

A Study on Economical Efficiency Evaluation Method of Sustainable Building Technologies Using Life Cycle Cost Analysis

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ABSTRACT: Recently, the sustainable buildings are stirring up great interests as the efficient energy saving and reduction of CO₂ emission plan for the preservation of earth environment. Sustainable building technologies, which realizes sustainable buildings, generally shares the life cycle with buildings, and saves operation costs by reducing energy consumption and CO₂ emission that are occurring at the operation stage of buildings. Accordingly, the economical efficiency evaluation of sustainable building technologies shall be analyzed in proportion to the saved costs through environment performance of sustainable building technologies during the life cycle of building. As this study presents the concrete evaluation method of economical efficiency using LCC Analysis, in which environment cost is considered, it is expected that the sustainable building technologies may be utilized at the time point of building design.

Keywords: Sustainable Building Technologies, Environment Cost, LCC Analysis
CO₂ Emission Reduction, Energy Saving

1. INTRODUCTION

1.1 Background and purpose of study

Recently, amid energy consumption and emission quantity of green house gas in the field of building industry are forming even higher part than any other industry¹, sustainable building technologies is able to

save energy and reduce CO₂ emission by improving energy efficiency. However, sustainable building technologies are undervalued in aspects of application due to occurrence of excessive investment. Accordingly, economical efficiency evaluation of sustainable building technologies shall be analyzed on basis of cost reduction derived from energy saving and CO₂ emission during the operation period.

As this study presents concrete evaluation method of economical efficiency using LCC

¹ IEA. 2008. Promoting Energy Efficiency Investments

Analysis, in which environment cost is considered, it is designed to provide the data that may be used in application of sustainable building technologies at the time point of building design.

1.2 Scope and method of study

In this study LCC Analysis was presented, in which environment cost was taken into account by means of economical efficiency evaluation that is suitable for sustainable building technologies through examination of various economical efficiency evaluation methods and sustainable building technologies. As for the environmental performance evaluation of sustainable building technologies, reduced quantity of energy and CO₂ emission was calculated through performance evaluation of sustainable building technologies. And as for economical efficiency evaluation, LCC Analysis was carried out after conversion of quantity of energy consumption and CO₂ emission into environment cost and applying interest rate, inflation rate and price rising rate. As for sensitivity analysis of environment cost, LCC Analysis was carried out in accordance with change in energy price and price of CO₂ emission right.

2. Examination of economical efficiency analysis of sustainable building technologies

2.1 Economical efficiency evaluation method

As for two economical efficiency evaluation methods, one is the method in which time value of money is considered, and the other is the method in which time value of money is not considered. It must be rational that economical efficiency evaluation for buildings with long life cycle shall include time value of money in the analysis method. Characteristics of typical evaluation method among economical efficiency evaluation methods, in which

time value of money is considered, are presented in Table 2.1

Table I: Comparison of economical efficiency evaluation²

Assessment Method	Characteristic
Discounted Payback Period	Though the payback period is decided in consideration of time value of assets, the money flow after completion of payback is not considered.
Net Present Value	The relative merits and demerits of counter plans are distinguished easily by calculating future income and expense are calculated on the basis of current value.
Saving to Investment Ratio	It takes a lot of time for calculation, and only the existence or non-existence of economical efficiency can be decided according to the value of rate of return
Benefit/Cost Ratio	The value is looked into in consideration of time value of assets, but it is not considered what occurs after the time point of profit occurrence.
Life Cycle Cost Analysis	This is suitable for the long-term and large amount of investment because it is evaluated after the total cost is converted equivalently to the value of reference time in the economical life cycle, and it is possible to define the field where operation cost can be reduced due to the detailed analysis of current operation cost in assets.

