an office building which covers 33.8m³ (4.5m x 7.5m) with four occupants, assuming that LD-IDECOAS provides two spaces of the same model. Each occupant was assumed as doing minor work such as computer work according to the standard of ISO-7703 and it was aimed to generate sensible heat load of 75W and latent heat load of 75W. Outline of the object model is shown in Table 1 and peak cooling load in this research adopted load calculated with TRNSYS 16 program of the previous research. Peak sensible heat load and latent heat load calculated as object model were 4.5kW and 0.2kW respectively. Room condition of the object model was assumed as 24℃ of dry bulb temperature and 55% of relative humidity.

Table 1. *Physical information of simulation building*

Location	Seoul, Republic of Korea (TMY2 weather data)	
Room	4.5 x 7.5 x 2.6 m³ in each room	
Schedule	AM 9:00 ~ PM 6:00 for 5 days a week	
Heat gain	Room 1	Room 2
	Occupant - 4 persons	Occupant - 4 persons
	Lights - 439 W	Lights - 439 W
	Computer - 920 W	Computer - 920 W
U-value	Exterior wall	1.779 W/m²K
	Roof	2.074 W/m²K
	Window	1.4 W/m²K

(2) Gas fired water heating boiler model

Thermal load was calculated using thermal load and electric power load of LD-IDECOAS obtained from simulation performed at the previous research (Kim et al. 2013). To calculate load of boiler, a calculation formula provided by Energy plus Engineering Reference was adopted and Boiler Efficiency Curve (Equation 4) according to partial load was obtained after calculating partial load factor according to the capacity of boiler applying Part Load Ratio (PLR) in order to calculate total thermal load required by boiler. The amount of fuel used is calculable using calculated requiring thermal load, thermal efficiency of boiler and efficiency according to partial load (Equation 5). Fuel used in the boiler was propane gas being used for the current pilot system. In equation 4, the constants are used as follows, C_1= 0.626428326, C_2=0.645643582, C_3=-0.77720685, C_4= 0.313806701.

$$BoilerEfficiencyCurve = C_1 + C_2 \cdot (PLR) + C_3 \cdot (PLR)^2 + C_4 \cdot (PLR)^3 \qquad (4)$$

$$Fuelused = \frac{BoilerLoad}{(NomThermalEfficiency) \cdot (BoilerEfficiencyCurveOutput)} \qquad (5)$$

(3) Fuel cell model

Like thermal load used in gas fired boiler, thermal load of fuel cell was based on the load applicable to LD part which is a dehumidifying part of LD-IDECOAS and electric power load was based on the whole electricity required by LD-IDECOAS and a simulation was conducted with these conditions. In order to investigate the general movement of fuel cell or reaction of partial load, PEMFC model type 170 provided by TRNSYS 17 was adopted and the result of the simulation was modified for the products using 10kW of Fuel Cell Power which are actually to be installed. The performance of a fuel cell is defined as function of the thermodynamic potential, the activation overvoltage and the ohmic overvoltage. The basic expression for the output voltage of fuel cell is

$$U_{cell} = E + \eta_{act} + \eta_{ohmic} \tag{6}$$

$$E = 1.23 - 0.00085 \cdot (T_{stack} - 298) + 0.0000431 \cdot T_{stack} \cdot \ln(p_{H2} \cdot p_{O2}{}^{0.5}) \tag{7}$$

$$\begin{aligned} \eta_{act} &= -0.95 + 0.00243 \cdot T_{stack} + 0.000192 \cdot T_{stack} \cdot \ln(A_{PEM}) \\ &- 0.000192 \cdot T_{stack} \cdot \ln(I_{FC}) + 0.000076 \cdot T_{stack} \cdot \ln(C_{O2}) \end{aligned} \tag{8}$$

$$\eta_{ohmic} = \frac{-I_{FC} \cdot t_{PEM}}{A_{PEM}} \cdot \frac{8}{exp[3.6 \cdot \frac{T_{stack} - 353}{T_{stack}}]} \cdot [1 + 1.64 \cdot \frac{I_{FC}}{A_{PEM}} + \gamma \cdot (\frac{I_{FC}}{A_{PEM}})^3] \tag{9}$$

where, E is called Thermodynamic Potential and calculated by temperature of stack (T_{stack}) and partial gas pressure (p_{H2},p_{O2}) variable if based on Nernst equation. η_{act} is called Activation overvoltage and calculated by temperature of stack (T_{stack}), PEM area (A_{PEM}) and internal current (I_{FC}) and calculated in negative value as being loss value. $\eta_{ohmic}$is called Ohmic overvoltage and calculated by four variables such as temperature of stack (T_{stack}), PEM area (A_{PEM}), internal current (I_{FC}), PEM thickness (t_{PEM}) and transport number for water and shows negative value.

