VECTOR DIAGRAM FOR THERMAL ECONOMICS OF ENERGY CONSERVATION BUILDINGS

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ABSTRACT - The **vector diagram for** thermal economics has-been developed to analyze energy saving methods in the planning of energy conservation buildings. In the diagram, the differential of initial cost is shown in the abscissa, and that of running cost in the ordinate. Using this, energy saving methods both in architectural design and building mechanical and electrical systems are dealt with in an integrated way. The gradient of the vector is used as a criterion of energy efficiency and cost effectiveness, and any answer suitable to different philosophy of building clients can be easily obtained using this graph. A computer program to calculate both the initial cost and the running cost for this diagram was developed, and a program for economical comparison of heat source systems in office buildings was also developed specially for the application in the north of central Japan, and they have been used for the **actual projects.**

INTRODUCTION

In the planning of energy conservation buildings, it is very important to judge the effectiveness of many energy saving methods both in architectural design and in building mechanical and electrical systems. Because, they are not always effective depending on many conditions such as the location and use of the building or economic reasons.

Many methods have been developed to analyze the effectiveness of energy saving methods up to the present, but many of them cannot analyze the effectiveness in architectural design and mechanical and electrical systems in an integrated way.

The amount of saved energy is often used in the evaluation of energy saving methods, and many statistical analysis methods or computer programs for energy simulation in buildings to calculate it have been developed. But even if energy consumption in the building can be reduced remarkably, it may not be cost-effective when initial investment is increased considerably.

The vector diagram for thermal economics has been developed to meet these requirements, and it has the following features.

1) Energy saving methods both in architectural design and in building mechanical and electrical systems are dealt with in an integrated way.
2) To estimate the effectiveness of energy saving methods, not only the amount of energy consumption (the running cost can be calculated using it) but also the initial investment (the initial cost) are considered.

INTEGRATED EVALUATION METHOD BY THERMAL ECONOMICS

Vector for Thermal Economics

Taking one method into consideration out of many energy saving methods, suppose two cases: the energy saving method is applied in the one case, and it is not in the other. The differential of initial cost and that of running cost of those two cases are calculated as follows.

$$\Delta IC = IC_1 - IC_0$$
$$\Delta RC = RC_1 - RC_0$$

where

ΔIC = differential of initial cost
IC_1 = initial cost when the energy saving method is applied
IC_0 = initial cost when the energy saving method is not applied
ΔRC = differential of running cost
RC_1 = running cost when the energy saving method is applied
RC_0 = running cost when the energy saving method is not applied

Next, plotting the point (ΔIC, ΔRC) on the Cartesian coordinate system where the abscissa shows the differential of initial cost and the ordinate does that of running cost, a two-dimensional vector can be obtained by drawing the arrow from the origin of the coordinate system to the point (ΔIC, ΔRC) as shown in Fig. 1.

The vector can be used for the evaluation of energy saving method from the viewpoint of both energy and economics, therefore it is called here the "vector for thermal economics".

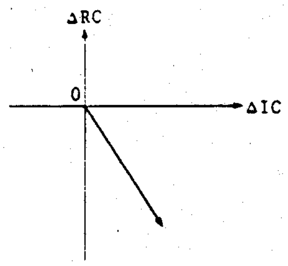

Fig. 1 Vector for Thermal Economics

Number of Years for Pay Back

In order to judge the effectiveness of each energy saving method, integrated evaluation of the initial cost and the running cost is required. For this purpose, the number of years for pay back is generally used, which means the length of time required to recover the increased investment by the annual saving owing to the decreased running cost. The shorter the number of years for pay back of the energy saving method is, the more desirable the adoption of the method is.

For the calculation of the number of years for pay back, loan interest rate and rate of increase in unit cost of energy are also taken into consideration. The increased amount of average annual expenditure owing to the increased initial cost is obtained as the following equation by the averaged interest rate method.

$$P = \Delta IC \left\{ (1-r)\cdot\frac{1}{T} + r\cdot i + (1-r)\cdot\frac{i}{2}\cdot\frac{T+1}{T} \right\}$$

where
P = increased amount of average annual expenditure
r = ratio of final remaining value
T = number of years for pay back
i = loan interest rate

On the other hand, the decreased amount of average annual expenditure owing to the decreased running cost can be expressed in the following.

$$I = \Delta RC \cdot \frac{(1+j)^T - 1}{T\cdot j} \quad (\text{when } j=0,\ I=\Delta RC)$$

where
I = decreased amount of average annual expenditure
j = rate of increase in unit cost of energy

The number of years for pay back can be calculated using the following equation which is derived from the above two equations assuming the ratio of final remaining value to be zero.

