DESIGN STRATEGIES FOR ENERGY CONSERVATION BUILDINGS

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ABSTRACT

Energy Conservation Buildings are very effective for restraint of global warming, because they can reduce CO_2 emissions in building operation, which account for 70% of Life Cycle emissions. To find the most suitable strategies for energy conservation, it is necessary to assess various combinations of energy conservation techniques based on both environmental and economic viewpoints. Since these assessments are laborious and time consuming, an assessment tool has been desired. This paper describes a computer program named "Integrated Assessment System for energy conservation (Eco-navi)" that allows engineers and architects to recombine several energy conservation techniques easily in early phase of architectural and building services planning. Through computer simulation, vector diagrams to find the most suitable combination will be presented.

INTRODUCTION

Although a single technique for energy conservation cannot achieve a significant energy reduction, combined techniques could do it. So many combinations should be assessed in four aspects of the Integrated Assessment System concept shown in Fig.1. Sakai presented a method that can find out the most suitable combination among many combinations using a vector diagram for Thermal Economics with a technique for energy conservation in performance order.

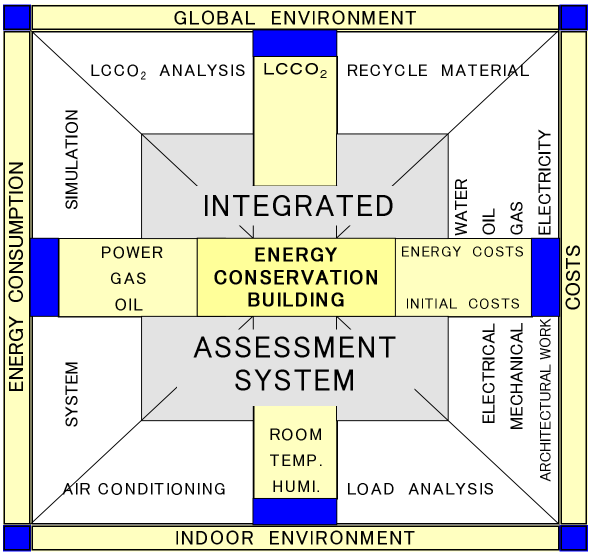


Figure 1 Concept of Integrated Assessment System

Two problems with the vector diagram should be considered. First, it is very difficult to find performance order, because a performance varies according to the other techniques to combine. Thus many trial and errors are required. Additionally these trial and errors require complex, laborious, and time consuming input data rearrangement. Secondly, this vector diagram has been based on only economics, however in recent years it has become desired to take into consideration global environment.

This paper presents:

(1) a simplified model for the Integrated Assessment System;

(2) a procedure for making vector diagrams easily;

(3) an algorithm for the automatic rearrangement of the input data;

(4) a vector diagram for Environmental Economics in addition to a vector diagram for Thermal Economics.

MODELS

The model for the Integrated Assessment System required (1) rapid assessment ability for recombination of energy conservation techniques, (2) ability to be used by persons with less technical experience, (3) ability to estimate with few information that can obtain in early phase of planning, and (4) easy explanation of outputs.

To comply with these requirements, a simplified model was developed by the following simplification methods. (1) Hour by hour simulation on peak cooling day, peak heating day to determine capacity of the building equipment, and on representative day of every month to estimate annual energy consumption. (2) It is assumed that each system is fixed and controlled ideally. (3) Capacity of equipment is determined automatically. (4) Energy usage of several systems that cannot be simulated is estimated by unit values based on measurements.

The model is composed of the thermal loads model, the energy system model, the Life Cycle CO_2 ($LCCO_2$) model, and the economic model.

The thermal loads model calculates air conditioning load using the weighting factor method and hot water supply load using unit values.

The energy system model is composed of subsystem models shown in Fig.2. The secondary subsystem model calculates coil load that is assumed to be equal to the sum of heat extraction rate, outdoor air load, and any other loads. In this process, effectiveness of the natural free cooling, control on outdoor air intake, total heat exchanger can be estimated. Fan and pump power is calculated based on maximum coil load, design temperature difference, motor efficiency, etc. Power consumption is calculated based on characteristic curve, giving input power versus part-load ratio. In this process, effectiveness of VAV, VWV, high efficiency motors, reduction of pipe and duct friction, large water or air temperature differential system is estimated.

