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Distributed Energy Management Using the Market-Oriented Programming

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1. Introduction

This chapter discusses energy planning in a small district composed of a set of corporate entities. Although the term "energy planning" has a number of different meanings, the energy planning in this chapter stands for finding a set of energy sources and conversion devices so as to meet the energy demands of all the tasks in an optimal manner. Since reduction of CO_2 emissions which are the main factor of global warming is one of the most important problems in the 21st century about preservation of the earth environment, recent researches on energy planning consider reducing impacts to the environment(Cormio et al., 2003; Dicorato et al., 2008; Hiremath et al., 2007).

On the other hand, corporate entities with energy conversion devices become possible to sale surplus energy by deregulation about energy trading. Normally conversion devices have non-linear characteristics; its efficiency depends on the operating point. By selling energy to other entities, one may have an opportunity to operate its devices at a more efficient point.

We suppose a small district, referred to be a "group", that composed of independent plural corporate entities, referred to be "agents", and in the group trading of electricity and heat energies among agents are allowed. We also suppose that a cap on CO_2 emissions is imposed on each agent. Each agent performs energy planning under the constraints on CO_2 emissions and by considering energy trading in the group.

An agent may take various actions for reduction: use of alternative and renewable energy sources, use of or replacement to highly-efficient conversion devices, purchase of emission credits, and so on. Use of alternative and renewable energy sources and purchase of emission credits are easier ways to reduce CO_2 emissions. However, there is no guarantee to get sufficient amount of such energy or credit at an appropriate price, because the amount of such energy and credit is limited and their prices are resolved in the market. On the other hand, installing a highly-efficient conversion device comes expensive.

Another way to reduce CO_2 emissions is energy trading among agents. Suppose that one agent is equipped with an energy conversion device such as boilers, co-generation systems, etc. If he operates his device according to his energy demands only, the operating point of the device cannot be the most efficient one. Energy trading among agents makes it possible to seek efficient use of devices, and as a result to reduce CO_2 emissions.

When we attempt to minimize energy cost under the constraints on CO_2 emissions in the group, it is not difficult by considering the entire group as one agent. But it is another matter

whether each agent will accept the centralized optimal solution because agents are independent. Therefore, we adopt a cooperative energy planning method instead of total optimization. By this method, we want to reduce energy consumption considering the amount of the CO_2 emissions in the entire group without undermining the economic benefit to each agent.
A software system in the control center in a power grid to control and optimize the performance of the generation and/or transmission system is known as an energy management system (EMS). We are considering a distributed software system that performs energy planning in the group. We call such a energy planning system for the group a distributed energy management system (DEMS).
Corresponding mathematical formulation of the energy planning is known as the unit commitment (UC) problem(Padhy, 2004; Sheble & Fahd, 1994). Although the goal of our research is solving the UC problem and deciding the allocation of traded energies in DEMSs, the main topic of this chapter is to discuss how to find an optimal energy allocation. In order to make the problem simple, we consider the UC problem with only one time period and all of the energy conversion devices are active. Most methods for the UC problem solve in centralized manner. But as mentioned before we cannot apply any centralized method. Nagata et al. (2002) proposed a multi-agent based method for the UC problem. But they did not consider energy trading among agents.
The interest of this chapter is how to decide the allocation of traded energies through coordination among agents. In DEMSs, an allocation that minimize the cost of a group is preferred; a sequential auction may be preferred. Therefore, we propose to apply the market-oriented programming (MOP)(Wellman, 1993) into DEMSs.
The MOP is known as a multi-agent protocol for distributed problem solving, and an optimal resource allocation for a set of computational agents is derived by computing general equilibrium of an artificial economy. Some researches, which uses the MOP, have been reported in the fields of the supply chain management(Kaihara, 2001), B2B commerce(Kaihara, 2005), and so on. Maiorano et al. (2003) discuss the *oligopolistic* aspects of an electricity market.
This chapter is organized as follows. Section 2 introduces the DEMSs and an example group. An application of the MOP into DEMSs is described in Section 3. The bidding strategy of agents and an energy allocation method based on the MOP is described. In Section 4, computational evaluation of the MOP method is performed comparing with three other methods. The first comparative method is an multi-items and multi-attributes auction-based method. The second one is called the individual optimization method, and this method corresponds to a case where internal energy trading is not allowed. The last one is the whole optimization method.

2. Distributed Energy Management Systems

2.1 Introduction

A software system in the control center in a power grid to control and optimize the performance of the generation and/or transmission system is known as an energy management system (EMS). This chapter addresses an operations planning problem of an EMS in independent corporate entities. Each of them demands electricity and heat energies, and he knows their expected demand curves. Moreover a cap on CO_2 emissions is imposed on each entity, and it is not allowed to exhaust CO_2 more than their caps. Some (or all) entities are equipped with energy conversion devices such as turbines; they perform optimal planning of purchasing primal energy and operating energy conversion devices in order to satisfy energy demands and constraints on CO_2 emissions.

We suppose a small district, referred to be a "group", that composed of independent plural corporate entities, referred to be "agents", and in the group trading of electricity and heat energies among agents is allowed. In the case of co-generation systems, demands should be balanced between electricity and heat in order to operate efficiently. Even when demands from himself are not balanced, if an agent was possible to sell surplus energy in the group, efficiency of the co-generation system might be increased. Normally conversion devices have non-linear characteristics; its efficiency depends on the operating point. By selling energy to other entities, one may have an opportunity to operate its devices at a more efficient point. There is a merit for consumers that they are possible to obtain energies at a low price.

It is possible to consider the whole group to be one agent, and to perform optimization by a centralized method, referred to be a "whole optimization". The whole optimization comes up with a solution which gives the lower bound of group cost; since each agent is independent, there exists another problem that each agent accepts the solution by the whole optimization or not.

The DEMS is a software (multi-agent) system that seeks optimal planning of purchasing primal energy and operating energy conversion devices in order to satisfy energy demands and constraints on CO_2 emissions by considering energy trading in the group. The cost for each agent is defined by the difference between the total cost of purchased energy and the income of sold energy; the cost of the group is defined by the sum of agent's costs. We are expecting that the group cost is minimized as a result of profit-seeking activities of agents.

Generally, energy demands are time varying and cost arises at starting conversion devices up. Although the goal of our research is solving the UC problem and deciding the allocation of traded energies in DEMSs, the main topic of this chapter is to discuss how to find an optimal energy allocation. In order to make the problem simple, we consider the UC problem with only one time period and all of the energy conversion devices are active.

In DEMSs, since a cap on CO_2 emissions is imposed on each agent, it is necessary that a producer is able to impute his overly-emitted CO_2 to consumers in energy trading. Therefore, we employ not only the unit price but also the CO_2 emission basic unit for energy trading. The CO_2 emission basic unit means the amount of CO_2 emitted by energy consumption of one unit. Power companies and gas companies calculate CO_2 emission basic unit of their selling energies in consideration of relative proportions of their own energy conversion devices or constituents of products, and companies have been made them public. Consumers are possible to calculate their CO_2 emissions came from their purchased energy. Note that CO_2 emission basic unit is considered just as one of attributes of a energy in DEMSs, and its value could be decided independent of relative proportions of energy conversion devices or constituents of products.

In a group, agents are connected by electricity grids and heat pipelines; they are able to transmit energies via these facilities. The electricity grid connects each pair of agents, but the heat pipeline is laid among a subset of agents. We do not take capacities of electricity grids and heat pipelines into account; also no wheeling charge is considered.