$$\Delta IC \left\{ 1 + \frac{i\cdot(T+1)}{2} \right\} = \Delta RC \cdot \frac{(1+j)^T - 1}{j}$$

Table.1 Gradient of Vector for Thermal Economics

i[%]	j[%] \ T[years]	3	5	10	15	20
6	0	0.373	0.236	0.133	0.099	0.082
	10	0.338	0.193	0.083	0.047	0.028
	20	0.308	0.159	0.051	0.021	0.009
8	0	0.387	0.248	0.144	0.109	0.092
	10	0.350	0.203	0.090	0.052	0.032
	20	0.319	0.167	0.055	0.023	0.010
10	0	0.400	0.260	0.155	0.120	0.103
	10	0.363	0.213	0.097	0.057	0.036
	20	0.330	0.175	0.060	0.025	0.011

Conversely, the gradient of the vector for thermal economics, that is ΔRC/ΔIC, can be calculated when i, j and T are given, and some example values by this calculation are shown in Table.1.

Decision Making using Vector Diagram for Thermal Economics

In the planning of energy conservation buildings, many energy saving methods are investigated. A chain vector as shown in Fig. 2 can be obtained putting vectors for thermal economics in ascending order in the number of years for pay back, calculating accumulated values of ΔIC and ΔRC of each method. The reference standard case is assumed to be in the origin of the coordinate system.

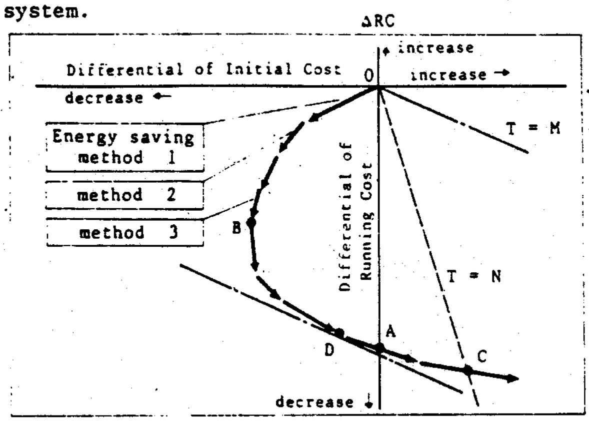

Fig. 2 Chain Vector for Thermal Economics

From the following four points of view, quick and exact decision making using this diagram is possible as to which of those energy saving methods should be adopted.

- Save energy without changing initial investment:
  Point A in Fig. 2 shows this case, therefore energy saving methods up to point A should be adopted.
- Save energy and minimize initial investment:
  Point B in Fig. 2 shows this case.
- Save energy using initial investment which can be recovered in N years:
  Point C in Fig. 2, which is the intersection point of the chain vector and the line drawn from the origin with the gradient of N years for pay back, satisfies this requirement. Therefore, energy saving methods up to point C should be adopted.
- Minimize total cost (summation of initial investment and running cost) over M years:
  Point D in Fig. 2, which is the point of tangency of the chain vector and the line with the gradient of M years for pay back shows this case.

APPROXIMATE CALCULATION METHOD FOR THERMAL ECONOMICS

A computer program to calculate approximately increase or decrease of both the initial cost and the running cost was developed to obtain the vector diagram for thermal economics. In this program, input data are simplified because this program is generally used in the early stage of planning. But in the heat load calculation, precise calculation is made by response-factor and weighting-factor method in the periodic steady state.

Simplified flow chart of the program is shown in Fig. 3, and Table.2 shows factors which can be analyzed in the program. Those are considered to be main factors among those which affect energy conservation in buildings.

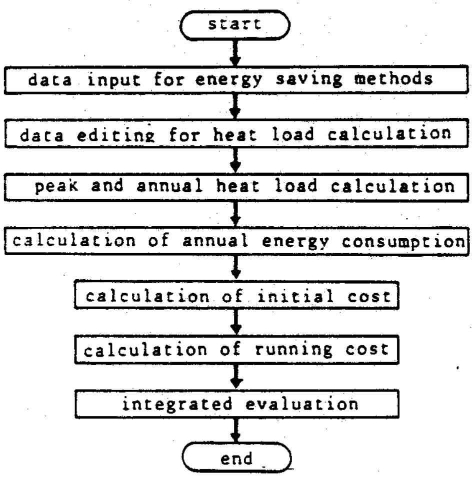

Fig. 3 Simplified Flow Chart

The components of which cost can be calculated in this program are only those that are affected by factors shown in Table.2. That is, cost for works which are unaffected by factors in Table 2, such as interior finish work, plumbing work or structural work is not considered in this program. Table.3 shows the components of which the initial cost and the running cost are calculated in the program.

