2004 Prize of Director General of Regional Bureau of Economy, Trade and Industry

Energy conservation through optimization of air-conditioning operation control tackled by entire company

Toyota Motor Corporation
Plant Engineering Division
Plant Planning Room

◎ **Key words: Rationalization of heating, cooling, and heat transfer (e.g. air-conditioning facilities and hot water supply facilities)**

◎ Outline of Theme

With unified efforts by those who develop and plan motive power and who operate it in each factory, energy conservation should be promoted in both aspects of operation control and operational management, through total handling of entire processes form heat source supply to air-conditioning units. Our activities are described in this document.

○ 1. Energy cost reduction including the operation of boilers as primary heat source, through establishing optimal operating techniques based on load forecasts.

○ 2. Energy cost reduction through reviewing the standards of operation, control, management, and maintenance for each factory.

◎ Implementation Period of the said Example

From January 2001 to March 2004

- Planning period: From January 2001 to June 2001 (6 months in total)
- Implementation period: From July 2001 to November 2003 (29 months in total)
- Effect confirmation period: Form June 2002 to March 2004 (22 months in total)

◎ Outline of the Business Establishment

- Production items: Automobiles
- Number of employees: 68,000
- Annual energy consumption (for FY2003, actual))
  - Electric power 2,216,678MWh
  - Fuel (crude oil equivalent) 362,298kL

◎ Outline of Target Facilities

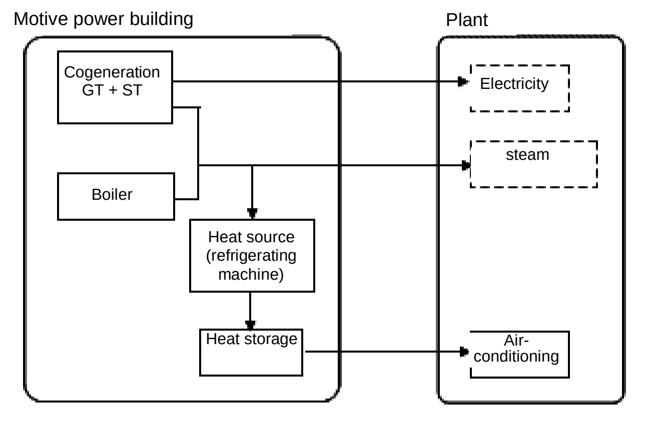

Fig. 1 Process flows in the target facilities

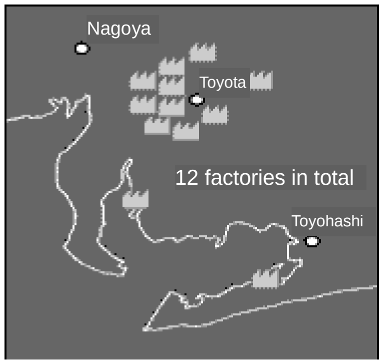

Fig. 2 Targeted factories

1. Reason for Theme Selection

Having a long term objective to halve the CO_2 intensity (kg-C/unit) of air-conditioning system in FY2007 compared to FY1995 level, we worked on transforming our air-conditioning method as the first phase of the activities (from FY1995 to FY2000), with a slogan of "challenges to the realization of highly efficient and comfortable air-conditioning system for plants in the 21st century". As a result of our activities, CO_2 intensity of air-conditioning system certainly shows a downward trend as shown in Fig. 4. As the second phase, we have been working together to develop an energy-conservation system for air-conditioning units with a series of process from energy supply to consumption. We also aim to implement more efficient measures in operational management, through establishment of optimal operating techniques based on the load forecast in the heat supply side (shaded area in on Fig. 3 indicates cogeneration, boilers, and refrigerating machines).

