500	500	500	500	500
Piping loss	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Total	12,515	6,669	10,167	6,669	6,552	10,167	6,669	10,167	6,669	10,167	6,669	10,167	6,669	4,500



* Two boilers in operation

(2) Load curve after adjustment of operation time

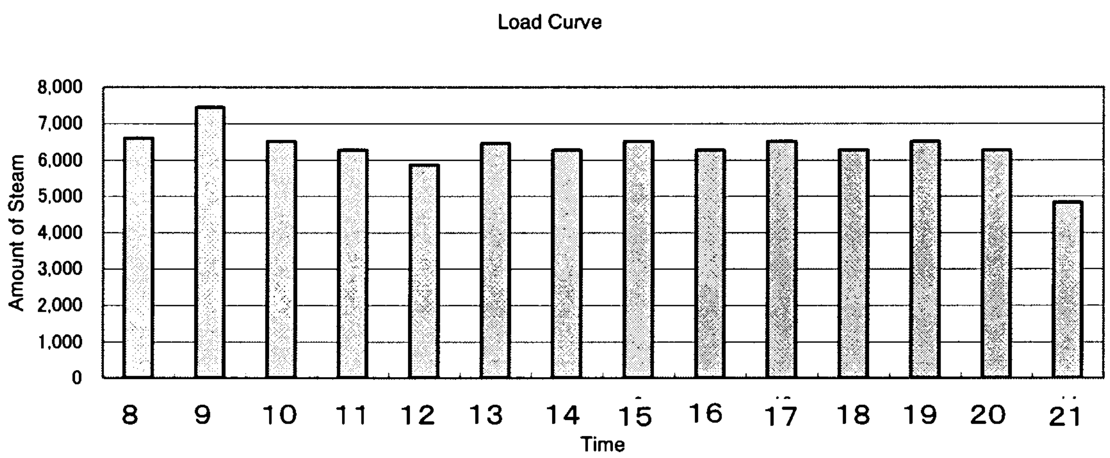
	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Details
Drying machine × 8	1,928	62	1,928	62	0	1,928	62	1,928	62	1,928	62	1,928	62		241.0 × 8 = 1928
Drying machine × 7		1,687	55	1,687	55	0	1,687	55	1,687	55	1,687	55	1,687	55	7.8 × 8 = 62.4
Drier 1	2,200	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026		
Drier 2		2,200	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	
Base load	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	
Utilities	500	500	500	500	500	500	500	500	500	500	500	500	500	500	
Piping loss	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	
Total	8,628	9,475	8,535	8,301	6,607	8,480	8,301	8,535	8,301	8,535	8,301	8,535	8,301	5,581	



* One boiler in opoeration

(3) Load curve after improvement for energy conservation

	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
Drying machine × 8	1,928	62	1,928	62	0	1,928	62	1,928	62	1,928	62	1,928	62		
Drying machine × 7		1,687	55	1,687	55	0	1,687	55	1,687	55	1,687	55	1,687	55	
①Recovery of warm effluent	-986	-986	-986	-986	0	-986	-986	-986	-986	-986	-986	-986	-986		・131.5kg/cycle/2 × 15units
②Recovery of condensate	-210	-210	-210	-210	0	-210	-210	-210	-210	-210	-210	-210	-210		・21.8kg/cycle/2 × 15units
③Heat insulation	-56	-56	-56	-56	0	-56	-56	-56	-56	-56	-56	-56	-56		・7.54kg/cycle/2 × 15units
④Lower liquid ratio	-22	-22	-22	-22	0	-22	-22	-22	-22	-22	-22	-22	-22		・2.93kg/cycle/2 × 15units
Drier 1	2,200	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026		
Drier 2		2,200	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	1,026	
①Recovery of waste heat	-217	-217	-217	-217	-217	-217	-217	-217	-217	-217	-217	-217	-217	-217	・219kg/h
②Control of exhaust moistur	-59	-59	-59	-59	-59	-59	-59	-59	-59	-59	-59	-59	-59	-59	・59kg/h
③Recovery of condensate	-192	-192	-192	-192	-192	-192	-192	-192	-192	-192	-192	-192	-192	-192	・192kg/h
Base load	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	
Utilities	500	500	500	500	500	500	500	500	500	500	500	500	500	500	
Piping loss	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	
①Heat insulation of pipes	-277	-277	-277	-277	-277	-277	-277	-277	-277	-277	-277	-277	-277	-277	・277kg/h
Total	6,609	7,456	6,516	6,282	5,862	6,461	6,282	6,516	6,282	6,516	6,282	6,516	6,282	4,836	



* One boiler in operation

7. Heating Furnace

7.1 Summary

(1) Present problems

Apparatus		Problem		Improving measure
Industrial furnace	1	Since the air ratio is as high as 1.6, the exhaust gas heat volume is large.	1	Introduce automatic combustion equipment for optimizing the air ratio.
	2	Since the furnace walls are not veneered, the radiation heat loss from the furnace walls is as large as 88,710 kcal/h.	2	Veneer the furnace walls with an optimum thickness.
	3	Since the exhaust gas is discharged at a high temperature of 1000°C, the exhaust gas is not recovered.	3	Introduce a recuperator for heat exchange between exhaust gas and combustion air, to recover the waste heat.

(2) Effect of energy conservation

No.	Improvement item	Production and energy consumption (Calorific value) 10,060 kcal/kg				Energy cost				Energy cost reduction rate	Invested amount	Recovering years
						Unit price	Before improvement	After improvement	Effect			
		Unit	Before improvement	After improvement	Effect	$/t·fuel	$/y	$/y	$/y	%	$	year
Production		t/y	7,200									
1	Optimization of air ratio	t/y	441.5	332.0	109.5	200	88,294	66,399	21,895	24.8	32,000	1.7
		Mcal/t	616.8	463.9	153.0	100	44,147	33,200	10,948	24.8		3.6
2	Intensification of heat insulation (50mm)	t/y	332.0	284.0	48.0	200	66,399	56,794	9,605	14.5	23,800	3.0
		Mcal/t	463.9	396.8	67.1	100	33,200	28,397	4,803	14.5		7.2
3	Installation of recuperator	t/y	284.0	200.1	83.9	200	56,794	40,019	16,775	29.5	50,000	3.7
		Mcal/t	396.8	279.6	117.2	100	28,397	20,010	8,387	29.5		9.5
	Total	t/y	441.5	200.1	241.4	200	88,294	40,019	48,275	54.7	105,800	2.6
		Mcal/t	616.8	279.6	337.3	100	44,147	20,010	24,138	54.7	105,800	6.1

Optimizing the air ratio not only brings about an energy cost saving but also increases the production output through a reduction in scale loss. For example, a change in air ratio from 1.6 to 1.2 would result in an annual production increase of 15 tons.

Assuming the same production output (7,150 tons/year), the reduction in scale loss would result in a 15-hour reduction in operating hours, which translates into a fuel cost saving of 42–138 dollars/year. However, this fuel cost saving would only be equivalent to about 0.2% of the total annual fuel cost, and would therefore have no significant impact on the length of the payback.

Important considerations for energy conservation involving combustion-type industrial furnaces are as follows:

(1) Reduction of exhaust gas waste heat

a) Keeping air ratio as close to unity as possible (1.2 or less)
Adjustment of air valve opening; automatic control of air valve according to the amount of fuel to be burned

b) Reduction of air intrusion and combustion gas release
Automatic furnace pressure control via flue damper

c) Recovery of waste heat using heat exchangers
Preheating of combustion air; exhaust gas boiler

(2) Reduction of other heat losses

a) Reduction of heat dissipation from furnace walls
Strengthening of heat insulation (veneering)

b) Reduction of cooling water waste heat
Strengthening of heat insulation; elimination of water cooling through introduction of heat insulator

c) Reduction of heat loss from openings
Radiation shield

As has been mentioned in the lecture, the following are the major considerations for the furnace at the model factory, with the rest more or less negligible:

1. a), b) Reduction of actual air ratio with air intrusion taken into account
2. a) Reduction of heat dissipation from furnace walls
1. c) Recovery of waste heat using heat exchangers

Of these three measures, the reduction of heat dissipation from furnace walls involves four options: 25, 50, 75 and 100 mm in terms of veneering thickness.

Waste heat recovery, on the other hand, involves two options: the introduction of heat exchangers while leaving the existing furnace as it is; and the introduction of heat exchangers after reducing the exhaust gas volume. The latter should normally be used.

Although the amount of heat recovered increases with the increase in exhaust gas volume, its effect will not reach beyond the sensible heat carried by the increased exhaust gas, as the heat exchanger effectiveness is less than 1. Therefore, this is not worthwhile economically, although it still depends on the cost of the heat exchanger.

The calculation of the heat balance and cost vs. benefit for each veneering thickness option in the case of applying it to the existing furnace on its own shows that 50 mm (Case C) is the most economical thickness.

Calculations of the heat balance and cost vs. benefit for the introduction of a heat exchanger with the existing furnace intact (Case I) and those for the introduction of a heat exchanger after a reduction in air ratio (Case H) show that system 2 is superior economically, as well as technically.

Although a choice of the three measures explained above, either used individually or in combination, depends on the budget, first priority should be given to a reduction in air ratio, then 50 mm-thick veneering, followed by the introduction of a heat exchanger, as can be seen from the payback tables.

Here, combining all three measures is given as the standard solution, as its payback period is only 1.6 years. (Case H of Heat Balance and Payback Table. ($0.2/kg-fuel)

$$\text{Payback year} = \frac{\log\left(\dfrac{\text{Annual fuel cost saving}}{\text{Annual fuel cost saving} - \text{Investment} \times \text{Interest}}\right)}{\log\left(1 + \text{Interest}\right)}$$

Heat Balance and Payback

(Low Fuel Charge 0.1 $/kg)

Operation=7200 h/year Interest=10%/year

Case Number			Original A	First Step Air Ratio B	Second Step Veneering C	Third Step Recuperator D	Ideal Improvement E
Air Ratio		−	1.6	1.2	1.2	1.2	1.2
Scale Loss Improvement		−	1	0.7	0.7	0.7	0.7
Insulation Thickness		mm	0	0	50	50	50
Wall Loss		MJ/h	371	371	216	216	216
Preheated Air Temp		℃	33	33	33	600	600
Fuel Consumption		kg/h	61.3	46.1	39.4	27.8	27.8
Annual Fuel Consumption		kg/year	441306	331919	283904	200043	200043
Annual Fuel Cost		US $/year	44131	33192	28390	20004	20004
Annual Fuel Cost Saving		US $/year	0	10939	4801	8386	24126
Input	Fuel's Heat Value	MJ/h	2581	1941	1660	1170	1170
Input	Preheated Air's Sensible Heat	MJ/h	0	0	0	272	272
Input	Scale Producing Heat	MJ/h	30	21	21	21	21
Output	Material's Sensible Heat	MJ/h	638	639	639	639	639
Output	Exhaust Gas Loss	MJ/h	1512	864	739	521	521
Output	Wall Loss	MJ/h	371	371	216	216	216
Output	Cooling Water Loss	MJ/h	84	84	84	84	84
Output	Scale's Sensible Heat	MJ/h	6	4	4	4	4
Total Input		MJ/h	2611	1962	1681	1463	1463
Total Output		MJ/h	2611	1962	1681	1463	1463
Input − Output		MJ/h	0	0	0	0	0
Investment of Air Control		US $	0	32000	0	0	32000
Investment of Insulation		US $	0	0	23800	0	23800
Investment of Air Preheat		US $	0	0	0	50000	50000
Total Investment		US $	0	32000	23800	50000	105800
Payback year	(Interest 10%)	year	0.0	3.6	7.2	9.5	6.1
	(Interest 5%)		0.0	3.2	5.8	7.3	5.1
	(Interest 3%)		0.0	3.1	5.4	6.7	4.8

Heat Balance and Payback

(High Fuel Charge 0.2 $/kg)

Operation=7200 h/year Interest=10%/year

Case Number			Original A	First Step Air Ratio B	Second Step Veneering C	Third Step Recuperator D	Ideal Improvement E
Air Ratio		–	1.6	1.2	1.2	1.2	1.2
Scale Loss Improvement		–	1	0.7	0.7	0.7	0.7
Insulation Thickness		mm	0	0	50	50	50
Wall Loss		MJ/h	371	371	216	216	216
Preheated Air Temp		℃	33	33	33	600	600
Fuel Consumption		kg/h	61.3	46.1	39.4	27.8	27.8
Annual Fuel Consumption		kg/year	441306	331919	283904	200043	200043
Annual Fuel Cost		US $/year	88261	66384	56781	40009	40009
Annual Fuel Cost Saving		US $/year	0	21877	9603	16772	48253
Input	Fuel's Heat Value	MJ/h	2581	1941	1660	1170	1170
Input	Preheated Air's Sensible Heat	MJ/h	0	0	0	272	272
Input	Scale Producing Heat	MJ/h	30	21	21	21	21
Output	Material's Sensible Heat	MJ/h	638	639	639	639	639
Output	Exhaust Gas Loss	MJ/h	1512	864	739	521	521
Output	Wall Loss	MJ/h	371	371	216	216	216
Output	Cooling Water Loss	MJ/h	84	84	84	84	84
Output	Scale's Sensible Heat	MJ/h	6	4	4	4	4
Total Input		MJ/h	2611	1962	1681	1463	1463
Total Output		MJ/h	2611	1962	1681	1463	1463
Input – Output		MJ/h	0	0	0	0	0
Investment of Air Control		US $	0	32000	0	0	32000
Investment of Insulation		US $	0	0	23800	0	23800
Investment of Air Preheat		US $	0	0	0	50000	50000
Total Investment		US $	0	32000	23800	50000	105800
Payback year	(Interest 10%)	year	0.0	1.7	3.0	3.7	2.6
	(Interest 5%)		0.0	1.6	2.7	3.3	2.4
	(Interest 3%)		0.0	1.5	2.6	3.2	2.3

