沼气工程与技术

Biogas Engineering and Application

Volume 1

董仁杰　[奥]伯恩哈特·蓝宁阁　主编

Edited by: Prof. Dr. DONG Renjie

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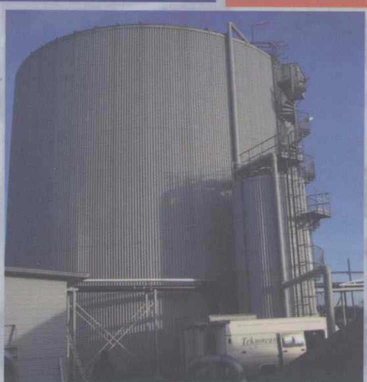

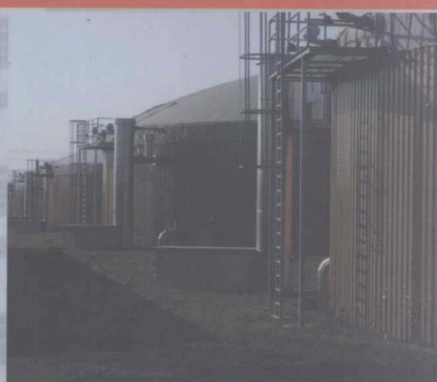

中国农业大学出版社

China Agricultural University Press

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- **Proceedings of ORBIT 2009 International Conference China "Biomass and Organic Waste as Sustainable Resources"**
  ORBIT 2009 年中国生物质与有机废弃物可持续利用国际会议论文集
- **Proceedings of 2010 Forum of Renewable Energy Promotion in Developing Countries**
  发展中国家可再生能源发展论坛论文集

中国农业大学出版社
·北京·

图书在版编目(CIP)数据

沼气工程与技术/董仁杰,[奥]伯恩哈特·蓝宁阁主编. —北京:中国农业大学出版社,2011.1
ISBN 978-7-5655-0190-6

Ⅰ.①沼… Ⅱ.①董… ②伯… Ⅲ.①沼气池-工程技术-国际学术会议-文集 Ⅳ.①S216.4-53

中国版本图书馆 CIP 数据核字(2011)第 012068 号

书　名　沼气工程与技术
作　者　董仁杰　[奥]伯恩哈特·蓝宁阁　主编

策划编辑	张秀环	**责任编辑**	季　方
封面设计	季　方　秦怡思　郑　川	**责任校对**	王晓凤　陈　莹
出版发行	中国农业大学出版社		
社　址	北京市海淀区圆明园西路 2 号	**邮政编码**	100193
电　话	发行部 010-62731190,2620	**读者服务部**	010-62732336
	编辑部 010-62732617,2618	**出　版　部**	010-62733440
网　址	http://www.cau.edu.cn/caup	**E-mail**	cbsszs@cau.edu.cn
经　销	新华书店		
印　刷	涿州市星河印刷有限公司		
版　次	2011 年 1 月第 1 版　2011 年 1 月第 1 次印刷		
规　格	889×1 194　16 开本　21.25 印张　672 千字		
定　价	150.00 元		

图书如有质量问题本社发行部负责调换

PREFACE

China has a long tradition in using biogas in rural areas. Nowadays globally relevant topics, such as environmental pollution from the industrialization in the agricultural area, rapid urbanization trough migration and climate change, are top issues on the international political agenda, and therefore also on the agenda of the Chinese Government. Large scale biogas technology is, in this context getting increasingly important as it is an instrument to tackle targets of circular economy, environmental protection, greenhouse gas emission reduction and renewable energy development within an emerging low carbon society.

Based on these drivers China has started within the recent years to set up middle-, large-and even mega-large biogas plants. Billions of RMB have been spent by the government to subsidies a first generation of middle and large scale biogas plants, which were mainly developed by up scaling traditional technologies with limited performance.

