Improvement of Heat Source System Efficiency Using a Cloud Service

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As one part of our cloud service menu in support of building and factory administration, we have developed and offer a service providing optimal heat source operation. The service is designed to assist the daily work of the facility operators who control the heat source system. We describe various functions for demand forecasting, optimization of heat source operation, cloud-linked control of the number of operating heat source units, addition of comments to items on the screen, and more. In addition, we provide a brief overview of the optimization calculations and technology that we utilize.

1. Introduction

Problems such as rising sea level, abnormal weather, and changes in the ecosystem, which are said to be caused by global warming, are no longer negligible, and consequently greenhouse gas reduction and energy conservation at the global level are required. Environmental regulations for industry (plants, etc.) and business (office buildings, etc.) are getting stricter year after year.

Also, since the Great East Japan Earthquake, in-house power generation facilities, especially cogeneration systems (CGS) have been widely introduced into heat source systems due to an increased need to ensure the supply of power at the time of a disaster, as part of business continuity planning (BCP). A CGS generates electricity with an internal combustion engine and also effectively utilizes the heat generated in facilities of various types. The challenge is to establish an operating plan for each facility that takes into account fluctuations in the power demand load and unit price of energy so that cost reduction, energy savings, and high-efficiency operation can be attained.

As techniques to solve the problems related to these goals, demand forecasting and optimization based on mathematical programming have received attention.

We have been working on cases where optimization is applied to the operating plan for the heat source system.[1] However, in order to formulate the problems so that an optimal solution can be obtained within a practical computation time, specialized and advanced knowledge is required, so the results of studies on optimization have not been widely utilized. Due to the recent acceleration of hardware and algorithms applicable to optimization,[2] the above-mentioned problems of computation time and problem formulation are being solved.

Meanwhile, due to the development of information and communication technologies and the development of communication infrastructure in recent years, the use of cloud services via the Internet is rapidly spreading. Cloud services are providing the applications and data manipulation for users who conventionally have used their PCs for this work.

In view of these circumstances, we have developed and launched the Heat Source Optimal Operation Support (OP) cloud service, which enables large-scale and complicated heat source systems to operate optimally.

This paper introduces the system.

2. Overview of Cloud Services

Azbil provides cloud services via the Internet for various users, including building owners, facility operators, and occupants of buildings. The provided cloud services include not only Heat Source Optimal Operation Support (OP), which is introduced in this paper, but also energy management (EM), building management (BM), tenant services (TS), etc. Customers can choose any desired services (table 1).

Table 1. Available services

Item	Features	Major Functions	Target Users
EM Energy management	Visualization of energy conservation results	• Analysis of consumption trends • Total energy management • Digital signage • Expert functions	Property managers (company owning the building)
TS Tenant services	Comfort Convenience	• ON/OFF of lighting and equipment • Air conditioning (AC) settings • AC control by request	Occupants (tenants)
BM Facility maintenance management	LCC reduction	• Facility maintenance management • Intermediate–long-term maintenance plan • Facility inspection support	Facility operator (building mgmt. co.)
OP Optimal operation planning	Energy conservation, CO2 reduction Cost reduction	• Demand forecasting • Optimal operation planning simulation • COP management	Property managers (company owning the building)
DR Demand response	Linkage of power demand to supply	• DR management function • Energy-aware equipment control	–

Services using the cloud system have the following three advantages.

(1) Improved usability

- Since access location and access devices are not limited, it is possible to provide services to users in a flexible way, according to their requests.
- The latest applications and information are always available.
- Since processing for services is provided by high-performance and large-capacity servers, it is possible to carry out advanced types of control and analysis.

(2) Better system management quality

- Since the system is managed entirely by specialists, improvement of management quality can be expected.
- Since the applications and necessary data are stored at a data center, they are highly secure in the event of a disaster or attempted illegal intrusion into the system.

(3) Reduction of cost

- Since users do not need to own hardware such as servers and expensive applications, they can use the services without making an initial investment.
- Costly maintenance and management of the hardware can be avoided.

Cloud services, due to their manner of use, have the various merits for the user that are described above.

3. Heat Source Optimal Operation Support (OP)

Heat Source Optimal Operation Support (OP) creates an optimal operation planning for heat sources based on the forecast amount of demand and optimized according to the desired objective (fig. 1). The objective can be selected from minimization of cost, minimization of CO_2 emissions, etc.

