REGIONAL DIFFERENCE OF ENERGY CONSUMPTION FOR HOT WATER SUPPLY SYSTEM

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ABSTRACT

This paper proposes useful techniques of regression analysis to estimate regional water temperatures for the optimum design of the hot water supply system. First yearly trends of changing air temperatures and water temperatures are surveyed about Sapporo, Sendai, Tokyo, Nagoya, Osaka and Kochi, which are typical cities with enough data to analysis from 1991 to 1994. Second three types of the explanatory variable of the regression model are examined: (a) the air temperature on that day, (b) the air temperature 1 or 2 days before and (c) the mean air temperature in a few days of the pasts. It is concluded that the regression model of (c) decreases standard errors of estimates. Finally coefficient of energy consumption for hot water supply, CEC/HW, are calculated from estimated regional water temperature.

INTRODUCTION

By the purpose to improve energy efficiency in operation of the central hot water supply system, the standard of CEC/HW (coefficient of energy consumption for hot water supply) has been set by the decree on the hotel and the hospital where trend to use hot water in more quantities than the other kinds of buildings. Even if the building is not dealt with for the regulation, to make the CEC for the building services clear is encouraged. In the present situation, the CEC/HW is not too much recognized yet by the architect compared with CEC/AC for air conditioning system.

Though the supplied water temperature of each area becomes necessary as the most basic data to calculate CEC/HW, the architect and the engineer have no means of getting regional information about the supplied water temperature. Because the water purification plants are not exhibiting the data about supplied water temperature. The previous studies[1] [2] about the water temperature of the river are extensively done from before but as the information for the hot water supplied system, it tends to be too detailed. The estimated equation of the supplied water temperature is not necessarily exact in the heat balance, but it is required to give the regional information of supplied water temperature from available data.

This paper studies about the method of estimating the regional water temperature from the air temperature, and will contribute to improve energy efficiency about the hot water supply system.

The CEC/HW is defined by the following equation [3]:

$$CEC/HW = \frac{\sum_{M=1}^{12}\left\{\frac{QS_M + QY_M + QP_M + QQ_M + QT_M}{EB \times EH}\right\} + QE}{\sum_{M=1}^{12} QHS_M} \quad (1)$$

$$EB = 0.78,\ EH = 1.0$$

- QHS_M: monthly pseudo-load of hot water supply [kcal]
- QS_M: same as QHS_M if tap water is used [kcal]
- QY_M: monthly piping heat loss [kcal]
- QP_M: monthly waiting heat loss [kcal]
- QQ_M: monthly piping heat loss of heat exchanger [kcal]
- QT_M: monthly heat loss at hot water storage [kcal]
- QE: energy consumption for circulating pump system [kcal]
- EB: thermal efficiency of heat source equipment
- EH: thermal efficiency of heat exchanger

The denominator of the equation (1) means the energy for making hot water on the theory, the molecule means the energy for supplying hot water actually. The monthly pseudo-load, QHS_M [kcal], is given by the following equation:

$$QHS_M = V_M \times (TH - THS_M) \quad (2)$$

- V_M: the monthly amount of using hot water [l]
- TH: the required temperature of hot water [°C]
- THS_M: the monthly supplied water temperature [°C]

The regional data of supplied water temperature, THS_M, are indispensable to calculate the CEC/HW. Unfortunately, there is not enough data for the architect and the engineer to refer directly and easily. The following equation (3) is making up the lack of the data, and estimates the THS_M from monthly mean of regional air temperature.

$$THS_M = a \times TA_M + b \quad (3)$$

- TA_M: the monthly mean air temperature [°C]
- a, b: regional coefficients defined on typical cities

While there is an advantage of simplicity in the equation (3), there is a disadvantage of the estimate precision. Because the air temperature changes remarkably during a month in Japan, the monthly estimation, THS_M, is too rough to evaluate energy consumption for hot water supply system.

Aiming for the estimated precision to improve, this paper tries to estimate daily supplied water temperature, THS_D, from three types of the air temperature like the following equations:

$$QHS_M = V_M \times \sum_{D=1}^{30} (TH - THS_D) \qquad (2)'$$

(a) $THS_D = a \times TA_D + b$,

(b) $THS_D = a \times TA_{xDbefore} + b$,

(c) $THS_D = a \times TA_{xDave} + b$

THS_D: the daily supplied water temperature [°C]

TA_D: the daily mean air temperature on that day [°C]

$TA_{xDbefore}$: the daily mean air temperature on *x* days before, [°C]

TA_{xDave}: the mean air temperature for *x* days of the past [°C]

After comparing between above the three kinds of the regression model, (a), (b) and (c), from viewpoint of the standard errors of estimation, this paper proposes regional coefficients, *a* and *b*, which are suitable for nine typical cities in Japan. Finally, the daily model (c) is compared with the monthly model on the CEC/HW.