The hot water supply system model calculates power consumption of hot water circulation pump based on operating schedule. This model describes the effectiveness of pumps operated intermittently, and the supply water temperature control.

The thermal storage tank model calculates the required daily total storage thermal energy in the tank, that equals the sum of daily total secondary system load plus the tank heat loss.

The plant model calculates the required energy rates e.g., gas and/or electric power, from the required energy rates of several secondary systems and/or thermal storage tank and/or hot water supply systems. The energy consumption of plant equipment can be calculated by hourly determination of the important parameters, e.g., temperature of heat sink/source, part-load ratio. These characteristics curves were determined based on the technical data obtained from manufacturer.

Cogeneration model is based on following assumption.

(1) electric application :system interconnection

(2) operation mode : following electrical load

(3) Electric load equals the sum of electric power

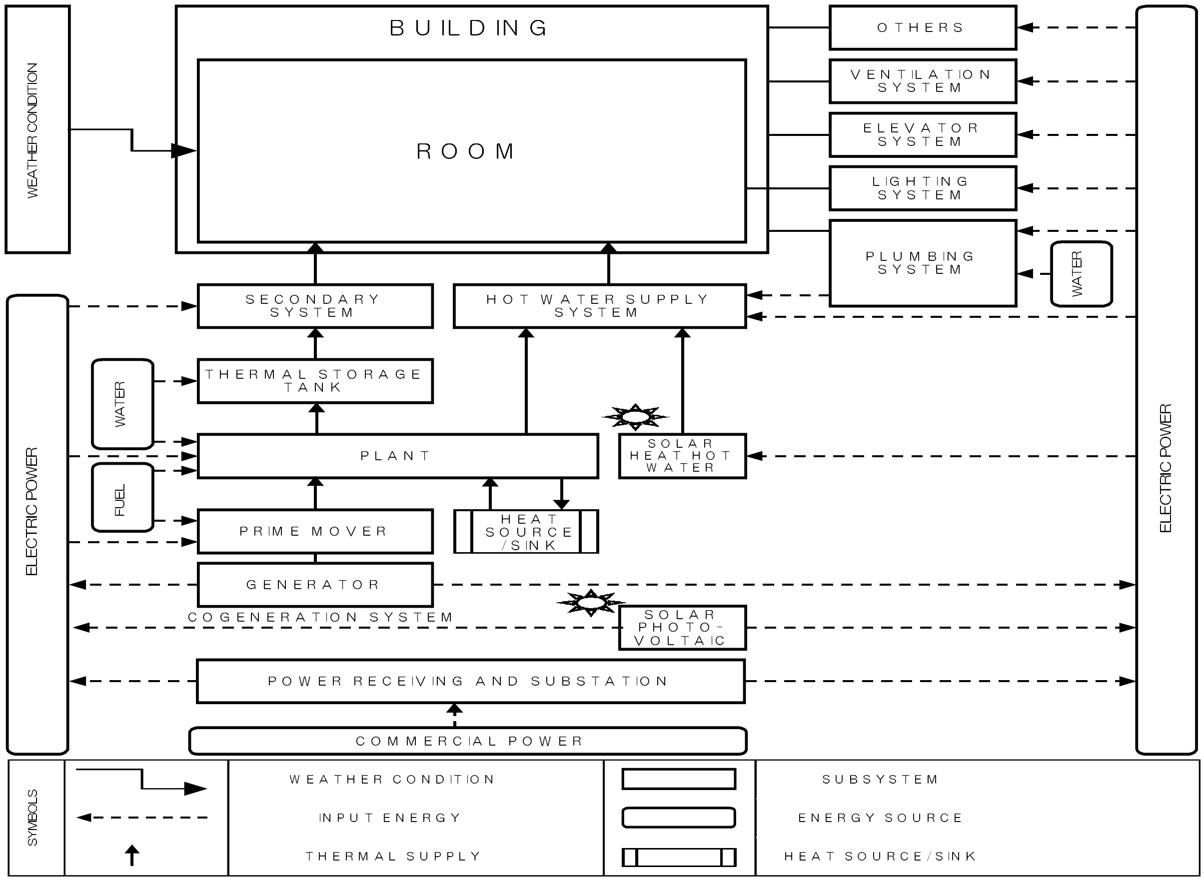


Figure 2 Energy Flow Diagram of Building

consumption of subsystems.