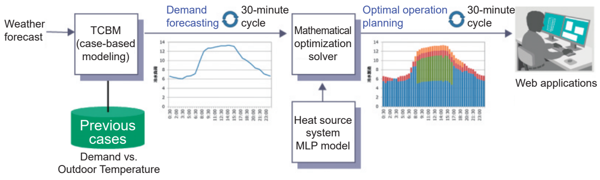


Fig. 1. Overview of the optimal operation planning for heat sources

3.1 Demand forecasting function

With this function, the consumption of chilled and hot water, electricity, and gas can be predicted up to 7 days ahead. The Topological Case-Based Modeling (TCBM)™ method,* which is a proprietary Azbil technology, is used for forecasting. In addition to the weather forecast data and the building's operation calendar, the operation schedule of the HVAC equipment, which is managed by Azbil's savic-net™ building management system, can also be used as input data for prediction. The system also can automatically revise the predicted values based on exponential smoothing, or the predicted values can be manually revised.

Figure 2 shows an example of the demand forecasting screen. The light color bars shows the results of prediction, and the dark color bars on the left side show the actual values.

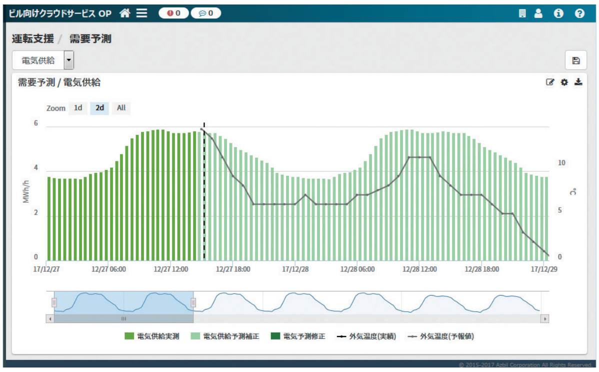


Fig. 2. Demand forecasting screen

* TCBM is a modeling method for instantiating data based on its degree of similarity to other input data. It refers to past examples similar to the present inputs to derive the necessary outputs. In this case-based reasoning method, since the input-output relationships are included in the past case serving as a basis, there is no need to build a special model prescribing the input-output relationships, and nonlinear input-output relationships can also be handled.

3.2 Heat Source Optimal Operation Support function

The optimal operation planning for the heat source is obtained by modeling the heat source system operation as a mixed integer linear programming (MILP) problem and by finding the optimal solution using a mathematical optimization solver. This function has the following characteristics.

- Based on the predicted load, the data is refreshed on a 30–minute cycle at the shortest.
- Partial load characteristics of the heat source are considered.
- The rise time required by the heat source for supplying heat is considered.
- Seasonal or hourly fluctuation of the unit price of energy is factored in.
- Annual restriction conditions (contract conditions for annual cumulative values, such as an annual minimum usage or annual load factor) are taken into consideration.

3.2.1 Dashboard

After logging into the system, the user is presented with the dashboard screen (fig. 3). On the dashboard, the user can intuitively grasp the latest load forecast results and the overview of the heat source operating plan. Details are described in table 2.

Fig. 3. Cloud dashboard screen for the system

Table 2. Description of dashboard tiles

Number	Tile name	Description
(1)	Heat source operation plan	Number of heat source units scheduled to operate, starting from the present time
(2)	Demand forecast	Demand forecast, starting from the present time
(3)	Weather forecast	Weather forecast for the present location
(4)	Power demand forecast	Actual consumption of electricity and the demand forecast
(5)	Yearly forecast	Forecast of indexes (for cost, CO_2 emissions, COP, etc.) at the end of the fiscal year

3.2.2 Heat source operating plan

On the heat source operating plan screen, based on the planned optimal operation planning the start/stop schedules for each heat source and the amount of energy generated are displayed. There are two types of screen, short-term and long-term.

On the short-term plan screen, in order to understand the optimal operation planning in detail, 30-minute data for up to seven days later is displayed. For equipment such as absorption chillers, which take a long time after startup to output at their full capacity, advanced time schedules that include the startup time are displayed for starting and stopping the equipment (fig. 4).

