Study on the Change of South Korea Outdoor Design Temperature according to the Assigned Period

A Young Nam, Jong Jun Park, Young Il Kim, and Kwang Seop Chung

Abstract—**Outdoor design temperature is important for selecting the proper capacity of heating and cooling systems of a building to save building energy. The purpose of the study is to investigate the change of South Korea outdoor design temperatures according to the assigned period. When heating design temperature was calculated by 8-year period, Seoul region was found to be the lowest at -10.86℃ with data period from 1982 to 1989, while Jeju region was the highest at 1.57℃ with data period from 1988 to 1995. When cooling design temperature was calculated by 8-year period, Daegu region showed the highest at 33.54℃ with data period from 1988 to 1995, while Incheon region showed the lowest at 29.48℃ with data period from 2008 to 2015. As for the correlation between heating design temperature and mean temperature, Gwangju and Jeju were found to be lower than 0.5, with 0.2798 and 0.2777, respectively, showing little correlation with the mean temperature. However, as for the correlation between cooling design temperature and mean temperature, Gwangju and Jeju were found to be higher than 0.5, with 0.6822 and 0.7879, respectively, showing strong correlation with mean temperature.**

Index Terms—**Outdoor design temperature, bin method, technical advisory committee (TAC).**

I. INTRODUCTION

In Paris Agreement, in which many countries participated, South Korea submitted a contribution plan aiming at the 37% reduction of carbon emission by 2030, and the Korean government is contemplating the reduction plan of carbon emission to achieve the goal [1]. For residential buildings, it is HVAC (Heating, ventilating, and air conditioning) that accounts for most of the energy consumption as shown in Fig. 1 [2]. The climate of South Korea requires much energy in heating and cooling due to the coexistence of summer and winter. It is necessary to use climatic design temperature properly lest there should be over or under capacity of the heating and cooling systems.

This study is about the change of the outdoor temperature of South Korea according to the assigned period and its effect on the capacity of heating and cooling systems. Outdoor temperatures are important for calculating heating and cooling loads. The design temperatures are calculated using Bin Method proposed by American Society of Heating, Refrigerating and Air-conditioning Engineers (hereinafter, referred to as 'ASHRAE').

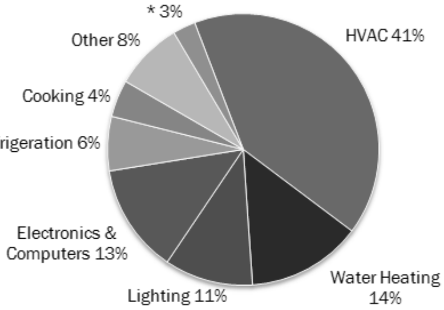

Fig. 1. Residential buildings total energy end-use in 2010.
*This chart includes an adjustment factorused by the EIA to reconcile two datasets.

II. CLIMATIC DESIGN TEMPERATURE

A. Definition of Climatic Design Temperatures for Heating and Cooling

If an air conditioning system of a building is designed using the highest temperature of the region, the capacity of the equipment could be over-designed since it is based on the weather conditions that have extremely slim probability of annual occurrence.

To prevent a system from being over-designed due to the extreme condition, ASHRAE first presented use of heating and cooling design temperatures by applying the concept of exceeding probability. These will then make the system from being over-designed. Also, these keep the room pleasant at the same time by calculating heating and cooling loads effectively [3].

The temperature which applies the concept of exceeding probability is calculated by the method of calculating the outdoor temperature from a cumulative curve [4]. It counts excess frequency rate from the curve based on the hourly measured weather data. The excess frequency rate is below certain percent of the curve, by 0.4%, 1.0%, or 2.0% [3]. This temperature is called TAC (Technical Advisory Committee) temperature. TAC temperature is lower than the highest temperature in summer and is higher than the lowest temperature in winter. These will reduce the temperature difference between outdoor and indoor. So, it can be said that the TAC temperature contributes to energy-saving. TAC temperature makes it possible to lessen equipment capacity, cut back on initial investment cost, and improve equipment efficiency in the event of partial load by determining equipment capacity [3].

