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DEVELOPMENT AND VERIFICATION OF VENTILATION CONTROL SYSTEM IN COMMERCIAL KITCHEN

Author

M. Aibara

Tokyo Gas Co., Ltd.

Tokyo, Japan

Co-authors

A. Okuda

Tokyo Gas Co., Ltd.

Tokyo, Japan

1. ABSTRACT

Recently in Japan, as elsewhere in the world, more attention is being placed on the energy-saving potential and comfort of kitchens because of the serious issue of global warming and increased awareness on hygienic and healthy labor environments.

Commercial kitchens in Japan are smaller in comparison to those in Europe and North America, and are areas in which cooking appliances with high heat loads are concentrated. Thus, in many cases, the heat and steam generated by cooking appliances spreads throughout the kitchen and causes the deterioration of the kitchen environment, or there is an increase in energy usage when the kitchens are not planned appropriately.

In this report, we introduce you to the development of a "Ventilation Control System," which is attracting attention as an energy-saving technology for commercial kitchens. This system detects the operational status of cooking appliances using temperature sensors installed in a ventilation hood, mounted above such appliances, and reduces ventilation volumes when the appliances are not in use. This enables the required power for fan operation and air-conditioning load to be reduced while maintaining a comfortable environment within the kitchen. In order to ensure that this system becomes widespread throughout Japan, the entire configuration is simplified so that the system can be purchased as a package, and the specifications for the installation method are simple and the system can be installed in the existing kitchens.

The system was installed in two actual kitchens to evaluate the accuracy of control, and to verify the level of comfort and energy-savings. The results confirmed that there are no problems with the system regarding the detection of the operational status of cooking appliances, using the temperature within the hood. It was also confirmed that there is minimal deterioration in comfort levels, and a high level of energy saving can be achieved.

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2. Introduction

Commercial kitchens in Japan are smaller than those in Europe and North America, and are densely packed with high heat-load kitchen appliances. In particular, gas kitchens are considered to be hot and oppressive working environments, which is why many users are now shifting to all-electric kitchens.

To solve the above issues, gas kitchen appliances with low heat radiation that reduce heat leakage into kitchens, called "*Suzuchu,*" have been developed and installed by gas companies. Although the developmental concept of "*Suzuchu"* is to make the users comfortable and to minimize energy consumption in kitchens, it is difficult to realize this concept by the sole use of low-radiance heat appliances without the proper planning of equipment such as ventilation and air conditioning devices.

Proper kitchen design methods have not been established because construction industries in Japan tend to place a low priority on commercial kitchens in building structures. Therefore, kitchens are filled with heat and steam generated by cooking appliances, and the kitchen environment deteriorates especially during summer periods of high heat and humidity. These poor environmental conditions may cause problems related to kitchen staff health, worker turnover, and food hygiene. Alternatively, more energy may need to be consumed in order to eject excess heat and steam from the kitchens.

Comfortable and energy-saving kitchens are gaining more attention lately because of global warming issues, a need to reduce electricity consumption during peak hours since the Great East Japan Earthquake, and an increasing awareness of hygienic labor environments. Currently, however, comfortable and energy-saving kitchens cannot be designed by many building designers or owners, because few people know how to properly plan such environments.

Under these circumstances, a "Ventilation Control System" has been developed to encourage the broad use of gas kitchens. The solution is focused on ventilation methods, and aims to establish design methods and systems that are applicable to entire kitchens and acceptable for use in Japan.

In this paper, the development of the "Ventilation Control System" is reported. Firstly, the outline of this system and the points of development for the expanded use of this system in the Japanese market are explained. Then, the results from the evaluation and verification of kitchen comfort and energy-savings are reported.

3. Specification of the system

3.1 Outline of the "Ventilation Control System"

・"Ventilation Control System"

The "Ventilation Control System" is an energy-saving system that controls air volume on demand, based on the operational status of kitchen appliances. Because this system reduces air volume when kitchen appliances are not being used, ventilation fan power and the air-conditioning load can be reduced.

