Analysis of Economics through Control Method of Heat Source Equipment in Seasonal Air conditioning Building

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Key words: Life cycle cost analysis, Non-operating number control, Same load operating number control, Non-same load operating number control

ABSTRACT: The term "energy saving is economical" is appropriate for the national view point and for design and assessment of one system, but not appropriate when choosing the system by comparing alternative systems in the early design step. Sometimes, non-energy saving system is more economical than energy saving system because of the price of electricity, gas or oil, which are used for operating the air conditioning system. Therefore, when designing a system, we should consider the efficient alternatives through economic assessment of energy saving method. However, research on non-operating number control of the system is not sufficient because it is more common to use operating number control of the system for most economic assessment of air conditioning systems. For this reason, this research can provide the economic operating number control method as basic design data. The data obtained through analysis of life cycle cost based on amount of yearly energy use, are produced by system simulation of HASP/ACLD/8501 and HASP/ACSS/8502 for six alternative heating · cooling systems based on seasonal air conditioning system, which is widely used for medium and large size office buildings in Busan.

Nomenclature

AC	: air conditioning
a_P	: expenses in the P year [Won/year]
E	: electricity
e	: price escalation rate [%]
G	: liquified natural gas [LNG]
i	: interest rate [%]
I_O	: initial cost [Won]
n	: useful life [year]
$NONC$	: non-operating number control
$NSLONC$	: non-same load operating number control
O	: light oil
ONC	: operating number control
P	: present worth [Won]
R	: retirement cost [Won]
$SLONC$	: same load operating number control

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1. Introduction

Modern buildings tend to be bigger and more luxurious along with the increasing residents' mental and physical requirement, leading to increase the importance of air conditioning systems. Therefore, various energy saving methods in buildings have been searched such as air temperature control, system number control, period air conditioning, waste heat recovery, passive energy technology etc.

Generally the term "energy saving is economical" means national level and also represents design and evaluation of a single system, but it is not appropriate when deciding alternatives in early design stage. Non-energy saving system might be economical than energy saving system because of the price of energy source such as electricity, gas and oil. Therefore, when designing a system, it is necessary to decide the most effective one through economic evaluation as well as energy saving method. However, current research[1-5] of energy saving method for economic evaluation is usually based on operating number control of heat source machines, but there is lack of research on economics of non-operating number control.

This research investigates economics of non-operating number control (*NONC*), same load operation number control (*SLONC*) and non-same load operation number control (*NSLONC*) based on six alternative heating · cooling systems, and provides the economic operating number control method as basic design data by LCC (Life Cycle Cost) analysis. Amount of yearly energy use are produced by system simulation of HASP/ACLD/8501 and HASP/ACSS/8502 for medium and large size office buildings in Busan.

2. LCC analysis method and setting up the standard

LCC analysis method can be divided into understanding the economic value of single system and deciding best economic alternative by comparing various systems in early design stage. The latter is common to use. Among the LCC analysis methods such as Present Worth Method, Finish Worth Method and Annual Worth Method, Present Price Method is most commonly used.

Present Price Method looks at all prices at the present point, so present price P considers price increase rate at the maintenance cost and is shown at formula (1).

$$P = I_o + \sum_{p=1}^{n} a_P \frac{(1+e)^P}{(1+i)^P} + \frac{R}{(1+i)^n} \tag{1}$$

If a_P is the same in each year ($a_P = a$), formula (1) can be converted into formula (2).

$$P = I_o + a(PWF) + \frac{R}{(1+i)^n} \tag{2}$$

PWF in formula (2) is Present Worth Factor occurring each year and is shown at formula (3).

$$PWF = \frac{(1+i)^n - 1}{i(1+i)^n} \tag{3}$$

Also, Present Worth Escalation Factor (*PWEF*) with increasing rate such as energy cost, water cost, taxes and insurances is at formula (4).

$$PWEF = \frac{\left\{\left(\frac{1+e}{1+i}\right)^n - 1\right\}}{\left\{1 - \left(\frac{1+i}{1+e}\right)\right\}} \tag{4}$$

Elements in LCC analysis are initial cost, maintenance cost and Retirement cost as shown at formula (1).

Initial cost is the cost for manufacture, transportation, operation and adjustment, and piping and ducting. Maintenance cost is the cost for energy, water · sewage, conservation, and general maintenance fee. General maintenance fee includes costs for labor operation, taxes and insurances. Taxes include property tax, urban planning tax, education tax, acquisition tax and registration tax. Insurance means insurance against loss which includes fire insurance and machine insurance.

