Analysis of the Effectiveness of the Campaign for District Heating Energy Savings Considering Seasonal Influence

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ABSTRACT

This research presents the results of the analysis of the effectiveness of the heating energy saving campaign. In 2011, the Korea District Heating Corporation provided incentives to participating households that had achieved more than 5% savings from the previous year, computed by comparing their total district heating energy consumption for three months (Dec. 1, 2010 to Feb. 28, 2011) to the same season in the previous year. Approximately 1% of the households that were being supplied with heating energy participated in the campaign.

To calculate the energy savings, the outliers were investigated and revised according to the theory of the exploratory data analysis method. The heating energy savings were calculated by deducting the total heat energy consumption in 2011 from that in 2010. The energy savings had to be applied after the revision, according to the fluctuations in the outdoor temperature or the exogenous factors. The results were compared using a regression model that employed the annual trend and another regression model for the lowest temperature to analyze the relationship between the annual household heat energy sales volume and the temperatures.

The comparison results showed that the annual trend had a significant influence but the temperature had none. Therefore, the energy savings were calculated without considering the temperature effectiveness. The energy consumption excluded the fluctuations that were considered statistically insignificant after the calculated savings were statistically assessed. The calculated saved energy was 929.6 *Gcal* (6.94%) out of the total consumption of 932.3 *Gcal*, after the statistically insignificant savings were excluded.

1. Introduction

Heat demand is closely related to outdoor temperature fluctuations. This relationship has been proven in many studies. J. Paik et al. (2010) proposed a regression analysis model to estimate heat demand by determining the outdoor temperature, wind velocity, and previous day's demand as the input variables. In this research, the wind velocity, which affects the sensory temperature was moderately correlated with annual heat demand (0.302~0.515) and was strongly correlated with the outdoor temperature (the average temperature) at around -0.95. In J. Paik et al. (2010), two models were proposed and evaluated: a model that considers only the outdoor temperature, and another model that considered both the outdoor temperature and the previous day's demand. The predictive models were evaluated based on a *Mean Absolute Percentage Error* (*MAPE*) that does not exceed 5% of the prediction error, and the evaluation results showed that the second model (including the previous day's demand) was superior. Also, M. Kim et al. (2009) induced the heat demand predictions while considering the outdoor temperature in a back propagation model in an artificial neural network, and presented the errors at the ±5% level as the result, despite periodic differences.

While it is true that the outdoor temperature is one of the most important factors of heat demand, the evaluation of the factors that influence heat demand to this day is considered to be simple relational expression with the outdoor temperature if the annual temperature fluctuates insignificantly. Many studies have proven lately that the fluctuation of the annual temperature is insignificant. H. Chang et al. (2009) evaluated the temperature in Seoul, Korea as having significantly increased since 1964, and marked only an approximately 1.5°C increase in the last 48 years, mainly due to the temperature increases in winter. C. Park et al. (2011) presented, an analysis of fluctuations in the seasonal average temperature considering changes in the meteorological observation methods and found that the adjusted average temperature had increased from 0.58°C per decade before the revision to 0.62°C per decade after the revision(with most of the impacts in the winter seasons).

This research analyzed the impacts of a heat energy saving campaign implemented as a demand management project by the Korea District Heating Corporation. The study estimated the heat energy savings considering the influence of the outdoor temperature fluctuations. Our methodology investigated the effectiveness of the outdoor temperature by analyzing the relationship between heat demand and the outdoor temperature annually in winter (Dec., Jan., and Feb.), and proposes adjusted values for heat demand based on its relationship with the outdoor temperature. The results allowed a computation of savings and presentation of an analysis of the statistical verification of the significance of the estimates.

2. Research Data and Methods

2.1 Research Data

The Korea District Heating Corporation (KDHC) has been implementing an incentive system as a demand management project for households that had saved heat energy in winter in the application year, compared with the previous winter (For the success household (energy savings 5% or more), organic rice will be presented as a gift). The program was originally classified as a load management project from 2006~2010, but was recently reclassified as demand management/energy efficiency initiative. The project's target is improved energy demand management by encouraging the district heat energy users to save energy.