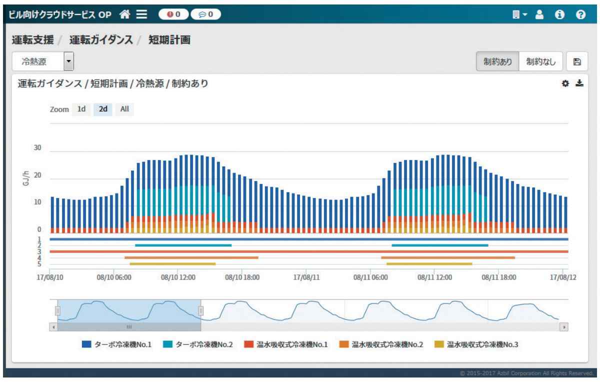


Fig. 4. Heat source operating plan (short-term)

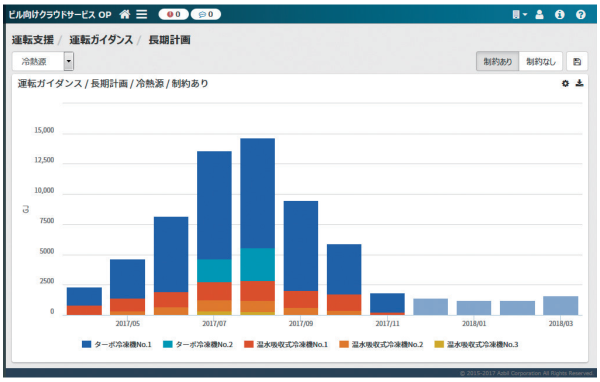


Fig. 5. Heat source operating plan (long-term)

The long-term plan screen is for gaining a rough understanding of the heat source operation plan for the year. It displays monthly data until the end of the fiscal year (fig. 5).

3.2.3 System COP management

The system coefficient of performance (COP) management screen shows the actual and forecast values for the operating efficiency of the heat source systems (fig. 6). There are three types of screen for showing 30-minute data, monthly data, and yearly cumulative data (fig. 6 shows yearly cumulative data).

The predicted value of the system COP is calculated from the demand forecast and the amount of energy consumed by the heat source system.

The energy consumption is calculated by the optimal operation planning. Using this function, it is possible to understand the transitions of the system COP for each hourly, monthly, or yearly period in advance so that measures for improving the efficiency of the heat source system can be considered.

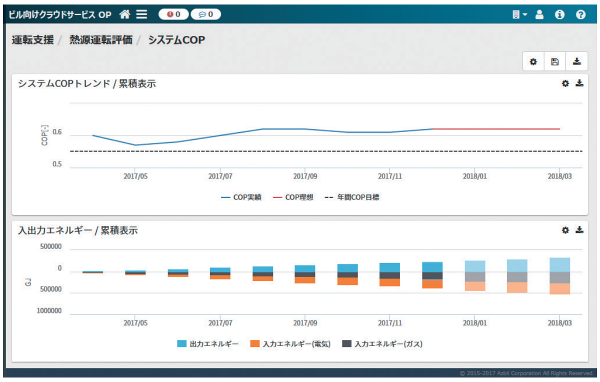


Fig. 6. System COP screen (yearly cumulative data)

3.2.4 Energy contract compliance status

The screen in figure 7 shows whether or not the planned optimal operation planning for gas satisfies the gas contract.

Generally a contract for gas consumption includes conditions such as yearly minimum consumption, a high limit on consumption for the high demand period, and a low limit on the annual load ratio.

On the visualization screen graph, gas consumption for the high demand period (December to March) and for the low demand period (April to November) are displayed on different axes so that the multiple gas contracts are displayed on the same graph. Since both actual and predicted gas consumption are plotted on the graph, it is possible to check the progress toward meeting the terms of the gas contract.

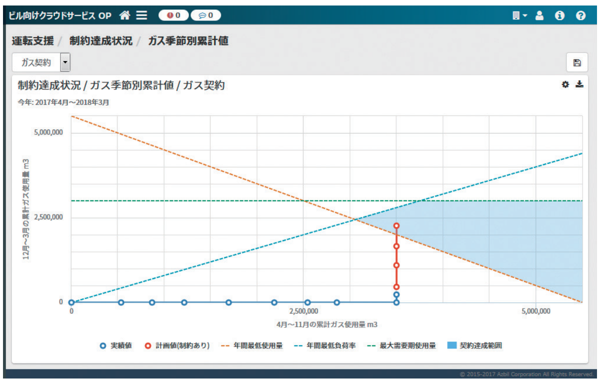


Fig. 7. Gas consumption check screen

3.2.5 User settings screen

In order to make an operating plan using the latest contract information, a user can input the unit cost or fuel adjustment charge on the Web application screen (fig. 8).

