



The Evaluation of Energy Efficiency of Apartment Units after Conversion of Balconies into an Integrated Part of Interior Living Space by Computing with ECO2 Software

Kim, Chang-Sung*

* Corresponding author, Dept. of Architectural Engineering, HyupSung Univ., South Korea (cskim815@daum.net)

ABSTRACT

Purpose: International efforts to save Earth's environment against global warming and environmental pollution have been made in many countries. Energy consumption of buildings has been continuously increasing, and it has been over 40% of total energy consumption in the world. Energy consumption of buildings in Korea reaches 24% of total energy consumption. So, Korea government has executed building energy rating systems to control energy consumption of buildings. **Method:** This study was carried out to evaluate the energy performance of apartment unit plans according to converting balconies into living areas. For the study, six types of input models were made. Two input models (SP1 and SP2) were the standard units that balcony areas were not converted into living areas, and four ones (EP1, EP2, EP3 and EP4) were the extended unit plans that balcony areas were turned into living areas. All of them were simulated with ECO2 software to assess building energy efficiency. **Result:** According to the results, the energy performance of the EP2 and EP4 models were 21.8% higher than SP1 model and 9.2% higher than SP2 model.

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KEYWORD

ECO2 Software
Collective Housing
Balcony
Energy Efficiency

에코 2 프로그램
공동주택
발코니
에너지 효율

ACCEPTANCE INFO

Received January 18, 2016
Final revision received February 10, 2016
Accepted February 12, 2016

1. Introduction

1.1. Background and Object of the Research

The climate change has posed a threat to survival of mankind. To cope with the climate change, many countries have made efforts to reduce the green house gas emission through the agreements such as United Nations Framework Convention on Climate Change in Rio (1992), Kyoto Protocol to the United Nations Framework Convention (1997), UN Climate Change Conference held in Copenhagen (2009), and agreed on Paris Agreement which has the legal binding force to share the responsibility to reduce the green house gas at 2015 United Nations Climate Change Conference (The twenty-first session of the Conference of the Parties (COP21)).¹⁾ The building part occupying over 40% of total global energy consumption is emitting the equivalent green house gas. So, energy efficient building is very important for the protection of global environment.

Many countries are enforcing green building certification criteria such as LEED (US), BREEAM (UK), CASBEE (Japan), and Korea government is implementing Energy Performance Index (EPI, 1979), Building Energy Efficiency Rating Certification

(BEERC, 2001), Green Building Certification Criteria (GBCC, 2002), and Green Home Architecture Standard (GHAS, 2009).²⁾ Also, Korean government set up the goal to reduce 30% of green house gas emission forecast in 2020, and decided the reduction goal for each fields as 34.3% in transportation, 26.9% in building, 26.7% in thermoelectric generation, 25% in public section, 18.5% in industry, 12.3% in wastes, 5.2% in agriculture and fishing.³⁾

Energy consumption of buildings in Korea is occupying over 24% of total energy consumption,⁴⁾ and residential building is occupying about 54% of building energy consumption. Therefore, Korean government reorganized Green Standard for Energy & Environmental Design (G-SEED) and Building Energy Efficiency Rating Certification (BEERC) by the enactment of Green Building Construction Support Act (2013) to evaluate environmental performance of building and energy consumption efficiency. Among them, BEERC evaluates the energy consumption and CO₂ emission volume for five items such as heating, cooling, lighting, hot water heating, and ventilation using ECO2 software to evaluate energy volume consumed in buildings.⁵⁾

2) C. S. Kim, The Analysis on the Evaluation Items of Korea Green Building Certification Criteria by the Case Studies of Collective Housing, Journal of KIEAE, 2013. 04

3) Ministry of Environment news release

4) Korea Energy Economics Institute, <http://keei.re.kr>

5) S. W. Park, A Study on Changes of the Energy Efficiency Rating according to the Revised Building Energy Efficiency Rating Certification System, Hanyang Univ. Master Thesis, 2015. 02

Meanwhile, the balcony installed in apartment units tends to be converted into living room or bedroom according to the promotion of sales and preference of resident in domestic apartment market, which is positive on residential area extension, but negative on loss of thermal buffer space by balcony. Therefore, this study suggests basic data for energy effective unit plans of apartment by evaluating energy performance of unit plans with ECO2 software according to the conversion of balcony into living space.