Table.2 Factors affecting Energy Conservation

	Factor
Architectural Design	(1) location (2) floor plan (3) orientation (4) core type (5) eaves (6) window glass composition (7) window area ratio to exterior wall (8) wall composition (9) wall insulation (10) width of perimeter zone
Mechanical and Electrical Systems	(1) heat from lights and occupants (2) room temperature and humidity (3) O.A. intake (4) type of air-conditioning system (a) standard system (b) free cooling system (c) air-to-air total heat exchanger (d) (b) + (c) (e) heat recovery system + (a) ~ (d) (f) VAV system + (a) ~ (d) (5) type of lighting system (a) standard system (b) daylight utilization system (c) turning off at lunch time

Table.3 Structure of Components of which Cost is calculated

- Initial cost
  - Architectural work
    - roofing . exterior wall . window . core wall. eaves . heat storage tank
  - HVAC work
    - heat source system for cooling energy supply
    - heat source system for heating energy supply
    - air-duct system
    - piping system for air-conditioners
    - piping system for FCU
  - Electrical work
    - sub-station
    - main-feeder
    - motor control
    - lighting system
- Running cost
  - Heat source systems
    - electricity by chillers
    - fuel oil, kerosine or city gas by boilers
    - electricity by auxiliary equipment
  - Fans and pumps
    - fans for ventilation
    - fans for air-conditioning
    - pumps for air-conditioning
  - Lighting
  - Transportation, Plumbing and others

Initial Cost for Architectural Work

Standard cost per unit area (or unit volume in the case of heat storage tank) is incorporated in the program and the initial cost for each component can be calculated multiplying it by the area of the component of the given building.

Initial Cost for HVAC Work

The following sub-systems are supposed in three model buildings in which air-conditioned areas are 2,000 m^2[21,528 ft^2], 10,000 m^2[107,639 ft^2] and 50,000 m^2 [538,195 ft^2].

- Heat source system for cooling energy supply
- Heat source system for heating energy supply
- Air-duct system
- Piping system for air-conditioners
- Piping system for FCUs

In those model buildings, cost for each sub-system at two reference loads (for example, 80 and 120 $kcal/m^2 \cdot h$[29 and 44$Btu/ft^2 \cdot h$] of summer peak cooling load in the case of piping system for air-conditioners) was calculated. Then, dividing these values by the air-conditioned area, cost per unit air-conditioned area was obtained, and which was incorporated in the program. The procedure to calculate the initial cost for each sub-system of HVAC work in the given building is shown in Fig. 4.

Initial cost for each sub-system is calculated in the program multiplying Co in Fig. 4 by the air-conditioned area of the given building.

Initial Cost for Electrical Work

Following four sub-systems of electrical systems are considered in the program.

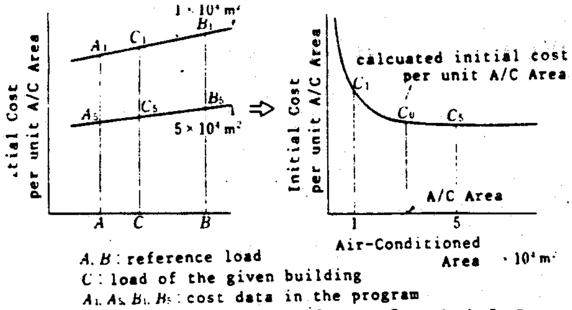

Fig. 4 Calculation Procedure of Initial Cost of HVAC Work

- Sub-Station
- Main-feeder
- Mortor Control
- Lighting System

In each sub-system, cost per unit electrical capacity is incorporated in the program. Therefore, initial cost for electrical work can be obtained after calculating each electrical capacity.

Calculation of Annual Energy Consumption

Breakdown of energy consumption in typical office buildings in Japan is as shown in Table.4 according to the survey of the actual condition of energy consumption[1) 2)].

In this program, annual energy consumption for heat source systems (primary cooling/heating energy supplying systems) is calculated by simplified energy simulation procedure for air-conditioning systems in representative days of each month[3)]. The calculation procedure is as follows:

1) Cooling or heating load of each air-conditioner is obtained by adding heat extraction rates of the rooms and outside air load hour by hour.
2) The load of heat source machines (chillers or boilers) is calculated by adding cooling or heating loads of the air-conditioners and increasing it by 10% taking into account of heat gain/loss in ducts and pipes.
3) The amount of energy consumption is calculated using mean C.O.P. and the load of heat source machines.

