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Commercial Kitchen Ventilation—Efficient Exhaust and Heat Recovery

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ABSTRACT

This paper outlines those considerations and requirements that are pertinent to the design and operation of a properly functioning exhaust system for a commercial kitchen. It embraces such subjects as air quality, energy conservation, air pollution control, sanitation, and fire safety. Determination of necessary and appropriate exhaust air volumes for various items of cooking equipment is discussed. The potential for heat recovery is detailed, together with a description of the technology involved.

INTRODUCTION

The state of the art in commercial kitchen ventilation is indeed essentially an art, accepting certain basic fundamentals of thermodynamics, environmental control, and air movement, but responding largely to experience and logic. Certainly, science is very much involved in kitchen ventilation; however, it is anything but an exact science. A typical application may involve many variables, some of which may be virtually unknown and/or difficult to estimate. Good judgment is a major factor in kitchen ventilation engineering and design.

Availability of research data is extremely limited. Indeed, most of what is known and accepted today is of recent origin and modern techniques have largely developed over the past few years.

This paper will endeavor to identify the challenges and potentials as they are seen and explain the responding philosophies and techniques to handle them.

COMMERCIAL KITCHEN VENTILATION

Commercial food service, in its many forms, constitutes one of the largest and most stable industries in the United States. A recent report to the Gas Research Institute indicated that there are more than 500,000 food service establishments in the U.S., that they serve 77 million people per day, and the cooking equipment under their exhaust hoods consumes more than 200 trillion Btu (211 trillion kJ) of gas annually. Some 45% of those Btu are wasted in the exhaust air through those hoods.

Kitchen ventilation is a vital component of this huge industry; it affects building air balance and energy efficiency and, if it malfunctions, can shut down the entire kitchen and restaurant.

The subject of commercial kitchen ventilation covers a number of factors or considerations that combine to form the basis of a system that will perform satisfactorily, be cost effective, and comply with applicable codes.

These factors include smoke capture, grease extraction and disposal, fire protection, and the maintenance of acceptable air quality and temperature in the kitchen space. Modern systems may also include air pollution control and heat recovery equipment.

Efficient grease extraction is extremely important. Grease that is not exhausted will collect in ductwork and create a fire hazard. To such areas, the difference between 90% and 95% efficiency is not 5% but rather 100%.

Centrifugal grease extraction has proved to be highly effective and is currently employed on most leading designs of exhaust hoods. Many such hoods are also equipped with internal wash systems using hot water with detergent injection to automatically dispose of the extracted grease.

Fire protection is equally important. There are approximately 27,000 restaurant fires annually in the U.S. and 30% of those originate in the kitchen. The fire protection system should be capable of not only extinguishing a fire on the cooking surface, but also effectively preventing the fire from entering the exhaust duct.

EFFICIENT EXHAUST

There have been numerous standards and codes written on desirable exhaust and air change rates. The parameters vary widely and should include some consideration of kitchen temperature control.

The most prominent component of a kitchen ventilation system is the exhaust hood. The primary function of the hood is to capture and exhaust smoke, grease vapors, and other contaminants generated by the cooking process. The volume of air required to accomplish this must be determined. It is important that this volume be kept to the minimum possible since it must be replaced by make-up air, which usually requires heating and/or cooling. The following are some of the concepts and procedures that

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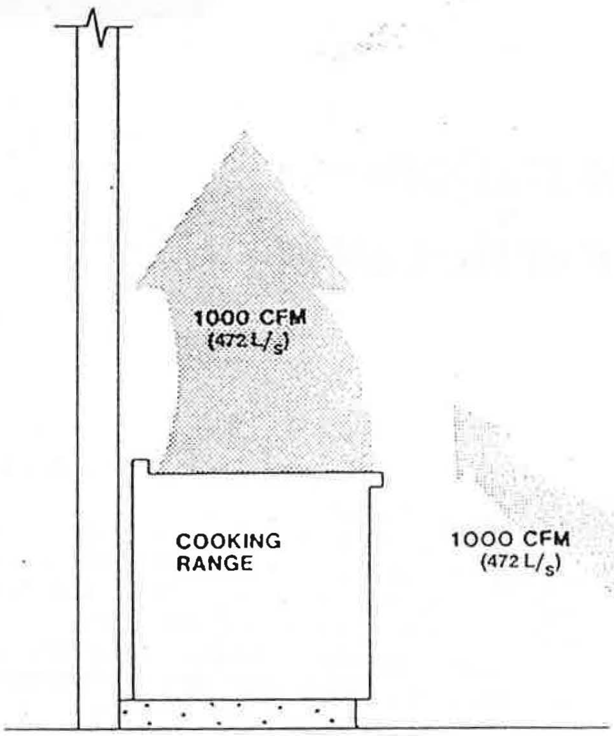


