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DEVELOPMENT OF BUILDING ENERGY MANAGEMENT SYSTEM FOR GAS AND ELECTRIC APPLIANCE

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ABSTRACT

Since energy prices in Japan have been soaring after the Great East Japan Earthquake but energy consumption, particularly in the commercial sector, has been increasing annually, energy conservation in buildings is of paramount importance. Energy conservation in large-scale buildings has almost been achieved by installing building-automation systems and by educating their operators. Although energy conservation in small-medium scale buildings has not yet progressed much, it has just recently started picking up some pace. A large variety of building-energy management systems (BEMS) for small-medium scale buildings has been developed and will come into the market in the upcoming years.

In small-medium scale buildings in Japan, many gas-engine driven heat pumps (GHPs) are installed along with electrically driven heat pumps (EHPs) as individual air conditioning systems.
GHP is an air-conditioning system which has high-efficiency, low electric power consumption and low running costs. More than 600,000 units of GHP have been installed since 1985. Lately, a new type of GHP called "GHP XAIR" has been developed. The GHP XAIR has a top class annual performance factor (APF) and a feature called "Energy-Saving Operation" which can decrease energy consumption by an average of around 20 % without sacrificing comfort, when compared with its general operation.

In addition to the installation of the GHP XAIR, a new BEMS called *Rakusho BEMS* has been developed to promote energy conservation in small-medium scale buildings. The *Rakusho BEMS* can control not only electrical facilities such as EHP, lighting and ventilation, but also gas facilities such as GHP and micro CHP. It can also visualize gas and electricity consumption, and can calculate, in advance, the amount of energy required. Furthermore it can analyze all measured data stored in the cloud server and provide useful energy consulting services to the users of the buildings without energy management experts.

The *Rakusho BEMS* has the following remarkable features:

- It can connect and communicate with GHP XAIR, and this makes it possible to achieve a large energy savings, of about 20 %, by using a variety of additional functions such as Predicted Mean Vote (PMV) control and schedule control.
- It is also efficient in conserving electrical power by EHP control and ventilation control linked to CO_2 concentration.
- It is applicable to the Demand Response Program.

Since 2013, several *Rakusho BEMS* have been installed in business-use buildings, commercial buildings and workout gyms. It will be one of the core systems for our Gas and Power business in the future.

Paper

1. Introduction

1.1 Circumstances surrounding the energy of Japan

Since energy prices in Japan have been soaring after the Great East Japan Earthquake but energy consumption, particularly in the commercial sector, has been increasing annually, energy conservation in buildings is of paramount importance [1]. Energy conservation in large scale buildings has almost been achieved by installing building-automation systems and by educating their operators. Although energy conservation in small-medium scale buildings has not yet progressed much, it has just recently started picking up some pace. A large variety of building-energy management systems (BEMS) for small-medium scale buildings has been developed and will come into the market in the upcoming years.

1.2 Significance of BEMS development that can control gas facilities

As the gas market in Japan will be deregulated before long, the development of a BEMS which can provide additional value for the customer would prove to be one of the advantages of differentiation from other competitors. Almost all of the existing BEMS developed in Japan can control only the electrical facilities, so a BEMS which can control gas facilities would provide some additional value and would thus make it possible to win the competition in the deregulated gas market.

2. Development of a new BEMS called *Rakusho BEMS*

A new type of BEMS called *Rakusho BEMS* has been developed to achieve energy and power saving mainly in small-medium scale buildings. With the *Rakusho BEMS* it is possible to control the facilities of both electricity and gas without bothering the customers.
In this section, the system configuration and the features of this BEMS are explained.

2.1 System configuration

The system configuration of the *Rakusho BEMS* is shown in Figure 1. This system consists of a controller, tablets and a cloud server. Features and roles of each component are described below.

2.1.1 Controller

A controller which is highly trusted in the industrial field is adopted in this system. It is set up in the customer's building. The main functions of the controller and the facilities controlled by them are shown in Table 1. The original application is installed in this controller which can collect data such as energy consumption and indoor conditions and can also control and monitor each facility. Several sensors such as CO_2 concentration sensors and/or pulse type detectors are also set up along with this controller to measure and collect energy data of the building. This controller is compatible with digital input-output and several types of control protocols including the open protocol such as BACnet to be able to control different facilities.