According to the "MOA National Agricultural Biomass Energy Industry Development Plan (2007-2015)", the policy target for developing middle and large scale biogas plants (MLBGPs) at large scale livestock and poultry farms is 8 000 with an annual biogas production of 670 million m^3 by 2015. The "NDRC Medium and Long Term Program of Renewable Energy Development Plan (2006-2020)" anticipates 10 000 MLBGPs at animal husbandries and another 6 000 MLBGPs processing industrial organic wastewater with an overall annual biogas yield of 14 billion m^3 and an installed electricity generation capacity of 3 GW by 2020 as part of the 15% Renewable Energy target in 2020 (Renewable Energy Law, 2006). The enforcement of those policies is part of the 12^{th} Five-Years Plan, but the biogas plant activities planned by the individual provinces are even going far beyond the national targets.

Novel business concepts are required and new technological solutions are emerging, such as multi-feedstock co-digestion at centralized biogas plants, using additional feedstock from straw, biomass grown on marginal and reclaimable land, biomass waste from urban sources. In terms of biogas use: the replacement of petroleum based fuels (CNG, LNG) by biogas as compressed bio-methane for vehicle operation, efficiently generated grid connected biogas power with high availability, biogas projects applied in climatically cold areas in China, viable biogas operation under carbon credit conditions, and so on. All that innovative approaches and objectives have to be seen as new challenges for the biogas technology industry development and have to be joint by setting up a professional and academic training and education system for biogas experts, more research and development and the demonstration of the application of new technologies adapted to the Chinese conditions.

Related international technical cooperation is established to share the experience from developed countries with China and China spreads in contrary its own experience to other developing countries, in order to help them to meet their renewable energy development targets in the context of common global low carbon society development. The 'giz' (Gesellschaft fuer Internationale Zusammenarbeit, Deutschland) supports with its Sino-German Biomass Utilization Project the publication of this book series issued by China Agriculture University, *Biogas Engineering and Application*. This publication shall be a viable platform for scientific and applied biogas technology articles for biogas experts involved in technological and political project development, project implementation and operation. *Biogas Engineering and Application* should be an important information source not only China-wide, it should be as well a source and platform for the international biogas society interested in biogas in China.

The Chief Editors

Prof. Dr. DONG Renjie
China Agricultural University (CAU)
Energy Engineering and Low Carbon Technology Laboratory
Biomass Engineering Center

Prof. Dr. phil.-habil. Bernhard Raninger
Shenyang Aeronautical University (SAU)
Institute for Clean Energy and Environmental Engineering
GIZ, Sino-German Biomass Utilization Project

Beijing, January 2011

前　言

中国农村使用沼气有着悠久的历史。目前，全球普遍存在的农村工业化所造成的环境污染以及城市化进程加速带来的人口流动和气候变化等，已经成为国际政治热点，同时也提上了中国政府的议事日程。在这样的环境下，大型沼气工程技术就变得越来越重要，因为它有助于在未来低碳社会中实现循环经济、环境保护、减排温室气体和生产可再生能源等目标。

在上述因素的驱动下，中国近年来开始建设大中型甚至超大型沼气工程。中国政府为第一代大中型沼气工程项目补贴了数十亿元资金，但是当时的大中型沼气工程技术大多来源于传统沼气池的放大，沼气工程的性能有限。

根据农业部《农业生物质能产业发展规划(2007—2015 年)》所提出的战略目标，到 2015 年，建成规模化养殖场、养殖小区沼气工程 8 000 处，年产沼气 6.7×10^8 m^3；国家发展和改革委员会发布的《可再生能源中长期发展规划》提出，到 2020 年，建成大型畜禽养殖场沼气工程 10 000 座、工业有机废水沼气工程 6 000 座，年产沼气约 1.4×10^{10} m^3，沼气发电装机容量达到 3×10^6 kW，为到 2020 年使可再生能源消费量达到一次能源消费总量的 15%(可再生能源法，2006)做出贡献。“十二五”规划中上述政策得到进一步强化，而且各省沼气工程建设任务将远超过国家的总体目标。