RANGE ONLY, NO HOOD.
THERMAL AIR CURRENTS COMING OFF THE
COOKING RANGE 1000 CFM$(472\ L/_s)$

Figure 1 *Range only; no hood*

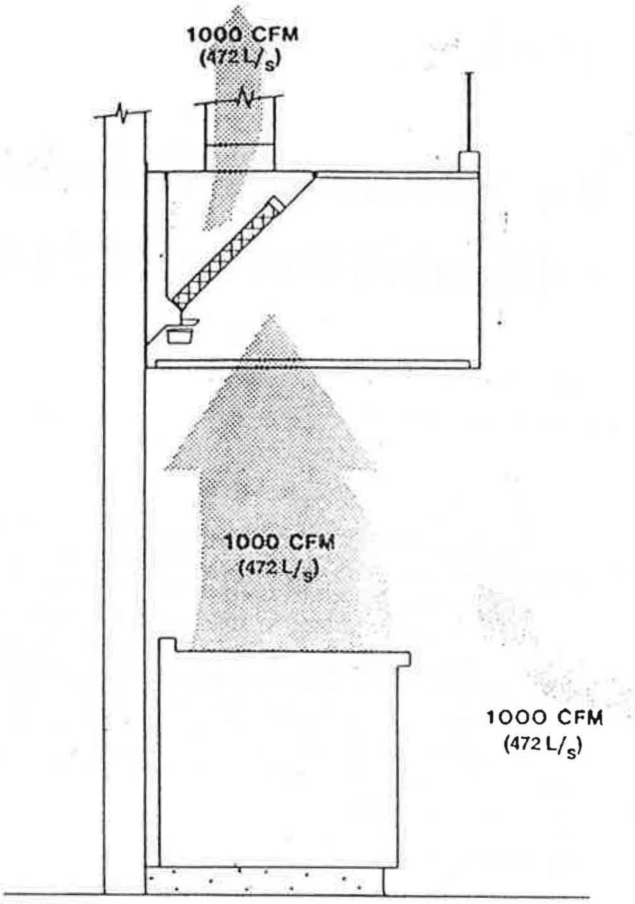
have been developed and applied successfully in the real world of commercial kitchens.

To start with, it is not the hood, but rather the cooking equipment, that determines the basic exhaust requirement; different types of cooking have different exhaust needs. Certainly the hood design and dimensions are important, but they also are essentially dictated by the cooking equipment.

Exhausting over hot cooking equipment is like handling most other hot processes; the thermal air currents must at least be matched. Heated surfaces of cooking equipment generate thermal air currents, and, just like any other heated surface, the temperature, area, and configuration of the surface are major factors in determining the extent of those currents. Variable as they may be, they establish the minimum exhaust volume.

Consider a single item of cooking equipment, as shown in Figure 1. When heated to operating temperature, it generates a thermal air flow, such as 1000 cfm (472 L/s). There is no hood or fan involved at this time, since a hood has no control over the thermal currents generated. As heated air rises from the cooking surface, the resulting low pressure at the surface causes room air to pull in to replace it. Thus, a pattern is established. Note that air is drawn in at the cooking surface level to sustain the cooking process.

When an exhaust hood is applied, as shown in Figure 2, the exhaust volume must at least equal the thermal air currents being received by the hood, otherwise the hood will overflow and eject some of the smoke and heated vapors into the kitchen.