2.1.2 Cloud server

The cloud server application of this system is installed in a server facility of Tokyo Gas Company. This server stores all the data collected by each controller set up in the customers' buildings. The collected data is transmitted to this server every minute by using a mobile phone line with an encrypted code. Using these data, this server makes the monthly energy saving reports, automatically. This server also manages the automatic start-stop control schedule of customer's facilities via all controllers.

Additionally, this server also has the feature of predicting hourly electricity and gas consumption by using a forecasted ambient temperature and the correlation formula made from previous data of energy consumption. Using this function, it calculates the amount of energy reduction by comparing the actual amount of energy consumption with the predicted amount. The calculation results are displayed on tablets.

2.1.3 Application installed in the tablet

The application which is specially developed for the *Rakusho BEMS* is installed in the tablet terminal, which is operated by each customer. This application makes the tablet display real-time measured data and energy saving amount, and it can remotely control the facilities connected to the controller. Since this application provides an intuitive operation, it makes it possible for its users to operate the facilities easily without experts.

This application has a user-friendly interface; the home-screen looks like an analog clock. The screen of the top page is shown in Figure 2. The level of actual energy measured every half hour is indicated in the outer circle and the level of predicted energy is indicated in the inner circle. This predicted level indicated in the inner circle helps the users know in advance, the time when power should be saved.

This application can also automatically make an area chart of predicted amount and a bar chart of actual amount of electricity and gas consumptions, which let the users know about any energy overuse. These charts are shown in Figure 3.

2.2 Features of *Rakusho BEMS*

Unlike other BEMS in Japan, the *Rakusho BEMS* can control not only electrical facilities such as EHP, lighting and ventilation, but also gas facilities such as GHP and micro CHP. It can also visualize gas and electricity consumption, and can calculate, in advance, the amount of energy required. Furthermore it can analyze all measured data stored in the cloud server and provide useful energy consulting services to the users of the buildings without energy management experts.

2.2.1 Energy-Saving Operation of GHPs

In small-medium scale buildings in Japan, many gas engine driven heat pumps (GHPs) are installed as individual air conditioning systems. GHP is an air-conditioning system which has high-efficiency, low electric power consumption and low running costs. More than 600,000 units of GHP have been installed since 1985.

Lately, a new type of GHP called "GHP XAIR" has been developed. The "GHP XAIR" has a top class annual performance factor (APF) and has a feature called "Energy-Saving Operation" which can decrease energy consumption without sacrificing comfort, when compared with its general operation. In the "Energy-Saving Operation" mode, it can reduce energy consumption by an average of around 20 % by optimizing the maximum rotational speed of a compressor and by other ways. [2] [3]

2.2.2 Customer follow-up service after installation

Maintaining customer follow-up service after the installations is another feature of the *Rakusho BEMS*. The follow-up service is to provide a monthly energy report to the customer that summarizes the analysis of the data stored in the server. This also quantifies the effect of energy-saving by comparing its levels, before and after the installation of BEMS. An example of the report is shown in Figure 4. This energy report is explained to the customer in-person and this helps us to build up trustful relationships with the customers.

3. Installation in a commercial building

3.1 Site overview

The *Rakusho BEMS* has been developed in 2013 and introduced into 4 buildings by July 2014. One example of a BEMS introduced in an existing commercial building is reported in this section. The outline of this building is shown in Table 2. The floor area of this building is 7,877 m^2. This building has 36 GHPs of 1,560 kW output and 5 ventilating facilities of 69.6 kW capacity.

3.2 System configuration

The system configuration of the *Rakusho BEMS* introduced in this building is shown in Figure 5.

The controller enclosed in the standardized box mounted on the rooftop is shown in Figure 6. This controller basically controls and monitors GHPs by using RS-232C serial communications. Since RS-232C serial communications cannot transmit a signal over a transmission distance of 15 m in general, this system also consists of a signal converter which converts the RS-232C signal into TCP/IP and makes the transmission distance longer.

This controller also controls and monitors the ventilating facilities. Prior to the introduction of the *Rakusho BEMS*, the ventilation facilities used to be manually started and stopped in the control room on the first floor. After the introduction of the *Rakusho BEMS*, the controller connected to remote I/O modules automatically operates the ventilating facilities according to the measured CO_2 concentration.

Furthermore, the controller is connected to sensors and pulse detectors to measure CO_2 concentrations and energy consumption, respectively. The controller collects these data and transmits them as an encrypted code to a cloud server which stores minute-by-minute data from all the *Rakusho BEMS* controllers.

