An Analysis of City Gas Consumption According to the Building Orientation of Apartment Buildings - Focused on a Case in Ulsan -

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Abstract

Effective energy management of buildings is currently necessary because of accelerated global climate change and impending resource crises. In particular, in the case of South Korea, city gas consumption makes up 11.8% of the total energy; 39.6% of this energy is used residentially. Therefore, in order to reduce city gas consumption, more effective residential use is needed. To address this issue, the objective of this study is to analyze the differences in city gas consumption according to the building orientation in apartment buildings; in South Korea, these types of buildings are almost exclusively residential. To achieve this objective, an apartment complex with over 1,000 households was selected. Then, the real city gas usage data in households of either 59.97m^2 or 84.96m^2 were collected. Next, according to the building orientation (i.e., whether the household is south-east or south-west facing), the data were analyzed statistically. As a result, in the 59.97m^2 and 84.96m^2 households, the total city gas used in 2012 was 9.2% and 8.4% greater, respectively, in south-west facing apartments compared with households facing south-east. These results were proven to be statistically significant using the analysis of variance (ANOVA). In the future, the findings of this study can be used to develop prediction models for city gas consumption in apartment buildings.

Keywords: City gas amount; analysis of variance; apartment building; descriptive analysis

1. Introduction

1.1 Background and Objective

According to the 2014 energy balance table of South Korea, the energy consumption per capita was 5.56 TOE, which ranks 26th among OECD nations. This is because the energy supply burden has been increased due to the insufficiencies of consumer management and the energy market infrastructure (KEEI 2014; Ulsan 2014). In this respect, the government must effectively manage all industry areas at this time. The city gas consumption in 2013 was 24.878 x 10^6 TOE, which represented 11.8% of the total end-use energy. In addition, according to the Korea City Gas Association report, approximately 39.6% of the total city gas used in 2013 was consumed in the form of residential use. Therefore, more effective residential use of city gas is necessary (KCGA 2014).

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For effective energy management, zero-energy building applied optimal insulation and MEP (mechanical, electric, and plumping) equipment can utilized. To achieve more efficient buildings, the building orientation should also be considered because this is a key point for obtaining sufficient solar heat such that the sun can be utilized as a heating source (Suh and Kim 2011). In addition, connecting this passive strategy with the energy policies of South Korea can also help to reduce the energy costs of consumers (Song 2010). Since several buildings are often times arranged together in apartment complexes, the building orientation of these buildings is an important factor (Cho *et al.* 2002; Kang and Jang 2005).

Therefore, the objective of this study is to analyze the differences of city gas consumption according to the building orientation (e.g., whether an apartment faces south-east or south-west). To achieve this objective, an apartment complex with over 1,000 households was selected, and the city gas consumption data for this complex was collected. In the future, the findings of this study can be used to develop prediction models for city gas consumption in apartment buildings.

1.2 Methodology

Fig.1. shows the methodology of this study. First, an apartment complex with over 1,000 households with south-east and south-west facing locations is selected. Second, the real city gas consumption data for 59.97m^2 and 84.96m^2 apartments are collected because these exclusive dwelling areas are the general apartment area of South Korea while the number of samples are sufficient. The collected data are the annual gas consumption values for each individual dwelling area. Third, a descriptive analysis is conducted to analyze the differences in city gas usage. Fourth, a hypothesis is established to identify whether or not the results are statistically significant and ANOVA analysis is conducted. Fifth, the normality test is conducted to prove that the samples have a normal distribution. The basic data, such as city gas consumption and household/exclusive dwelling area information, are collected from the Korea City Gas Association.

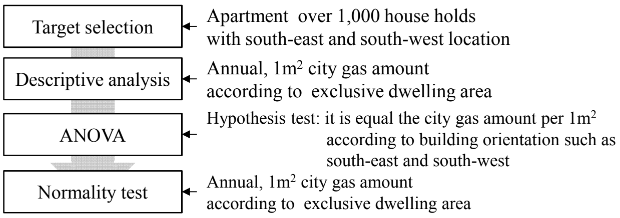


Fig.1. Methodology

2. Literature Review

2.1 Status of Ulsan

As shown in Table 1., Ulsan consumes 25,529,000 TOE, 12.27% of 208,120,000 TOE which is the total energy consumption amount, so it is the city that consumes energy the most, showing the highest consumption amount at the megapolis level and 37% of it is consumed by industry. We can see that population distribution and lifestyle have features of the industrial city.