沼气工程发展的新商业模式和新技术不断涌现，例如集中沼气工程上的多原料联合发酵，就使用秸秆、边际土地的能源作物和城市有机废弃物作为沼气工程的原料。在沼气的利用方面，则有用压缩沼气源甲烷作为车用燃料代替化石能源(压缩天然气和液化天然气)，在可行的地方实施沼气高效发电并网，在中国寒冷地区实施建设沼气工程，碳交易机制支持下的沼气工程建设等。上述各种创新的模式和技术都是沼气工程发展的机遇和面临的挑战，必须通过对沼气工程技术人员的培训、更多的研究、以及适合中国国情的沼气工程的开发和示范，实现沼气工程创新模式和技术的整合。

中国与发达国家之间已经建立了相关国际合作机制；中国也同时向其他发展中国家派遣自己的专家，帮助他们实现可再生能源的目标，以推动全球低碳社会的进程。德国国际合作机构(Gesellschaft fuer Internationale Zusammenarbeit, Deutschland－giz)的中德生物质能优化利用项目支持由中国农业大学出版社出版的本系列书籍《沼气工程与技术》。该出版物将成为沼气工程技术、政策、建设和运行等各个方面专家的科研和应用论文交流的平台，供沼气专家与学者交流讨论。《沼气工程与技术》不仅是中国国内沼气行业的重要信息来源，也是关注中国沼气发展的国际同行的信息资源平台。

董仁杰 博士　教授
中国农业大学能源工程与低碳技术研究室
中国农业大学生物质工程中心常务副主任

伯恩哈特·蓝宁阁 博士　教授
沈阳航空航天大学清洁能源和环境工程研究所
中德生物质能优化利用项目
德国国际合作机构

2011 年 1 月于北京

TABLE OF CONTENT

PREFACE

1. BIOMASS RESOURCES ASSESSMENT

2. ANAEROBIC DIGESTION PROCESS RESEARCH

3. CO-FERMENTATION

4. ANAEROBIC DIGESTION PROCESS TECHNOLOGY

5. CLIMATE RELEVANT BIOGAS EMISSIONS

6. DIGESTATE APPLICATION

目　　录

DEVELOPMENT OF OPTIMIZATION MODEL AND CASE STUDY FOR BIOMASS ENERGY SYSTEM IN JAPAN

GAO Weijun[1], REN Hongbo[2], LI Haifeng[3], Yutaka Tonooka[4]

1. *The University of Kitakyushu, Japan*; 2. *Ritsumeikan University, Japan*; 3. *Saga University, Japan*; 4. *Saitama University, Japan*

Contact: Prof. Gao Weijun, The University of Kitakyushu, 1-1 Hibikino, Wakamatsu, Kitakyushu, Fukuoka, 808-0135, weijun@env.kitakyu-u.ac.jp

EXECUTIVE SUMMARY

To decrease global warming caused by increasing concentrations of CO_2 from burning fossil fuels, and to develop alternative energy sources, it has become desirable to construct alternative, renewable energy systems. Potential alternative energy sources include solar cells, wind turbines, biomass, etc. Among these, biomass is considered to be the most promising. For example, the current global energy consumption is estimated to be 8 000 MTOE (million tons of oil equivalent) per annum and will increase to as high as 15 000 MTOE by the year 2050. And it is estimated that by the year 2050 annual energy supply by biomass will amount to 4 400 MTOE. This comparison indicates that, in the future, biomass is expected to significantly contribute to the global energy supply. Industrial, agricultural livestock and forest residues can be used as a biomass energy source, or energy crops such as trees and sugarcane can be grown specifically for conversion to energy. Methods for utilizing biomass include direct burning, gasification, and liquefaction.

