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Development of a Fully Vented Gas Range

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ABSTRACT

A test method has been developed to evaluate the capture effectiveness of residential range/vent systems. Capture of cooking vapors, flue products, and heat are determined, as well as the thermal efficiency of the range-top burners. A canopy hood 18 in (457 mm) above the top of conventional gas and electric ranges was tested at full input loaded with pots full of water (9 in by 9 in) (229 mm by 229 mm). The downdraft range was tested with both 9 in (229 mm) and 5 in by 7 in (127 mm by 178 mm) pots. In addition, the shape of the range hood (beveled vs. rectangular) was evaluated.

Several new concepts were evaluated for possible use in the design of a "fully vented" range. These concepts include direct venting of the top burners by drawing flue products out through the burner aeration bowls, air curtains, side curtains, and application of the coanda effect. The relative effectiveness of each of these approaches is discussed. Testing of a prototype fully vented range is also discussed.

INTRODUCTION

Background

The advent of tighter housing has led to increased concerns about indoor air quality and excess humidity levels. Most gas appliances, with the exception of gas ranges and some space heaters, are vented (all of the flue products are removed from the indoor environment). The gas range with a vent hood can be considered to be semi-vented because the removal of flue products and cooking vapors is not 100% complete. There may, in the future, be a need for a fully vented range for certain types of installations.

Objective

The objective of this program is to develop a gas range/vent system that removes at least 95% of the flue products and cooking vapors from the indoor environment without reducing the thermal efficiency of the range, increasing the kitchen space-conditioning load, or increasing the sound level of the range/vent system.

DISCUSSION

Methodology

Instrumentation. The range vent test chamber (RVTC) was developed to evaluate both existing and new range ventilation systems. The chamber and procedure were, in part, based on work by a manufacturer (Sarnosky 1984). The nominal outside dimensions of the RVTC (see Figure 1) are 8 ft by 10 ft by 8 ft (2.4 m by 3.05 m by 2.4 m) of standard 2 in by 4 in (51 mm by 102 mm) frame construction. The walls and ceiling are insulated with fiberglass and covered with aluminum on the inside surfaces. The floor is insulated and tiled. One end of the chamber is an air distribution plenum 2 ft (0.61 m) deep with perforated metal (1/16 in [1.6 mm] holes on 1/8 in [3.2 mm] centers; 23% open area) separating the plenum from the interior of the chamber. Forced air supplied to the RVTC enters the chamber through the plenum and exits through the ventilation system being tested. Appropriate cabinets and cupboards are simulated with aluminum boxes (see Figure 2).

Airflow, dry-bulb, and dew point temperatures and oxides of nitrogen measurements are made in each airstream (inlet and vent). The temperatures and oxides of nitrogen concentrations are also determined at three fixed points inside the RVTC (see Figure 3). The three points are located on a vertical axis 2 ft (0.61 m) from the front of the system under test. On this axis, they are 1 ft (0.3 m) from both the floor and ceiling and at the midpoint between the floor and ceiling. Inside the chamber, mean radiant temperatures (1 ft [0.3 m] from the pots at 3 ft [0.91 m] and 5 ft [1.52 m] from the floor) and the static pressure at the wall are also measured, along with the water evaporation and energy input rates for the test range. Table 1 lists specifications for the instrumentation. Figure 4 is a schematic of the test chamber.

Initially, the psychrometric measurements were made using aspirated wet/dry-bulb thermometers, per ANSI/ASHRAE Standard 41.6-1982. This approach was discarded because, for some of the test conditions and sample points, the dry-bulb temperature was quite high (>150°F [65°C]), making it difficult to ensure proper wetting and reducing confidence in the measurement.

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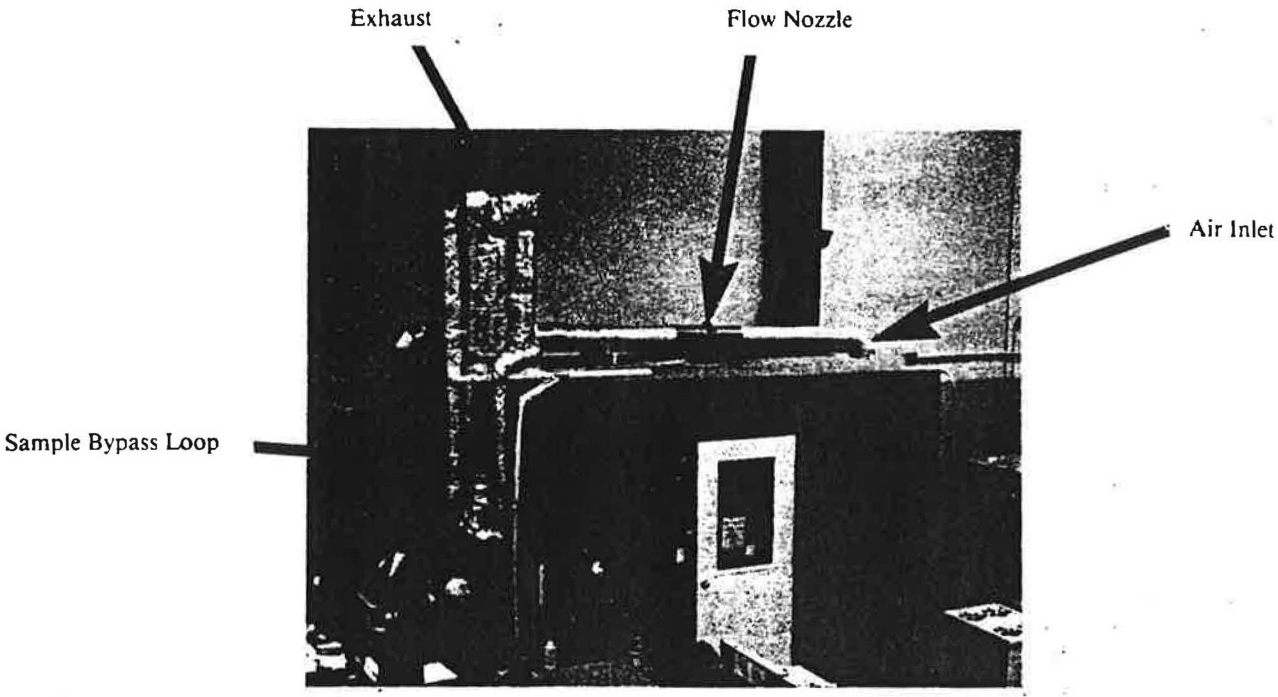
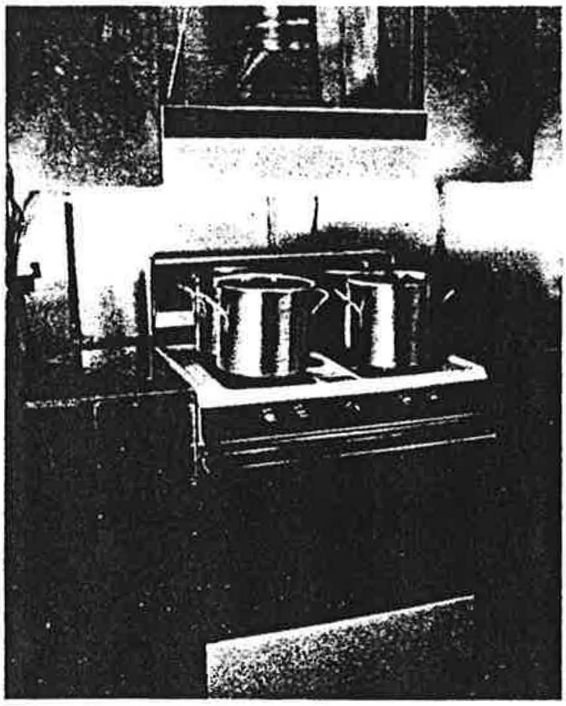