HOOD BALANCED TO THERMAL AIR CURRENTS
COMING OFF THE COOKING SURFACE.
NET EXHAUST FROM KITCHEN 1000 CFM$(472\ L/_s)$

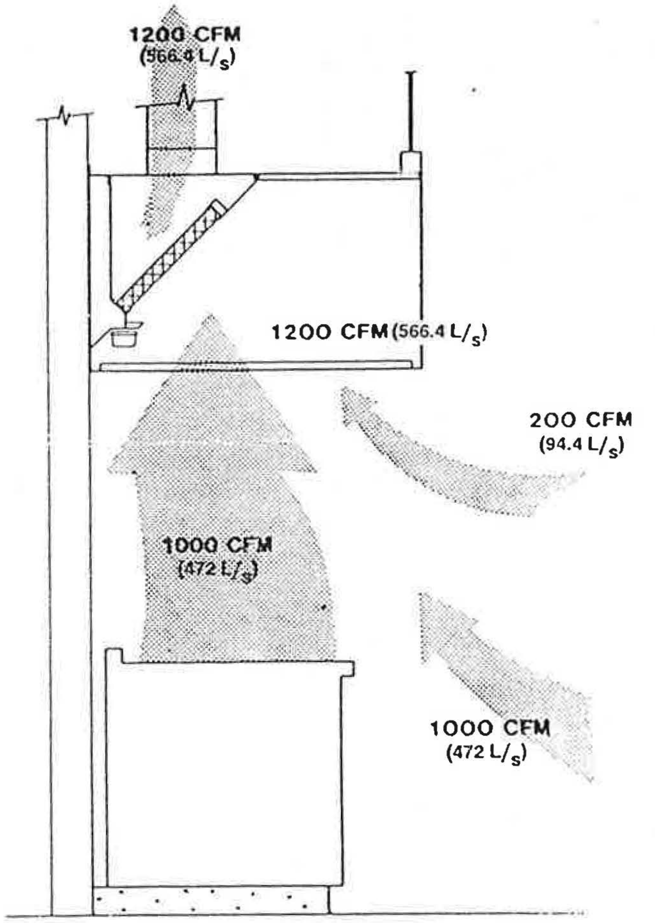
Figure 2 *Hood balanced to thermal currents*

Equal flow will work under ideal conditions but leaves no capture velocity at the front lip of the hood since all the air is coming from the cooking surface and entering the hood from below. Theoretically, no capture velocity is needed at that point since thermal and exhaust flows are in equilibrium.

However, in the real world it is necessary to add safety factors, as shown in Figure 3, to counteract cross-currents, turbulence, and surges in thermal currents. These safety factors are derived from a combination of calculation, experience, and good judgment. They vary according to application, hood type, and manufacturer. In this case a 20% safety factor is applied and thus an increase in the exhaust volume to 1200 cfm (566.4 L/s).

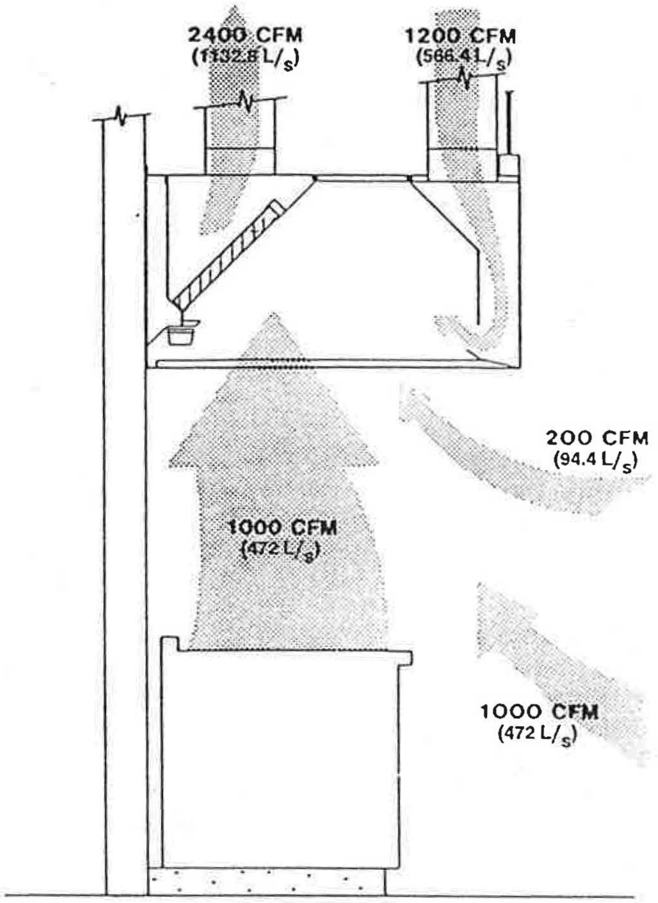
The additional 200 cfm (94.4 L/s) enters the hood at the front lip and thus establishes the "upper level" capture velocity. It does not change the "lower level" capture velocity significantly since nothing has changed at the cooking surface. In the event of a thermal surge, the extra air is drawn in at the "lower level" and subtracts from the "upper level" safety margin.

It should be pointed out that with hot equipment the highest capture velocity will always be at the lower level unless the exhaust volume is much greater than it needs



ADD A 20% SAFETY FACTOR TO COUNTER TURBULENCE, CROSS CURRENTS, THERMAL SURGES, ETC.
NET EXHAUST FROM KITCHEN 1200 CFM(566.4 L/s)

Figure 3 *Add 20% safety factor*



50% COMPENSATING HOOD
NET EXHAUST FROM KITCHEN 1200 CFM(566.4 L/s)

Figure 4 *50% compensating hood*

to be. This is exactly opposite to operation over cold equipment. Some hood designers calculate performance requirements under cold conditions and, on paper, arrive at substantial upper-level capture velocities. They tend to ignore thermal air currents and, consequently, end up with a hood that does not operate properly.