METHOD

In case the data of distributed water temperatures are given at the entrance of all buildings, *QHS* could be calculated more exactly. Actually, it is impossible to investigate minutely water temperatures entering the each building. In this paper, therefore, the *THS* is estimated from temperatures of the raw water or the purified water in the water purification plants.

The data of the air temperature and the water temperature are collected for the period from 1991 to 1994 about nine cities [4]. The air temperatures are referred to the AMeDAS, Automated Meteorological Data Acquisition System, and the water temperatures are gotten with the cooperation of the regional purification plants. This paper treats the typical six cities: Sapporo, Sendai, Tokyo, Nagoya, Osaka and Kochi, which have enough data to analysis. Each water purification plant has the records of the raw water or the purified water. Some of the plants have the records of the connected distribution plants. Table 1 shows that there are differences on the recording instrument and interval between purification plants.

REGIONAL TREND

Yearly Trend

The regional trend of changing air and water temperatures for six cities are shown in Fig. 1. There is analogy between changes of the air and water temperature through the year for every city except Sapporo. Sapporo has conspicuous seasonal characteristics; the water temperatures little change in winter, and are rising slowly compared to the air temperatures from the spring to the summer.

Seasonal Trend

The relationship between the air temperatures and the water temperatures would change according to seasonal changes of climate in Japan. This paper divides a year into four seasons to clear the seasonal trend: the winter is the heating period from December to March, the spring is the period from April to May, the summer is the cooling period from June to September, and the autumn is the period from October to November.

The plots of the water temperatures by the air temperatures are show in Fig. 1. The different symbols are given to respective seasons. The figures illustrate how the water temperatures change in the each period. In every city except Sapporo, there is a linear relationship between the water temperatures and the air temperatures through the year. While Sapporo winter clearly show that the water temperatures are constantly between 2°C and 3°C no matter what the air temperatures are. For only Sapporo, therefore, an analysis of winter should be distinguished from the other seasons.

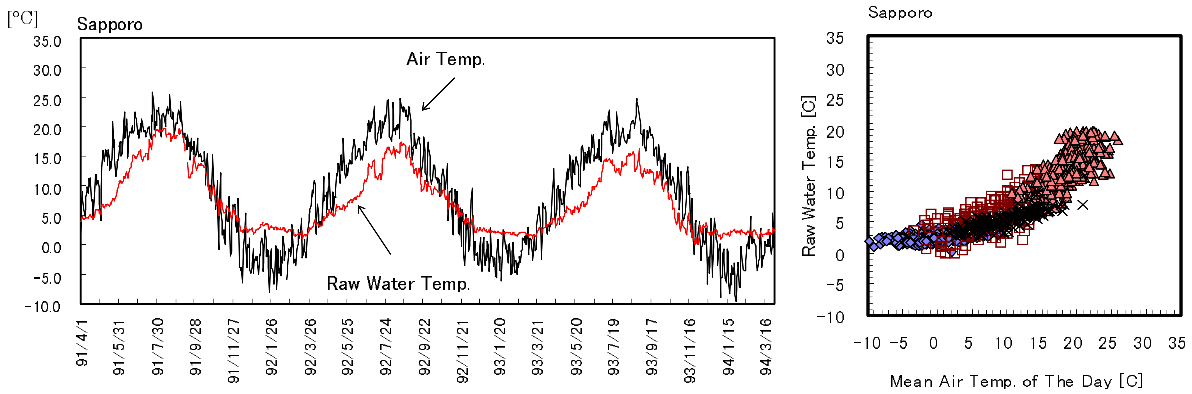
Distribution Effect

The purification plants in Sendai, Tokyo, and Osaka have records both the purified water and the distributed water. These water temperatures are compared and the differences between them are shown in Fig. 2. The figure dose not show common trends to three cities. The distributed water temperatures are higher than the purified water temperatures in Sendai. The tendency of Tokyo is contrast to one of Sendai. There is little differences between these temperatures in Osaka . In this paper, therefore, the distribution effects are not discussed any more, and either records of the raw or the purified water are used to estimate the water temperatures.

