A Simple Method to Continuous Measurement of Energy Consumption of Tank Less Gas Water Heaters for Commercial Buildings

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Abstract:although energy consumptions of hot water supply in restaurants or residential houses are large amount, guidelines for optimal design are not presented. measurements of energy consumption of tank less gas water heaters very difficult unless gas flow meters were installed. however a gas flow meters is hardly installed for individual heater. in this study, a simple method to estimate gas consumption of such appliances form temperature of exhaust gas and electric current was presented. experiments of japanese major hot water gas heaters were conducted change under conditions of various water flow rate at constant output temperature. the empirical equations, which related gas consumption to exhaust gas temperature and operative current, were obtained for each type of water heaters, each manufacturer and overall heaters. verification of the method was conducted at a commercial building. some thresholds to decide status of operation, such as anti-freeze operation, were set, and sufficient accuracy of around 10 % error was achieved.

INTRODUCTIONS

Energy consumptions of hot water supply in restaurants or residential houses are nearly 40 % of total energy consumptions. High efficient water heaters, such as condensing water heaters or heat pump water heaters have been developed in Japan. Japanese government has been subsidizing such water heaters for effective energy use. Although heaters should be designed appropriately, a design guideline for hot water load has not been prepared for all types of buildings. Heat pump water heaters, which have high COP, must have hot water storage tanks, because the maximum capacity is small. Therefore, the capacity of storage tank should be properly designed to match daily hot water demand.

A design standard of hot water demand at restaurants and residential houses has not been established yet. Although surveys on hot water consumption are needed, measurements of flow rate have difficulties. A simple method to estimate energy consumption from properties that can easily be measured was proposed in this study. One of authors (Yamaha, 2004) had conducted experiments for one manufacturer of gas water heater to make empirical equations to estimate gas consumption. Gas consumption could be estimated from exhaust gas temperature and electric current. In this study, products of major Japanese manufacturers were tested to expand the equations to various heaters.

EXPERIMENTAL SETUPS

Figure 1 shows a schematic diagram of experimental setup. Water that was adjusted at certain temperature was store in tanks and pumped to water heaters. Temperature at the surface of pipes was measured by thermo couples. An electromagnetic flow meter measured flow rate of water. A mass flow meter measured flow rate of gas.

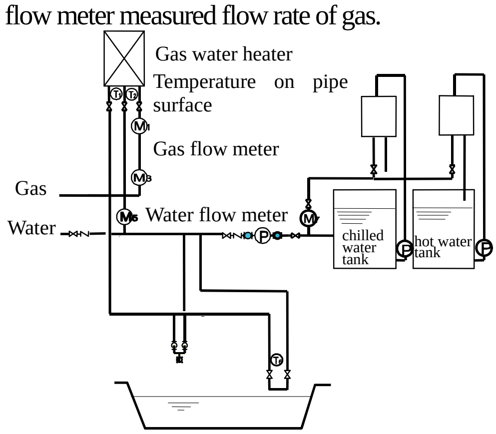

Fig.1. Schematic diagram of experimental setup

Table 1 shows the water heaters and conditions of experiments. Supply water temperature was set to 8 ˚C (46.4 °F) for winter, 14 ˚C (57.2 °F) for intermediate season and 20 ˚C (68 °F) for summer. Temperature of hot water was set to 3 or 4 conditions from 42 ˚C (107.6 °F) to maximum temperature of each heater.

Figure 2 shows an experimental protocol. After an installation of heater was finished, the maximum flow rate was determined letting tap valve fully open. Once the maximum flow rate had been determined, 80, 60, 40, 20 % of that value were taken as experimental conditions. As shown in Figure 2, the experiments were stared at the maximum flow rate, and flow rates were reduced in every 4 minutes.