The project aims to give an incentive to households that had saved more than 5% in their energy consumption in the winter of 2011 (Dec. 2010 to Feb. 2011) compared with the winter in 2010 (Dec. 2009 to Feb. 2010). In the 2011 heat energy saving campaign, 0.9% of the eligible households participated (10,175 households of a total of 1,088,100 households receiving heat energy from KDHC) for a 0.9% participation rate.

Table 1. Current State of Participation by Households in the Energy Saving Campaign

District	Total No. of Complexes	Total No. of Households	No. of Participating Households	Participation rate (%)
Gyeonggi	1,167	632,805	6,336	1.00
Gyeongsang	189	143,436	2,260	1.58
Seoul	381	250,064	671	0.27
Total	1,841	1,088,100	10,175	0.94
Chungcheong	104	61,795	908	1.47
Total	3,682	2,176,200	20,350	0.94

2.2 Research Methods

2.2.1 Data Revision

This study investigated and revised the outliers of analysis data including exclusion of household observations with zero energy consumption 2010 and 2011 (due to the impossibility of calculating their energy consumption). Also, the household observations of outlier were excluded by comparing the distribution of their heat energy consumption in 2011 with that in 2010.

The outlier investigation can be divided into the classical *Exploratory Data Analysis* (*EDA*) method and the sensitivity analysis (Tukey, 1977). EDA provides mainly the method of exploration by distribution and classifies the average ± fourfold in the standard deviation, and the observation value exceeds the outer fence in the box plot as the outlier (Tukey, 1977). The sensitivity analysis was considered a methodology for calculating the influence on the model when each observation value was removed (Cook, 1986).

This research explored the outliers according to the characteristics of distribution as a classical method and excluded such outliers as detected from the analysis, as the research aims to calculate the energy consumption.

The *Interquartile Range* (*IQR*) is the difference of three quartiles and one quartile and refers to a measure to represent the degree of data spread out. The box plot is one of the powerful measures to exhibit the data characteristics, along with the *IQR* combination with the median-centric. At this time, the outlier of the data is expressed using $1.5 \times IQR$. In the normal distribution, one quartile and three quartiles appear as $\mu - 0.6745\sigma$ and $\mu + 0.6745\sigma$, respectively. That is, *IQR* was calculated as 1.349σ . In other words, $1.5 \times IQR$ had a larger probability of 0.349% than $\mu + 2.698\sigma$. As the outer fence appeared double-folded as $2 \times IQR$, the probability can be marked as zero (0), as it is separated by 4.7215σ from the population mean μ. Likewise, the probability that the standard deviation has a higher than ± 4 times value is considered 0 in fact (U. Baik, 1987).

2.2.2 Temperature Effectiveness Analysis

The linear regression model was applied to the expression of the relationship between the outdoor temperature and energy consumption. The linear regression model is a typical approach to analyzing annual trends. Figure 1 shows the process of analyzing the temperature effectiveness.

(1) Model Establishment	Model A: $y_t = \alpha + \beta_a \cdot t$ (t : 1, 2, …) Model B: $y_t = \alpha + \beta_b \cdot Atemp_t$ Model C: $y_t = \alpha + \beta_c \cdot Ltemp_t$ Where, Atemp: Average temperature Ltemp: Lowest temperature
↓	
(2) Model Performance Result	Model Suitability Statistics for Three Models - *F*-statistic - *R*-square and Adjusted *R*-square - *BIC* (*Bayesian Information Criterion*)
↓	
(3) Model Evaluation and Selection	The final model to be selected after examining each model evaluation statistic synthetically