2.2 Example Group

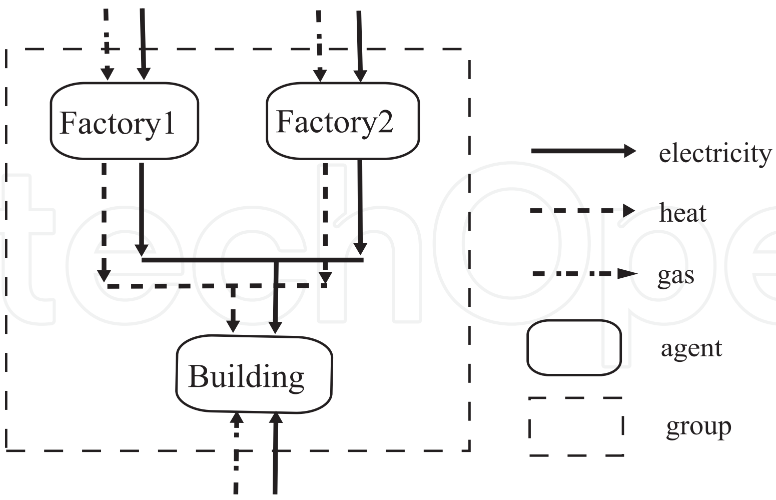

Fig. 1. An example group

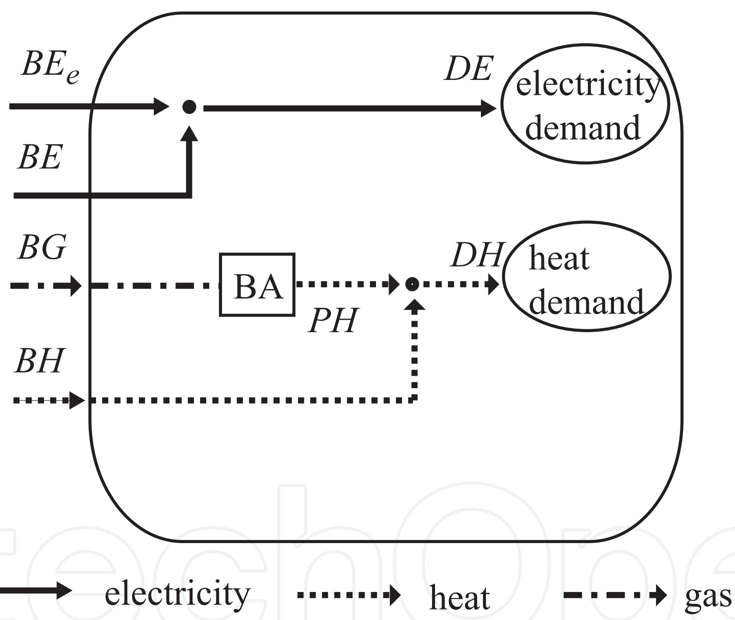

Fig. 2. A building model

Figure 1 depicts an example group that is a subject of this chapter. This group is composed of three agents: Factory1, Factory2, and Building. The arrows indicate energy flows; two factories purchase electricity and gas from outside of the group and sell electricity and heat in the group, and Building purchases electricity, gas and heat from both of inside and outside of the group.

Composition of each agent is shown in Fig. 2 and Fig. 3. BA is a boiler and GT is a gas-turbine. BE_e and BE express electricity purchased from outside and inside of the group, respectively. BG expresses gas purchased from outside of the group; BH expresses heat purchased from

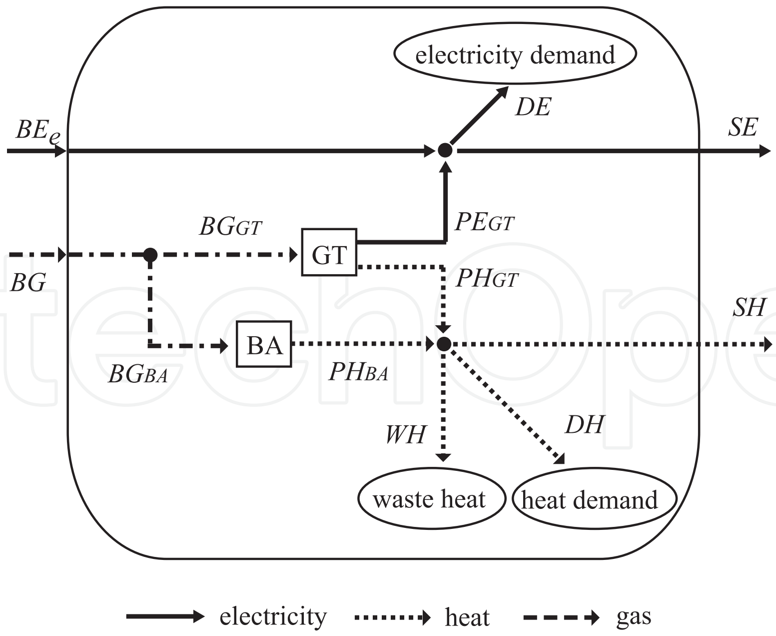

Fig. 3. A factory model

inside of the group. PH is the produced heat and PE is the generated electricity. DE, DH, and WH express electricity demand, heat demand, and waste heat, respectively. Building tries to meet his electricity demand by purchasing electricity from inside and outside of the group, and he tries to meet his heat demand by producing heat with his boiler and by purchasing heat in the group. Factories tries to meed his electricity demand by generating electricity with his gas-turbine and by purchasing electricity from outside of the group, and he tried to meet his heat demand by producing heat with his boiler and/or gas-turbine.

3. Application of the Market-Oriented Programming into DEMSs

3.1 Market-Oriented Programming

The Market-Oriented Programming (MOP)(Wellman, 1993) is a method for constructing a virtual perfect competitive market on computers, computing a competitive equilibrium as a result of the interaction between agents involved in the market, and deriving the Pareto optimum allocation of goods. For formulation of the MOP, it is necessary to define (1) goods, (2) agents, and (3) agent's bidding strategies.

A market is opened for each good, and the value (unit price) of a good is managed by the market. Each agent cannot control the value, and he makes bids by the quantity of goods in order to maximize his own profit under the presented values. Each market updates the value in compliance with market principles (Fig. 4). Namely, when the demand exceeds the supply, the market raises the unit price; when the supply exceeds the demand, the market lowers the unit price. The change of unit price is iterated until the demand is equal to the supply in all markets; the state is called an equilibrium.

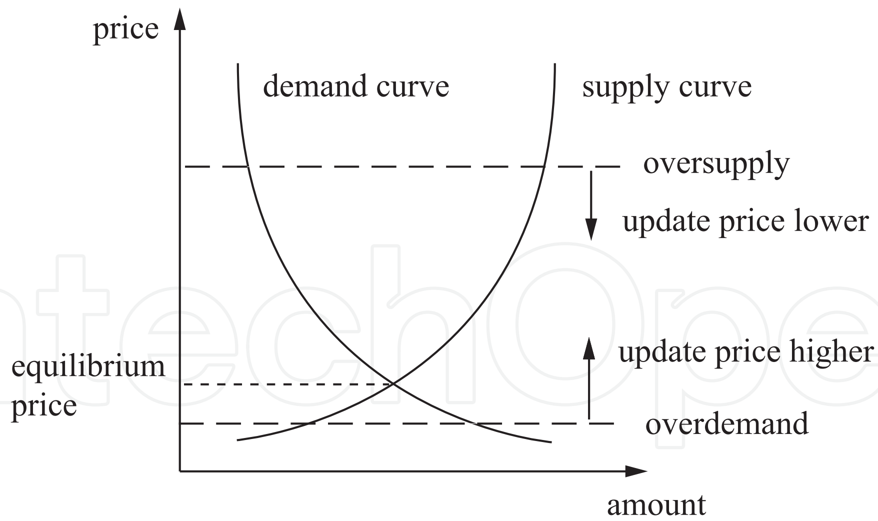

Fig. 4. Price updating in the market

3.2 Formulation of Markets

For the formulation of MOP, we define (1) goods (2) agents, and (3) agent's bidding strategies as follows:

(1) goods
Electricity and heat traded in the group are goods.

(2) agents
A corporate entity in the group is an agent, and an agent that has energy converters such as turbines can become a producer or a consumer, but it cannot be a producer and a consumer at the same time.

(3) agent's bidding strategies
Bidding strategies will be described in Section 3.3.