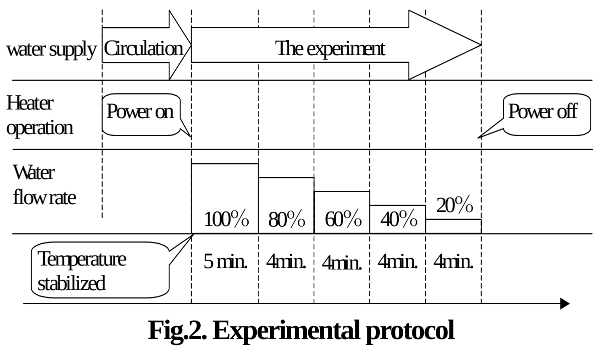

Fig.2. Experimental protocol

RESULTS AND EQUATIONS

Tab.1. Heaters used in the study and experimental conditions

Heaters		Conditions		
Manufacturers Name	Nominal Capacity	Supply hot water temp. (˚C)	(ºF)	Water temp. (˚C)
N	28 kW (95,500 BTU/h)	42, 48, 60, 75	108, 118, 140, 167	8 (46.4 ºF) (for winter) 14 (57.2 ºF) (for inter-mediate) 20 (68 ºF) (for summer)
	42 kW (143,300 BTU/h)	42, 48, 60, 75	108, 118, 140, 167	
	87.5 kW (298,600BTU/h)	42, 50, 60, 75	108, 122, 140, 167	
	87.5 kW* (298,600BTU/h)	42, 50, 60, 75	108, 122, 140, 167	
P	28 kW (95,500 BTU/h)	42, 50, 60	108, 122, 140	
	42 kW (143,300 BTU/h)	42, 50, 60	108, 122, 140	
R	28 kW (95,500 BTU/h)	42, 50, 60, 75	108, 122, 140, 167	
	42 kW (143,300 BTU/h)	42, 50, 60, 75	108, 122, 140, 167	
	87.5 kW (298,600BTU/h)	42, 50, 60, 75	108, 122, 140, 167	
T	28 kW (95,500 BTU/h)	42, 50, 60	108, 122, 140	
	56 kW (191,077BTU/h)	42, 50, 60, 75	108, 122, 140, 167	
	56 kW * (191,077BTU/h)	42, 50, 60, 75	108, 122, 140, 167	

*condensing heaters

Figure 3 shows one example of results of experiments. As flow rate of hot water, or output of heater varied, gas flow rate, temperature of exhaust gas and electric current were changed. The gas flow rate was changed in same manner as water flow rate. The value of temperature of exhaust gas and electric current happened to increase, nevertheless water flow rate went down. Supply air blowers and burners were controlled to maintain the temperature of hot water constant. These values depended on the manufacturers control strategy since the temperature of how water was controlled by burners and supply air blowers. Although these values fluctuated in a microscopic viewpoint, there was a positive correlation among gas consumption and measured values throughout experiments. Therefore, we concluded that the gas consumption could be estimated from regression equations from experiments.

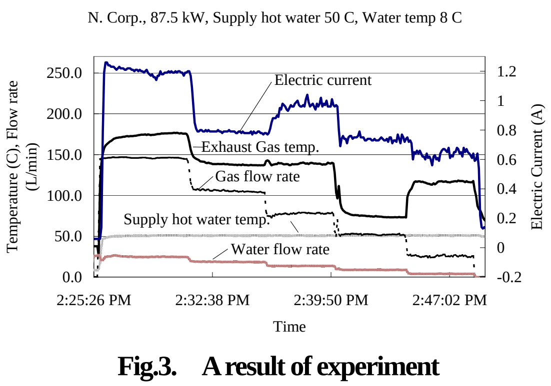

Fig.3. A result of experiment

Measured values were normalized in the following way to obtain regression equations. They were normalized by maximum measured value. Consequently, a capacity of specific heater was taken into account of normalized value. The actual gas consumption could be obtained by multiplying predicted vale and the capacity of heater. Furthermore, errors by installation of sensors in field would be avoided since measure value of temperature might be changed according to the place where the sensors were installed.

$$I^* = I_{measured} / I_{\max} \quad (1)$$

$$t^* = (t - t_{outdoor}) / (t_{\max} - t_{outdoor}) \quad (2)$$

$$Q^* = Q_{measured} / Q_{\max} \quad (3)$$

The averages of measured values were calculated for the period when operation was considered to be stable. The regression equations were calculated from these averages. Following equations indicate the significance of independent variables. According to t-stat of each regression, temperature of exhaust gas and electric current were significant variables.

Equations (4) to (6) are equations that included all manufacturers heaters. As sufficient number of experiments was conducted for each heater, manufacture and model specified equations were also obtained for more precise estimation if manufacture or model number was identified. Only equations for overall heaters were presented in this paper.

$$Q^* = 1.008 t_e^* - 0.076 \quad R^2 = 0.76 \quad (4)$$

	t Stat	Degree of freedom	$t_{0.99}$
Intercept	-5.1	756	2.58
t^*_e	48.9		

$$Q^* = 0.339 I^* + 0.776 t_e^* - 0.211 \quad R^2 = 0.80 \quad (5)$$

	t Stat	Degree of freedom	$t_{0.99}$
Intercept	-12.1	755	2.58
I^*	12.35		
t^*_e	29.1		

$$Q^* = 0.346 I^* + 0.776 t_e^* - 0.016 t_{hw}^* + 0.111 t_{\sup}^* - 0.212 \quad R^2 = 0.80 \quad (6)$$

	t stat	Degree of freedom	$t_{0.99}$
Intecept	-10.1		
I^*	12.29		
t^*_{eb}	27.59	753	2.58
t_{hw}	1.08		
t_{supp}	-0.45		

Figures 4 to 6 show comparison of predicted value with measurements. The error between prediction and measurements was smaller for large number of variables.