Figure 1 **Range vent test chamber**

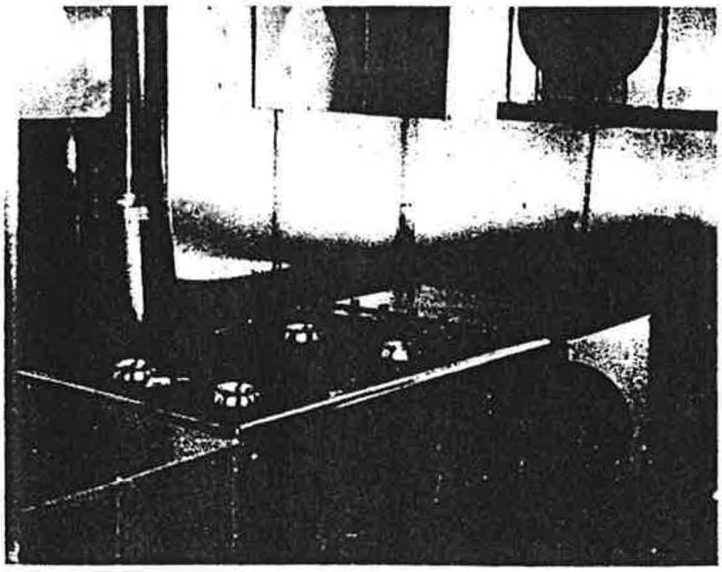
Procedure. The following procedure was followed for each test:

1. The desired vent flow rate is set with the range off.
2. Open pots of water are placed on the range.
3. The desired burners of the range are turned on.
4. The room is sealed.
5. The inlet airflow is adjusted to maintain zero static pressure (gage) in the room.
6. After the conditions in the RVTC have attained an equilibrium condition (<1° change in wall temperatures over a 10 min period), the data are recorded.
7. The chamber is then purged to prepare for the next test run.

Calculations. The calculation used to determine the capture of flue products, cooking vapors, and heat assumes that the capture effectiveness (E) can be characterized by the ratio of the concentration in the



Conventional



Downdraft

Figure 2 Gas ranges in RVTC

TABLE 1
INSTRUMENTATION

Parameter	Method	Model Type	Location
Air Flow	Nozzle	4" — AMCA/ASHRAE	B, C
Dry Bulb Temperature	Beaded Thermocouple	Type T	A, C, E, F
Dew Point Temperature	Chilled Mirror Hygrometer	General Eastern Hydro MI with heated sensor	A, C, E
Mean Radiant Temperature	Globe Thermometer	8" Black Copper Sphere	E
Air Velocity	Hot Wire Anemometer	Datametrics #100 VT	E
NO/NO_2	Chemiluminescent	Thermo Electron Corp. Model 14A	A, C, E
Weight	Electronic Platform Scale	Electroscale Model DR-525	G
Static Pressure	Inclined Manometer	Merriam Inst.	F
Energy	Gas — Wet Meter Electric Meter	American Meter Duncan Electric	G G

A — Ambient
B — Inlet Duct
C — Vent Exhaust Duct
E — Chamber Interior (Various Points)
F — Chamber Walls (Various Points)
G — Range

chamber (C) to the concentration in the vent airstream (V) with adjustment for ambient concentration (A) (Sarnosky 1984). Thus,

$$E = 1 - \frac{(C - A)}{(V - A)} \quad (1)$$

For calculating the capture of flue products (*EF*), NO_x concentrations are used. Neglecting the water vapor in flue products, capture of cooking vapors (*EC*) is calculated based on the absolute humidity (e.g., lb of water/lb of dry air). The heat capture (*EH*) is based on the enthalpy (e.g., Btu/lb of dry air). The derivation of Equation 1 is presented in Appendix A.

