

An Analysis of the CO₂ Emission Reduction Performance of Sustainable Technologies Applicable to Apartment Houses in Korea

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ABSTRACT: 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 CO₂ emissions reduction. The technologies examined for the study include; 'exterior-insulation', 'double-envelope system', 'radiant floor heating/cooling system', 'photovoltaic system', 'solar thermal system' and 'geo-thermal system'. Energy estimation was carried out by 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 apartment house. The CO₂ emission rates of each technology was calculated by multiplying respective "carbon emission factor(CEF)". In order to attain reliability of the result, the simulation data were compared with actual energy consumption data, and the two were found to be within the margin of error. The result of the study indicates that the performance of CO₂ emission reduction can be achieved best by 'solar thermal system', followed by 'double envelope system' , 'geo-thermal system', 'exterior-insulation', 'photovoltaic system' and 'radiant floor heating/cooling system', in descending order. 'radiant floor heating/cooling system' is found to be the least effective system in reducing CO₂ emission. The study concludes that in order to reduce CO₂ emission effectively, a careful analysis should be conducted in selecting sustainable building technologies.

Keywords: CO₂ emission, Sustainable building technologies, Energy estimation

1. INTRODUCTION

Unprecedented global warming and the rapid rise of energy prices in recent days have led Korean government to implement vigorous action plans for the reduction of

CO₂ emissions in every economic sector. In the building sector which constitutes about 25% of total energy consumption in Korea, apartment houses account for 85% of construction market. Consequently, in order to effectively reduce CO₂ emission

performance 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 CO₂ emissions reduction.

2. Research Scope and Methodology

A Survey was conducted to investigate to the actual energy consumption and energy use pattern of a sample apartment houses. Questionnaires were distributed to an 18-story apartment building with 72 households in Asan City, and energy consumption data was collected for one year from October 2006 to September 2007.

At the same time, the energy performance of the sample apartment house was simulated with "EnergyPlus" program, and the result was compared with the actual consumption data. Through this comparison "EnergyPlus" program was verified as a valid tool to simulate the energy performance for the purpose of the research.

Sustainable building technologies applicable to apartment houses were also identified through literature review. These technologies were applied to a prototype apartment house, and the energy performances were analyzed by using "EnergyPlus" as a simulation tool. The energy consumption data were then converted to CO₂ emissions data by using carbon emission factor(CEF) of various fuel resources.

3. Identification of Sustainable Technologies Applicable to Apartment Houses

In order to identify major sustainable building technologies applicable to apartment houses in Korea, relevant research was reviewed. Technologies were classified in terms of design components and their energy consumption characteristics were examined.(see Table I)

Table I indicates that building technologies which affect more than two energy resource, thus have greater energy potentials, are; *Aspect Ratio and SVR, Exterior Insulation, Double Envelope System, Space Allocation, Radiant Floor Heating/Cooling System, Co-generation System, Photovoltaic System, Solar Thermal System, Geothermal System, and Biomass System*. These strategies can be used in apartment houses to reduce energy consumption, and consequently to reduce CO₂ emissions. Among these, co-generation system, biomass systems were excluded from analysis due to insufficient technologies development and/or economical feasibility. Building shape and plan were also not considered, as they are more related to subjective aspects of building design. Therefore, it was finally determined to include *Exterior insulation, Double Envelope System, Radiant Floor Heating/Cooling System, Photovoltaic system, Solar Thermal System, Geothermal System* as sustainable technologies applicable in apartment houses in Korea.

4. Validation of Simulation Tool

4.1 Simulation Tool

'EnergyPlus' program was selected as a simulation tool. The program is based on DOE-2.1E and BLAST, and is useful in modelling 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 balanced-based zone

simulation, multi-zone air flow, thermal comfort, and photovoltaic systems.[5]

4.2 Comparison of Actual Energy Consumption and Simulated Energy Consumption

In order to secure the validity of energy simulation, actual energy consumption data of a sample apartment house was compared with the result of 'EnergyPlus' simulation.