The load factor of each generator is calculated based on input capacity and number of generator, and electrical load. The power efficiency and the waste heat recovery efficiency are calculated from characteristic curves (i.e., efficiency versus load factor). The energy consumption of prime mover is calculated by the power efficiency, and the thermal power produced by the prime mover is calculated from heat recovery efficiency. The thermal power is used cooling, hot water supply, heating, and released to the air. Lack of heat recovery is “input ” of the plant model.

The plumbing system model calculates the water supply load based on unit daily total water supply load per square meter of each floor area, time schedules, and monthly schedules. The power consumption of the pump for gravity water supply system is calculated assuming that it starts when the water in the tank is less than 50 % and stops when the water in the tank is full. The power consumption of the pump for booster pump water supply system is calculated considering the part load characteristic.

The lighting system model calculates the power consumption based on the lighting density (i.e., input power of the luminaire per unit square meter), and a time schedule. These values are reflected in the air conditioning load calculation. This model describes several lighting control systems.

The elevator model calculates power consumption based on the daily total power consumption of an elevator, and an operating schedule.

The ventilation system model calculates the power consumption of the fan based on the unit fan power per square meter of each room in witch ventilation system is required, and an operating schedule.

The electrical substation model calculates the load loss and the no-load loss of the transformer. The capacity of the transformer installed can be calculated by the maximum building total power consumption obtained from simulation results on peak summer day, and the demand factor. The no-load loss is calculated by the transformer capacity, and no-load loss factor based on a catalog. The load loss is calculated by the hourly load factor obtained from the simulation, and rated loss based on a catalog. This model describes the effectiveness of low-loss transformer, and improvement of power factor using phase advance capacitor.

The photovoltaic generation model calculates the solar radiation incident on the collector surface based on the solar position, normal direct solar radiation, and horizontal sky radiation. The solar and sky radiation obtained from the weather files. The generated power is calculated based on the solar energy, the energy conversion efficiency, inverter efficiency, and several factors for ambient air temperature, fouling, and deterioration.

The solar heating system model is the model of simple and conventional solar system, which is composed of the collector, the storage tank, and the solar heat-collecting pump. This model calculates collected heat amount based on the solar radiation incident on the collector surface, and the efficiency of the collector. The energy is stored in a water tank and used for hot water supply. The load on the auxiliary equipment is calculated assuming that it operates when the energy in the tank is depleted.

The LCCO$_2$ model calculates the carbon emissions from material manufacturing, transportation, construction, operation, maintenance, reform, and demolition. Each process is as follows:

(1) material manufacturing process : emissions during in-plant manufacturing of such materials as steel and cement;

(2) transportation process : emissions during transportation of materials between plants and construction site;

(3) construction process : emissions from building construction;

(4) operating process : emissions from building operation;

(5) maintenance process : emissions from replenishing daily consumption, maintenance and repair;

(6) reform process : emissions from full scale replacement of deteriorated equipment and interior/exterior materials every 20 or 30years;

(7) demolition process : emissions from demolishing the building and clearing the site.

These emissions are calculated by unit values of CO$_2$ emissions for materials those include recycle materials for buildings, and energy sources.

The economic model calculates energy costs and initial costs. Initial cost calculation disregards common characteristics between Energy Conservation Buildings and typical buildings, accounting only for relative cost of energy conservation techniques. Architectural initial costs are calculated by unit costs per square meter for each material. Lighting, ducting, and piping costs are calculated by unit costs per square meter of floor area. Equipment costs are calculated based on the requirements decided by system simulation. Energy costs including electric power, gas, and water are calculated based on the charges systems of typical electric power companies, gas companies, and local governments in Japan. Oil costs are calculated by input unit price.