Fig. 8. Energy contract settings screen

Sometimes a heat source cannot operate due to a breakdown or maintenance. The user can set the time span during which the heat source will be stopped on the Web application screen (fig. 9). The optimization calculation process allows the creation of plans that take into account the settings for exceptions. Moreover, settings for exceptions that have been configured for the BA system as a whole can be automatically applied to heat source planning.

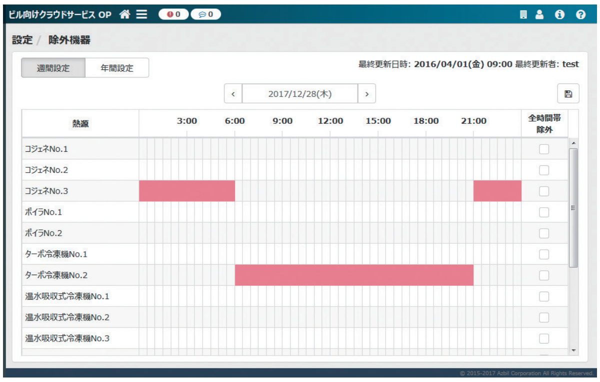


Fig. 9. Screen for configuring exceptions to the heat source schedule

3.3 Coordinated control of the number of operating units

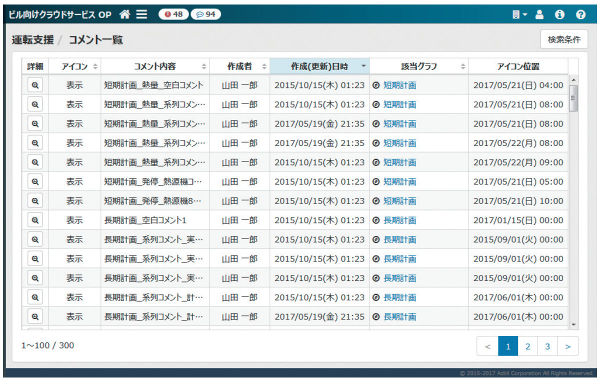
The optimal operation planning displayed on the cloud's monitoring screen can be shared with the function that controls the number of operating units at the work site. Role sharing between the cloud computing and the automatic control is conceived such that the control parameters based on the optimal operation planning are determined in the cloud, and the automatic control, based on those control parameters, manages the fluctuations in demand.

3.4 Comment function

It possible to add comments anywhere on a graph with a click of the mouse. The added comments are displayed as icons on the graph (fig. 10), and they also can be displayed in a list (fig. 11). The list has a search function, so the comments can be filtered by conditions such as creation time, corresponding graph, creator, or content of comments.

This function is expected to be useful as a tool for communication between users, whether they are inside or outside of the building.

Fig. 10. Adding comments



詳細	アイコン	コメント内容	作成者	作成(更新)日時	該当グラフ	アイコン位置
	表示	短期計画_熱量_空白コメント	山田 一郎	2015/10/15(木) 01:23	短期計画	2017/05/21(日) 04:00
	表示	短期計画_熱量_系列コメン…	山田 一郎	2015/10/15(木) 01:23	短期計画	2017/05/21(日) 08:00
	表示	短期計画_熱量_系列コメン…	山田 一郎	2017/05/19(金) 21:35	短期計画	2017/05/21(日) 08:00
	表示	短期計画_熱量_系列コメン…	山田 一郎	2017/05/19(金) 21:35	短期計画	2017/05/22(月) 08:00
	表示	短期計画_熱量_系列コメン…	山田 一郎	2015/10/15(木) 01:23	短期計画	2017/05/22(月) 09:00
	表示	短期計画_発停_熱源機コ…	山田 一郎	2015/10/15(木) 01:23	短期計画	2017/05/21(日) 05:00
	表示	短期計画_発停_熱源機8…	山田 一郎	2015/10/15(木) 01:23	短期計画	2017/05/21(日) 10:00
	表示	長期計画_空白コメント1	山田 一郎	2015/10/15(木) 01:23	長期計画	2017/01/15(日) 00:00
	表示	長期計画_系列コメント_実…	山田 一郎	2015/10/15(木) 01:23	長期計画	2015/09/01(火) 00:00
	表示	長期計画_系列コメント_実…	山田 一郎	2015/10/15(木) 01:23	長期計画	2015/09/01(火) 00:00
	表示	長期計画_系列コメント_実…	山田 一郎	2015/10/15(木) 01:23	長期計画	2015/09/01(火) 00:00
	表示	長期計画_系列コメント_計…	山田 一郎	2015/10/15(木) 01:23	長期計画	2017/06/01(木) 00:00
	表示	長期計画_系列コメント_計…	山田 一郎	2017/05/19(金) 21:35	長期計画	2017/06/01(木) 00:00