8. Blower for Dust Collector

8.1 Summary

No.	Improvement measure	Before improvement (kWh)	After improvement (kWh)	Effect		Investment (US$)	Payback years
				Energy saved (kW)	Cost saved (US$/year)		
1	Change of motor 75 kW→37 kW Damper control → Inverter control	257,760	158,880	99,880	19,800	55,500	3.45

8.2 Change of motor from 75 kW to 37 kW

From the Table   Motor efficiency = 0.94

$L_i' = 28.0 \times \frac{1}{0.94} = 29.8$ (kW)

∴ Power conservation = 31.5 – 29.8 = 1.7 kW

8.3 Damper Control → Inverter control

1) Motor input at present

Motor input at 800 m^3/min = 31.5 kW

Motor input at 300 m^3/min

From power consumption curve of discharge damper control

Motor input $L_{i1} = \frac{0.74}{1.05} \times 31.5 = 22.2$ kW

2) Motor input after improvement

Motor input at 800 m^3/min = 29.8 kW

Motor input at 300 m^3/min

From power consumption curve of inverter control

Motor input $L_{i2} = \frac{0.07}{1.05} \times 29.8 = 2.0$ kW

Inverter input $L_{i3} = 2.0 \times \frac{1}{0.9} = 2.2$ kW

∵ Inverter efficiency = 0.9

∴ Power conservation at 800 m^3/min

= 31.5 – 29.8 = 1.7 kW

Power conservation at 300 m^3/min

= 22.2 – 2.2 = 20 kW

8.4 Power conservation

(1) At present

Hour	0-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-24	Day total
Blower No.1	0	0	31.5	22.2	22.2	31.5	0	31.5	22.2	22.2	31.5	31.5	22.2	22.2	31.5	0	322.2
Blower No.2	0	0	31.5	22.2	22.2	31.5	0	0	31.5	22.2	22.2	31.5	0	0	0	0	214.8
Blower No.3	0	31.5	22.2	22.2	31.5	0	31.5	22.2	22.2	31.5	31.5	22.2	22.2	31.5	0	0	322.2
Total kW	0	31.5	85.2	66.6	75.9	63	31.5	53.7	75.9	75.9	85.2	85.2	44.4	53.7	31.5	0	859.2

(2) After improvement

Hour	0-1	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	Day total
Blower No.1	0	0	29.8	2.2	2.2	29.8	0	29.8	2.2	2.2	29.8	29.8	2.2	2.2	29.8	0	192
Blower No.2	0	0	29.8	2.2	2.2	29.8	0	0	29.8	2.2	2.2	29.8	0	0	0	0	128
Blower No.3	0	29.8	2.2	2.2	29.8	0	29.8	2.2	2.2	29.8	29.8	2.2	2.2	29.8	0	0	192
Total kW	0	29.8	61.8	6.6	34.2	59.6	29.8	32	34.2	34.2	61.8	61.8	4.4	32	29.8	0	512
Re-duced kW	0	1.7	23.4	60	41.7	3.4	1.7	21.7	41.7	41.7	23.4	23.4	40	21.7	1.7	0	347.2

8.5 Annual reduct cost

Annual power conservation = 347.2 × 25 days × 12 months = 104,160 kWh

Anual reduced cost = 104,160 × US$0.17 /kWh = US$17,701 ($0.17/kWh)

= 104,160 × US$0.08 /kWh = US$8,333 ($0.08/kWh)

8.6 Investment

Inverter capacity = 37 kW same as motor kW

Investment = 37 kW × 3 units US$500/kW = US$55,500

Payback period = $\frac{69,930}{17,707}$ = 3.9 years ($0.17/kWh)

or

$$n = \frac{\log\left(\frac{17{,}707}{17{,}707 - 69{,}930 \times 0.1}\right)}{\log(1 + 0.1)}$$

$$= \frac{\log\left(\frac{17{,}707}{10{,}714}\right)}{\log 1.1} = \frac{0.218}{0.0414}$$

$$= 5.3 \text{ years}$$

$$\text{Payback period} = \frac{69{,}930}{8{,}333} = 8.4 \text{ years}$$

or

$$n = \frac{\log\left(\frac{8{,}333}{8{,}333 - 69{,}930 \times 0.1}\right)}{\log(1 + 0.1)}$$

$$= \frac{\log\left(\frac{8{,}333}{1{,}340}\right)}{\log 1.1} = \frac{0.793}{0.0414}$$

$$= 19.2 \text{ years}$$

9. Pump

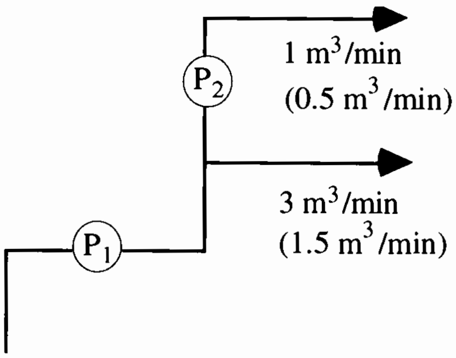
9.1 Summary

No.	Improvement measure	Before improvement (kWh)	After improvement (kWh)	Effect		Investment (US$)	Payback years
				Energy saved (kW)	Cost saved (US$/year)		
1	Booster pump Change of pump 22 kW→11 kW	105,264	69,840	35,424	6,402 ($0.17/kWh)	24,990	4.0 ($0.17/kWh)
					3,012 ($0.08/kWh)		48.4 ($0.08/kWh)

9.2 After improvement

1) Install a booster pump (P2)

2) Change the exiting pump (22 kW) to new pump (P1) as shown on right figure.



- Decision of motor capacity of (P1)

  Axial power P_1 is obtained by equation (3) on page 76 of Textbook No.7.

  $$P_1 = \frac{0.163 \cdot 1 \cdot 4 \cdot 10}{0.76} = 8.58 \text{ kW}$$

So we choose 11 kW motor for new pump (P1)

- Decision of motor capacity of (P2)

  η = 69% (from Fig. 47 of Textbook No.7)

  Axial power P_2 is obtained by equation (3) on page 76 of Textbook No. 7.

  $$P_2 = \frac{0.163 \cdot 1 \cdot 1 \cdot 10}{0.69} = 2.36 \text{ kW}$$

So we choose 3.7 kW motor for booster pump (P2)

① Motor input at flow rate 4 m^3/min

(a) New pump (P1)

η_M: 0.92 (from Table on ECCJ Factory page 32, High Efficiency Motor)

$$L_{i1} = \frac{0.163 \cdot 1 \cdot 4 \cdot 10}{0.76} \times \frac{1}{0.92} = 9.32 \text{ kW}$$

(b) Booster pump (P_2) Flow rate = 1 m^3/min

η_M: 0.86 (from Table on ECCJ Factory page 32, High Efficiency Motor)

$$L_{i2} = \frac{0.163 \cdot 1 \cdot 1 \cdot 10}{0.69} \times \frac{1}{0.86} = 2.75 \text{ kW}$$

(c) Total motor input L_{iT}

$$L_{iT} = L_{i1} + L_{i2}$$
$$= 9.32 + 2.75$$
$$= 12.07 \text{ (kW)}$$

② Motor input at flow rate 2 m^3/min

(a) New pump (P_1)

η: 73%

η_M: 0.88

$$L_{i1} = \frac{0.163 \cdot 1 \cdot 2 \cdot 10}{0.73} \times \frac{1}{0.88} = 5.07 \text{ kW}$$

(b) Booster pump (P_2) Flow rate = 0.5 m^3/min

η: 62%

η_M: 0.80

$$L_{i2} = \frac{0.163 \cdot 1 \cdot 0.5 \cdot 10}{0.62} \times \frac{1}{0.80} = 1.64 \text{ kW}$$

(c) Total motor input L_{iT}

$$L_{iT} = L_{i1} + L_{i2}$$
$$= 5.07 + 1.64 = 6.71 \text{ (kW)}$$

9.3 Power conservation after improvement

1) At flow rate 4 m^3/min

Motor input at present	18.85 (kW)
Motor input after improve.	12.07 (kW)
Power conservation	6.78 (kW)

2) At flow rate 2 m^3/min

Motor input at present	10.39 (kW)
Motor input after improve.	6.71 (kW)
Power conservation	3.68 (kW)

(3) Annual power conservation

6.78×12 hrs $\times$ 300 days + 3.68×12 hrs $\times$ 300 days = 37,656 kWh

Annual cost reduction

37,656 kWh $\times$ US\$0.17/kWh = \$6,402/y

37,656 kWh $\times$ US\$0.08/kWh = \$3,012/y

(4) Investment

(11 kW + 3.7 kW) $\times$ \$US1,730 = US\$25,431

(5) Payback period (\$0.17/kWh)

$$\frac{25{,}431}{6{,}402} = 4.0 \text{ years}$$

$$n = \frac{\log\left(\dfrac{6{,}402}{6{,}402 - 25{,}431 \times 0.1}\right)}{\log(1.1)}$$

$$= \frac{\log\left(\dfrac{6{,}402}{3{,}859}\right)}{\log(1.1)} = \frac{0.220}{0.0414} = 5.3 \text{ years}$$

Payback period (\$0.08/kWh)

$$\frac{25{,}431}{3{,}012} = 8.4 \text{ years}$$

or

$$n = \frac{\log\left(\dfrac{3{,}012}{3{,}012 - 25{,}431 \times 0.1}\right)}{\log(1 + 0.1)}$$

$$= \frac{\log\left(\dfrac{3{,}012}{469}\right)}{\log(1.1)} = 19.5 \text{ years}$$

10. Compressors

10.1 Summary

(1) Present problems

1) Compressors are continuously operated irrespective of the change in the consumption of compressed air. The number of operating compressors should be adjusted to suit the consumption.
2) Though compressed air with a pressure of 5 kg/cm^2 is needed, the discharge pressure of compressors is 7 kg/cm^2, being rather higher than needed. Even if the pipeline pressure loss is taken into account, the pressure can be lowered to 6 kg/cm^2.
3) The suction temperature is as high as 50°C though the open air temperature is 33°C. If the open air is directly sucked, the electric power consumption can be lowered.

(2) Effect of energy conservation

No	Improvement measure	Before improvement (kWh/y)	After improvement (kWh/y)		Effect		Investment (US$)	Payback years
					Energy saved (kWh/y)	Cost saved (US$/y)		
1	Operation method	375,000	Case 1	285,690	89,310	17,951	15,000	0.84
			Case 2	290,820	84,180	16,920		0.89
			Case 3	285,270	89,730	18,036		0.83
2	Intake air temperature	375,000	355,125		19,875	3,995	5,000	1.25

Electric charge 0.201 US$/kWh

No	Improvement measure	Before improvement (kWh/y)	After improvement (kWh/y)		Effect		Investment (US$)	Payback years
					Energy saved (kWh/y)	Cost saved (US$/y)		
1	Operation method	375,000	Case 1	285,690	89,310	8,484	15,000	1.77
			Case 2	290,820	84,180	7,997		1.88
			Case 3	285,270	89,730	8,524		1.76
2	Intake air temperature	375,000	355,125		19,875	1,888	5,000	2.65

Electric charge 0.095 US$/kWh

10.2 Adjustment of operating units

If the flow rate of each compressor is known beforehand, the number of operating compressors is adjusted according to the necessary air quantity. To decide the compressors to be operated, the following procedure is used.

(1) Compressors are first classified into the screw type and the reciprocating type, and then arranged in order from ones with larger capacity.

(2) Until a total value of compressors exceeds the necessary flow rate of air, the compressors to be operated are decided in order of the screw type and the reciprocating type.

(3) Of the compressors, one unit will be operated intermittently — the compressor that will make the off period as short as possible should be selected.

By deciding the compressors to be operated for each hour following the above-mentioned procedure, and by determining the electric power consumed by each compressor, the consumed wattage of the whole can be calculated.

Incidentally, the consumed electric power of a compressor operated intermittently can be calculated from the rate of load hours and idling hours.

By setting the following for the compressor to be operated intermittently;

Flow rate:	Q_{max}	m^3/min
Electric power during load hour:	W_l	kW
Electric power during idling hours:	W_u	kW

and by setting an air quantity Q_r to be supplied by this compressor, the load hours t_l and the idling hours t_u are determined as follows.

$$t_l = \frac{Q_r}{Q_{max}} \qquad t_u = \frac{Q_{max} - Q_r}{Q_{max}}$$

Therefore, the consumed electric power during the intermittent hours is

$$W = W_l \frac{Q_r}{Q_{max}} + W_u \frac{Q_{max} - Q_r}{Q_{max}}$$

$$= \frac{Q_r}{Q_{max}} (W_l - W_u) + W_u$$

The result of these calculations are shown in Table 1 and 2.