The range thermal efficiency (*R*) is determined as

$$R = \frac{970 \times M}{I} \quad (2)$$

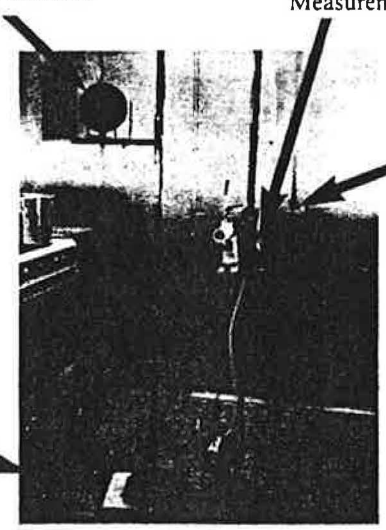


Figure 3 Instrumentation in RVTC

where 970 Btu/lb (2260 kJ/kg) is the latent heat of vaporization of water, *M* is the evaporation rate of the water, and *I* is the energy input rate.

The winter and summer space-conditioning loads (*SW* and *SS*) are calculated as make-up air (*A*) plus or minus the heat load from the range. For winter, the heat load is subtracted from the make-up air load. For summer, the heat load is added to the make-up air load. The make-up loads are based on the following Cleveland design temperatures: 7°F (−14°C) outdoor and 70°F (21°C) indoor during the winter (107.2 Btu/lb [250 kJ/kg]: AMW); and 89°F (32°C) dry-bulb/75°F (24°C) wet-bulb outdoor and 80°F (27°C) dry-bulb/67°F (19°C) wet-bulb indoor during the summer (31.9 Btu/lb [74 kJ/kg]: AMS). The heat load (*L*) is determined as

$$L = (1 - EH) \times I \quad (3)$$

Thus,

$$SW = AMW - L \quad (4)$$

and

$$SS = AMS + L \quad (5)$$

State-of-the-Art Review

Evaluation of several currently available range/vent systems was carried out:

- A conventional gas range
  - With all four burners loaded with 9 in by 9 in (229 mm by 229 mm) pots full of water under a beveled canopy hood 18 in (457 mm) above the range top (nominal dimensions—30 in by 21 in (70 mm by 53 mm) with a 22° bevel such that the front edge is 23.5 in (600 mm) wide;
  - The rear two burners in use under the same canopy hood;
  - The front two burners in use under both the canopy hood and a rectangular hood (same dimensions without the bevel).

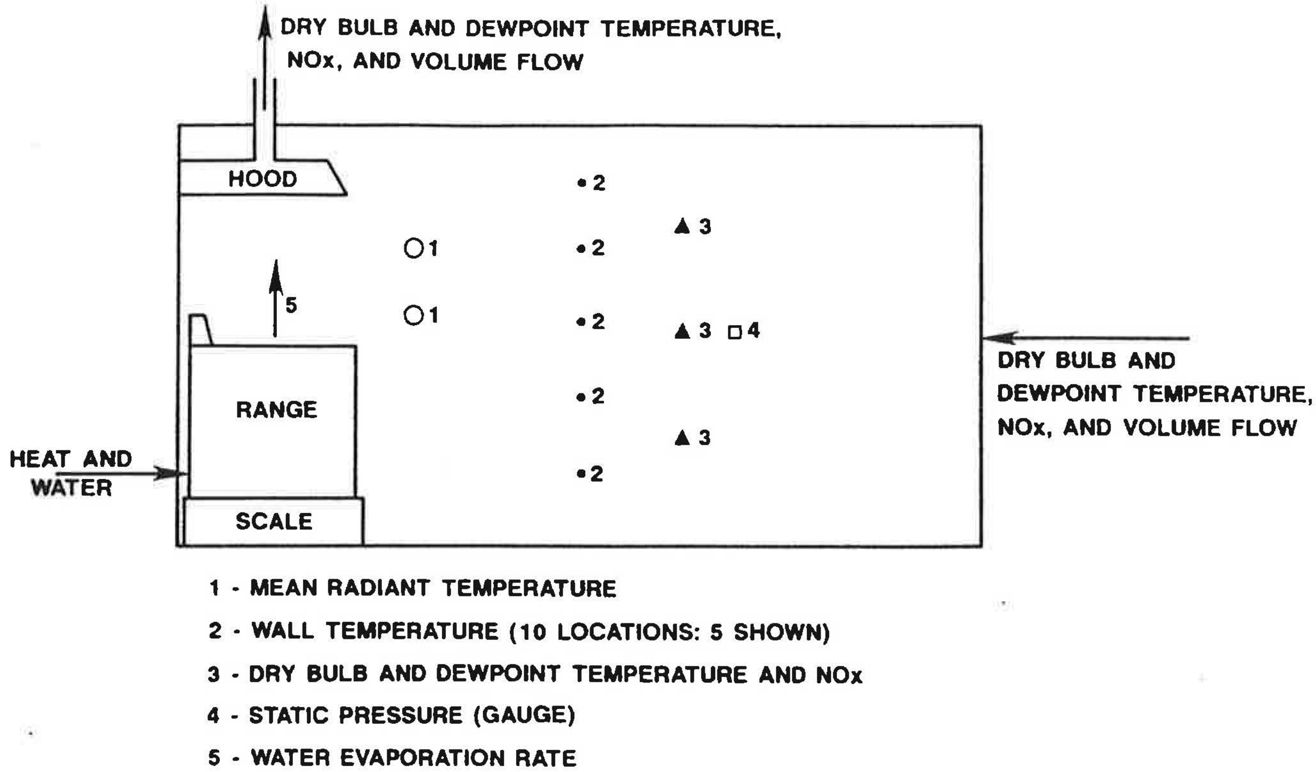


Figure 4 Schematic of RVTC

- An electric range under the canopy hood, also with four 9 in by 9 in (229 mm by 229 mm) pots of water on the burners.
- A gas downdraft range was tested with:
  - 9 in by 9 in (229 mm by 229 mm) pots and
  - 7 in by 5 in (17 mm by 127 mm) pots.