Figure 1. Process of Analysis of Temperature Effectiveness

The *F*-statistic appears as a measure to assess the statistical validity of the regression models. The variance ratio, *F*, represents the test statistics and can be expressed as $F = MSR/MSE \sim F(k-1, n-k)$. Thus, *k* stands for the number of independent variables. *R*-square is explained as the size of the distributions of the regression models among the total distributions, has a value that is between 0 and 1, and is considered the estimated regression model that is suitable as the value approaches 1. *R*-square (R^2) was obtained via *SSR/SST*. As the value of *R*-square (R^2) tended to increase as more explanatory variables were added, the adjusted *R*-square was used to supplement the faults of R^2. The adjusted R-square was explained as $1-(n-1/n-p)\cdot(SSE/SST)$. The *Bayesian Information Criterion* (BIC) represents the information statistic for examining the suitability of the models according to the increasing numbers of the independent variables of the models and the data. BIC was explained as $n \cdot ln(SSE/n) + k \cdot ln(n)$. The following table shows the *Analysis of the Variance* (*ANOVA*) Table. *n* represents the number of data.

Table 2. The Analysis of the Variance Table

Source	*Sum of Square*	*Degree of freedom*	*Mean Square*	*F*
Model	*SSR*	*k-1*	*MSR = SSR/(k-1)*	*MSR/MSE ~ F (k-1, n-k)*
Error	*SSE*	*n-k*	*MSE = SSE/(n-k)*	
Total	*SST*	*n-1*		

We developed three models. Model A excludes temperature fluctuations. Model B includes average temperature and Model C includes lowest temperature as explanatory variables. Then we compared the goodness-of-fit statistics for the three models. If the goodness-of-fit of the models, considering the temperature, appears much greater than that of Model A, the result of the revision of the annual energy consumption with the temperature should be applied.

2.2.3 Savings Calculation

Savings are defined as the quantity obtained by deducting the energy consumption in 2011 from that in 2010. At this time, the energy consumption in 2011 is applied after revising it according to the temperature fluctuations or the exogenous factors. Moreover, the energy consumption is required to calculate the savings per group after dividing it into a few different groups, as the apartments show absolutely different energy consumption values according to area. The savings for a specific energy consumption section *h* is expressed as follows:

$$\begin{aligned} E_{Savings} &= \left\{ \sum_{i=1}^{n_h} EC_{hi,2010} \right\} - \left\{ \sum_{i=1}^{n_h} EC_{hi,2011} \right\} \\ &= n_h \cdot EC_{Avg.Diff.} \\ &= n_h \cdot \left\{ \overline{EC_{h,2010}} - \overline{EC_{h,2011}} \right\} \end{aligned}$$

where, $E_{Savings}$: Energy Savings

EC : Energy Consumptions

$EC_{Avg.Diff.}$: Difference of Average Energy Consumptions

Thus, *h* is a subscript that represents the energy consumption section, *i* is a subscript that represents the individual households in group *h*, and n_h stands for the total number of households in group *h* and $\overline{EC_{h,year}} = \left(\sum_{i}^{n_h} EC_{hi,year} / \sum_{i}^{n_h} N_{hi,year} \right)$, where $N_{Households}$ is the number of household.

2.2.4 Assessment of the Calculated Energy Savings

The paired t-test, which compared the average difference between the paired samples, was used to assess the statistical significance of the calculated energy savings. It was assumed that "there was not much difference in the average heating energy consumption before and after the participation in the campaign." In other words, it is explained as $H_0 : \mu_1 = \mu_1 (= D) = 0$ All the D_i values that were produced from the difference in the heat energy consumption per household before and after the participation, X_{1i} and X_{2i}. The null hypothesis (D) follows a normal distribution that shows the symmetry centrically at 0 when those X_{1i} and X_{2i} values follow the normal distribution. The statistic was calculated as $\hat{T} = \frac{\overline{D}}{S_D / \sqrt{n}}$, and the degree of freedom conducts the verification using the (household-1) *t*-distribution (provided that in case the number of households exceeds an appropriate level (more than 25 households in general), the standard normal distribution is assumed). Thus, the formula can be set as $\overline{D} = \sum_{i=1}^{n} D_i$ and $S_D = \sqrt{\sum_{i=1}^{n} \frac{(D_i - \overline{D})^2}{n-1}}$.