Table 1. Energy Amount Consumption (Unit: 1,000 TOE)

Province	Industry	Transport	Residential and Commercial	Public	Total
Seoul	1,133	4,576	8,844	1,014	15,568
Busan	1,656	2,458	2,133	222	6,470
Daegu	1,284	1,266	1,726	159	4,434
Incheon	3,980	4,605	1,931	182	10,697
Gwangju	426	900	1,010	66	2,403
Daejeon	410	795	1,187	120	2,513
Ulsan	22,673	1,743	818	295	25,529
Whole Country	115,155	36,938	37,256	4,483	208,120

Source: 2013 Energy statistics annual report, Ministry of Trade

In addition, Ulsan has a 104.7% average supply rate of housing and 85% of it is apartment houses, furthermore its energy consumption is significantly greater than that of general housing. For the energy efficiency and reduction in fossil fuels of these central households, we can comprehend the pattern and quantitative amount of energy consumption by analyzing the amount of city gas currently consumed and this will help us review the estimated amount of alternative energy such as waste heat from industrial complexes of Ulsan that will be supplied to apartment houses in the future. Thus, this research selected Nam borough where the population is the largest among the 5 boroughs as a target for the energy analysis of apartment houses for households in Ulsan.

Furthermore, Table 2. shows the ratio of households by apartment house complexes in Ulsan. As a result of categorizing 65,633 households in a total of 379 complexes, the authors could see that the number of complexes with more than 300 households represents 62% of the total. Complexes with less than 100 households were 242, with generation taking up 15.2% although its number was many. So this research examined the amount of gas consumption of complexes with the highest generation numbers and especially targeted apartment complexes that use city gas by more than 1,000 households and selected A apartment complex which is the biggest in Nam borough.

Table 2. Apartment Households Proportion (Ulsan)

Division	Complex	Households	Proportion (%)
Under 100	242	9,967	15.2
101~300	84	15,061	22.9
301~500	20	8,187	12.5
501~700	16	9,805	14.9
701~1000	9	7,481	11.4
Over 1,000	8	15,132	23.1
Total	379	65,633	100.0

In the case of the energy resource of dwellings, it is largely electricity and city gas and the amount of city gas for apartment houses corresponds to hot water and heating excluding cooking. Concerning the trend of city gas, the consumption amount from July to August can be seen as the amount used for cooking rather than heating or hot water and the consumption amount in other seasons can be estimated to be for heating and hot water. Especially during December, January and February, winter shows a high consumption amount which indicates the heating load. Like the report that energy consumption amount by use in our country's households is divided into 44.2% for heating, 23.8% for hot water and 19.1% for electronic devices, we can see that most energy is consumed for heating and hot water. Therefore, this study focuses on city gas consumption as a heating resource.

Table 3. Nationwide City Gas Supply Ratio

Province	Ratio (%)	Households	Ratio (%)
Seoul	93	Gangwon	47.4
Busan	76.2	Chungbuk	56.2
Daegu	81.7	Chungnam	48.8
Incheon	89.5	Jeonbuk	59.3
Gwangju	84.2	Jeonnam	44
Daejeon	82.1	Gyeongbuk	51.5
Ulsan	86.3	Gyongnam	60.2
Gyeonggi	84	Jeju	6.2

Table 3. is the national penetration rate of city gas shown in a national major statistics index investigated by Ulsan in 2013. Eighty six point three percent of 422,177 households in Ulsan use city gas and this shows that a high city gas penetration rate following Gwangju, Seoul, Daejeon and Incheon in the country is steadily increasing. Therefore, analysis of city gas consumption amount becomes an index that can show the energy trend of housing facilities and through variance in city gas consumption amount, we can analyze various variables that affect other consumption amounts.

As mentioned above, 86.3% of Ulsan households use city gas and it can be said to be individual heating generation that uses city gas. Besides, according to the basic plan of city, household and environment organization in Ulsan in 2020, the city gas supply ratio will be bigger if gas supply in about 91 places, 6,537,000m^2 is included because they are still being developed or will be developed after being selected as the region for organization and re-development.