Getting back to the example in Figure 3, there is now a system that should perform adequately at minimum practical exhaust volume. This would surely be the most expedient and logical way to go.

But the local code official may claim that this hood, at this size, must exhaust 2400 cfm (1132.8 L/s) to comply with code. One popular response to that is to add a supply air plenum, as shown in Figure 4, and introduce untempered air directly into the hood interior, short-circuiting it to the filters. Since it has already been determined that a total of 1200 cfm (566.4 L/s) needs to come from the kitchen space, only 1200 cfm (566.4 L/s) can be introduced to satisfy the 2400 cfm (1132.8 L/s) exhaust. There is now a balanced condition with the proper amount of air coming from the kitchen space but at the expense of twice the exhaust volume, thus larger duct, shaft, and fan, and the addition of the untempered air fan and ductwork and the HVAC system sees no change in tempered air volume. This would be a 50% short-circuit hood.

As another example, what if 4800 cfm (2265.6 L/s) is called for, as shown in Figure 5? Simply increase the short circuit to 3600 cfm (1699.2 L/s). The required 1200 cfm (566.4 L/s) is still retained and now it is a 75% hood.

The 3600 cfm (1699.2 L/s) literally compensates for the surplus exhaust and thus the term "compensating hood," which is often applied to that design. The 4800 cfm (2265.6 L/s) exhaust permits the 3600 cfm (1699.2 L/s) supply. Conversely, the 3600 cfm (1699.2 L/s) supply literally compels the 4800 cfm (2265.6 L/s) exhaust. If the exhaust is increased to 12,000 cfm (5664 L/s), then the supply volume could be increased to 10,800 cfm (5097.6 L/s) and thus have a 90% compensating hood, but what is gained?

It is sometimes claimed that by injecting the short-circuit air in specific ways to create venturi effects, vortexes, etc., the capture effect can be increased at the front lip and thus reduce the net air volume drawn from the kitchen. This may be so in some cases, but keep in mind the balance between thermal and exhaust. In the sample case, the net saving could only apply to the 200 cfm (04.4 L/s) and it would hardly be desirable to reduce that to zero. The 1000 cfm (472 L/s) generated by the cooking equipment has not changed.

TABLE 1
Thermal Currents Chart

	Approx. Surf. Temp.		Thermal Current Volume Related to Cooking Surface			
			ELECTRIC		GAS	
EQUIPMENT	**°F**	**°C**	**CFM per ft^2**	**L/s·m^2**	**CFM per ft^2**	**L/s·m^2**
Ovens, Steamers, Kettles	210°	(99°)	20	102	25	127
Braising Pan	150°	(66°)	30	152	50	254
Chicken Broaster	350°	(177°)	35	178	55	279
Fryers	375°	(191°)	35	178	60	305
Griddle & Ranges	375°	(191°)	35	178	40	203
Hot Top Ranges	800°	(427°)	85	432	100	508
Grooved Griddles	500° 600°	(260°) (316°)	65	330	75	381
Cheese Melters	250°	(121°)	25	127	35	178
Woks	500°	(260°)	—	—	120	609
Salamanders, High Broilers	350°	(177°)	60	305	70	355
Charbroilers	600° 700°	(316°) (371°)	75	381	175	889
Broilers (Live Charcoal)	1500°	(816°)	—	—	200	1016
Mesquite Broilers	1500° 2000°	(816°) (1093°)	—	—	250	1270
Work Tops, Spreaders, etc.	—	—	5	25	5	25

From "The Actual CFM," Gaylord Engineering Bulletin, 1984, Gaylord Industries, Inc., Tualatin, OR.

Again, the thermal air currents are variable but they can be estimated with sufficient accuracy to design a dependable exhaust system. It has been done for some time now and a thermal currents chart has been formulated for this purpose (see Table 1).

In reviewing the thermal currents chart, the types of cooking equipment have been generalized and both gas and electric have been included. There are simply too many types and makes of equipment to list them all. The velocities were arrived at by a combination of calculation, laboratory tests, and readings taken in commercial kitchens. An appropriate multiplier should be applied to absorb disturbing influences such as cross drafts, local turbulence, and thermal surges. This multiplier, or safety factor, will vary with the style and make of exhaust hood. Table 1A includes factors applying to ventilators (Gaylord Industries, Inc. 1984).