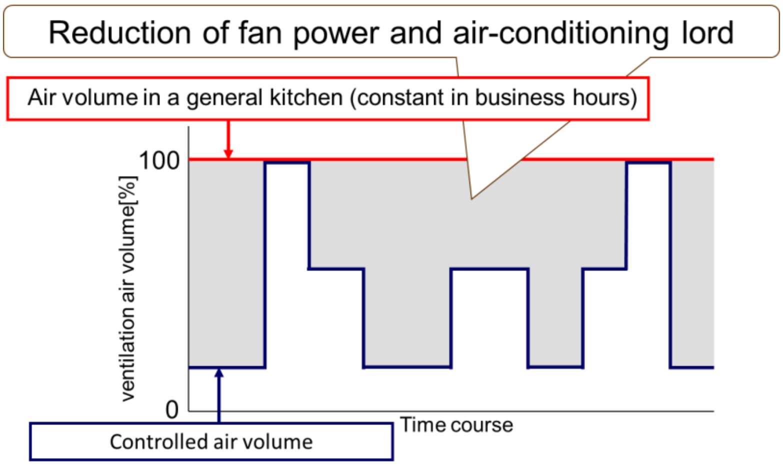


Figure 1. Diagram of ventilation control

・System components

Figure 2 shows the system configuration. The primary components are a main terminal device that controls the entire system, temperature sensors installed in ventilation hoods, motor dampers connected with ducts, inverter panels that control fan rotation speed, and sub-terminal devices that connect signals between the main terminal device and temperature sensors or motor dampers.

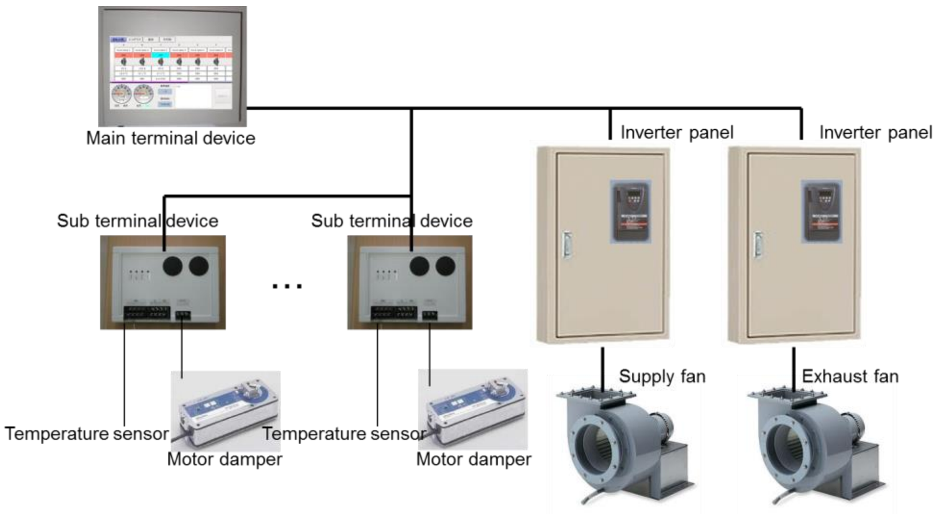


Figure 2. System configuration

・Operational Principle

This system detects the operational status of cooking appliances by using hood temperatures, adjusts the total volume of ventilation by using inverters, and controls the air volume balance between hoods by usage of motor dampers.

3.2 System Features

・An acceptable system for use in Japan

Since construction industries in Japan tend to place a low priority on commercial kitchens in building structures, some features of this system below were considered for easy acceptance by these industries.

[Points of development]

・**Energy-savings**: This is the main purpose of system development.

・**Comfort level**: The comfort level should either be maintained or increased, as compared to the situation prior to system installation.

・**Safety**: The system must be safe, even if any issues arise. The safety level should be equal to, or greater than that which was present prior to system installation.

・**Simplification of construction**: The construction works of this system should be minimalized, because kitchen areas in Japan are subject to short construction times, and are completed at the end of the entire construction process. As well, the system should be compact, because kitchen areas in Japan are small.

・**Low-cost**: The initial costs should be cut in order to obtain a return on their investment at an early date by running a cost reduction analysis. As a guide, the payout time is roughly 5 to 8 years according to hearings with professionals in the construction industry.