1.2. Method and Range of Research

This study has been conducted as the follow up study of the energy efficiency evaluation of apartment units by heating degree day method⁶⁾ and ECO2 software simulation⁷⁾. So, some of input variables and evaluation models used in previous research were applied to the research.

The apartment unit which unit area was less than 85m², preferred in domestic apartment market, was selected as evaluation model, and three categories such as building energy demand, building energy consumption, and primary energy demand were calculated using ECO2 software. The process of this study is as follows:

Firstly, surveyed current state of energy efficiency rating certificate for collective housing and characteristic of ECO2 software.

Secondly, set up input models, and arranged physical parameters of input models for simulating with ECO2 software.

Thirdly, evaluated energy performance of input models by calculating three evaluation categories such as energy demand, energy consumption, and primary energy demand.

Fourthly, performed comparative analysis of primary energy demand on each input model.

2. Current State of Building Energy Efficiency Rating Certificate and Characteristics of ECO2 Software

2.1. Current State of Building Energy Efficiency Rating Certificate

The building energy efficiency rating certificate system was established in 2001, and total energy reduction rate of evaluation model was calculated on the base of the heating degree days method until August 2013. The building energy efficiency rating certificate system was changed with the method of ECO2 software simulation by Green Building Construction Support Act enacted

on September 2013.

2,423 units of residential buildings and 1,388 units of non-residential buildings have been certified until September 2015. Based on [Table 1], 775 units obtained main certification and 1,648 units obtained preliminary certification. And, it is expected that the numbers of certification will be continuously increased. [Table 2] Currently, building energy efficiency rating certification is evaluated as 10 ranks from highest rank 1+++ to lowest rank 7.

Table 1. Certification numbers of collective housing (September 2015)

year	2001	2002	2003	2004	2005	2006	2007	2008
MC	-	-	-	2	2	2	6	29
PC	1	2	6	8	28	14	68	63
year	2009	2010	2011	2012	2013	2014	2015	Total
MC	39	63	92	90	105	200	145	775
PC	127	83	141	212	360	267	268	1,648

MC: Main Certification , PC: Preliminary Certification

Table 2. Criteria of building energy efficiency rating certification

Assessment Type	Primary energy consumption per unit area and year(kWh/m ² ·year)			
Assessment Categories	Energy consumption of heating, cooling, hot water heating, lighting and ventilation			
	Rank 1+++	less than 60	Rank 3	more than 190 less than 230
	1++	more than 60 less than 90	4	more than 230 less than 270
	1+	more than 90 less than 120	5	more than 270 less than 320
	1	more than 120 less than 150	6	more than 320 less than 370
	2	more than 150 less than 190	7	more than 370 less than 420

2.2. Characteristics of ECO2 software

ECO2 software calculates energy demand per unit area and year, energy consumption, and primary energy demand for five items of heating, cooling, lighting, hot water heating, and ventilation based on the global building energy evaluation standard ISO 13790⁸⁾ and DIN V18599⁹⁾.¹⁰⁾

Energy demand is the energy volume that building demands to maintain comfortable indoor environment under specific environmental condition, and energy consumption is calculated considering equipment efficiency to supply energy volume to

8) ISO 13790 is global standard for building heating and cooling energy consumption calculation and used for building energy efficiency evaluation. (Refer to http://www.phiko.kr/bbs/board.php?bo_table=z3_01&wr_id=812)

9) DIN V 18599 is an energy interpretation algorithm developed to evaluate building energy efficiency in Germany. (Refer to S. W. Park, A Study on Changes of the Energy Efficiency Rating according to the Revised Building Energy Efficiency Rating Certification System, Hanyang Univ. Master Thesis, 2015. 02)

10) J.W. Jeon, A Study on the Energy Saving Design for Public Office Buildings Using ECO 2 Program, Joongang Univ. Master Thesis, 2013. 08

