Evaluation of the environmental and economic performance of sustainable building technologies for apartment houses in Korea

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Abstract

This study aims to evaluate the economic and environmental performance of sustainable building technologies applicable to multi-family residential buildings in Korea. The technologies investigated for the study include; 'exterior insulation', the 'double envelope system', the 'floor radiant heating/cooling system', the 'solar hot-water system' and the 'photovoltaic system'. The energy performance of each technology was evaluated using "EnergyPlus" as the simulation program. A sensitivity analysis was conducted in order to determine the relative influence of each technology in terms of energy consumption reduction in a sample building. A life-cycle cost analysis of a sample building designed with conventional technologies was also conducted to compare the result with the sustainable building technologies. The result of the study indicates that with the sustainable building technologies, although the initial investment costs are higher than conventional technologies, are more economical in terms of life-cycle cost due to the reduction of energy and environmental costs.

Keywords: sustainable technologies, apartment houses, energy analysis, CO_2 emission reduction, life cycle cost analysis, CO_2 emission right price.

1 Introduction

Unprecedented global warming in recent days has led to a great concern worldwide for the reduction of CO_2 emissions. In Korea, the housing sector constitutes about 10% of total CO_2 emissions related to energy consumption in Korea. Since apartment houses account for 85% [1] of the housing market in Korea, in order to effectively reduce CO_2 emissions in the building sector,

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apartment houses should be the first place to be considered. However, since there are few research data related to CO_2 emission performance and the economic feasibility of applicable building strategies, it is difficult for architects and engineers to determine viable solutions in building design and construction. The objectives of the study are to analyze the performance of sustainable building technologies and to provide designers and engineers with reliable technical data in terms of CO_2 emission reduction economic feasibility.

2 Research scope and methodology

A sample building, a typical 18-story apartment building with 72 households in Asan City, Korea, was selected for the study. The actual energy consumption data of the building with relevant weather data and user patterns was collected for one year from October 2006 to September 2007. At the same time, the energy performance of the sample building was simulated with the "EnergyPlus" program, and the result was compared with the actual consumption data. Afterwards, sustainable building technologies were applied to the building and the energy performances were analyzed. The energy consumption data were then converted to CO_2 emissions data by using the carbon emission factor (CEF) of various fuel resources. Finally, life cycle analyses were conducted considering the energy cost and the environmental cost.

3 Sustainable technologies applicable to apartment houses

There are numerous sustainable technologies available for building applications. In this study, however, the technologies being developed for apartment buildings as a part of the Korean government's "Low Energy Sustainable Apartment

Table 1: Characteristics of sustainable technologies.

Technology	Applied Location	Energy Serve	Type/Size
Exterior Insulation	Exterior Wall	Heating/Cooling	THK200mm dry Construction type
Double Envelope System	South Window	Heating/Cooling Ventilation	box-shape double envelope, glazing U-value: 2W/㎡K
Radiant Floor Heating/Cooling	Existing Floor Heating Coil	Heating/Cooling	refrigerator capacity: 3.6RT/house, COP 3.0
Photovoltaic	Roof	Electricity	144 panels(1,584mm*787mm, 170w each), total area of array: 180㎡
Solar Thermal	Balcony Guard Rail (Evacuated Tube)	Heating Hot water	40 houses in upper 10 floors (9~18F), 12㎡ in each house, Avg. radiation: 3,500kcal/㎡.day
Geothermal	Underground	Heating/Cooling	vertical closed circuit type heat pump, 100RT each building

Program" [2] were selected. They are considered as viable alternatives in terms of the state of art of available technology, and reflect the unique characteristics of Korean houses. These technologies are listed in Table 1.

4 Analysis of CO_2 emission reduction performance

4.1 Simulation tool

In order to estimate energy performance, the 'EnergyPlus' program was selected as a simulation tool. The program is based on DOE-2.1E and BLAST, and is useful in modeling building heating, cooling, lighting, ventilating, and other energy flows. The program includes many innovative simulation capabilities, such as time steps of less than an hour, modular systems and plant integrated with heat balance-based zone simulation, multi-zone air flow, thermal comfort, and renewable energy systems such as photovoltaics [3].