4. Result of installation in a real building

The comparison of the energy consumption before and after the introduction of the *Rakusho BEMS* is shown in Table 3. The amount of electric power and city-gas consumptions has been reduced after the introduction of this system. The factors behind these effects are discussed below.

4.1 Consideration on the reduction in the amount of electric power consumption

The comparison of the operating time of ventilation facilities before and after the introduction of the *Rakusho BEMS* is shown in Figure 7. The actual operating time on each floor after the BEMS installation and total operating time before the BEMS installation are represented by a bar chart. The ratio of the actual operating time to the previous operating time is represented by a line chart. The operating time before the BEMS installation is assumed as 7 hours per day as per customer interviews.

The controller starts the ventilation facility on the second floor every 30 minutes and stops it 10 minutes after it started as scheduled. For example, it starts at 10:00, stops at 10:10, starts again at 10:30. In contrast, the ventilation facilities on the third to the fifth floor are controlled according to the CO_2 concentration measured on each floor. The controller starts or stops the ventilation facilities when the CO_2 concentration is more than 900 ppm or less than 800 ppm, respectively.

The *Rakusho BEMS* can reduce power consumption because of the shorter operating times of the ventilation facilities as shown in Figure 7. This graph shows that the actual operating times of every facility after the BEMS installation are shorter than the operating times before the BEMS installation. The actual operating time of the ventilation facilities on the third floor, which is the shortest, has been reduced by 83.9 % compared to the previous one. The actual operating times of the ventilation facilities controlled according to CO_2 concentrations on the third to the fifth floor are shorter than that controlled by a simple schedule on the second floor.

Moreover, the *Rakusho BEMS* can achieve not only energy reduction but also CO_2 concentration management in the building, simultaneously. Since the CO_2 concentrations measured in the buildings with the *Rakusho BEMS* were all less than 1,000 ppm, as required by the building environment and sanitation management index, the *Rakusho BEMS* proved to be effective in maintaining a good building environment. [4]

4.2 Consideration on the reduction in the amount of city gas consumption

The *Rakusho BEMS* can reduce the city gas consumption because of the “Energy-Saving Operation” of the GHP XAIR. The annual reduction rate of gas consumption by "Energy-Saving Operation" of GHP XAIR is reported to be around 20 % as described in section 2.2.1.

Since the proportion of the GHP XAIR to all the GHPs installed in this building is half, the proportion of gas consumption reduction by using the "Energy-Saving Operation" is estimated to be 10 %. Additionally, the management by this BEMS can reduce the idle operating times of all the GHPs by an average of 10 minutes per day. This will make the annual total gas consumption reduce by 1.4% on average. Therefore, the total amount of gas consumption reduced by this BEMS is estimated to be 11.4 %, and this is taken as a reference value.

As shown in Table 3, the actual gas consumption reduction rate from April to July was 7.3 % which is less than the reference value of 11.4 %. The reason why the actual gas consumption reduction rate could not reach the reference value is that the measured data did not fully include the data for summer and winter. The city gas consumption can be reduced by the "Energy-Saving Operation" feature effectively, in summer and winter. Therefore, the actual reduction rate for the whole year is thought to approach the reference value hereafter.

4.3 Prospects of annual energy saving

The results of estimation of energy savings in a whole year due to the introduction of the *Rakusho BEMS* are shown in Table 4. After the introduction of this system, the reduction rates of electric power and city gas consumptions are 3.8 % and 11.4 %, respectively.

The reduction in power consumption is due to the reduction of the operating times of the ventilation facilities by the *Rakusho BEMS.* Since the operating times of these facilities on the second to the fifth floor were thought to be operated 7 hours per day, as per customer interviews, the operating times were estimated to be decreased by half by this system. Here, the average load factor of the ventilation facilities is assumed to be 65 %. Using the number of operating days and this average load factor, the reduction amount of the power consumed is calculated as below:

Amount of power reduction = 60.3 kW × 65 % × 7 hours × 363 days × 50 %

The reduction of city gas consumption occurs due to the “Energy-Saving Operation” feature of the GHP XAIR, as explained in Section 4.2.

Additionally, the peak power demand is expected to be reduced by a maximum of 12.6 % from the peak level of 312 kW that was measured before the introduction of the *Rakusho BEMS*. By shutting down all the ventilation facilities on a 65 % load factor, the peak power would be able to reduce by up to 39 kW. It would be socially meaningful to reduce the peak power of the demand side, because the power supply capacities are especially insufficient after the Great East Japan Earthquake.