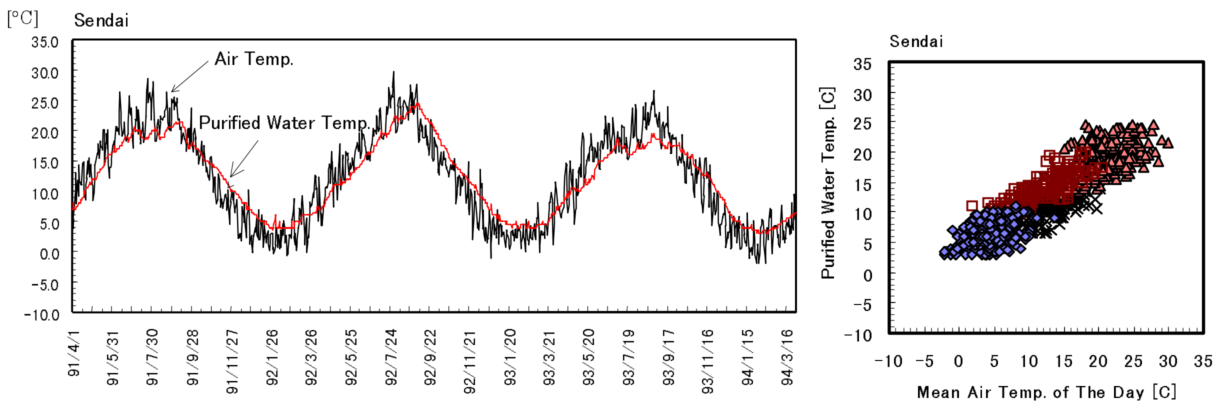
Table 1 Recording conditions of the purification plant

CITY	PERIOD	KIND OF WATER	SENSOR	INTER-VAL
Sapporo	Apr. 1991 Mar. 1994	Raw	manual	daily
Sendai	Apr. 1991 Mar. 1994	Purified Distributed	manual manual	daily daily
Tokyo	Apr. 1993 Nov. 1994	Purified Distributed	automatic automatic	timely timely
Nagoya	Jan. 1991 Aug. 1994	Purified	rod type	daily
Osaka	Apr. 1991 Dec. 1994	Purified Distributed	automatic automatic	timely daily
Kochi	Jan. 1991 Nov. 1994	Raw	manual	daily

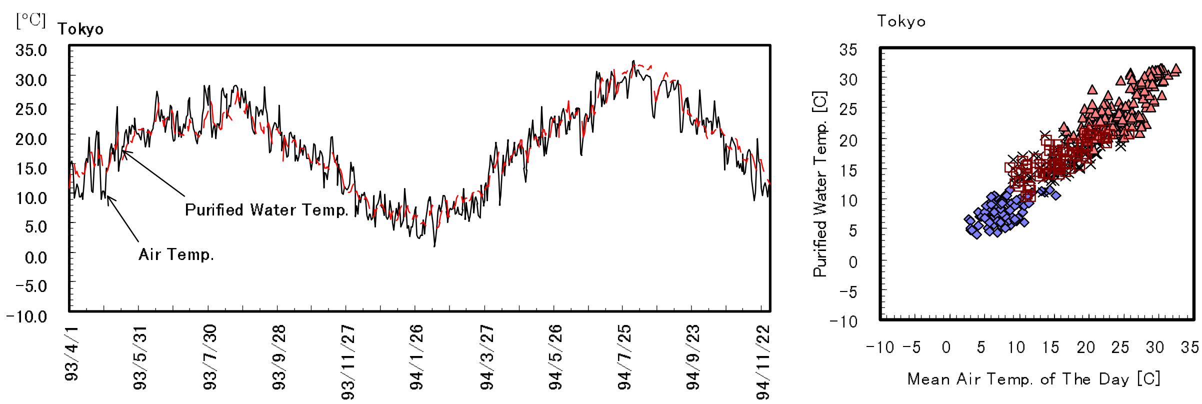
Raw : Measurement at the entrance of the purification plant,
Purified : Measurement at the exit of the purification plant,
Distributed : Measurement at the point on the way of distribution