VERIFICATION OF EQUATIONS

The equations obtained from experiments were verified in a real commercial building. The building was a pet shop. Figure 7 shows a diagram of measurements. Water flow rate instead of gas consumption was measured for hot water consumption. Therefore, hot water flow rate was calculated from predicted gas consumption by following equation.

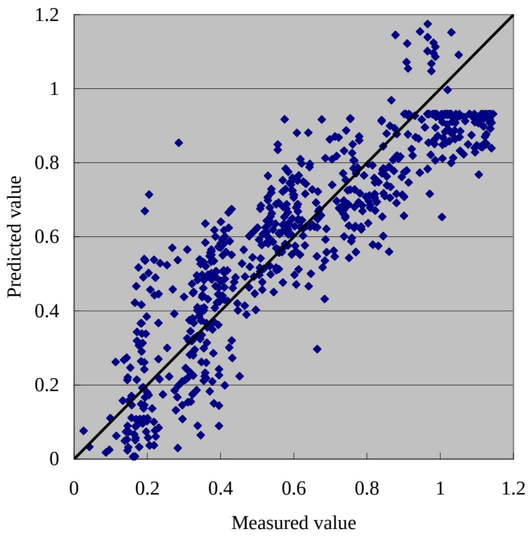

Fig.4. A comparison between prediction and measurements for one independent variable.

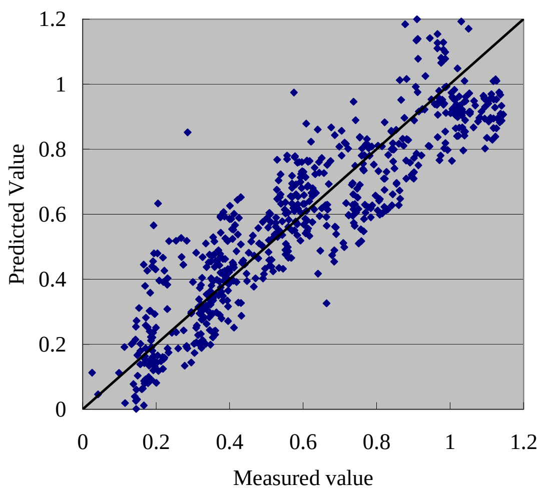

Fig.5. A comparison between prediction and measurements for two independent variables.

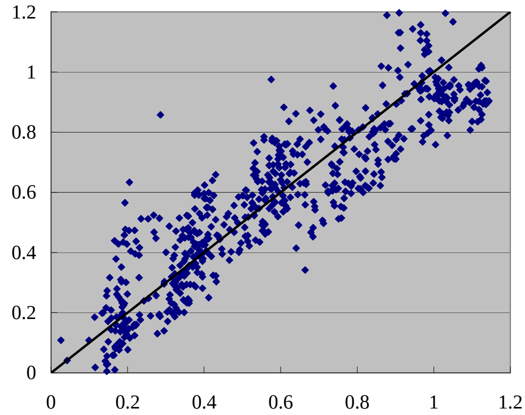

Fig.6. A comparison between prediction and measurements for four independent variables.

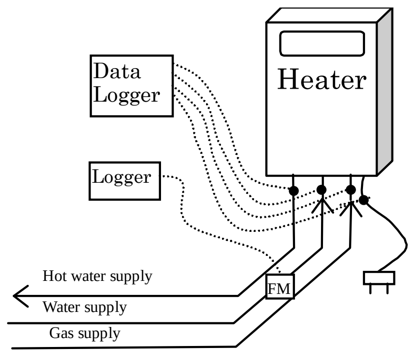

Fig.7. Measurement setups

$$F = \frac{1000 \cdot Q}{\eta_m \cdot \rho \cdot Cp \cdot \Delta t} \tag{7}$$

The efficiency η_m was measured in the experiments, which was 71.5 % for all heaters.

The measurements were carried out on 13 of December 2005. It was found that prediction could not be performed by only adopting the equation in some conditions of operation. As shown in Figure 8, exhaust gas temperature went down gradually after combustion was stopped. The equations calculated gas consumption for such state of exhaust gas when heater was not operating. In winter, operation of anti-freezing electric heater occurred in cold day. The exhaust gas temperature increased as well as electric current, and the equations yielded value without operation.