The amount of energy consumption for lighting (Fo in Table.4) is obtained based on input data for heat load calculation, and that for transportation, plumbing and others (Go in Table.4) is calculated using the figures in Table.4 and the total floor area of the building.

As for amounts of energy consumed by fans and pumps (Co, Do and Eo in Table.4), they are also calculated based on the figures in Table.4 with modification considering the type of air-conditioning systems and peak cooling/heating loads.

Calculation of Running Cost

The amount of kerosene, fuel oil, city gas and electricity consumed in the given building by heat source systems are calculated based on the type of the heat source machine. And assuming that equipment other than heat source machines is driven by only electricity, the amount of electricity consumption by them is also calculated.

Then, the running cost can be obtained using unit cost of each energy which is incorporated in the program.

EXAMPLES OF EVALUATION OF EFFECT OF EACH ENERGY SAVING METHOD

The effectiveness of each energy saving method was analyzed from the viewpoint of both energy and economics using the vector diagram for thermal economics. Examples of results are shown in Fig. 5 ~Fig. 7, and the origin of these diagrams indicate the reference model building shown in Table.5.

The results show the followings:

- As for the type of the floor plan, type (e) or (d) in Fig. 5 is desirable.
- Fig. 6 indicates that the reduction of window area has a very large effect on the decrease of both the initial cost and the running cost.
- Energy saving systems for air-conditioning such as type (c) (d) or (e) in Fig. 7 are cost effective; number of years for pay back for those systems are less than 5 years.

Table.4 Energy Consumption in the Office Building in Japan

Building total energy consumption *434 Mcal/m².a	Air-conditioning *205 Mcal/m².a	Heat source systems *87 Mcal/m².a	Heat source machines	**69.5 Mcal/m².a	A_o
			Auxiliary equipment	**17.5 Mcal/m².a	B_o
		Fans and pumps *118 Mcal/m².a	Fans for ventilation	**47.2 Mcal/m².a	C_o
			Fans for air-conditioning	**41.3 Mcal/m².a	D_o
			Pumps for air-conditioning	**29.5 Mcal/m².a	E_o
	Lighting	*140 Mcal/m².a			F_o
	Transportation, Plumbing, Others	*89 Mcal/m².a			G_o

. Figures are shown as the primary energy consumption (conversion factor: 1 kWh = 2,450 kcal = 9,720 Btu) per gross floor area
. Figures with suffix "*" are shown in Ref. 1) 2)
. Figures with suffix "**" are based on the analysis of several selected office buildings

Table.5 Model Building for Fig.5~Fig.7

Factor	Model Building Data
location	Tokyo
use	office building
number of floors	9 floors above G.L.
total floor area	10,000m² (107,000ft²)
rentable ratio	78%
floor plan	aspect ratio 1 : 1.5 center core
window glass composition	single: 8mm (0.31 in)
window area ratio to wall	50%
wall insulation	roof 25mm (1.0 in) exterior wall 25mm (1.0 in)
room temperature and humidity	summer 27°C (81°F) 60% RH winter 21°C (70°F) 40% RH intermediate 24°C (75°F) 50% RH
occupancy	perimeter 0.15 person/m² (0.014 p/ft²) interior 0.20 person/m² (0.019 p/ft²)
light	perimeter 15 W/m² interior 20 W/m²
O.A. intake	20 m³/h.person (11.8 cfm/person)
AC system	perimeter FCU (2 pipes) interior central duct (CAV)
operating hours	summer 8:00 - 18:00 winter 7:00 - 18:00 intermediate 8:00 - 18:00

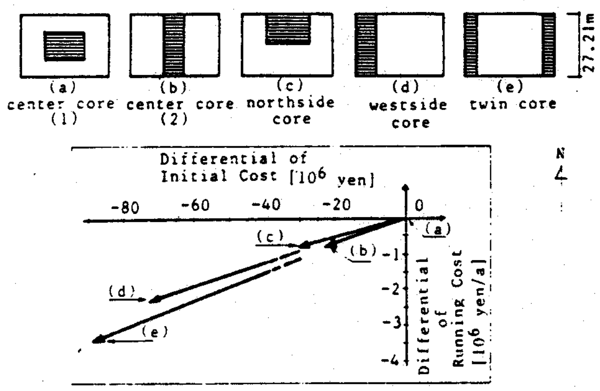

Fig. 5 Type of the Floor Plan

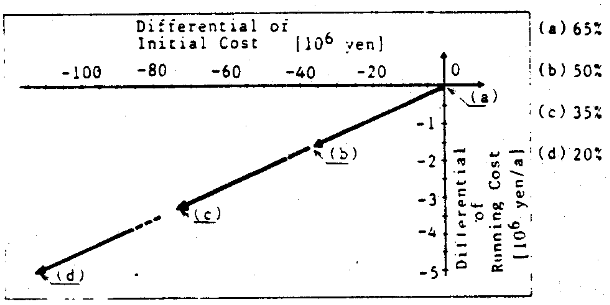

Fig. 6 Ratio of Window Area to Exterior Wall

EXAMPLES OF EVALUATION OF ACCUMULATED EFFECTS OF ENERGY SAVING METHODS

In the planning of energy conservation buildings, not only the analysis of each method, but also the evaluation of accumulated effects of those methods is important.