In Japan, biomass has been a relatively small portion of the overall energy budget, supplying about 1% of the total primary energy consumed in 2004. The Japanese government has tried to promote biomass energy use in an effort to solve global warming. For instance, The Ministry of Agriculture, Forestry and Fisheries (MAFF) has predicted biomass energy use of 110.5-210.1 PJ in the future energy demand and supply plan in 2010.

According to previous research, although having an obvious environmental benefit, the biomass energy system is not attractive from the view point of economy. However, it is believed that as the development of biomass fuel convention technologies and the improvement of other aspects, the biomass energy system will become competitive with the conventional energy system in the future.

In this paper, a linear programming model is developed. The objective is to minimize annual cost of an energy system equipped with a biomass combined heat and power plant, combining with a back-up boiler. The model reports the optimal biomass system capacities that customers could employ given their energy requirements. As an illustrative example, using this model, an investigation is conducted of the introduction feasibility of the biomass energy system for the science and research park in Kitakyushu, Japan. According to the results, currently, although having a good environmental merit, it is not a good choice to introduce biomass energy system from the economic point of view.

Key words: Design; Evaluation; Biomass system; optimization; Economic effect; Environmental effect

1 Introduction

To decrease global warming caused by increasing concentrations of atmospheric carbon dioxide (CO_2) from burning fossil fuels, and to develop alternative energy sources, it has become desirable to construct alternative, renewable energy systems. Potential alternative energy sources include solar cells, wind turbines, and biomass. Among these, biomass is considered to be the most promising. For example, the current global energy consumption is estimated to be 8 000 MTOE (million tons of oil equivalent) per annum. The energy consumption will increase to higher than 15 000 MTOE by the year 2050. And it is estimated that by the year 2020 the annual energy supply by biomass will amount to 1 600 MTOE and by the year 2050 to 4 400 MTOE. This comparison indicates that, in the future, biomass is expected to significantly contribute to the global energy supply. Industrial, agricultural livestock and forest residues can be used as a biomass energy source, or energy crops such as trees and sugarcane can be grown specifically for conversion to energy. Methods for utilizing biomass include direct burning, gasification, and liquefaction[1-2].

In Japan, biomass has been a relatively small portion of the overall energy budget, supplying about 1% of the total primary energy consumed in 2004. The Japanese government has tried to promote biomass energy use in an effort to solve global warming. For instance, The Ministry of Agriculture, Forestry and Fisheries (MAFF) also predicts biomass energy use of 110. 5-210. 1 PJ in the future energy demand and supply plan in 2010[3].

In this study, a linear programming model is developed, using a commercial software package LINGO[4]. The model evaluates the introduction feasibility of a biomass energy system in a specific district. It takes the customer's selections (e. g. system capacity, etc.), combines them with pre-collected data (electric rate schedules, carbon tax rate, government economic incentives, electric and thermal load profiles, and biomass energy system performance) and analyzes the information using time series analysis. Finally, overall evaluation results regarding economic, energetic and environmental effects can be obtained, according to the simulation for various scenarios.

As an illustrative example, using this model, an investigation is conducted of the introduction feasibility of the biomass energy system for the science and research park in Kitakyushu (KSRP), Japan. In addition, corresponding economic, environmental and energetic effects are determined.

2 Evaluation model of biomass energy system

2.1 Description of the evaluation model

In order to adopt the biomass energy system effectively, it is necessary to take into consideration various aspects including local conditions, energy demands, as well as technical and market information. As shown in *Figure* 1, firstly, the electricity and heat demands of the customer, regional energy tariffs (electricity and city gas), and the biomass energy utilization technologies should be investigated. Then the model is executed and the optimal results are reported. The objective of the model is to minimize annual total cost including investment cost and running cost. In addition, by analyzing the installed capacity, energy prices as well as supply share while considering the balance between supply and demand of energy resources, the operational characteristics of the integrated energy system are evaluated. The calculation is taken hour by hour in a total year (8 760 hours).

