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Appraisal of Building Energy Systems considering Environment Constraint Conditions

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ABSTRACTS

This study aims to find out sector effects with the appraisal of building energy systems of urban ecosystem considering cost effects and environmental constraints condition such as climatic change factors including CO_2 gas which are not dealt in the institutional boundary as components standards and performance standards on energy performance of each part of a building applied on heavy energy spending buildings at present. The results of the appraisal of building energy systems shows that the existing building energy systems are not enough to fulfill the environmental condition under the environmental constraints supposing QELROs(Quantified Emission Limitation and Reduction Objectives) of carbon-dioxide exhaust. Henceforth, it is needed to fulfill the environmental criteria required by the Climatic Change Agreement for improving the adiabatic performance of each part of a building and active using of the solar energy.

KEYWORDS : Urban Ecosystem, Building Energy System Appraisal, Linear Programming Model, MARKAL

1. INTRODUCTION

In recent years studies on applying ecology to urban environments and architecture have focused on such subjects as circulation in the material world, the food chain involving production, consumption and decomposition process of the ecosystem, and humans' management upon the natural environments. Conservation of the natural ecosystem requires widespread recognition the men are part of the complex environment and that the ecosystem should be analyzed, maintained and controlled from the holistic perspective rather than approached as a separate biosphere.

This study is premised on the assumption the humans' excessive consumption of energy is a primary cause for the pollution and destruction of the ecosystem.

This paper defined a city for an 'Urban Ecosystem', which is one of the constituents in ecosystem, to establish a methodology for the research of the energy flow in building and city. In addition, this study aims to appraise sector effects of building energy systems considering cost effects and environmental constraints condition, which have not been dealt in the institutional regulations of component standards and performance standards

2. THE STATE OF THE GREENHOUSE GAS EMISSION

The word 'Global Warming' means the state of uprising mean temperature of earth. The tendency of rising temperature in atmosphere is also found in Korean Peninsula(Park, 1994, see Figure 1). The amount of emission is forecasted to be 148.5 million carbon ton in 2000 which is 2.3 times to 65.2 million in 1995, and 217 million in 2010. Most of the advanced countries have controlled the emission of greenhouse gas from 1990, but Korea would keep up emitting CO_2 gas for a long time due to the development of economy and increasing consumption of energy(see Table 2, 3).

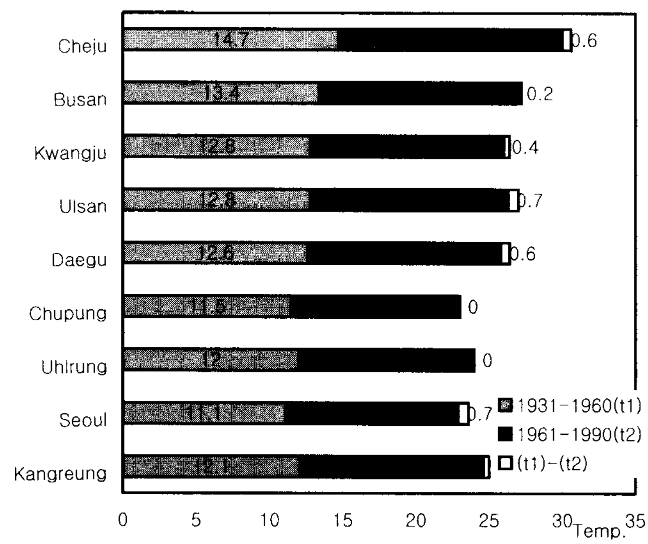


Figure 1. Air Temperature Change in Korean Peninsula(comparison of air temperature(℃) of last 30 years from 1931)

Table 1. Annual Change of CO_2 Emission (Unit: GJ), source Lim(1997)

Year / Division	1990	1991	1992	1993	1994	1995
Industry	87,282	101,317	110,889	121,988	127,703	132,768
Transportation	42,198	48,142	55,206	62,930	71,040	80,868
Housing & Commercial	64,592	61,804	62,302	64,389	62,648	69,374
Public/Etc.	6,985	6,841	5,101	4,991	4,997	4,522

3. ESTABLISHING THE APPRAISAL MODEL OF BUILDING ENERGY SYSTEMS

3.1 Concepts of the appraisal of building energy systems

The appraisal of building energy systems means economical assessment of the cost-benefit analysis to the incipient investment and the maintenance costs, which will be put into the system considering energy demand.