2.2 Economical efficiency evaluation method of sustainable building technologies

Sustainable building technologies shares life cycle with buildings, and it realizes environment performance during the life cycle of buildings. Most sustainable building technologies reduce operation cost effectively by decreasing energy consumption and CO₂ emission consumed at buildings. With recent rapid increase of international oil prices and reinforcement of EU Convention on Climate Change, increase of energy price and CO₂ emission right is being actualized.³ Accordingly, energy cost and environment-related cost became to have significance in economical efficiency evaluation of buildings. So, as for LCC analysis of sustainable building technologies, economical efficiency shall be evaluated as environment performance is converted into environment cost such as, energy cost and CO₂ emission cost.

² Lee, G. H, et al. 2002. A Study on Development of Building Evaluation Program Considering Environmental and Economic Performance. pp8-41

³ Financial Times, 2008, Green policies push up energy prices

3. Cases of LCC Analysis on sustainable building technologies

Figure 2.1 presents the LCC analysis procedure of sustainable building technologies in which environment cost is considered, which was proposed in this study

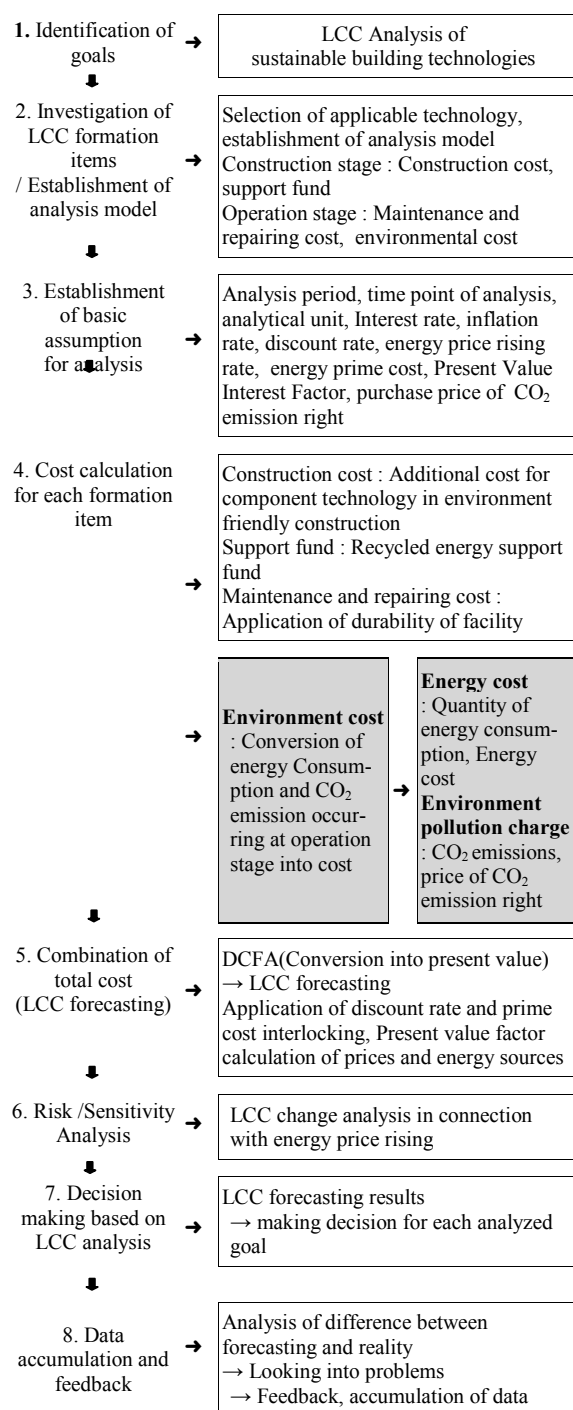


Figure 1: LCC Analysis procedure of

sustainable building technologies

3.1 Establishment of analysis standard

Analysis standard for LCC analysis of sustainable building technologies is presented in Table 3.1