3.3 Bidding Strategies

Let $\mathcal{P} = \{p_1, \cdots, p_n\}$ be a set of agents. The set $\mathcal{E}$ of electricity energies is defined as follows:

$$\mathcal{E} = \{E_{ij} | p_i, p_j \in \mathcal{P}\} \cup \{E_{ei} | p_i \in \mathcal{P}\}, \tag{1}$$

where E_{ij} denotes electricity supplied from agent p_i to agent p_j, and E_{ei} denotes electricity that agent p_i purchased from outside of the group. The electricity E_{ij} is a pair $(\alpha_{E_{ij}}, \beta_{E_{ij}})$; $\alpha_{E_{ij}}$ is the unit price, and $\beta_{E_{ij}}$ is the CO_2 emissions basic unit of E_{ij}. The electricity E_{ei} is also a pair $(\alpha_{E_{ei}}, \beta_{E_{ei}})$. There exists only one kind of electricity in outside of the group, i.e. $\forall i, j$, $\alpha_{E_{ei}} = \alpha_{E_{ej}}$ and $\beta_{E_{ei}} = \beta_{E_{ej}}$.
The set of heat energies is represented by $\mathcal{H} = \{H_{ij}\}$, $(i, j = 1, \cdots, n, i \neq j)$, where H_{ij} denots heat that is supplied from agent p_i to agent p_j. Also the heat H_{ij} is a pair $(\alpha_{H_{ij}}, \beta_{H_{ij}})$; $\alpha_{H_{ij}}$ is the unit price, and $\beta_{H_{ij}}$ is the CO_2 emissions basic unit.
$\mathcal{K} = \{K_{wi}\}$, $(i = 1, \cdots, n)$ represents the set of other energies, such as gas, that are supplied to agent p_i from outside of the group. K_{wi} is a pair $(\alpha_{K_{wi}}, \beta_{K_{wi}})$; $\alpha_{K_{wi}}$ is the unit price, and $\beta_{K_{wi}}$ is the CO_2 emissions basic unit.

The amount of traded electricity $E \in \mathcal{E}$ is expressed by a map $Q : \mathcal{E} \to \mathbb{R}^+$, where $\mathbb{R}^+$ is the set of non-negative real numbers. Here the following equations must hold for purchased electricity BE_i and sold electricity SE_i of agent p_i:

$$BE_i = \sum_{j \neq i \vee j=e} Q(E_{ji}), \text{and} \tag{2}$$

$$SE_i = \sum_{j \neq i \vee j=e} Q(E_{ij}). \tag{3}$$

The amount of traded heat $H \in \mathcal{H}$ is expressed by a map $R : \mathcal{H} \to \mathbb{R}^+$. The following equations must hold for purchased heat BH_i and sold heat SH_i of agent p_i:

$$BH_i = \sum_{j \neq i} R(H_{ji}), \text{and} \tag{4}$$

$$SH_i = \sum_{j \neq i} R(H_{ij}). \tag{5}$$

BK_{wi}, DE_i, DH_i, and WH_i express the amount of purchased energy K_{wi}, the demand, the head, and the waste heat of agent p_i, respectively.
The cost J_i of agent p_i is calculated by the following equation:

$$\begin{aligned} J_i = & \sum_{j \neq i \vee j=e} \alpha_{E_{ji}} \cdot Q(E_{ji}) + \sum_{j \neq i} \alpha_{H_{ji}} \cdot R(H_{ji}) + \sum_{K_{wi} \in \mathcal{K}} \alpha_{K_{wi}} \cdot BK_{wi} \\ & - \sum_{j \neq i} \alpha_{E_{ij}} \cdot Q(E_{ij}) - \sum_{j \neq i} \alpha_{H_{ij}} \cdot R(H_{ij}). \end{aligned} \tag{6}$$

The CO_2 emissions CO_{2i} of agent p_i is calculated by the following equation:

$$\begin{aligned} CO_{2i} = & \sum_{j \neq i \vee j=e} \beta_{E_{ji}} \cdot Q(E_{ji}) + \sum_{j \neq i} \beta_{H_{ji}} \cdot R(H_{ji}) + \sum_{K_{wi} \in \mathcal{K}} \beta_{K_{wi}} \cdot BK_{wi} \\ & - \sum_{j \neq i} \beta_{E_{ij}} \cdot Q(E_{ij}) - \sum_{j \neq i} \beta_{H_{ij}} \cdot R(H_{ij}). \end{aligned} \tag{7}$$

Let K_i be the cap on CO_2 emissions for agent p_i. Then the following equation must hold.

$$CO_{2i} \leq K_i \tag{8}$$

Let $\mathcal{U}_i = \{u_1, \cdots, u_m\}$ be the set of energy conversion devices of agent p_i. Each device has input-output characteristic function:

$$\Gamma_k : \mathbb{R}^{+\{IE_k, IH_k, IK_{wik}\}} \to \mathbb{R}^{+\{OE_k, OH_k\}}, \tag{9}$$

where IE_k is the amount of input electricity, IH_k is the amount of input heat, IK_{wik} is the amount of input energy K_{wi}, OE_k is the amount of output electricity, and OH_k is the amount of output heat for device u_k. The form of a characteristic function depends on the conversion device; in the case of gas boiler it could be expressed by the following function:

$$OH_k = p(IK_{wik})^b + d, \tag{10}$$

where p, b, and d are parameters. For adding constraints on output range, inequality can be used:

$$\underline{OH_K} \leq OH_k \leq \overline{OH_k}, \tag{11}$$

where $\underline{OH_K}$ and $\overline{OH_k}$ are the minimum output and the maximum output, respectively.
The following energy balance equations for each energy must hold in each agent.

$$BE_i + \sum_{k=1}^{m} OE_k = DE_i + SE_i + \sum_{k=i}^{m} IE_k \quad (12)$$

$$BH_i + \sum_{k=1}^{m} OH_k = DH_i + SH_i + WH_i + \sum_{k=i}^{m} IH_k \quad (13)$$

$$\forall K_{wi} \in \mathcal{K} : BK_{wi} = \sum_{k=i}^{m} IK_{wik} \quad (14)$$

Agent p_i will decide his bids for the markets by solving the following minimization problem.

$$\begin{aligned} \min \quad & J_i \\ \text{s.t.} \quad & (8), (12), (13), (14) \\ & \forall u_k \in \mathcal{U}_i : \Gamma_k \end{aligned} \quad (15)$$

Each agent finds the amount of purchased/sold energies and input energies for his conversion devices that minimize his own cost under the constraints of energy balance, the cap on CO_2 emissions, characteristics of devices.
Bidding strategies of agents introduced in Section 2.2 could be expressed as follows.
Building

$$\min \quad \alpha_{BE_e} BE_e + \alpha_{BE} BE + \alpha_{BG} BG + \alpha_{BH} BH \quad (16)$$

$$\text{s.t.} \quad PH = p_{BA} BG^{b_{BA}} - d_{BA} \quad (17)$$

$$BE_e + BE = DE \quad (18)$$

$$BH + PH = DH \quad (19)$$

$$\beta_{BE_e} BE_e + \beta_{BE} BE + \beta_{BG} BG + \beta_{BH} BH \leq K_{\text{Building}} \quad (20)$$

Factory

$$\min \quad \alpha_{BE_e} BE_e + \alpha_{BG} BG - \alpha_{SE} SE - \alpha_{SH} SH \quad (21)$$

$$\text{s.t.} \quad PE_{GT} = p_{GT_E} (BG_{GT})^{b_{GT_E}} - d_{GT_E} \quad (22)$$

$$PH_{GT} = p_{GT_H} (BG_{GT})^{b_{GT_H}} - d_{GT_H} \quad (23)$$

$$PH_{BA} = p_{BA} (BG_{BA})^{b_{BA}} - d_{BA} \quad (24)$$

$$BE_e + PE_{GT} = DE + SE \quad (25)$$

$$PH_{GT} + PH_{BA} = DH + SH + WH \quad (26)$$

$$BG = BG_{GT} + BG_{BA} \quad (27)$$

$$\beta_{BE_e} BE_e + \beta_{BG} BG - \beta_{SE} SE - \beta_{SH} SH \leq K_{\text{Factoriy}} \quad (28)$$

3.4 Demand-Supply Curves

It is know that one of necessary conditions for the convergence of the MOP is convexity of the production possibility set(Wellman, 1993). The characteristic function of energy conversion devices is important of the convexity. For example, when the function is given by Equation (10), the parameter b must hold that $b < 1$. A typical example of demand-supply curves in DEMSs is shown in Fig. 5. There exist two characteristics in DEMSs.