4.2 Energy saving effects of sustainable technologies

Table 2 shows the energy saving effects of sustainable technologies when they were applied to the sample building. Negative(-) values indicate the reduction of energy consumption when a technology was applied to the building. It was found that the magnitude of reduction in greater as the following order; *geothermal system> double envelop system > exterior insulation> solar thermal system > photovoltaic system> radiant floor heating/cooling system.* The increase of electricity consumption in geothermal, solar thermal and double envelope is due to the increased fan and pump operation for the technologies.

Table 2: Energy saving effects of sustainable technologies.

	Natural Gas (LNG) Saving (MWh)			Electricity Saving (MWh)				Total (MWh)	Order
	Heating	Hot Water	Total	Cooling	Individual elec. Use	Collective elec. use	Total		
Exterior Insulation	-174.1	-	-174.1	-4.6	-	-	-4.6	-178.7	3
Double Envelope	-260.6	-	-260.6	-48.7	+5.3	-	-43.4	-304.0	2
Radiant Heating/Cooling	-	-	-	-7.1	-	-	-7.16	-7.16	6
Solar Thermal	-	-175.6	-175.6	-	+11.7	-	+11.7	-163.9	4
Photovoltaic	-	-	-	-	-	-28.9	-28.9	-28.95	5
Geothermal	-659.7	-	-659.7	-	+207.9	-	+207.9	-451.8	1

4.3 CO_2 emission reduction of sustainable technologies

The amount of CO_2 emissions may be different from the amount of energy consumption, as CO_2 emission factors between various fuels are different from one another. In this study, the value of 0.002231 ton/Nm^3 [4] suggested by the

IPCC (Intergovernmental Panel on Climate Change) was used for natural gas (LNG). For electricity, the value of 0.000424 ton/kwh was applied, which was established by the KEEI (Korea Energy Economics Institute) [5].

Table 3: CO_2 emission reduction of sustainable technologies.

	CO_2 emission reduction from Natural Gas(LNG), ton			CO_2 emission reduction from Electricity, ton				Total	Order
	heating	hot water	Sub total	cooling	Individual elec. use	Collective elec. use	Sub total		
Exterior Insulation	-31.7	-	-31.7	-1.9	-	-	-1.9	-33.6	2
Double Envelope	-47.3	-	-47.3	-20.6	+2.2	-	-18.4	-65.7	1
Radiant Heating/Cooling	-	-	-	-4.9	-	-	-4.9	-4.9	6
Solar Thermal	-	-31.9	-31.9	-	+5	-	+5	-26.9	4
Photovoltaic	-	-	-	-	-	-12.3	-12.3	-12.3	5
Geothermal	-120.0	-	-120.0	-	+88.1	-	+88.1	-31.9	3

Table 3 shows the amount of CO_2 emission reduction of sustainable technologies when they were applied to the sample building. Among the sustainable technologies, *double envelope* was found to have the best performance in CO_2 emission reduction, followed by *exterior insulation, geothermal, solar thermal, photovoltaic and radiant heating/cooling* in descending order. For the geothermal system, although energy reduction potential is the greatest, the effect of CO_2 emission reduction has decreased because of the increased electricity consumption for the increased pump operation power.

5 Analysis of economic performance

5.1 Life cycle cost analysis method

Since sustainable building technology shares its life cycle with buildings and realizes environmental performance during the life cycle of buildings, life cycle cost analysis was performed to identify the economic feasibility of sustainable technologies. In the analysis, energy cost and $CO_{2\ emission}$ trading cost during the life cycle of the building were emphasized.

The values of economic variables such as the discount rate, the inflation rate, energy price escalation, etc. were set as the average values during the last ten years in the Korean market. The life span of the analysis was set to be 40 years. The initial costs of installing systems were supplied from corresponding manufacturers, while the government incentive for renewable technologies were set to be 50% of the installation cost. The $CO_{2\ emission}$ trading cost was estimated based on IPCC practice, which at the time of the study was about 25 Euros per ton (Yeom [6]). The life cycle cost analysis based on these variables well represents the current trend and situation in Korea. However, the kaleidoscopic nature of the global economic market and energy situation may not secure any definite analysis for future perspectives.