6) C. S. Kim, K. W. Seo, A Study on the Evaluation of the Building Energy Efficiency in Accordance with the Shapes of the Apartment Unit Plans, KIEAE Journal, 2013. 08

7) C. S. Kim, The Influence of Unit Plan Shapes to the Energy Efficiency of Collective Housing Simulated by ECO2 Software, KIEAE Journal, 2015. 12

building. Primary energy demand is energy volume¹¹⁾ including energy loss to occur during the whole process – the collection, manufacturing, transportation, conversion, and supplying of fuel – that supply energy to building, and it is calculated by multiplying conversion factor to energy consumption according to the purpose profile of building and heating type.

ECO2 software can not calculate sun shading effect by shading devices such as louver, eaves, balcony and earring, etc, and, it is not able to calculate the heating and cooling peak load during the year because it calculates energy performance of building through average monthly weather data.

3. Evaluation Model Set-up

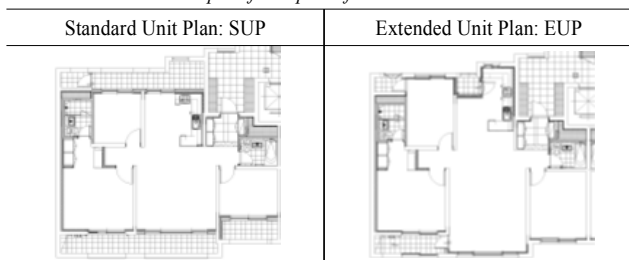
3.1. Outline of Input Models

The apartment unit plans that unit area was less than 85m² were selected as input models, and their front width and ceiling height are 9.3m and 2.4m, respectively. The insulation standard of southern region was applied for simulation, and individual heating system was chosen. [Table 3]

Table 3. Summary of input models

Region	Southern region
Area of unit plan	85 m ²
Front width	9.3 m
Ceiling height	2.4m
Heating system	individual heating
Boiler capacity and efficiency	22.2 kW/87%
Lighting density	10 W/m ²
Infiltration	4

Shapes of unit plans for Simulation



3.2. Physical Characteristics of Input Models

The heating loss areas of the outer windows and walls that greatly influence on the energy performance of input models were calculated, and shown in [Table 4]. The heated area of standard unit plan(SUP) that balcony spaces were not integrated into living spaces such as living room or bed room was calculated as 84.99m², and the heated area of extended unit plan(EUP) that balcony spaces

were integrated into living spaces was calculated as 102.96m². The heated area of EUP was 17.97m² larger than the area of SUP. The outer wall areas for SUP and EUP were calculated as 42.35m² and 53.44m², respectively, and the outer wall area of EUP was 11.09m² larger than the wall area of SUP. The window area of SUP and EUP were calculated as 27.36m².

Table 4. Heat loss area of input models (unit: m²)

Building components		SUP	EUP	
Heated area	Window	Front	18.72	18.72
		Rear	8.64	8.64
		Sub total	27.36	27.36
	Outdoor wall	Front	10.94	10.94
		Rear	11.26	11.26
		Side part	0	11.09
		Side wall	20.15	20.15
		Sub total	42.35	53.44
	Parts in contact with unheated space	Wall	11.47	16.27
		Door	2.20	2.20
		Others	3.74	3.74
		Sub total	17.41	22.21
	Unheated area	Front door		2.20
Outdoor wall		Side wall	4.21	4.21
Area of unit plan		84.99	102.96	

3.3. Evaluation Conditions of Input Models

The side unit located on middle stories of apartment was set-up for evaluation, and the thermal performance values of input models according to structural components has been calculated referring the heat transmission coefficient standard of southern region¹²⁾ [Table 5], and the values applied to evaluation of input models.

3.4. Input Model Set-up according to Window Systems

PVC windows were applied for the evaluation of input models. The input models of SUP were set-up with two ones (SP 1, SP 2) by whether the balcony window was installed or not, and the input models of EUP were set-up with four ones (EP 1, EP 2, EP 3, and EP 4) according to the window systems installed on the balcony. So, six input models have been evaluated. The thermal performance values of six input models according to window systems are shown in [Table 6].