The results of the testing are shown in Table 2 for airflow rates from 0 to 500 cfm (236 L/s). The NO_x capture, water capture, heat removal, and thermal efficiency are shown in Figure 5. The space-conditioning loads are shown in Figure 6.

The following conclusions can be drawn from the data:

1. The capture of flue products, cooking vapors, and heat from the conventional gas range is less than 65% at 100 cfm (47.2 L/s) with the canopy hood (largely due to the front burners) and increases to greater than 90% at 350 cfm (165 L/s).
2. The rectangular profile hood has a substantially higher capture effectiveness than the beveled profile at the same airflow rate.
3. The capture of flue products with the downdraft gas range is nearly 100%. The capture of cooking vapors and heat varies directly with airflow rate and inversely with pot height.
4. The thermal efficiency of the conventional gas range is degraded about 0.6 percentage points per 100 cfm (47.2 L/s).
5. The thermal efficiency of the downdraft gas range is degraded about 7 percentage points per 100 cfm (47.2 L/s).
6. The winter space-conditioning load increases with increasing airflow rate, largely due to make-up air requirements.
7. The summer space-conditioning load is greatest at 0 cfm. As the airflow increases, the space-conditioning load first decreases to a minimum and then increases. This relationship is a function of the heat capture effectiveness, energy input to the range, and make-up air requirements.

New Concepts

In order to achieve the objectives of this project, various modifications to the range and vent components of the system were evaluated. Modifications to the range involved exhausting products of combustion directly through the aeration bowl of the top burners and a new grate design to counteract the deleterious effects on the range efficiency. Modifications to the vent system included sheet metal side curtains, air curtains on the sides of the range, and a column of air directed upward between the front burners.

Range Modifications. The range modifications consisted of two components added to the aeration bowl (see Figure 7):

1. An exhaust manifold that collects the flue products from the holes in the aeration bowl, and
2. A "cone" grate that replaces the standard "finger" grate, contains the flue products, and increases the turbulence on the bottom of the cooking utensil.

The configuration shown in Figure 8 was optimized through extensive parametric evaluation of various dimensions. With this configuration it was found that the minimum