Recent concept of the appraisal of building energy system should make clear the order of technology for cost optimization and establish evaluation methodology to analyze the conditions of environmental constraints and set up archetype of appraisal. The appraisal methods for building energy systems have two aspects; component standards for architectural planning stage and performance standards(see Table 4).

The component standards are used for heat performance regulation to building components and for the minimum criteria for energy conservation.

The performance standards which are concepts of EBL(Energy Budget Level) and EPI(Energy Performance Index) based definition on a centi-leveled criterion of building's energy consumption and appraise the energy efficiency of the buildings or building's energy systems.

After construction, the energy auditing is considered as a part of building energy management by estimating the potentiality and important factors for energy conservation on building components or equipments.

Table 2. Domestic Energy Demand in Commercial and Public Sector in 1995, Korea(unit: PJ), source: KIER, 1997

Energy / Resources	Heating Hot Water Supply	Cooling	Cooking	Office Facility	Lighting	Total
Coal	0.6	0.0	0.0	0.0	0.0	0.6
Oil	128.4	0.1	1.5	0.0	0.0	130.0
Gas	33.3	2.7	29.6	0.0	0.0	65.6
Electricity	0.0	20.2	0.0	25.5	95.1	140.8
Local Heating	0.8	0.0	0.0	0.0	0.0	0.8
Coal	0.1	0.0	0.3	0.0	0.0	0.4
Heat Energy	0.1	0.0	0.0	0.0	0.0	0.1
Total	163.1	23.1	31.7	25.5	95.1	338.6

Table 3. Energy Consumption Structure in Domestic Sector(%), source Lim, 1997

Year / Sector	1980	1985	1990	1995	1996	1997
Industry	44.1	42.6	48.1	51.7	51.4	50.3
Transportation	13.0	14.3	18.9	22.3	22.6	22.6
Housing Commercial	37.3	38.7	29.3	24.1	24.0	25.2
Public/Etc.	5.6	4.5	3.7	2.0	2.0	2.0

Table 4. Feature Comparison by Building Energy Appraisal Method

Division	Component Standard	Performance standard	Energy Auditing	Appraisal of Building System
Appraisal Level	Planning Stage	Planning Stage	Using Stage	Using Stage
Appraisal Factor	Performance and Equipments Factors	Building and Equipments Factors	Building and Equipments Factors	-Building and Equipments Factors -Environmental Constraints
Input Data	-Feature of Building Components -Planning Factors -Equipment Factors -Etc	-Feature of Building Components -Architectural Planning Factors -Equipment Factors -Etc	-Feature of Building Components -Architectural Planning Factors -Equipment Factors -Etc	Oil Price Reduction Rate Energy Efficiency Life Cycle Incipient Cost Energy Balance Appraisal Duration
Environment Performance	Impossible to be Appraised	Impossible to be Appraised	Impossible to be Appraised	Possible to be Appraised
Methodology	Performance Appraisal through Simulation	Total Appraisal through Simulation and Energy Performance Index	-Simulation by Data of Operation Monitoring and Building Factor -Potentiality Appraisal of Energy Saving	Optimization and Appraisal of Environmental Compatibility by LP Model
Period	Short Term	Short Term	Short Term	Middle & Long Term
Etc	Hard to be Related to Local Energy Master Plan	To be Related to Local Energy Master Plan	To be Related to Local Energy Master Plan	To be Related to Local Energy Master Plan and Environmental Plan

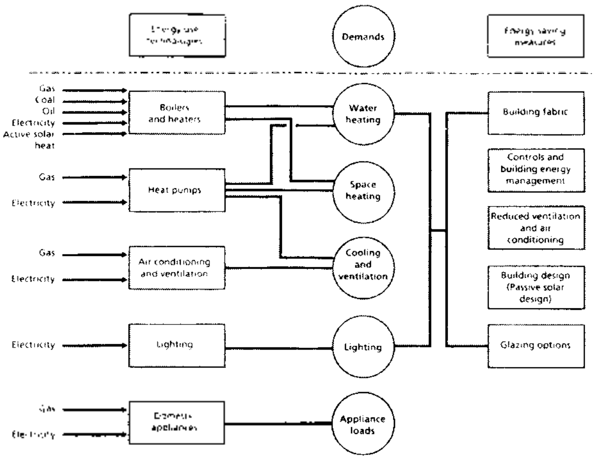


Figure 2. Building Energy System Route Map, source HMSO, "An Appraisal of Energy Research, Development, Demonstration & Dissemination", 1994. p657