11) Korean Regulations for Building Energy Efficiency Rating Certification (2013. 09. 01)

12) Korea Energy Agency, Guideline for preparation of Building Energy Saving plan, 2011

Table 5. Thermal performance of structural components

Building components		TC	Th	TR	TT
		W/m·K	m	m ² ·k/W	W/m ² ·K
Exterior wall	Outdoor heat transfer resistance	-	-	0.043	0.411
	1 Brick	0.6	0.2	0.333	
	2 Insulation No.1	0.032	0.06	1.875	
	3 Gypsum board	0.18	0.0125	0.069	
	Indoor heat transfer resistance	-	-	0.11	
Side wall	Outdoor heat transfer resistance	-	-	0.043	0.368
	1 Concrete	1.6	0.2	0.125	
	2 Insulation No.2	0.038	0.09	2.368	
	3 Gypsum board	0.18	0.0125	0.069	
	Indoor heat transfer resistance	-	-	0.11	
Structure in contact with unheated space	Outdoor heat transfer resistance	-	-	0.043	0.415
	1 Brick	0.6	0.2	0.333	
	2 Insulation No.3	0.027	0.05	1.851	
	3 Gypsum board	0.18	0.0125	0.069	
	Indoor heat transfer resistance	-	-	0.11	

TC : Thermal Conductance, Th : Thickness, TR : Thermal Resistance, TT : Thermal Transmittance

Table 6. Thermal performance of windows installed to input models

Setting up items		SHGC	TT	
		-	W/m ² ·K	
SUP	SP 1	Exterior wall 22mm low-e pair glass (5mm low-e+12mm air+5mm)	0.516	2.1
		Balcony no windows	-	-
	SP 2	Exterior wall 22mm low-e pair glass (5mm low-e+12mm air+5mm)	0.516	2.1
		Balcony 22mm pair glass (5mm+12mm air+5mm)	0.688	2.8
EUP	EP 1	Exterior wall 22mm low-e pair glass (5mm low-e+12mm air+5mm)	0.516	2.1
		Balcony 22mm low-e pair glass (5mm low-e+12mm air+5mm)	0.516	2.1
	EP 2	Exterior wall 22mm low-e pair glass (5mm low-e+12mm air+5mm)	0.516	2.1
		Balcony 39mm low-e triple glass (5mm low-e+12mm air +5mm+17mm air+6mm)	0.399	1.6
	EP 3	Exterior wall 22mm low-e pair glass (5mm low-e+12mm air+5mm)	0.516	2.1
		Balcony 52mm low-e triple glass (6mm low-e+17mm air +6mm+12mm air+5mm)	0.399	1.5
EP 4	Exterior wall 22mm low-e pair glass (5mm low-e+12mm air+5mm)	0.516	2.1	
	Balcony Interior side: 22mm low-e pair glass +exterior side: 22mm pair glass	0.355	1.4	

SHGC: Solar Heat Gain Coefficient, TT : Thermal Transmittance

4. Energy Performance Evaluation for Input Models

4.1. Energy Performance Evaluation for Input Models of Standard Unit Plan

In order to evaluate the energy performance of SUP models (SP

1 and SP 2), the energy demand, energy consumption, and primary energy demand were calculated through simulating the energy performances of heating, cooling, lighting, hot water heating, and ventilation with ECO2 software. Simulation results are presented in [Table 7]. Main results of [Table 7] are as follows.

(1) Energy demand was calculated into 110.9 kWh/m² in SP 1, and 96.5 kWh/m² in SP 2. So, energy demand of SP 2 was 13.0% less than SP 1.

(2) Energy consumption was calculated into 114.7 kWh/m² in SP 1, and 114.5 kWh/m² in SP 2. So, energy consumption of SP 2 was 0.2% less than SP 1. There was not much difference between 2 models.

(3) Primary energy demand was calculated into 162.2 kWh/m² in SP 1, and 154.5 kWh/m² in SP 2. So, primary energy demand of SP 2 was 4.7% less than SP 1.