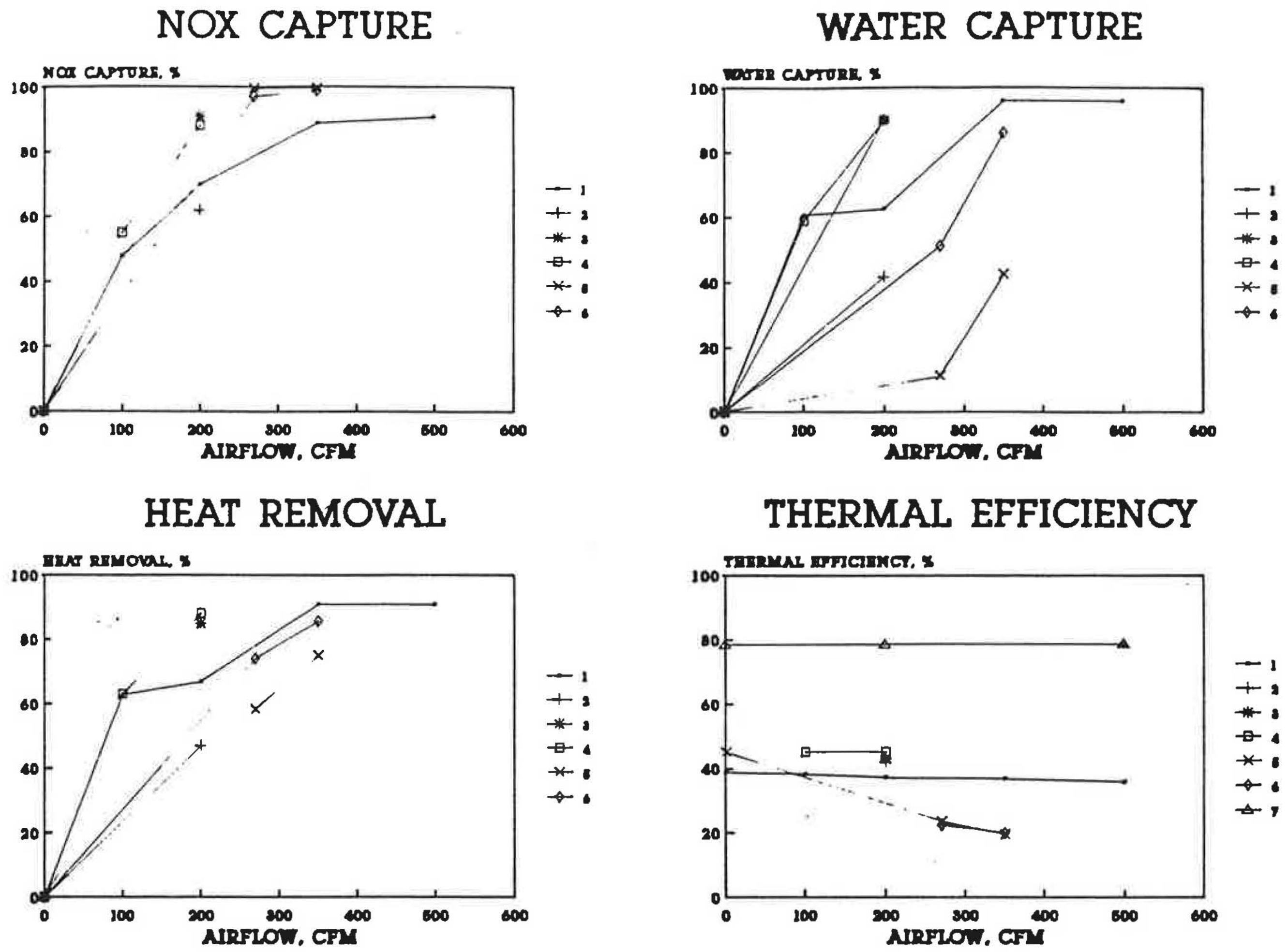


Figure 5 State of teh art review test results

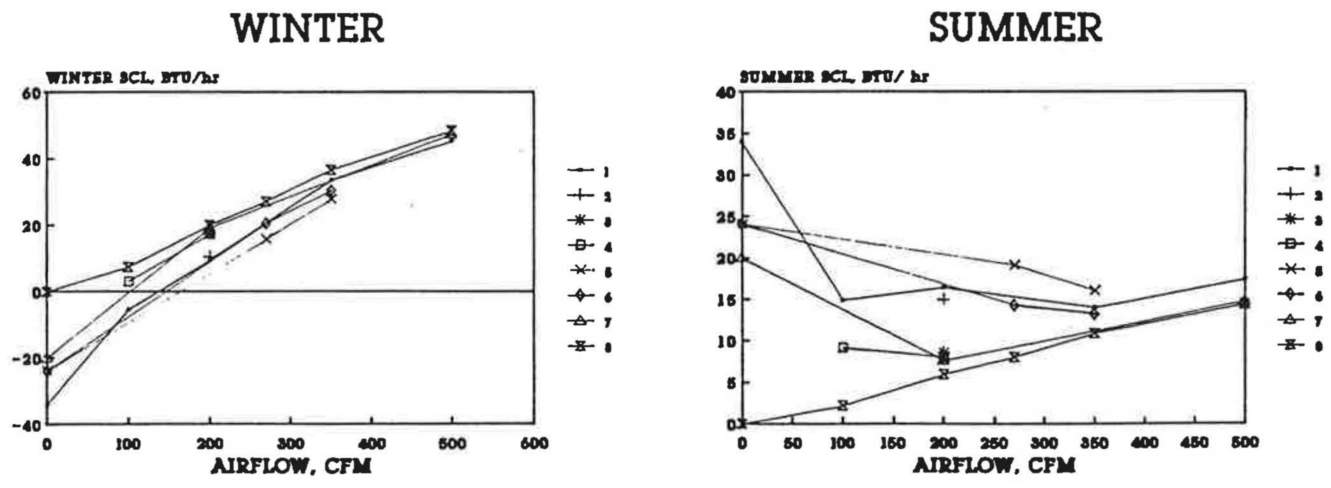


Figure 6 State of the art review space conditioning loads

airflow that would result in complete combustion (CO < 0.08% on an air-free basis) was about 2 cfm (0.9 L/s). At 2 cfm (0.9 L/s), nearly 80% of the flue products were captured and the thermal efficiency was substantially higher than with the finger grate.

Vent Modifications. As for vent modifications, it was felt that vertical, planar jets of air, parallel to the bouyant plume generated by the range burners and located along the sides of the range, could be useful in preventing escape of contaminants and reducing the effect of cross-drafts. Methods of analyzing the performance of these plane jets include considering them as an air curtain or as a push-pull hood.

A method of analysis for a recirculating air curtain has

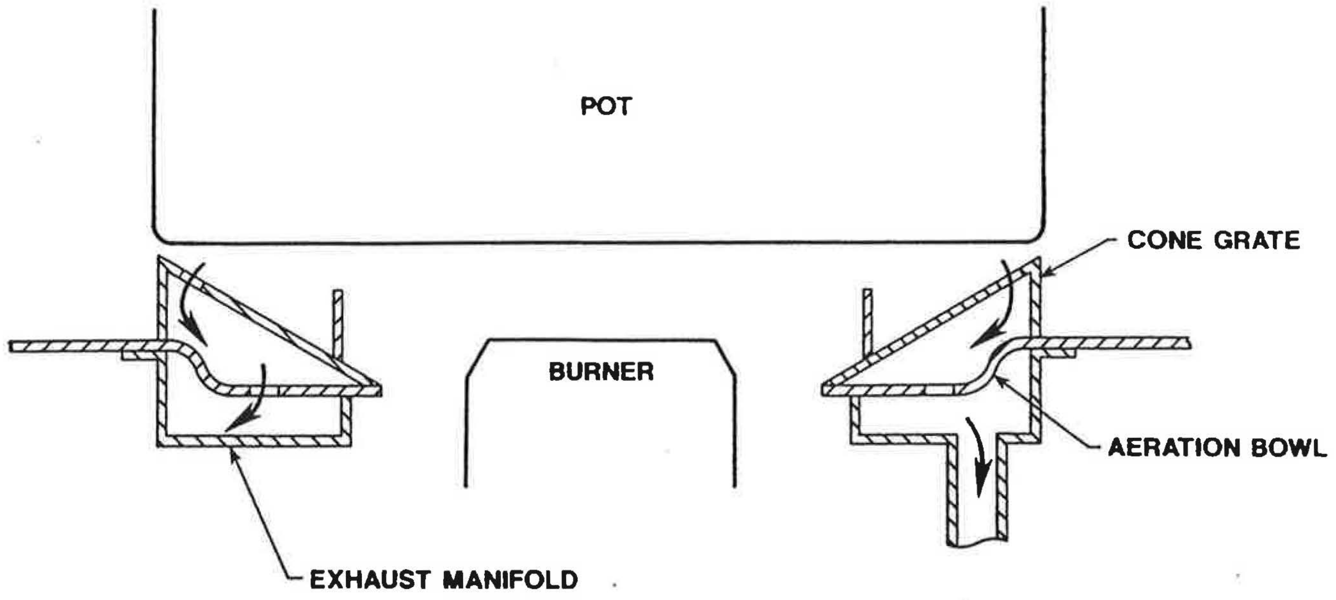


Figure 7 Cross-section of burner/aeration bowl with "cone" grate and exhaust manifold.