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B. Climatic Design Temperature Types

As for calculating heating and cooling design temperatures in South Korea [5], the Equipment Manual of the Society of Air-Conditioning and Refrigerating Engineers of Korea (SAREK) presents two representative values. The first one is designated by the Ministry of Land, Infrastructure and 7UDQVSRUW KHUHLQDIWHU UHIHUUHG WR DV µ02/,7¶ [6], which is shown in Table I, and these values are the outdoor condition calculated by ASHRAE based on seasonal (summer and winter) TAC 2.5% during the statistical period from 1983 until 1994 [7].

TABLE I: MOLIT STANDARD DESIGN OUTDOOR TEMPERATURE

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The second value was presented by ASHRAE, and initially, this value was calculated as a pair of dry bulb & web bulb temperature data on the basis of summer time (June to September, 2,928 hours) percentiles 1.0%, 2.5%, and 5.0%, and winter time (December to February, 2,160 hours) percentiles 99.0% and 97.5% [5]. However, from 1997, ASHRAE made it a rule to decide outdoor conditions using 0.4%, 1.0% and 2.0%, marking the percentiles of the yearly total 8,760 hours for cooling design temperature, and using 99.6% and 99.0%, marking the percentiles of the yearly total 8,760 hours for heating design temperature. This method is called as ASHRAE Bin Method, and generally ASHRAE recommends the use of outdoor conditions by calculating climatic design temperature off by 1.0% from the extreme value [8].

The heating and cooling design temperatures which MOLIT presented for heating and cooling design, is the value calculated with the data in the past. The study is intended to calculate the outdoor climatic design temperature with changing the weather data period for calculation by ASHRAE Bin Method which is internationally used.

The study compares the TAC temperature difference between seasonal and yearly calculation. Also it examines the trend of changing temperature, and finds the relationship between TAC temperature and the mean temperature.

III. THE METEOROLOGICAL STATION FOR MEASURING OUTDOOR TEMPERATURE AND MEASUREMENT METHOD

The Korea Meteorological Administration (hereinafter UHIHUUHG WR DV µ.0$¶ LV SURYLGLQJ WKH ZHDWKHU GDWD PHDVXUHG at each weather station online free of charge. The surface weather observation at the KMA is implemented through automatic observation based on Automated Synoptic 2EVHUYLQJ 6\VWHP KHUHLQDIWHU UHIHUUHG WR DV µ$626¶ DQG passive observation by eye observation. The outdoor temperature and other weather conditions are measured by installing ASOS at each public meteorological station controlled by KMA. The temperatures are measured at a public meteorological station at the height of about 1.2-1.5m above ground (or the surface of deep snow), which are automatically observed by the platinum resistance thermometer [9]. The study collected the observed data online, and used them in this paper.

IV. ASHRAE BIN CALCULATION METHOD

A. Weather Data Acquisition and Checking Number of Data

The actual measured weather data are acquired through the KMA-operated weather data open portal site [9]. The design temperatures for heating and cooling are calculated using Bin Method proposed by ASHRAE. ASHRAE recommends the use of minimum 8 year hourly data for the purpose of calculating the heating and cooling design temperatures, and more than 85.0% of the monthly data should be obtained at the least. The study acquired the hourly measured outdoor temperature data from 1982 to the recent year of 2015. The measured data were checked for abnormality [10].

B. Pseudo Counts Calculation

It is necessary to arrange the acquired data by month. Also, it is important to check whether monthly arranged data are up to more than 85.0%; also, it is desirable to give a weighted value by calculating Pseudo Counts (P.C.) to prevent data from being lopsided due to non-measured data [10].

Equation (1) is the formula for finding P.C. It should be found by dividing the QXPEHU expected R hourly data in a month by the number of actually hourly measured month data [10]. For example, the total number of data acquired in November from 2008 until 2015 should be 5,760 (24 hour u 30 day u8 year), but the number of actual measured data is 5,758, then the value of P.C. becomes 1.000347 with 5760 divided by 5758.

$$\text{Pseudo Counts} = \frac{\grave{U}}{\acute{U}} \qquad (1)$$

C. Setting up Bin Interval and Calculation of Final Bin Range Value

Divide each temperature range in the ascending order with a Bin interval as 0.5 , or 1.0 S by finding the minimum and maximum value of total acquired data [10]. After that, count the number of data belonging to each temperature range. Multiply the Bin range data by P.C. For example, the number of the Bin range data from above 1.0 to below 1.5 is 100 among the number of 5,758 data acquired in November from 2008 until 2015. The final Bin range value is 100.0347 through the application of the previously found P.C, 1.000347. [10].