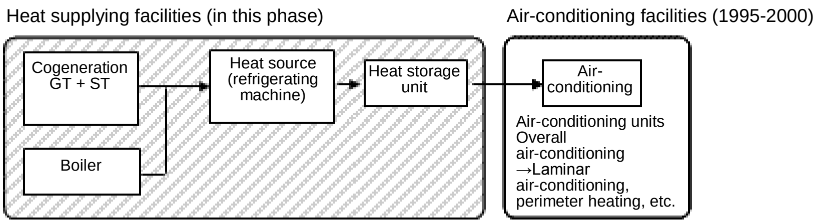

Fig. 3 Process flows in the target facilities and category of measures

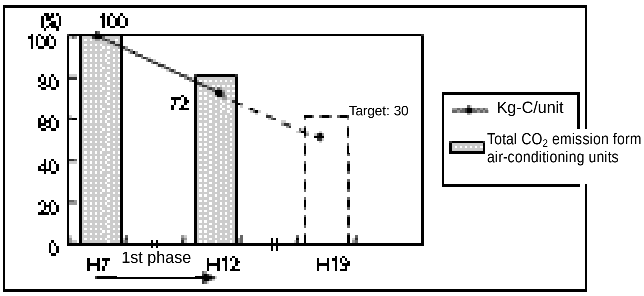

Fig. 4 Changes in CO_2 intensity of air-conditioning system

2. Understanding and Analysis of Current Situation

(1) Current Operation Status in Heat Supply Facilities

As shown in Fig. 5, heat supply facilities consist of cogeneration, boilers, refrigerating machines, and heat storage unit, aiming to obtain both stable heat supply and energy-efficient operations at the same time. However, the factories have various combinations of systems and load patterns for the air-conditioning systems depending on their characteristics. Therefore, the operation of the facilities is largely dependent on hunch and knack of operators.

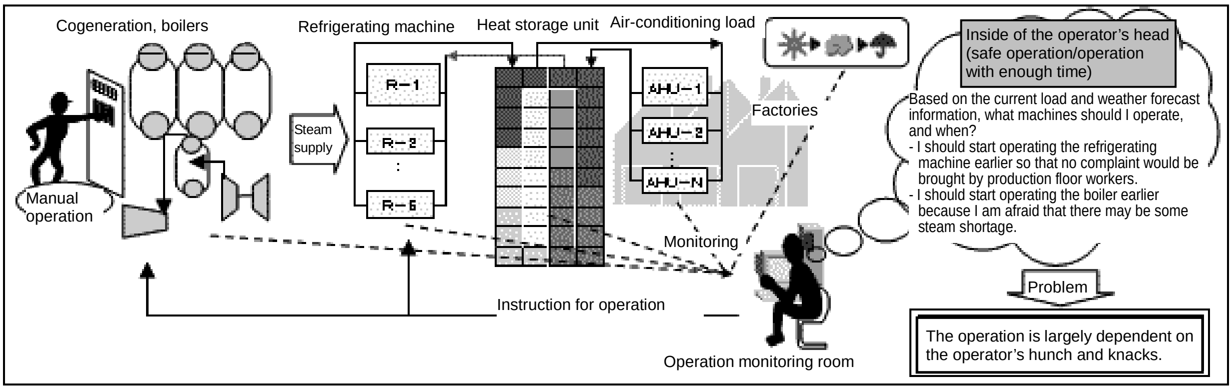

Fig. 5 Current state of monitoring on motive power operations

(2) Current Status in Operational Management (machine operation, control, management, and maintenance)

Conditions of each factory are shown in Table 1. Optimization achievement rates of each production factory are shown in Fig. 6.

[Results from the hearings (cooling)] ....Concentrated heat source

Plant		A	B	C	D
Air-conditioning units	Operating standard	△	△	△	×
	Control value (temperature at an air outlet)	△	△	△	△
	Control method	○	○	○	○
	Maintenance standard	○	○	○	○
Water supply pump	Operating standard	△	△	○	△
	Control value (pressure)	○	△	△	○
	Control method	○	×	×	○
	Maintenance standard	△	△	△	△
Refrigerating machine	Operating standard	△	△	△	△
	Control method	○	○	○	○
	Maintenance standard	○	○	○	○
Coolant water	Flow rate adjustability	○	○	○	○
	Control value (temperature)	○	○	○	○
	Control method	△	△	△	[illegible]

Legends: ○: Optimal △: Some improvement needed ×: Large difference from others

Table 1 Results from the hearing on cooling process (abstract)

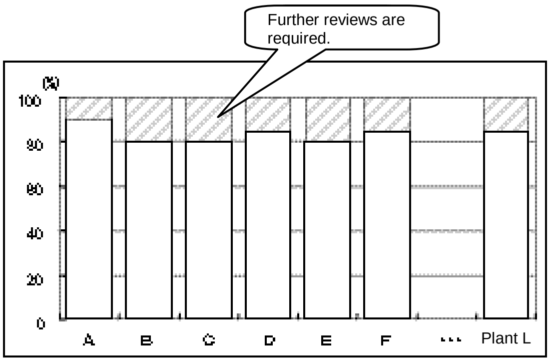

Fig. 6 Optimization achievement rate of each factory

⇒ Wide dispersion in the facility operation, control, management, and maintenance processes among the factories.