Generally, insurance against loss means fire insurance in building services. Retire cost divided into removal cost and disposal cost.

Table 1 Premise condition of taxes and fire premium

Property tax	Inital cost × 0.8 × 0.003 × *PWEF*
City planning tax	Inital cost × 0.8 × 0.002 × *PWEF*
Education tax	Property tax × 0.2
Acquisition tax	Inital cost × 0.8 × 0.02
Registration tax	Inital cost × 0.8 × 0.008
Fire premium	Inital cost × 0.00078 × *PWEF*

General management cost, which is a biggest portion in LCC analysis, uses data from Japan,[6] but there are some differences for taxes and insurances. Therefore, in this paper, these data are rearranged for Korean case shown as Table 1.

3. LCC analysis according to operating number control method

3.1 Sample building and selection of air conditioning system alternatives

Energy use amount for buildings is influenced by building characteristics and equipment characteristics of air conditioning system. Building characteristics are the main elements for heat load. They influence heat load and are various such as total floor area, window area ratio, typical floor area, orientation, number of floor and U-value of the structure. When the simulation for single unit air conditioning system is done, we should consider how much the elements could effect energy use for the building, and then select a sample building. However, when we evaluate various air conditioning systems in a building, equipment characteristics are more important than building characteristics. When we consider economics for an air conditioning system based on annual energy use such as this research, it is more effective to have a sample planed building.

Therefore, in this paper, sample buildings are selected for more selectable elements and materials based on survey of actual condition data[7] for existing offices. The size is bigger than medium which normally has an air conditioning system.

Table 2 Summary of sample buildings

Name of sample building		S-1	S-2
Gross area (m^2)		29,184	12,902
HVAC gross area (m^2)		18,540	6,948
Stories below, above ground		3, 15	2, 5
Window area ratio (%)		35.6	28
Cooling load (kW)	Room	2,284	831
	Equipment	3,067	1,083
Heating load (kW)	Room	1,516	542
	Equipment	2,745	988

Sample buildings are medium size (S-2) and big size (S-1) reinforced concrete structure, facing to the south. Finishing material for S-1 is aluminium complex panel and that of S-2 is granite. U-value of outer wall and inner wall of S-1 are 0.62 $W/m^2 \cdot K$ and 2,44 $W/m^2 \cdot K$, and those for S-2 are 0.65 $W/m^2 \cdot K$ and 3.07 $W/m^2 \cdot K$. U-values of ground floor and roof for S-1 and S-2 are 0.57 $W/m^2 \cdot K$ and 0.49 $W/m^2 \cdot K$. Cooling load and heating load of S-1 and S-2 by maximum heat load calculation for total air conditioning floor area are 3,067 kW · 2,745 kW and 1,083 kW · 988 kW.

Generally, operation method of heat source equipment are divided into non-number control by single operation and number control by multiple separating operation. For number control, it is possible to separate same volume or non-same volume, but normally same volume separating operation is used in the field. There are various number control methods such as the method controlled by heat amount, by temperature difference, by return air temperature and by air volume. Those methods are more effective when adopting individual amount control. In the case of installing multiple heat source machine, individual machine is controled as individual amount rate being the same or priority operating for higher required machine then controlled by the remained one.

Table 3 HVAC system cases

AC system	Constant air volume + Fan coil unit	
HC system	Cooling	Heating
Case-Ⅰ	Electricity centrifugal refrigeration machine	LNG steam boiler
Case-Ⅱ	Electricity centrifugal refrigeration machine	Light oil steam boiler
Case-Ⅲ	LNG absorption refrigeration machine	LNG steam boiler
Case-Ⅳ	Light oil absorption refrigeration machine	Light oil steam boiler
Case-Ⅴ	LNG absorption chiller-heater	
Case-Ⅵ	Light oil absorption chiller-heater	

This research shows six alternative heat source systems by energy sources (electricity, LNG, light oil) for summer and winter. In terms of heat source equipment and pump, operating number control (*ONC*), which includes same load operating number control (*SLONC*) and non-same load operating number control (*NSLONC*), and non-operating number control (*NONC*) by single operation as shown at Table 3. These make eighteen different alternatives.

3.2 System simulation term and annual energy use amount calculation

For the previous sample buildings, annual amount of energy use should be calculated for economical analysis based on air conditioning energy cost, in order to estimate energy costs and analyze economics.