VECTOR DIAGRAMS

A vector diagram for Thermal Economics is a visual tool for energy conservation and cost saving, as shown in Fig.4d. The origin indicates standard building (without energy conservation design) costs. Differential of initial cost between a standard building and an Energy Conservation Building is measured horizontally, and differential of energy cost is measured vertically. The gradient of each vector indicates cost performance of energy conservation technique. By connecting vectors in performance order, economic performance can be analyzed. In other words, this diagram shows evolving process from a standard building to an Energy Conservation Building. Each generation building combines energy conservation technique successively in performance order. A gradient of a straight line that is drawn from the origin to the end point of each vector shows payback year.

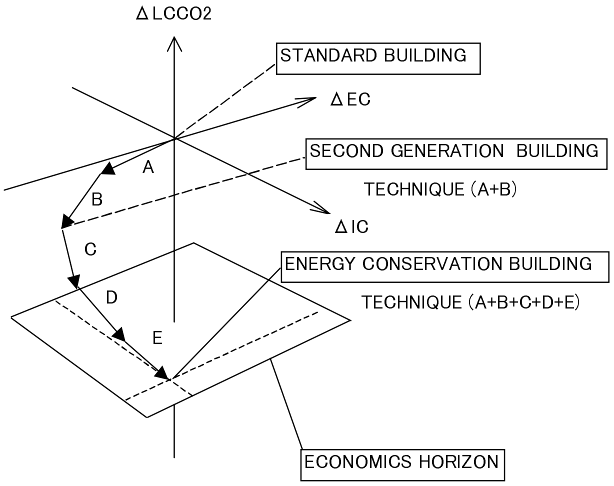
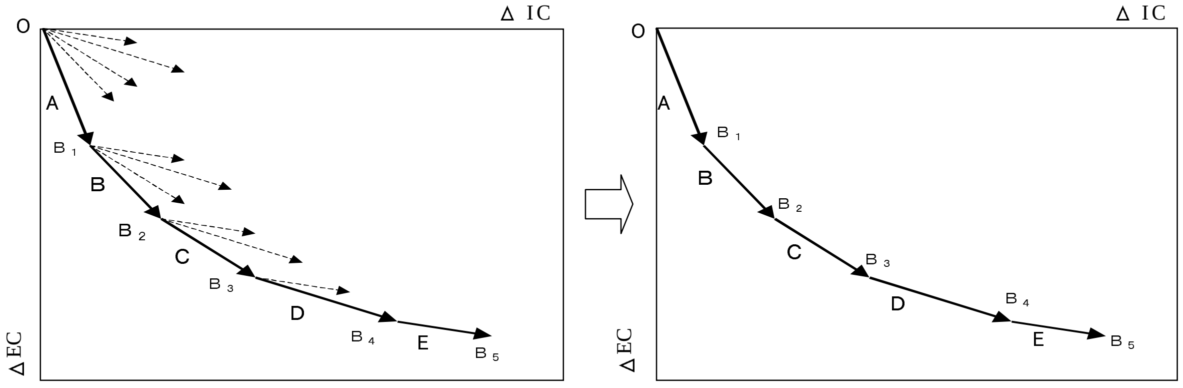


Figure 3 Integrated Vector Diagram

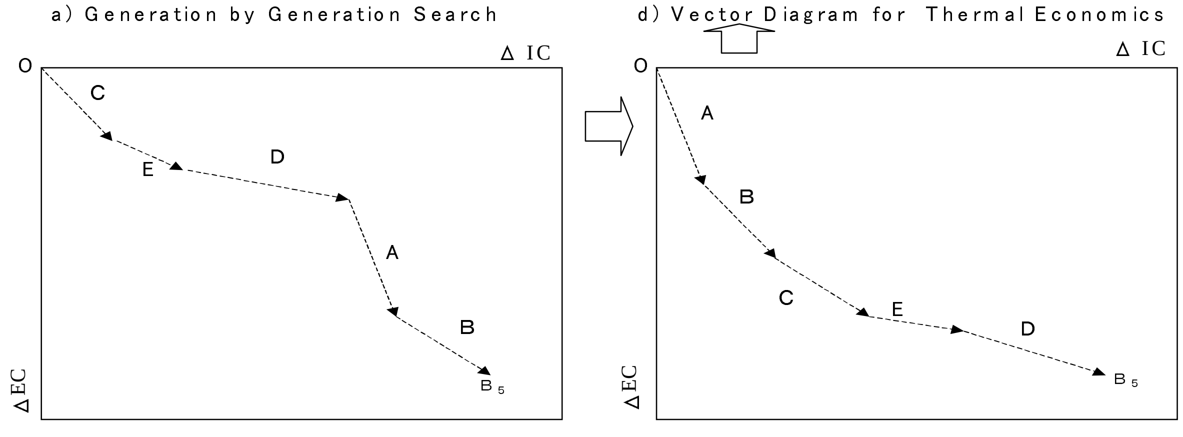
Table 1 Condition of each Point on Vector Diagram