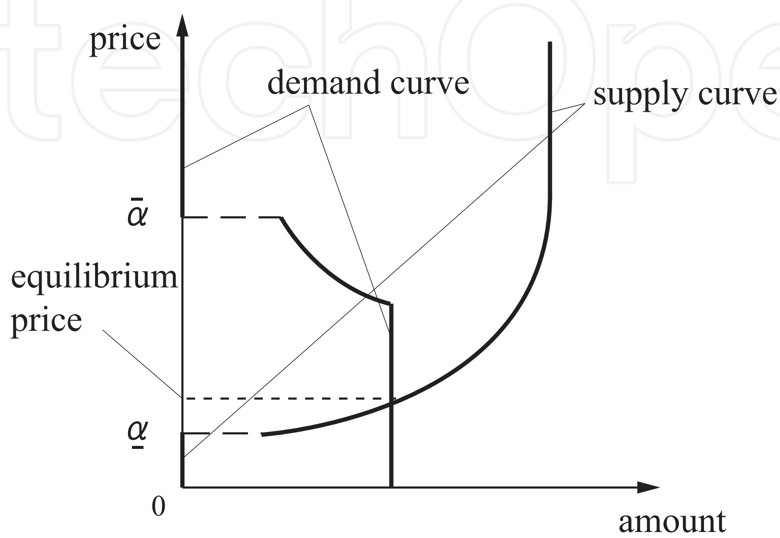

Fig. 5. Demand-supply curves in DEMSs

The first characteristic is that the demand (resp. supply) curve has a gap in the amount between 0 and some positive value at the price $\overline{\alpha}$ (resp. $\underline{\alpha}$). This is caused by that agents tries to maximize their economic profits. Namely, $\overline{\alpha}$ and $\underline{\alpha}$ are marginal prices so that agents are able to make a profit. It is profitable for a consumer to purchase the energy in the group when the price is lower than $\overline{\alpha}$, then he will bid a positive value. If the price is higher than $\overline{\alpha}$, it is profitable to purchase the energy from outside of the group, then his bid will become 0. Similarly, a producer will not supply energy in the group when the price is lower than $\underline{\alpha}$.

The second characteristic is that there exists a upper limit of the amount for both of the demand and the supply curves. The upper limit for the demand curve comes from the energy demand of consumers, and the upper limit for the supply curve comes from capacities of energy conversion devices.

3.5 Execution Procedure

Due to the characteristics described in Section 3.4, a case may happen that no crossing exists, therefore a simple MOP procedure does not converge to the equilibrium.

There exist two types for such a situation.

1. Over-demand at $\overline{\alpha}$ (Fig. 6)
   When producers are not able to supply enough energy to meet the demand of consumer agents, the demand exceeds the supply even at (just below of) $\overline{\alpha}$. At the next turn, the price becomes a little bit higher than $\overline{\alpha}$, then the demand becomes 0. Therefore vibration of price may appear.

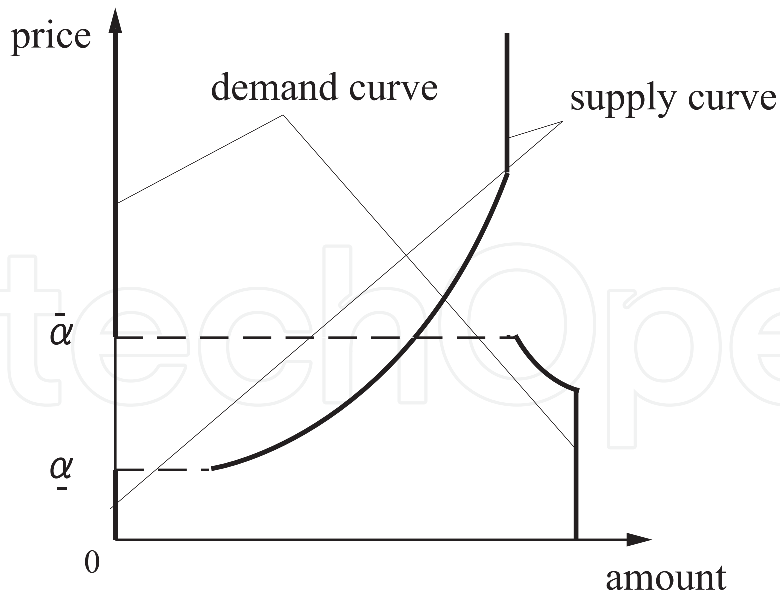

Fig. 6. Over-demand at $\overline{\alpha}$

In this case, the supplied energy is shared among consumer agents and the shortage must be managed by other methods. By introducing a cap on the demand in the MOP procedure, we realize that.

2. Over-supply at $\underline{\alpha}$ (Fig. 7)
   When suppliers produce an ample of energy, the amount of the supply may exceeds the demands at (just above of) $\underline{\alpha}$. At the next turn, the price becomes a little bit lower than $\underline{\alpha}$, then the supply becomes 0. Also in this case, vibration of price may appear.

   This kind of situation may occur when a supplier hold a co-generation system and his heat demand is not much. He operate the co-generation system in order to meet the electricity demand. But at the same time, plenty of heat will also produced. He may sell the heat even if the price is 0, but may not sell when the price becomes negative.

   In this case, the energy demand is shared among producer agents and the rest is dumped. By introducing a cap on the supply in the MOP procedure, we realize that.

The idea described above 1. and 2. is realized by the following procedure, see Fig. 8. In the following the consumer is denoted by p_{con}, and the set of producers is denoted by $\mathcal{S}$.
At **Step1**, one market is established for each energy and for each consumer. The initial value is a pair (α_0, β_0), where α_0 is the initial unit price and β_0 is the initial CO_2 emissions basic unit. In each market, $d = \infty$, and $s_{p_i} = \infty$ for each $p_i \in \mathcal{S}$.
At **Step2**, the market presents 3-tuple (α, β, d) to the consumer, and (α, β, s_{p_i}) to producer $p_i \in \mathcal{S}$, where, α is the unit price, β is the CO_2 emissions basic unit, d is the upper bound of the demand, and s_{p_i} is the upper bound of the supply.
At **Step3**, the consumer and the producer decide the amount of the demand and the supply based on the condition that the market presents, respectively. The bidding strategy described in Section 3.3 is used for the decision.
At **Step4**, the market updates the price or the upper bound according to the supply and the demand. The bid amount by the consumer is denoted by $bid_{p_{con}}$, and the bid amount by the

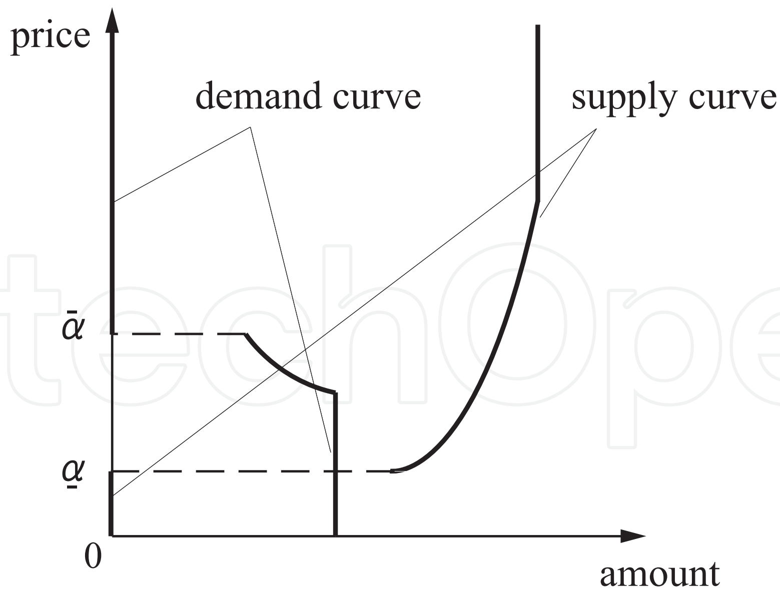

Fig. 7. Over-supply at $\underline{\alpha}$

producer p_i is denoted by bid_{p_i}. At **Case 2.3** and **Case 3.3**, the value of α is updated according to the equality (29):

$$\alpha := \alpha + \gamma(bid_{com} - \sum_i bid_{sup_i}), \tag{29}$$

where $\gamma > 0$ is a parameter. The equality (29) raises the unit price when over-demand, and lowers it when over-supply.
Steps from 2 to 4 are repeated until the condition of **Step4-Case 1** holds in all markets.