SIMULATION RESULT

(1) Solution heating load and electric load

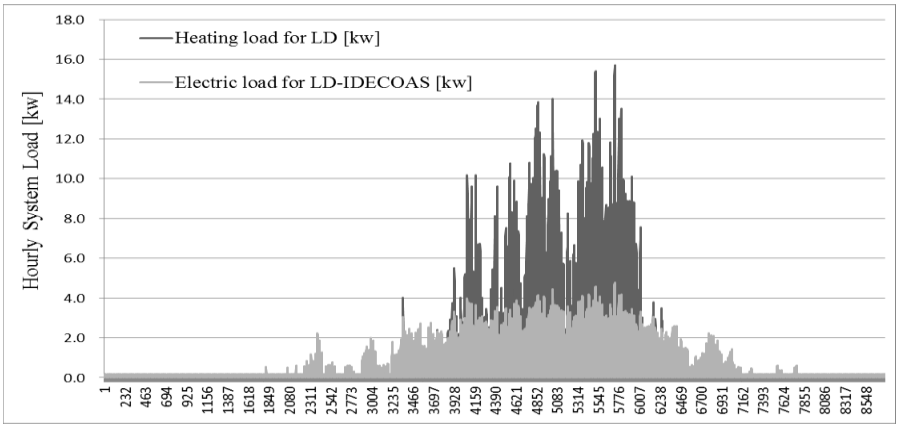

Figure 3. *Hourly load for LD-IDECOAS*

Simulation and energy analysis of this research were performed for 8,760 hours in total and LD-IDECOAS was analyzed as using 4,975kWh of electricity and 7,219kWh of heat annually. At this moment, the annual maximum thermal load is 15.7kW and the maximum electric power load is 4.8kW. Figure 3 shows an hourly profile of heating load and electric load used in LD-IDECOAS. With the nature of this system, the consumption of heat and electricity is huge during hot and humid summer so load is concentrated in summer season.

(2) Energy consumption

In this research, fuel consumption and purchased electricity of the boiler were compared with fuel consumption and the amount of electricity production of fuel cell. Table 2 illustrates the annual amount of energy consumed by boiler and fuel cell for each month. Since fuel cell was assumed to be operated based on thermal load, it showed that purchased electricity was required in few months except June, July, August and September. In table 2, shows a negative value is shown in red and parentheses. This means that the fuel cell is producing more electricity than the electricity required by LD-IDECOAS. At this point, the result of comparing the methods of using the existing gas fired water heating boiler and purchased electricity and fuel cell showed that fuel cell used gas 1.7 times more than the existing boiler system did yet was able to produce electricity 38% more annually than electricity required for operating LD-IDECOAS system.

Table 2. *Monthly fuel and electricity consumption*

Month	Based system		Proposed system	
	Propane [kg]	Purchased electricity [kwh]	LNG [m3]	Purchased electricity [kwh]
Jan	0.0	72.4	0.0	72.4
Feb	0.0	65.4	0.0	65.4
Mar	0.0	76.7	0.0	76.7
Apr	2.1	159.3	7.4	132.0
May	19.4	466.2	64.3	237.8
Jun	129.0	817.4	373.1	(337.7)
Jul	301.1	1059.5	793.2	(1088.3)
Aug	335.1	1113.3	866.7	(1158.6)
Sep	108.8	730.8	311.7	(219.3)
Oct	4.6	264.8	16.9	200.8
Nov	0.0	76.2	0.0	76.2
Dec	0.0	72.4	0.0	72.4
sum	900.0	4974.6	2433.8	(1870.2)

(3) Primary energy saving

Fuel consumption and electric consumption of boiler and fuel cell obtained with the simulation were converted into primary energy. Source-site ratio provided by ENERGY STAR was adopted as conversion factor. Source energy is a value where all the losses of various kinds of energy source used in commercial buildings from raw fuel condition until being used in a building were taken into account. Source-site ratio are used as follows, Electricity (Grid Purchase) =3.34, Natural gas=1.047, Propane=1.01. Figure 4 illustrates primary energy consumption and saving yearly. The result of calculation showed that primary energy consumption used 23.5% less energy compared with the use of the existing boiler.