・Points of the specification

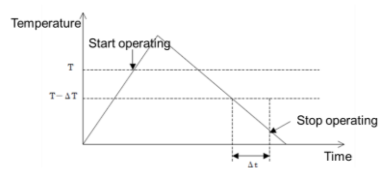
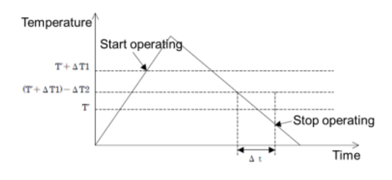
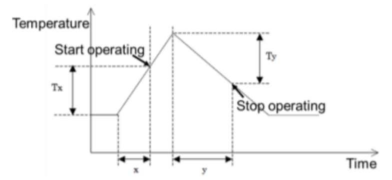
(1)Packaged system consists of a minimum number of components

Unlike foreign systems, which use dedicated hoods, this system uses versatile equipment without replacement of hoods. Additionally, it is packaged to minimize fieldwork such as power distribution work.

(2)Detection by temperature sensors in the hoods

The temperature in the exhaust hood is measured as an indicator of the operational status of cooking appliances. This method can reduce installation space, failure risks in oily and humid environments, and equipment and installation costs as compared to the method of direct air volume measurement. Each sensor in the hoods has an individual temperature threshold, which detects the operation of cooking instruments. There are three types of detection methods, using standard temperature, temperature differences, and temperature gradients.

Table 1 Types of detection method hoods

Standard Temperature	Temperature Difference	Temperature Gradient
		

(3)Fail-safe design

Various fail-safe systems using the method of Fault Tree Analysis are equipped in this system to avoid any dangerous failures, even if any issues arise. For example, when cooking appliances are not operational, the exhaust air volume from each hood is maintained at a value of at least 30 KQ, as required by Japanese law. Additionally, the exhaust air volume is automatically switched to the maximum value when the feedback signals of the air damper position and inverter frequency do not match with the command value after a certain period of time. Furthermore, the air damper is opened and closed automatically during nighttime to avoid sticking. In addition, even if any undetected issues arise, the system can be deactivated by a manual operable switch installed in the kitchen.

(4)Simple control with mode choice method

In this system, the air damper position and inverter frequency need to be adjusted properly before completion to make the air of each hood flow at a designated volume in response to the operational status of cooking appliances. However, if all air dampers and inverters are controlled individually according to the operational status of cooking appliances, the number of controls would become enormous; if the number of hoods is denoted as N, then the combinations of controls would increase by the square of N. Therefore, the hoods that have significant effects on air volume reduction are preferentially selected. The control combinations of the air damper positions and inverter frequencies of selected hoods are patterned in less than ten. For example, the hood in which the operation time is short and the difference in air volume between operating and non-operational times is large should be preferentially controlled, because that hood has a significant effect on air volume reduction.

(5)Wireless communication

A wireless communication system is employed to simplify the wiring work in the kitchens. This system has been developed by adding these features in two actual kitchens. The evaluation and verification results of comfort and energy savings are reported below.

4. Introduction examples

4.1 Case #1

4.1.1 Outline of building equipment

This system was installed in kitchen A of the staff canteen, which provided about 650 meals a day. The controllability, comfort levels, and energy-savings of the system were evaluated from data obtained throughout the year.

Figure 3 shows the kitchen layout, the design air volume of the exhaust hoods, and cooking appliance types. The air supplied into the kitchen was air-conditioned prior to entry, and the preset temperature was varied seasonally. The preset temperature of the staff canteen next to the kitchen was identical to that of the kitchen.