D. Cumulative Distribution Function Counts & Calculate Climatic Design Temperatures

Add all individual monthly calculated final Bin range values according to the same temperature Bin range. It means adding the whole 12 month ¶ values for each Bin ranges. Next, accumulate the final Bin range values from the lowest to the highest temperature range consecutively. The accumulated values show the whole period of one year with at least 8-year data.

Calculate the design temperatures for heating and cooling using the accumulated values through Cumulative Distribution Function (CDF) [10]. Find the number (Z) that belongs to the certain percentage (%) of the total accumulated values. Using the cumulative Bin range value (*k*) approximates to Z; calculate the outdoor temperature corresponding to Z using the linear interpolation. As an example, Fig. 2 is the graph for finding the outdoor temperature in the event of 2.0% cooling design temperature.

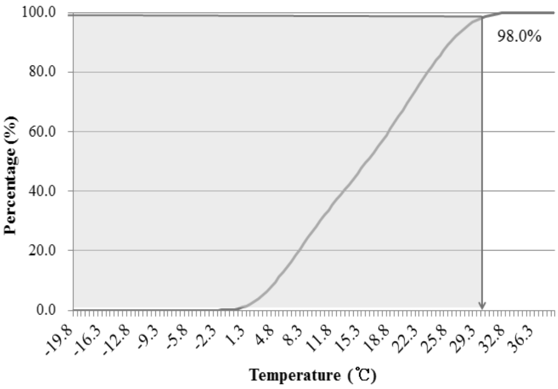


Fig. 2. CDF graph.

The outdoor temperature value against Z is calculated by the linear interpolations (2) and (3), which show example equations of design temperature in the event of 2.0% cooling design temperature, which means 98.0% in the whole [10].

$$\mathrm{CDF}_{\mathrm{DB}}^{k} < 0.98 < \mathrm{CDF}_{\mathrm{DB}}^{k+1} \tag{2}$$

$$T_{\mathrm{DB}}^{2.0\%} = T_{\mathrm{DB}}^{k} + \frac{(0.98\text{-}\mathrm{CDF}_{\mathrm{DB}}^{k})}{(\mathrm{CDF}_{\mathrm{DB}}^{k+1}\text{-}\mathrm{CDF}_{\mathrm{DB}}^{k})}\Delta T_{\mathrm{DB}} + \frac{\Delta T_{\mathrm{DB}}}{2} \tag{3}$$

Here, $T_{DB}^{2.0\%}$ (℃ or ˚F) means 2.0% cooling design temperature while T_{DB}^{k} represents the central temperature value at a Bin temperature range belonging to *k*, and ΔT_{DB} refers to the Bin temperature interval.

V. RESULTS

A. Comparison of TAC Values by Season and by Year

In the Equipment Manual of SAREK, there are the design temperatures that were calculated by the previous ASHRAE Bin method which uses only seasonal data [5]. The study calculated the design temperature by new version of ASHRAE Bin method using the outdoor temperature data acquired from KMA. These temperatures are compared with same calculation period of the outdoor temperature, from 1982 to 2006, for 25 years. The seasonal TAC temperatures and the yearly TAC temperatures are marked as “by season” and “by year”, respectively, in Table II.

The result of comparing the seasonally calculated TAC 2.5% and the yearly calculated TAC 1.0%, the difference is shown within ±0.5℃ due to the difference from 0.0℃ to the highest 0.46℃ in absolute value.

B. Counting by 8-Year Period

The study separated the data from 1982 to 2015 into 8 consecutive years. These 8 years are from 1982 to 1989 (82-89), from 1988 to 1995 (88-95), from 1995 to 2002 (95-02), from 2001 to 2008 (01-08), and from 2008 to 2015 (08-15), respectively. For each period, climatic design temperature for 1.0% cooling and 99.0% heating are calculated using the ASHRAE Bin Method, and indicated in Table III and IV.