Moreover, creation of a society where energy consumption is low with high efficiency is being propelled for reinforcement of an escape from oil and independent energy among 10 policy directions for green growth of government, and since there is a plan to expand the supply of group energy such as the local heating of buildings, Ulsan needs to adopt measures for this. Therefore this research intends to comprehend the current situation in using city gas by targeting apartment complexes in Nam borough where gas consumption is the highest among apartment houses in Ulsan, in order to anticipate the amount of city gas consumed by apartment houses in the future and analyze the correlation of city gas consumption according to the exclusive dwelling area by selecting apartment complexes with more than 1,000 households.

2.2 Previous Studies

For effective energy use in residential buildings, various investigations looking into the relationship between energy and influential factors have been conducted. This research can be divided into two groups regarding the relationship between the building orientation and energy consumption.

First, some research has focused on the correlation between various factors of residential buildings and their energy consumption by analyzing the real data collected from sample buildings. For example, Kim (2005) analyzed the energy load according to the aspect ratio of selected buildings and Kim (2013) investigated the city gas consumption according to the floor plan.

Second, energy simulation studies have been conducted in an attempt to identify how much energy is consumed by using energy analysis programs. For example, to estimate the average consumption of city gas in apartment buildings in Seoul, Shim (2006) analyzed the simulation results obtained with the eQUEST program. Additionally, Jung (2006) analyzed the annual heating and cooling energy consumption according to site plan changes with an energy simulation program.

Likewise researches mostly conducted analysis and evaluation using energy analysis examined in design step and researches that measure the energy consumption amount from the maintenance management aspect regarding existing buildings are being carried out. Also, there have been several researches that collected and analyzed data on the consumption amount of actual city gas but researches on the statistical analysis of consumption amount of city gas by exclusive dwelling areas, which are the objective of this research are still lacking. In this study, real data were collected and analyzed. Additionally, the statistical significance of the results was determined via ANOVA analysis.

3. Data Collection Methods

In this study, statistical analysis was conducted with the city gas consumption data collected between January and December in 2012. As a target sample, the largest apartment complex in Ulsan that utilizes city gas as a heating source was selected. In addition, to minimize the impact caused by the physical characteristics of macroscopic variables such as completion year, MEP equipment, exclusive dwelling area, etc., sample households were intentionally selected in nine buildings within one complex. However, for a more accurate study, the controlled variables should be considered in future studies. Table 4. shows an overview of the selected target. This complex was built in 1999 and has a total of 1,302 households. The exclusive dwellings in this complex can be classified into five groups based upon their area: 40.80m^2, 59.97m^2, 81.87m^2, 84.96m^2, and 114.60m^2 apartments.

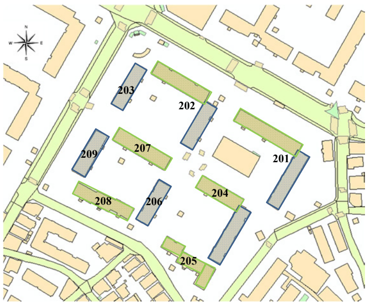
Table 4. Overview of Selected Target

Location	Yaeum-dong, Ulsan
Completion date	November, 1999
Households	1,302
Number of buildings	9
Floors	25
Heating source	City gas

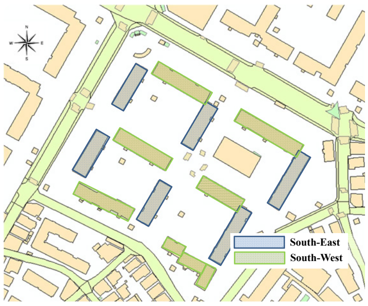
As shown in Fig.2.(a), the selected complex consists of 'ㅡ' and 'ㄱ' type buildings. The number of buildings of each type is three and nine, respectively.

In the case of the building orientation, this is classified into whether a household is south-east or south-west facing, as shown in Fig.2.(b). Buildings 201, 202, and 204 each have both directions.