These concepts are not new. They were included in the report from a study of kitchen ventilation carried out in 1972 under ASHRAE supervision (Talbert et al. 1973).

Code authorities are also beginning to respond. For example, the International Conference of Building Officials has revised Chapter 20 of the Uniform Mechanical Code to recognize that not all cooking equipment requires the same exhaust volume. It now lists four categories of equipment and four sets of figures (Uniform Mechanical Code 1982, 1985).

In summary, arbitrarily establishing exhaust volumes for hoods, no matter what type of cooking equipment is involved, is, in most cases, an overkill—wasteful and expensive. Likewise, introducing internal make-up air to compensate for excessive air volume results in larger fans, larger ducts and duct shafts, an additional supply fan and ductwork, and the costs of operating the supply fan. It is simply not an efficient ventilation system. Designing a hood to meet the requirements of the cooking equipment by taking a straightforward approach, based on sound engineering principles, results in an efficient, energy-saving system.

"ACTUAL CFM"

To determine the "actual cfm" required to properly ventilate a given piece of cooking equipment, use the "actual cfm" method as follows:

TABLE 1a
Safety Factor Chart

Ventilator Styles	**Multiplier***
Backshelf Style	1.05
Pass-Over Style	1.15
Wall Mounted Canopy, End Closed	1.05
Wall Mounted Canopy, End Open	1.20
Island Style, Single	1.50
Island Style, Double	1.30

* Safety factor may vary with different hood manufacturers.

From "The Actual CFM," Gaylord Engineering Bulletin, 1984, Gaylord Industries, Inc., Tualatin, OR.

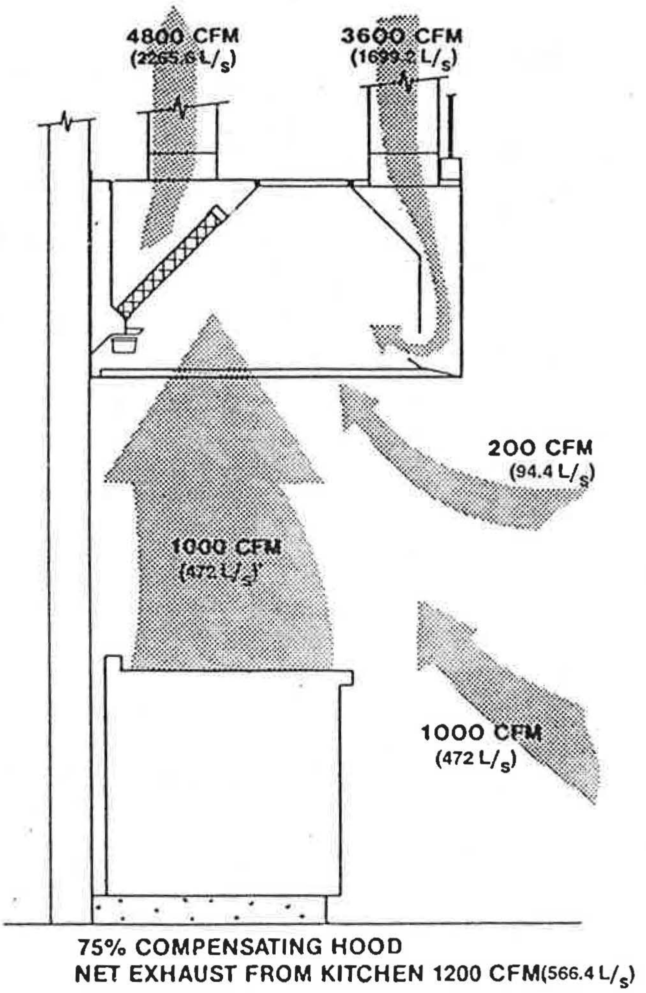


Figure 5 *75% compensating hood*

1. Determine the cooking surface area, including flue vents (in ft^2) of each piece of equipment in the cooking line.
2. Select the appropriate thermal current velocity from the thermal currents chart for each piece of equipment in the cooking line and multiply that figure by the area (in ft^2), to determine the cfm for that piece.
3. Multiply each cfm by the safety factor given in the safety factor chart. This is the volume in cfm necessary to properly exhaust smoke, heat, fumes, etc., from that particular piece of cooking equipment.

Having determined the actual volume of air that needs to be exhausted, the next logical move is to design an exhaust hood that will perform effectively at that volume and be accepted by the regulatory authorities. Such designs have been developed utilizing high-velocity entry slots configured to maintain the necessary capture pattern at various air volume rates. (See Figure 7.)