In this research, HASP/ACLD/8501 and HASP/ACSS/8502 are used which are internationally admitted. For system simulation, the amount of equipment are basically used such as Table 4 based on alternatives at Table 3.

Simulation conditions for air conditioning equipment are adiabatic mixing+cooling for summer and adiabatic mixing+heating+recirculated water humidification for winter. Cold water temperature for entrance and exit of freezer is 12℃ and 7℃, and temperature for entrance and exit of freezer water is 37℃ and 32℃. Hot water temperature for space heating is 60℃. Pressure of suction freezer and fire tube steam boiler is 785 kPa.

Air conditioning system is CAV+FCU system and single duct floor unit mode shown as Fig. 1. Air conditioning equipment covers inner zone load, while FCU covers outer zone load of a 5 m depth room. In order to reduce outdoor air load, heat recovery is installed in an air conditioning equipment. Flux in an air conditioning equipment can be controlled by a 3-way valve and that in FCU by a 2-way valve. Indoor conditions are 20℃ and 26℃ of air temperature, and 40% and 50% of humidity in winter and summer. Circulation pump operates

Table 4 Main equipment capacity of systems

Categories		S-1		S-2	
		ONC	*NONC*	*ONC*	*NONC*
AHU of standard story	Cooling coil (kW)	130×1 EA	130×1 EA	145×1 EA	145×1 EA
	Air volume of SF(CMH)	17,270×1 EA	17,270×1 EA	18,520×1 EA	18,520×1 EA
Refrigerator (kW)		1,583×2 sets	3,166×1 set	528×2 sets	1,056×1 set
Cooling tower (kW)		2,041×2 sets (2,722×2 sets)*	4,082×1 set (5,444×1 set)	680×2 sets (907×2 sets)	1,360×1 set (1,814×1 set)
Steam boiler (kW)		1,872×2 sets**	3,744×1 set	748×2 sets	1,496×1 set

*Capacity only Case-Ⅲ to Case-Ⅵ **Capacity only Case-Ⅰ to Case-Ⅳ

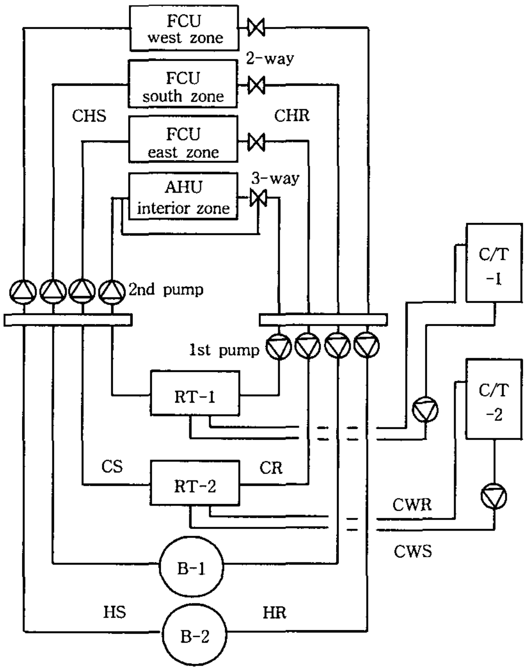

Fig. 1 Flow diagram of operation number system.

1st and 2nd order. For the climatic analysis, Busan region standard meteorological data is used, and cooling and heating periods are from June to September and from December to March. Heat value from lighting is 25 W/m^2, number of people in a room is 0.2 person/m^2 and fresh air import amount is 25 m^3/person·h. Air infiltration amount is calculated by the number of ventilation, which is 0.3 for summer and winter. Heat capacity for the structure is 12.6 kJ/m^3·K. Since the efficiency change of in-

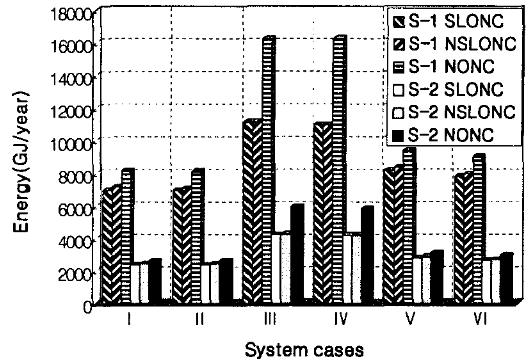

Fig. 2 Energy consumption of system cases.

put data can be collected through considering regular capacity and input, partial load characteristics for an equipment are reflected during the simulation.

Table 5 is annual energy consumption amount calculated through considering air conditioning types, heat source types and types of pumps and pans.