Table II: Outline of analysis standard

Technology Type	Solar Hot Water System Geothermal Heating and Cooling System
Building Type	Multi-family Residential Building
Location	Asan city, Chungaheongnam-do
Household Number	72 Households
Stories number	18 stories
Unit Household Area	Private 119.4 m ² , Public 26.2 m ²
Heating and Cooling Type	Heating : Boiler Cooling : Multi Air-conditioner

3.2 Establishment of basic assumption

Analysis variables for LCC analysis of sustainable building technologies are presented in Table 3.3. Discount rate was calculated using average value of interest rate during last ten years, price rising rate and energy price rising rate. As for interest rate, interest rate of 5-year treasury bond in consideration of price rising rate, and Composite Consumer Price Index was used on behalf of price rising rate in order to reflect energy price rising. As for energy price, price rising rate of electric power and gas was used in apartment.

Table III: Analysis variables for LCC Analysis of sustainable building technologies

Analysis variables	Contents of Standard
Period of analysis	40 years
Time point of analysis	Time point of initial use of buildings
Discount Rate	Insert Rate : 6.68 % Price rising rate : 2.93% Nominal Discount Rate : 3.64% Electricity Price rising rate : 0.91% Electricity Escalation : 5.72% City water Price rising rate : 9.68% City water Escalation : -2.74% City gas Price rising rate : 10.75% City gas Escalation : -3.68%

3.3 Cost calculation for each formation items

Cost items for LCC analysis of sustainable building technologies are

presented in Fig. 3.3. In this study, environment cost items were established in consideration of environmental performance of sustainable building technologies

Const- ruction stage	Design cost	
	Construction cost : Equipment cost, Installation cost, Construction/Public work cost, Labor cost	
	Support fund : Energy recycling facility support fun	
Opera- tion stage	Maintenance and repairing cost : Checking cost, Replacement cost	
	Environ- ment cost	Energy cost : Environmental performance evaluation of sustainable building technologies , Calculation of energy consumption quantity
		Environment pollution charge : Calculation of CO ₂ emissions according to energy consumption quantity
Disposal stage	Removal cost	
	Remain value	

Figure 2:Cost items for LCC Analysis of sustainable building technologies

CO₂ emissions shall be calculated in order to calculate environment pollution charge. However, currently any proper CO₂ emission factor is not calculated in Korea. Accordingly, in case of fossil fuel the carbon emission factor established by IPCC⁴ has been used, and in case of electricity field the 0.424(CO₂ton/MWh) of CO₂ emission factor announced by Korea Energy Economics Institute⁵ in the year 2005 has been used. Calculation method of CO₂ emissions was divided into the method for fossil fuel and the method for electricity, and CO₂ emissions and environment pollution charge were calculated as follows.

1) CO₂ emissions (TCO₂) of fossil fuel

= TOE(consumption quantity of fuel × net calorific value/10⁷)
× carbon emission factor (IPCC factor) × CO₂ conversion factor(44/12)

2) CO₂ emissions of (TCO₂) of electricity

= electricity consumption × CO₂ emission factor(0.424 CO₂ton/MWh)

⁴ IPCC. 2006. 2006 IPCC Guideline for National Greenhouse Gas Inventories

⁵ Korea Energy Economics Institute. 2005. A Study on the Basic Research for Preparation of the 3rd National Communication of Republic Korea under the United Nations Framework Convention on Climate Change

Table IV: Computation of environment pollution charge

Energy Type	Energy Consumption	CO ₂ Emissions				Environment pollution charge	
		TOE	Carbon Emission Factors	CO ₂ Emission /Conversion Factors	TCO ₂	Emission Right Price (Won/ton)	Unit Environment pollution charge (Won /Unit)
Elec	1KWh	-	-	0.424	0.000424	38,577.33	16.36
Gas	1Nm ³	0.000955	0.637	44/12	0.002231	38,577.33	86.06

1TOE = calorific value/ ton of crude oil = 10⁷Kcal

* In case of CO₂ emission calculation

: Advised standard of IPCC - Net calorific value applied

TOE = Energy Consumption × Net Caloric Value / 10⁷

TC = TOE × Carbon Emission Factors (IPCC Factors)