Figure 6 illustrates the typical airflow pattern for a slot-type canopy hood. Figure 7 shows a hood that has been engineered to operate at variable air volumes consistent with thermal airflow generated by the cooking equipment. This approach results in smaller duct and fan sizing, and minimizes the complexity and cost of installation.

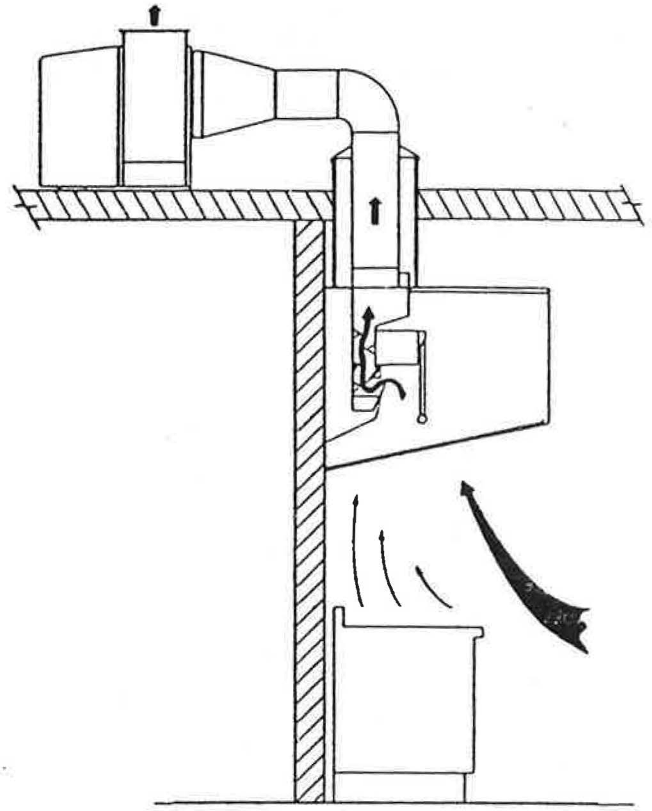


Figure 6 *Normal exhaust hood*

There are more things to be considered in kitchen ventilation than just the exhaust hood. Minimum air change rates are required to dilute odors involved with food preparation. Such rates will vary from kitchen to kitchen, but a study carried out in 1970 suggested that 12 air changes per hour be a minimum figure (Veterans Administration 1970).

Temperature must also be considered in relation to air volume. The typical commercial kitchen develops the most concentrated heat load in the building. Some 90% of this kitchen internal heat load is radiant heat generated by the hot cooking surfaces. That radiant heat loss wastes 20%

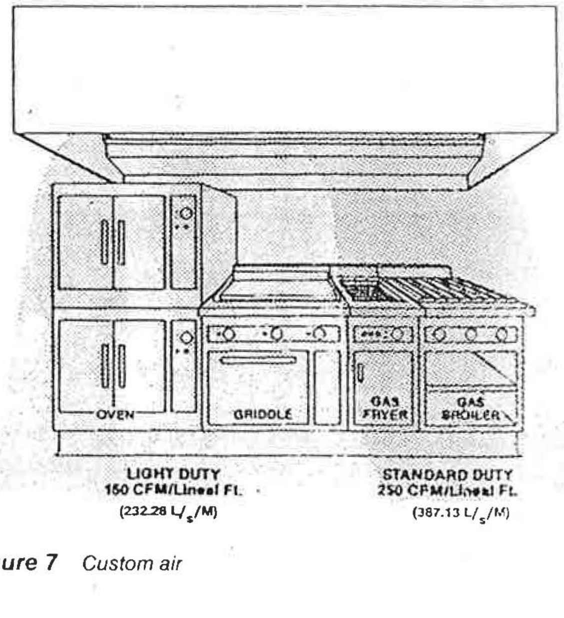


Figure 7 *Custom air*

TABLE 2
Typical Energy Use in a Restaurant

		%	
A.	Food Preparation (Cooking)	45	*1
	HVAC (Inc: Kitchen Vent.)	32	*2
	Sanitation (HW & DISH'W)	12	
	Lighting	8	
	Refrigeration	2	
	Misc.	1	
		100	

B. *1 ENERGY UNIT WASTED TO EXHAUST AIR

Type of Cooking	Typical Mix		Waste to Air	Related to Total Energy of Restaurant
Gas	65%		50%	15%
Electric	35%		36%	6%
Combined	100%	Av.	45%	21%

C. *2 KITCHEN VENTILATION (Exhaust and Make-up) Typically consumes 10% to 15% of total energy consumption. In northern areas, heating of make-up air can consume 7% to 10% of total energy.