Since the actual gas consumption data read from the meter did not separate heating,

hot water and cooking, a representative household energy consumption data[6],[7] obtained from Korea Energy Economics Institute were used to distinguish the use pattern. Actual electricity consumption data were classified into cooling and electric appliances based on the appliance use pattern obtained from questionnaire survey[8]. The weather data of the area gathered from Korea Meteorological Administration was used for the simulation.

Table I : Classification of Sustainable Technologies

Component	System	Technology		Energy Resources					index
				Natural Gas		Electricity		Water (elec)	
				Heating	Hot Water	Cooling	Lighting, Appliance		
Water Resources Utilization	Grey Water System	Biological Water Treatment						●	[2],[3]
		Grey Water Reuse System						●	[2],[3]
	Rainwater Harvest	Rainwater Collection and Reuse						●	[2],[3]
Building Design	Shape	Aspect Ratio, SVR		●		●			[1],[4]
	Envelope	Exterior Insulation (Air-Tightness, High Insulation)		●		●			[2],[4]
	Aperture	Triple Glazing, Shading Device	Double envelope System	●		●			[2],[4]
		Natural Ventilation		●		●			
	Plan	Space Allocation		●		●			
				●					
Mechanical System	Heating System	Radiant Ceiling Heating		●					[2],[3]
		Radiant Floor Heating	Radiant Floor Heating/Cooling System	●					[2],[3]
	Cooling System	Radiant Floor Cooling				●			
	Water/Sanitary System	Water Efficient Appliances						●	[2],[3]
	Ventilation System	Heat Recovery System		●					[4]
Primary Energy/ Electricity	High Efficiency Equipment	District Heating System		●					[1],[3]
		Co-generation System		●		●	●		[4]
	Renewable Energy	Photovoltaic System				●	●		[2],[4]
		Solar Thermal System		●	●		●		[2],[4]
		Geothermal System		●		●	●	●	[4]
		Wind Power System				●	●		[4]
		Biomass System		●			●		[4]

The result shown in figure 1 indicates that the deviation of gas consumption is less than

10%, while the difference in electricity consumption data. Moreover, the annual patterns of consumption are found to be very similar with one another. Therefore, the simulation data can be considered quite reliable, and 'EnergyPlus' can be used as a simulation tool with a high confidence.

5. Energy Performance of Sustainable Technologies

5.1 Energy Simulation of a Prototype Apartment House

The energy consumption of prototype apartment house was simulated using 'EnergyPlus'. A typical apartment house, an 18-story apartment with 72 household with 120m² floor area each, was selected as the prototype house. The liquefied natural gas(LNG) was used for heating and electricity for cooling. The major input data for the simulation are show in Table III.

The heating energy consumption of the building was simulated to be 1022.18MWh/yr, while cooling energy was 272.51MWh/yr. Overall, the building's energy requirement was 1294.79MWh/yr., and monthly energy consumption was shown in Figure 2.

Table II : Actual Energy Consumption of Sample Apartment House

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Natural Gas (m ³)	18286	14303	10302	4458	3149	2210	1952	1916	2443	3750	10063	16449
Electricity (KWh)	26928	23328	25272	23688	25056	25560	28368	28800	24624	24192	23544	27864
Water (ton)	1080	936	1296	1296	1512	1584	1584	1656	1440	1296	1152	1080