4. Computational Experiments

4.1 Energy Trading Decision Methods

This section introduces other energy allocation methods briefly.

4.1.1 Individual Optimization

Under the individual optimization method, each agent purchases energy only from outside of the group, and optimizes its running plan of conversion devices. By using this method, we can calculate group cost and cost for each agent under a condition that internal energy trading is not used.

4.1.2 Whole Optimization

The whole optimization method considers the group as one agent, and does optimization for the whole group. In this case the cap on emissions is imposed on the whole group. We can calculate lower bound cost for the group by using this method. This lower bound is optimal, and we cannot get better plan than that. With this method, we can get an energy purchase and running plan of devices, but we cannot get cost and CO_2 emission for each agent.

Step 1 Establish Markets

Step 2 Present Conditions

Step 3 Bid

Step 4 Update Condition

Case 1 $bid_{p_{con}} = \Sigma_{p_i \in \mathcal{S}} bid_{p_i}$

If this condition holds in all markets, the MOP procedure finishes.

Case 2 $bid_{p_{con}} < \Sigma_{p_i \in \mathcal{S}} bid_{p_i}$

Case 2.1 $d < \Sigma_{p_i \in \mathcal{S}} bid_{p_i}$

The market raises d.

Case 2.2 $d \geq \Sigma_{p_i \in \mathcal{S}} bid_{p_i} \wedge \alpha \leq \underline{\alpha}$

The market lowers s_{p_i} for each $p_i \in \mathcal{S}$. The value of s_{p_i} is decided in proportion to bid_{p_i} and under the constraint of an equality $\Sigma_{p_i \in \mathcal{S}} s_{p_i} = bid_{p_{con}}$.

Case 2.3 $d \geq \Sigma_{p_i \in \mathcal{S}} bid_{p_i} \wedge \alpha > \underline{\alpha}$

The market lowers α.

Case 3 $bid_{com} > \Sigma_{p_i \in \mathcal{S}} bid_{p_i}$

Case 3.1 $bid_{p_{con}} > \Sigma_{p_i \in \mathcal{S}} s_{p_i}$

The market raises s_{p_i} for each $p_i \in \mathcal{S}$.

Case 3.2 $bid_{p_{con}} \leq \Sigma_{p_i \in \mathcal{S}} s_{p_i} \wedge \alpha \geq \overline{\alpha}$

The market lowers d. The value of d is $\Sigma_{p_i \in \mathcal{S}} s_{p_i}$.

Case 3.3 $bid_{p_{con}} \leq \Sigma_{p_i \in \mathcal{S}} s_{p_i} \wedge \alpha < \overline{\alpha}$

The market raises α.

The MOP procedure goes back to **Step2**.

Fig. 8. Execution procedure

4.1.3 Multi-attribute and Multi-item Auction

Miyamoto et al. (2007) proposed an energy trading decision method based on English auction protocol(David et al., 2002). This method is a multi-attribute auction because it uses two attributes: unit price and CO_2 emission basic unit. Also it is a multi-item auction because energy demands could be divided into several demands with small energy amount.

This method expresses energy value by

$$\nu = \lambda\alpha + \mu\beta, \tag{30}$$

where α is unit price, β is CO_2 emission basic unit, and λ and μ are parameters. A consumer shows three items: amount of energy demand, λ and μ. Producers bid three items: their amount of energy supply, α, and β. After some iterations, winning producers get rights to supply.

When an agent holds a conversion device, such as a gas turbine, that is able to produce more than one types of energy, electricity trading and heat trading are inseparable for the agent. Therefore, in (Miyamoto et al., 2007) we adopted a sequential method; we decide electricity trading first and then decide heat trading.

4.2 Configuration

In the following experiments, we used parameters shown in Tables 1 and 2.

α_{BE_e}[yen/kWh]	10.39
β_{BE_e}[kg-CO_2/kWh]	0.317
α_{BG}[yen/m^3]	28.6
β_{BG}[kg-CO_2/m^3]	1.991

Table 1. Unit price and CO_2 emission basic unit of electricity and gas from outside of the group

	Building	Factory 1	Factory 2
p_{BA}	35.03	37.22	37.02
b_{BA}	0.85	0.85	0.85
d_{BA}	5000	8000	8000
$\overline{PH_{BA}}$	10000	10000	5000
p_{GT_E}	-	17.91	16.32
b_{GT_E}	-	0.85	0.85
d_{GT_E}	-	6000	6200
$\overline{PE_{GT}}$	-	50000	30000
p_{GT_H}	-	31.84	25.87
b_{GT_H}	-	0.85	0.85
d_{GT_H}	-	2200	2200

Table 2. Parameters of energy conversion devices

Table 1 shows unit price and CO_2 emission basic unit of electricity and gas purchased from outside of the group. These values are taken from Web pages of power and gas company in Japan.
Table 2 shows parameters of conversion devices, where $\overline{PH_{BA}}$ is the maximum output heat of the boiler, and $\overline{PE_{GT}}$ is the maximum output electricity of the gas-turbine.

4.3 Ex1: Evaluation of Concurrent Evolution

This experiment is done in order to evaluate the concurrent evolution of electricity and heat trading. Table 3 shows energy demands and the cap on CO_2 emissions for each agent.

	Building	Factory 1	Factory 2
DE[kWh]	12000	40000	20000
DH[Mcal]	10000	30000	15000
K[kg-CO_2]	7500	20000	15000

Table 3. Ex1: energy demands and caps on emissions

Experimental results are shown in Tables 4, 5, 6, and 7.
By the auction method (Table 5), the producer agent assumes that amount of heat trade is zero when the agent calculate a bid for electricity auction. The agent cannot allow for emissions reduction through heat trading, and electricity sales of Factory 2 resulted in only 4748.1[kWh]. The agent cannot produce further electricity due to the caps.

	Factory 1	Factory 2	Building	total
BE_e[kWh]	51.4	0.0	2000.0	2051.4
BG[m^3]	10802.9	9195.3	342.5	20340.7
BE[kWh]	-	-	10000.0	10000.0
BH[Mcal]	-	-	10000.0	10000.0
SE[kWh]	0.0	10000.0	-	10000.0
SH[Mcal]	6747.2	3252.8	-	10000.0
CO_2[kg-CO_2]	20000.0	14402.7	6745.9	41148.6
cost[yen]	309497.0	159258.5	134302.6	603058.1

Table 4. Ex1: energy allocation by the MOP method

	Factory 1	Factory 2	Building	total
BE_e[kWh]	2303.3	1840.5	6704.6	10848.4
BG[m^3]	10357.1	7240.9	342.5	17940.5
BE[kWh]	-	-	5295.4	5295.4
BH[Mcal]	-	-	10000.0	10000.0
SE[kWh]	547.3	4748.1	-	5295.4
SH[Mcal]	9999.0	1.0	-	10000.0
CO_2[kg-CO_2]	20000.0	15000.0	4158.4	39158.4
cost[yen]	320144.3	184830.9	120837.9	625813.1

Table 5. Ex1: energy allocation by the auction method

	Factory 1	Factory 2	Building	total
BE_e[kWh]	0.0	0.0	0.0	0.0
BG[m^3]	13152.0	7331.0	342.5	20825.5
BE[kWh]	-	-	12000.0	12000.0
BH[Mcal]	-	-	10000.0	10000.0
SE[kWh]	8760.0	3240.0	-	12000.0
SH[Mcal]	10000.0	0.0	-	10000.0
CO_2[kg-CO_2]	-	-	-	41463.6
cost[yen]	-	-	-	595609.3

Table 6. Ex1: energy allocaiton by the whole optimization method

On the other hand, Factory 2 succeeded to sell electricity of 10000[kWh] by the MOP method (Table 4), because the agent could take emissions reduction through heat trading into consideration. This trade could not be achieved through sequential method such as the auction method. The MOP method succeeded to obtain better solution by deciding electricity and heat trade concurrently.