If the number of operating units is not adjusted, all compressors will operate from 8:00 to 21:00. In this case, the compressors that are not required will be left in the idling condition, so the electric power used for the idling is a loss. The electric power loss calculated in this way is shown in the bottom stage of Table 1 and 2.

10.3 Reduction of discharge pressure

Power necessary for compressing the air varies by the ratios of pressure at the inlet and outlet of a compressor. As the intake pressure is nearly equal to the atmospheric pressure, the necessary power is reduced by decreasing the discharge pressure. This relationship is shown in Fig. 36 of the textbook.

The maximum pressure of the working side is 5 kg/cm^{2}g. Therefore, supposing that the outlet pressure of the compressor is decreased from 7 kg/cm^{2}g (8 kg/cm^{2}a) to 6 kg/cm^{2}g (7 kg/cm^{2}a), with a pressure loss in the piping taken into account, the necessary power is, from Fig. 36, reduced from 4.5 kW/(m^3/min) to 4.15 kW/(m^3/min), and the consumed electric power is reduced by 7.8%.

10.4 Temperature reduction of intake air

Power necessary for compressing the air is proportionate to the volume of intake air. As the volume of air is proportionate to the absolute temperature, a necessary power for compressing certain volume of air is increased when the temperature of the intake air rises.

When the present temperature of intake air 50°C is dropped to 33°C by taking the atmosphere as is,

$$\frac{33 + 273}{50 + 273} = 0.947$$

namely, the consumed electric power is reduced by 5.3%.

Power necessary for compressing also varies by moisture, besides temperature. When the intake air is cooled down with water, together with removal of moisture content, a large effect can be attained. This relationship is shown in Fig. 37 of the textbook chapter 14.

Table 1 Compressor Operation Schedule

Case 1

time	0 ~ 8	8 ~ 9	9 ~ 12	12 ~ 13	13 ~ 14	14 ~ 21	21 ~ 24	
required flow rate	2.5 m³/min	11.0 m³/min	6.0 m³/min	2.5 m³/min	9.0 m³/min	7.0 m³/min	2.5 m³/min	
SCREW TYPE No. 13		continuous	continuous		continuous	continuous		
Flow rate 4.0 m³/min Load 30 kW Unload 18 kW		4.0 m³/min 30 kW	4.0 m³/min 30 kW		4.0 m³/min 30 kW	4.0 m³/min 30 kW		
SCREW TYPE No. 14		continuous			continuous			
Flow rate 3.2 m³/min Load 25 kW Unload 13 kW		3.2 m³/min 25 kW	(13 kW)		3.2 m³/min 25 kW	(13 kW)		
RECIPRO TYPE No. 15	intermittent	continuous	intermittent	intermittent	intermittent	continuous	intermittent	
Flow rate 3.0 m³/min Load 25 kW Unload 5.0 kW	2.5 m³/min 21.7 kW	3.0 m³/min 25 kW	2.0 m³/min 18.3 kW	2.5 m³/min 21.7 kW	1.8 m³/min 17 kW	3.0 m³/min 25 kW	2.5 m³/min 21.7 kW	
RECIPRO TYPE No. 16		intermittent						
Flow rate 1.8 m³/min Load 18 kW Unload 3.6 kW		0.8 m³/min 10 kW	(3.6 kW)	(3.6 kW)	(3.6 kW)	(3.6 kW)		
Average Power	21.7 kW	90.0 kW	48.3 kW	21.7 kW	72.0 kW	55.0 kW	21.7 kW	Total
Power Consumption	173.6 kWh	90.0 kWh	144.9 kWh	21.7 kWh	72.0 kWh	385.0 kWh	65.1 kWh	952.3 kWh
Loss of unload	–	(0 kWh)	(49.8 kWh)	(3.6 kWh)	(3.6 kWh)	(116.2 kWh)	–	(173.2 kWh)

Table 2 Compressor Operation Schedule

Case 2

time	0 ~ 8	8 ~ 9	9 ~ 12	12 ~ 13	13 ~ 14	14 ~ 21	21 ~ 24	
required flow rate	2.5 m^3/min	11.0 m^3/min	6.0 m^3/min	2.5 m^3/min	9.0 m^3/min	7.0 m^3/min	2.5 m^3/min	
SCREW TYPE No. 13		continuous			continuous	continuous		
Flow rate 4.0 m^3/min Load 30 kW Unload 18 kW		4.0 m^3/min 30 kW	(18 kW)		4.0 m^3/min 30 kW	4.0 m^3/min 30 kW		
SCREW TYPE No. 14		intermittent	intermittent		continuous	intermittent		
Flow rate 3.2 m^3/min Load 25 kW Unload 13 kW		2.2 m^3/min 21.3 kW	3.0 m^3/min 24.3 kW		3.2 m^3/min 25.0 kW	3.0 m^3/min 24.3 kW		
RECIPRO TYPE No. 15	intermittent	continuous	continuous	intermittent			intermittent	
Flow rate 3.0 m^3/min Load 25 kW Unload 5.0 kW	2.5 m^3/min 21.7 kW	3.0 m^3/min 25 kW	3.0 m^3/min 25 kW	0.7 m^3/min 9.7 kW	(5 kW)	(5 kW)	2.5 m^3/min 21.7 kW	
RECIPRO TYPE No. 16		continuous		continuous	continuous			
Flow rate 1.8 m^3/min Load 18 kW Unload 3.6 kW		1.8 m^3/min 18 kW	(3.6 kW)	1.8 m^3/min 18 kW	1.8 m^3/min 18 kW	(3.6 kW)		
Average Power	22.4 kW	94.3 kW	49.3 kW	27.7 kW	73.0 kW	54.3 kW	22.4 kW	Total
Power Consumption	179.2 kWh	94.3 kWh	147.9 kWh	27.7 kWh	73.0 kWh	380.1 kWh	67.2 kWh	969.4 kWh
Loss of unload	–	(0 kWh)	(64.8 kWh)	–	(5 kWh)	(60.2 kWh)	–	(130.0 kWh)

Case 3

Table 3 Compressor Operation Schedule

time	0～8	8～9	9～12	12～13	13～14	14～21	21～24	
required flow rate	2.5 m³/min	11.0 m³/min	6.0 m³/min	2.5 m³/min	9.0 m³/min	7.0 m³/min	2.5 m³/min	
SCREW TYPE No. 13		continuous	continuous		continuous	continuous		
Flow rate 4.0 m³/min Load 30 kW Unload 18 kW		4.0 m³/min 30 kW	4.0 m³/min 30 kW		4.0 m³/min 30 kW	4.0 m³/min 30 kW		
SCREW TYPE No. 14		continuous			intermittent	intermittent		
Flow rate 3.2 m³/min Load 25 kW Unload 13 kW		3.2 m³/min 25 kW	(13 kW)		2.0 m³/min 20.5 kW	3.0 m³/min 24.3 kW		
RECIPRO TYPE No. 15	intermittent	continuous	intermittent	intermittent	continuous		intermittent	
Flow rate 3.0 m³/min Load 25 kW Unload 5.0 kW	2.5 m³/min 21.7 kW	3.0 m³/min 25 kW	2.0 m³/min 18.3 kW	2.5 m³/min 21.7 kW	3.0 m³/min 25 kW	(5 kW)	2.5 m³/min 21.7 kW	
RECIPRO TYPE No. 16		intermittent						
Flow rate 1.8 m³/min Load 18 kW Unload 3.6 kW		0.8 m³/min 10 kW	(3.6 kW)	(3.6 kW)	(3.6 kW)	(3.6 kW)		
Average Power	21.7 kW	90.0 kW	48.3 kW	21.7 kW	75.5 kW	54.3 kW	21.7 kW	Total
Power Consumption	173.6 kWh	90.0 kWh	144.9 kWh	21.7 kWh	75.5 kWh	380.1 kWh	65.1 kWh	950.9 kWh
Loss of unload	–	(0 kWh)	(49.8 kWh)	(3.6 kWh)	(3.6 kWh)	(60.2 kWh)	–	(117.2 kWh)

11. Transformer

No.	Improvement measure	Before improvement	After improvement (kWh)	Effect		Investment (US$)	Payback years
				Energy saved (kW)	Cost saved (US$/year)		
1	Power factor improvement	0.87	0.95		19,112 ($0.17/kWh)	5,000	0.3 ($0.17/kWh)
					9,556 ($0.08/kWh)		0.5 ($0.08/kWh)

11.1 **For Fuji** ($0.017/kWh)

1) Annual demand charge before improvement

   1,422 [kW] × US$14/kW × (1.85 – 0.87) × 12 [month] = US$234,118

2) Annual electric charge after improvement

   1,422 [kW] × US$14/kW × (1.85 – 0.95) × 12 [month] = US$215,006

3) Annual reduced cost

   US$234,118 – US$215,006 = US$19,112

4) Investment

   Condenser capacity: 200 kVA

   Investment = 200 kVA × US$25/kVA = US$5,000

   $$\text{Pacyback period} = \frac{5,000}{19,112} = 0.3 \text{ year}$$

   or

$$n = \frac{\log\left(\dfrac{19,112}{19,112 - 5,000 \times 0.1}\right)}{\log(1 + 0.1)}$$

$$= \frac{\log\left(\dfrac{19,112}{18,612}\right)}{\log(1.1)} = \frac{0.0115}{0.0414} = 0.3 \text{ year}$$

11.2 For Sakura ($0.08/kWh)

1) Annual demand charge before improvement

   1,422 [kW] × US$7/kW × (1.85 – 0.87) × 12 [month] = US$117,059

2) Annual electric charge after improvement

   1,422 [kW] × US$7/kW × (1.85 – 0.95) × 12 [month] = US$107,503

3) Annual reduced cost

   US$117,059 – US$107,503 = US$9,556

4) Investment

   Condenser capacity: 200 kVA

   Investment = 200 kVA × US$25/kVA = US$5,000

   Pacyback period $= \frac{5,000}{9,556} = 0.5$ year

   or

$$n = \frac{\log\left(\frac{9,556}{9,556 - 5,000 \times 0.1}\right)}{\log(1 + 0.1)}$$

$$= \frac{\log\left(\frac{9,556}{9,056}\right)}{\log(1.1)} = \frac{0.0233}{0.0414} = 0.6 \text{ year}$$

(1) At present

Load A													
Hour	**0-1**	**1-2**	**2-3**	**3-4**	**4-5**	**5-6**	**6-7**	**7-8**	**8-9**	**9-10**	**10-11**	**11-12**	**12-13**
Pump	10.39	10.39	10.39	10.39	10.39	10.39	10.39	10.39	18.85	18.85	18.85	18.85	18.85
Blower No.1	0	0	0	0	0	0	0	0	31.5	22.2	22.2	31.5	0
Blower No.2	0	0	0	0	0	0	0	0	31.5	22.2	22.2	31.5	0
Blower No.3	0	0	0	0	0	0	0	31.5	22.2	22.2	31.5	0	31.5
Compressor	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	90	59.1	59.1	59.1	25.3
Others	167.91	167.91	167.91	167.91	167.91	167.91	167.91	136.41	405.95	455.45	446.15	459.05	124.35
Total (A)	200	200	200	200	200	200	200	200	600	600	600	600	200
Hour	**13-14**	**14-15**	**15-16**	**16-17**	**17-18**	**18-19**	**19-20**	**20-21**	**21-22**	**22-23**	**23-24**	**Day total**	
Pump	18.85	18.85	18.85	18.85	18.85	18.85	18.85	10.39	10.39	10.39	10.39	350.88	
Blower No.1	31.5	22.2	22.2	31.5	31.5	22.2	22.2	31.5	0	0	0	322.2	
Blower No.2	0	31.5	22.2	22.2	31.5	0	0	0	0	0	0	214.8	
Blower No.3	22.2	22.2	31.5	31.5	22.2	22.2	31.5	0	0	0	0	322.2	
Compressor	75.6	62.9	62.9	62.9	62.9	62.9	62.9	62.9	21.7	21.7	21.7	1047.2	
Others	451.85	442.35	442.35	433.05	433.05	473.85	464.55	95.21	167.91	167.91	167.91	6942.72	
Total (A)	600	600	600	600	600	600	600	200	200	200	200	9200	

Load B													
Hour	**0-1**	**1-2**	**2-3**	**3-4**	**4-5**	**5-6**	**6-7**	**7-8**	**8-9**	**9-10**	**10-11**	**11-12**	**12-13**
Lighting	0	0	0	0	0	0	0	60	60	60	60	60	60
Others	300	300	300	300	300	300	300	240	740	740	740	740	240
Total (B)	300	300	300	300	300	300	300	300	800	800	800	800	300
Hour	**13-14**	**14-15**	**15-16**	**16-17**	**17-18**	**18-19**	**19-20**	**20-21**	**21-22**	**22-23**	**23-24**	**Day total**	
Lighting	60	60	60	60	60	60	60	60	60	60	0	960	
Others	740	740	740	740	740	740	740	240	240	240	300	11740	
Total (B)	800	800	800	800	800	800	800	300	300	300	300	12700	

Hour	**0-1**	**1-2**	**2-3**	**3-4**	**4-5**	**5-6**	**6-7**	**7-8**	**8-9**	**9-10**	**10-11**	**11-12**	**12-13**
Total (A+B)	500	500	500	500	500	500	500	500	1400	1400	1400	1400	500
TR. Loss	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	21.72	21.72	21.72	21.72	8.75
TR pry kW	508.75	508.75	508.75	508.75	508.75	508.75	508.75	508.75	1421.72	1421.72	1421.72	1421.72	508.75
kvar	242.2	242.2	242.2	242.2	242.2	242.2	242.2	242.2	867.6	867.6	867.6	867.6	242.2
Hour	**13-14**	**14-15**	**15-16**	**16-17**	**17-18**	**18-19**	**19-20**	**20-21**	**21-22**	**22-23**	**23-24**	**Day total**	
Total (A+B)	1400	1400	1400	1400	1400	1400	1400	500	500	500	500	21900	
TR. Loss	21.72	21.72	21.72	21.72	21.72	21.72	21.72	8.75	8.75	8.75	8.75	352.67	
TR pry kW	1421.7	1421.7	1421.7	1421.7	1421.7	1421.7	1421.7	508.75	508.75	508.75	508.75	22252.67	
kvar	867.6	867.6	867.6	867.6	867.6	867.6	867.6	242.2	242.2	242.2	242.2	12692.2	
											Power factor = 22253/25618=0.87		

(2) After improvement (before p. f improv.)