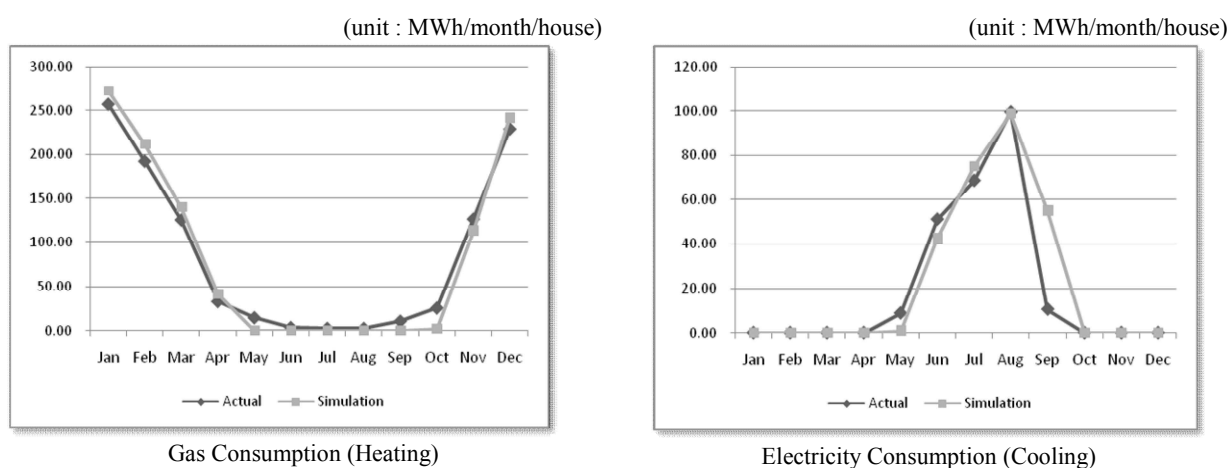


Figure 1 : Comparison of Actual Energy Consumption and Simulation Result

5.2 Energy Saving Effects of Sustainable Technologies

Energy simulations were conducted for the technologies previously identified Table IV shows the conditions of sustainable technologies applied to the prototype apartment house. Each technology was applied to the house, and the result was compared with the one without the application. Double Envelope system was a box-shape with a 300mm cavity space. Radiant floor heating/cooling system utilized existing radiant heating coils for cooling. Photovoltaic panels were mounted on the building roof, while solar evacuated tubes installed in the balcony guard rails. Geothermal heat-pump system was a

vertical closed circuit type using bore holes.[9]

Table V shows the energy saving effects of sustainable technologies. Negative(-) values indicate the reduction of energy consumption when a technology was applied to the building. It was found that the magnitude of reduction is greater as the following order. ; **Geothermal System> Solar thermal System> Double Envelope System> Exterior insulation> Photovoltaic System> Radiant Floor Heating/Cooling System**. The increase electricity consumption in geothermal, solar thermal and double envelope is due to the increased fan and pump operation for the technologies.

Table III : Input Data for Simulation

variables		input
temp setting		22°C ~ 26°C
ventilation rate		0.5ACH
human activity		sensible heat: 70W, latent heat: 45W
internal gain		total: 9.46W/m ²
wall	exterior	U-value: 0.49(W/m ² °C)
	interior	U-value: 3.1(W/m ² °C)
glazing		U-value: 2.7(W/m ² °C)
slab		U-value: 0.65(W/m ² °C)
heating period		Nov, Dec, Jan, Feb, Mar
cooling period		Jun, Jul, Aug

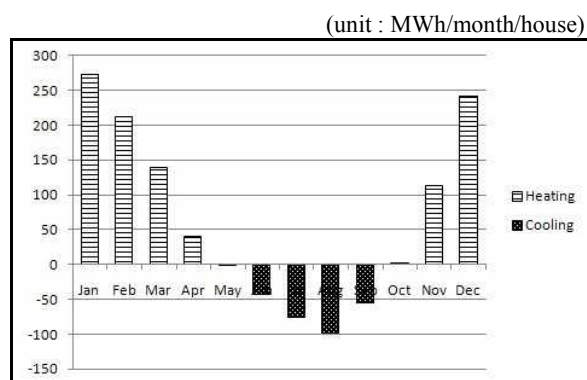


Figure 2 : Monthly Energy Consumption

Table IV : Sustainable Technologies Applied in the Building

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

6. Analysis of CO₂ Emission Reduction Performance of Sustainable Technologies

6.1 Carbon Dioxide Emission Factor (CEF)

Carbon emission factor(CEF) is the carbon content per unit of energy released for a particular fuel. CO₂ emission factor is the product of CEF multiplied by CO₂ conversion factor. In order to estimate the amount of CO₂ emissions released from building energy use, CEF each fuel type should be established. Since there are no standard CEF values developed in Korea, CEF values issued by IPCC(inter-governmental Panel on Climate Change)[10] was used for liquefied natural gas(LNG) and CO₂ emission factor developed by KEE(Korea Energy Economics Institute)