Fig. 8 and Fig. 9 show the results of this evaluation of accumulated effects in the case of the reference model buildings shown in Table 5, which are supposed to be situated in Tokyo (lat. 35° 41'N, long. 139° 46'E), and Sapporo (lat. 43° 03'N, long. 141° 20'E). Sapporo is located in the north of Japan, and its climate is colder compared with that of Tokyo.

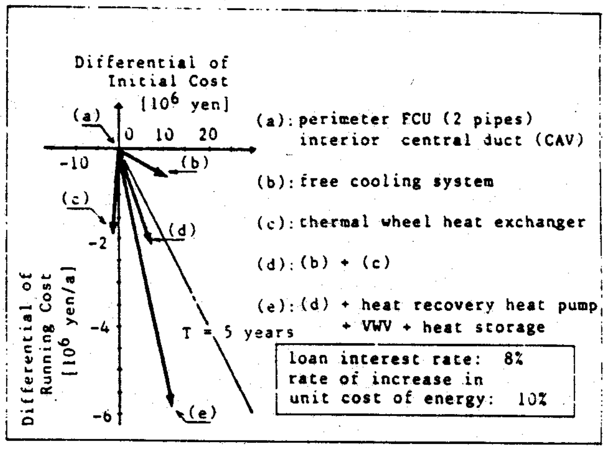

Fig. 7 Type of Air-conditioning Systems

Fig. 8 and Fig. 9 show almost the same results as a whole, and they suggest that energy conservation can be achieved without increasing initial investment in those areas. Decreased amounts of the initial cost and the running cost in Sapporo are more than those in Tokyo, especially the effect of thermal insulation is remarkable, which indicates that insulation in the district of colder climate is more advantageous.

Another example is shown in Fig. 10 whose reference model building is shown in Table.6, and it is supposed to be situated in Sydney, Australia. The result shows that architectural planning and reduction in thermal load have large effect on the decrease of running cost and active solar system is not cost effective in this case.

This program has been used for the analysis of many actual projects of energy conservation buildings such as the "Super Energy Conservation Building; Ohbayashi Corporation Technical Research Institute", and it has been proved to be very useful.

Table.6 Model Building in Sydney

Factor	Model Building Data
location	Sydney
use	office building
number of floors	4 floors above G.L.
total floor area	3,140m² (33,700 ft²)
rentable ratio	
floor height	3.6m (11.8 ft)
ceiling height	2.5m (8.2 ft)
floor plan	aspect ratio 1:2 southside core
window glass composition	single: 8mm
window area ratio to wall	50%
insulation	roof : 25mm exterior wall: without
room temperature and humidity	summer 24°C (75°F) 50% winter 21°C (70°F) 30%