Fig. 11. List of comments

3.5 Smart guidance function

By registering specific guidance information and the conditions for displaying it in the system in advance, it is possible to automatically display the icon associated with that type of guidance information on a graph when the specified conditions are met (fig. 12).

With this function, not only judgments based on past actual data, but also guidance based on future predicted data or plans can be output. Specifically, the function may be used for monitoring the upper limit of the demand forecast value, displaying guidance in advance for starting or stopping the heat source system, understanding the progress toward achieving management indexes, etc.

Fig. 12. Displaying smart guidance on a graph

4. Optimization Calculation Process

This section gives an overview of the optimization calculation process and describes the technology used.

4.1 Overview of the optimization calculation process

First, we will explain the basic process when this function is executed. In the optimization calculation, the optimal operation planning, that is, the operation variables ("0" or "1" integer variables representing the start/stop state of each piece of equipment at each time point on each prediction target date and representative day, and the continuous variables representing the input and output calories) are calculated using MILP.

Whenever an optimization calculation is carried out, the mathematical model file that was created when the program was installed, the parameters set by the user on the screen (settings for exceptions, energy unit price, etc.), results data, which changes as time goes by, and predicted data are passed to the optimization solver.

(In the mathematical model file, the objective of the operation plan and the constraints on it are formulated as an equation expressing an objective function and its constraints, written in a format that can be read by the optimization solver (hereinafter the mathematical model)).

When the program is installed, the mathematical model is appropriately formulated in consultation with the user, taking into consideration the objective of the operating plan (cost cutting, CO2 emission reduction, saving energy, etc.) and the constraints (the input/output characteristics of each piece of equipment, interconnections among equipment, energy purchasing sources, and energy supply destinations, operational rules, and the contracts for purchasing various types of energy).

4.2 Modeling techniques

To ensure that the operating plan calculated by the optimization calculation described above is practical in terms of the situation at the work site, it is necessary to adequately and appropriately formulate the mathematical model. This section gives a summary of the technology related to creation of the mathematical model used by this service.

4.2.1 Handling various facility configurations

In making a mathematical model of a facility (considering the input/output characteristics of each piece of equipment, the interrelations among the equipment, energy purchasing sources, and destinations for supplied energy), since our model formulation method is abstract and standardized, it can handle sites with complicated configurations where various types of equipment and energy are used. For example, facility equipment such as various types of chillers, boilers, cogeneration equipment, heat storage tanks (all with the availability of auxiliary power) can be modeled. Also, types of energy such as steam, gas, electricity, cold, heat, and petroleum can be modeled.

Figure 13 shows an example of a facility configuration.

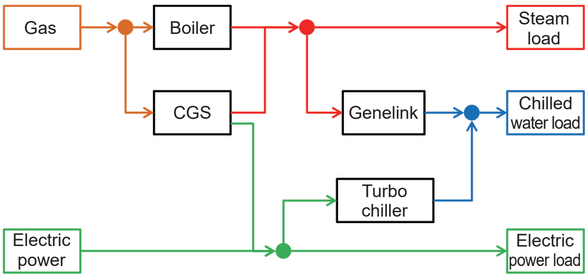


Fig. 13. Example of the relationships among types of equipment and energy

In addition, types of equipment with nonlinear partial load characteristics can also be approximately modeled using piecewise linear functions.

To approximate functions that have complex forms, the number of segments should be increased. However, as the number of segments increases, the scale of the MILP problem to be solved also increases, and consequently the calculation time will increase. In our service, proprietary techniques are used to automatically generate the piecewise linear functions while adjusting the trade-off between the fitting accuracy and the number of segments, in order to avoid increasing the calculation time while maintaining enough accuracy for practical purposes.

4.2.2 Modeling the constraints

There are various constraints to be incorporated into the mathematical model, as described in section 4.1. A one-time formulation of the constraints using simple equations or inequalities based on information supplied by the customer is often insufficient (the calculated operating plan will not be practical). The main reason is that the constraints include implicit assumptions that are not clarified, or the absoluteness of compliance with the constraints has not been established. (There are constraints which are desirable but which may be relaxed in order to improve the outcome or to allow compliance with conflicting constraints.)