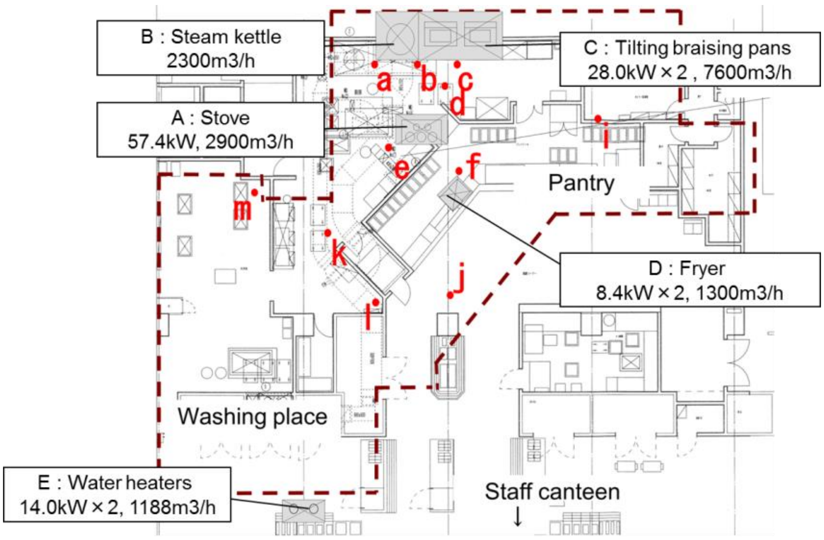
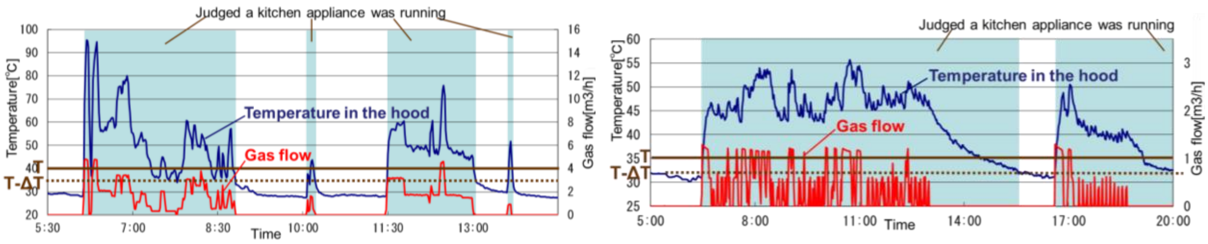


Figure 3. Layout of kitchen A

4.1.2 Verification of controllability, comfort level, and energy savings

・Controllability

Thermometers and gas flowmeters were installed on each hood and all cooking appliances, respectively. By use of these sensors, the correlation between the hood temperature and the operating status of the appliances was monitored. The position of the thermometers and the temperature thresholds "T" and “T-ΔT" were selected when the system was installed on July 2010, with "T" being used to determine when the cooking appliances begin operation, and “T-ΔT" being used to determine when the appliances ceased operation. Over a year, from April 2011 to March 2012, the relationship between the actual operational status of each appliance and the determined hood temperatures were investigated to examine the accuracy of control by the hood temperature (figure 4). This study helped us to estimate the best installation position of sensors and the temperature threshold for each cooking appliance. Since the accuracy of the control was sometimes reduced by the fluctuation of seasonal room temperatures, alternative options regarding the judgment method were added (Refer to Table 1).



Hood A Hood D

Figure 4. Relationship between operating status and hood temperatures

・Comfort level

Thermal environmental measurements made under both operational (controlled) and non- operational (not controlled) system conditions were carried out for a few days in each season. Up to 5 thermo-hygrometers were set at height directions (FL+100, 600, 1100, 1600, 2100 mm) in the areas under the controlled hoods, and temperatures were measured every minute. In each season, a pair of days with similar conditions was selected, with the system being operational on one day and not operational on the other. The thermal environmental data from these two days were compared. Figures 5 (ⅰ)-(ⅲ) show the average temperature of each height of point b, point e, and point f. In comparison with each point temperature between days of operation and non-operation, there was an observable difference at point e and point f of FL+1100 in winter. At all other points, the differences at the working area (FL+1100, +1600) were less than 1°C, and there was little difference in the whole kitchen.