3. Progress of the Activities

(1) Implementation Structure

In order to establish a system and various standards which could be appropriately applied to production sites, we determined to promote our activities by practicing the “Toyota Way (knowledge and Improvement)”, as a joint work activity involving not only planning department but also operations and production sites of 12 factories of the company.

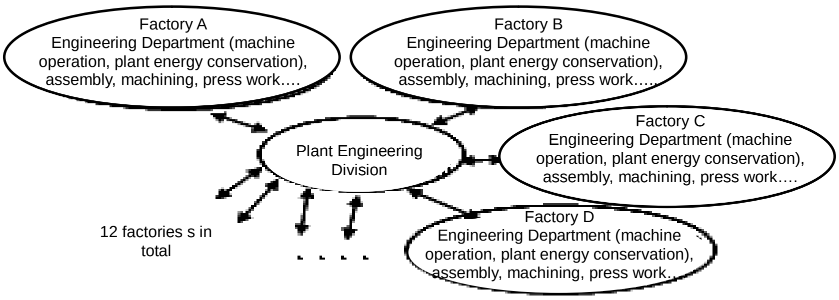

Fig. 7 Implementation Structure

(2) Target Settings

Target to be achieved in FY2003

Reduction of CO_2 intensity of air-conditioning system:
-14% (index: 72→62)
⇒CO_2 reduction amount of 2,000 t (5% reduction)

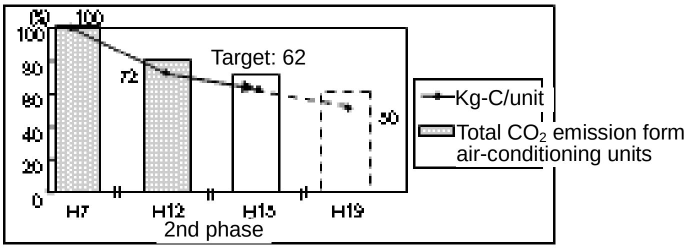

Fig. 8 Changes in CO_2 intensity of air-conditioning system

(3) Problem Points and Responses

	a) Current status of operation of heat supply facilities and installations	b) Current status of operational management
Problems	- Operation of heat supply facilities and installations ⇒ Largely dependent on hunch and knacks of operators.	- Operation, control, management, and maintenance of each facility ⇒Large dispersion among factories
Measures to be placed	- Establishment of optimal operation techniques based on the load forecast.	- Reviewing operation, control, management, and maintenance standards for improvement, and expanding their implementation.
Procedures	① Make a list of experienced operators' hunch and knacks. - Information for operation planning. - How to decide on increasing or decreasing number of units to be operated. - How to decide machines to be operated. ② Sort out previous data (for 2 years), and discuss and determine factors taken into load forecasting. ③ Study on starting and performance characteristics of each facility ④ Study on operational constraints of each facility. - Handling on prevention of concurrent activation. ⑤ Discuss a screen layout where the current status is easily viewed. ⑥ Develop the system ⑦ Study and discuss accuracy of the load forecast and adequacy of the operation plan	① Study details of operation, control, management, and maintenance standards of each factory. - Identify the best standards of the company. - Research the best standards outside the company. ② Study and discuss various standards which may contribute to the highest energy-conservation. - Maintain the operation environment. - Discuss logically plausible standard values. ③ Select a model process from each manufacturing process (assembly, machining, press work, etc.) ④ Have a trial of the proposed standards. ⑤ Analyze energy conservation effects and work environment data. Evaluate how the conservation effect was sensed. ⑥ Find out optimal values by repeating from ② to ⑤.

	- Identify issues and take measures on them. ⑧ Have a trial of implementation ⑨ Analyze energy conservation effects and work environment data. Evaluate how the conservation effect was sensed. - Eliminate any discrepancies or flaws identified during the implementation. Follow ⑦ to ⑨ in both summer and winter periods.	⑦ Prepare a new standard for each manufacturing process.

Table 2 Summary of measures items

4. Details of Measures

(1) Establishment of Optimal Operation Techniques Based on the Load Forecast

1) Focus point

It is required to establishment a system under the consideration of a linkage of all motive power facilities, taking full account of not only forecasted air-conditioning load but also operational characteristics and efficiency of primary energy source such as cogeneration system and boiler.