5.2 Economic assessment of sustainable technologies

Table 4 presents the result of the life cycle cost analysis of sustainable technologies. The negative(-) sign indicates the additional cost that occurs when the technology is applied to the building, compared to the case without such application. The positive(+) sign, on the other hand, represents the financial gain that can be achieved, compared to the case without technology application. The result indicates that the *geothermal system* has the best performance in life cycle cost saving, followed by *double envelope, solar thermal, exterior insulation and radiant heating/cooling* in descending order. However, the *photovoltaic system* shows a negative value, meaning that the total life cycle cost of the system is greater than that of a conventional system due to excessive initial cost, thus economically unfeasible even considering the energy saving and CO_2 emission reduction.

Table 4: CO_2 emission reduction of sustainable technologies.

	Exterior insulation	Double Envelope system	Radiant heating cooling	Solar thermal system	Photo-voltaic system	Geo-thermal system
Initial Cost	-231,597	-269,942	-18,523	-307,200	-225,938	-1,023,796
Financial Incentive	-	-	-	154,920	113,716	649,850
Sub-total	-231,597	-269,942	-18,523	-152,280	-112,222	-373,946
O&M	-7,074	-176,218	138,415	-218,062	-23,021	43,097
Energy Cost	652,239	1,487,276	79,250	796,804	28,820	3,067,837
CO_2 Right Price	86,408	183,867	3,135	113,474	7,387	391,949
Sub-total	731,573	1,494,925	220,800	695,197	13,186	3,502,884
Total	499,975	1,224,983	202,277	542,917	-99,035	3,128,938

6 Conclusion

Since apartment houses account for 85% of the housing market in Korea, in order to effectively reduce CO_2 emissions in the building sector, apartment houses should be the first place to be considered. However, since there are few research data related to CO_2 emission performance and the economic feasibility of applicable building strategies, it is difficult for architects and engineers to determine viable solutions in building design and construction. The objectives of the study are to analyze the performance of sustainable building technologies and to provide designers and engineers with reliable technical data in terms of CO_2 emission reduction economic feasibility.

The technologies examined in the study are those being developed for apartment buildings as a part of the Korean government's "Low Energy Sustainable Apartment Program". A typical apartment building was selected as a sample building for the study. The actual energy consumption data of the building with relevant weather data and user patterns was collected and compared with the simulated energy performance using the "EnergyPlus" program. Afterwards, sustainable building technologies were applied to the building and the energy performances were analyzed. The energy consumption data were then converted to CO_2 emissions data by using the carbon emission factor (CEF) of various fuel resources. Finally, life cycle analyses were conducted considering the energy cost and the environmental cost. The result of the study can be summarized as follows.

1) Among the sustainable technologies, it was found that the magnitude of energy saving is greater in the following order; *geothermal system> double envelop system > exterior insulation> solar thermal system > photovoltaic system> radiant floor heating/cooling system.*
2) On the other hand, the *double envelope system* was found to have the best performance in CO_2 emission reduction, followed by *double envelope, exterior insulation, geothermal, solar thermal, photovoltaic and radiant heating/cooling* in descending order. For the geothermal system, although the energy reduction potential is the greatest, the effect of CO_2 emission reduction has decreased because of the increased electricity consumption for the increased pump operation power.
3) The result indicates that *geothermal system* has the best performance in life cycle cost saving, followed by *double envelope, solar thermal, exterior insulation and radiant heating/cooling* in descending order. However, *photovoltaic* shows a negative value, meaning that the total life cycle cost of the system is greater than that of a conventional system due to the excessive initial cost, thus it is economically unfeasible even considering the energy saving and CO_2 emission reduction.
4) The result of the life cycle cost analysis presented in this study well represents the current trend and situation in Korea. However, considering the kaleidoscopic nature of the global economic market and the energy situation, the result should be used only as a reference in design decision-making. It is recommended that future analysis should consider a variety of scenarios and provide a number of alternative suggestions.

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