(4) SP 1 and SP 2 models were all evaluated as Rank 2 based on the standard of building energy efficiency rating certificate as shown in [Figure 1].

Table 7. Energy performance of SUP models (kWh/m²)

	Energy demand						Relative ratio (%)
	Heating	Cooling	Hot water	Lighting	Ventilation	Total	
SP 1	17.6	44.4	30.7	18.3	0.0	110.9	100
SP 2	20.3	27.3	30.7	18.3	0.0	96.5	87.0
	Energy consumption						Relative ratio (%)
	Heating	Cooling	Hot water	Lighting	Ventilation	Total	
SP 1	41.9	9.8	35.5	18.3	9.3	114.7	100
SP 2	45.4	6.0	35.5	18.3	9.3	114.5	99.8
	Primary energy consumption for certification						Relative ratio (%)
	Heating	Cooling	Hot water	Lighting	Ventilation	Total	
SP 1	33.1	27.0	26.4	50.2	25.5	162.2	100
SP 2	35.8	16.6	26.4	50.2	25.5	154.5	95.3

Relative ratio = (simulation result of input model / SP 1) x 100

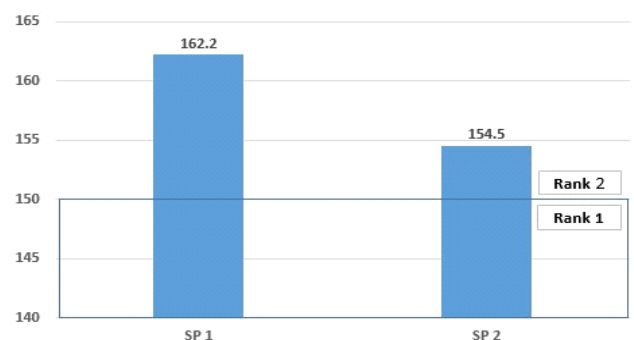


Figure 1. Building energy efficiency rating of SUP models (unit : kWh/m²)

4.2. Energy Performance Evaluation for Input Models of Extended Unit Plan

In order to evaluate the energy performance for EUP models (EP 1, EP 2, EP 3, EP 4), the energy demand, energy consumption, and

primary energy demand were calculated the same ways as SUP models were calculated. The calculation results are presented in [Table 8]. Main results are as follows.

(1) Energy demand was calculated into 95.7 kWh/m² in EP 1, 93.3 kWh/m² in EP 2, 92.8 kWh/m² in EP 3, and 92.3 kWh/m² in EP 4. Energy demand of EP 2, EP 3, and EP 4 models were 2.5%, 3.0%, and 3.6 % lower than EP 1 model, respectively.

(2) Energy consumption was calculated into 112.0 kWh/m² in EP 1, 112.0 kWh/m² in EP 2, 111.3 kWh/m² in EP 3, and 111.9 kWh/m² in EP 4. Energy consumption of EP 2, EP 3, and EP 4 models were 0%, 0.6%, and 0.1 % less than EP 1 model, respectively. The difference of energy consumption among 4 models was not much.

(3) Primary energy demand was calculated into 151.5 kWh/m² in EP 1, 150.2 kWh/m² in EP 2, 149.7 kWh/m² in EP 3, and 149.6 kWh/m² in EP 4. Primary energy demand of EP 2, EP 3, and EP 4 models were 0.9%, 1.2%, and 2.1 % lower than EP 1 model, respectively.

(4) EP 1 and EP 2 models were evaluated as Rank 2, and EP 3 and EP 4 models were evaluated as Rank 1 based on the standard of building energy efficiency rating certificate as shown in [Figure 2].