2) Details

[Efforts to systemization]

a) Identification of basic requirements

As we experienced failures in load forecasts in the past, we had detailed hearing from operators and repeated discussions on why the failures occurred. Our accuracy target of the air-conditioning load forecast had been set on an average error up to 0.3 unit of refrigerator (within a range of the fluctuation in the heat source system). We also determined the basic requirements as follows:

- Hunch and knacks of operators should be logically incorporated into the system.
- The load forecasts should be made on electric power, steam, and heat (air-conditioning) for the next 48 hours in 30 minute intervals.
- Control cycle should be for 30 minutes.
- The operation plans should be made on cogeneration system, boilers, refrigerating

machines, and heat exchangers.

- Actual performance data should be fed back in every 30 minutes to modify the load forecast and operation plans.
- Setting operation costs as an objective function, an operation plan to minimize the costs should be made.

As shown in Fig. 9, the system should be built on the above requirements and contain three basic functions of load forecasting, plant modeling, and optimal operation planning.

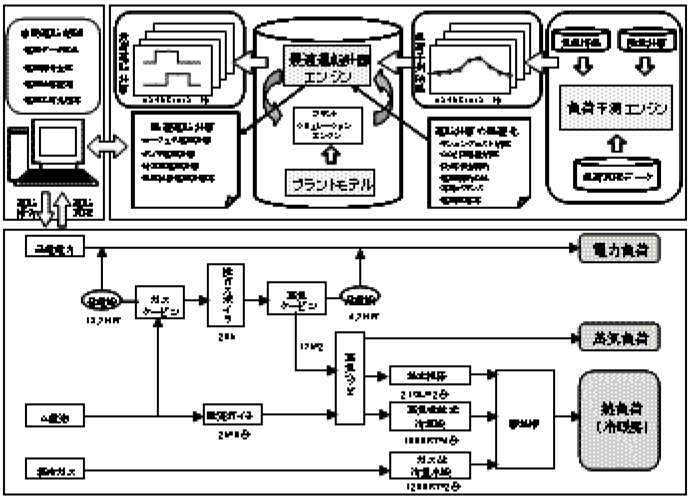

Fig. 9 System outline (Factory B)

b) Measures to improve the accuracy of load forecast for air-conditioning

First of all, in a step of input factor selection, we decided to adopt not only general factors such as actual load records, weather forecasts (temperature) and date, but also operation conditions (1st shift or 2nd shift) and discomfort index (DI), after examining weight of various factors, taking account of peculiarity of air-conditioning system in the factory. For the weather forecasts factor, where the largest weight was placed, the following measures were implemented.

As shown in Fig. 10, we have concluded a service agreement with a private weather report agency to receive pinpoint forecast data for the next 48 hours in every third hour based on actual weather data around the factory which we would forward to the agency. In order to keep the average error of the load forecast for air-conditioning within 0.3 unit of refrigerating machine, we set a target for weather forecast accuracy at an average error of 0.5℃ or below. Both a statistic error correction by a least-square method and a short-term error correction based on the most recent amount of errors and upward trend data were carried out. The results of our improvement plan are shown in Fig. 11.

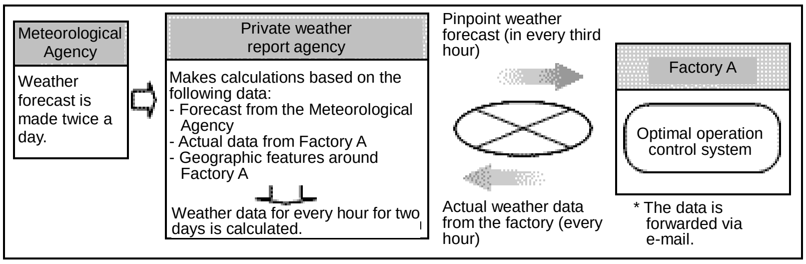

Fig. 10 Weather forecast reporting system

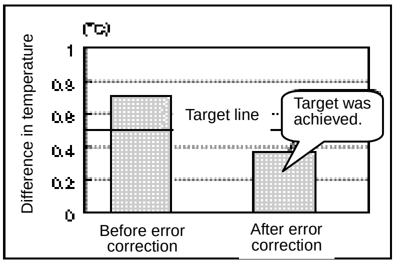

Fig. 11 Average error in temperature

【Verification of accuracy】

a) The case of normal conditions (occurrence ratio: 99%)

Due to high accuracy of the weather and load forecasts for the air-conditioning system, we were able to run the operations without waste (See Fig. 12 to 14).