Furthermore, by fixing the installed capacity or the running schedules of an existed energy system, the economic, environmental and energetic effects of the biomass energy system can be evaluated through the execution of the model. In this study, the linear analytical model is constructed by using the optimization tool LINGO according to the objective function and various constraints.

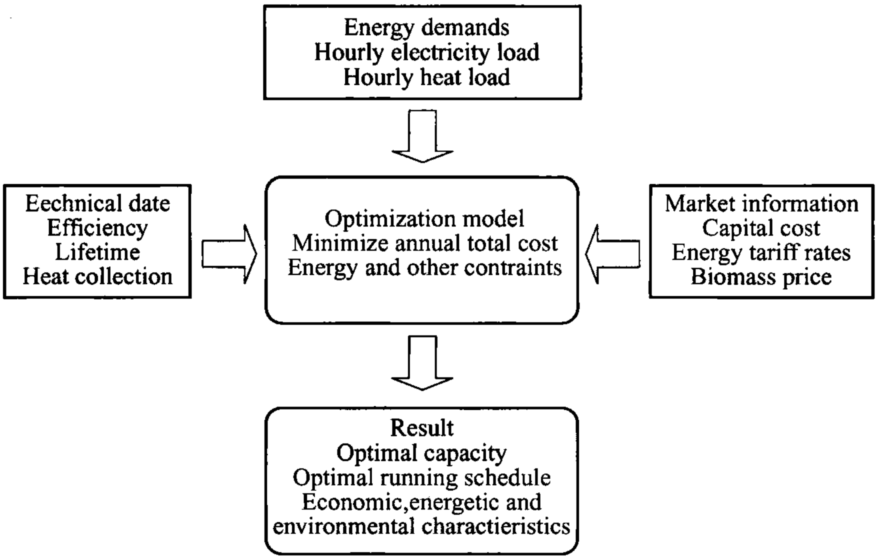


Figure 1 Flow chart of the model

2.2 Objective function and main constraints

The objective function of thebiomass application process is to minimize annual total cost for the local customer, taking into account of the costs of the decision. Specifically, system investment cost C_{Inv}, running and maintenance cost C_{OM}, biomass fuel cost C_{Bio}, as well as natural gas cost C_{Gas} and gird electricity cost C_{Elec}. Thus, the overall objective to be minimized is:

$$Min \quad C_{total} = C_{Elec} + C_{Bio} + C_{Gas} + C_{Inv} + C_{OM} \tag{1}$$

Annualized investment cost is shown in Eq. (2).

$$C_{Inv} = F\max p \cdot FCost \cdot YF \tag{2}$$

$F\max p$ is the capacity of biomass equipments, $FCost$ is the capital cost of the equipment, and YF is annualized coefficient.

The O&M cost is composed of fixed and variable cost, as illustrated in Eq. (3).

$$C_{OM} = \sum_m \sum_d \sum_h \sum_u EGen_{m,d,h,u} \cdot FOMv + F\max p \cdot FOMf \tag{3}$$

$EGen$ is the electricity generation from the biomass system, $FOMv$ and $FOMf$ are the unit cost coefficient for variable and fixed O&M costs, respectively. m , d , h and u are month, day, hour, and end-user, respectively.

The biogas fuel cost is calculated by multiplying total biogas consumption and the fuel price, as shown in Eq. (4)

$$C_{Bio} = \sum_m \sum_d \sum_h \sum_u PBio_{m,d,h,u} \cdot BPrice \tag{4}$$

here, $PBio$ is the biomass consumption, $BPrice$ is the price for biomass fuel.