5. Conclusion

In this paper, the overview of the *Rakusho BEMS* which can control gas facilities and an introductory example in a commercial building were reported. In the building mentioned in this introductory example, effective reduction of energy consumption by this *Rakusho BEMS* installation was demonstrated. Since the investigation in this introductory example reported here has been conducted only for four months, the exact evaluation of the energy reduction effect will be continued through a whole year hereafter.

We believe that this *Rakusho BEMS* would be not only a device for the building facilities management system but also one of the main things which can make firm relationship to customers or society. We hope the *Rakusho BEMS* can contribute to the realization of a sustainable society by cooperating with the Smart Energy Network [5] and the Demand Response Program, in the future.

References

[1] U.S. Energy Information Administration, http://www.eia.gov/countries/analysisbriefs/Japan/japan.pdf, (search date: 2014.8.19)

[2] Y. Furuhashi and T. Yoshida, A Study on the Energy-Saving Operation of GHP -Part1 Testing Method and Test Result of Cooling Mode-, Technical papers of annual meeting the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan, pp97-100 (2013).

[3] T. Yoshida and Y. Furuhashi, A Study on the Energy-Saving Operation of GHP –Part2 Test Result of Heating Mode and Estimation of Annual Energy-Saving Effect, Technical papers of annual meeting the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan, pp101-104 (2013).

[4] The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan, SHASE-S 102 (2011).

[5] Tokyo gas Company, http://www.tokyo-gas.co.jp/techno/challenge/002_e.html, (search date: 2014.8.19).

List of Tables

Table 1. Main functions of the controller

		Function
Visualization	Electric power	Meters
	City gas	Meters
	Indoor condition	Temperature, humidity, illuminance, CO_2 concentration
Air-conditioning facility (GHP・EHP)	compressor unit	Energy-saving operation
	Indoor unit	On/Off, Operation mode, Preset temperature
Lighting		On/Off
Ventilation		On/Off, Air volume
Pump/Fun		On/Off
Micro CHP		On/Off
Automatic control		Cutting peak power demand
		Schedule
		Preset temperature management, CO_2 concentration management
		Outdoor air cooling

Table 2. Overview of a commercial building in which *Rakusho BEMS* is introduced

Date of establishment	June, 1998
Site area	2,336 m^2
Number of floors	5F
Total floor space	7,877 m^2
Air-conditioning facility	Total GHP output: 1,560 kW
Ventilation facility	Total capacity: 69.6 kW

Table 3. A comparison of the energy consumption before-after introduction of *Rakusho BEMS*

Consumption	Before	After	Reduction rate
Electric power	436,131 kWh	421,044 kWh	3.5 %
City gas	33,416 m^3	30,973 m^3	7.3 %

1 m^3 of city gas supplied from our company is 45 MJ.

Table 4. The estimate of energy savings of a whole year by the introduction of Rakusho BEMS

Estimated	Reduction amount	Rate
Peak power demand	39 kW (Max potential)	12.6 %
Electric power	49,764 kWh	3.8 %
City gas	11,439 m^3	11.4 %

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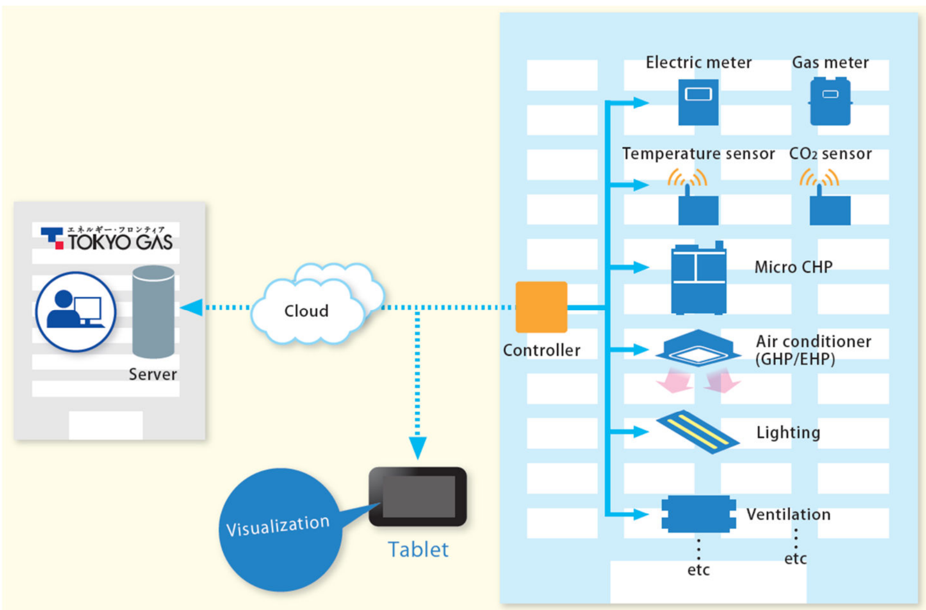