D. Thus, recovery of up to 50% of the wasted energy will handle the heating of make-up air.

From a paper by David K. Black, presented at the Air Movement and Distribution Conference, Purdue University, May 28-29, 1986.

to 35% of the actual energy input to the cooking equipment; allowing for typical diversity, it averages 10% to 12% of the manufacturers' rated output.

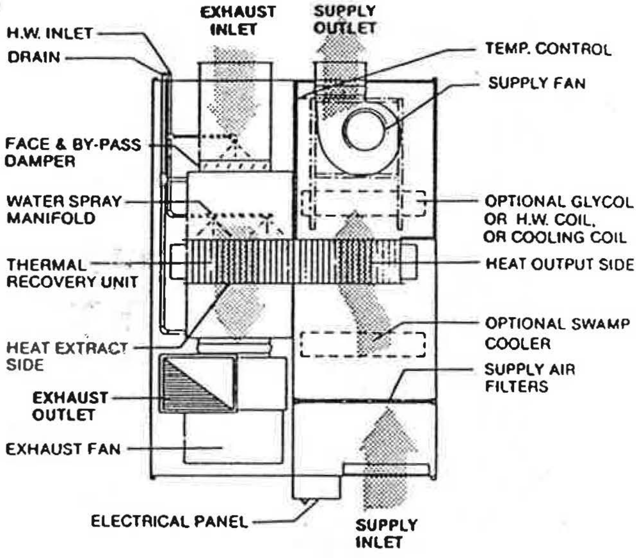
This radiant heat converts, of course, to sensible heat load in the kitchen. For example, a 3 ft long hot-top range operating at 700°F to 800°F surface temperature can radiate 24,000 Btu/h (7032 W), thus adding 2 tons (7.04 kw) to the internal heat load.

To make matters worse, the cook is subjected directly to the radiant heat close to its source. It is difficult to protect him or her. The ASHRAE-supervised study (1973) disclosed that to provide a comfortable environment for a cook standing continuously in front of such hot cooking surfaces would require air temperatures below 0°F (– 18°C) for his or her face, around 32°F (0°C) for his or her waist, and 70°F (21°C) for his or her legs.

Movement of air between the kitchen and adjacent space should always be to the kitchen, not from it. To accomplish this it is necessary to design for a balance between supply and exhaust that will result in a slight negative pressure in the kitchen. Differential between the two may be anywhere from as low as 5% up to 25% or more, consistent with individual job conditions, but the resultant negative pressure should not exceed .02 in (4.98 Pa) (NFPA).

HEAT RECLAIM

Several studies have been made on energy distribution in restaurants and kitchens. Table 2 (Gaylord Industries, Inc. 1984) gives a typical analysis. Section A lists energy consumption of the various activities as a percent of total energy for the restaurant. Section B tabulates the percent of energy input to cooking equipment that is converted to convection heat and wasted in the exhaust air. Section C points out the energy consumed by the kitchen ventilation system. Section D stresses that simply recovering 50% of the exhaust heat can save all the fuel otherwise needed to temper the necessary make-up air.



PLAN VIEW WITH TOP REMOVED

Figure 8 *Heat reclaim unit*

Air-to-air heat recovery devices such as runaround coils, heat pipe coils, counterflow plate exchangers, and thermal wheels are available with recovery factors exceeding 50%. The typical heat pipe coil generally achieves 65% heat recovery and, when handling kitchen hood exhaust air at 100°F (38°C), can heat the replacement air to 65°F (18°C) from an outside ambient temperature of 0°F (– 18°C).

Figure 8 shows a typical heat reclaim unit. Each commercial heat reclaim unit is furnished with a control cabinet that houses the start and stop buttons and the electrical, plumbing, and detergent injection system for the