Table 5. shows the number of households according to their building orientation. The number of households facing south-east and south-west are 558 and 744, respectively. In this study, the city gas consumption data of 59.97m^2 and 84.96m^2 apartments have a sufficient number of samples; the differences of their



(a)



(b)

Fig.2. (a) Selected Buildings (a) and (b) Building Orientation

annual and normalized (by area) consumption were analyzed. In addition, since various factors, such as the weather, income level, and environment, can all influence gas consumption, it is necessary to minimize the effect of these factors (Roh 2014). Therefore, an apartment complex with over 1,000 households with the same date of construction was selected and analyzed.

Table 5. Households According to Arrangement

Direction	Exclusive dwelling area (m^2)	Number of households
South-east	40.80	0
	59.97	184
	81.87	95
	84.96	279
	114.60	0
	Total	558
South-west	40.80	78
	59.97	246
	81.87	0
	84.96	234
	114.60	186
	Total	744

To analyze the city gas consumption, this study utilizes ANOVA analysis to identify whether or not the average differences of the two groups is statistically significant. The following hypotheses were established:

Hypothesis 1 (59.97m^2):

$$H_o: \mu_{CFE} = \mu_{CFW}$$
$$H_1: \mu_{CFE} \neq \mu_{CFW}$$

Where

μ_{CFE}: City gas amount (south-east)

μ_{CFW}: City gas amount (south-west)

Hypothesis 2 (84.96m^2):

$$H_o: \mu_{CEE} = \mu_{CEW}$$
$$H_1: \mu_{CEE} \neq \mu_{CEW}$$

Where

μ_{CEE}: City gas amount (south-east)

μ_{CEW}: City gas amount (south-west)

Hypotheses 1 and 2 represent whether or not the average differences of city gas consumption are statistically significant according to the direction (south-east and south-west) of the apartments (59.97m^2 and 84.96m^2). Hypothesis 1 states that the city gas consumption difference is statistically significant between the smaller (59.97m^2) south-east and south-west facing apartments, and Hypothesis 2 states that the city gas consumption difference is statistically significant between the larger (84.96m^2) south-east and south-west facing apartments.

4. Data Analysis

4.1 Descriptive Analysis

Table 6. shows the descriptive analysis for the annual consumption in 59.97m^2 apartments. The apartments where city gas consumption is 0 (due to external factors such as moving) were excluded; the number of selected households facing south-east and south-west is 182 and 245, respectively. As shown in Table 3., the average gas consumption of south-east facing households is 685.30m^3. Alternatively, the households that face south-west had an average gas consumption of 748.62m^3. In addition, the standard deviations were 329.86m^3 and 316.19m^3, respectively.

The skewness is a measure of the asymmetry of the samples' distribution. In this case, the south-east and south-west facing households show positive skews of 0.38 and 0.23, respectively. On the whole, this is similar to the normal distribution. Kurtosis refers to density level around the average. Because the south-east and south-west facing apartments show kurtosis values of -.35 and -.38, respectively, they both have platykurtic distribution.

Table 6. Descriptive Analysis of Total Gas Consumption: 59.97m^2 Apartments

Statistics	South-East	South-West
N	182	245
Mean	685.30	748.62
Median	678.36	749.40
Std. Dev	329.86	316.19
Skewness	.38	.23
Kurtosis	-.35	-.38

Table 7. shows the annual consumption of the 84.96m^2 apartments. The number of selected households facing south-east and south-west is 212 and 235, respectively. As shown in Table 7., the average gas consumption of the households facing south-east is 861.47m^3. Alternatively, the south-west facing households had an average gas consumption

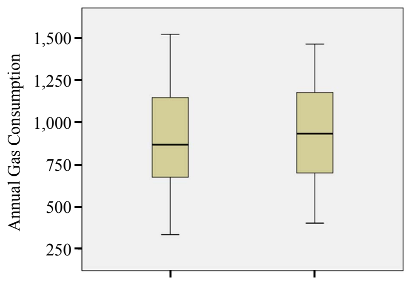
of 934.13m^3. The standard deviations were 292.33m^3 and 285.30m^3, respectively. These standard deviations decreased compared to the 59.97m^2 apartments. As for the skewness and kurtosis, the 84.96m^2 apartments also demonstrated a positive skew and platykurtic distribution, similar to the 59.97m^2 apartments.