3. Energy Savings Results

3.1 Data Revision Results

A total of 339 household observations with zero (energy consumption in either 2010 or 2011) were excluded from the analysis leaving data from 9,836 households to be analyzed.

Table 3. Current State of Households that Had 0 Heat Energy Consumption

<table>
<tr><th rowspan="2">Description</th><th rowspan="2">No. of Participating Households</th><th rowspan="2">2010 Energy Consumption = 0</th><th colspan="2">2010 Energy Consumption > 0</th></tr>
<tr><th>2011 Energy Consumption = 0</th><th>2011 Energy Consumption > 0</th></tr>
<tr><td>Gyeonggi</td><td>671</td><td>142</td><td>58</td><td>6,136</td></tr>
<tr><td>Gyeongnam</td><td>6,336</td><td>43</td><td>17</td><td>1,169</td></tr>
<tr><td>Daegu</td><td>908</td><td>27</td><td>12</td><td>992</td></tr>
<tr><td>Seoul</td><td>1,031</td><td>21</td><td>5</td><td>645</td></tr>
<tr><td>Chungbuk</td><td>1,229</td><td>10</td><td>4</td><td>894</td></tr>
<tr><td rowspan="2">Total</td><td rowspan="2">10,175</td><td>243</td><td>96</td><td rowspan="2">9,836</td></tr>
<tr><td colspan="2">339</td></tr>
</table>

The data that exceeded four times the standard deviation of the average rate of curtailment were excluded. The rate of curtailment of each household was defined as ($EC_{i,2011} / EC_{i,2010} - 1$), and the guidelines for excluding the outlined data are as follows.

- $Minimum\ Guideline = Average - 4 \times Standard\ \ Deviation = 0.3115 - 4 \times 5.953 = -23.5005$
- $Maximum\ Guideline = Average + 4 \times Standard\ \ Deviation = 0.3115 + 4 \times 5.953 = 24.1235$

Table 4. Guidelines for Verification of Outliners

No. of	Average	Standard	Min.	Max.	Average ± 4×(Standard

Households		Deviation	Value	Value	Deviation)	
					Min.	Max.
9,836	0.312	5.953	-0.997	279	-23.501	24.124

The exploration of the outliners resulted in a total of 9,811 remaining households after 25 households were deducted from the data.

3.2 Analysis of the Temperature Effectiveness

The heat energy sold for household consumption in the winter has been increasing each year (by 4.6% per year on the average). The conversions to the daily average sales quantity were used to analyze the temperature effectiveness, excluding the influence on the leap year.

Table 5. Annual Energy Sales and Temperature Data

Year (Winter)	Energy Sales	No. of Days	Average Daily Sales	Variation Rate	Average Temperatur e	Minimum Temperatur e
2007 (2006.12 - 2007.2)	4,368,600	90	48,540	-8.3%	1.4	-6.4
2008 (2007.12 - 2008.2)	5,004,440	91	54,994	13.3%	1.8	-9.0
2009 (2008.12 - 2009.2)	4,962,473	90	55,139	0.3%	1.1	-10.8
2010 (2009.12 - 2010.2)	5,591,841	90	62,132	12.7%	-1.0	-12.3
2011 (2010.12 - 2011.2)	5,960,875	90	66,232	6.6%	-1.3	-7.1

(Source of the energy sales: Website of KDHC; source of the average and minimum temperatures: website of the Korea Meteorological Administration)

Figure 2 shows the development of the daily heat energy sales, the average temperature, and the minimum temperature. While the average temperature and the daily heat energy consumption show an inverse relationship, the minimum temperature shows a tendency to be unrelated to the daily consumption.