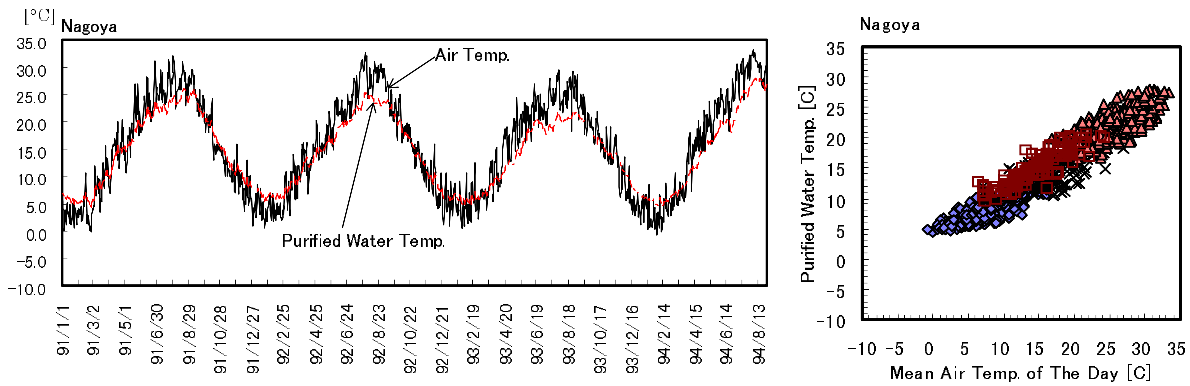
Sapporo



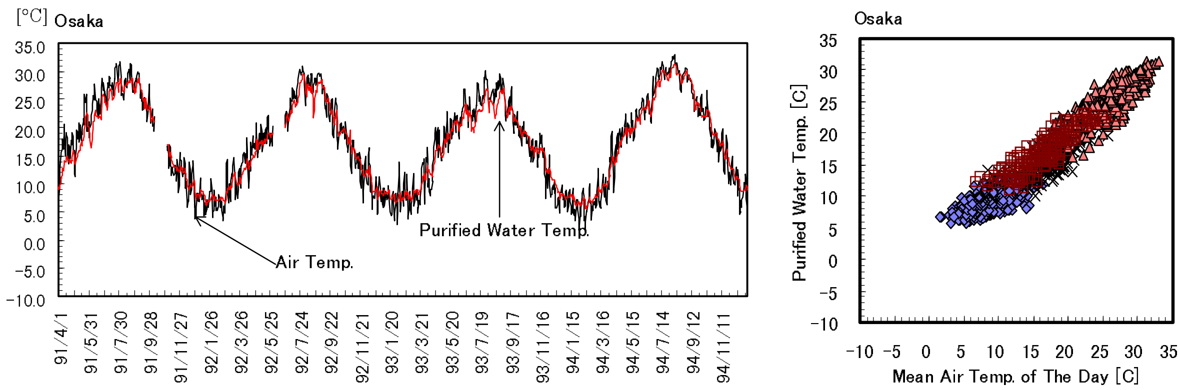
Sendai



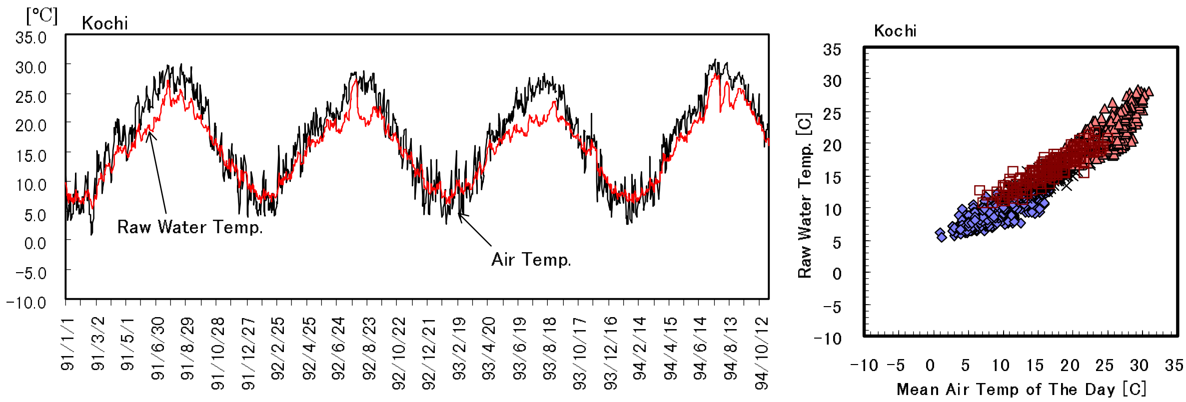
Tokyo



Nagoya



Osaka



Kochi

triangle: Summer (From June to September), square: Autumn (From October to November), rhombus: Winter (From December to March), cross: Spring (From April to May)

Figure 1 Regional trend of changing air temp. and water temp. Left side: the line graph of the time series for air and water temp., Right side: plots of the water temp. by the air temp.