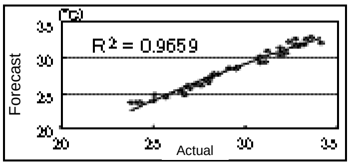

Fig. 12 Forecasted vs. actual outdoor temperatures

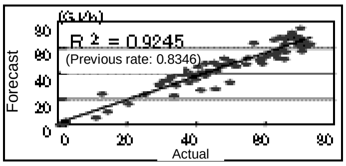

Fig.13 Forecasted vs. actual air-conditioning load

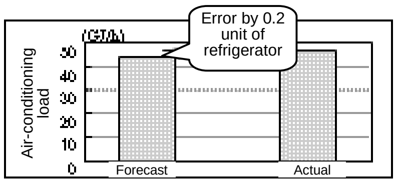

Fig. 14 Average error in air-conditioning load

b) The case when the load forecast was largely missed (occurrence ratio: 1%)

If outdoor air is in a condition different from a pattern in the previous records, excessive machine operation will be planned due to a large difference between the forecast and actual data, as shown in the initial forecast in Fig. 15. However, as shown in Fig. 16, we can run the operations efficiently by making some corrections on the load forecast based on the actual data feed back in every half an hour.

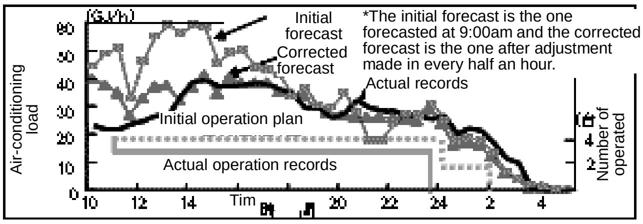

Fig. 15 Load forecasts and modifications on operation plans

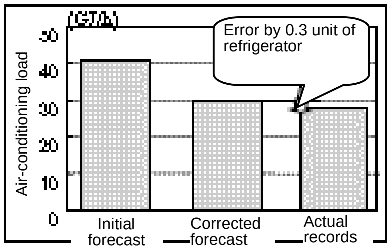

Fig. 16 Average error in air-conditioning load

c) The case when the load significantly changes due to integration or expansion of production lines (timely basis)

Our load forecasts were based on the records in the past 5 years. It was revealed that it might take more than 1 month to improve an accuracy of the forecasts if the load changes by a large margin. In order to solve this issue, we added new load forecasting which placed larger weight on the records in the past one year and a function to make calculation using an increase/decrease ratio entered into the system. This made it possible to recover the forecast accuracy within a day or so. The load forecasting having larger weight on the actual records in the past year was adopted after running some simulations and verifying that it would not induce any problems in regular cases.

[Results]

Operational adequacy of the system and impact on work environment was evaluated in cooperation with engineering and manufacturing departments in two seasons where air-heating or air-cooling was needed. Through the evaluation, it was confirmed that there was no problem with the system. Since the summer in FY2002, where the system was initially implemented, we continue to keep both stable supply and energy-conservation at the same time (See Fig. 17).

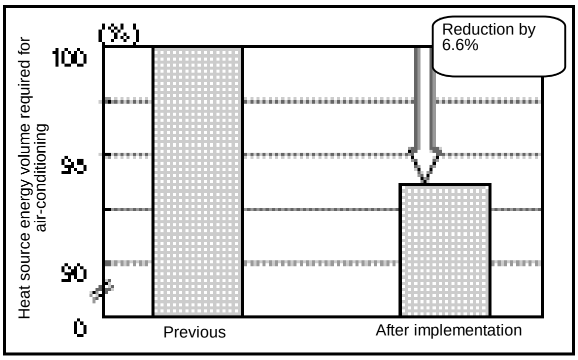

Fig. 17 Reduced energy cost

3) Reduction effect of the measures

CO_2 reductions: -500t/year

(2) Reviews on the Operation, Control, Management, and Maintenance Standards and Expansion of the Application

○ Preparation of harmonized standards throughout the company

In order to prevent the standards from being an impractical series of theoretical values, our working group members repeatedly exchanged opinions with operators and made trials and evaluations using actual units on site, before preparing the standards which could be practically implemented in the manufacturing and operation sections. The standards, which had been different in each section, were unified into the optimal values as shown in Table 3. Details on the shaded columns are described in the following sections.