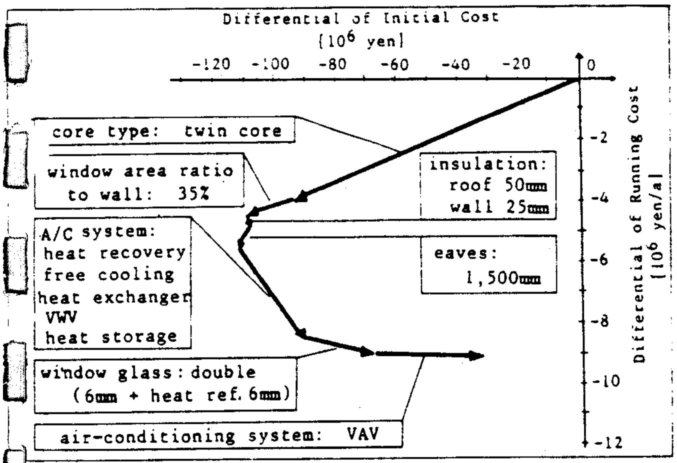

Fig. 8 Vector Diagram for Thermal Economics of Model Building in Tokyo

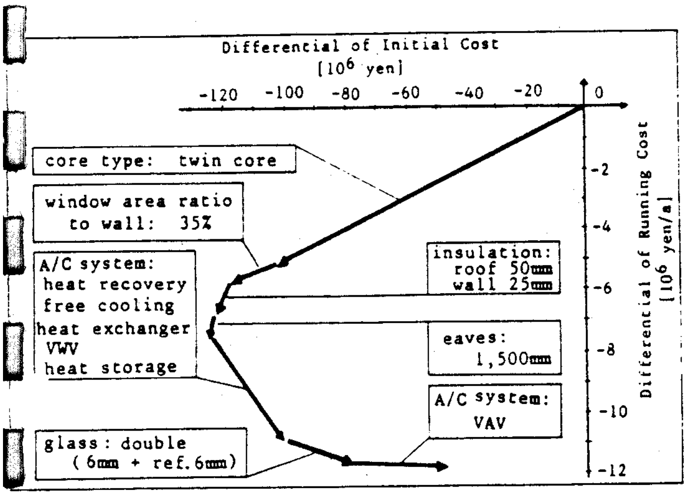

Fig. 9 Vector Diagram for Thermal Economics of Model Building in Sapporo

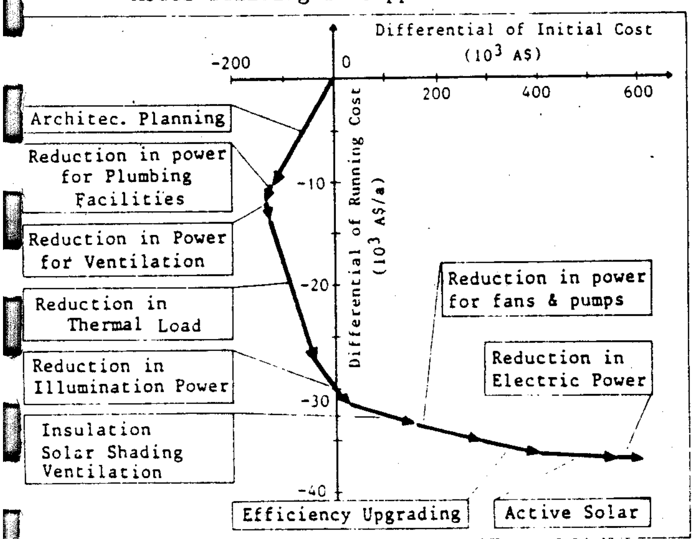

Fig. 10 Vector diagram for Thermal Economics of Model Building in Sydney

A PROGRAM FOR ECONOMICAL COMPARISON OF HEAT SOURCE SYSTEMS

This computer program was specially developed to apply the vector diagram for thermal economics to the specific cases in the actual designing in detail and to achieve energy conservation. It can evaluate heat source systems (primary cooling/heating energy supplying systems) in office buildings in the Hokuriku district (the northern part of central Japan). Simplified flow chart of this program is as shown in Fig. 11, and it consists of two parts: one is applicable to medium-sized (total floor area; 1,000~15,000 m^2 [10,800~161,500 ft^2]) office buildings to evaluate their heat source systems, and the other to make calculation of peak and annual cooling/heating loads for any buildings.

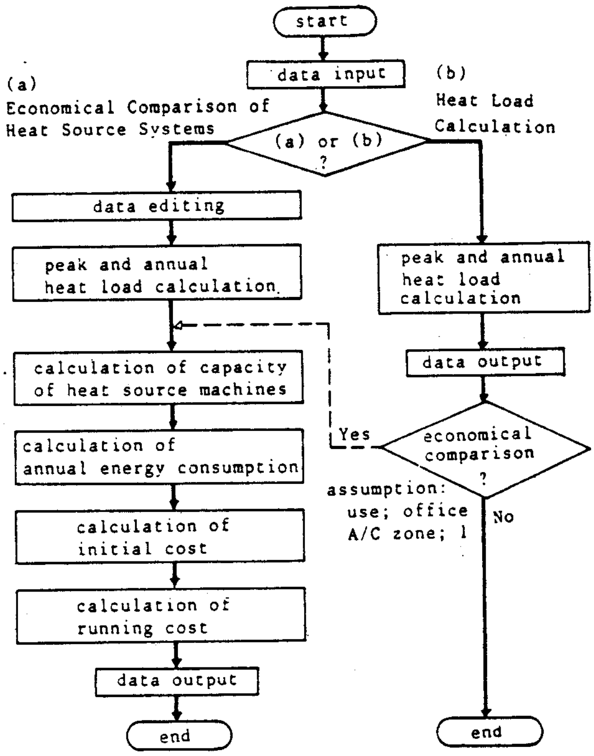

Fig. 11 Simplified Flow Chart

The former part of this program, based on almost the same algorithm as the before-mentioned program, has following features.

