A Comparison of CO_2 Emission in Apartment Buildings according to the Insulation Performance by Life Cycle Assessment

Hye Sung Yang[a*], Jae Gyu Shin[a], Yu Min Kim[a], Soon Joo Kang[b], Jang Yeul Sohn[c]

[a] Dept. of Sustainable Architectural Engineering, Hanyang University, Korea

[b] College of Architecture, Konkuk University, Korea

[c] College of Architecture, Hanyang University, Korea

*corresponding author: comet8255@naver.com

(Received 30 November 2009; accepted 7 December 2009)

As time passes, the equipment of apartment buildings has been outdated and also the performance of the insulation of them has been deteriorated. Subsequently, the consumption of the energy and the emission of CO_2 have been increased. By improving the insulation performance of houses, the CO_2 emission which is a major contributor of greenhouse effect can be decreased. In this research, the CO_2 emission from apartment buildings during whole life cycle is evaluated and compared one another according to the insulation performance. As a result, in the whole life cycle of buildings, CO_2 emission is 347.25(TON-CO_2/a unit) in the case of apartments in 1990's, 275.17 (TON- CO_2/a unit) in the case of general apartment in 2008, 220.91 (TON- CO_2/a unit) in the case of Green Home performance, and 182.16(TON-CO_2/ a unit) in the case of passive house performance.

Key words: Life Cycle Assessment (LCA), CO_2 emission, Insulation Material, Apartments, Reconstruction

1. INTRODUCTION

1.1 Background and objective

CO_2 emission from fossil fuel accelerates green house effect. Especially, the CO_2 emission from the life cycle of buildings is considerable. Since the performance of insulation in the old apartments mostly built in the 1970's has been deteriorated, excessive energy is consumed and unnecessary CO_2 is emitted. Therefore, CO_2 emission from houses needs to be regulated to reduce environmental load. An Energy-Saving house which has improved insulating performance can be one solution to decrease the CO_2 emission. A new standard[1] to encourage construction of energy saving apartments is planned to be enacted in 2009. Adopting this Green Home Standard makes it possible to save energy and decrease the CO_2 emission. In the previous study[2], the CO_2 emission from deteriorated apartments and newly built apartments based on Life Cycle Assessment (LCA) was estimated. It compared the CO_2 emitted from the new apartment to that from the apartments in 1990's. Reconstruction makes the performance of insulation and efficiency of heating and cooling equipment be improved.

In this research, the CO_2 emission from apartments during whole life cycle is evaluated and four cases are compared one another according to the insulation performance.

1.2 Definition of Energy-Saving Houses

1) Passive House

Passive House is a house which is able to minimize the energy consumption and CO_2 emission especially by using highly efficient insulation. Since passive houses adopt the powerful insulation, the thermal conductivity coefficient of walls in passive house is generally about 0.09~0.15W/m^{2}K.

2) Green Home

Since adopting the thermal performance of passive house to apartments can be economically inefficient, practically applicable thermal performance is proposed[1]. The thermal conductivity coefficient of walls in Green Home is determined as 0.36W/m^{2}K.

2. Method

The more insulation material is used to improve the thermal performance, the more CO_2 emission is produced in construction stage. Conversely, the less CO_2 emission is produced in the maintenance stage. The CO_2 emission during life cycle of buildings is estimated and four cases are evaluated. The methods are briefly shown in table1.

---

[1] Ministry of Land, Transport and Maritime Affairs(2009) 'The Construction Standard of Green Home for Low Carbon, Green Growth'

[2] Shin, Jae-Gyu (2009) A study on the Reconstruction Judgment Method of Deteriorated Apartment Housing According to the CO_2 emission

Construction process can be divided into material production, transport, and execution stage. For apartments built in 1990's, the CO_2 emission in the construction stage is estimated in the previous study[3] shown as table2. Since the thermal performance is influenced by mainly insulation material, the scope of this study is limited to the influence of the insulation material. In the material production and transport stages, after estimating the increased CO_2 emission by increased insulation material, the increment of the CO_2 emission is added to the CO_2 emission in the case of apartment in 1990's. It is assumed that the CO_2 emission in execution stage is not affected by the amount of the insulation material.

In material production stage, after the CO_2 emission per a unit volume from the insulation material is estimated by Input-Output Analysis(IOA), CO_2 emission per a unit($59m^2$) is evaluated. In transport stage, the CO_2 emission from a truck to carry the insulation material is estimated by IOA, and the required number of trucks is estimated according to the amount of insulation material. Then, the CO_2 emission per unit is evaluated.