TCO₂ = TC × CO₂ Conversion Factors (44/12)

CO₂ Emission Right Price (basic date 2008.5.1)

: EUA Trading Price(24.75\$) × Exchange Rate(1,558.68 Won)

Environment pollution charge

= Energy Consumption × Unit Environment pollution charge

3.4 Environment performance of sustainable building technologies

3.4.1 Solar hot water system

In case of facing due south, there were 40 households among 72 households at 10 stories of mid and top part of buildings where evacuated glass tubes solar collectors could be installed. At the objects of this study, Hot water production of solar hot water system was 194ℓ per day. On assumption that there were 4 people in a unit household, it could be estimated that required hot water per day was 300ℓ, so dependence rate of solar hot water system was about 64.8%.

Like contents in Table 3.3, solar hot water system could reduce 26.9ton of CO₂ per year by reducing 32,020.2m³ of gas, though it caused 11,680.0kWh of electricity to be used more a year.

Table V: Result of environment performance evaluation of solar hot water system (on the basis of a year)

Division		Application	Non-application
Electricity consumption and CO ₂ emission	Electricity (kwh)	11,680.0	0
	CO ₂ calculation factor	0.000424	
	CO ₂ (ton)	5.0	0
Gas consumption and CO ₂ emission	Gas(m ³)	25,525.9	39,839.8
	CO ₂ calculation factor	0.002231	
	CO ₂ (ton)	57.0	88.9
Energy saving and CO ₂ reduction	Electricity (kwh)	-11,680.0	
	Gas(m ³)	+32,020.2	
	CO ₂ (ton)	+26.9	

3.4.2 Geothermal heating and cooling system

As for geothermal heating and cooling system, annual energy consumption for air conditioning was computed through computer simulation using eQUEST 3.6. Electricity consumption was increased by 30.29% per year due to cooling-heating system, but gas consumption was decreased by 100%.

Like the contents in Table 3.4, solar hot water system could reduce 45.7ton of CO₂ per year by reducing 55,282.3 m³ of gas, though it caused 182,876.3kWh of electricity to be used more a year.

Table VI: Result of environment performance evaluation of geothermal heating and cooling system (on the basis of a year)

Division		Application	Non-application
Electricity consumption and CO ₂ emission	Electricity (kwh)	292,653.9	109,777.6
	CO ₂ calculation factor	0.000424	
	CO ₂ (ton)	124.1	46.5
Gas consumption and CO ₂ emission	Gas(m ³)	0	55,282.3
	CO ₂ calculation factor	0.002231	
	CO ₂ (ton)	0	123.3
Energy saving and CO ₂ reduction	Electricity (kwh)	-182,876.3	
	Gas(m ³)	+55,282.3	
	CO ₂ (ton)	+45.7	

3.5 Economical efficiency evaluation of sustainable building technologies

3.5.1 Solar hot water system

Construction cost for solar hot water system was calculated as additional cost occurring in the 40 households at 10 stories of mid and top part of buildings where the system was installed, and support fund for renewable energy was established as 50% of construction cost.⁶ And in case of construction cost to which solar hot water system was not applied, cost for rails was computed replacing solar collectors. Replacement cost was calculated based on

the 15 years of durability of hot water boiler, but it was excluded because the cost was occurring in common.

As it is presented in Table 3.5, in case of solar hot water system application, ₩642,081,000 of earnings would occur for 40 years, and it was estimated that cost retrieve would be possible in 15 years after application.