The whole optimization method worked out an optimal solution (Table 6), and Factory 1 which has the most efficient gas turbine produced most electricity and heat for Building. As a result, the group does not buy any electricity from the outside. As for group costs, we can say that group cost by the MOP method is not so different from cost by the whole optimization. Note that this method cannot decide the cost and CO_2 emissions for each agent.

	Factory 1	Factory 2	Building	total
BE_e[kWh]	7780.0	0.0	12000.0	19780.0
BG[m^3]	8806.0	6463.0	1247.0	16516.0
BE[kWh]	-	-	0.0	0.0
BH[Mcal]	-	-	0.0	0.0
SE[kWh]	0.0	0.0	-	0.0
SH[Mcal]	0.0	0.0	-	0.0
CO_2[kg-CO_2]	19999.0	12867.8	6286.8	39153.6
cost[yen]	332685.8	184841.8	160344.2	677871.8

Table 7. Ex1: energy allocation by the individual optimization method

The resulting plan by the individual optimization was expensive because internal energy trading was not used. The result (Table 7) shows effectiveness of the internal energy trading.

4.4 Ex2: Evaluation for Consumer's Demand Change

This experiment is done in order to evaluate efficiency of the methods under a change of consumer's demands. Energy demands and caps on CO_2 emissions for each agent are shown in Table 8. We fixed electricity demand and increased head demand by 10000[Mcal] of Building who is a consumer in the group. In this case, factories begin to start their boiler as electricity demand increases. In order to exclude influences of emissions constraints, the cap on emissions for Building was set enough large as 35000[kg-CO_2].

	Building	Factory 1	Factory 2
DE[kWh]	12000	40000	20000
DH[Mcal]	10000∼110000	30000	15000
K[kg-CO_2]	35000	30000	20000

Table 8. Ex2: energy demands and caps on emissions

4.4.1 Comparison on Group Cost

Figure 9 shows transitions of group costs by each method when heat demand of Building changes.

Costs by all methods except the individual optimization are constant until 90000[Mcal]. This is because heat was over produced in order to produce electricity and internal trading of heat does not effect the group costs. When heat demand exceeds 100000[Mcal], agents have to start their boiler to meet the heat demand, and then the group costs increases.

In comparison to the individual optimization, which does not use internal trading, other three methods succeeded to reduce the group costs. This result shows that it is possible to reduce a group cost by introducing internal energy trading. For every heat demands, the MOP method obtains near optimal solutions, and they were better than the solutions by the auction method. This is an effect of the concurrent evolution.

4.4.2 Comparison on Agent Costs

Figure 10 shows transitions of CO_2 emissions for each agent by the MOP method, and Fig. 11 shows transitions by the auction method.

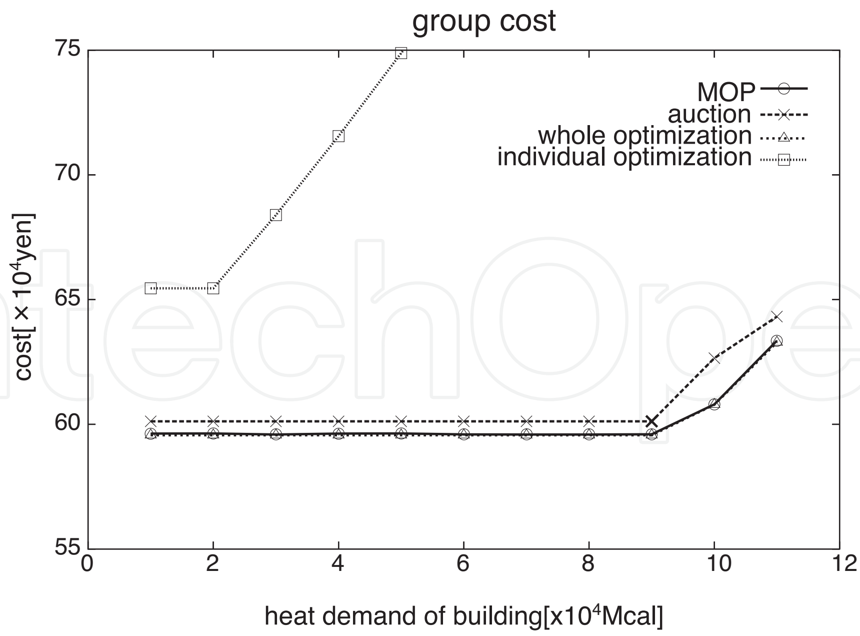

Fig. 9. Ex2: transition of group cost

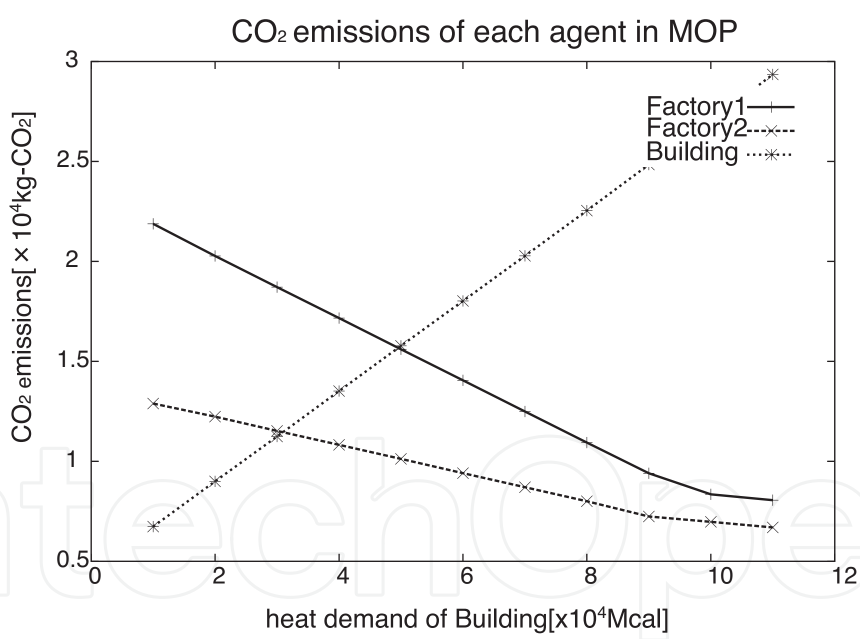

Fig. 10. Ex2: transition of CO_2 emissions by the MOP method

As depicted in Fig. 10, by the MOP method emissions by Building increases linearly, and emissions of Factories 1 and 2 decease as heat demand increases. In this experiment, since CO_2 emission basic unit of heat is fixed as a positive value[1], emissions by consumers increases as heat demand increases, and producers can reduce their emissions by shifting emissions to the consumer.

[1] Actually the value is the same with a basic unit calculated by assuming that Building use its own boiler.