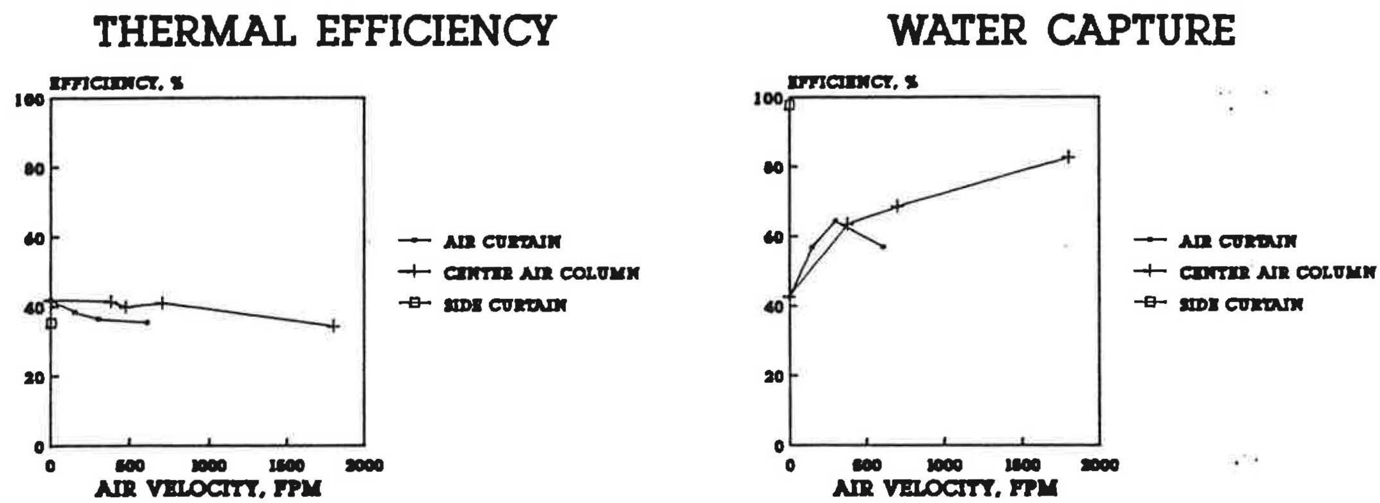


Figure 8 Vent modifications test results

been presented by Hayes and Stoeker (1969). If a slot width of 0.5 in (13 mm), a room temperature of 86°F (30°C), a plume mean temperature of 137°F (58°C), and a height of 18 in (457 mm) are assumed, Hayes and Stoecker suggest a minimum jet velocity of 240 ft/min (1.2 m/s), which gives a jet flow rate of 20 cfm (9.4 L/s) per side.

A method of analysis for a push-pull hood has been developed by Shibata et al. (1982). The small scale of the range hood is not within the range of the conditions given in this reference. However, it appears that a velocity of about 100 ft/min (0.51 m/s) from a 2 in (51 mm) wide slot, requiring a jet airflow rate of 25 cfm (11.8 L/s) per side, would be a rough projection of the optimum conditions.

Water capture effectiveness and range thermal efficiency, as discussed above, were measured with various vent modifications and the front two burners of the range operating. The 9 in by 9 in (229 mm by 229 mm) pots of water were placed on all four burners. For all modifications, except the sheet metal side curtains, the air velocity was measured with a hotwire anemometer (see Table 1) 2 in (51 mm) from the outlet of the structure. The baseline condition (200 cfm (94 L/s) airflow with the beveled hood 18 in (457 mm) above the range) resulted in a 42% capture of water vapor and 42% thermal efficiency (Table 2, column 2).

In order to quantify the maximum effect of a perfect air curtain, solid side curtains were installed. The capture effectiveness increased from 42% to nearly 100%. The thermal efficiency decreased from 42% to about 35%. Side curtains are being widely applied in the commercial foodservice industry for obvious reasons. The addition of walls adjacent to a residential range may not be acceptable unless they are easily movable.

Various configurations of air curtains with several air jet velocities, including the specifications suggested above, were tested. The air curtains resulted in a maximum capture of about 65% of the water vapor at an air velocity of 300 ft/min (1.5 m/s) with a thermal efficiency of 36%.