- It can evaluate heat source systems shown in Table.7.
- Standard weather data of Toyama (the city situated in the north of central Japan: lat. 36° 42'N, long. 137° 12'E) is incorporated in the program, and it can be modified by input data.
- The initial cost and energy cost are not the averaged value in all Japan, but those in the Hokuriku district taking into account of local situations. Some examples of these data are shown in Table.8 and Table.9.

Table.7 Heat Source Systems

Heat Source Systems	Heat Source Machines
A. Heat Pump Systems	Air-Source Heat Pump (reciprocating) Water-Source Heat Pump (reciprocating) Air-Source Heat Pump (screw) Air-Source Packaged Heat Pump Water-Source Packaged Heat Pump
B. Heat Pump Systems with Heat Storage	Air-Source Heat Pump (reciprocating) Water-Source Heat Pump (reciprocating) Air-Source Heat Pump (screw)
C. Water-Cooled Chiller + Boiler	Centrifugal Chiller + Oil-fired Boiler Reciprocating Chiller + Oil-fired Boiler Screw Chiller + Oil-fired Boiler Centrifugal Chiller + Kerosene-fired Boiler Reciprocating Chiller + Kerosene-fired Boiler Screw Chiller + Kerosene-fired Boiler
D. Water-Cooled Chiller + Boiler with Heat Storage	Centrifugal Chiller + Oil-fired Boiler Reciprocating Chiller + Oil-fired Boiler Screw Chiller + Oil-fired Boiler Centrifugal Chiller + Kerosene-fired Boiler Reciprocating Chiller + Kerosene-fired Boiler Screw Chiller + Kerosene-fired Boiler
E. Absorption Water Cooling and Heating Unit	Gas-fired Absorption Unit Oil-fired Absorption Unit Kerosene-fired Absorption Unit

Table.8 Examples of Initial Cost of Architectural Work

	material composition	material thickness [mm]	insulation thickness [mm]	standard cost [10^4 yen/m^2]
Exterior Wall	concrete insulation (polystyrene) mortar (without ins.) or plasterboard (with ins.)	170 0 ~ 50 25 12	0 25 50	2.066 2.296 2.376
Curtain Wall	aluminum (or glass) air space insulation (mineral fiberboard) asbestos-cement board	3 -- 0 ~ 50 12	0 25 50	7.546 7.776 7.856
ALC	ALC air space plaster board	120 -- 12	--	1.754
Window Glass	single double absorptive reflective absorptive/reflective reflective + transparent	8 6 + 6 8 8 8 6 + 6	--	1.01 4.20 1.44 2.54 2.64 5.62

Table.9 Examples of Initial Cost of Air-Conditioning Work

	Heat Storage tank	Medium capacity	Medium cost	Large capacity	Large cost
Reciprocating Chiller	with	30	26.8	100	17.5
	without	30	31.7	100	19.2
Centrifugul Chiller	with	300	12.9	1,000	9.9
	without	300	13.6	1,000	10.0
Air-Source Screw Heat Pump	with	300	21.3	1,000	18.5
	without	300	22.4	1,000	19.1
Absorption Unit	without	300	19.4	700	14.8

capacity[USRT]
cost[10^4 yen/USRT]

Application Example of the Program

This program was applied to evaluate energy conservation techniques in the actual building, that is the "Hyakusen Building" in Toyama, and the calculated results were compared with measured values. The reference building which is in the origin of Fig. 12, and the actual building are as shown in Table.10.

Table.11 shows the example of results of this analysis, and Fig. 12 is the vector diagram for thermal economics of this actual building in Toyama. These results show that heat pump system with heat storage is most economical among five types of heat source systems.