Table1. Method and Process for the CO_2 emission Estimation

Stages		Method
Construction Stage	Material-production	CO_2 emission per a unit is estimated by IOA
	Transport	CO_2 emission from a truck is estimated by IOA
	Execution	It is assumed CO_2 emission in execution is same in 4 cases
Maintenance Stage		Required energy per year is estimated by TRANSYS and changed into CO_2 emission
Destruction Stage	Demolition	The example of ferroconcrete building is applied
	Transport	CO_2 emission from a truck is estimated by IOA

Table2. CO_2 emission in construction stage for APT in 1990's

CO_2 emission	CO_2 emission per a household($59m^2$)
0.812 Ton-CO_2/ m^2	47.91 Ton-CO_2

Table3. CO_2 emission in demolition for a ferroconcrete APT

CO_2 emission	CO_2 emission per a household($59m^2$)
0.000304 Ton-CO_2/ m^2	0.017 Ton-CO_2

3 Kim, Jong-Yeob (2005) Evaluating CO_2 Emission in Construction Stages of Apartment Buildings by Life Cycle Assessment

In maintenance stage, the required energy per year is estimated by the TRANSYS simulation. The heating and cooling load is estimated and evaluated according to cases.

The destruction stage is divided into building demolition and transport for destruction. The CO_2 emission for building demolition is refers to a previous study[4] shown as table3. It is assumed that the CO_2 emission in demolition stage is not affected by the amount of the insulation material. The CO_2 emission from insulation material in transport stage for destruction is estimated according to the amount of insulation material, and it is added to the CO_2 emission in building demolition stage to estimate the whole CO_2 emission in destruction stage.

2.1 Model outline

The base model is a $59m^2$ apartment in Seoul. Figure1 shows the basic plan. An apartment block consists of 60 units.

Figure1. Floor plan of the basic unit

2.2 Assessment for the construction stage

In material production stage, since the thermal performance is different from each other, the input of the insulation material is also changed. The insulation material is Styrofoam and the amount is gradually increased according to the improvement of the thermal performance, which is shown in table4. By CO_2 emission per unit volume in table5, the CO_2 emission for a household is estimated.

In transport stage, the number of trucks for the transport of the insulation material is estimated by using CO_2 emission from a truck in table6. The distance for transport is 30km, which is the average distance for transport, and the means of transport is 8-ton trucks. Under the condition, the CO_2 emission per a truck is estimated as 23.57 Ton-CO_2, and the number of trucks is shown in table7. Since the transport for material is conducted in large-scale, CO_2 emission is estimated by a block unit.

4 The Environmental Load Unit Composition and Program Development for LCA of Building (2009)

Table4. Thermal Conductivity Coefficient (Unit : W/m^{2}K)

	APT in 1990's		APT in 2008	Green Home	Passive House
wall	0.58	→	0.47	0.36	0.12
slab	1.16	→	0.81	0.21	0.14
win.	3.37	→	3.00	1.50	0.83

Table5. CO_2 emission from production of insulation-material

	Insulation Material Input(m^3)	CO_2 emission Per unit volume (Ton-CO_2/ m^3)
APT in 1990's	3.841 m^3	0.1424
APT in 2008	4.725 m^3	
Green Home	6.168 m^3	
Passive House	18.529 m^3	

Table6. CO_2 emission from trucks

Module	CO_2 emission (Ton-CO_2/a truck)
5.1~8 ton truck	9.82E-02
8.1-15 ton truck	5.32E-02

Table7. The number of truck required for a household

	Insulation material input (m^3) for a block	The required number of truck for a household
APT in 1990's	230	0.0494
APT in 2008	284	0.0608
Green Home	370	0.0793
Passive House	1,112	0.2383

2.3 Assessment for the maintenance stage

TRANSYS program is used to estimate the energy consumption in buildings. Table4 shows the thermal conductivity coefficient of each case.

The thermal conductivity coefficient for apartment in 1990's is based on the minimum standard in 1990's, and that for general apartment in 2008 is based on the minimum standard in 2008. Green Home standard[1] was applied for Green Home. For passive house, four cases of passive houses in Germany and one case in Korea is selected and the thermal conductivity coefficients were averaged. By using this data, the simulation was performed to estimate required energy per year.

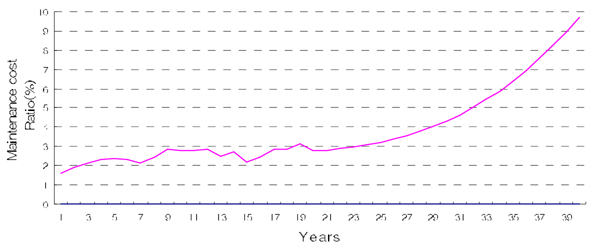

Figure2. Maintenance Cost Ratio

Table8. Caloric Values and Carbon Emission Coefficients

		Caloric value	Carbon Emission coefficient
Oil	Crude Oil	10,000kcal/kg	0.829 TC[5]/TOE[6]
	Gasoline	8,300kcal/.L	0.783 TC/TOE
	Kerosene	8,700kcal/L	0.812 TC/TOE
	Gas oil	9,200kcal/L	0.837 TC/TOE
Electric Power		860kcal/kWh	0.787 TC/TOE

Figure2 shows the maintenance ratio[7] of apartments for 40 years. To estimate the energy for 40 years, the simulation results are applied as the energy consumption of the first year. This ratio is based on actual data from 32 apartments for 19 years, and estimated the rest maintenance cost data for 40 years.