TABLE II: COMPARING SEASONALLY AND ANNUALLY CALCULATED TEMPERATURES

Section	City	by season	by year	*ΔT*
99.0% Heating (℃)	Seoul	-9.60	-9.70	-0.10
	Incheon	-8.90	-8.90	0.00
	Daejeon	-9.10	-8.64	0.46
	Gwangju	-5.30	-5.47	-0.17
	Daegu	-5.90	-6.08	-0.18
	Busan	-3.90	-4.10	-0.20
	Ulsan	-4.70	-4.91	-0.21
	Jeju	0.90	0.99	0.09
1.0% Cooling (℃)	Seoul	30.70	30.99	0.29
	Incheon	29.80	30.00	0.20
	Daejeon	31.30	31.55	0.25
	Gwangju	31.20	31.45	0.25
	Daegu	32.60	32.87	0.27
	Busan	30.10	30.32	0.22
	Ulsan	31.80	32.05	0.25
	Jeju	30.70	30.83	0.13

* Period of the proceeded data: 1982-2006 (25 years)

C. Correlation with Mean Temperature

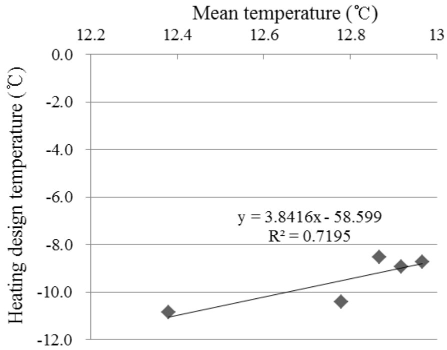
The study averaged the temperature for 8 years in Table V. Next, the study found correlation between climatic design temperatures and the mean temperature. The correlation with 99.0% heating design temperature is shown in Table VI and the correlation with 1.0% cooling design temperature is shown in Table VII, respectively. Fig. 3 shows the correlation graph between mean temperature and (a) 99.0% heating, and (b) 1.0% cooling design temperature in Seoul.

TABLE III: THE CALCULATED 99.0% HEATING TEMPERATURE

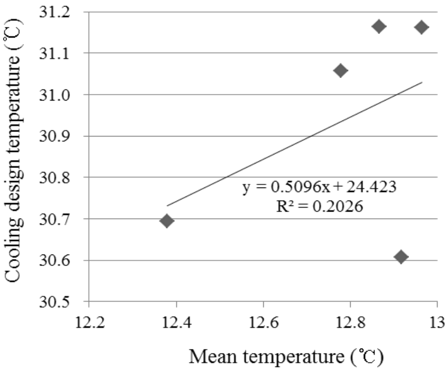
99.0% Heating	Period (℃)				
	82-89	88-95	95-02	01-08	08-15
Seoul	-10.86	-8.54	-8.73	-8.93	-10.42
Incheon	-9.96	-7.82	-8.07	-7.99	-8.99
Daejeon	-9.83	-7.75	-8.03	-7.75	-9.11
Gwangju	-6.25	-4.63	-5.01	-4.99	-5.65
Daegu	-7.20	-5.30	-5.22	-4.96	-5.75
Busan	-5.02	-3.11	-3.09	-3.32	-3.73
Ulsan	-5.86	-4.44	-4.20	-3.77	-5.06
Jeju	0.40	1.57	1.44	1.38	0.89

TABLE IV: THE CALCULATED 1.0% COOLING TEMPERATURE

1.0% Cooling	Period (℃)				
	82-89	88-95	95-02	01-08	08-15
Seoul	30.69	31.16	31.16	30.61	31.06
Incheon	29.65	29.91	30.37	29.65	29.48
Daejeon	31.67	32.09	31.25	30.97	31.33
Gwangju	31.25	31.72	31.38	31.52	31.76
Daegu	32.27	33.54	32.86	32.78	33.15
Busan	30.29	30.51	30.24	30.02	30.21
Ulsan	31.89	32.38	31.86	31.96	31.93
Jeju	30.34	30.81	30.96	30.93	31.21



(a) 99.0% Heating design temperature



(b) 1.0% Cooling design temperature

Fig. 3. Correlation with mean temperature graph in Seoul.