3.2 Building's energy demand analysis

The commercial buildings are becoming luxurious and huge. As the commercial buildings that spend energy more than others have tendency to be more luxurious and huge, the use of energy is gradually increasing.(The Energy Technology Research Center.1996)

Energy reliance to import tops 97% in 1997 and there can be an exceeding energy conservation potentiality in commercial building sector. Figure 2 presents the overall energy flow in building energy system from final energy to useful energy. Energy demand in domestic building sector has structural characteristics that it is mainly originated in cooling-heating purpose. Therefore in the commercial and public sector, the heating, cooling, ventilating and hot water supply part could be considered to have the highest energy conservation potentiality. Generally, energy used in heating is influenced by the improvement of insulation and the combustion efficiency of boiler or boiling devices.

3.3 Establishment appraisal model of building energy system

3.3.1 Developing the appraisal theory

The appraisal principle of the building energy system using the linear programming model could be presented as follows; If we assume there are devices of heat resources in building as many as $S_1 \ldots\ldots S_m$, the amounts of heat supplied $s_1 \ldots\ldots s_m$, the kinds of building energy system to satisfy heat demand from devices $D_1 \ldots\ldots D_m$, amounts of saved energy are $d_1 \ldots\ldots d_n$, then the useful energy transferred to demand of devices of heat resource D_m from supply S_m will be C_{ij}. The equation of heat transfer satisfying devices of heat resource demands will be found as follows;

the variable x_{ij} above means the flow of energy from supplied heat s_i to devices of heat resource demand d_j. The c_{ij} are coefficients of object function. The x_{ij} and s_i are coefficients and constants in each constraints equation given for input data. And x_i is the optimization of building energy system to be delivered.

$$
\begin{aligned}
& Min \sum_{i=1} \sum_{j=1} c_{ij} x_{ij} \\
& s.t. \sum_{j=1} x_{ij} \le s_i (i = 1, \cdots, m) \\
& \sum_{j=1} x_{ij} \ge d_j (j = 1, \cdots, n) \\
& x_{ij} \ge 0 \forall i, j
\end{aligned}
$$

3.3.2 Definition of object function

(1) Function of net reduction cost rate

Function of net reduction cost rate $Y(t)$ is the sum of the costs put into building energy system according to annual costs within a period of time t.

The variable t means years from 1 to T, which changes at regular intervals not necessarily by 1 year but by 5 or 10 years. The variable j means season; j=1(summer) j=2(winter), j=3(spring and fall)

Y(t) = Energy supply costs
+ incipient cost of building energy system
+ long term maintenance cost

If this is presented as sum of each object function :

$$
\begin{aligned}
YC(t) = & \sum \left[c_S(t, fd, s) i(t, fd, s) \right] S(t, f, s) \\
& - \sum c_S(t, f, s) S(t+1, f, s) \\
& + \sum c_K(t, \tau) K(t, \tau) \\
& + \sum \frac{1}{\mu(d)} \sum \frac{K(t, \delta)}{e(t, \delta)} \sum c_T(t, f, \delta) b_D(t, d, \delta) i(t, f, \delta) \\
& + \sum c_Q(t, \beta) Q_d(t, \beta) \sum c_T(t, f, \beta) i(t, f, \beta) \\
& + \sum E(t, j, \alpha) \left[c_E(t, \alpha) + c_{TE}(\alpha) + \sum c_T(t, f, \alpha) \right] \\
& + \sum H(t, j, \alpha) \left[c_H(t, \alpha) + c_{TH}(\alpha) + \sum c_T(t, f, \alpha) \right] \\
& + \sum h(t, j, \alpha) H_c(t, j, \alpha) \left[c_H(t, \alpha) + c_{TH}(\alpha) + \sum c_T(t, f, \alpha) i(t, f, \alpha) \right]
\end{aligned}
$$