Load A

Hour	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13
Red of Pump	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	6.78	6.78	6.78	6.78	6.78
Red of Blwr	0	0	0	0	0	0	0	1.7	23.4	60	41.7	3.4	1.7
Red of Comp	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	3.6	7.16	7.16	7.16	1.01
Total (A)	195.45	195.45	195.45	195.45	195.45	195.45	195.45	193.75	566.22	526.06	544.36	582.66	190.51

Hour	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	Day total
Red of Pump	6.78	6.78	6.78	6.78	6.78	6.78	6.78	3.68	3.68	3.68	3.68	125.52
Red of Blwr	21.7	41.7	41.7	23.4	23.4	40	21.7	1.7	0	0	0	347.2
Red of Comp	3.02	7.32	7.32	7.32	7.32	7.32	7.32	7.32	0.87	0.87	0.87	89.92
Total (A)	568.5	544.2	544.2	562.5	562.5	545.9	564.2	187.3	195.45	195.45	195.45	8637.36

Load B

Hour	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13
Red of Lght	0	0	0	0	0	0	0	32.5	32.5	32.5	32.5	32.5	32.5
Total (B)	300	300	300	300	300	300	300	267.5	767.5	767.5	767.5	767.5	267.5
Total (A+B)	495.45	495.45	495.45	495.45	495.45	495.45	495.45	461.25	1333.7	1293.6	1311.9	1350.2	458.01

Hour	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	Day total
Red of Lght	32.5	32.5	32.5	32.5	32.5	32.5	32.5	32.5	32.5	32.5	0	520
Total (B)	767.5	767.5	767.5	767.5	767.5	767.5	767.5	267.5	267.5	267.5	300	12180
Total (A+B)	1336	1311.7	1311.7	1330	1330	1313.4	1331.7	454.8	462.95	462.95	495.45	20817.36

(3) Before p f improvement

Hour	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	
kW	495.45	495.45	495.45	495.45	495.45	495.45	495.45	461.25	1333.7	1293.6	1311.9	1350.2	
p. f	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.85	0.85	0.85	0.85	
kVA	550.50	550.50	550.50	550.50	550.50	550.50	550.50	512.50	1569.08	1521.84	1543.36	1588.42	
kvar	239.96	239.96	239.96	239.96	239.96	239.96	239.96	223.39	826.57	801.68	813.02	836.75	
Hour	**12-13**	**13-14**	**14-15**	**15-16**	**16-17**	**17-18**	**18-19**	**19-20**	**20-21**	**21-22**	**22-23**	**23-24**	**Day total**
kW	458.01	1336	1311.7	1311.7	1330	1330	1313.4	1331.7	454.8	462.95	462.95	495.45	20817.36
p. f	0.9	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.9	0.9	0.9	0.9	
kVA	508.90	1571.76	1543.18	1543.18	1564.71	1564.71	1545.18	1566.71	505.33	514.39	514.39	550.50	
kvar	221.82	827.98	812.92	812.92	824.26	824.26	813.97	825.31	220.27	224.22	224.22	239.96	

(4) After p f improvement by 200 kVA condensor

Hour	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	
kvar	39.96	39.96	39.96	39.96	39.96	39.96	39.96	23.39	626.57	601.68	613.02	636.75	
kVA	497.06	497.06	497.06	497.06	497.06	497.06	497.06	461.84	1473.56	1426.64	1448.02	1492.78	
Pi	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	
Pc	1.81	1.81	1.81	1.81	1.81	1.81	1.81	1.56	15.92	14.93	15.38	16.34	
Pt	6.31	6.31	6.31	6.31	6.31	6.31	6.31	6.06	20.42	19.43	19.88	20.84	
TR pry kW	501.76	501.76	501.76	501.76	501.76	501.76	501.76	467.31	1354.14	1312.99	1331.74	1371.00	
Hour	**12-13**	**13-14**	**14-15**	**15-16**	**16-17**	**17-18**	**18-19**	**19-20**	**20-21**	**21-22**	**22-23**	**23-24**	**Day total**
kvar	21.82	627.98	612.92	612.92	624.26	624.26	613.97	625.31	20.27	24.22	24.22	39.96	7253.216
kVA	458.53	1476.23	1447.83	1447.83	1469.22	1469.22	1449.82	1471.20	455.25	463.58	463.58	497.06	
Pi	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	
Pc	1.54	15.98	15.37	15.37	15.83	15.83	15.41	15.87	1.52	1.58	1.58	1.81	
Pt	6.04	20.48	19.87	19.87	20.33	20.33	19.91	20.37	6.02	6.08	6.08	6.31	
TR pry kW	464.05	1356.48	1331.57	1331.57	1350.33	1350.33	1333.31	1352.07	460.82	469.03	469.03	501.76	21119.87
												Power factor = 21120/22331 = 0.95	

12. Lighting

12.1 Summary

No.	Improvement measure	Before improvement (kWh)	After improvement (kWh)	Effect		Investment (US$)	Payback years
				Energy saved (kWh)	Cost saved (US$/year)		
1	Utility area 500 lx→300lx (sodium lamp) Mercury lamp → Sodium lamp	288,000	131,000	157,000	26,520 ($0.17/kWh) 12,480 ($0.08/kWh)	49,050	1.9 ($0.17/kWh) 4.0 ($0.08/kWh)

(1) Countermeasure

1) Reduce illuminance at utility area from 500 lx to 300 lx.
2) Lamp change form mercury lamp to high pressure sodium lamp.

Necessary numbers of lamps N_1 at utilities area are obtained as follows.
Specification of high pressure sodium lamp: 250 W, 120 lm/W

$$N_1 = \frac{300 \times 20 \times 50}{120 \times 250 \times 0.69 \times 0.8} = 18.1 \rightarrow 19 \text{ lamps}$$

Necessary numbers of lamps N_2 at working area are obtained as follows.

$$N_2 = \frac{500 \times 60 \times 50}{120 \times 250 \times 0.69 \times 0.8} = 90.6 \rightarrow 91 \text{ lamps}$$

Total number of sodium lamps = 19 + 91 = 110 lamps
Total power consumption of sodium lamps = 250 × 110 = 27.5 kW

(2) Power conservation after improvement

Power conservation = 60.0 – 27.5 = 32.5 kW
Annual power conservation = 32.5 × 16 hrs × 25 days × 12 months = 156,000 kWh

(3) Annual reduced cost

Annual reduced cost = 156,000 × US$0.17/kWh = US$26,520
= 156,000 × US$0.08/kWh = US$12,480

(4) Investment

Investment = US$450/lamps × 110 = US$49,500

(5) Payback period

Payback period $= \frac{49{,}500}{26{,}520} = 1.9$ years (US$0.17/kWh)

or

$$n = \frac{\log\left(\frac{26{,}520}{26{,}520 - 49{,}500 \times 0.1}\right)}{\log(1 + 0.1)}$$

$$= \frac{\log\left(\frac{26{,}520}{21{,}570}\right)}{\log(1.1)} = \frac{0.0897}{0.0414} = 2.2 \text{ years}$$

Payback period $= \frac{49{,}500}{12{,}480} = 4.0$ years (US$0.08/kWh)

or

$$n = \frac{\log\left(\frac{12{,}480}{12{,}480 - 49{,}500 \times 0.1}\right)}{\log(1 + 0.1)}$$

$$= \frac{\log\left(\frac{12{,}480}{2{,}530}\right)}{\log(1.1)} = \frac{0.219}{0.0414} = 5.3 \text{ years}$$

13. Air Conditioning

13.1 Summary

Effect of Improvement Cases

Improvement cases	Before	After	Effect of improvement		Investment	Payback years
Case 1 : To change temperature setting	24 [°C]	26 [°C]	25.3 [MWh/y]	7525 [$/y]	0 [$]	0 [y]
Case 2 : To reduce outside fresh air	30 [m^3/h/p]	25 [m^3/h/p]	17.3 [MWh/y]	5175 [$/y]	0 [$]	0 [y]
Case 3 : To change lighting fixtures	20 [W/m^2]	15.4 [W/m^2]	13.3+132 (*1) [MWh/y]	43590 [$/y]	504000 (*2) [$]	11.6 [y]
Case 4 : Combination of Case 1, 2, and 3	Case 1 + 2 + 3		53.3+132 [MWh/y]	55590 [$/y]	504000 [$]	9.1 [y]

*1: Energy saving for lighting is included.

*2: In order to change the conventional fluorescent lamps to Hf lamps, it is necessary to change the lighting fixtures to those suitable to Hf lamps.
With the existing building, it is usually impossible to change the layout or the number of lighting fixtures.
In case 3 and 4, it was assumed that the layout or the number of lighting fixtures were not changed.

13.2 Cooling load calculated on the given conditions (Case 0)

Cooling load of the room R5S (south side room in the 5th floor) calculated on the given conditions is shown in Table 1 and Fig.1. Peak cooling load is 71.8 [kW] at 12 o'clock.

Cooling load of the room R5N(north side room in the 5th floor) calculated on the given conditions is shown in Table 2 and Fig.2. Peak cooling load is 61.2 [kW] at 12 o'clock

Peak cooling load of the 5th floor is 133 [kW] at 12 o'clock.

Assuming that cooling load of each floor is the same, cooling load of the whole building is 1,330 [kW]. Cooling load per unit area of the air-conditioned room is 115.4 [W/m^2].

13.3 Effects of energy conservation techniques

Peak & annual cooling load, energy consumption, initial cost, and saved running cost were calculated for the following cases.

Case 1: To change temperature settings
- 24 [°C], 50 [%], (9.5 [g/kgDA])..................26 [°C], 50 [%], (10.7 [g/kgDA]
- Cost..0

Case 2: To reduce outside fresh air intake
- 30 [m^3/h/P] ....25 [m^3/h/P]
- Cost..0

Case 3: To change lighting fixtures to high efficiency type
- 20 [W/m^2]..15.4 [W/m^2]

1) Existing lighting fixture (conventional fluorescent lamp)
   40 W × 3 lamps/unit (9000 lm/unit)
   127.5 W/unit (energy consumption)
   1800 units/building
2) High efficiency lighting fixture (Hf fluorescent lamp)
   32 W × 2 lamps/unit (9000 lm/unit)
   98 W/unit (energy consumption)
   1800 units/building

- Cost...0

Case 4: Combination of Case 1, 2, and 3

Table 1 Cooling Load of the Room R5S (South side room in the 5th floor)

COOLING LOAD CALCULATION SHEET

Floor	5	F
Room Name	R5S	
Room Air Temperature	24	[C]
Room Air Humidity	9.5	[g/kgDA]

Time			8	9	10	11	12	13	14	15	16	17	18
Δ θo : Air Temp. Difference	[deg C]		5	7	8	9	9	9	9	9	8	8	7
Δ Xo : Air Humidity Difference	[g/kgDA]		10	10	10	10	10	10	10	10	10	10	10
Δ θe : Equivalent Temp. Difference	[deg C]	roof	11	16	21	27	31	34	35	34	32	28	23
		N	6	7	7	8	9	10	10	10	11	11	11
		E	16	20	21	21	18	16	14	13	12	11	10
		S	4	6	8	11	13	15	16	16	14	13	11
		W	4	5	7	8	9	11	14	18	22	25	25
Sn : Solar Heat Gain	[W/m2]	N	38	42	43	43	43	43	43	40	38	76	99
		S	40	77	131	171	180	157	108	56	36	30	20

Exterior Walls or Roof

	Aw(m2)	Kw(W/m2C)		Direction												Day Total
Roof	0	0		roof	0	0	0	0	0	0	0	0	0	0	0	0
Wall-1	0	0		N	0	0	0	0	0	0	0	0	0	0	0	0
Wall-2	37	1.17		E	779	952	996	996	866	779	693	649	606	563	519	8398
Wall-3	113.92	1.17		S	800	1066	1333	1733	1999	2266	2399	2399	2133	1999	1733	19860
Wall-4	37	1.17		W	260	303	390	433	476	563	693	866	1039	1169	1169	7359
Total					1839	2322	2718	3161	3341	3608	3784	3914	3778	3731	3421	35617

Interior Walls etc.