Beyond 300 ft/min (1.5 m/s), the capture decreased

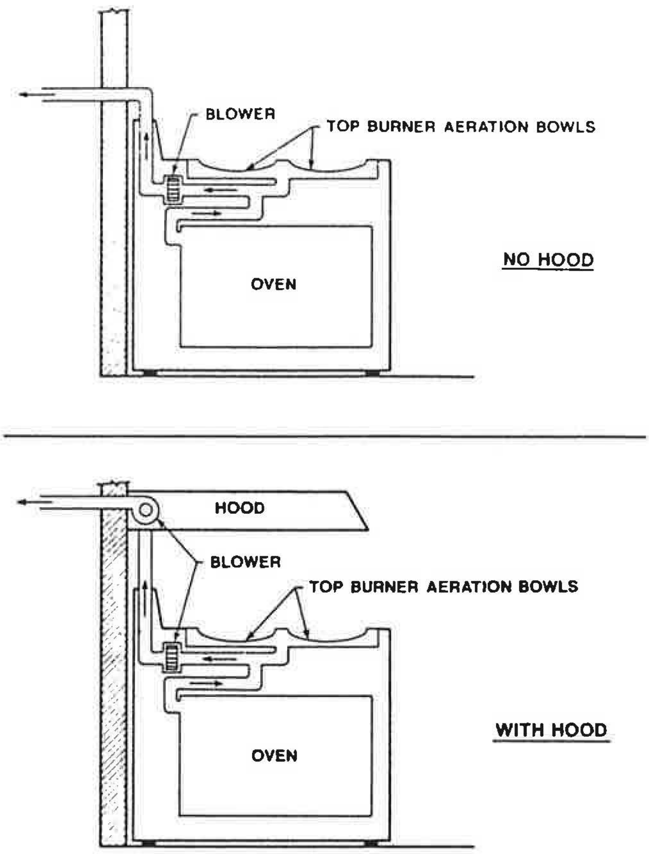


Figure 9 Fully vented range installation configurations

and the range efficiency continued to drop. The heat transfer rates were overpredicted by a factor of two or more when using the air curtain analysis. Those methods of analysis do not appear to be applicable to the range hood conditions.

An upward-directed column of air between the front burners was tested. The column of air was expected to induce airflow via the "coanda" effect (Kelso et al. 1986; Reba 1966). The capture increased at a rate of about 2.2 percentage points per 100 ft/min (0.5 m/s) velocity while the thermal efficiency decreased at a rate of 0.6 percentage points per 100 ft/min (0.5 m/s). The maximum velocity tested was 1800 ft/min (9.1 m/s), which would be an unacceptably high velocity. The addition of a 9 in by 1 in by 18 in (229 mm by 254 mm by 457 mm) rectangular structure inside the column of air made no measurable difference. The close-coupled range and hood configurations and the tall pots minimized the effect of these plume control measures. The results of the vent modification tests are shown in Figure 8.

PROTOTYPE RANGE

A prototype range was developed applying the direct-venting approach discussed above. As shown in Figure 9, the oven is also tied into the venting system. Only minor modifications to the oven were required to compensate for the new design. Two different installation configurations of the fully vented range are shown in Figure 9. The first would be for an installation in which removal of cooking vapors was not deemed necessary. The second would be, for instance, a tight house, where removal of the cooking vapors would be desired. Figure 10 is a photograph of the fully vented range prototype.

Testing of the prototype (Figure 11) showed that the capture of flue products, with 9 in pots (229 mm), meets the proof-of-concept goal and that the efficiency of the top burners of the vented range is higher than the standard range for all pot sizes tested.

CONCLUSIONS

It was found that a bevel-edged canopy hood is 50% to 60% effective at an airflow rate of 100 cfm (47.2 L/s). The effectiveness increases to 85% to 95% at airflows in excess of 350 cfm (165 L/s) or with a rectangular-shaped hood at lower airflows. The downdraft range is nearly 100% effective capturing flue products but relatively ineffective capturing cooking vapors from pots. The thermal efficiency

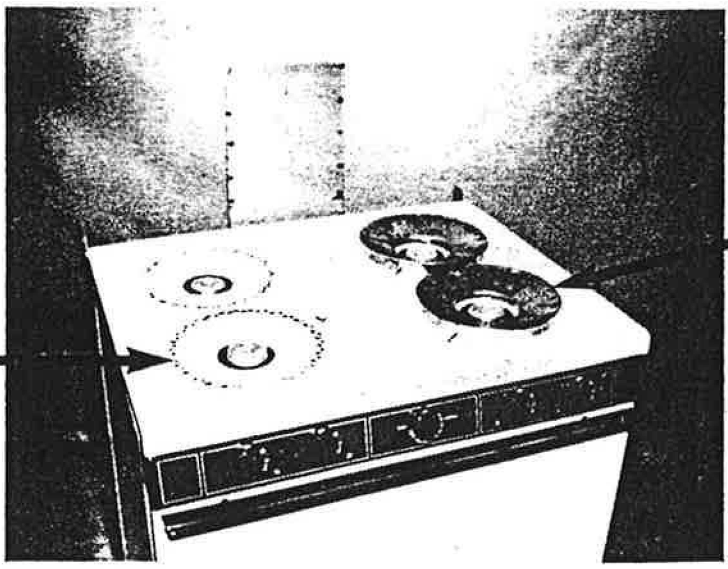


Figure 10 Fully vented gas range

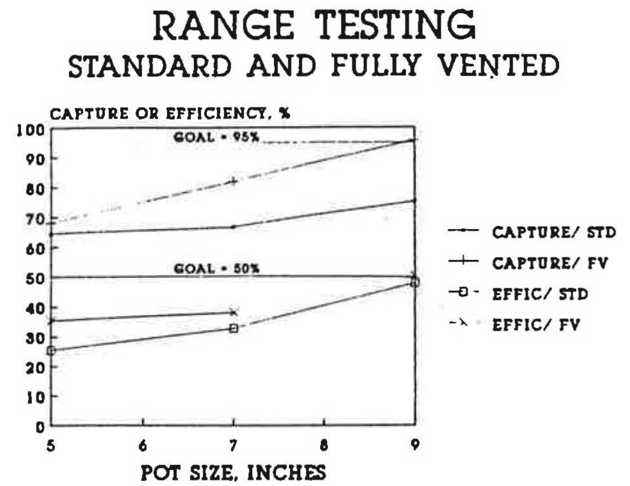


Figure 11 **Results of testing full vented and standard range with various size pots**

with a downdraft system is reduced at a rate per unit volume airflow more than 10 times the canopy hood.

Side curtains were shown to be effective but, unlike the commercial foodservice market, the acceptance of such a feature in the residential market may be limited. Both air curtains on the side of a range and a column of air between the top burners were found to have fairly limited effectiveness, with an 18 in (457 mm) gap, except at extremely high velocity levels.

The concept of direct-venting flue products from the aeration bowl of the top burners was incorporated into a fully vented range prototype. The fully vented range concept both meets the proof-of-concept goals and provides HVAC design flexibility currently unavailable with gas ranges.