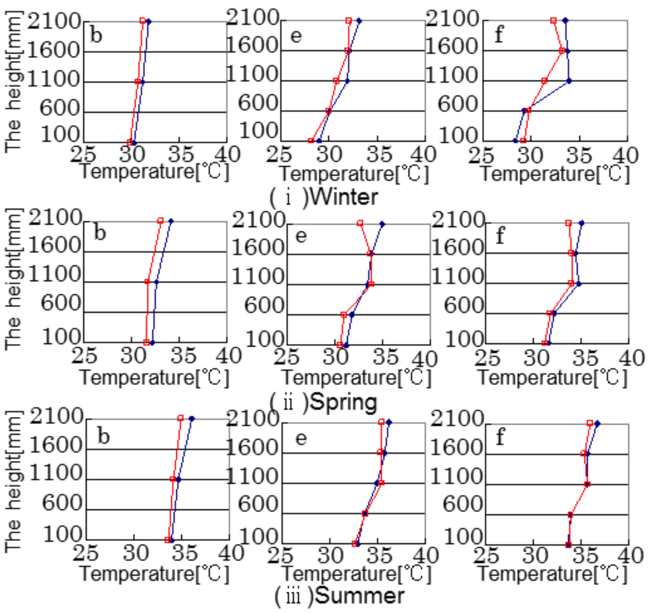


Figure 5. Time-averaged temperatures

・Energy-savings

The measurement results observed throughout the year showed that this system could reduce electricity by 41% for the air supply, by 73% for the exhaust fan, and by 40% for the air-conditioning load as compared to the case without system installation. From these results, the energy reduction effect of the system was calculated. With the assumptions that the kitchen was operated 240 days a year and the COP (Coefficient of Performance) of the air conditioning equipment was 3.0, the electricity used in this kitchen could be reduced by 49%, and the electricity reduction amount was 49,870 kWh per year.

4.2 Case #2

4.2.1 Outline of building equipment

This system was installed in kitchen B of the staff canteen, which provided about 100 meals a day. The effects on the thermal environment and energy-savings of the system were evaluated from data obtained in winter. Figure 6 shows the layout of the kitchen, the controlled exhaust hoods (A - G), and cooking appliances. In this kitchen, the exhaust air system was a single line and the air supply system was made up of double lines. Regarding the latter, one line carried conditioned air at 24°C supplied constantly from VHS, and the other carried outside air supplied from edges of double hoods, of which the volumes were variable and linked to the volume of exhaust air. Since the operating time of the steam convection oven and the rice cooker was short and the air reduction volume was large, the hoods for these two appliances were mainly controlled in this kitchen. Therefore, the combinations of the air damper positions and inverter frequencies are consolidated within ten patterns.

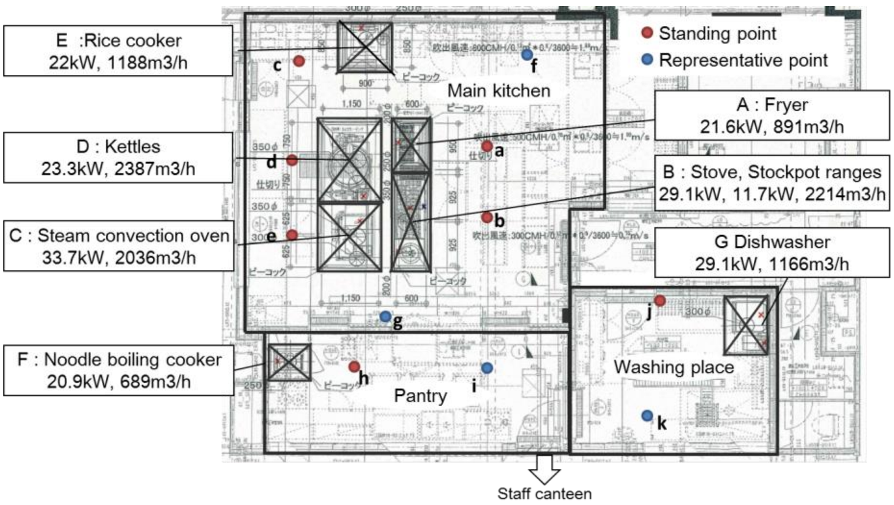


Figure 6. Layout of kitchen B

4.2.2 Verification of comfort level and energy-savings

The measurements of the thermal environment under both operational (controlled) and non-operational (not controlled) system conditions were carried out on 8 weekdays, from February 12 to 21, 2014. Table 2 shows the measurement items, all of which were measured every minute at the points from #a to #k shown in Figure 6. These points are the standing positions of kitchen staff while cooking, and the representative points of the room. In actuality, the measurement points of the standing kitchen staff were slightly displaced to avoid the direct effects of outside air from the double hoods, and so as to not disturb cooking. The data from two days of similar conditions, in particular on February 18 and 19, were selected. February 19 was the day on which the system was operated, while the system was offline on February 18. The thermal environmental data from these two days were compared.