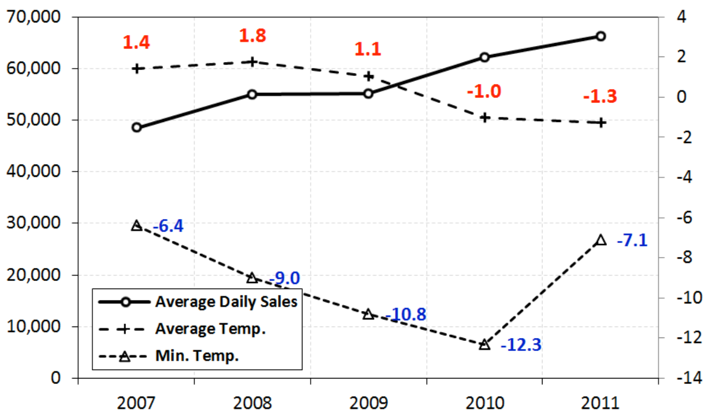

Figure 2. Annual Energy Sales and Temperature Tendency

As described earlier in the Methodology, the three models that considered the temperature and that did not consider it are defined hereafter. The variable y_t refers to the daily average energy sales in year *t*.

Model A: $y_t = \alpha + \beta_a \cdot t$ $(t: 1, 2, \ldots)$
Model B: $y_t = \alpha + \beta_b \cdot Atemp_t$ ($Atemp$: Average Temperature)
Model C: $y_t = \alpha + \beta_c \cdot Ltemp_t$ ($Ltemp$: Lowest Temperature)

The results of three different regression models are shown in Figure 3.

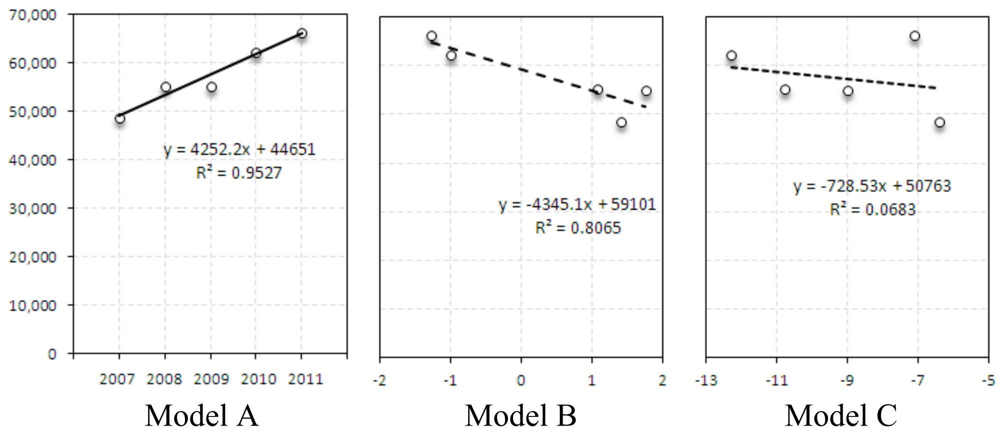

Figure 3. Regression Analysis Results

The evaluation of each model in the statistic showed that the basic model, Model A, is superior to the other models in which alternative specifications of temperature variations were incorporated. Model C appears inappropriate, as its result is statistically insignificant and its R^2 is 6.8%, close to 0%. Model A's R^2 is 95.3% and its adjusted R^2, 93.7%, and Model B significantly differs with an R^2 of 80.7% and an adjusted R^2 of 74.2%. As a result, Model A was determined as superior.

Table 6. Model Evaluation Results

Model	*F*-statistic	*P*-value	R^2	Adjusted R^2	*RMSE*	*BIC*
Model A	60.38	0.004	95.3%	93.7%	1,730.5	75.23
Model B	12.50	0.039	80.7%	74.2%	3,498.8	82.27
Model C	0.22	0.671	6.8%	-24.2%	7,677.5	90.13

The basic model, Model A, was deemed to be the most significant model. The estimated regression equation was explained as $y_t = 44{,}651 + 4{,}252 \cdot t$. According to this equation, the average daily energy consumption *i* winter 2012 (*t* = 6) was estimated as 70,163 *Gcal*/day. Therefore, the total energy sales in winter 2010 were approximated as $70{,}163 \times 91\, days = 6{,}384{,}833$ *Gcal*.