Net reduction rate is consisted of the amount of reduction costs $Y(t)$, investment costs, and reduction costs. Therefore the total cost TC will be found as ('r' is annual rate of reduction);

$$
\begin{aligned}
TC(t) = & \sum \sum (1+r)^{1-k} (1-r)^{-n(t-1)} YC(t) \\
& + \sum (1+r)^{-n(t-1)} [J(t) + V(t)]
\end{aligned}
$$

V(t): salvage Value

$J(t)$, total investment costs, will be computed through this equation

$$J(t) = \sum cA(t, \tau) A(t, \tau)$$

(2) The environment function

The environment function will be consisted of the environmental pollutants, which are produced by investment to energy facilities, capacity and use of energy source devices, of energy conversion devices, and volume of energy-consuming equipments during energy supply. Therefore the object function of environment function could be described, considering environmental materials x, in this way;

$$\begin{aligned}\Omega(x) = n\sum\sum va(t,f,s,x)S(t,f,s) \\ + \sum vi(t,\tau,x)A(t,\tau) \\ + \sum\left[va(t,\beta,x)Qa(t,\beta) + vc(t,\beta,x)K(t,\beta)\right] \\ + \sum i(t,f,a)va(t,a,x)K(t,a) \\ + \sum vc(t,a,x)i(t,f,a)h(t,j,a)H_c(t,j,a) \\ + \sum va(t,a,x)i(t,f,a)H(t,j,a) \\ + \sum\frac{1}{\mu(d)}\sum\frac{or(t,d,\delta)vc(t,\delta,x)}{e(t,\delta)}\sum K(t,\delta)\end{aligned}$$

4. APPRAISAL OF BUILDING ENERGY SYSTEM

4.1 Introduction of building energy system

In this paper, the useful energy in heating and hot water supply part was defined 70 PJ to estimate the energy systems of business buildings under the standard of total useful energy of domestic commercial sector for 117PJ in 1995 The probability of introduction of solar energy system will be also considered and evaluated during appraisal. The variable decided as the optimizing solution in lineal programming presents generally the annual value. The time variable in evaluation model is inputted by a year, and the units for performance, efficiency, costs are converted to energy units (GJ; Giga Joule) to appraise the performance to environmental requirements. TOE(Ton Oil Equivalents) or joule , calorie were used for units in energy systems.

4.1.1 Evaluation program

This is a kind of energy system model whose characteristics are compared with existing system's in table 5. With this model, the optimization to the object function chosen as the multi periodic lineal program model is available, the object function mainly used here is overall system reduction costs. This model makes it possible to use the object functions based on the environmental criteria like CO_2 diminishment, and also helps set up an optimized energy systems to satisfy the demand for useful energy in each sector. In these process, it shows an optimized building energy system.

The general process of building energy system appraisal by model MARKAL, which was developed in a multi-national project over a period of two decades by Energy Technology Systems Analysis Programme(ETSAP), is as follows; Appraisal in this thesis is performed under the consideration of the mutual costs for building energy systems and the conflicts among environmental constraints.