Table 2 Measurement items

Measurement items	Point No.	Height
Temperature, Humidity	a ~ e	FL+ 600, 1100, 1600, 2100
	f, g	FL+ 1100, 2100
	h ~ k	FL+ 1100
Globe thermometer, Wind velocity	a ~ k	FL+ 1100
CO_2 concentration	b	FL+ 1100

・Comfort level

Figure 7 shows time-averaged temperatures and MRT (Mean Radiant Temperature) measured during 7:00-14:00 at the main kitchen on the controlled day and the non-controlled day. The temperatures on the controlled day were higher at all measurement points. In particular, the differences were large at heights of 600 mm and 1,100 mm. Temperature differences due to heights on the controlled day were smaller than those observed on the non-controlled day. In addition, the PMV (Predicted Mean Vote) was calculated for a comfort evaluation. Figure 8 shows the time-averaged PMV during 7:00-14:00 at each point. Compared with the non-controlled day, the variation in PMV values among measurement points on the controlled day was small. The PMV values at all points, except for the point e, were within ±0.5. This suggested that this kitchen was subject to comfortable working conditions. CO_2 concentrations were also measured, but no exhaust gas leakage from the hoods was detected. Therefore, the reason why the temperature on the controlled day was higher was thought to be due to the reduction of supplied outside air volume, rather than due to exhaust gas leakage.

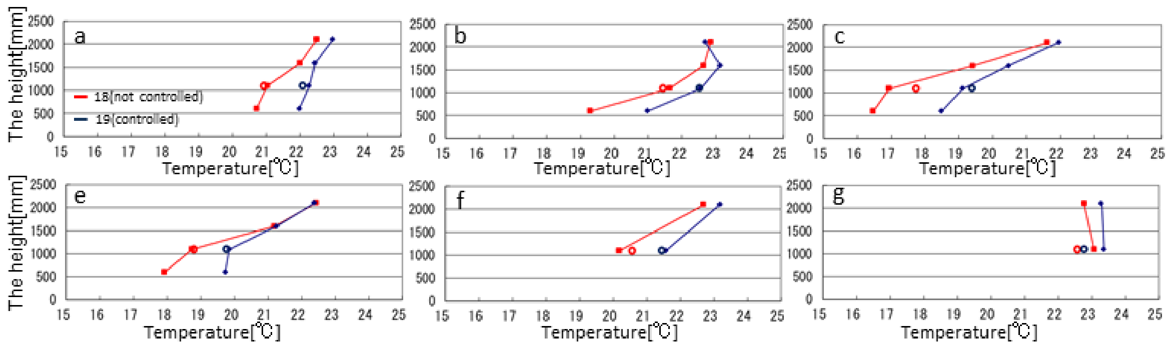


Figure 7. Time-averaged temperatures and MRT

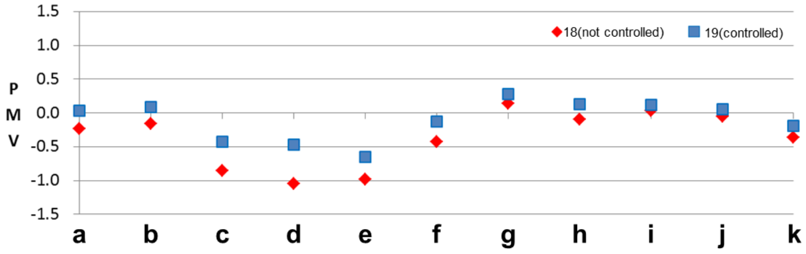


Figure 8. Time-averaged PMV

・Energy-savings

On the controlled day, the power consumption of the supply fan and the exhaust fan was 10.5 kWh, while it was 25.4 kWh on the non-controlled day. The energy reduction effect provided by this system was 59%.

5. Conclusion

The development of an energy-saving technology in commercial kitchens, termed a "Ventilation Control System," was introduced, and the verification results of energy-savings and comfort levels were reported. The results showed that the installation of this system in two actual kitchens could save energy without affecting comfort in commercial kitchens. Since in Japan, few people have complete knowledge about both cooking appliances and ventilation and air-conditioning systems in kitchens, gas companies involved in both cooking appliances and air-conditioning systems would play an important role in the field of commercial kitchens. It would be advantageous for customers to use our various kitchen-based technologies, which have been established by ample research and development, for a comprehensive planning of kitchens. Efforts like these would be extremely important to encourage the spread of gas kitchens, and to retain customers from the point of view of energy companies.