Generally, in order to compare energy amount used by air conditioning system, their units should be the same. In this research, when choosing equipment, lower caloric power is used as 10,500 kJ/kw for electricity, 46,200 kJ/m^3 for LNG and 36,120 kJ/L for light oil. Table 5 shows the conversion to primary energy consumption by energy source.

The results from alternative systems and control types of two sample buildings shown as Fig. 2, are as follows. Centrifugal refrigeration machine + light oil steam boiler (Case-Ⅱ) with same load operating number control system is

Table 5 Source energy for HVAC systems

Categories		Case-Ⅰ		Case-Ⅱ		Case-Ⅲ		Case-Ⅳ		Case-Ⅴ		Case-Ⅵ	
		E (Mw)	*G* (km^3)	*E* (Mw)	*O* (kL)	*E* (Mw)	*G* (km^3)	*E* (Mw)	*O* (kL)	*E* (Mw)	*G* (km^3)	*E* (Mw)	*O* (kL)
S-1	*SLONC*	569.93	22.33	570.74	27.44	407.39	148.96	419.27	182.95	418.75	82.11	419.85	94.61
	NSLONC	585.10	22.45	586.21	27.58	407.39	149.07	419.27	183.08	418.74	86.86	419.84	100.00
	NONC	657.31	27.57	658.41	34.68	495.96	239.41	515.65	301.12	518.41	85.50	520.18	98.62
S-2	*SLONC*	193.34	7.98	193.96	9.83	130.81	62.46	138.98	76.92	135.10	29.85	136.27	34.40
	NSLONC	200.20	7.99	200.82	9.85	130.81	63.52	138.98	76.94	135.10	31.90	136.27	36.72
	NONC	209.76	10.33	210.21	12.64	150.29	95.30	159.76	116.58	158.64	31.42	159.62	36.17

the most energy efficient one, while LNG absorption refrigeration machine+LNG steam boiler system (Case-Ⅲ) with single capacity non-operating number control system uses biggest amount of energy. Non-operating number control, same load operating and non-same load operating number control have 12.4%, 30.2%, 11.7%, and 10%, 29.9%, 9.1% of energy saving against centrifugal refrigeration machine system (Case-Ⅰ, Ⅱ), absorbtion refrigeration machine system (Case-Ⅲ, Ⅳ) and absorbtion chiller-heater system (Case-Ⅴ, Ⅵ). Same load operating number control system reduces 2.6%, 0.3% and 2.6% energy than non-same load operating system.

3.3 LCC analysis and examination

In order to have an accurate economical assessment for alternative systems, this research uses LCC analysis method based on useful life and periodical value. Useful lifes for the equipments are 15 years for boilers and 10 years for pumps regardless the kinds in Korea according to the building regulation, while those for turbo freezer, absorption machine and fire tube steam boiler and pumps are 15 years according to the equipment in Japan.[8]

In this research, useful life of an air conditioning system for the LCC analysis assumes 15 years, and total cost of an air conditioning system for 15 years is calculated using present worth method, which is used when each equipment has a similar useful life. The price for each equipment is based on the price list of May 2002 from a reference company. Preservation cost applies 1.5% of the initial cost. General management cost is based on taxes and fire insurance, and excludes operating labor cost. Unit price for each energy source is

Table 6 Price of source energy (May, 2002)

Kind	Price
Electricity (the general)	Base rate: 7,680 Won/kw Use rate: July, August 96.5 Won/kw, October~March 67.2 Won/kw The others: 62.8 Won/kw
LNG (business)	Heating rate: 496.18 Won/m^3 Cooling rate: 293.83 Won/m^3
Light oil (the general)	655 Won/L
City water (business)	Base rate: 14,500 Won Use rate: 760 Won/m^3 (over 300 m^3), 740 Won/m^3 (100~300 m^3)
Drain (business)	Use rate: 780 Won/m^3 (over 300 m^3), 750 Won/m^3 (100~300 m^3)

Table 7 Initial cost of system cases (Unit: 1,000 Won)