Table 7. Model Evaluation Method

Statistic	Evaluation Method	Model Evaluation Results		
		Model A	Model B	Model C

F-statistic and P-value	P-value less than 0.05	◎	○	X
R-square	Explanation power increases as it approaches 100%	◎	○	X
Adjusted R-square	Explanation power increases as it approaches 100%	◎	○	X
RMSE (Root of the mean square error)	Better if smaller (Distribution of Error)	◎	△	△
BIC (Bayesian Information Criterion)	Better if smaller (Suitability of the Model)	◎	△	△

◎: Very Good, ○: Good, △: Normal, X: Bad

As a result, the relationship of the temperature effectiveness and the energy consumption remains inferior to Model A based on the annual trend. Therefore, the savings were calculated without revising the temperature effect.

3.3 Calculated Energy Savings

The energy savings were calculated as follows: first, the heating energy consumption in winter 2010 was set as the basis; second, the average energy consumption per household was calculated for 2010 and 2011, respectively; third, the difference between 2010 and 2011 was drawn; fourth, the energy savings were calculated by multiplying the number of households; and last, the weights of the energy savings compared to 2010 were calculated.

The analysis showed that the total energy consumption was determined as 6.96% (932.3 *Gcal*). Table 8 shows the detailed calculations of the energy savings per consumption section based on 2010. The energy savings were detected in the household groups that used less than 700*Mcal* and more than 2,500*Mcal* energy, and were found to have been insignificant in the other household groups, using 700-2,500*Mcal* energy.

Table 8. Energy Saving Consumption Details

Sub-group of energy consumption (*Mcal*)	No. of Households (a)	Average Energy Consumption (*Gcal*/household)			Savings Rate (d / b)
		2010 (b)	2011 (c)	Difference (d = b - c)	
Less than 400	5,717	0.14	0.14	0.002	1.43%
400-700	606	0.51	0.46	0.046	9.02%
700-1,000	210	0.84	0.99	-0.155	-18.45%
1,000-1,500	273	1.26	1.53	-0.267	-21.19%
1,500-2,000	307	1.76	2.03	-0.272	-15.45%
2,000-2,500	388	2.26	2.32	-0.059	-2.61%
2,500-3,000	402	2.75	2.71	0.040	1.45%
3,000-3,500	381	3.25	3.14	0.106	3.26%
3,500-4,000	349	3.75	3.42	0.328	8.75%
4,000-4,500	279	4.24	3.75	0.487	11.49%
4,500-5,000	220	4.74	4.08	0.660	13.92%
5,000-6,000	328	5.48	4.87	0.608	11.09%
6,000-7,000	181	6.44	5.57	0.866	13.45%
7,000-8,000	85	7.43	6.06	1.366	18.38%
8,000-9,000	41	8.50	7.06	1.439	16.93%
9,000-10,000	25	9.52	6.92	2.596	27.27%

More than 10,000	19	15.96	12.87	3.090	19.36%
Total	9,811	1.37	1.27	0.095	6.93%

3.4 Assessment of the Calculated Energy Savings

The average energy consumption was recorded as 0.095 *Gcal*. The results of the paired *t*-test showed that the energy savings appeared to have had a *P*-value that was much smaller than 0.05 and that the confident sections do not contain 0. Thus, the results were analyzed as statistically significant. In other words, this means the energy savings were not achieved by accident.

Table 9. Results of the Statistical Assessment of the Total Energy Savings

No. of House-holds	Average	Standard Deviation	Standard Difference	*95% CI*		Degree of Freedom	Statistic	*P*- value
				Min.	Max.			
9,811	-0.095	0.89	0.009	-0.11	-0.08	9,810	-10.6	< 0.0001

3 groups (less than 400Mcal, 2,500~3,00Mcal, over 10,000Mcal) in the energy consumption savings per group were statistically not significant (P-value greater than 5%). Although these groups were found to have had energy savings, such savings are considered to have been achieved by accident, or, to be more exact, these groups had 0 savings.