Table 7. Descriptive Analysis of Total Gas Consumption: 84.96m^2 Apartments

Statistics	South-East	South-West
N	212	235
Mean	861.47	934.13
Median	848.29	933.75
Std. Dev	292.33	285.30
Skewness	.09	.02
Kurtosis	-.99	-.99

Fig.3. shows the box plot of the annual gas consumption in the 59.97m^2 and 84.96m^2 apartments according to their building orientation. The box plot clearly reconfirms that there is a difference in the averages of each type of exclusive dwelling. In detail, south-west facing households (59.97m^2 and 84.96m^2) consumed an increased amount of gas: 63.32m^3 and 72.66m^3, respectively. This shows that the households facing south-west consumed 9.2% and 8.4% more city gas, respectively, than the south-east facing households.

However, it is necessary to prove that these average differences are statistically significant; this was done through ANOVA analysis. In addition, we must also determine whether or not the selected samples are normally distributed (Kang and Rhee 2014).



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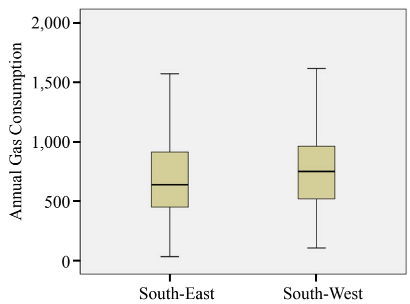


(b)

Fig.3. Box Plot of Annual Amount of Gas Consumption of (a) 59.97m^2 and (b) 84.96m^2 Apartments

To compare the city gas consumption of 59.97m^2 and 84.96m^2 apartments, it is necessary to analyze the annual consumption, as mentioned above. In addition, if the city gas is analyzed the consumption of annual city gas as a function of the household size (per m^2), it is possible to develop a prediction model for the gas consumption according to the size (area) of each exclusive dwelling through regression analysis. Thus the analysis should be considered in future studies.

Table 8. Descriptive Analysis of Normalized Gas Consumption: 59.97m^2 Apartments

Statistics	South-East	South-West
Mean	11.42	12.48
Median	10.64	12.49
Std. Dev	5.50	5.27
Skewness	.38	.23
Kurtosis	-.35	-.38

Table 8. shows the descriptive analysis of the normalized gas consumption (per m^2) of the 59.97m^2 apartments. The number of samples is the same as the number of annual samples of the 59.97m^2 apartments. As shown in Table 5., the south-east facing households consumed an average of 11.42m^3 of gas (per m^2 of the apartment). Alternatively, the households facing south-west consumed 12.48m^3 of gas (per m^2 of the apartment). The skewness and kurtosis values were the same as the annual consumption values because the same set of samples was used.

Table 9. Descriptive Analysis of Normalized Gas Consumption: 84.96m^2 Apartment

Statistics	South-East	South-West
Mean	10.61	11.99
Median	10.22	11.98
Std. Dev	3.44	3.35
Skewness	.09	.02
Kurtosis	-.99	-.99

Table 9. shows the consumption of 84.96m^2 apartments normalized to their area. As shown in Table 9., the normalized average consumption of households facing south-east and south-west was 10.61m^3/m^2 and 11.99m^3/m^2, respectively. Therefore, it is concluded that, according to building orientation, there is a clear difference in terms of city gas consumption per 1m^2 of 84.96m^2.

In addition, in the case of the comparison between annual total gas consumption (Tables 6. and 7.) and 1m^2 gas consumption (Tables 8. and 9.), it was shown that the annual total consumption of the 84.96m^2 apartments increased more than the 59.97m^2 apartments. However, it was shown that the consumption per 1m^2 of the 84.96m^2 apartments decreased more than the 59.97m^2 apartments. In other words, the authors determined that as the size (area) of an exclusive dwelling increases, the annual total gas consumption increases and the normalized gas consumption (per m^2 of the apartment) decreases.