Table VII: LCC computation result of solar hot water system (unit : ₩1,000)

Item				Present value factor	Application		Non-application	
					Cost	Present value	Cost	Present value
Construction Stage	Construction Cost	Equipment cost		1.00	171,840	171,840	-	-
		Installation cost		1.00	104,000	104,000	-	-
		Labor cost		1.00	34,000	34,000	-	-
		Total				309,840	2,640	2,640
	Support fund			1.00	154,920	154,920	0	0
	Grand total					154,920		2,640
Operation Stage	Maintenance and repairing cost	Checking cost	Annual	20.89	3,098	64,715	0	0
		Replacement cost	3years	6.64	4,000	26,551	0	0
			20years	0.49	174,240	85,167	0	0
		Total				176,433	0	0
	Environment cost	energy cost	Elec	15.60	612	9,548	0	0
			Gas	94.55	16,120	1,524,149	25,160	2,378,822
			Total			1,533,700	25,160	2,378,822
		Environment pollution charge	Elec	15.60	191	2,980	0	0
			Gas	94.55	2,427	229,422	3,787	358,072
			Total			232,403	3,787	358,072
		Total				1,766,100		2,736,893
	Grand total					1,942,533		2,736,893
	LCC						2,097,453	

3.5.2 Geothermal heating and cooling system

As for construction cost of geothermal heating and cooling system, the cost was established with 4.1 million per 1RT, which was standard of governmental support fund, and support fund for renewable energy was established as 50 % of construction cost.⁷ Replacement cost for geothermal cooling-heating system was calculated as durability of heat pump was established to be 25 years, and in case the system was not installed, the cost was calculated as the durability of

⁶ www.knrec.or.kr(Korea New&Renewable Energy Center)

⁷ ibid

boiler and multi air conditioner was established to be 15 years.

As it appears in Table 3.5, in case geothermal cooling-heating system was installed, ₩2,962,072,000 of earnings would occur for 40 years, and it was estimated that the cost retrieve would be possible in 12 years after application.

Table VIII: LCC computation result of geothermal heating and cooling system (unit: ₩1,000)

Item			Present value factor	Application		Non-application	
				Cost	Present value	Cost	Present value
Construction Stage	Construction Cost	Equipment cost	1.00	-	-	-	-
		Installation cost	1.00	-	-	-	-
		Labor cost	1.00	-	-	-	-
		Total		1,299,700	1,299,700	275,904	275,904
	Support fund		1.00	649,850	649,850	0	0
	Grand total			649,850	649,850		275,904
Operation Stage	Maintenance and repairing cost	Checking cost	Annual	20.89	0	0	0
		Replacement cost	15year	0.93	0	275,904	255,574
			25year	0.41	519,880	212,476	0
		Total			212,476		255,574
	Environment cost	energy cost	Elec	15.60	49,386	770,416	20,102
			Gas	94.55	0	0	34,912
			Total			766,056	3,614,493
		Environment pollution charge	Elec	15.60	4,874	76,036	1,796
			Gas	94.55	0	0	5,250
			Total			76,036	524,396
		Total				846,452	4,139,372
	Grand total				1,058,929		4,394,946
	LCC				1,708,778		4,670,850

3.6 Sensitivity analysis of environmental cost

The charges related to environment is increasing due to intensifying regulations of convention on climate change, and it is forecasted that energy price and price of CO₂ emission right will continuously and sharply rise as international crude oil price is rapidly rising. Accordingly, economical efficiency evaluation of sustainable building technologies shall be analyzed in consideration of real rising rate of environmental cost.

As for analysis of change in LCC according to rising of environmental cost, the counter plan 1 and 2 were established and compared, for one case with application

and the other without application respectively. In the counter plan 1, which was the standard of change in LCC, the LCC value evaluated previously was used. And in the counter plan 2, the LCC was calculated, applying the energy price and the purchase price of CO₂ emission right, on which 100% of rising rate of international oil price and purchase price of CO₂ emission right during the last one year(2007. 6~ 2008. 5). As for the counter plan 2, if the rising rate of 78.49% of the international oil price⁸ and the rising rate of 23.68% of purchase price of CO₂ emission right⁹ are reflected on the domestic energy price, the rising rate of 3.47% in electricity, 40.94%, in gas and 23.68% in purchase price of CO₂ emission right may be assumed.