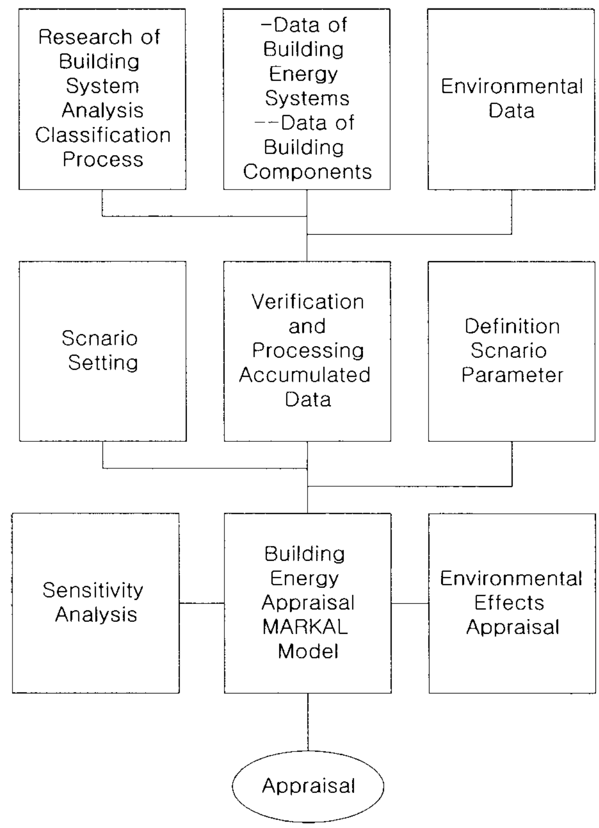


Figure 3. Process of Appraisal of Building Energy System by MARKAL Model

Table 5. Classification and Characteristics of Energy System Appraisal Model

	Model	Analysis Period	Method	Analysis Rage
Energy System Model	EFOM	Middle.Long Term	Lineal Programming	Energy System, Environment. Electric Power
	MARKAL	**Middle, Long term**	**Dynamic Lineal Programming**	**Energy System, Environment, Electric Power**
Modularized Model	ENEP	Short, Middle , Long term	Simulation	Energy System, Environment, Electric Power
	Super/OLAD E-BID	Middle, Long term	Minimum Cost Method	Electric Power, Demand Control, Environmental Effects
	NEMS	Short, Middle , Long term	Lineal Programming	Macro Economics. Environment, Energy Policy
Integrated Model	MELODIE	Long term	Econometrics	Energy. Economics, Environment
	ESG	Long term	Econometrics, Lineal Programming	Macro Economics, Energy, Environment. Demand Control

Seoul Local Government. "Research on Establishment of the Energy Planning of Seoul District", 1997, pp.116 ~ 117(reconstructed).

4.1.2 Input data for appraisal

Input data used in appraisal model are as follows

(1) Used energy computed by area unit considering factors of heating and cooling loads of buildings

Computing used energy by area unit considering factors of heating and cooling loads of buildings. In this study, the highest values of office building heating-cooling loads are applied to estimate the amount of energy consumption of commercial buildings by square meters, and the range of building energy system appraisal is limited to heating energy by lack of useful data(see table 6).

Table 6. The Highest Value of Cooling & Heating Load of Office Building, source: Ministry of Construction & Transportation, No.1992-44

Division / Scale		Small Building	Middle Building		Large Building
Building	District*		Under 8th Floor	Over 8th Floor	Under 19th Floor
Heating Load of Buildings need heating	1st	38.2	29.3	37.6	31.1
	2nd	36.5	28.0	36.1	29.8
	3rd	23.1	23.1	23.0	19.0

*District 1st Seoul, Kyung-ki, In-chon, Kang-won, Chung-buk

2nd Chung-nam, Tae-chon, Chungbuk, Kyung-buk,Tea-ku

3rd Pusan, Kwang-u, Kyungnam, Chongnam, Cheju island

(2) Heat performance data of glazing and building skins

As the thermal performance of glazing and building skin is such an important factor of direct influence to heating-cooling loads in buildings, it functions one of the important factors of energy conservation in total annual energy consumption. Table 8 presents data for building energy system appraisal.

(3) Heating-cooling loads and building core type

Table 7. Types of Building Core and characteristics of Heating Load, Source: Ministry of Construction and Transportation, 1994, p.2-47(reconstruction)

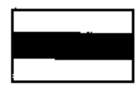
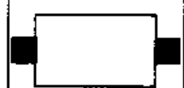
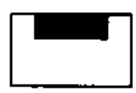
Core Type	Plan	Heat Load	Thermal Performance Index	Incipient Cost
Centered A		High	100	Middle
Centered A		High	92	Middle
Separated Double		Middle	76	High
Eccentric		Middle	67	Middle
Distributed		Middle	60	High
Eccentric Double		Low	54	High

Table 8. Input Performance and Cost Data of Material and Design Factor(*K=0.5kcal/m²hr℃, Price data from the List of Prices April 1998, Performance Index from "Codes for Energy conservation of Office building and Commercial Facility", Ministry of Construction and Traffic, 1994, and the energy conservation effects were relatively decided among factors)