[11] was used for electricity in the study.(see Table VI)

6.2 CO₂ Emission Reduction

Among the sustainable technologies, **Solar thermal** was found to have the best performance in CO₂ emission reduction, followed by **Double Envelope, Exterior insulation, Geothermal, Photovoltaic, and Radiant heating/cooling** in descending order. The order of CO₂ emission reduction performance was different from that of energy performance, because the majority of electricity in Korea is produced by nuclear plants which emit less CO₂. Table VII show the result of CO₂ emission reduction of each technology. Negative(-) values indicate the reduction of CO₂ emission when technology was applied to the building.

Table V : 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	-183.32	-	-183.32	-3.28	-	-	-3.28	-180.04	4
Double Envelope	-231.67	-	-231.67	-34.47	+5.26	-	-29.21	-260.88	3
Radiant Heating/Cooling	-	-	-	-7.16	-	-	-7.16	-7.16	6
Solar Thermal	-	-323.59	-323.59	-	+0.06	-	+0.06	-323.53	2
Photovoltaic	-	-	-	-	-	-28.95	-28.95	-28.95	5
Geothermal	-688.69	-	-688.69	-	+217.01	-	+217.01	-471.68	1

Table VI : Carbon Dioxide(CO₂) Emission Factor

fuel	unit	TOE	Carbon Emission Factor(CEF)	CO ₂ Conversion Factor	CO ₂ Emission Factor
electricity	MWh	-	-	0.424	0.424
natural gas (LNG)	Nm3	0.000955	0.6370	44/12	0.002231

Table VII : CO₂ 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	-32.55	-	-32.55	-1.39	-	-	-1.39	-33.94	3
Double Envelope	-41.14	-	-41.14	-14.62	+2.23	-	-12.39	-53.53	2
Radiant Heating/Cooling	-	-	-	-3.04	-	-	-3.04	-3.04	6
Solar Thermal	-	-57.47	-57.47	-	+0.02	-	+0.02	-57.45	1
Photovoltaic	-	-	-	-	-	-23.95	-23.95	-23.95	5
Geothermal	-122.31	-	-122.31	-	+92.01	-	+92.01	-30.29	4

7. Conclusion

In Korea, the effect of CO₂ emission reduction in apartment building will be substantial as apartment house account for 85% of construction market. However, since there are few research data related to CO₂ emission performance 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 CO₂ emissions reduction. 'EnergyPlus' program was selected as a tool to simulate building energy performance. The research findings can be summarized as follows.

- 1) Through intensive literature review considering building and energy characteristics, sustainable technologies which can reduce CO₂ emissions in apartment houses were identified as follows; **Exterior insulation, Double Envelope System, Radiant Floor Heating/Cooling System, Photovoltaic System, Solar Thermal System, Geothermal System.**

- 2) It was found that the magnitude of energy saving effect is grater as the following order; **Geothermal System> Solar thermal System> Double Envelope System> Exterior Insulation> Photovoltaic System> Radiant floor Heating/Cooling System.** The increase of electricity consumption in geothermal, solar thermal and double envelope in due to the increased fan and pump operation for the technologies.

- 3) As the magnitude of CO₂ emission reduction is dependent upon carbon emission factor of a particular fuel, the order of CO₂ emission reduction among sustainable technologies is different for the order of energy saving, **Solar thermal** was found to have the best performance in CO₂ emission reduction,, followed by **Double Envelope System, Exterior insulation, Geothermal System, Photovoltaic and Radiant Heating Cooling** in descending order.

As global warming and energy scarcity are threatening human sustainability, all sectors of the society should make energy efforts to reduce energy consumption and CO₂ emission. The application of the findings may be limited to apartment houses

design and engineering in Korea,. Although more detailed technical and energy data are needed for future refinement, the result of the study can be used as a guideline for selecting sustainable building technologies to effectively reduce CO₂ emission in apartment houses in Korea.

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