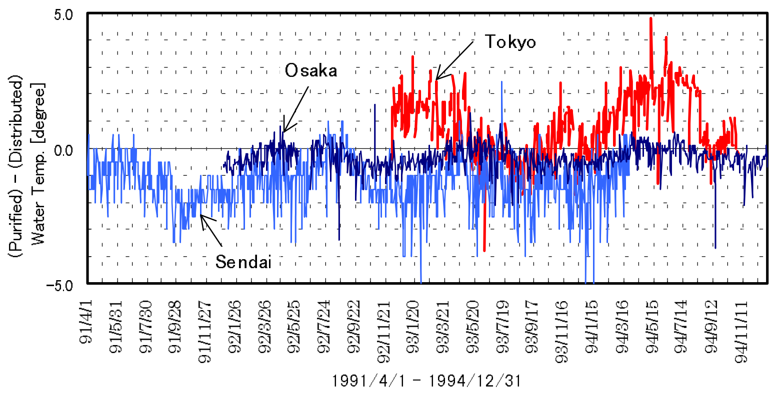


Figure 2 Values of subtraction: the purified water temp. minus the distributed water temp.

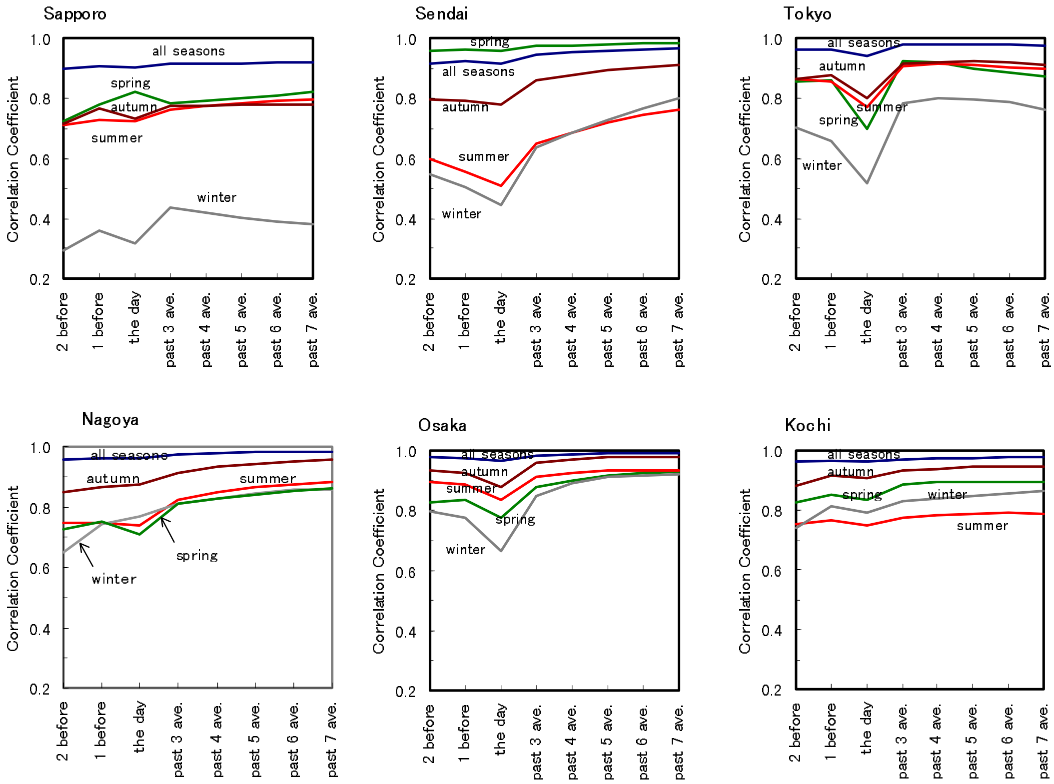


Figure 3 The correlation coefficients between TA and T_w

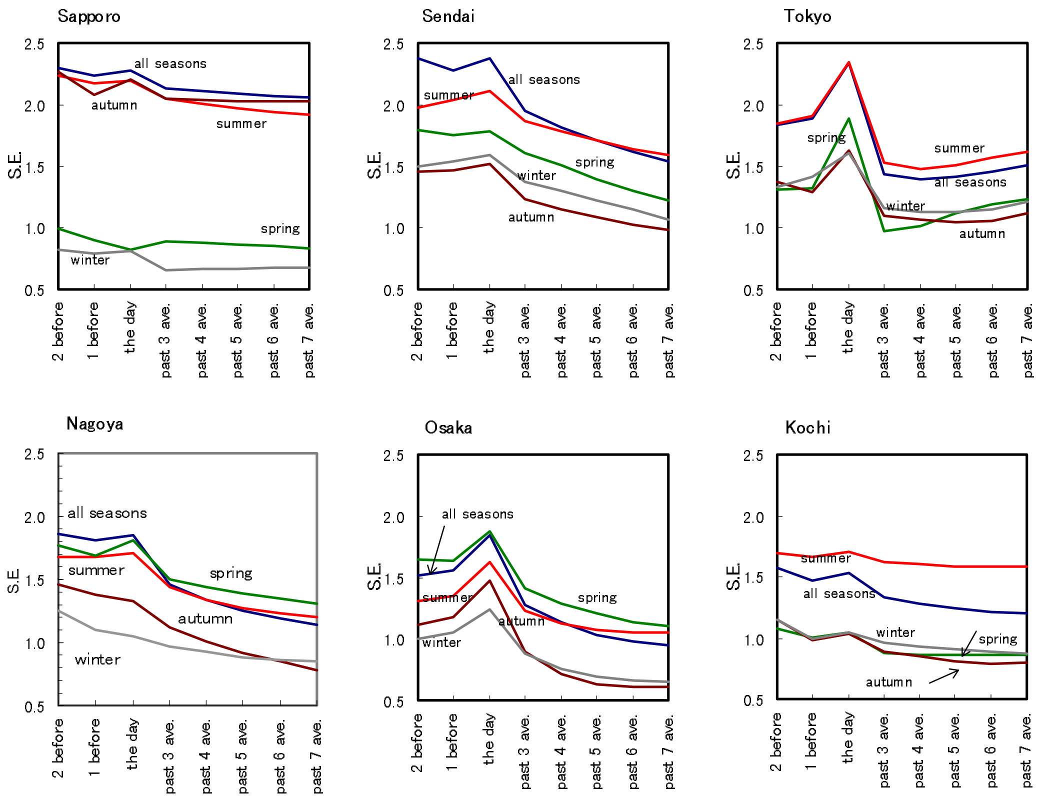


Figure 4 The Standard errors of estimates

REGRESSION ANALYSIS

Correlation

It thinks that the water temperature undergoes influence by the air temperature several days before. This paper investigates correlation between the water temperatures, T_w, and three types of the air temperatures: (a) TA_D, (b) $TA_{xDbefore}$, (c) TA_{xDave}, where T_w is the daily mean of the water temperature.

The correlation coefficients between the T_w and each *TA* are shown in Fig. 3. There are five lines in each figure: the all- seasons line, the winter line, the spring line, the summer line, and the autumn line. The figures show that there is high correlation more than 0.95 between the T_w and (c) TA_{xDave}. The all- seasons lines mark high correlation coefficients, because yearly changes of *TA* are larger than the seasonal ones.

Standard errors of estimates

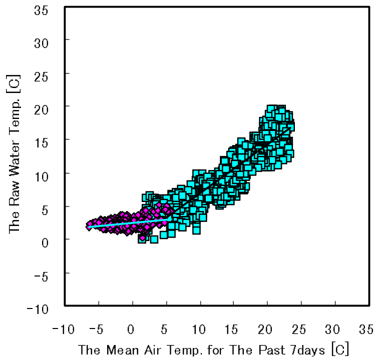
Both the all- seasons T_w and the seasonal T_w are analyzed by linear regression models. The standard errors of estimates (*S.E.*) are shown in Fig. 4 in the same way of Fig. 3. The figures show that the *S.E.* is smallest when the TA_{7Dave} are set to the explanatory variable. The tendency is common to almost all cities.