Building Factor		Performance Index*	Investment won/㎡	Conservation Effect	Difference between Incipient Investments $/10^9cal	$/GJ
Glazing	Double Layer(3-6A-3)12mm	52	18,300	0.0	0	0
	Double Layer(5-6A-5)18mm	46	61,300	16.3	43,000	1,103
	Double Layer + Insulation Film(3+6A+3)12mm		27,800	4.9	9,500	244
	Double Layer + Insulation Film(5+6A+5)16mm		70,800	21.7	52,500	1,346
	Double Layer - Heat Mirror (HM88)		71000	23.9	52,700	1,351
	Triple Layer:21mm	36	100,000	27.2	81,700	2,095
	Triple Layer:33mm	31	120,000	33.4	81,700	2,095
Building Skin	Aluminum Curtain Wall	119.9*	100,000	0.0	-	-
	PC Curtain Wall	102.7*	80,000	0.7	-	-
	Brick Wall	100.0*	58,334	1.0	-	-
	Dual Skin	80.0	230,000	3.12	-	-
Design Factor	Centered Core A	100	2,500,000	0.0	0	0
	Centered Core B	92	2,550,000	1.4	50,000	1,282
	Separated Dual Core	76	3,000,000	4.5	500,000	12,821
	Eccentric Core	67	2,700,000	6.3	200,000	5,128
	Distributed Core	60	3,500,000	7.6	1,000,000	25,641
	Eccentric Dual Core	54	3,200,000	8.8	700,000	17,749

4.1.3 Deciding variables in appraisal scenario

(1) Prices of energy resources

The kinds of energy resources put into energy system of office building sector are oil, LNG, atomic power, and hydraulic power, which are supplied fully by import. It was the price of the basic period year that calculated based on a data of 1995. The price of energy in this study were converted to standard unit $/PJ to be available in appraisal of energy tactics. And the future prices of energy resources after basic year are applied with those of forecasted characteristics according to the feature of each scenario.

(2) Environmental restraints.

Conditions of environmental restraints, premised on the introduction of total sum regulation to reduce CO_2 emission from the environmental scenario, are set up the standard regulation condition in environmental constraints for 4000 kton in the year of 2015, same to the level in 1995.

The basic value 4,000 kton which is estimated from the amount of CO_2 discharged in commercial sector for heating purpose but it excluded that in domestic industry, transportation and housing sectors are assumed to carry out the total sum regulation based on the amount of CO_2 emission in 1995.

(3) reduction rate

This evaluation applied 10% reduction rate for analysis in each scenarios.

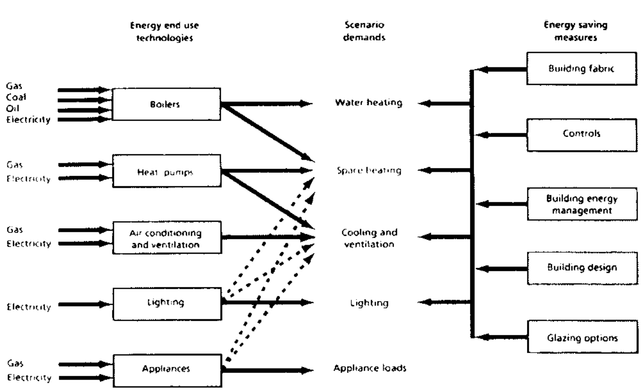


Figure 3. Route Map for Energy Use in Building, Source: HMSO, "An Appraisal of Energy Research, Development, Demonstration & Dissemination", 1994. p.111

4.2 Establishment of appraisal scenarios for building energy system.

The appraisal conditions were established Case I to Case IX, and were performed to the years of 1995, 2000. 2010, 2015.

4.3 Results of Building Energy Systems Appraisal by Cases

The competitive powers of devices of heat source like oil boiler for heating, gas boiler and electric boiler including solar energy systems through cost evaluation were compared and analyzed by Case I. But the results of Case I to Case V seem to be deeply influenced by oil price policy re environment policy and change of international oil price, for it has assumption of invariable oil price, that is insisting the oil boiler is found to be competitive in scenario of Figure 4 Base Scenario.