Table.11 Example of Output

		AIR-SOURCE HEAT PUMP	AIR-SOURCE HEAT PUMP (HEAT STORAGE)	RECIPROCATING CHILLER + BOILER	RECIPROCATING CHILLER + BOILER (HEAT STORAGE)	GAS-FIRED ABSORPTION UNIT
A. CALCULATED RESULTS						
1) HEAT SOURCE CAP. - S	(USRT)	223.	109.	225.	113.	225.
- W	(MCAL/H)	635.	310.	552.	552.	590.
2) MAX. ELEC. DEMAND	(KW	485.	430.	478.	424.	397.
3) ELEC. CONSUMPTION	(MWH/A)	1451.	1467.	1416.	1423.	1352.
4) GAS CONSUMPTION	(1000M**3/A)	0.	0.	0.	0.	98.
5) OIL CONSUMPTION	(KL/A)	0.	0.	21.	21.	0.
6) KEROSENE CONSUMPTION	(KL/A)	0.	0.	0.	0.	0.
7) HEAT STORAGE TANK	(M**3)	0.	1022.	0.	1022.	0.
8) OFF-PEAK ELEC. CONSUMP.	(MWH/A)	0.	170.	0.	102.	0.
9) AREA FOR HEAT SOURC. M.	(M**2)	101.	50.	80.	57.	35.
B. INITIAL COST	(10**4YEN)					
1) ARCHITECTURAL WORK		21376.	24082.	21706.	24480.	21122.
2) HVAC WORK		19192.	17633.	21303.	18662.	21984.
3) ELECTRICAL WORK		9596.	8931.	9610.	8955.	8537.
TOTAL		50164.	50646.	52619.	52097.	51643.
C. RUNNING COST	(10**4YEN/A)					
1) ELECTRICITY		4985.	4694.	4880.	4642.	4521.
2) GAS		0.	0.	0.	0.	710.
3) OIL		0.	0.	161.	161.	0.
4) KEROSENE		0.	0.	0.	0.	0.
5) CITY WATER		0.	8.	23.	21.	26.
6) MAINTENANCE		55.	52.	298.	292.	41.
TOTAL		5043.	4754.	5361.	5116.	5298.

Table.10 Actual and Reference Building

	Actual Building	Reference Building
window area ratio	50%	S,N 23.9% E,W 20.8%
dow glass	single: 8mm	double: 6mm + 6mm
sulation	roof: 25mm ext. wall: 0mm	roof: 50mm ext. wall: 25mm
location	Toyama	
use	office building	
number of floors	8 floors above G.L.	
total floor area	11,042m²	
rentable ratio	84.2%	

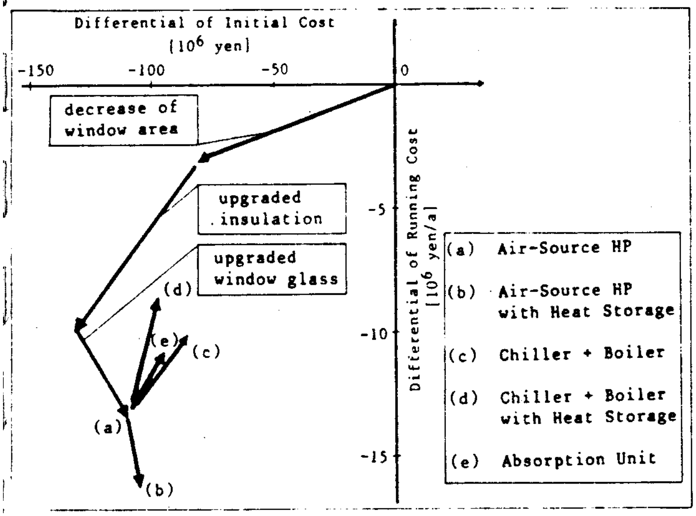

Fig. 12 Vector Diagram for Thermal Economics of the Actual Building in Toyama

Table.12 shows the comparison of the calculated results and measured values, and it indicates that the error of calculated electricity consumption is within 10% compared with the measured data.

Table.12 Comparison of Calculated and Measured Data

	(a) Measured	(b) Calculated	(b)/(a)
Maximum Electrical Demand [kW]	483	464	0.96
Capacity of Heat Pump [USRT]	80 x 2	84 x 2	1.05
Volume of Heat Storage Tank [m³]	400	471	1.18
Total Electricity Consumption [kWh]	1,363.2	1,476.3	1.08
Electricity Consumption for A/C [kWh]	507.1	455.4	0.90

In the many actual projects, this program has been used, and it is very useful in deciding the type of heat source systems.

DISCUSSION

The evaluation method of energy conservation buildings in an integrated way has been developed.
And computer programs to calculate both the initial cost and the running cost in the early stage of the planning were developed, and the error of the calculated running cost was shown to be within 10% compared with the measured value. The accuracy of the initial cost was not shown clearly in the figure because it depends on many conditions in the actual case.

CONCLUSIONS

The vector diagram for thermal economics, in which the initial cost is shown in the abscissa, and the running cost in the ordinate, has been developed. The vector diagram can be used for the evaluation of energy saving methods both in architectural design and in building mechanical and electrical systems in an integrated way. It is applicable to buildings not only in Japan but also in the world in the same way. It has shown that energy conservation in the building can be achieved without increasing the initial investment.

And computer programs for the vector diagram for thermal economics have been developed, and the program for economical comparison of heat source systems was developed for the application in office buildings in the northern part of central Japan.

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