Point	Building Generation	Combination of Techniques	Effectiveness of Energy Conservation
Origin	Standard Building	—	—
B_1	First generation building	A	OB_1 (Technique A)
B_2	Second generation building	A+B	B_1B_2 (Technique B)
B_3	Third generation building	A+B+C	B_2B_3 (Technique C)
B_4	Fourth generation building	A+B+C+D	B_3B_4 (Technique D)
B_5	Energy Conservation Building	A+B+C+D+E	B_4B_5 (Technique E)



a) Generation by Generation Search

d) Vector Diagram for Thermal Economics



b) Through the Generations Search (First Trial)

c) Through the Generations Search (Second Trial)

Figure 4 Procedure for Making Vector Diagram

A vector diagram for Environmental Economics is a diagram that replaces energy cost by $LCCO_2$ emissions.

These vectors can be shown as three-dimensional vector in space that consists of the two-dimensional surface of economics and one dimension of environment, i.e., $LCCO_2$ emissions, as shown in Fig.3. A vector diagram for Thermal Economics is an orthogonal projection of this three-dimensional vector on economics horizon. Similarly a vector diagram for Environmental Economics is an orthogonal projection on initial cost-environment surface. Therefore two kinds of performance order, economic performance (i.e., dEC/dIC) order and environmental performance (i.e., $dLCCO_2/dIC$) order can be created.

Two kinds of procedures for making vector diagram (i.e., to find performance order) are considered. One is “generation by generation” search shown in Fig.4a, and the other is “through the generations” search shown in Fig.4b-4d. “Generation by generation” search requires determination of the best performance energy conservation technique in each generation by trial and errors. On the other hand “through the generations” search makes a vector diagram combing energy conservation techniques in random order through all generations, as shown in Fig.4b. Then it is recombined energy conservation techniques based on the gradient of each vector, as shown in Fig.4c, and proceeds until vectors connect in performance order, as shown in Fig.4d.

The important point to note is the number of trial and errors. If there are five energy conservation techniques, “generation by generation” search requires 14(=5+4+3+2) times of trial and errors. On the other hand “through the generations” search, in my experience, requires only 2 or 3 times of trial and errors. It is obvious that the more techniques are adopted, the more efficient “through the generations” search in comparison with “generation by generation” search. However, the input data arrangement according to the recombination of energy conservation techniques in each generation is very time consuming. This program requires one shot execution for each generation (i.e., each building). For example, to adopt technique ”A” in first generation instead of technique “C”, all generations’ input data must be modified. If technique “A” means “reduction of four windows’ area”, 20(= 4windows x 5generations) data must be modified, and proceeds until the order (C, E, D, A, B) is changed into the order (A, B, C, D, E) as shown in Fig.4 and Table 1.