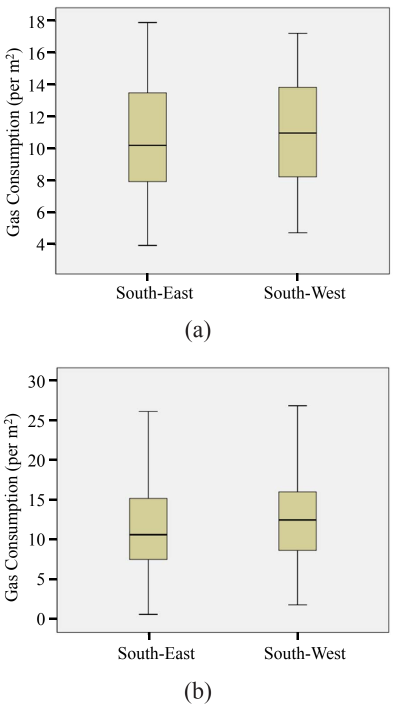


Fig.4. Box Plot of Normalized Gas Consumption for the (a) 59.97m^2 and (b) 84.96m^2 Apartments

Fig.4. shows the box plot of the normalized consumption for the 59.97m^2 and 84.96m^2 apartments. As shown in Fig.4., differences can be seen between the averages of the 59.97m^2 and 84.96m^2 apartments. In detail, in both the 59.97m^2 and 89.64m^2 apartments, south-west facing households have higher normalized gas consumption; these households consume 1.06m^3 and 1.38m^3 more, respectively, compared to their south-east facing counterparts. In other words, gas consumption was increased by 9.2% and 8.4% in each exclusive dwelling, similar to the results observed for the annual consumption. Additionally, we can see that the building orientation of the 59.97m^2 apartments has a greater impact on the normalized gas consumption compared to the 84.96m^2 apartments.

4.2 Analysis of Variance

To verify the hypotheses established in this study via descriptive analysis, ANOVA analysis was conducted. Table 7. shows the F-Test results of annual city gas consumption of the 59.97m^2 apartments according to their building orientation.

The p-value of the F-test can identify whether or not the collected data of two groups is statistically significant. As shown in Table 10., the p-value is 0.04; this means that the average difference between the two groups is statistically significant because the null-hypothesis has been rejected (p-value<0.05).

Table 10. F-test Results of Total Gas Consumption: 59.97m^2

	Sum of Squares	Df	Mean Square	F	Sig
Between Groups	418,724.82	1	418,724.82	4.03	.04
Within Groups	44,090,769.79	425	103,742.98		
Total	44,509,494.62	426			

Table 11. shows the F-test result of the annual city gas consumption in the 84.96m^2 apartments according to their building orientation. In this case, the p-value is 0.03. This suggests that the difference between these two groups is statistically significant.

Table 11. F-test Results of Total Gas Consumption: 84.96m^2

	Sum of Squares	Df	Mean Square	F	Sig
Between Groups	118,900.73	1	118.900.73	4.78	.03
Within Groups	37,078,614.14	445	83.322.72		
Total	37,197,514.87	446			

Tables 12. and 13. show the F-test results of the normalized city gas consumption in the 59.97m^2 and 84.96m^2 apartments. The p-values are 0.04 and 0.03 respectively. Therefore, it is confirmed that there are statistically significant differences, similar to the statistical significance in the annual consumption.

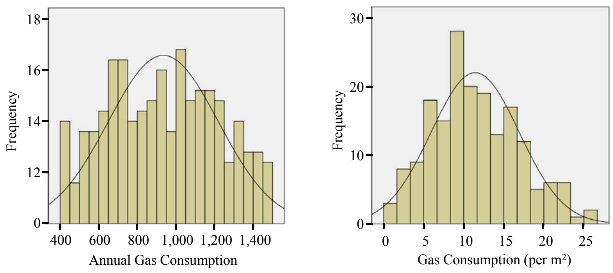
Table 12. F-test Results of Normalized Gas Consumption: 59.97m^2

	Sum of Squares	Df	Mean Square	F	Sig
Between Groups	116.42	1	116.42	4.03	.04
Within Groups	12,259.69	425	28.84		
Total	12,376.12	426			

Table 13. F-test Results of Normalized Gas Consumption: 84.96m^2

	Sum of Squares	Df	Mean Square	F	Sig
Between Groups	16.47	1	16.47	4.78	.03
Within Groups	5,136.82	425	3.46		
Total	5,153.29	426			