	Aw(m2)	Kw(W/m2C)	d (ND)													Day Total
Ceiling	576	1.49	0		0	0	0	0	0	0	0	0	0	0	0	0
Floor	576	1.49	0		0	0	0	0	0	0	0	0	0	0	0	0
Wall-1	213.12	0.84	0.25		313	403	448	492	492	492	492	492	448	448	403	4923
Wall-2	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
Wall-3	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
Wall-4	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
Total					313	403	448	492	492	492	492	492	448	448	403	4923

Windows (heat transmission due to air temp. difference)

	Ag(m2)	Kg(W/m2C)	BLIND													Day Total
Window-1	49.6	6.29	OPENED		2184	2808	3120	3432	3432	3432	3432	3432	3120	3120	2808	34318
Window-2	49.6	4.95	CLOSED		1719	2210	2455	2701	2701	2701	2701	2701	2455	2455	2210	27007
Total					3903	5018	5575	6133	6133	6133	6133	6133	5575	5575	5018	61325

Windows (Solar heat gain)

	Ag(m2)	SC(ND)	BLIND	Direction												Day Total
Window-1-N	0	0	OPENED	N	0	0	0	0	0	0	0	0	0	0	0	0
Window-2-N	0	0	CLOSED	N	0	0	0	0	0	0	0	0	0	0	0	0
Window-1-S	49.6	0.96	OPENED	S	1905	3666	6238	8142	8571	7476	5143	2666	1714	1428	952	47902
Window-2-S	49.6	0.53	CLOSED	S	1052	2024	3444	4495	4732	4127	2839	1472	946	789	526	26446
Total					2956	5691	9681	12638	13303	11603	7982	4139	2661	2217	1478	74347

Lighting

	Af(m2)	L(W/m2)														Day Total
	576	20			11520	11520	11520	11520	11520	11520	11520	11520	11520	11520	11520	126720

Office Equipments

	Af(m2)	qs, ql (W/m2)														Day Total
(sensible heat)	576	10			5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	63360
(latent heat)	0	0			0	0	0	0	0	0	0	0	0	0	0	0
Total					5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	63360

Human Body

	Af(m2)	qs, ql (W/m2)	P (P/m2)													Day Total
(sensible heat)	576	62.8	0.1		3617	3617	3617	3617	3617	3617	3617	3617	3617	3617	3617	39790
(latent heat)	576	55.8	0.1		3214	3214	3214	3214	3214	3214	3214	3214	3214	3214	3214	39790
Total					6831	6831	6831	6831	6831	6831	6831	6831	6831	6831	6831	75145

Air Infiltration

	Vi (m3/h)															Day Total
(sensible heat)	311.04				729	938	1042	1146	1146	1146	1146	1146	1042	1042	938	11462
(latent heat)	311.04				2585	2585	2585	2585	2585	2585	2585	2585	2585	2585	2585	28432
Total					3314	3523	3627	3731	3731	3731	3731	3731	3627	3627	3523	39894

Outside Fresh Air

	Vo (m3/h)															Day Total
(sensible heat)	1728				4052	5210	5789	6368	6368	6368	6368	6368	5789	5789	5210	63677
(latent heat)	1728				14360	14360	14360	14360	14360	14360	14360	14360	14360	14360	14360	157956
Total					18412	19570	20148	20727	20727	20727	20727	20727	20148	20148	19570	221633

													Day Total
Room Cooling Load	(sensible heat)	30637	35268	40361	44467	45312	43879	40434	36721	34400	33910	32155	417545
	(latent heat)	5799	5799	5799	5799	5799	5799	5799	5799	5799	5799	5799	63787
	TOTAL	36436	41067	46160	50266	51111	49678	46233	42520	40199	39709	37953	481332
Outside Fresh Air Cooling Load													Day Total
	(sensible heat)	4052	5210	5789	6368	6368	6368	6368	6368	5789	5789	5210	63677
	(latent heat)	14360	14360	14360	14360	14360	14360	14360	14360	14360	14360	14360	157956
	TOTAL	18412	19570	20148	20727	20727	20727	20727	20727	20148	20148	19570	221633
Total Cooling Load													Day Total
	(sensible heat)	34689	40478	46150	50835	51680	50247	46802	43089	40189	39699	37364	481222
	(latent heat)	20159	20159	20159	20159	20159	20159	20159	20159	20159	20159	20159	221744
	TOTAL	54848	60636	66309	70993	71839	70405	66961	63247	60347	59857	57523	702965

Table 2 Cooling Load of the Room R5S (North side room in the 5th floor)

COOLING LOAD CALCULATION SHEET

Floor	5	F												
Room Name	R5N													
Room Air Temperature	24	[C]												
Room Air Humidity	9.5	[g/kgDA]												
Time				8	9	10	11	12	13	14	15	16	17	18
Δ θo : Air Temp. Difference		[deg C]		5	7	8	9	9	9	9	9	8	8	7
Δ Xo : Air Humidity Difference		[g/kgDA]		10	10	10	10	10	10	10	10	10	10	10
Δ θe : Equivalent Temp. Difference		[deg C]	roof	11	16	21	27	31	34	35	34	32	28	23
			N	6	7	7	8	9	10	10	10	11	11	11
			E	16	20	21	21	18	16	14	13	12	11	10
			S	4	6	8	11	13	15	16	16	14	13	11
			W	4	5	7	8	9	11	14	18	22	25	25
Sn : Solar Heat Gain		[W/m2]	N	38	42	43	43	43	43	43	40	38	76	99
			S	40	77	131	171	180	157	108	56	36	30	20

Exterior Walls or Roof																
	Aw[m2]	Kw[W/m2C]		Direction												Day Total
Roof	0	0		roof	0	0	0	0	0	0	0	0	0	0	0	0
Wall-1	113.92	1.17		N	1066	1200	1200	1333	1466	1599	1599	1599	1733	1733	1733	16261
Wall-2	37	1.17		E	779	952	996	996	866	779	693	649	606	563	519	8398
Wall-3	0	0		S	0	0	0	0	0	0	0	0	0	0	0	0
Wall-4	37	1.17		W	260	303	390	433	476	563	693	866	1039	1169	1169	7359
Total					2105	2455	2585	2761	2808	2941	2985	3115	3378	3464	3421	32019
Interior Walls etc.																
	Aw[m2]	Kw[W/m2C]	d [ND]													Day Total
Ceiling	576	1.49	0		0	0	0	0	0	0	0	0	0	0	0	0
Floor	576	1.49	0		0	0	0	0	0	0	0	0	0	0	0	0
Wall-1	213.12	0.84	0.25		313	403	448	492	492	492	492	492	448	448	403	4923
Wall-2	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
Wall-3	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
Wall-4	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
Total					313	403	448	492	492	492	492	492	448	448	403	4923
Windows (heat transmission due to air temp. difference)																
	Ag[m2]	Kg[W/m2C]	BLIND													Day Total
Window-1	49.6	6.29	OPENED		2184	2808	3120	3432	3432	3432	3432	3432	3120	3120	2808	34318
Window-2	49.6	4.95	CLOSED		1719	2210	2455	2701	2701	2701	2701	2701	2455	2455	2210	27007
Total					3903	5018	5575	6133	6133	6133	6133	6133	5575	5575	5018	61325
Windows (Solar heat gain)																
	Ag[m2]	SC[ND]	BLIND	Direction												Day Total
Window-1-N	49.6	0.96	OPENED	N	1809	2000	2047	2047	2047	2047	2047	1905	1809	3619	4714	26094
Window-2-N	49.6	0.53	CLOSED	N	999	1104	1130	1130	1130	1130	1130	1052	999	1998	2603	14406
Window-1-S	0	0	OPENED	S	0	0	0	0	0	0	0	0	0	0	0	0
Window-2-S	0	0	CLOSED	S	0	0	0	0	0	0	0	0	0	0	0	0
Total					2808	3104	3178	3178	3178	3178	3178	2956	2808	5617	7316	40499
Lighting																
	Af[m2]	L[W/m2]														Day Total
	576	20			11520	11520	11520	11520	11520	11520	11520	11520	11520	11520	11520	126720
Office Equipments																
	Af[m2]	qs, ql [W/m2]														Day Total
(sensible heat)	576	10			5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	63360
(latent heat)	0	0			0	0	0	0	0	0	0	0	0	0	0	0
Total					5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	63360
Human Body																
	Af[m2]	qs, ql [W/m2]	P [P/m2]													Day Total
(sensible heat)	576	62.8	0.1		3617	3617	3617	3617	3617	3617	3617	3617	3617	3617	3617	39790
(latent heat)	576	55.8	0.1		3214	3214	3214	3214	3214	3214	3214	3214	3214	3214	3214	39790
Total					6831	6831	6831	6831	6831	6831	6831	6831	6831	6831	6831	75145
Air Infiltration																
	Vi [m3/h]															Day Total
(sensible heat)	311.04				729	938	1042	1146	1146	1146	1146	1146	1042	1042	938	11462
(latent heat)	311.04				2585	2585	2585	2585	2585	2585	2585	2585	2585	2585	2585	28432
Total					3314	3523	3627	3731	3731	3731	3731	3731	3627	3627	3523	39894

Outside Fresh Air																
	Vo [m3/h]															Day Total
(sensible heat)	1728				4052	5210	5789	6368	6368	6368	6368	6368	5789	5789	5210	63677
(latent heat)	1728				14360	14360	14360	14360	14360	14360	14360	14360	14360	14360	14360	157956
Total					18412	19570	20148	20727	20727	20727	20727	20727	20148	20148	19570	221633

Room Cooling Load													Day Total
	(sensible heat)	30756	32814	33725	34608	34654	34788	34831	34739	34148	37043	37993	380098
	(latent heat)	5799	5799	5799	5799	5799	5799	5799	5799	5799	5799	5799	63787
	TOTAL	36555	38613	39523	40406	40453	40586	40630	40538	39947	42842	43792	443885
Outside Fresh Air Cooling Load													Day Total
	(sensible heat)	4052	5210	5789	6368	6368	6368	6368	6368	5789	5789	5210	63677
	(latent heat)	14360	14360	14360	14360	14360	14360	14360	14360	14360	14360	14360	157956
	TOTAL	18412	19570	20148	20727	20727	20727	20727	20727	20148	20148	19570	221633
Total Cooling Load													Day Total
	(sensible heat)	34808	38024	39513	40975	41022	41155	41199	41107	39937	42832	43203	443775
	(latent heat)	20159	20159	20159	20159	20159	20159	20159	20159	20159	20159	20159	221744
	TOTAL	54967	58183	59672	61134	61181	61314	61357	61265	60095	62990	63361	665519