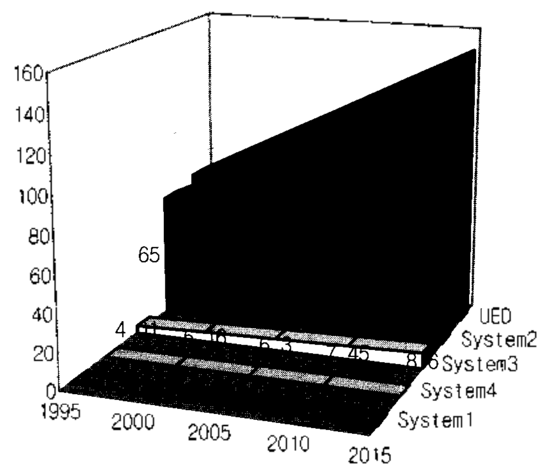


Figure 4. CAES I Base Scenario

UED: Annual Useful Energy Demand(unit: PJ)

System 1: Solar Energy + Double Glazing + Aluminum Curtain Wall + Centered Core A type

System 2: Conventional Building Energy System(Fuel)

System 3: Conventional Building Energy System(Gas)

System 4: Conventional Building Energy System(Etc.)

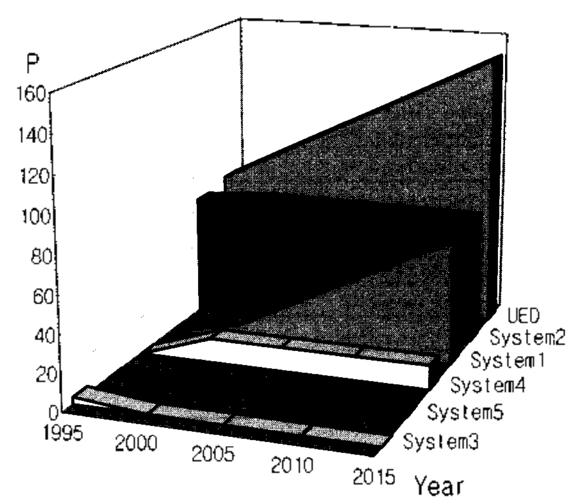
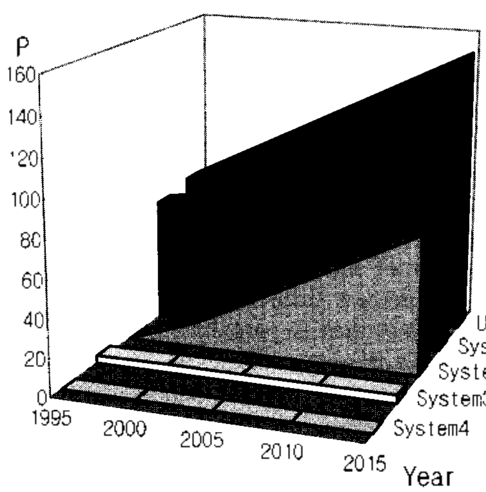


Figure 5. CASE VI: Glazing & CO_2 Scenario

UED: Annual Useful Energy Demand(unit; PJ)
System 1: Solar Energy + Triple Glazing + Aluminum Curtain Wall + Centered Core A type
System 2: Conventional Building Energy System(Fuel)
System 3: Conventional Building Energy System(Gas 1)
System 4: Conventional Building Energy System(Gas 2)
System 5: Conventional Building Energy System(Etc)

Figure 6. CASE Ⅷ: Core Scenario
UED: Annual Useful Energy Demand(unit; PJ)
System 1: Conventional Building Energy System(Gas)
System 2: Conventional Building Energy System(Fuel)
System 3: Conventional Building Energy System(Etc)
System 4: Solar Energy + Double Glazing + Aluminum Curtain Wall + Centered Core A type



When we suppose the environmental regulation of CO_2 discharge for 4,000 kton to the level in 1995, in Case VI - Case IX, the passive solar energy is regarded as the most competitive heat source technology (see Figure 5).

The use of solar energy is found to be available for an alternative energy in future when the CO_2 discharge regulation be operative. There will be no significant changes in competitive relationships among building energy systems under the assumption of the invariable oil price.