The results of the statistical verification of the energy savings showed that the savings (1.2% of 9.5 *Gcal*) of the group that used less than 400Mcal energy were statistically more significant than the savings (1.46% of 16.2 *Gcal*) of the other group that used 2,500-3,000*Mcal* energy. On the other hand, the increase in the energy consumption [calculated as 2.6% (23 *Gcal*)] for the section between 2,000 and 2,500 *Mcal* was also considered statistically invalid.

Table 10. Results of the Statistical Verification of the Energy Consumption Savings per Group

Sub-group of energy consumption (*Mcal*)	No. of House-holds	Ave-rage	Standard Deviation	Standard Differ-ence	*95% CI*		Degree of Free-dom	Statis-tic	*P*-value
					Min.	Max.			
Less than 400	5,717	0.00	0.22	0.00	-0.01	0.00	5,716	-0.57	0.28
400-700	606	-0.05	0.46	0.02	-0.08	-0.01	605	-2.48	0.01**
700-1,000	210	0.16	0.95	0.07	0.03	0.28	209	2.37	0.01**
1,000-1,500	273	0.27	1.11	0.07	0.13	0.40	272	3.97	< 0.001**
1,500-2,000	307	0.27	1.20	0.07	0.14	0.41	306	3.97	< 0.001**
2,000-2,500	388	0.06	0.97	0.05	-0.04	0.16	387	1.21	0.11
2,500-3,000	402	-0.04	0.95	0.05	-0.13	0.05	401	-0.85	0.20
3,000-3,500	381	-0.11	1.14	0.06	-0.22	0.01	380	-1.81	0.04**
3,500-4,000	349	-0.33	1.11	0.06	-0.44	-0.21	348	-5.54	< 0.001**
4,000-4,500	279	-0.49	1.16	0.07	-0.62	-0.35	278	-6.99	< 0.001**
4,500-5,000	220	-0.66	1.50	0.10	-0.86	-0.46	219	-6.53	< 0.001**
5,000-6,000	328	-0.61	1.52	0.08	-0.77	-0.44	327	-7.26	< 0.001**
6,000-7,000	181	-0.87	1.75	0.13	-1.12	-0.61	180	-6.65	< 0.001**
7,000-8,000	85	-1.37	2.01	0.22	-1.80	-0.93	84	-6.25	< 0.001**

8,000-9,000	41	-1.44	1.89	0.30	-2.04	-0.84	40	-4.87	< 0.001**
9,000-10,000	25	-2.60	2.56	0.51	-3.65	-1.54	24	-5.06	< 0.001**
over 10,000	19	-3.09	7.14	1.64	-6.53	0.35	18	-1.89	0.04**

** is statistically significant at the significance level of less than 5% (by one side t-test).
* is statistically significant at the significance level of less than 10% (by one side t-test).

5. Conclusion

The calculation of the net energy consumption savings needs to be calculated relative to a baseline, and the computations in this paper used models incorporating temperature variations to develop that baseline. The baseline adjustments are an important step in deriving defensible energy savings estimates. The modeling work showed that savings of 932.3 *Gcal* - (9.5 *Gcal* + 16.2 *Gcal*) + 23 *Gcal* = 929.6 *Gcal* (6.94%) were achieved after excluding the savings of 9.5 Gcal (1.2%) of the section that used less than 400 *Mcal*, the savings of 16.2 *Gcal* (1.46%) of the section that used 2,500-3,000 Mcal, and the increase of 23 *Gcal* (2.6%) in the section that used 2,000 and 2,500 *Mcal*.

This thesis found that although the heat energy consumption is closely related to the temperature, annual temperature fluctuations are minor and are statistically significant as an explanatory variable. As a result, other factors were proposed to be considered to explain fluctuations in annual energy consumption other than the temperature fluctuations. Also, the calculated energy savings were statistically analyzed, and the effectiveness of the energy saving effects of the campaign according to the results was assessed.

The results of study will be provided that the energy savings for each participating generation will have the motivation. By induction to practice energy conservation, not only energy consumption can be reduced but also improvement of the national energy saving policy can be contributed.

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