Operation standard of air-conditioning unit	From the time when manufacturing lines start running to 30 minutes before the 2nd shift ends (to be stopped during a break)
Operation standard of secondary water-supply pump	In summer: To be stopped when outdoor temperature drops to 25 ℃ or below and be operate d when it reaches at 27 ℃ or above. In winter: To be stopped when outdoor temperature reaches 17℃ or above, and be operate d when it drops to 15 ℃ or below.
Control method of secondary water-supply pump	Real end pressure control: 0.2MPa
Temperature control method for coolant water	Priority in control: (1) operation of cooling fans; (2) pump inverter
Maintenance method for pumps	Resistance reduction with lining application (to the pumps running for over 10 years)
Temperature at the air outlet of air-conditioning unit	In summer: 26 ℃ (highest) In winter: 17 ℃ (lowest)

Table 3 Standards harmonized throughout the company during the improvement activities

<Case 1> Improvements in operation of secondary water supply pump (in summer)

1) Focus point

Logically speaking, it is not necessary to have air go through cool water coils if temperature at the air outlet of air-conditioning unit is higher than outdoor temperature during the summer. Based on the fact, we discussed if the cool water supply could be stopped at the source as far as required conditions are met.

2) Details

[Previous situation]

The cooled/heated water pumps were manually operated by an operator depending on outdoor temperature and were stopped at the end of the line operation for the day. OA and RA dampers of air-conditioners had a fixed operation to keep certain numbers of ventilation cycles.

[Details of the improvement]

Outdoor temperature (25 ℃ or below) and operation conditions (to be suspended: lunch hour and in between shifts) were set as conditions for suspending the pumps. Automatic function was added to change OA and RA dampers of air-conditioners at a given temperature (25℃).

After the measures were implemented, based on a report by operators saying that they could not distinguish the pump suspension due to machine failure from the one for energy-conservation, an indicator saying "suspension for energy conservation" was added on the monitoring screen.

[Results]

The temperature inside the factory while the pumps were suspended was maintained at +4℃or below compared to outdoor air, as shown in Fig. 18. No complaint was filed by operators.

3) Reduction effect of the measures

<u>CO_2 reductions: -461t/year</u>

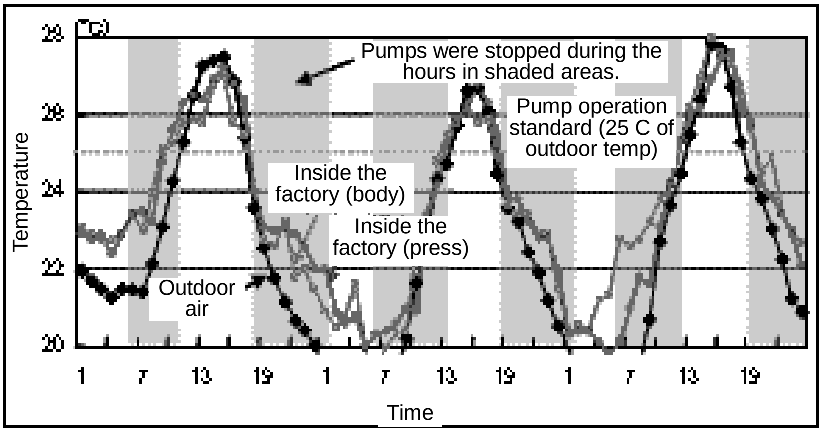

Fig. 18 Changes in temperatures at outdoor and inside the factory (Factory D)

<Case 2> Improvements in temperature control method for coolant water

1) Focus point

Among the ancillary equipment of refrigerating machines, operation and control of the unit with lower power should be prioritized.

2) Details

[Previous situation]

Under the control process of the coolant water system, amount of coolant water is firstly increased when temperature of coolant water raises, and if the temperature still goes higher, then the fan in the cooling tower will be operated, as shown in the "Previous Control" part in Fig. 19,.

[Details of the improvement]

After checking the capacity of the fans and pumps, the fan with lower power was given priority, as shown in "Improved Control" part in Fig. 19.

(The fan power was increase by 30kWand the pump power was increased by 52kW by switching from 6P to 4P.)

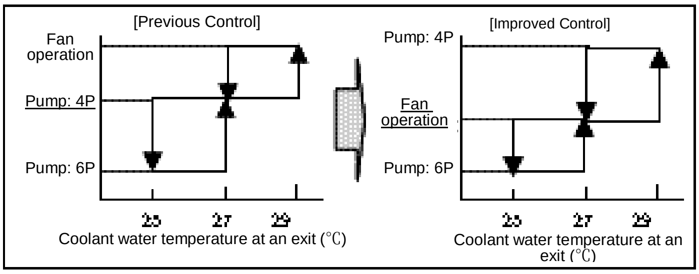

Fig. 19: Reviews on the control process

[Result]

In addition to satisfying required temperature of the coolant water, electric power reduction by 30% was achieved, as shown in Fig. 20.