So the subprogram that allows us to rearrange input data through all generations automatically in required order is needed. The algorithms shown in Fig.5 is as follows:

(1) Initialize all generations’ new input data under the standard building condition

(2) Store each generation’s difference data between the nth generation and n-1th generation by comparison of each input data obtained on the first trial

(3) Transcribe each generation’s difference data on new input data from the generation to the last generation in required order

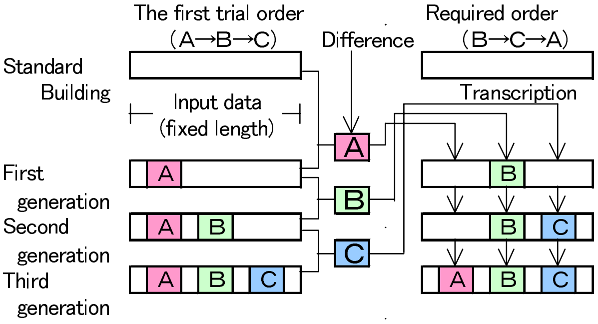


Figure 5 Rearrangement of Input Data

This rearrangement subprogram can generate new input data through all generations in required order from the input data obtained on the first trial. Each parameter value for each generation is chosen between the value for the Energy Conservation Building and that for the standard building as shown in Table 3.

ASSESSMENT RESULTS

To examine the applicability of the Integrated Assessment System described here, a large office building was selected. Outline of this building is shown in Table 2. This building is divided 8 zones, upper floor, middle floors, south, and north block of the first floor, atrium, shopping floor, restaurant floor, and basements, as shown in Fig.6. The typical floor plan is shown in Fig.7. Table 3 compares the design parameters of the standard building and the Energy Conservation Building. Fig.8 and Fig.9 show vector diagrams in economic performance order. These vector diagrams show that Energy Conservation Building (with a total of 11 techniques adopted) achieved:

(1) Initial cost : 750 million yen (7.5%) increase

(2) Energy cost : 91 million yen (57%) reduction

(3) Payback years : 8.3 years

(4) $LCCO_2$ emissions : 8.1 $kg\text{-}C/m^2.year$ (26%) reduction

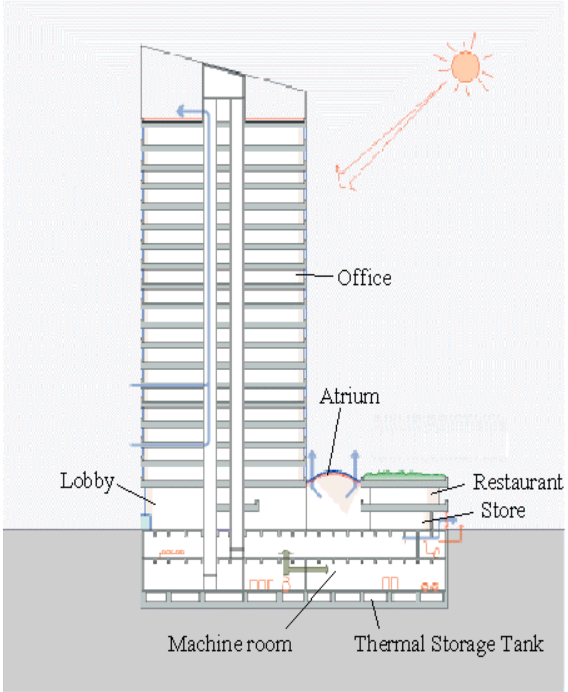


Figure 6 Model of Building for Example

Table 2 Outline of Building for Example

Location	Tokyo
Total floor area	36400m^2
Building type	Office
Structure	S+SRC
Number of floors	2 story bellow 20 stories above ground
Typical floor area	1490m^2