Figure 4 also indicates that the *S.E.* of the winter are smaller than the one of the all- seasons for every city. The tendency of Sapporo is remarkable; the difference between the winter and the all- seasons is about 1.5 °C. For the other cities the *S.E.* of the winter are from 0.4°C to 0.7°C smaller than the ones of the all- seasons. While the *S.E.* of the spring and the summer are not so small as the ones of the winter; and are nearly equal to, or sometimes larger than *S.E.* of the all- seasons. The seasonal analysis, therefore, is not always better than the annual analysis except Sapporo.

Treatment of Sapporo Winter

In the case of Sapporo, the daily mean air temperatures often drop to sub- zero during the winter, while the T_w does not change remarkably and it is constantly between 2°C and 3°C. There are some reasons for the little change of the T_w. One is that the water characteristics change at 4°C; 4°C water has smallest volume and highest density. Another reason is that the purification plant record the flowing raw water temperature without being frozen.

The data of Sapporo, therefore, are analyzed by dividing a year into two periods to improve the precision of estimation: (1) the winter, (2) the other seasons from April to October. The recorded and predicted T_w for both the periods are shown in Fig. 5. The winter relationship is given by $Y = 0.11X + 2.48$, and the other $Y = 0.74X - 0.42$. Since T_a in the winter change from -5°C to 5°C, the range of the T_w is estimated from 2°C to 3°C. When the T_w is not required so exactly, the water temperatures can be regarded as 2.5°C constantly during the winter.



rhombus: The Winter (From December to March),
square: The Other seasons (From April to November)

Figure 5 Recorded and estimated the T_w by the TA_{7Dave} in Sapporo

DISCUSSION

Comparison between daily models

It is already found that the annual analysis is better than the seasonal one for Sendai, Tokyo, Nagoya, Osaka, and Kochi, and that Sapporo should be analyzed by dividing a year into two periods. It is clearly shown that the *S.E.* become small, when the TA_{7Dave} is set to the explanatory variable of the regression model. Table 2 shows regional regression lines, and compares explanatory variables (a) TA_D and (c) TA_{7Dave} at the size of the *S.E.* It is cleared that the regression model of (c) decreases the *S.E.* For Sapporo the separated analysis makes the *S.E.* of the winter 0.65°C. For the other cities the *S.E.* of (c) is from 0.3°C to 0.9°C smaller than ones of (a).

Compared to the model (a), the model (c) is found excellent in point of the precision.

Table 2 Comparing regression lines and *S.E.* between Type (a) and Type (c)

City	(a): input the TA_D into X	
	Regression Line	*S.E.*
Sapporo	$Y = 0.53X + 2.60$	2.27
Sendai	$Y = 0.72X + 3.42$	2.38
Tokyo	$Y = 0.89X + 2.23$	2.33
Nagoya	$Y = 0.72X + 3.36$	1.85
Osaka	$Y = 0.86X + 2.09$	1.84
Kochi	$Y = 0.73X + 3.14$	1.53
City	(c): input the TA_{7Dave} into X	
	Regression Line	*S.E.*
Sapporo	$Y = 0.11X + 2.48$ (W) $Y = 0.74X - 0.42$ (O)	0.65 (W) 2.06 (O)
Sendai	$Y = 0.79X + 2.65$	1.54
Tokyo	$Y = 0.95X + 1.06$	1.51
Nagoya	$Y = 0.75X + 2.91$	1.14
Osaka	$Y = 0.91X + 1.35$	1.02
Kochi	$Y = 0.75X + 2.71$	1.20

(W): the winter from December to March,
(O): the other seasons from April to October

Comparison between monthly model and daily model in the process of the CEC/HW calculation

This paper supposes that the business hotel of the construction condition to be the same exists in 6 cities: Sapporo, Sendai, Tokyo, Nagoya, Osaka and Kochi, and the pseudo-load of hot water supply and CEC/HW are calculated as a test in the conventional monthly model and the daily model (c).

The standard operation condition of the hot water facilities is shown in Table 3. The regression coefficients of the monthly model are shown in Table 4.

Table 5 and Table 6 shows the molecule, the denominator of the equation (1) and estimated CEC/HW from the monthly model and the daily model (c), respectively. Figure 6 shows regional differences of the estimated CEC/HW. As for CEC/HW as the energy saving index, the smaller the value is, the higher evaluation becomes.

When showing CEC/HW in the line graph, the difference between cities and the difference by the estimate method become clear.