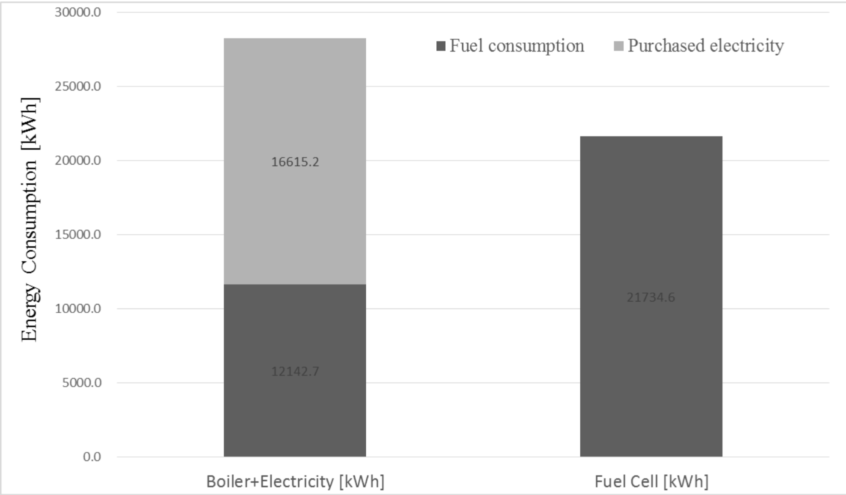

Figure 4. *Primary energy consumption*

(1) CO_2 emission

For analysis of CO_2 emission quantity, it was calculated with tCO_2 formula provided by IPCC (Intergovernmental Panel on Climate Change) and then compared. tCO_2 is calculable with the following Equation 10 to 12 and conversion factor of CO_2 provided by IPCC is used. The existing system was calculated based on fuel consumed by boiler and purchased electricity and improved system was obtained with the use of fuel consumed by fuel cell and of electricity remained after generation. The result of the calculation showed an effect of reducing approx. 9% of CO_2 emission annually.

$$toe = \text{Heating Value } (kcal)/(10^7\, kcal) \tag{10}$$

$$TC = toe(\text{Low Heating Value}) \times \text{carbon emission factor}(\frac{TC}{toe}) \tag{11}$$

$$tCO_2 = TC \times (\frac{44}{12}) \tag{12}$$

CONCLUSION

In this research, to construct an energy-saving system substituting for the existing boiler and purchased electricity, that provides thermal energy and electric energy necessary for LD unit of LD-IDECOAS, fuel cell which is able to generate heat and electricity simultaneously was selected. Accordingly, the effect of energy saving when using fuel cell and the effect of CO_2 emission reduction were analyzed quantitatively. If applying fuel cell to cover the amount of heat required by LD, approx. 70% more gas is consumed annually than that being consumed when using the existing gas fired water heating boiler and purchased electricity, however, it produces 40% more electric power. Resultingly, the result of conversion into primary energy consumption showed that fuel cell system reduced 23.5% of primary energy as well as 9% of CO_2 emission compared with the existing heat and electricity supply system. As a result, fuel cell can cover all necessary amount of heat required by LD-IDECOAS and directly generates electricity, there are a lot of advantages in both economic and environmental terms compared to purchasing electricity.

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REFERENCES

M.H. Kim, J.S. Park, J.W. Jeong*. 2013. Energy saving potential of liquid desiccant in evaporative cooling-assisted 100% outdoor air system, *Energy*, Vol.59, pp.725-736.

TRNSYS 17, 2012. TRaNsient SYstem Simulation program Volume 4

Energy Plus Engineering Reference, 2013. The Reference to Energy Plus Calculations

Nelson Fumo, Pedro J. Mago, Louay M. Chamra 2009. Energy and economic evaluation of cooling, heating, and power systems based on primary energy, *Applied Thermal Engineering*, Vol.29, pp.2665–2671

P. J. Mago, L. M. Chamra and A. Hueffed 2009. A review on energy, economical, and environmental benefits of the use of CHP systems for small commercial buildings for the North American climate, *Int. J. Energy Res*. Vol.33, pp.1252–1265

Kwang Ho Lee a, Richard K. Strand 2009. SOFC cogeneration system for building applications, part 1: Development of SOFC system-level model and the parametric study, *Renewable Energy*, Vol.34, pp.2831–2838

V. Dorer, R. Weber, A. Weber, 2005. Performance assessment of fuel cell micro-cogeneration systems for residential buildings, *Energy and Buildings*, Vol.37, pp.1132-1146

Mann R.F., Amphlett J.C., Hooper M.A.I., Jensen H.M., Peppley B.A. and Roberge P.R. 2000. Development and application of a generalized steady-state electrochemical model for a PEM fuel cell, *Power Sources* Vol.86, pp.173-180