Categories		S-1						S-2					
		Case-Ⅰ	Case-Ⅱ	Case-Ⅲ	Case-Ⅳ	Case-Ⅴ	Case-Ⅵ	Case-Ⅰ	Case-Ⅱ	Case-Ⅲ	Case-Ⅳ	Case-Ⅴ	Case-Ⅵ
AHU+FCU+Total heat exchanger	*ONC*	485374	485374	485374	485374	485374	485374	162423	162423	162423	162423	162423	162423
	NONC	485374	485374	485374	485374	485374	485374	162423	162423	162423	162423	162423	162423
Refrigerator+Cooling tower	*ONC*	282100	282100	428580	428580	479100	479100	168920	168920	190240	190240	216440	216440
	NONC	238080	238080	354000	354000	377200	377200	110080	110080	146400	146400	159400	159400
Steam boiler	*ONC*	100800	91200	100800	91200	-	-	72000	61800	72000	61800	-	-
	NONC	73800	68700	73800	68700	-	-	46400	39200	46400	39200	-	-
Pumps+Piping	*ONC*	139982	139982	170724	170724	170724	170724	49000	49000	58728	58728	58728	58728
	NONC	175800	175800	209452	209452	209452	209452	56533	56533	66494	66494	66494	66494
Total	*ONC*	1008256	998656	1185478	1175878	1135198	1135198	452343	442143	483391	473191	437591	437591
	NONC	973054	967954	1122626	1117526	1072026	1072026	375436	368236	421717	414517	388317	388317

Table 8 Present worth to fifteen years of useful life (Unit: 1,000 Won)

Categories		S-1						S-2					
		Case-Ⅰ	Case-Ⅱ	Case-Ⅲ	Case-Ⅳ	Case-Ⅴ	Case-Ⅵ	Case-Ⅰ	Case-Ⅱ	Case-Ⅲ	Case-Ⅳ	Case-Ⅴ	Case-Ⅵ
Initial cost	*SLONC*	1008256	998656	1185478	1175878	1135198	1135198	452343	442143	483391	473191	437591	437591
	NSLONC	1008256	998656	1185478	1175878	1135198	1135198	452343	442143	483391	473191	437591	437591
	NONC	973054	967954	1122626	1117526	1072026	1072026	375436	368236	421717	414517	388317	388317
Energy cost	*SLONC*	2521611	2804452	1743703	3958133	1522043	2618600	832524	934316	594494	1534973	482877	885000
	NSLONC	2551079	2835312	1744390	3960213	1539910	2700989	845268	947198	601068	1535172	490559	920429
	NONC	2681823	3042986	2236264	5924940	1701077	2836356	854414	984359	753208	2175511	532826	951060
City water & Drain cost	*SLONC*	64051	64051	57762	58361	94392	90574	22824	22824	20486	20743	33956	32498
	NSLONC	64837	64837	57912	58605	97274	93138	23143	23143	20542	20818	35191	33583
	NONC	67383	67383	60514	61188	96563	92838	23297	23297	20958	21234	34274	32870
Maintenance cost	*SLONC*	102993	102012	121096	120115	115960	115960	46206	45164	49378	48336	44699	44699
	NSLONC	102993	102012	121096	120115	115960	115960	46206	45164	49378	48336	44699	44699
	NONC	99397	98876	114676	114155	109507	109507	38350	37615	43078	42342	39666	39666
Management cost	*SLONC*	65998	65370	77599	76971	74308	74308	29609	28941	31641	30974	28643	28643
	NSLONC	65998	65370	77599	76971	74308	74308	29609	28941	31641	30974	28643	28643
	NONC	63694	63360	73485	73151	70173	70173	24574	24104	27604	27133	25418	25418
Total	*SLONC*	3762911	4034543	3185640	5389459	2941902	4034640	1383508	1473391	1179392	2108218	1027768	1428433
	NSLONC	3793165	4066189	3186477	5391783	2962652	4119594	1396571	1486591	1186022	2108492	1036685	1464947
	NONC	3885352	4240561	3607566	7290961	3049347	4180901	1316074	1437612	1266567	2680739	1020502	1437332

on Table 6. Interest rate is used 12%, which is a mean interest rate of construction loan between 1984 and 2001. Price increase rate is 10%, water and sewerage cost increase rate is 9% which is mean value between 1992 and 2001, tax and insurance increase rate is 3%, energy cost increase rate is 15%, 8% and 18%[2] which is mean increase rate of electricity, LNG and light oil between 1980 and 2001.

Table 7 shows initial cost details of each sample building alternative. Electricity centrifugal refrigeration machine+light oil steam boiler system (Case-Ⅱ) is the most economical among them. Initial cost for number control is 3%, 5% and 6% higher than non-number control, in centrifugal refrigeration machine method (Case-Ⅰ, Ⅱ), absorption refrigeration machine method (Case-Ⅲ, Ⅳ) and absorption chiller-heater method (Case-Ⅴ, Ⅵ) in the case of S-1, and 17%, 12%, 11% in the case of S-2. Which is higher than S-1.