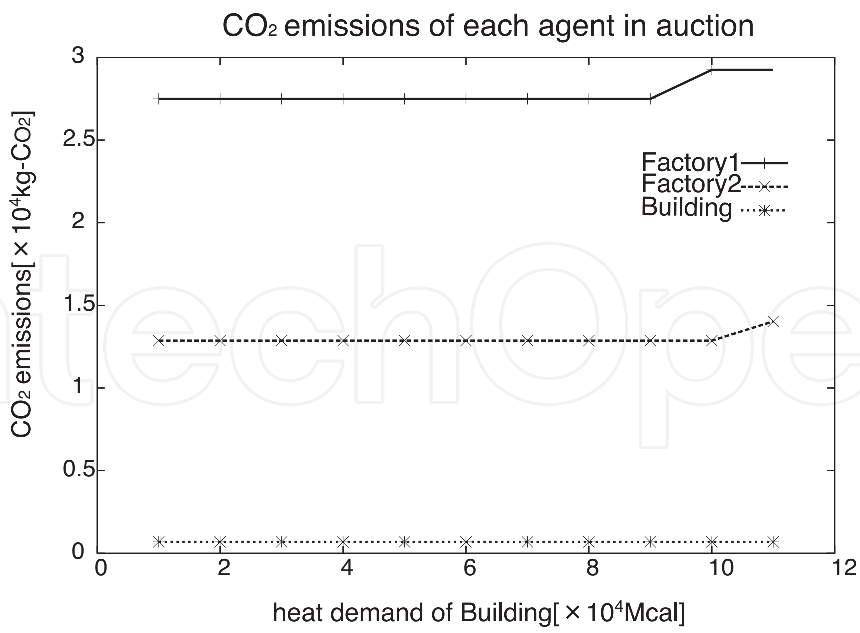

Fig. 11. Ex2: transition of CO_2 emissions by the auction method

On the other hand, as depicted in Fig. 11, by the auction method emissions by each agent were constant. In the auction method, producers can decide CO_2 emission basic unit for their bid. In this experiment, since caps on emissions for each agent was large enough, producers chose zero as CO_2 emission basic unit for their bids in order to reduce costs. As a result, CO_2 emissions by Factory 1 and 2 stayed at high level, and emissions by Building stayed at low level.

The MOP method at this point does not include a mechanism to change a value of CO_2 emission basic unit dynamically. This may cause a situation that results by the MOP becomes worse than the auction method when a cap on emissions for a producer is small. In order to confirm this prospect, the next experiment is done by changing caps on emissions for a producer.

4.5 Ex3: Evaluation on Caps on Emissions Change

	Building	Factory 1	Factory 2
DE[kWh]	12000	40000	20000
DH[Mcal]	10000	30000	15000
K[kg-CO_2]	7500	20000	11000∼20000

Table 9. Ex3: energy demands and caps on emissions

Energy demands and caps on CO_2 emissions for each agent are shown in Table 9. We fixed the cap on CO_2 emissions for Factory 1 as 20000[kg-CO_2], and changed the cap for Factory 2.

4.5.1 Comparison on Group Cost

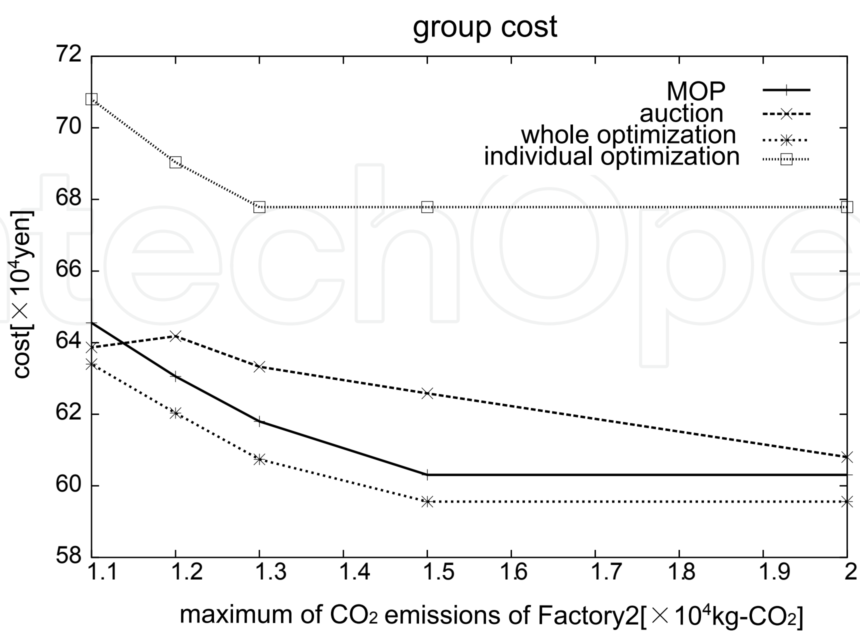

Fig. 12. Ex3: transition of group cost

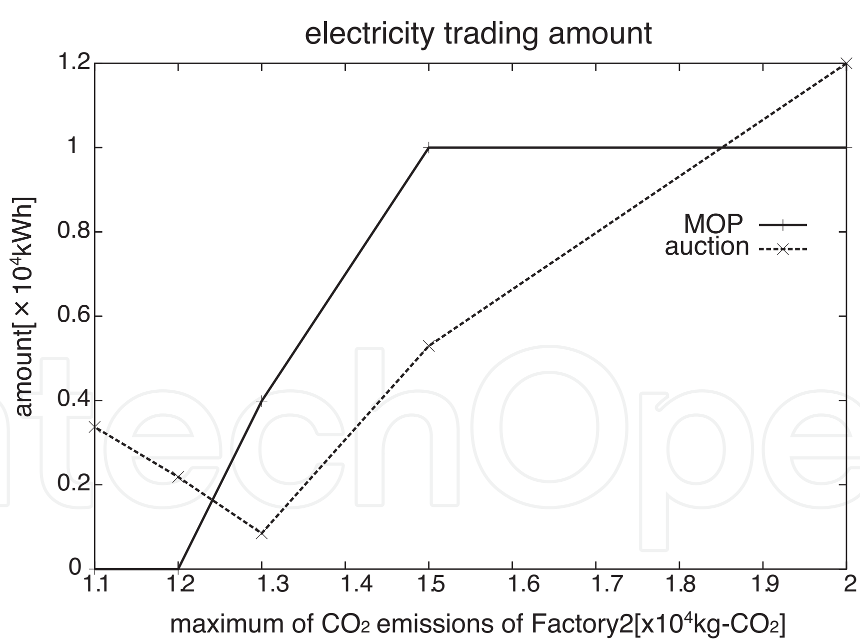

Fig. 13. Ex3: transitions of electricity trade of Factory2

Figure 12 shows transitions of group costs by each method when the cap on emissions for Factory 2 changes.

As depicted in Fig. 12, group costs by the MOP method are lower than the costs by the auction method when the caps on emissions for Factory 2 is larger than or equals to 12000[kg-CO_2]. The group cost by the auction method, however, becomes low when the cap is 11000[kg-CO_2]. Figure 13 shows transitions of electricity trade of Factory 2 by the MOP and the auction methods. When the cap was 11000[kg-CO_2], electricity was not traded internally by the MOP method, but was traded by the auction method. Since the MOP method at this point does not include a mechanism to change a value of CO_2 emission basic unit dynamically, Factory 2 chose zero as its supply for electricity market when the cap was less than or equals to 12000[kg-CO_2].
In the auction method, producers can decide CO_2 emission basic unit for their bid. Table 10 show combinations of unit price and CO_2 emission basic unit of bids by Factory 2. The table shows that Factory 2 selected a scheme to reduce emissions by setting unit price as zero and emission basic unit as a positive value when the cap was less than or equals to 12000[kg-CO_2]. As a result, the auction method succeeded to trade electricity internally for every cases.

	Factory 1		Factory 2	
$K_{Factory2}$	α	β	α	β
20000	0	0.9577	8.7153	0
15000	0	0.9577	8.7153	0
13000	0	0.9577	8.7153	0
12000	0	0.9577	0	1.1149
11000	0	0.9577	0	0.9577

Table 10. Ex3: change of unit price and CO_2 emission basic unit

As described above, we found that the MOP method at this point may lose an opportunity to deal internally in same special cases such as the cap on emissions for a producer is small.

4.6 Ex4: Evaluation on CO_2 Emissions Reduction

This experiment is done in order to evaluate possibility of CO_2 emissions reduction by the methods. Energy demands and caps on CO_2 emissions for each agent are shown in Table 11.