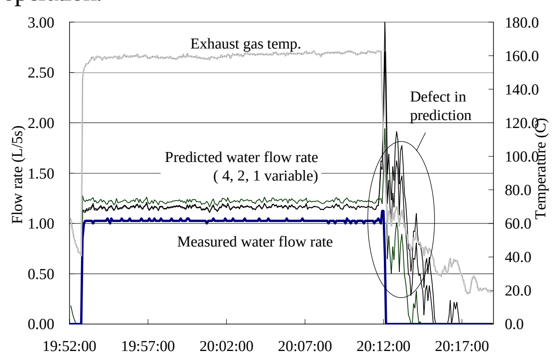

Fig.8. A defect in prediction

Some thresholds were needed to adopt the equation to actual hot water heater. The electric current and supply water temperature was used to avoid these defects in prediction. We set thresholds of 25 C for supply water temperature of and 0.3 A for electric current. For conditions below these thresholds, the calculations were not conducted. Figure 9 shows effect of these thresholds. Estimation was improved.

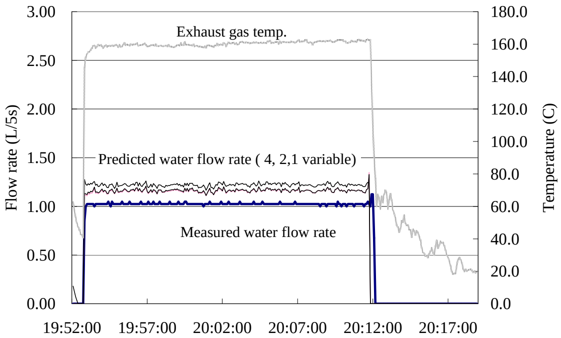

Fig. 9. A result of correction

VERIFICATION OF ACCRUACY

These modifications were made and daily hot water was predicted. In designing a water heater, capacity of heater is decided from maximum hourly hot water consumption and daily total hot water consumption. Therefore, these values of measurements and prediction were compared by using an index defined following equation.

$$Er = \frac{F_{predicted} - F_{measured}}{F_{measured}} \times 100 \qquad (8)$$

Maximum temperature among measurement was taken to calculate normalized value. The result was less than measurements. It could be considered that the maximum temperature was too high for estimation. There was some unexpected value measured during operation. Considering these errors, percentile of 0.5 % of measurement should be taken as maximum temperature.

The results are shown in table 2. When value of percentile of 0.5 % was taken, normalized vale became larger as the denominator of Equation (2) decreased. Consequently, predicted value became closer to measurements. The accuracies of prediction were around 10 %, although maximum temperature had an influence on the results.

Tab.2. Accuracy of prediction

	one	Two	Four
Max	-25.7	-23.7	-5
Square error	3769	3253	2171
0.5%	-12.0	-10.2	0.07
Square error	2956	2872	4802

DISCUSSIONS

The objective of this study was to establish measurement of hot water consumption in simple way. Therefore, fewer variables are preferable considering time and cost of measurements. As shown in statistical analysis, two variables, exhaust gas temperature and electric current were significant.

The equations obtained from experiments were valid on the experimental conditions. To adapt to existing application, several thresholds to avoid defect in predication should be considered. In this study, they are 0.3 A for electric current and 25 ˚C for hot water supply temperature. The validity of these values must be confirmed by further measurements.

The accuracy of prediction was around 10 %. Since the method presented in this paper was a simple one using up to four measuring points, the perfect prediction was not expected. A number of applications, in which information of hot water consumption could be obtained, is more important than accurate measurements. We consider that accuracy of 10 % is sufficient to obtain information for optimal design.

CONCLUSIONS

Materials for designing hot water supply system for commercial buildings were not sufficient, nevertheless proportion of energy consumption of hot water was large. A simple method that could predict hot water consumption measuring up to four points was proposed.

Products of Japanese major manufactures were tested to obtain empirical equations for gas consumption prediction. An exhaust gas temperature, a hot water supply temperature, a water temperature and an electric current were taken as independent variables for regression analysis. The empirical equations with sufficient credibility were obtained.

The equations were adapted to an actual application for verification. Some thresholds to adapt equations were taken to avoid defect in prediction, which were the exhaust gas temperature after stopping operation and anti freezing heater in winter. The results of prediction around 10 % errors were obtained.

In future studies, measurements will be carried out for various applications. The materials for design will be presented.

NOMENCLATURE

I: electric current [A], *t*: temperature [C], *Q*: gas consumption [kW], *Er*: the index of error, *F*: hot water flow rate [L/s], □: density of water [kg/m3], *Cp*: Specific heat of water [kJ/kg K], η_m :Efficiency of heater: □*t* temperature difference [K].

Suffixes

$_{measured}$: measured value, $_{outdoor}$: value of outdoor, $_{max}$: maximum value through measurements, $_{e}$: exhaust gas, $_{hw}$: hot water, $_{sup}$: supply water.

REFERENCES

[1] Motoi Yamaha and Masayo Takahashi, 2004, An analysis method for operations of hot water heaters by artificial neural networks, 2004 International Conference for Enhanced Building Operations (ICEBO), Paris