Table 8. Energy demand of input models of EUP models (kWh/m²)

	Energy demand						Relative ratio (%)
	Heating	Cooling	Hot water	Lighting	Ventilation	Total	
EP 1	21.2	25.7	30.7	18.3	0.0	95.7	100
EP 2	21.7	22.6	30.7	18.3	0.0	93.3	97.5
EP 3	21.2	22.7	30.7	18.3	0.0	92.8	97.0
EP 4	21.9	21.5	30.7	18.3	0.0	92.3	96.4
	Energy consumption						Relative ratio (%)
	Heating	Cooling	Hot water	Lighting	Ventilation	Total	
EP 1	43.2	5.7	35.5	18.3	9.3	112.0	100
EP 2	44.0	5.0	35.5	18.3	9.3	112.0	100
EP 3	43.2	5.0	35.5	18.3	9.3	111.3	99.4
EP 4	44.1	4.8	35.5	18.3	9.3	111.9	99.9
	Primary energy consumption for certification						Relative ratio (%)
	Heating	Cooling	Hot water	Lighting	Ventilation	Total	
EP 1	33.8	15.6	26.4	50.2	25.5	151.5	100
EP 2	34.3	13.8	26.4	50.2	25.5	150.2	99.1
EP 3	33.8	13.8	26.4	50.2	25.5	149.7	98.8
EP 4	34.5	13.1	26.4	50.2	25.5	149.6	98.9

Relative ratio = (Simulation result of input model / EP 1) x 100

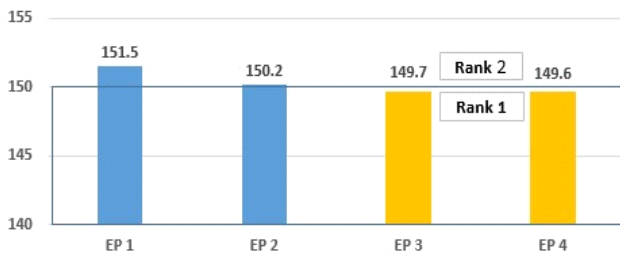


Figure 2. Building energy efficiency rating of EUP models (unit : kWh/m²)

4.3. Energy Performance Comparison between SUP and EUP Models

As shown in [Table 7] and [Table 8], primary energy consumption of SUP models in hot water heating, lighting, and ventilation were the same as EUP models. In order to compare the energy performance of SUP models with the energy performance of EUP models, primary energy consumption in heating and cooling were analyzed. For the comparison, SUP models (SP 1 and SP 2) were set up as base case.

(1) Comparison of the results of SP 1 model with EUP models

Based on [Table 9], the energy performance of EUP models increased 1.1%(EP 1, EP 3)~4.2%(EP 4) in heating load, and decreased 42.2%(EP 1)~51.5%(EP 4) in cooling load compared to results of SP 1 model, which indicated that the cooling load decrease improved energy performance of EUP models. The energy performance of EUP models was improved 17.8%(EP 1)~21.8%(EP 3, EP 4) compared to SP 1 model.

Table 9. Comparison of primary energy consumption of SP 1 model with EUP models in heating and cooling (kWh/m²)

	heating		cooling		total	
	PEC	RR	PEC	RR	PEC	RR
SP 1	33.1	100.0	27.0	100.0	60.1	100.0
EP 1	33.8	102.1	15.6	57.8	49.4	82.2
EP 2	34.3	103.6	13.8	51.1	48.1	80.0
EP 3	33.8	102.1	13.8	51.1	47.6	79.2
EP 4	34.5	104.2	13.1	48.5	47.6	79.2

PEC= Primary Energy Consumption,

RR(Relative Ratio)=(result of extended input model / SP 1) x 100

(2) Comparison of the results of SP 2 model with EUP models

Based on [Table 10], the energy performance of EUP models decreased 3.6%(EP 2)~5.6%(EP 1, EP 3) in heating load, and also decreased 6.0%(EP 1)~21.1%(EP 4) in cooling load compared to results of SP 2 model, which indicated that energy performance improvement by cooling load was larger than by heating load. The energy performance of EUP models was improved 5.7%(EP 1)~9.2%(EP 3, EP 4) compared to SP 2 model.