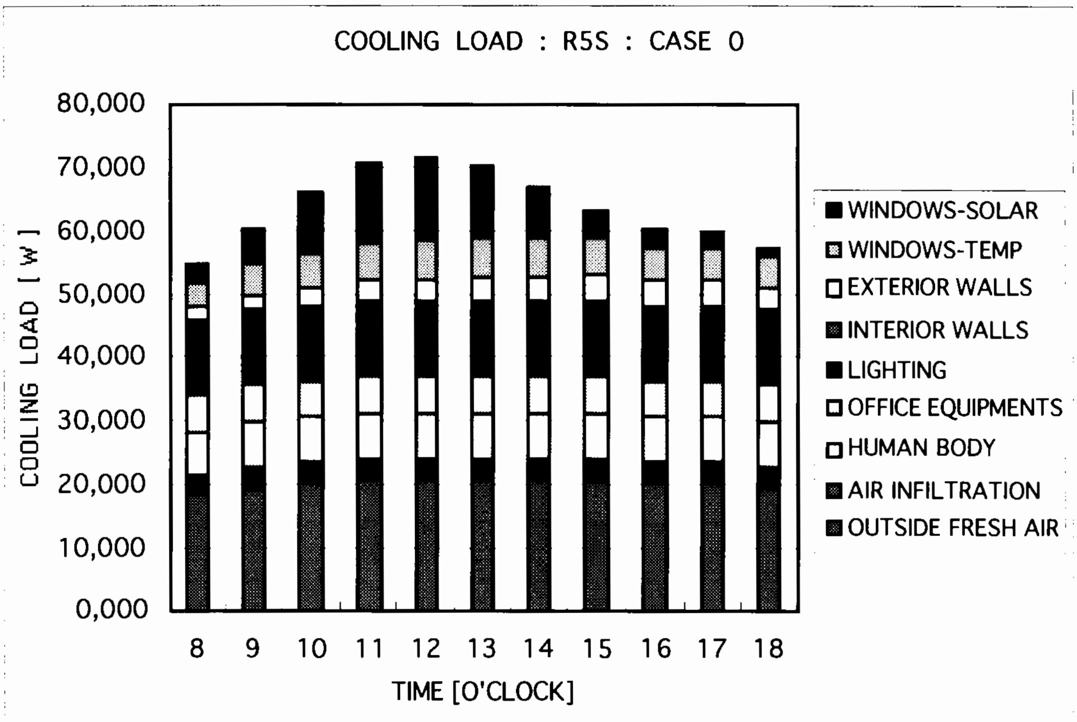


Fig. 1 Cooling Load: R5S: Case 0

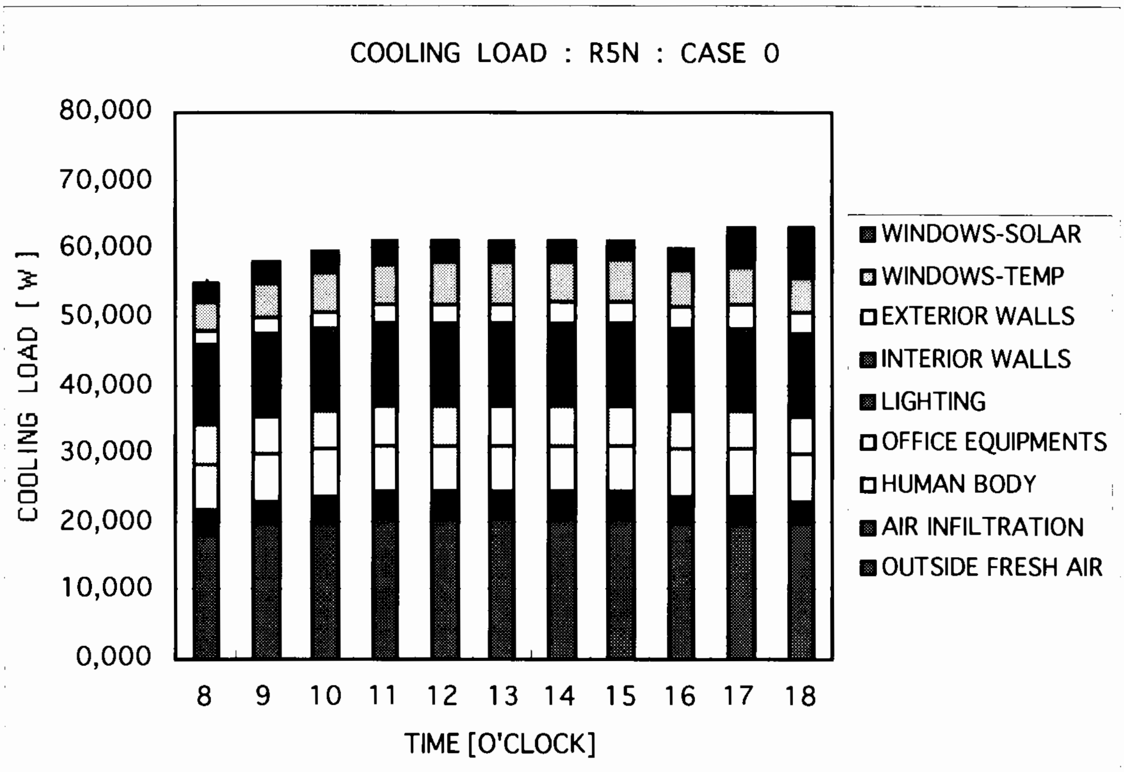


Fig. 2 Cooling Load: R5N: Case 0

Cooling load of the whole building in the summer peak day with the Case 0, 1, 2, 3, and 4 are shown in Fig. 3.

In Table 3, peak and annual cooling load of the building are shown.

Table 3 Peak & Annual Cooling Load of the Building

Improvement cases	Peak load (12:00) [kW]			Annual load [MWh/y]
	South room	North room	Building total	Building total
Case 0 : Existing building	71.8	61.2	1,330	1,330
Case 1 : To change temperature setting	66.8	56.1	1,229	1,229
Case 2 : To reduce outside fresh air	68.4	57.7	1,261	1,261
Case 3 : To change lighting fixtures	69.2	58.5	1,277	1,277
Case 4 : Combination of Case1, 2, 3	61.2	50.5	1,112	1,112

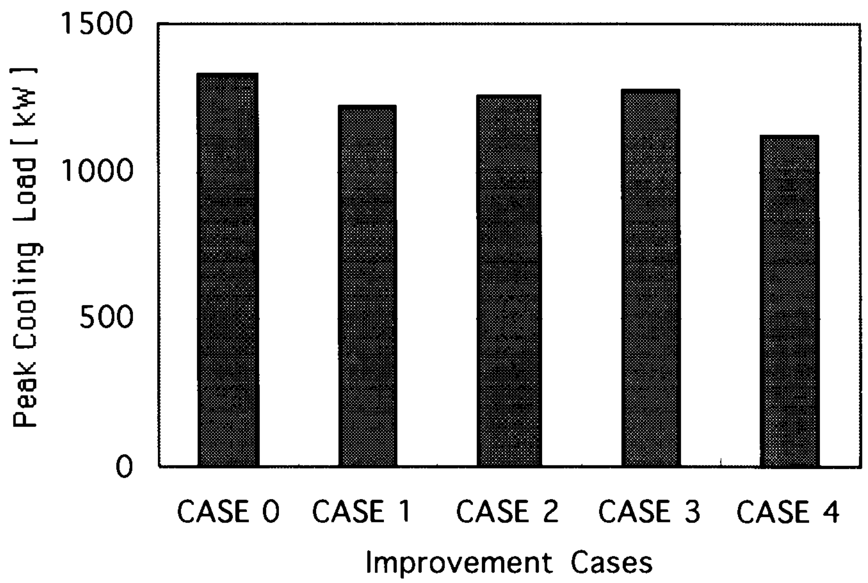


Fig. 3 Improvement Cases

14. Heat Insulation

14.1 Summary

(1) When fuel price is low ($0.1/kg)

Apparatus	Improvement item	Present data			Improvement effect					Energy reduction rate	Invested amount	Investment recovering years
					Specific consumption		Energy cost					
		Production	Energy consumption	Specific consumption	Reduced specific consumption	Specific consumption after improvement	Before improvement	Reduced amount	After improvement			
		ton-steam/y	t-oil/y	Mcal/t-steam	Mcal/t	Mcal/t	$/y	$/y	$/y	%	$	years
No.1 Boiler	Intensification of heat insulation	42,000	3,152	755.0	10.51	744.47	315,200	4,387	310,813	1.39	12,216	3.4
No.2 Boiler	Intensification heat insulation	36,000	2,842	794.2	12.23	781.95	284,200	4,377	279,823	1.54	7,147	1.9
Heating furnace	Intensification heat insulation	7,200	441	616.2	37.63	578.55	44,100	2,693	41,407	6.11	23,550	21.8
Steam piping	Intensification heat insulation							3,496			34,304	Not recoverable

(2) When fuel price is low ($0.2/kg)

Apparatus	Improvement item	Present data			Improvement effect					Energy reduction rate	Invested amount	Investment recovering years
					Specific consumption		Energy cost					
		Production	Energy consumption	Specific consumption	Reduced specific consumption	Specific consumption after improvement	Before improvement	Reduced amount	After improvement			
		ton-steam/y	t-oil/y	Mcal/t-steam	Mcal/t	Mcal/t	$/y	$/y	$/y	%	$	years
No.1 Boiler	Intensification of heat insulation	42,000	3,152	755.0	10.51	744.47	630,400	8,774	621,626	1.39	12,216	1.6
No.2 Boiler	Intensification heat insulation	36,000	2,842	794.2	12.23	781.95	568,400	8,754	559,646	1.54	7,147	0.9
Heating furnace	Intensification heat insulation	7,200	441	616.2	37.63	578.55	88,200	5,386	82,814	6.11	23,550	6.0
Steam piping	Intensification heat insulation							6,992			34,304	7.1

14.2 No. 1 boiler

(1) Present condition

50 mm unspecified insulation is used to as the hot insulation material, but considering that the surface temperature is still high and is 150°C, the hot insulation cannot be said sufficient.

(Calculation of the quantity of dissipation heat)

If the surface temperature is known, the quantity of dissipation heat per unit area can be determined by equation 3-9 and -12 (p.26, 27) of Textbook. The quantity of dissipation heat per unit area, when the ambient air temperature is 33°C, emissivity is 0.85, is

From the vertical wall:

$$Q_r = 5.68 \times 0.85 \left(\left(\frac{273 + 150}{100}\right)^4 - \left(\frac{273 + 33}{100}\right)^4 \right)$$

$$= 1{,}122 \text{ W/m}^2$$

$$Q_c = 2.56\,(150 - 33)^{.25} \times (150 - 33) = 985 \text{ W/m}^2$$

$$Q = Q_r + Q_c = 2{,}104 \text{ W/m}^2$$

From the cylindrical wall:

$$Q_r = 5.68 \times 0.85 \left(\left(\frac{273 + 150}{100}\right)^4 - \left(\frac{273 + 33}{100}\right)^4 \right)$$

$$= 1{,}122 \text{ W/m}^2$$

$$Q_c = 2.44\,(\,(150 - 33)/2.9\,)^{.25} \times (150 - 33) = 719 \text{ W/m}^2$$

$$Q = Q_r + Q_c = 1{,}841 \text{ W/m}^2$$

Surface area is

Vertical wall: $2.9^2 \times 3.14/4 \times 2 = 13.2$ m^2

Cyrindrical wall: $2.9 \times 3.14 \times 6 = 54.7$ m^2

The quantity of dissipation heat is 2,104 × 13.2 + 1,841 × 54.7 = 128,476 W.

As the annual operting hours are 4,200 h/y, the heat loss is

128,476 × 4,200 = 5.40 × 10^5 kWh/y = 19.44 × 10^8 kJ/y.

The thermal conductivity of unspecified insulation is

$$Q_a = \frac{\lambda\,(\theta_1 - \theta_0)}{L}$$

$$\lambda = Qa \frac{L}{(\theta_1 - \theta_0)} = 2104 \times \frac{0.05}{(175 - 150)} = 4.21 \text{ W/m·K}$$

(2) Improvement

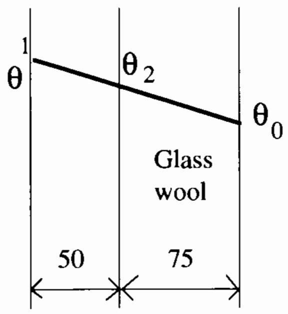
Applying hot insulation to the surface to reduce the quantity of dissipation heat

(Selection of hot insulation material)

Hot insulation and cold insulation materials stated by JIS are seven types including rock wool, glass wool, cattle hair felt, calcium silicate, polystyrene foam, water repellent pearlite and hard urethane foam. Of these, cattle hair felt, polystyrene foam and hard urethane foam are used mainly for cold insulation, with the maximum temperatures 70°–100°C, so these materials are not usable. Of the remaining four types, calcium silicate and water repellent pearlite are high in the maximum working temperature, but the thermal conductivity is relatively high. Incidentally, ceramic fiber is also available, but it is not used for this sort of low-temperature heat insulation because of its very high cost. Thus, either rock wool or glass wool is most suitable for this purpose.
Physical properties of rock wool and glass wool are very similar, but rock wool is higher in the maximum working temperature and slightly higher in the thermal conductivity. Besides that, for shape as well, bulk fiber, sheet, felt, tubular, belt and blanket are prepared for selection according to the place of use. Moreover, these are classified by density, ones with high density are also high in the maximum working temperature.
As this boiler is 175°C in the maximum working temperature, glass wool is the best suit. For shape, the hot insulation board No.2, 48K is used.

(Calculation of the quantity of dissipation heat)

Using equations 3-1 thru 3-14 (p.25–28) of Textbook, the surface temperature and the dissipation heat per unit area are calculated.



The quantity of heat conduction is determined by

$$Q_a = \frac{\lambda_1}{L_1}(\theta_1 - \theta_2) = \frac{\lambda_2}{L_2}(\theta_2 - \theta_0).$$

As shown in the textbook, the thermal conductivity of glass wool 48K is expressed by cubic equation.

$0.0328 + 8.44 \times 10^{-5}\,\theta + 5.84 \times 10^{-7}\,\theta^2$ W/k or

$0.0282 + 7.2584 \times 10^{-5}\,\theta + 5.0224 \times 10^{-7}\,\theta^2$ Kcal/m°C

To make the calculation simple, fix the thermal conductivity as 0.052 W/m·K. Thickness of the hot insulation material is set to be 75 mm, which is the economical hot insulation thickness as stated in JIS (Table 26). As θ_1 = 175°C and θ_a = 33°C, $Q_c + Q_r$ is determined by supposing to. From the relationship of $Q_a = Q_c + Q_r$, t_2 and t_0 are calculated as

$$\theta_2 = \theta_1 - (Q_c + Q_r)\frac{L_1}{\lambda_1} \qquad \theta_0 = \theta_2 - (Q_r + Q_c)\frac{L_2}{\lambda_2}$$

and the calculation is made repeatedly until the determined value is close to the assumed value.

The value of Q_a when the assumed value is almost reached is the quantity of dissipation heat.

In this case the quantity of dissipation heat per unit area is

From the vertical wall: 88 W/m^2

From the cylindrical wall: 85 W/m^2

By multiplying this by area

$88 \times 14.6 + 85 \times 58.9 = 6,291$ W

Heat loss for one year: 2.64×10^4 kW·h/y = 9.504×10^7 kJ/y

The heat loss is reduced to 5% compared with the condition before improvement.