Therefore, when making a mathematical model at the time of the initial installation, it is necessary to identify and clarify the constraints in order to appropriately incorporate them into the mathematical model. Specifically, it is necessary to repeat a cycle consisting of editing the mathematical model, trial of the optimization calculation and checking of results, and analysis. Efficient use of this work cycle is important for improving the quality of the final mathematical model.

To facilitate the editing work of mathematical models, and particularly the modeling of new constraints, we have a collection of templates for formalizing the constraints that are typically found. In addition, with a listing of the types of constraints in this manner, it is possible to know which ones were used or not used, so accidental omission of constraints can be reduced.

Additionally, we use proprietary formulation techniques in order to make it easy to check the degree of constraint satisfaction, the balance between strict constraint application and accomplishment of the objective, the competing relationship between constraints, etc.; and to adjust the degree of constraint relaxation and/or the scope of application. As a result, since the work cycle described above can be efficiently executed, it is possible to formulate a mathematical model with the constraints sufficiently incorporated to calculate a practical heat source operating plan according to the situation at the site.

4.3 Acceleration of annual constraint calculation

The optimization calculation recalculates the heat source optimal operation planning based on the energy load forecast every 30 minutes. The plan is optimized not only for the short-term period represented by the specified number of days, but also for compliance with the long-term energy contracts (up to one year).

However, the calculation load for large-scale MILP optimization is generally large, so it is difficult in a short time to execute an optimization calculation that considers long-term energy contracts. Accordingly, our service uses various techniques to shorten the calculation time.

One of them is to divide the MILP problem into an upper-level problem (for annual constraints) and a lower-level problem (optimization for prediction target date), and then to reduce the frequency of solving the upper-level problem.

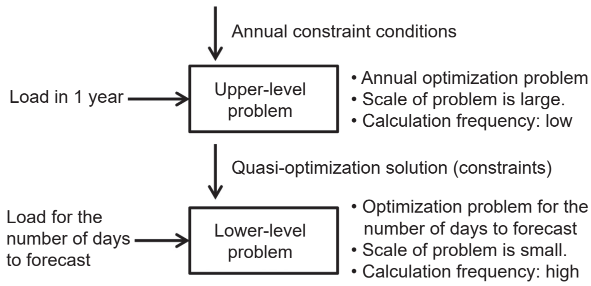


Fig. 14. Upper- and lower-level problems

When solving the upper-level problem (for annual constraints), it is necessary to consider the energy load prediction for the number of days to be predicted, the representative load pattern for up to one year, the annual energy contracts, and all other constraints. Since it would take a long time to calculate a strictly optimal solution, a “quasi-optimization” method is employed, which allows sufficient precision for practical purposes but can be calculated in a shorter time.

Quasi-optimization refers to, for example, finding a relaxed solution in which some integer variables are relaxed, or calculating an executable solution by increasing the gap between the upper and lower bounds in the branch and bound method.[3]

On the other hand, when solving the lower-level optimization problem for prediction target date, the solutions obtained by solving the upper-level problem are reincorporated into the constraints every time, and then optimization is carried out considering the energy load forecast for the specified number of future days. If the solution of the lower-level problem satisfies the new constraints that have been incorporated, it is possible to obtain an operating plan that conforms to the annual energy contracts for prediction target date.

Since the lower-level problem is smaller in scale than the upper-level one, it can be calculated in a short time. In this way, it is possible to provide a heat source operating plan every 30 minutes that takes into account the long-term (up to one year) energy contracts while reducing the scale of the problem.

5. Conclusions

This paper has introduced our Heat Source Optimal Operation Support (OP) cloud service.

It seems likely that the operation of heat source systems in buildings and factories will become more complex in the future, in view of the annually increasing amount of environmental regulations, the introduction of various kinds of heat source equipment, expansion of the use of natural energy, facility reconfiguration for business continuity planning, changes to support demand response, etc. It is also expected that it will become more difficult to find skilled facility operators due to a decline in the labor force. Therefore, in order to maintain and improve the quality of heat source system operation, the effective use of mathematical optimization technology is necessary.

As a next step, we would like to apply mathematical optimization technology to other fields, such as scheduling problems and production planning.

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Trademarks

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