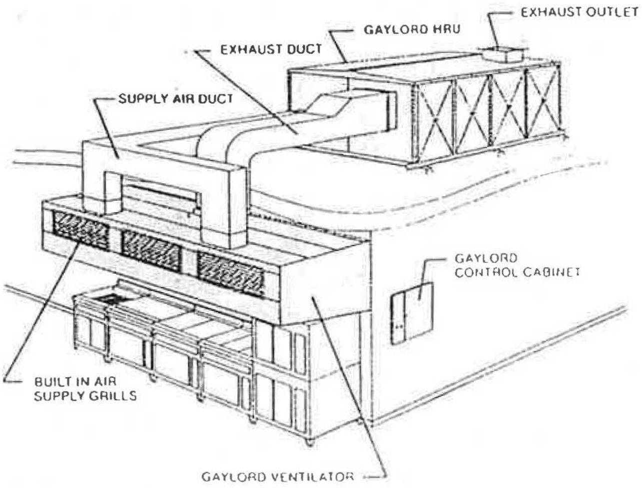


Figure 9 *Heat reclaim application*

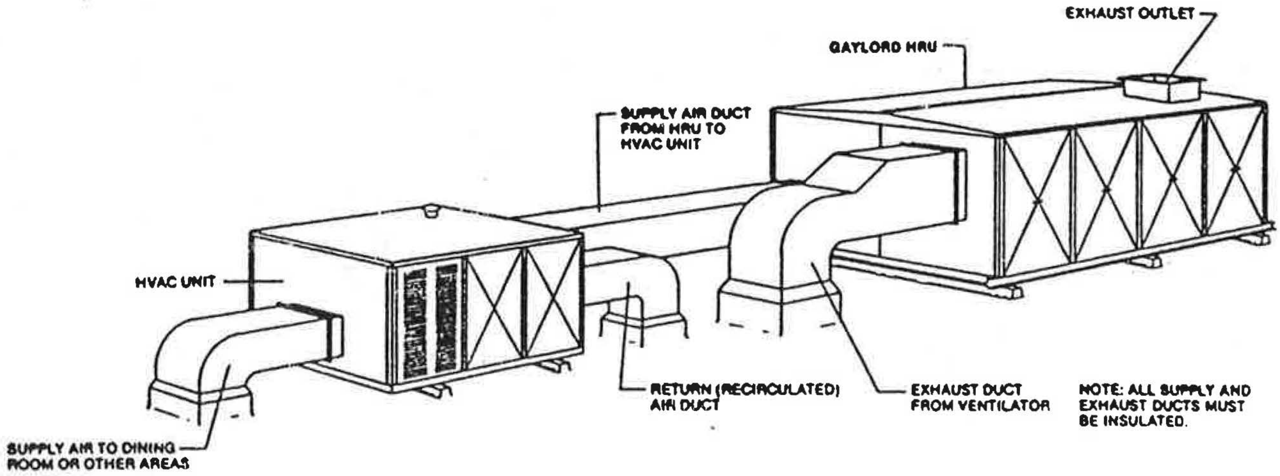


Figure 10 *Heat reclaim applied to HVAC supply*

operation of the heat reclaim unit. This same cabinet would control the cleaning cycle for the ventilator if a water-wash-type ventilator was used in conjunction with the heat reclaim unit.

A face and bypass damper assembly is located at the exhaust inlet. A temperature control, located in the supply air plenum downstream from the thermal recovery unit, is set to the desired supply air temperature. This control senses the temperature of the air leaving the thermal recovery unit and adjusts the face and bypass damper, directing the air either through or around the thermal recovery unit as necessary to maintain the set temperature.

When tempering of the supply air is required, the exhaust air is directed through the heat extract end of the thermal recovery unit. Waste heat is extracted and transferred internally to the heat output end of the thermal recovery unit, through which the supply air is drawn and thereby warmed. Supply air leaving the heat reclaim unit may be ducted directly to the ventilator make-up air discharge or any other distribution system.

In situations where additional short-term heating is needed to handle extremely low temperatures, supplementary heat is furnished. When tempering of the supply air is not required, the face and bypass dampers automatically adjust to direct the exhaust air around the thermal recovery unit. Various methods of cooling the air for summer operation may be added as an option.

At the end of the cooking day, the "stop" button on the control cabinet is pushed, shutting off both supply and exhaust fans and actuating the integral wash-down system of the heat reclaim unit and ventilator (if a water-wash-type ventilator is used). The average wash cycle runs for 5 to 7 minutes and automatically shuts off at the end of its timed cycle. All water is automatically drained from the heat reclaim unit and connecting piping, thus providing effective freeze-up protection.

APPLICATION

Figure 9 shows a typical arrangement where make-up air is supplied directly to the kitchen. Figure 10 shows make-up air supplied indirectly via the HVAC system to public areas and then to the kitchen.

Savings in fuel consumption can be considerable. For example, a typical restaurant in Chicago, operating 16 hours per day, seven days a week, and exhausting 5000 cfm (2360 L/s) could save in excess of 500 million Btu (527.5 million kJ) per winter by employing air-to-air heat recovery. Even if compared to high-efficiency, direct-fired gas heaters, the saving in natural gas amounts to some 540,000 ft^3 (15,282,000 L).

Consistent with climate conditions, hours of operation, and fuel costs, heat recovery employed on kitchen exhaust should prove highly cost effective.

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