(3) Investment effectiveness

1) Heat insulation installation cost

Heat insulation installation cost per unit volume, a, can be found using the following formula, on which the economic heat insulation thickness calculation method specified by JIS A 9501, as quoted on p. 34 of the textbook, is based:

$a = 1.2\ (12{,}000X_0^{-K} + 100) \times 10^3$ yen/m^3,

where X_0: Heat insulation thickness in mm (assumed 75 mm)

K: Coefficient (= 1.28, as the boiler outside diameter = 2900 mm)

Substituting $X_0 = 75$ and $K = 1.28$ yields:

a = $2,216/$m^3$

Multiplying this by the boiler surface area (14.6 + 58.9 = 73.5 m^2) and the heat insulation thickness (0.075 m) results in:

Heat insulation installation cost = $2,216 \times 73.5 \times 0.075$ = $12,216

2) Energy saving effect of stepped up heat insulation

As quoted in model factory, energy unit price is specified as follow:

Heat value of fuel: 11,700 W·h/kg = 42,119 kJ/kg

Fuel charge: $0.1/kg (when fuel prices is low) and $0.2/kg (when fuel price is high)

Also, heat dissipation before and after improvement is as follows:

Before: 19.44×10^8 kJ/y p.a.

After: 9.50×10^7 kJ/y p.a.

The energy saving effect then becomes:

$(19.44 \times 10^8 - 9.50 \times 10^7)/42{,}119 \times 0.1$ = $4,390 p.a. (when fuel price is low)

$(19.44 \times 10^8 - 9.50 \times 10^7)/42{,}119 \times 0.2$ = $8,780 p.a. (when fuel price is high)

3) Recovery period of improvement cost

Recovery period = heat insulation installation cost/energy saving effect

$$n = \frac{\log\left(\frac{4,390}{4,387 - 12,216 \times 0.1}\right)}{\log(1 + 0.1)} = 3.4 \text{ years (when fuel price is low)}$$

$$n = \frac{\log\left(\frac{8,780}{8,774 - 12,216 \times 0.1}\right)}{\log(1 + 0.1)} = 1.6 \text{ years (when fuel price is high)}$$

At 150°C, the external wall of No. 1 Boiler was very hot, with large amounts of heat dissipation, so that the energy saving effect was significant, resulting in an investment recovery period of a year.

14.3 No. 2 boiler

(1) Present condition

50 mm unspecified insulation is used to as the hot insulation material either, the surface temperature is high and is 150°C, and the quantity of dissipation heat per unit area is

From the vertical wall: $Q = Q_r + Q_c = 2,105$ W/m^2

From the cylindrical wall: $Q = Q_r + Q_c = 1,902$ W/m^2

The surface area is

Vertical wall: $2.1^2 \times 3.14/4 \times 2 = 6.9$ m^2

Cylindrical wall: $2.1 \times 3.14 \times 4.8 = 31.7$ m^2

The quantity of dissipation heat is

$2,105 \times 6.9 + 1,902 \times 31.7 = 74,818$ W.

As the annual opeating hours are 7200 h/y, the heat loss is

$74,818 \times 7200 = 5.39 \times 10^8$ W/y

The thermal conductivity of unspecified insulation is

$\lambda = 4.21$ W/m·K

(2) Improvement

Like the case of the No. 1 Boiler, the glass wool hot insulation board No.2, 48K is used, and the thickness is set as 75 mm.

Likewise, as the quantity of dissipation heat per unit area after hot insulation is

From the vertical wall: $Q = Q_r + Q_c = 88$ W/m^2

From the cylindrical wall: $Q = Q_r + Q_c = 85$ W/m^2

The surface area is

Vertical wall: $2.25^2 \times 3.14/4 \times 2 = 8.0$ m^2

Cylindrical wall: $2.25 \times 3.14 \times 4.95 = 35.0$ m^2

The quantity of dissipation heat is

$88 \times 8.0 + 85 \times 35.0 = 3{,}679$ W.

For one year it is $3{,}679 \times 7{,}200 = 2.65 \times 10^4$ kW·h/y $= 9.54 \times 10^7$ kJ/y.

(3) Investment effectiveness

1) Heat insulation installation cost

Since heat insulation installation cost per unit volume is the same as No. 1 Boiler, total installation cost can be obtained by multiplying it by the boiler surface area (8 + 35 = 43 m^2) and heat insulation thickness (0.075 m) as follows:

Heat insulation installation cost = $2{,}216 \times 43 \times 0.075 = \$7{,}147$

2) Energy saving effect of stepped up heat insulation

Heat dissipation before and after improvement is:

Before: 19.40×10^8 kJ/y

After: 9.54×10^7 kJ/y

The energy saving effect then becomes:

$(19.40 \times 10^8 - 9.54 \times 10^7)/42{,}119 \times 0.1 = \$4{,}377$ p.a. (when fuel price is low)

$(19.40 \times 10^8 - 9.54 \times 10^7)/42{,}119 \times 0.2 = \$8{,}754$ p.a. (when fuel price is high)

3) Recovery period of improvement cost

Recovery period:

$$n = \frac{\log\left(\dfrac{4{,}377}{4{,}337 - 7{,}147 \times 0.1}\right)}{\log(1 + 0.1)} = 1.9 \text{ years (when fuel price is low)}$$

$$n = \frac{\log\left(\dfrac{8{,}754}{8{,}754 - 7{,}147 \times 0.1}\right)}{\log(1 + 0.1)} = 0.89 \text{ year (when fuel price is high)}$$

Since No. 2 Boiler has longer operating hours than No. 1 Boiler, the energy saving effect of stepped up heat insulation is considerable, resulting in an even shorter recovery period.

14.4 Dyeing machine

(1) Present condition

Dyeing machines involve the three processes of dyeing, fixing and softening, and heat losses must be calculated for each process separately, as the treatment temperature and duration differ from process to process. Calculations should be conducted based on the tank surface temperature given for the treatment temperature of each process.

As the tank is made of stainless steel, it is assumed that ε = 0.35, where ε is emissivity. The tank is almost cylindrical in shape, and separate calculations must be made of the cylindrical surface wall and the vertical walls, as in the case of a boiler.

Each process has a heating period, and the heat loss during this period should be calculated assuming that the tank surface temperature is the average of the treatment temperature and room temperature.

Detailed calculation results for heat loss per operation cycle are shown in the following table:

Operation period	Portion	Surface temp. (°C)	Surface area (m^2)	Dissipation heat (W/m^2)	Time/cycle (h)	Dissipation heat/cycle
Heat up to dyeing	Cylindrical wall	61.5	9.33	224	60/60	7,539
	Vertical wall	61.5	2.74	243	60/60	2,399
	Total					9,938
Dyeing	Cylindrical wall	90	9.33	528	40/60	11,821
	Vertical wall	90	2.74	571	40/60	3,753
	Total					15,576
Heat up to fixing	Cylindrical wall	54	9.33	156	20/60	1,746
	Vertical wall	54	2.74	167	20/60	553
	Total					2,299
Fixing	Cylindrical wall	75	9.33	361	20/60	4,035
	Vertical wall	75	2.74	391	20/60	1,285
	Total					5,320
Softening	Cylindrical wall	45	9.33	80	20/60	900
	Vertical wall	45	2.74	86	20/60	285
	Total					1,185
Total per 1 unit						34,318

Dyeing machines are operated three times a day 300 days a year, and this brings their annual heat loss per unit to the following:

$34{,}318 \times 3 \times 300 = 3.089 \times 10^7$ kJ p.a.

(2) Improvement

As the dyeing machines are not provided with heat insulation, there is considerable heat loss associated with them, and therefore a heat insulator should be provided over the tank surface. Since the tank surface temperature is low, only 90°C maximum, the material of the insulator can be polyethylene foam, which has a low thermal conductivity.
The thickness of the heat insulator is to be set to 15 mm, as the benefit of a further increase in thickness in terms of heat loss reduction would be limited.
Assuming that heat stored in the tank shell and heat insulator is negligible, a detailed calculation was made of heat loss per operation cycle after the provision of heat insulation, using $\lambda = 0.031 + 0.000186\theta$, and $\varepsilon = 0.23$, where λ and ε are thermal conductivity and emissivity, respectively, and the results are shown in the following table:

Operation period	Portion	Surface temp. (°C)	Surface area (m^2)	Dissipation heat (W/m^2)	Time/cycle (h)	Dissipation heat/cycle
Heat up to dyeing	Cylindrical wall	42	9.33	52	60/60	1,758
	Vertical wall	42	2.74	53	60/60	527
	Total					2,286
Dyeing	Cylindrical wall	51	9.33	114	40/60	2,553
	Vertical wall	50	2.74	120	40/60	787
	Total					3,340
Heat up to fixing	Cylindrical wall	40	9.33	37	20/60	419
	Vertical wall	40	2.74	38	20/60	126
	Total					545
Fixing	Cylindrical wall	46	9.33	80	20/60	900
	Vertical wall	46	2.74	83	20/60	272
	Total					1,172
Softening	Cylindrical wall	37	9.33	20	20/60	222
	Vertical wall	37	2.74	21	20/60	67
	Total					289
Total per 1 unit						7,632

The annual heat loss per unit is then calculated as follows:

$7{,}632 \times 3 \times 300 = 6.87 \times 10^6$ kJ p.a.

(3) Investment effectiveness

1) Heat insulation installation cost

As in the case of glass wool, the unit cost is calculated using the formula given in the textbook. However, the calculation result is halved for polyethylene foam, as the unit cost of polyethylene foam is about half that of glass wool.
This results in unit cost = 3,561/m^3, assuming that insulation thickness = 15 mm and tank diameter = 1.32 m.
Multiplying this by the tank surface area (9.33 + 2.74 = 12.07 m^2) and the heat insulation thickness (0.015 m) yields:
Heat insulation installation cost = 3,561 × 12.07 × 0.015 = $645

2) Energy saving effect of heat insulator installation

$(3.089 \times 10^7 - 6.87 \times 10^6)/42{,}119 \times 0.1 = \$57$ p.a. (when fuel price is low)

$(3.089 \times 10^7 - 6.87\times 10^6)/42{,}119 \times 0.2 = \$114$ p.a. (when fuel price is high)

3) Recovery period of improvement cost

Recovery period:

$$n = \frac{\log\left(\dfrac{57}{57 - 645 \times 0.1}\right)}{\log(1 + 0.1)}$$ = Not recoverable (when fuel price is low)

$$n = \frac{\log\left(\dfrac{114}{114 - 645 \times 0.1}\right)}{\log(1 + 0.1)}$$ = 8.8 years (when fuel price is high)

14.5 Drying machine

(1) Present condition

Drying machines are provided with a 20 mm-thick glass wool heat insulator.
As the drying machines are rectangular in shape, heat dissipation must be calculated for the top, side walls and base separately.
Assuming that heat stored in the shell and heat insulator is negligible, the heat loss per unit is calculated in detail using internal temperature = 82°C, λ = 0.052 W/m·K and ε = 0.23, where λ and ε are the thermal conductivity of glass wool and emissivity, respectively, and the results are shown in the following table:

Portion	Surface temp. (°C)	Surface area (m^2)	Dissipation heat (W/m^2)	Dissipation heat (W)
Roof	45	102	95	9,723
Vertical wall	47	230	92	21,132
Bottom	50	102	85	8,664
Total per 1 unit				39,519

Since drying machines are operated 13 hours a day 300 days a year, the annual heat loss per unit comes to the following:

$39{,}519 \times 13 \times 300 = 1.541 \times 10^5$ kWh p.a. $= 5.548 \times 10^8$ kJ p.a.

(2) Improvement

To strengthen the heat insulation of the drying machines, the thickness of the heat insulator is to be increased.

Glass wool, the same material as the existing heat insulator, is to be used, with the thickness set to 50 mm, which, according to Table 25 of the textbook, is the most economical at an internal temperature of 100°C.

The heat loss per operation cycle after the strengthening of heat insulation was calculated in detail, assuming that $\lambda = 0.052$ W/m·K and $\varepsilon = 0.23$, where λ and ε are the thermal conductivity of glass wool and emissivity, respectively, and the results are shown in the following table:

Portion	Surface temp. (°C)	Surface area (m^2)	Dissipation heat (W/m^2)	Dissipation heat (W)
Roof	40	102	44	4,508
Vertical wall	41	230	43	9,897
Bottom	42	102	42	4,271
Total per 1 unit				18,676

The annual heat loss per unit comes to the following:

$18{,}676 \times 13 \times 300 = 7.284 \times 10^4$ kWh p.a. $= 2.622 \times 10^8$ kJ p.a.

(3) Investment effectiveness

1) Heat insulation installation cost

The unit price of glass wool at an installed thickness of 50 mm is given as \$2,704/m^3 from the table.

Multiplying this by the surface area of the drying machine (102 + 230 + 102 = 434 m^2) and insulator thickness (0.05 m) yields:

Heat insulation installation cost = $2{,}704 \times 434 \times 0.05$ = \$58,677

2) Energy saving effect of heat insulator installation

$(5.546 \times 10^8 - 2.622\times 10^8)/42{,}119 \times 0.1$ = \$694 p.a. (when fuel price is low)

$(5.546 \times 10^8 - 2.622\times 10^8)/42{,}119 \times 0.2$ = \$1,388 p.a. (when fuel price is high)

3) Payback period of improvement costs

According to the following calculation formula, the investment cannot be recovered as the antilogarithm of the numerator of the right hand side becomes negative, indicating that the investment is too large compared to the expected energy saving effect.