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APPENDIX A

DERIVATION OF EFFECTIVENESS EQUATION
Adapted from Sarnosky (1984)

Assume a two-zone model. The cooking zone is the space between the range and the hood. See Figure A1 where:

A = Concentration of contaminant in ambient, lb/lb air
C = Concentration of contaminant in room, lb/lb air
V = Concentration of contaminant in exhaust, lb/lb air
F = Flow rate of air through exhaust duct, lb air/h (equals flow rate of makeup air)
Q = Release rate of contaminant, lb/h
E = Hood capture effectiveness, dimensionless fraction of contaminant release rate, which is captured and exhausted by hood.

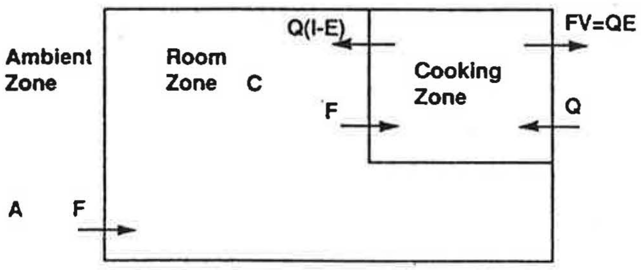

Figure A1: Two-zone model

Consider a mass balance about the room zone:

Mass leaving room = mass supply in makeup + mass escaping cooking

$$FC = FA + Q(1 - E)$$

$$F(C - A) - Q = -EQ$$

$$(Q/Q) - (F/Q)(C - A) = E$$

$$1 - (F/Q)(C - A) = E$$

Consider a mass balance about the entire room including the cooking zone:

Mass exhausted = mass drawn from ambient + mass released

$$FV = FA + Q$$

$$F(V - A) = Q$$

$$(F/Q) = [1/(V - A)]$$

Substituting into the room zone mass balance

$$1 - [1/(V - A)](C - A) = E$$

$$1 - [(C - A)/(V - A)] = E$$

TABLE 2A
STATE OF THE ART REVIEW (I-P UNITS)

Airflow, cfm	Range/Vent System (1) 1	2	3	4	5	6	7	Makeup Air (2)
NO_x CAPTURE, %								
0	0				0	0	0	
100	48			55				
200	70	62	91	88				
270					99.5	97.1		
350	89				99.5	98.8		
500	91							
WATER CAPTURE, %								
0	0				0	0	0	
100	61			59				
200	63	42	90	90			79.7	
270					11	51.3		
350	96				42.5	86		
500	96						94.8	
HEAT REMOVAL, %								
0	0				0	0	0	
100	63			63				
200	67	47	85	88			76.5	
270					58.2	74		
350	91				74.8	85.6		
500	91						91.4	
RANGE EFFICIENCY, %								
0	38.8				44.9		78.5	
100	38.2			45				
200	37.1	42	43	45			78.6	
270					23.4	22.4		
350	36.8				19.4	19.8		
500	35.8						78.7	
WINTER SPACE CONDITIONING LOAD, Btu/h								
0	−34000	−17000	−17000	−17000	−24000	−24000	−20000	0
100	−5310			2980				7390
200	9540	10500	17300	17300			19200	20040
270					15600	20450		27050
350	33550				27700	30315		36650
500	45330						47330	48330
SUMMER SPACE CONDITIONING LOAD, Btu/h								
0	34000	17000	17000	17000	24000	24000	20000	0
100	14900			9100				2200
200	16470	15000	8600	7900			7600	5970
270					19090	14220		8060
350	14020				16030	13170		10920
500	17400						14750	14400

(1) 1 Conventional gas range with canopy hood
2 Same as #1 with front 2 burners only
3 Same as #1 with rear 2 burners only
4 Same as #2 with rectangular hood
5 Gas downdraft with 9" high pot
6 Gas downdraft with 5" high pot
7 Electric range with canopy hood
(2) For space conditioning load calculation

TABLE 2B
STATE OF THE ART REVIEW (SI UNITS)

	Range/Vent System (1)							
Airflow, L/s	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Makeup Air (2)**
NO_x CAPTURE, %								
0	0				0	0	0	
47	48			55				
94	70	62	91	88				
127					99.5	97.1		
165	89				99.5	98.8		
236	91							
WATER CAPTURE, %								
0	0				0	0	0	
47	61			59				
94	63	42	90	90			79.7	
127					11	51.3		
165	96				42.5	86		
236	96						94.8	
HEAT REMOVAL, %								
0	0				0	0	0	
47	63			63				
94	67	47	85	88			76.5	
127					58.2	74		
165	91				74.8	85.6		
236	91						91.4	
RANGE EFFICIENCY, %								
0	38.8				44.9		78.5	
47	38.2			45				
94	37.1	42	43	45			78.6	
127					23.4	22.4		
165	36.8				19.4	19.8		
236	35.8						78.7	
WINTER SPACE CONDITIONING LOAD, W								
0	−9962	−4981	−4981	−4981	−7032	−7032	−5860	0
47	−1556			873				2165
94	2795	3077	5069	5069			5626	5872
127					4571	5992		7926
165	9830				8116	8882		10738
236	13282						13868	14161
SUMMER SPACE CONDITIONING LOAD, W								
0	9962	4981	4981	4981	7032	7032	5860	0
47	4366			2666				645
94	4826	4395	2520	2315			2227	1749
127					5593	4166		2362
165	4108				4697	3859		3200
236	5098						4322	4219

(1) 1 Conventional gas range with canopy hood
2 Same as #1 with front 2 burners only
3 Same as #1 with rear 2 burners only
4 Same as #2 with rectangular hood
5 Gas downdraft with 229 mm high pot
6 Gas downdraft with 127 mm high pot
7 Electric range with canopy hood
(2) For space conditioning load calculation