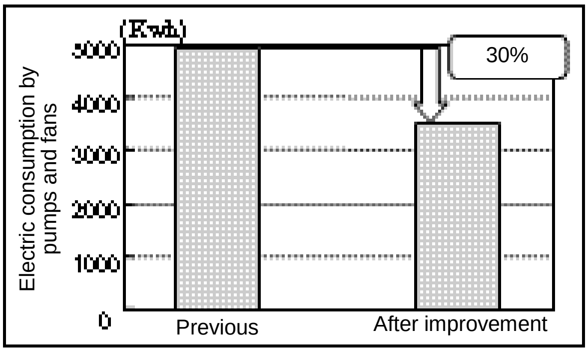

Fig. 20 Comparison in electric power consumptions before and after the improvement (Factory A)

3) Reduction effect of the measures

CO_2 reductions: -17t/year

<Case 3> Improvements in pump maintenance method

1) Focus point

A lining method, which is usually applied to reduce friction resistance of water-supply system components, such as a piping, should be applied to the pumps.

2) Details

[Step 1]

An evaluation was made using a modified pump, which originally had a capacity of 75kW and operation hours over 2,500h/year (See Fig. 21 and 22).

As shown in Fig. 23, it resulted in electric power reduction by 9.7% exceeding the theoretical value (electric power reduction by 5 to 6%).

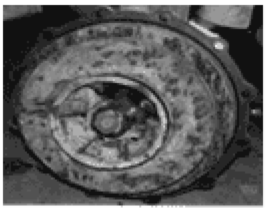

Fig. 21 Disassembled impeller

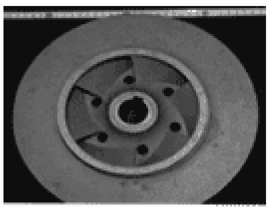

Fig. 22 After lining application

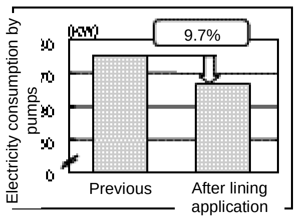

Fig. 23 Confirmed impact

【Step 2】

Based on the above result, we decided to make the modification only on the pumps whose capital investments would be paid back within three years (pumps with capacity of 55kW or above and operation hours of 2,500h/year or over), and 58 units of applicable equipment were modified.

3) Reduction effect of the measures

CO_2 reductions: -245t/year

<Case 4> Improvement in temperature at the air outlet of the air-conditioning unit (in winter)

1) Focus point

At a factory where large amount of heat is generated by machines (machinery plant), quantity of heat (25 ℃at the air outlet) for the number of ventilation cycles is provided even when temperature inside the factory is above the standard (17℃). Considering the above, we discussed to find out how to lower the temperature at the air outlet.

2) Details

[Previous status]

The temperature at the air outlet of the air-conditioning unit was controlled with cascade control (set to be automatically variable depending on outdoor temperature and room temperature in the factory).

Perimeter area: Constantly 25 ℃at the air outlet

Interior area: Variable between 25 and 18 ℃

[Details of the improvement]

To ensure that work area temperature is always 17 ℃or above, the setting of the cascade control were changed to the temperatures shown in Fig. 24 and 25 for further operation.

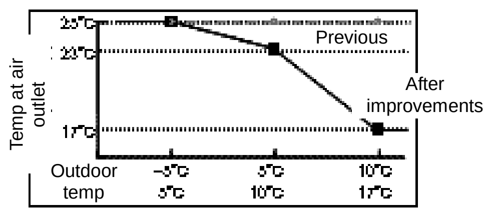

Fig. 24 Temperature setting at perimeter area

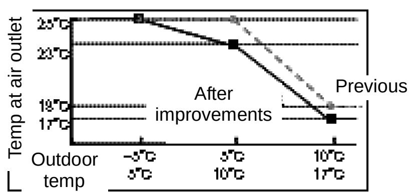

Fig. 25 Temperature setting at interior area

[Results]

Without any complaint reported by operators, we achieved reduction in amount of heat by 28% after satisfying the required room temperature in the factory (Fig. 26 and 27).