Recovery period:

$$n = \frac{\log\left(\dfrac{694}{694 - 58{,}677 \times 0.1}\right)}{\log(1 + 0.1)} = \text{Not recoverable (when fuel price is low)}$$

$$n = \frac{\log\left(\dfrac{1{,}388}{1{,}388 - 58{,}677 \times 0.1}\right)}{\log(1 + 0.1)} = \text{Not recoverable (when fuel price is high)}$$

Apart from the fact that drying machines operate at low internal temperatures, surface temperatures are also low, because of the 20 mm-thick glass wool heat insulator already in place, keeping the heat dissipation to very low levels. As a result, the benefit of strengthened heat insulation via increased heat insulator thickness would not be sufficient to recoup the investment, when interest payments are taken into account.

14.6 Heating furnace

(1) Present condition

Of heat loss of industrial heating furnaces, heat losses related to refractory materials composing the furnace wall include one that accumulated within the refractory materials, and one dissipated from the surface of furnace wall through refractory materials.

In the case of a batch furnace (one which is run intermittently) of which the industrial heating furnace is run by 8h/day, the accumulation heat loss is large and it sometimes present a ratio higher than that of dissipation heat loss.

Besides that, in the case of a continuous furnace, where accumulation heat loss occurs only at the starting of the furnace, the ratio is as very low as negligible.

In the case of this furnace, a continuous furnace, the accumulation heat loss is considered negligible.

(Calculation of the quantity of dissipation heat)

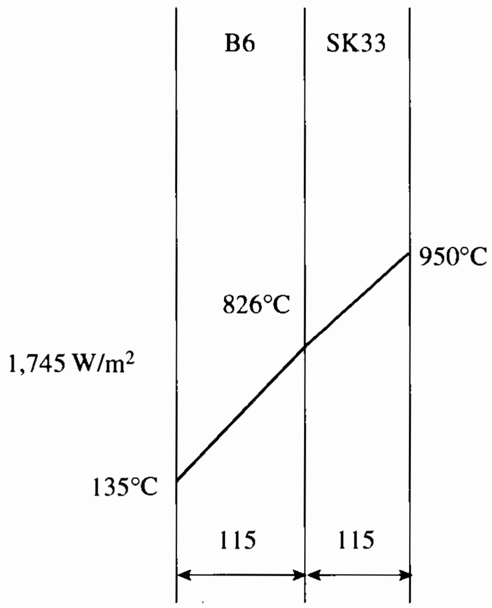
The quantity of dissipation heat is calculated using equations 3-2 thru 3-16 (P.25-28) of Textbook. As the furnace is tubular in shape, calculation is made separately for thetubular portion and flat portion.

Physical properties necessary for calculation are quoted from the textbook.

Thermal conductivity of fire clay brick:	Fixed as 1.6 W/mÆK
Thermal conductivity of insulating brick B6:	Fixed as 0.29 W/mÆK
Thermal conductivity of ceramic fiber:	Fixed as 0.17 W/mÆK
Furnace temperature (= inner surface temperature of furnace wall):	950°C
Ambient air temperature:	33°C
Emissivity of outer surface:	0.85
Inside diameter of furnace:	1200 mm

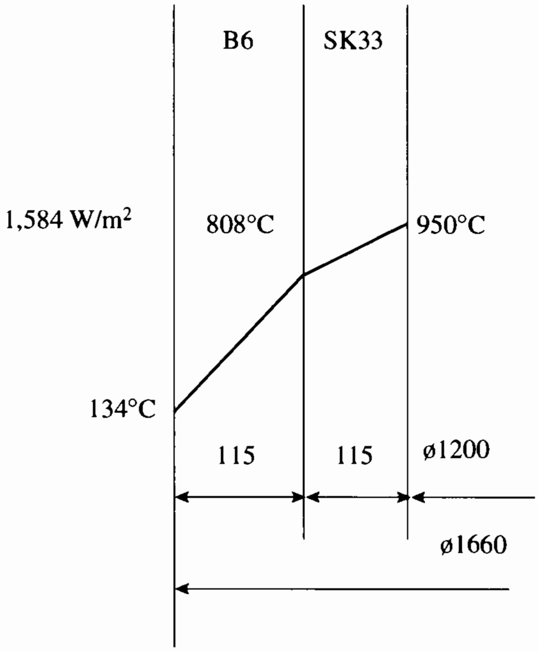
The result of calculation is the following:

1) Flat wall portion



	Thermal conductivity (W/m·K)
SK33	1.6
B6	0.29

2) Tubular portion



3) Total of heat loss from furnace wall

Tubular wall portion	$1{,}584 \times (1.66 \times \pi \times 12) =$	99,128 W
Flat wall portion	$1{,}745 \times (1.2^2 \times \pi / 4 \times 2) =$	3,947 W
Total		103,075 W

(2) Improvement

To reduce the quantity of dissipation heat from the outer surface of furnace wall, the use of refractory materials with low thermal conductivity is effective. In the case of this furnace, of which the furnace temperature is so high as 950°C, the refractory material used inside the furnace must be one with high heat resistance temperature (950°C and higher).

Besides that, as this furnace is an atmosphere furnace, the refractory material is in contact with gas. A refractory material ideal for these conditions is ceramic fiber, and in our country as well ceramic fiber is widely used for furnaces of this type.

For the configuration of furnaces using ceramic fiber, the following two methods are typical:

1) A method which, leaving the existing refractory lining, applies ceramic fiber to the inner face of the furnace, called the "veneering."

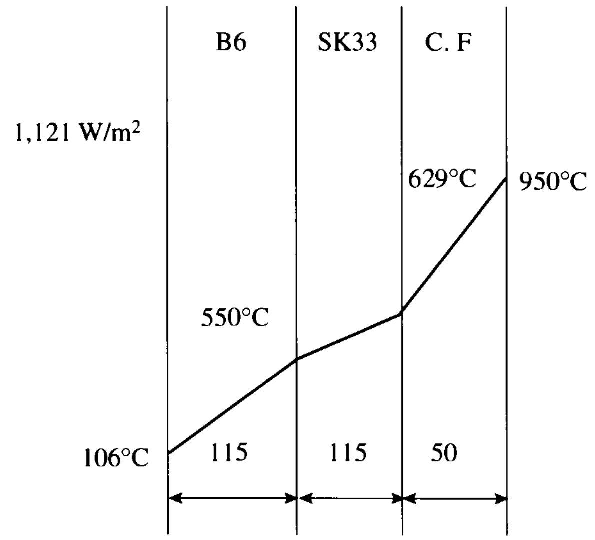
This method is simple in construction and low cost, but there is a limit in the reduction of heat loss.

2) A method which, removing all the existing refractory lining, applies ceramic fiber anew. Though this method is costly, heat loss can be reduced a lot. Many of newly installed furnaces apply this furnace wall configuration using ceramic fiber only.
The reduction effects of heat loss by these two methods are calculated as follows.
Here, in the "veneering" of the method (1), 50 mm ceramic fiber for 1260°C is applied to the inner face of the furnace wall, and in the method (2), 200 mm ceramic fiber for 1260°C is used in one layer.

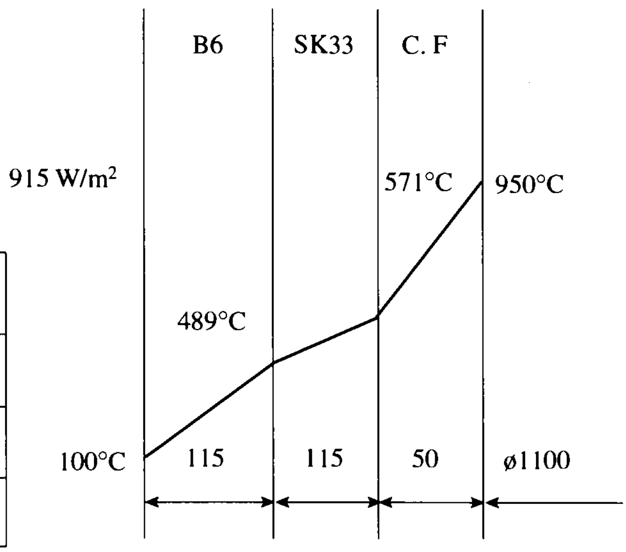
(Calculation of the quantity of dissipation heat)

Case A

1) Flat wall portion



2) Tubular wall portion



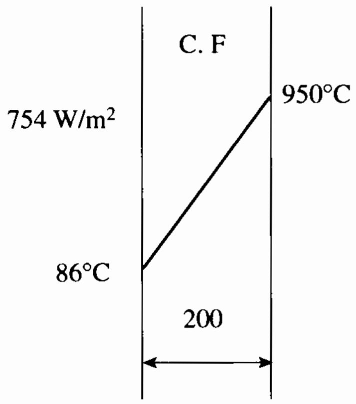
	Thermal conductivity (W/m·K)
Ceramic fiber	0.174
SK33	1.63
B6	0.29

3) Total

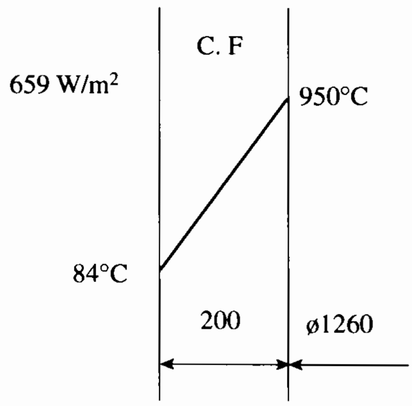
Tubular wall portion	$915 \times (1.66 \times \pi \times 12)$	=	57,261 W
Flat wall portion	$1{,}121 \times (1.1^2 \times \pi /4 \times 2)$	=	2,321 W
Total			59,582 W

Case B

1) Flat wall portion



2) Tubular wall portion



	Thermal conductivity (W/m·K)
Ceramic fiber	0.174

3) Total of heat loss from furnace wall

Tubular wall portion	$659 \times (1.66 \times \pi \times 12)$	=	41,241 W
Flat wall portion	$754 \times (1.\ 26^2 \times \pi /4 \times 2)$	=	1,880 W
	Total		43,121 W

(3) Summary

The quantity of dissipation heat is reduced to 73% in Case A and to 42% in Case B, the latter can attained more energy conservation effect.

However, Case B requires the removal of all the existing refractory material from the wall, and as lot of relatively expensive ceramic fiber is used, the cost for improvement is higher.

Whereas, Case A applies ceramic fiber over the existing refractory material of the furnace wall, so the construction is simple and the cost is less.

Because of this. the latter is often used as a method for the energy conservation of existing furnaces.

(4) Investment effectiveness

1) Heat insulation installation cost

Case A: Veneering

When the thickness of the heat insulation is 50 mm, installation cost per unit area becomes $500/m^2.

Multiplying this by the interior surface area (45.2 +1.9 = 47.1 m^2) yields:

Heat insulation installation cost = 500 × 47.2 = $23,550

Case B: All Ceramic Fiber

When the thickness of the heat insulation is 200mm, installation cost per unit area, including the removal cost of the existing furnace lining material, becomes $1,500/m^2.

Multiplying this by the interior surface area (62.5 + 2.5 = 65 m^2) yields:

Heat insulation installation cost = 1,500 × 65 = $97,500

2) Energy saving effect of stepped up heat insulation

As it is a continuous fumace, operating hours are assumed to be 24 × 300 = 7,200 p.a. Heat dissipation before and after improvement, as well as energy saving effect, can then be calculated as follows:

Case A

Heat dissipation

Before: 99,128 × 7200 = 7.137 × 10^8 Wh

After: 59,582 × 7200 = 4.290 × 10^8 Wh

Energy saving effect:

(7.137 × 10^8 – 4.290 × 10^8) / 11,700 × 0.1 = $2,433 p.a. (when fuel price is low)

(7.137 × 10^8 – 4.290 × 10^8) / 11,700 × 0.2 = $4,866 p.a. (when fuel price is high)

Case B

Heat dissipation

Before: 99,128 × 7200 = 7.137 × 10^8 Wh

After: 43,121 × 7200 = 3.105 × 10^8 Wh

Energy saving effect:

(7.137 × 10^8 – 3.105 × 10^8) / 11,700 × 0.1 = $3,446 p.a. (when fuel price is low)

(7.137 × 10^8 – 3.105 × 10^8) / 11,700 × 0.2 = $6,892 p.a. (when fuel price is high)

3) Recovery period of improvement cost

<u>Case A</u>

Recovery period

$$n = \frac{\log \left(\dfrac{2{,}693}{2{,}693 - 23{,}550 \times 0.1} \right)}{\log (1 + 0.1)} = 22 \text{ years (when fuel price is low)}$$

$$n = \frac{\log \left(\dfrac{5{,}386}{5{,}386 - 23{,}550 \times 0.1} \right)}{\log (1 + 0.1)} = 6.0 \text{ years (when fuel price is high)}$$

<u>Case B</u>

$$n = \frac{\log \left(\dfrac{3{,}694}{3{,}694 - 97{,}500 \times 0.1} \right)}{\log (1 + 0.1)} = \text{Not recoverable (when fuel price is low)}$$

$$n = \frac{\log \left(\dfrac{7{,}388}{7{,}388 - 97{,}500 \times 0.1} \right)}{\log (1 + 0.1)} = \text{Not recoverable (when fuel price is high)}$$