Table 10. Comparison of primary energy consumption of SP 2 model with EUP models in heating and cooling (kWh/m²)

	heating		cooling		total	
	PEC	RR	PEC	RR	PEC	RR
SP 2	35.8	100.0	16.6	100.0	52.4	100.0
EP 1	33.8	94.4	15.6	94.0	49.4	94.3
EP 2	34.3	95.8	13.8	83.1	48.1	91.8
EP 3	33.8	94.4	13.8	83.1	47.6	90.8
EP 4	34.5	96.4	13.1	78.9	47.6	90.8

PEC= Primary Energy Consumption,

RR(Relative Ratio)=(result of extended input model / SP 2) x 100

(3) Overall results

As shown in the above description, the heating load of EUP models increased a little bit compared to SP 1 model, however, the cooling load of EUP models highly decreased compared to SP 1 model. The energy performance of EP 3 and EP 4 model were decreased 21.8% compared to SP 1 model. [Figure 3]

Also, the heating load and cooling load of EUP models were improved compared to SP 2 model. The energy performance of EP 3 model and EP 4 model decreased 9.2% compared to SP 2 model. [Figure 4]

However, the sun shading effect by balcony cannot be evaluated in the research because of the limit of ECO2 software, which can be the reason to highly increase cooling load in summer.

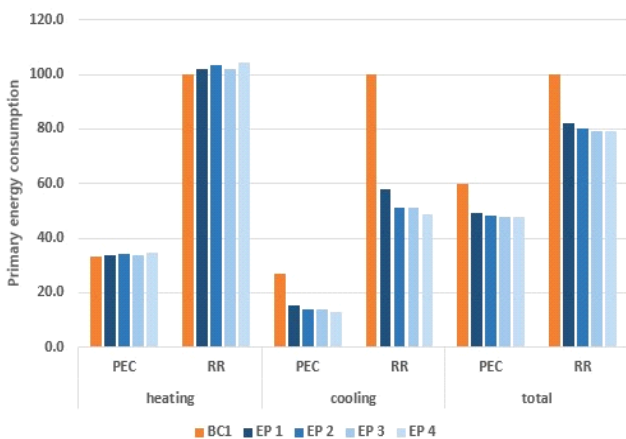


Figure 3. Comparison of primary energy consumption of EUP models to SP 1 model in the heating and cooling load (unit: PEC=(kWh/m², RR=%)

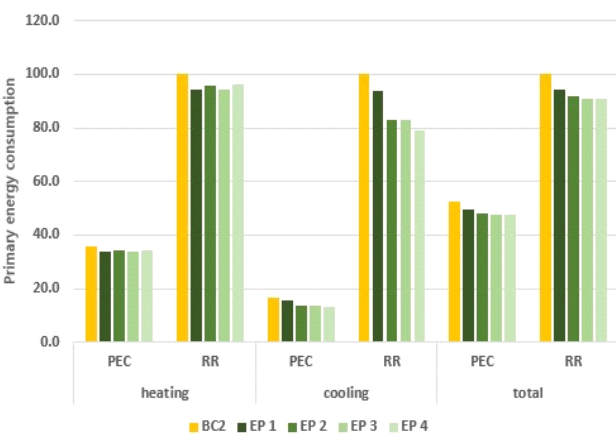


Figure 4. Comparison of primary energy consumption of EUP models to SP 2 model in the heating and cooling load (unit: PEC=(kWh/m², RR=%)

5. Conclusions

The energy performance of apartment unit plans was evaluated according to balcony conversion and window composition using ECO2 software. This research proposes basic data for energy effective apartment unit plans. The summaries of the research are

as follows.

(1) According to the evaluation results of the SUP and EUP models, the primary energy consumption of SP 2 model was decreased 4.7% compared to SP 1 model, and the primary energy consumption of EP 2, EP 3, and EP 4 models decreased 0.9%, 1.2%, and 2.1 % compared to EP 1 model, respectively.

(2) Energy performance of EUP models increased 1.1%~4.2% in heating load, and decreased 42.2%~51.5% in cooling load compared to SP 1 model that balcony windows were not installed.

(3) Energy performance of EUP models decreased 3.6%~5.6% in heating load, and 6.0%~21.1% in cooling load compared to SP 2 model that balcony windows were installed.

(4) In the research, however, the sun shading effects by balcony could not be calculated because of the limit of ECO2 software. So, the cooling load of SUP models might be excessively calculated in summer. Therefore, there should be additional study on it.

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