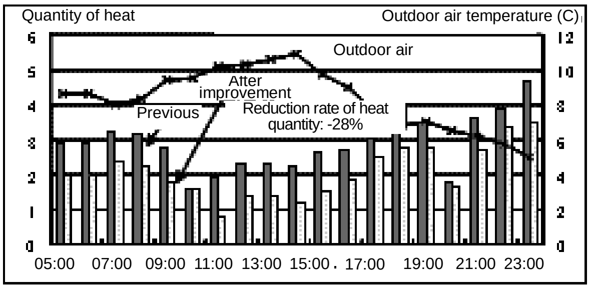

Fig. 26 Changes in consumed amount of heat and outdoor temperature (Factory C No. 4)

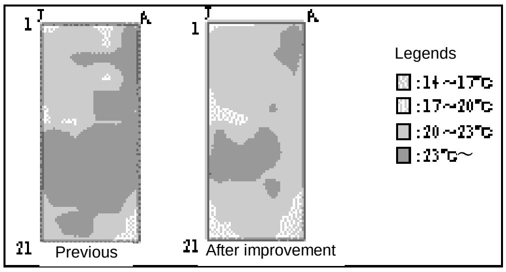

Fig. 27 Distribution of room temperature (Factory C No. 4)

3) Reduction effect of the measures

CO_2 reductions: -692t/year

5. Effect of Achieved after Implementing Measures

(1) Direct Impact

Actual impacts in FY2003, including not only the cases presented this time (the shaded sections) but also other implemented measures, were summarized in Table 4,

		CO_2 reductions (t/year)
a) Measures	Establishment of optimal operation control system for heat source of air-conditioning	500
b) Measures	Reviews on operation standard of air-conditioning unit	146
	Reviews on operation standard of secondary water-supply pump	461
	Changes in control method of secondary water-supply pump	15
	Changes in temperature control method for coolant water	17
	Application of lining on pumps	245
	Reviews on temperature at the air exit of air-conditioning unit	692
Others	Handling of previous cases	227
	Installation of an air supply unit to take outdoor air into the factory	315
Total		2,618

Table 4 Summary of the impacts

CO_2 reductions: -2,618t (target: -2,000t)

Value of the impact: 176 million yen

Pay back period: 1.7 years

CO_2 intensity of air-conditioning system was also reduced by approximately 20% (target: 14% reduction) compared to FY2000, as shown in Fig. 28.

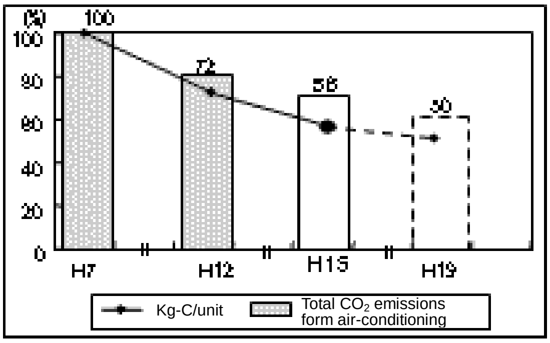

Fig. 28 Change s in CO_2 intensity of air-conditioning system

(2) Other Impact

Elimination of early startup of boilers due to improved accuracy in load forecasting and improvement in combustion efficiency of boilers and cogeneration system with optimal utilization of extracted steam form cogeneration system resulted in 6.6% reduction of Nox, Sox, and soot dust. By incorporating 'hunch and knacks' of experienced operators into the system, the man-hours required for motive power operations were reduced.

6. Summary

As a result of our activities tackled by entire company and efforts to gather various opinions from operations departments and manufacturing sections, we have succeeded in developing a system that can be optimally applied to the manufacturing sections and the standards appropriate to manufacturing processes.

Under the system established by developing optimal operating techniques, we continuously keep both stable air-heating supply and energy-efficient operations for over 2 years. We have also made a significant achievement in "energy conservation without spending much money", through reviewing various standards. As to CO_2 intensity of air-conditioning system and CO_2 reductions, our achievement largely exceeded initial targets. Those reductions contributed significantly to reductions in dust and total cost (including energy cost and maintenance cost).

Although the measures described above have not been implemented in some factories because of their characteristics and types of machines, such measures will be implemented through future improvement activities.

7. Future Plans

- With further development and improvement of energy conservation techniques, we aim to halve the CO_2 intensity of air-conditioning system in FY2007.
- We will summarize these energy conservation cases into a database and utilize it to facilitate extensive implementation of the measures in overseas plants.