To change the energy to the CO_2 emission Carbon Emission Coefficient of IPCC[8] is applied. Electricity is used for cooling and kerosene is used for heating energy. Table8 shows the caloric value and carbon emission coefficient for each source. The CO_2 emission can be estimated by multiplying the carbon emission by 44/12, which is molecular ratio of the C(carbon) and CO_2. It is shown in Eq. (1).

$$CO_2 \text{ Emission} = C(\text{Carbon})\text{emission} \times (44/12) \quad (1)$$

2.4 Assessment for the building destruction stage

Ferroconcrete building is applied to estimate CO_2 emission in destruction stage. 11.5ton trucks are used and they cover 60km in destruction stage. The CO_2 emissions in this stage can be figured out by using The LCI DB[9] in table6.

---

5 TC(Ton Carbon)

6 TOE(Ton of Oil Equivalent): 10^{7}kcal

7 Safety Diagnosis Manual for Housing Reconstruction(2008) Korea Infrastructure Safety and Technology Corporation

8 IPCC(Intergovernmental Panel on Climate Change)

9 LCI DB(Life cycle Inventory Database)

3. RESULTS

The CO_2 emission in construction stage is shown in table9, and the simulation result and the CO_2 emission for 40 years is shown in table10. The CO_2 emission in destruction stage is shown in table11 and figure3 shows the ratio of each stage.

The accumulated CO_2 emission for the whole life cycle of buildings is 347.05 TON-CO_2 per a unit in the case of apartment in 1990's, 274.96 TON-CO_2 in the case of general apartment performance in 2008, 220.69 TON-CO_2 in the case of Green Home, and 181.71 TON-CO_2 in the case of passive house.

Table9. CO_2 emission in construction stage (Ton-CO_2/a unit)

	APT in 1990's	APT in 2008	Green Home	Passive House
CO_2 from Production for insulation material	0.5470	0.6728	0.8784	2.6386
CO_2 from Transport for insulation material	0.0012	0.0014	0.0019	0.0056
CO_2 from Execution for insulation material and from Construction for the other materials	47.2337	47.2337	47.2337	47.2337
SUM	47.7819	47.9080	48.1140	49.8779

Table10. Heating and Cooling Load by TRANSYS (kW/year) and CO_2 emission in maintenance stage

	APT in 1990's	APT in 2008	Green Home	Passive House
Heating	8,419	7,263	5,479	4,022
Cooling	82	109	125	264
Total	8,501	7,372	5,582	4,286
CO_2 emission for 40 years (Ton-CO_2/a unit)	299.25	227.03	172.55	131.80

Table11. CO_2 emission in destruction stage (Ton-CO_2/a unit)

	APT in 1990's	APT in 2008	Green Home	Passive House
Destruction	0.0179	0.0179	0.0179	0.0179
Transport	0.0021	0.0026	0.0034	0.0104
SUM	0.0200	0.0205	0.0213	0.0283

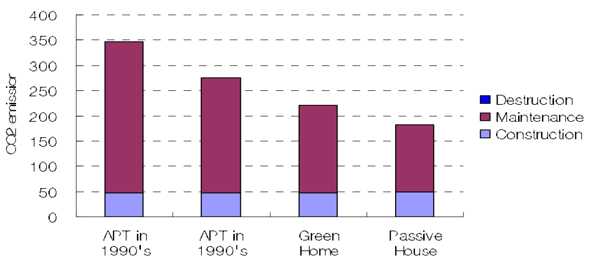

Figure3. CO_2 emission comparison among cases

The difference of CO_2 emission between apartment in 1990's and general apartment in 2008 was 72.08 TON-CO_2 (20.76%), and 126.33 TON-CO_2 (36.38%) when they are rebuilt as Green Home performance, and 165.08 TON-CO_2 (47.54%) when they are rebuilt passive house performance.

4. CONCLUSIONS

The result shows that the increment of CO_2 emission in construction stage according to the amount of insulation material is very small. Since the CO_2 emission in the maintenance stage occupies the largest part in the whole life cycle, the decrement due to the improvement of insulation performance is much bigger. This means that increment of the CO_2 emission in the material production and transport stages does not play a significant role in the whole life cycle of buildings. Also, the case of passive house shows the best performance to decrease the CO_2 emission from houses. However, LCC analysis is required to apply the passive house performance to apartment houses since it can be economically inefficient. It is focused on the amount of insulation material in the house in this research, therefore, it is necessary to proceed the study including CO_2 emission from the other materials.

ACKNOLEDGEMENT

This work was supported by the Brain Korea 21 Project in 2009 and Sustainable Building Research Center of Hanyang University which was supported the SRC/ ERC program of MEST

REFERENCES

[1] Shin, Jae-Gyu (2009) A study on the Reconstruction Judgment Method of Deteriorated Apartment Housing According to the CO_2 emissions

[2] Kim, Jong-Yeob (2005) Evaluating CO_2 Emission in Construction Stages of Apartment Buildings by Life Cycle Assessment

[3] Korea Institute of Construction Technology (2004) The Environmental Load Unit Composition and Program Development for LCA of Building

[4] Korea Infrastructure Safety and Technology Corporation(2009) Safety Diagnosis Manual for Housing Reconstruction