Comparing the monthly model shown in Table 5 and the daily model (c) shown in Table 6, there is not a change in the pseudo-load of hot water supply too much about Sendai, Tokyo and Nagoya. On the other hand, the estimated values of both the energy consumption and the pseudo-load from the daily model (c) increases substantially about Sapporo, Osaka and Kochi. In the result only 0.02 ~ 0.03 values of CEC/HW decreased.

As shown in the Fig. 6, the evaluation is higher in the cold district, Sapporo or Sendai, compared with the mild district. The regional differences of CEC/HW depends on the structure of the computation equation, the equation (1). This problem doesn't refer any more because it comes off the subject of this paper.

Table 3 The standard operation condition of the hot water facilities

required hot water temperature		43℃
hot water temperature in the storage		60℃
hot water temperature in the pipe		60℃
temperature of air conditioned room		
	from July to September	26℃
	during the other seasons	22℃

Table 4 Regression coefficients of the monthly model[3] for the typical cities: $THS_M = a \times TA_M + b$

Typical City	regional coefficients a	b
Sapporo	0.6639	3.466
Sendai	0.6054	4.515
Tokyo	0.8516	2.473
Nagoya	0.7272	3.361
Osaka	0.8851	3.189
Kochi	0.9223	2.907

Table 5 Estimated CEC/HW from the monthly model for the typical cities

typical city	molecule: energy consumption (Gcal)	denominator: pseudo-load (Gcal)	CEC/HW from the monthly model
Sapporo	555.62	366.27	1.52
Sendai	520.07	340.57	1.53
Tokyo	443.07	284.15	1.56
Nagoya	480.42	311.82	1.54
Osaka	413.71	262.12	1.58
Kochi	425.98	270.88	1.57

Table 6 Estimated CEC/HW from the daily model (c) for the typical cities

typical city	molecule: energy consumption (Gcal)	denominator: pseudo-load (Gcal)	CEC/HW from the daily model (c)
Sapporo	585.73	389.28	1.50
Sendai	515.65	337.16	1.53
Tokyo	439.53	281.44	1.56
Nagoya	481.74	312.83	1.54
Osaka	433.58	277.30	1.56
Kochi	468.71	303.54	1.54

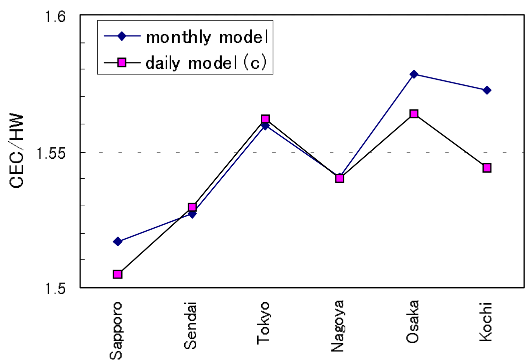


Figure 6 Regional differences of the estimated CEC/HW

CONCLUSIONS

This paper propose the regional regression lines estimating the water temperatures effectively. From above consideration, the authors reach the following conclusions.

(1) About the explanatory variable of the regression model, the TA_{xDave}, the mean air temperature in a few days of the pasts, is better than the TA_D, the mean air temperature on that day, from viewpoint of the standard errors of estimates.

(2) Sendai, Tokyo, Nagoya, Osaka, and Kochi are recommended the annual regression analysis. Since Sapporo has colder winter than the other cities, the winter from December to March should be analyzed separately.

(3) Comparing in the monthly model and the daily model (c), it is found that the estimated value of both

the energy consumption and the pseudo-load increases substantially, and that the value of CEC/HW decreases a little about Sapporo, Osaka and Kochi.

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REFERENCES

[1] Arai, T. and Nishizawa, T.: *Treatise on water temperature*, Kyoritsu Shuppan, 1974, Japan

[2] Moore, A. M.: *Correlation and analysis of water-temperature data for Oregon streams*, U.S. Geological Survey Water-Supply Paper, 1819-K, pp. 1 - 53, 1967

[3] Institute of Building Energy Conservation: *Guidelines of the energy conservation and methods of calculation for the building*, Institute of Building Energy Conservation, pp. 273 - 298, 1993, Japan

[4] The committee of studies on ground data prepared and examined for design for hot water supply systems in The Society of Heating, Air- Conditioning and Sanitary Engineers of Japan: *Report (2) of studies on ground data prepared and examined for design for hot water supply systems*, The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan, pp. 4 - 81, 1996, Japan