Using above standards, the results of present price for 15 useful life of each alternative are shown at Table 8.

Gas absorption chiller-heater method (Case-Ⅴ) is most economical and the price of light oil absorption refrigeration machine+light oil steam boiler method (Case-Ⅳ) is the highest. In terms of the control system, same load operating number control is the most economical followed by non-same load operating number control and non-operating number control. Centrifugal refrigeration machine method, absorption machine method and absorption chiller-heater method are 0.9%, 0.2% and 1.6% economical than non-same load operating method.

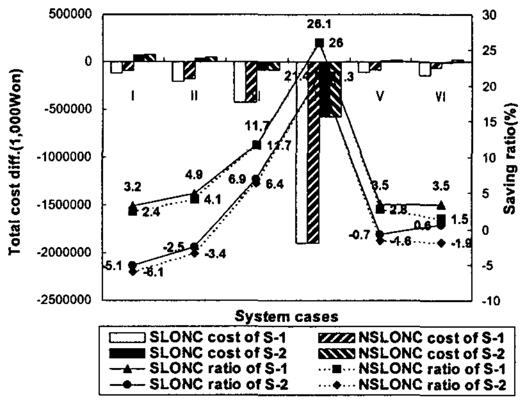

Fig. 3 Total present worth differentials and saving ratio of sample buildings between *ONC* and *NONC*.

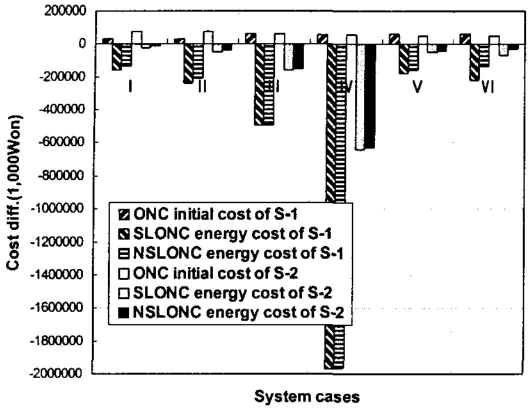

Fig. 4 Initial cost and energy cost differentials of system cases between *ONC* and *NONC.*

Figure 3 shows total present price difference as well as the saving rate between non-operating number control and number control. It shows that it is more economical when adopting number control for a big building (S-1). For a medium size building (S-2), number control system is more economical for absorption cold and hot water system, but non-number control type is more economical for electricity centrifugal refrigeration machine (Case- I , II) and LNG absorption chiller-heater, which are commonly used nowadays. This means that the result is different according to the size of the building. The reason seems to be that energy cost rate is less than the initial cost difference for number control and non-number control shown at Fig. 4.

Therefore, number control system should be encouraged for energy saving, but we should consider more carefully when adapting number control system of heat source equipment during the early design stage of an air conditioning system for economical consideration.

4. Conclusions

This research investigates economics of number control method based on six alternative heat source systems by life cycle cost analysis for 15 years of useful life. The results are as follows:

(1) For energy saving, centrifugal refrigeration machine + light oil steam boiler method with same load operating number control method is the most energy efficiency, while LPG absorption refrigeration machine + LNG steam boiler method with same amount non-number control method requires the highest energy use. Same load operating and non-same load operating number control method save 12.4%, 30.2%, 11.7 % and 10%, 29.9%, 9.1% energy for centrifugal refrigeration machine method (Case- I , II), absorption refrigeration machine method (Case-III, IV) and absorption chiller-heater method (Case-V, VI), against non-number control method. Same load operating number control method saves 2.6%, 0.3%, 2.6% compared to non-same load operating method.

(2) In terms of initial cost, electricity centrifugal refrigeration machine + light oil steam boiler is most economical. Number control method has 3%, 5%, 6% higher for centrifugal refrigeration machine, absorption refrigeration machine method, and absorption chiller-heater method than non-number control method for a big building, while 17%, 12%, 11% increase for a medium size building.

(3) Same load operating number control is the most economical on present worth for 15 useful life buildings. Number control is more economical for all alternatives for a big sample building. However while number control is more economical for LNG and light oil absorption refrigeration machine and light oil absorption chiller-heater method for a medium size sample building, non-number control system is more economical for electricity centrifugal refrigeration machine and LNG absorption chiller-heater method. Therefore, more careful examination is required when adopting an number control system for heat source equipment when designing an air conditioning system.

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