	Building	Factory 1	Factory 2
DE[kWh]	12000	40000	20000
DH[Mcal]	10000	30000	15000

Table 11. Ex4: energy demands and caps on emissions

Table 12 shows caps on CO_2 emissions for each agent, and CO_2 emissions basic units which were used for the MOP method. At first, we calculated minimal CO_2 emissions by using the individual optimization method for each agent. Values of this emissions were the caps at the first step, then the caps are decreased in the same rate r%. We evaluated whether each method is able to obtain a feasible solution. In case of the MOP method, we decreased also the CO_2 emissions basic unit in the same rate, so that Building meets the cap constraint.

r[%]	$K_{Factory1}$	$K_{Factory2}$	$K_{Building}$	β_E	β_H
0	16999	11000	6286	0.317	0.226
1	16829	10890	6223	0.313	0.223
2	16659	10780	6161	0.310	0.221
3	16489	10670	6098	0.307	0.219
4	16319	10560	6035	0.304	0.216
5	16149	10450	5972	0.301	0.214
6	15979	10340	5909	0.297	0.212
7	15809	10230	5846	0.294	0.210

Table 12. Ex4: caps on CO_2 emissions and basic units

r[%]	MOP	Auction	Whole
1	-	725400	710533
2	-	727623	717715
3	-	-	725179
4	-	-	732999
5	-	-	741153
6	-	-	749876
7	-	-	-

Table 13. Ex4: group costs when emissions basic units in Table 12 are used

r[%]	MOP	Auction	Whole
1	710927	725400	710533
2	718397	727623	717715
3	725862	-	725179
4	733687	-	732999
5	741854	-	741153
6	751673	-	749876
7	-	-	-

Table 14. Ex4: group costs when $\beta_E = 0.502$, $\beta_H = 0.020$

Group costs by each method when emissions basic units in Table 12 were used are shown in Table 13. The whole optimization method succeeded to reduce CO_2 emissions of 6% from the individual optimization. This shows that by using internal energy trading it is possible to reduce CO_2 of maximally 6% in this case. The auction method succeeded to reduce emissions in 2%, and the MOP method failed to reduce.

In the case of this example, Factories have to operate their gas turbine further to produce electricity for internal trade, and then their emissions increases. On the other hand, since Factories have overly produced heat, internal trade of heat does not increase their emissions. Factories need to shift their emissions onto selling electricity.

Therefore, we set CO_2 emissions basic unit of electricity (resp. heat) as 0.502[kg-CO_2/kWh] (resp. 0.020[kg-CO_2/m^3]), and examined again. Results are shown in Table 14. In this case,

the MOP method succeeded to reduce emissions in 6%, and the group cost was close to that of the optimal solution. The auction method is not able to reduce further since Factories cannot allow for heat trade. The result shows that the MOP method is effective also for CO_2 emissions reduction.
The above discussion suggests to develop CO_2 emissions basic unit control mechanism in the MOP method. To do that, we have to develop the following two methods: 1) a method to sense a situation where basic unit should be adjusted, and 2) a method to adjust the basic unit. Our resent research considers how to realize the CO_2 emissions basic unit control mechanism(Sugimoto et al., 2008a;b).

5. Conclusion

This chapter considered energy management in a group which is composed of plural corporate entities. Entities perform optimal planning of purchasing primal energy and operating energy conversion devices in order to satisfy energy demands. Moreover a cap on CO_2 emissions is imposed on each entity, and it is not allowed to exhaust CO_2 more than their caps. This chapter discussed effectiveness the energy trading in the group.
In order to make the problem simple, we supposed the UC problem with only one time period and all of the energy conversion devices were active, and we discussed how to decide energy allocation among entities. So far, we had proposed an auction based method(Miyamoto et al., 2007), but the method had a problem on efficiency. Therefore we proposed the MOP based method for deciding energy allocation. In order to decide energy allocation in DEMSs, we formulated the group, and showed the MOP based execution procedure.
Next this chapter compared energy trading decision methods by computational experiments. The proposed MOP method succeeded to obtain better solutions than the previous auction method. We, however, found a necessity to develop CO_2 emissions basic unit control mechanism in the MOP method.
Directions of next research includes a) the CO_2 emissions basic unit control mechanism(Sugimoto et al., 2008a), b) groups with plural consumers(Sugimoto et al., 2008b), and c) planning over plural periods.

6. References

Cormio, C., Dicorato, M., Minoia, A. & Trovato, M. (2003). A regional energy planning methodology including renewable energy sources and environmental constraints, *Renewable and Sustainable Energy Reviews* **Vol.7**: 99–130.

David, E., Schwartz, R. & Kraus, S. (2002). An english auction protocol for multi-attribute items, *Lecture Notes in Computer Science* **Vol.2531**: 52–68.

Dicorato, M., Forte, G. & Trovato, M. (2008). Environmental-constrained energy planning using energy-efficiency and distributed-generation facilities, *Renewable Energy* **Vol.33**: 1297–1313.

Hiremath, R., Shikha, S. & Ravindranath, N. (2007). Decentralized energy planning; modeling and application – a review, *Renewable and Sustainable Energy Reviews* **Vol.11**: 729–752.

Kaihara, T. (2001). Supply chain management with market economics, *Intl. J. of PRODUCTION ECONOMICS* **Vol.73**(No.1): 5–14.

Kaihara, T. (2005). A study on resource allocation with buying behavior in b to b commerce, *Elec. Eng. in JAPAN* **Vol.153**(No.1): 63–72.

Maiorano, A., Song, Y. & Trovato, M. (2003). Modelling and analysis of electricity markets, *Operation of Market-oriented Power Systems*, Springer, pp. 13–49.

Miyamoto, T., Kitayama, T., Kumagai, S., Mori, K., Kitamura, S. & Sindo, S. (2007). An energy trading system with consideration of co_2 emissions, *Electrical Engineering in Japan* **Vol.162**(No.4): 1513–1521.

Nagata, T., Ohono, M., Kubokawa, J., Sasaki, H. & Fujita, H. (2002). A multi-agent approach to unit commitment problems, *Proceedings of the IEEE Power Engineering Society Transmission and Distribution Conference*, pp. 64–69.

Padhy, N. P. (2004). Unit commitment – a bibliographical survey, *IEEE Transactions on Power Systems* **Vol.19**: 1196–1205.

Sheble, G. B. & Fahd, G. N. (1994). Unit commitment literature synopsis, *IEEE Transactions on Power Systems* **Vol.9**: 128–135.

Sugimoto, Y., Miyamoto, T., Kumagai, S., Mori, K., Kitamura, S. & Yamamoto, T. (2008a). Co2 emission basic unit control mechanism in a distributed energy management system using the market oriented programming, *Proceedings of ICSET 2008*, pp. 583–588.

Sugimoto, Y., Miyamoto, T., Kumagai, S., Mori, K., Kitamura, S. & Yamamoto, T. (2008b). An energy distribution decision method in distributed energy management systems with several agents, *Proceedings of the 17th IFAC World Congress*, pp. 664–669.

Wellman, M. P. (1993). A market-oriented programming environment and its application to distributed multi-commodity flow problems, *Journal of Artificial Intelligence Research* **Vol.1**: 1–23.

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Forecasts point to a huge increase in energy demand over the next 25 years, with a direct and immediate impact on the exhaustion of fossil fuels, the increase in pollution levels and the global warming that will have significant consequences for all sectors of society. Irrespective of the likelihood of these predictions or what researchers in different scientific disciplines may believe or publicly say about how critical the energy situation may be on a world level, it is without doubt one of the great debates that has stirred up public interest in modern times. We should probably already be thinking about the design of a worldwide strategic plan for energy management across the planet. It would include measures to raise awareness, educate the different actors involved, develop policies, provide resources, prioritise actions and establish contingency plans. This process is complex and depends on political, social, economic and technological factors that are hard to take into account simultaneously. Then, before such a plan is formulated, studies such as those described in this book can serve to illustrate what Information and Communication Technologies have to offer in this sphere and, with luck, to create a reference to encourage investigators in the pursuit of new and better solutions.