Although the average difference between the two groups can be identified through ANOVA analysis, the normality test is necessary to verify whether or not the collected data is normally distributed (Kang and Rhee 2014). In this study, the normality test is conducted to check the normality of the collected data. Generally, to check the goodness of fit of selected samples, the



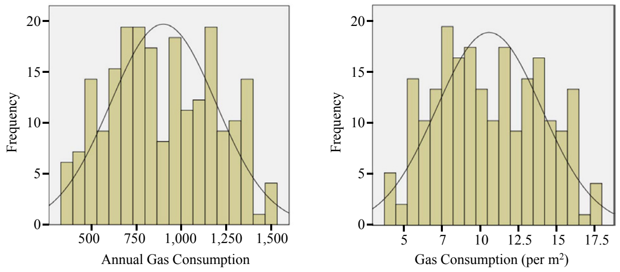
	Kolmogorov-Smirnov			Shapiro-Wilk		
Group	Statistic	df	Sig.	Statistic	df	Sig.
South-East	.063	182	.07	.982	182	.062
South-West	.038	245	.20*	.990	245	.102

*This is the lower bound of true significance.

Fig.5. Normality Test: 59.97m^2 Apartments

Kolmogorov-Smirnov and Shapiro-Wilk tests are used. The Kolmogorov-Smirnov test is typically used when there are more than 50 samples.

As shown in Fig.5., the residuals of the 59.97m^2 -apartment samples were analyzed. As a result, because the p-value of the Kolmogorov-Smirnov test is greater than 0.05, the null-hypothesis is accepted. This means that the residuals are normally distributed. In addition, the histogram shape of Fig.5.(a) is confirmed to be the normal distribution.



	Kolmogorov-Smirnov			Shapiro-Wilk		
Group	Statistic	df	Sig.	Statistic	df	Sig.
South-East	.07	212	.08	.973	212	.07
South-West	.06	235	.20*	.972	235	.13

*This is the lower bound of true significance.

Fig.6. Normality Test: 84.96m^2 Apartments

Fig.6. shows the results of the residuals in the 84.96m^2 apartments. As a result, because the p-value of the Kolmogorov-Smirnov test is greater than 0.05, the null-hypothesis is accepted, similar to the result for the 59.97m^2 apartments. The histogram also confirms that the residuals are normally distributed, as shown in Fig.6.(a).

5. Conclusion

The objective of this study is to analyze the differences in city gas consumption according to the building orientation of apartment buildings. Apartment buildings were the subject of this study because, in South Korea, these types of buildings are almost exclusively residential. To achieve this objective, an apartment complex with more than 1,000 households was selected. Then, the real city gas usage data in households of either 59.97m^2 or 84.96m^2 were collected. Next, according to the building orientation (i.e., whether the household is south-east or south-west facing), the data were analyzed statistically.

As a result, the authors determined that the annual city gas consumption of south-east facing households (both 59.97m^2 and 84.96m^2 apartments) is increased by 63.32m^3 and 72.66m^3, respectively, compared to south-west facing households. In the 59.97m^2 apartments, this gas consumption increase is 9.2% (relative to south-west facing apartments). The increase is 8.4% for south-west facing 84.96m^2 apartments. Additionally, the normalized city gas consumption of the south-west facing 59.97m^2 and 84.96m^2 apartments is increased by 1.06m^3 and 1.38m^3, respectively. This means that the normalized consumption of the 59.97m^2 apartments is larger than the consumption of the 84.96m^2 apartments. Finally, the authors performed ANOVA analysis to confirm that these results are statistically significant.

As mentioned above, 86.3% of Ulsan households use city gas and they can be said to be individual heating generation that uses city gas. Besides, according to the basic plan of city, household environment organization, in Ulsan in 2020, the city gas supply ratio will be bigger if gas supply in about 91 places, 6,537,000m^2 is included because they are still being developed or will be developed after being selected as the region for organization and re-development. Therefore, it is important to predict the city gas consumption of Ulsan. In the future, the findings of this study can be used to develop prediction models for city gas consumption in the apartment buildings of Ulsan.

The limitation of this study is that, although this data was collected and analyzed in nine buildings of one apartment complex in an attempt to minimize the impact of exterior factors, it is still necessary to verify and compare the authors' results with the data from other complexes.

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