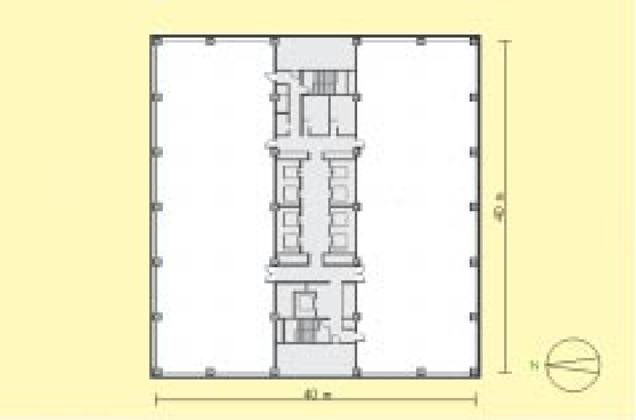


Figure 7 Typical Floor Plan of Building for Example

Table 3 Comparison of Standard and Energy Conservation Building

Energy Conservation Technique	Design Parameter		Building	
			Standard	Energy Conservation
Extra-high-voltage avoiding	Received voltage	V	20000	6000
Atrium temp. easement	Set point summer/winter	℃	26/22	30/15
Control on outdoor air intake during pre cooling/heating	-	-	No	Yes
Total heat exchanger	Exchange efficiency	%	0	70
Use of Air Flow Window	Window type	-	Heat absorbing 10mm	AFW
Reduction in friction in duct system	Reduction percentage	%	0	10
Large water or air temp. differential system	Temp. differential	℃	5	8
Cogeneration & Thermal Storage Tank system	Plant system	-	Turbo-chiller & Gas fired boiler	CGS+TST
Use of high efficiency motors for secondary system	Motor efficiency	-	0.8	0.85
Use of high frequency lamp	Luminaire type	-	Conventional lamp	High frequency lamp
Lighting control	Reduction percentage of lighting	%	0	8
Reduction of infiltration	Air change	-	2	0.5
Insulation of exterior wall	Thickness	mm	15	20
VAV	Secondary system type	-	CAV	VAV
VWV	Secondary system type	-	CWV	VWV
Natural free cooling	Outdoor air/Min. O.A	-	1.0	1.0-4.0
Control on outdoor air intake by measuring CO$_2$	-	-	No	Yes
Natural ventilation of office on summer night time	Air change	-	0	2
Natural ventilation of machine room, etc.	Reduction percentage of fan power	%	0	30
Photovoltaic power generation	Energy conversion efficiency	%	0	8