TABLE V: MEAN TEMPERATURE OF 8 YEARS

Average	Period (℃)				
	82-89	88-95	95-02	01-08	08-15
Seoul	12.38	12.87	12.97	12.92	12.78
Incheon	11.88	12.25	12.60	12.74	12.50
Daejeon	12.74	13.24	13.04	13.19	13.08
Gwangju	13.67	14.07	14.06	14.11	14.29
Daegu	13.71	14.28	14.46	14.55	14.65
Busan	14.32	14.77	15.06	14.79	15.03
Ulsan	13.83	14.25	14.49	14.61	14.36
Jeju	15.49	15.73	16.05	16.15	16.09

TABLE VI: CORRELATION BETWEEN 8 YEARS MEAN TEMPERATURE AND 99.0% HEATING DESIGN TEMPERATURE

City	$y = ax + b$	R^2
Seoul	$y = 3.8416x - 58.60$	0.7195
Incheon	$y = 1.8999x - 32.11$	0.5083
Daejeon	$y = 4.1143x - 62.22$	0.7611
Gwangju	$y = 1.4979x - 26.34$	0.2798
Daegu	$y = 2.0135x - 34.54$	0.7013
Busan	$y = 2.1771x - 35.86$	0.6421
Ulsan	$y = 2.4883x - 40.26$	0.8381
Jeju	$y = 0.9105x - 13.34$	0.2777

TABLE VII: CORRELATION BETWEEN 8 YEARS MEAN TEMPERATURE AND 1.0% COOLING DESIGN TEMPERATURE

City	$y = ax + b$	R^2
Seoul	$y = 0.5096x + 24.42$	0.2026
Incheon	$y = 0.2004x + 27.33$	0.0383
Daejeon	$y = -0.1142x + 32.96$	0.0028
Gwangju	$y = 0.7887x + 20.45$	0.6822
Daegu	$y = 0.7394x + 22.33$	0.3409
Busan	$y = -0.1065x + 31.83$	0.0329
Ulsan	$y = -0.0298x + 32.43$	0.0018
Jeju	$y = 1.0041x + 14.88$	0.7879

VI. CONCLUSIONS

The conclusions of this study are as follows.

1) The calculation period of the outdoor temperature is as same as 25 years as ASHRAE calculated, and the result of comparing the calculation method of setting up 2.5% by season, and 1.0% by year shows within ±0.5℃ due to the absolute temperature value different from 0.0℃ to the highest 0.46℃.
2) When the study calculated 99.0% heating design temperature by 8-year period, it was found that Seoul region showed the lowest -10.86℃ which the data duration was from 1982 to 1989, while Jeju region showed the highest 1.57℃ which the data duration was from 1988 to 1995.
3) The trend of 8-year 99.0% heating design temperature change is that Incheon, Daejeon and Gwangju showed the appearance of ascent-descent-ascent-descent; Daegu and Ulsan regions showed the appearance of ascent-ascent-ascent-descent, and Busan and Jeju region showed the appearance of descent-ascent-descent-descent.
4) When the study calculated 1.0% cooling design temperature by 8-year period, it was found that Daegu region showed the highest 33.54 ℃ which the data duration was from 1988 to 1995, and Incheon region showed the lowest 29.48℃ which the data duration was from 2008 to 2015. Overall, Daegu region showed the highest temperature while Incheon region showed the lowest temperature except for the time when Busan was the lowest 30.24℃ which the data duration was from 1995 to 2002.
5) The trend of 8-year 1.0% cooling design temperature change is that Seoul, Daejeon, Daegu, and Busan showed the appearance of ascent-descent-descent- ascent.
6) As for the correlation between mean temperature and 99.0% heating design temperature, Gwangju and Jeju were found to be lower than 0.5, with 0.2798 and 0.2777, respectively, showing no correlation with 99.0% heating design temperature; in case of other regions, there is a correlation with the 99.0% heating design temperature by more than 0.5.
7) As for the correlation between mean temperature and 1.0% cooling design temperature, Gwangju and Jeju were found to be higher than 0.5, with 0.6822 and 0.7879, respectively, showing a correlation with 1.0% cooling design temperature; in case of other regions, they were found to have no correlation with the 1.0% cooling design temperature by less than 0.5.

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