3.6.1 Solar hot water system

In case of solar hot water system, LCC of the counter plan 2 increased by 33.78% based on the counter plan 1, and in case the system was not applied it rose by 40.38%. So, earnings that is expected to derived from installation of solar hot water system appeared to be ₩629,886,000 in the counter plan 1 and ₩1,021,410,000 in the counter plan 2, so it rose by 62.16%. It is assumed that the reason was that in case solar hot water system was not applied gas consumption, which had high rising rate, was occurring more.

3.6.2 Geothermal heating and cooling system

In case of geothermal heating and cooling system, the LCC of the counter plan 2 increased by 2.63% based on the counter plan 1, and in case the system was not applied it rose by 31.83%. So, the earnings that is expected to derived from installation of geothermal heating and cooling system appeared to be ₩2,962,072,000 in the counter plan 1 and ₩4,403,896,000 in the

⁸ www.opec.org

⁹ www.pointcarbon.com

counter plan 2, so it rose by 48.68%. It is assumed that the reason was that geothermal heating and cooling system was using electricity as energy source, which had low price rising rate, and in case the system was not used, household was using gas as energy source as well as electricity, which had high price rising rate.

3.7 Characteristics of domestic energy price in Korea

When environment performance, LCC analysis and sensibility analysis of environmental cost for economical efficiency evaluation are integrated, it is found out that gas consumption had bigger influence than electricity consumption in every evaluation. This is because CO₂ emission factor of gas was higher than that of electricity, and price rising rate of gas was three times higher than price rising rate of general commodities. On the other hand, CO₂ emission factor of electricity of Korea was very low by obtaining 39.59% of domestic electricity production from atomic power plants. And price rising rate of electricity was very stable taking place under price rising rate of general commodities by obtaining 75.64% of electricity production from atomic power and coal, which is produced in Korea.¹⁰ At present, it is estimated that reduction gas consumption is effective in case sustainable building technologies is applied in Korea. However, it is necessary to carry out the clear environment influence evaluation as to atomic power in the field of electric power, and the influence of recycling energy and LNG on the electricity charge shall be analyzed because they are playing bigger and bigger roles in electric power market.

4. CONCLUSION

In this study, the economical efficiency evaluation method of sustainable building technologies using LCC analysis was presented. Presenting the LCC analysis procedure of sustainable building technologies in which the environment cost was considered and showing LCC analysis method practically, this study was designed to help designers understand easily and utilize it at the planning stage. Economical efficiency evaluation method of sustainable building technologies presented in this study and result of evaluation are as follows.

- 1) Environmental cost caused by energy consumption and CO₂ emission shall be considered in LCC Analysis of sustainable building technologies
- 2) Main variables were established as energy price was reflected, in order to carry out LCC Analysis of sustainable building technologies, where environment cost was considered.
- 3) Environment cost items were established in order to carry out LCC Analysis of sustainable building technology, where environment cost was considered. Environmental cost was composed of energy cost and environment pollution charges. Calculation of environment cost need energy consumption quantity and CO₂ emissions calculated from performance assessment of sustainable building technologies
- 4) As for environment performance evaluation result of solar hot water system and geothermal heating and cooling system, reduction of energy consumption during the operation period led to decrease of CO₂ emission. According to LCC analysis, initial investment cost was increasing, but economical efficiency was secured during the analysis period by reducing environment cost.
- 5) As for sensitivity analysis result, it was identified that gas had the highest sensitivity among the environmental costs. So, in case

¹⁰ www.keei.re.kr (Korea Energy Economics Institute)

rapid rising of energy price continues, strategy in which gas consumption is reduced is required.

In this study economical efficiency evaluation was analyzed centering on construction cost in construction stage and maintenance and repairing cost and environment cost in operation stage. However, in order to get more clearly economical efficiency evaluation, all cost during the life time shall be considered. In the future studies, analysis of variables as to special situations related to energy sources and trend of main equipment shall be analyzed.

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