The gas cost is composed of natural gas base service fee$GBase$ and volumetric charge, as shown in Eq. (5). The volumetric charge is calculated with cumulative gas consumption $PGas$ for backup boiler use multiplied by the tariff rate $GPrice$.

$$C_{Gas} = \sum_m GBase_i + \sum_m \sum_d \sum_h \sum_u PGas_{m,d,h,u} \cdot GPrice_m \tag{5}$$

The electricity purchase cost is described by Eq. (6).

$$C_{Elec} = \sum_m EBase + \sum_m \sum_d \sum_h \sum_u PElec_{m,d,h,u} \cdot EPrice_{m,d,h} \tag{6}$$

$EBase$ is the base charge for electricity purchase, $PElec$ is the amount of electricity purchase, $EPrice$ is the electricity tariff rate.

A balance of supply and demand has to be achieved for both heat and electric power at each point in time, as shown in Eq. (7).

$$Cload_{m,d,h,u} = EGen_{m,d,h,u} + PElec_{m,d,h,u} + \mu \cdot PGas_{m,d,h,u} + \gamma_u \cdot RHeat_{i,m,d,h,u} \quad \forall m,d,h,u \tag{7}$$

RHeat is the amount of recovered heat from on-site power generation. μ and γ are the efficiencies for direct gas use and recovered heat, respectively.

Another key performance constraint is that the biomass plant must operate below maximum operating capacity of the units, as illustrated in Eq. (8).

$$\sum_u EGen_{m,d,h,u} \leqslant F\max p \quad \forall m,d,h \tag{8}$$

Constraint is also set to how much heat can be recovered from the biomass CHP plant, as described in Eq. (9).

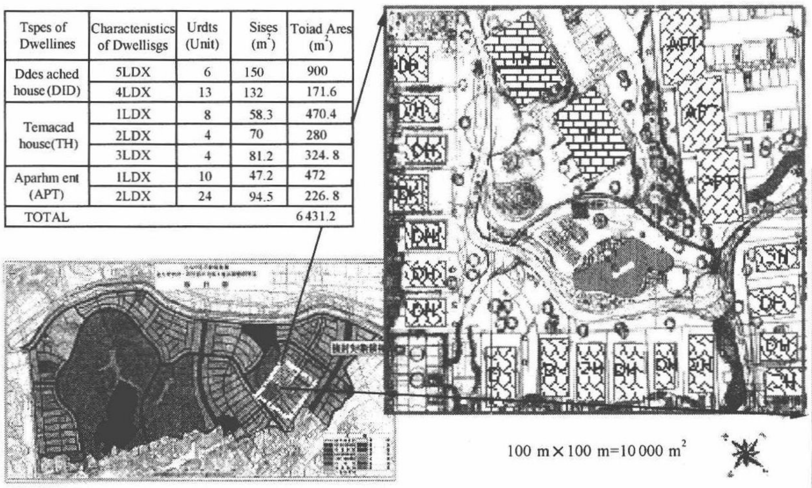
$$\sum_u RHeat_{m,d,h,u} \leqslant \alpha \cdot \sum_u EGen_{m,d,h,u} \quad \forall m,d,h \tag{9}$$

α is the heat to power ratio of the CHP plant.

3 Illustrative example

3.1 Research object

In this study, the residential area in KSRP, Japan is selected for a case study by considering a biomass energy system. *Figure* 2 is the project plan and shows the area comprising 19 Detached Houses (DH), 16 Terrace Houses (TH) and 34 Apartments (APT), whose total floor areas are 2 626 m^2, 1 075.2 m^2 and 2 740 m^2, respectively[5].



Tspes of Dwellines	Characteristics of Dwellisgs	Urdts (Unit)	Sises (m^2)	Toiad Ares (m^2)
Ddes ached house (DID)	5LDX	6	150	900
	4LDX	13	132	171.6
Temacad house(TH)	1LDX	8	58.3	470.4
	2LDX	4	70	280
	3LDX	4	81.2	324.8
Aparhm ent (APT)	1LDX	10	47.2	472
	2LDX	24	94.5	226.8
TOTAL				6431.2

Figure 2 Outline of the housing complex development

3.2 Load assessment

According to the energy consumption unit data in Kyushu, it is possible to assess the unit load per square meter for heating, cooling, hot water and electricity for different months for various types building[6]. *Figure* 3 illustrates the mean value of electricity and thermal loads in winter and summer. From the data, it can be concluded that: on one hand, peak loads for thermal demand for various dwellings in winter is about 3 times that in summer; on the other hand, the electricity load for various dwellings in winter is approximately the same as in summer.