Figure 1. Schematic illustration of *Rakusho BEMS*

Figure 2. Home-screen of tablet application

Figure 3. Comparison of actual and predicted energy consumptions on the tablet application

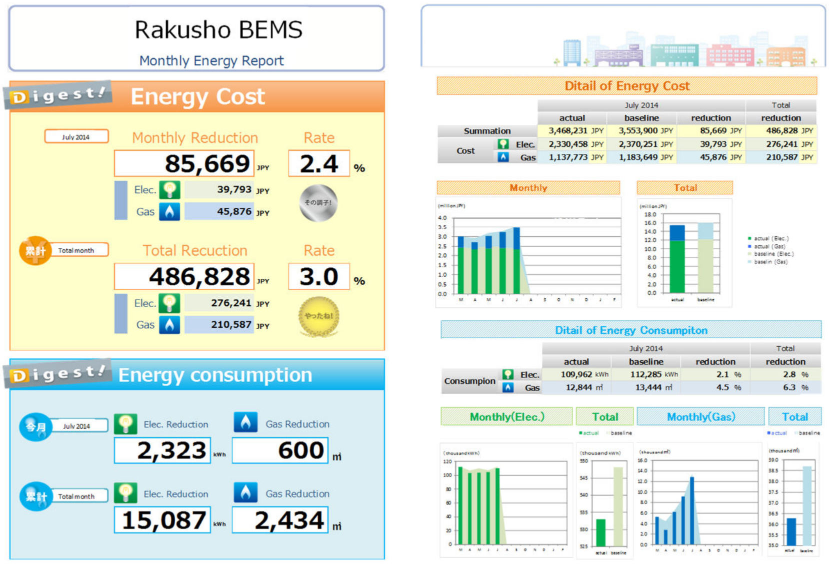

Figure 4. Example of the energy report