Considering CO_2 total sum regulation as a environmental constraints condition, oil boiler and double layer glazing were chosen for competitive associations and for a remarkable change gas boiler, and triple layer glazing(33 mm) association were selected to share the total energy consumption.

Case VI to case IX is scenarios of building skin and CO_2 under the condition of CO_2 total sum discharge restriction in 2015.

With choosing for analysis subject the association of existing heat engines (Oil Boiler + Gas Boiler + Electricity Boiler + Solar Energy Equipments) + Double Layer Glazing (12mm + Insulation Film) + Aluminum Curtain Wall + Centered Core Type for analyzing subjects, we could conclude that the portion which will be charged by solar-energy and brick wall association will gradually increase, and that solar-brick wall system was found to be more competitive association than oil boilers and brick wall system.

5. DISCUSSION

This study intends to appraised upon sector effects by taking into account the cost efficiency of building energy systems and environmental regulations which have not been viewed under the energy efficiency standards set on component standards of a building and regulations on the performance standards. The energy and environment system optimisation model MARKAL has been applying to forecasts gas emissions as environment constraint condition and energy effects of future building technologies of building sector in Korea. Also, this study relies on a vast amount of data and scenario assumptions.

From this study, the building energy systems under the consideration of environmental constraints conditions using lineal programming model MARKAL was appraised to energy effects of future building technologies and CO_2 emissions reduction potential in building sector in Korea.

The findings from analysis show that existing building energy systems are vulnerable to the future requirements for CO_2 total sum regulation under the condition that they control total sum of domestic CO_2 discharge to the level in 1995. It is prospected to affect to the patterns of building's energy consumption, when the law of environmental pollutants discharge is established. Data of building constituents based on the energy performance are needed to be applying to the appraisal method for building's energy system showed in this study, and data of energy balance are also needed.

With additional researches, this study is going to be applied to analysis and appraisal of the total effects originated individual building's energy systems, to which have been impossible under the separately founded energy standards for buildings or total energy standards simply established.

Finally, the goal on reducing CO_2 gas emission in Korea compelled by UN Framework Convention on Climate Change should be established carefully considering it's influence on national economy and the practical performing possibility. It will be easy to confront the situations of not only carrying out the duty but also having economic disadvantage which are happened in the advanced countries at present, when received the burden without provisions including deep analysis and research for the reason that it is the world tendency or the press made by advanced countries. Therefore, Our country should prepare the comprehensive prearranged plan by finding the attainable plan through deep research including minimizing method of the various effects to the national economy of which can be caused by each CO_2 gas reduction scenario.

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NOMENCLATURE

$S(t, f, s)$: Supply amount of primary energy source(f) from supply source(s) in period(t),

$K(t, \tau)$: Equipment capacity of usable energy technology(τ) that shows energy unit and mean of energy product and process,

$H(t, j, a)$: Heat amount of processed by period(t) and heat product facility(a)

$M(t, j, a)$: Disable equipment capacity during maintenance of convert technology(a) in period(t) and season(j)

$i(t, fd, f, s)$: Require amount of energy(fd) that unit amount of energy source(fs) from energy supply source(s)

$I(f, \tau)$: Stock amount of energy source(f) which remote amount of energy technology(τ) per unit

$i(t, f, \tau)$: Input parameter of energy technology(τ) against energy source(f) that it shows input amount of energy source(f) of per unit of (τ)

$o(t, f, \tau)$: Output parameter of energy source(f) from energy technology(τ). Amount of output amount of energy source(f) per unit of

$e(t, \tau)$: Overall efficiency of energy technology(τ)

$e_H(j, a)$: Heat transfer efficiency from energy conversion technology(a)

$L(\tau)$: Durable years of energy technology(τ)

$Qa(t, \beta)$: Capacity of Process technology(β), period(t)

$Q(t, f, \beta)$: Amount of energy source(f) from period (t) and energy process technology(β)

N: The year of each evaluation period.

$\omega(j, d)$: Energy ratio of energy demand in season(j)

$\mu(d)$: Equipment capacity decision parameter of energy demand factor(d) which represents amount of useful energy

m_H: Ratio of average heat demand of equipment capacity to extra heat capacity of peak load