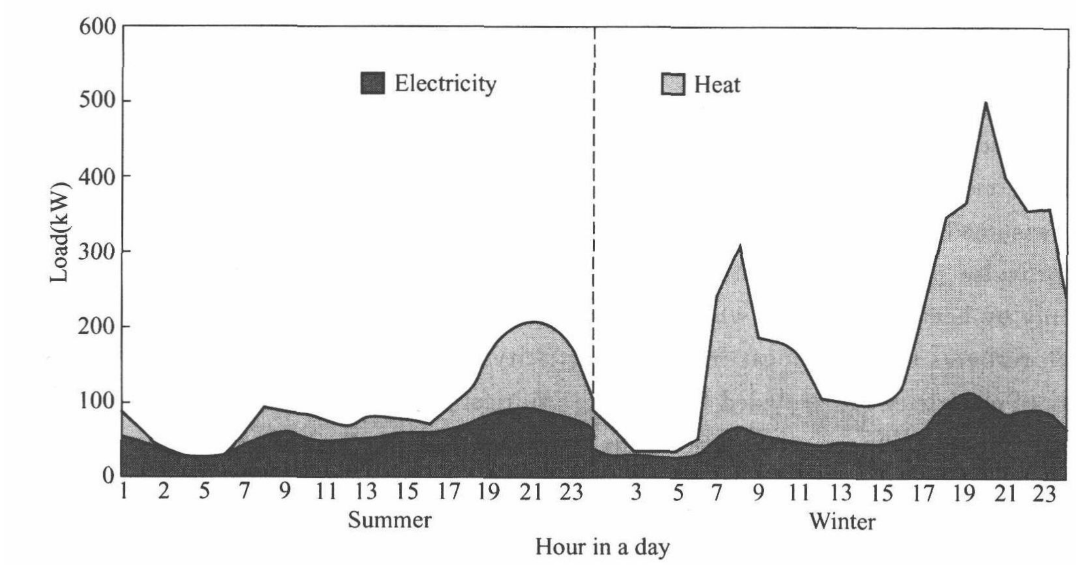


Figure 3 Electricity and thermal demands

3.3 Market information

In the paper, a time of use electricity tariff for residential buildings is employed, as shown in *Table* 1. Besides the basic charge, different rates are set for peak-time, day-time and night-time, respectively[7]. The gas tariff is composed of basic charge and flow charge, which are 1 501.50 Yen/month and 196.76 Yen/m^3, respectively[8].

In this study, a biomass gas engine CHP system is assumed for adoption. Various characteristics about the equipment are assumed according to previous study, as shown in *Table* 2[9-11]. The parameters of grid electricity and city gas are determined according to the investigation of local companies[7-8].

Table 1 Electricity tariff

Season	Load period	Base Charge (Yen)	Energy charge(Yen/kWh)
Summer	on-peak	1 155	32.01
	mid-peak		20.13
	off-peak		7.19
Winter	on-peak		26.70
	mid-peak		20.13
	off-peak		7.19

Table 2 Other parameters

Item		Value
Electric Utility	Efficiency (%)	38
	Carbon intensity (kg/kWh)	0.375
City gas	Carbon intensity (kg/kWh)	0.18
Biomass CHP system	Electricity efficiency (%)	32
	Heat efficiency (%)	52
	Capital cost (10^4 Yen/kW)	70
	Lifetime (a)	20
Boiler	Efficiency (%)	80
Heat exchanger	Efficiency (%)	95