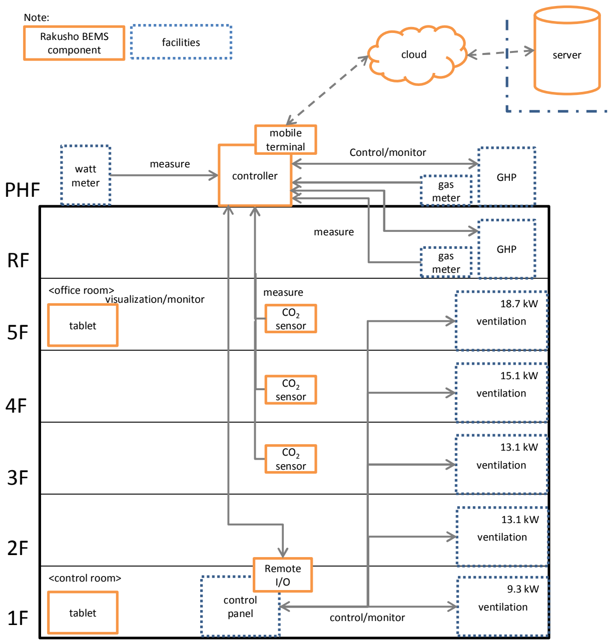

Figure 5. System configuration in a commercial building

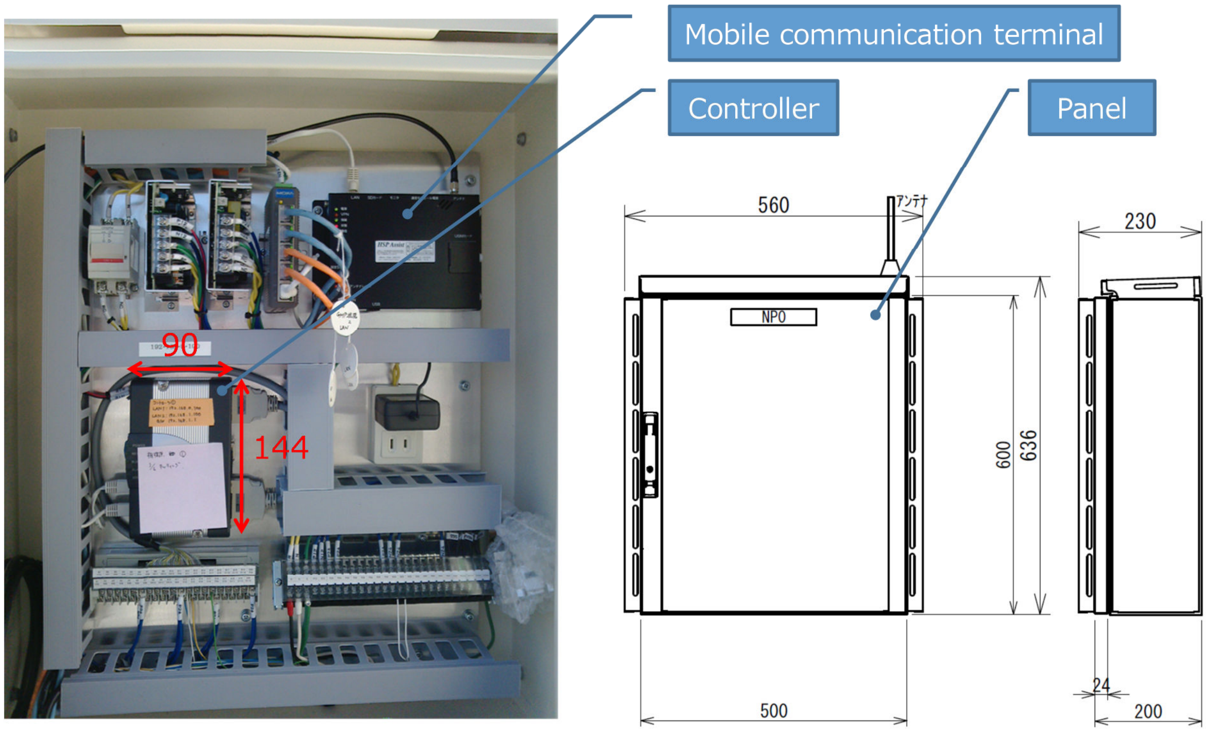

Figure 6. Appearance of the controller

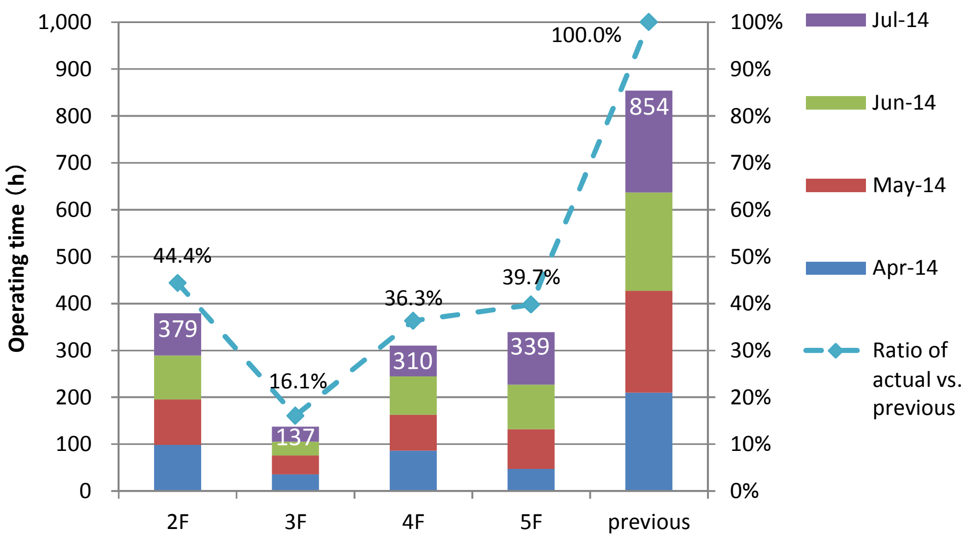

Figure 7. Operation time comparison of ventilation facilities for four months