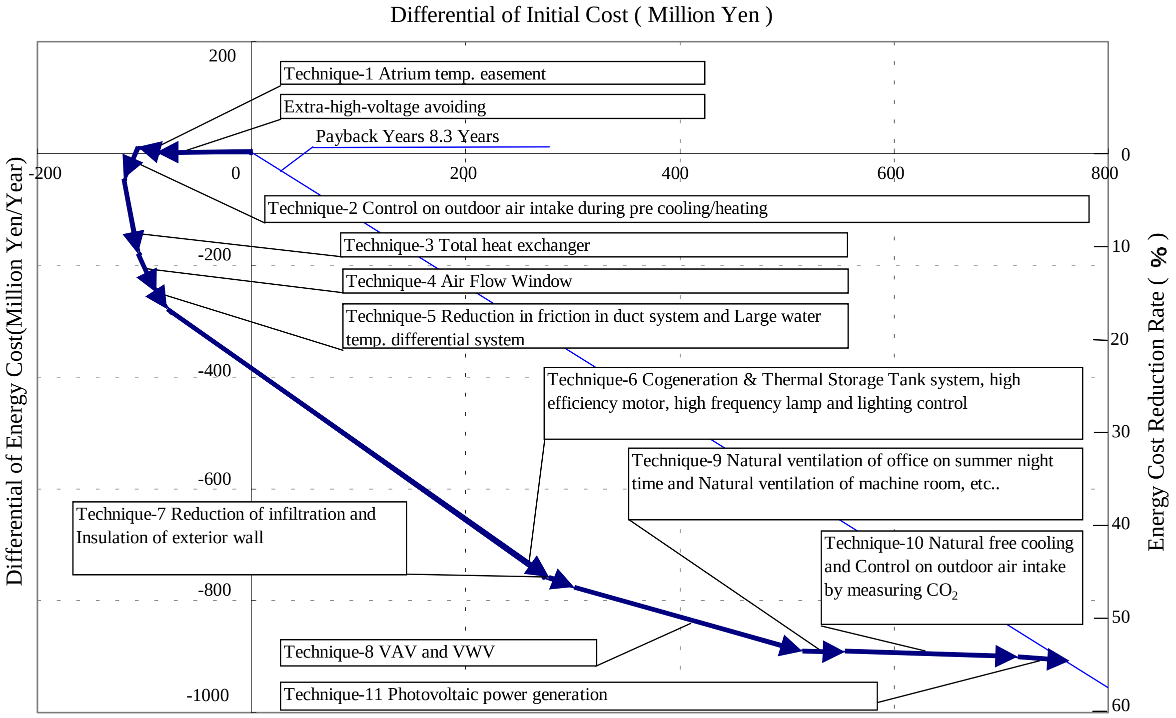


Figure 8 Vector Diagram for Thermal Economics

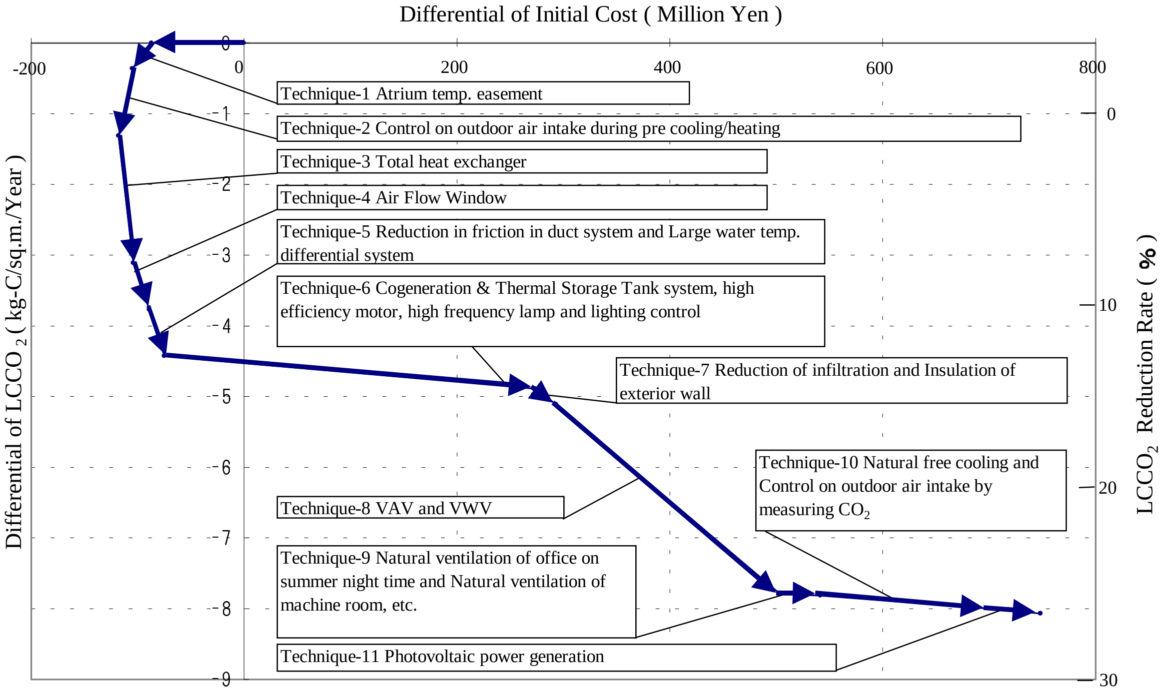


Figure 9 Vector Diagram for Environmental Economics

These vector diagrams can be used as follows. For example, if the required initial cost is 300 million yen, the combination of technique-1 through 7 can be selected from Fig.8. The energy cost, payback year can be indicated at the end point of 8th vector in Fig.8, and $LCCO_2$ emissions can be indicated at the end point of 8th vector in Fig.9.

CONCLUSIONS

Until now it took several weeks to make a vector diagram for Thermal Economics. The Integrated Assessment System for energy conservation described here allows architects or building services engineers to make the vector diagrams for Thermal and Environmental Economics in a few days. There are two reasons for this time saving. One is the development of simplified model that can describe the energy systems and the energy conservation techniques of the buildings. The other is the development of input data rearrangement system for the recombination of energy conservation techniques. By using integrated vector diagrams, designers can propose the best strategy for satisfying clients' environmental and economic requests.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the support of Keizo Shimizu, Ph.D., Kanji Sakai, Ph.D., Kenjiro Yamaguti, Yoshitugu Takei, Kazuharu Takemoto, and Hisataka Kaneda of Obayashi Corporation.

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