THE CASE FOR ENTIRELY REMOVING THE GAS RANGE FROM INDOORS

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ABSTRACT

The gas range is used for cooking and very often also as a supplemental heater. Gas range use produces large amounts of combustion byproducts. When exfiltration is eliminated by tightly insulating a dwelling, then adequate mechanical ventilation must be provided. But this ventilation process introduces cold air in cold climates (and hot air in warm climates) that takes extra energy to heat (or cool). There may then be overall economic advantages to eliminating natural gas ranges as kitchen appliances. A simulation model is presented to assess total utilization of energy and consumer costs for the case of substituting electric for gas ranges. Results for a conservative estimation of energy expenditures for cooking and heating seems to recommend switching to electric cooking in colder climates. The present model does not yet include simulation for air cooling in warm climates.

INTRODUCTION

Gas ranges are a major source of carbon monoxide and oxides of nitrogen. The full extent of their pollution capabilities ought to have been suspected some years back. It has become only too obvious in the last few years due to careful invéstigations by Good et al., 1981; Hollowell, 1976; Melia, 1978, 1979; Sterling, 1979; Tanaka, 1981; Traynor, 1971; Wade, 1975; and others. It is especially noteworthy that production of carbon monoxide increases immediately and appreciably when cooking pots are put over burners. Thus the process of cooking tends to cut off the available oxygen and increases the production of carbon monoxide. The rates with which carbon monoxide is produced are shown in Figure 1. These have now been verified by other investigators.

These findings indicate that by-products of combustion of natural gas are not necessarily decreased by proper adjustment of the amount of air fed into the flame. Putting pots on the stove by itself will lead to unavoidable increase in carbon monoxide. The degree of pollution from combustion by-products is a function of the total available living space, its ventilation rate and the emission rate of polluting sources. Also, some methods of ventilation are surprisingly ineffective. For instance, Sterling and Sterling (1979) have shown that a typical fan over a stove or in an open window, but without cross ventilation, each need 25 minutes before achieving noticeable results when compared to not ventilating at all. On the other hand, cross ventilation is immediately effective in removing polluted air (See Figure 2).

The full extent of pollution due to gas range use is not limited to cooking. The gas range very often is used as a secondary source of heat. In a recent survey Sterlng and Kobayashi (1979) have found that about half the urban dwellers in their sample misuse the gas range as a supplemental house heater. Figure 3 indicates the extent of increased gas range use during cold weather in New York City. It is very likely that wherever gas ranges are available, they are misused as heating

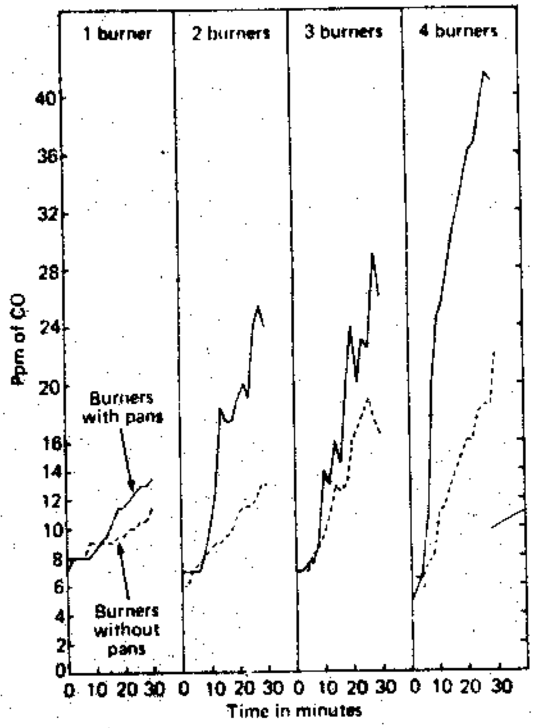


Figure 1. Increases in CO when using 1 to 4 covered and uncovered burners.

sources, especially by the urban poor but also by the urban middle classes who fail to get adequate heat in their apartments. Very often the use of the gas range as a heater is coupled with additional efforts to insulate or seal the dwelling. It should be noted that large numbers of children and pregnant women are among those present when gas ranges are used as heaters.

One other aspect increases the danger of misuse of gas ranges as heaters. Of households that use the burners as a source of heat, 93% also put pots of water on them to humidify the premises. In this way they increase substantially the amount of carbon monoxide and other combustion by-products.

The pollution burden caused by gas ranges in contemporary houses has been somewhat counteracted by exfilteration through loose fitting windows and doors and cracks in walls, especially in wood construction. But modern methods and materials of insulation can eliminate this "natural" ventilation almost entirely and the motivation to reduce costs of heating or cooling leads many householders to insulate as tightly as possible. Often additional incentive is provided by outright grants (as in Canada) and tax benefits. As a result, houses containing gas ranges may be turned into extremely hazardous environments. While no exact study has been made of these newly created circumstances, we might get some limited understanding of how insulation impedes exfilteration by comparing the rate of CO build up in tenement dwellings and in similar houses receiving rent subsidies that permit repairs of cracks in doors, windows and walls (See Figure 4).

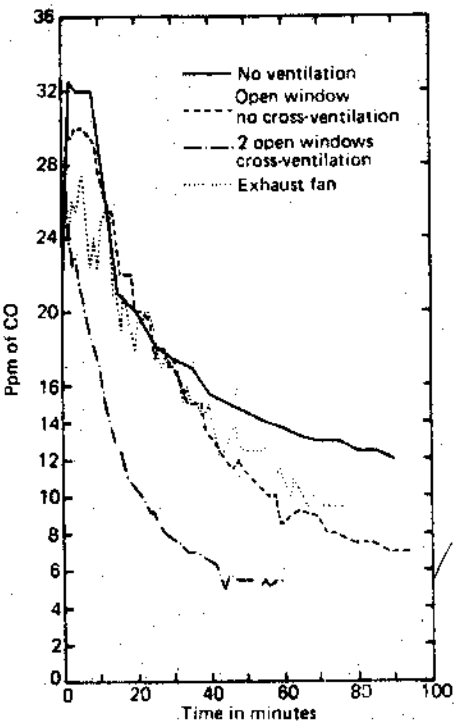


Figure 2. Disappearance of CO from the kitchen under different conditions and ventilation.

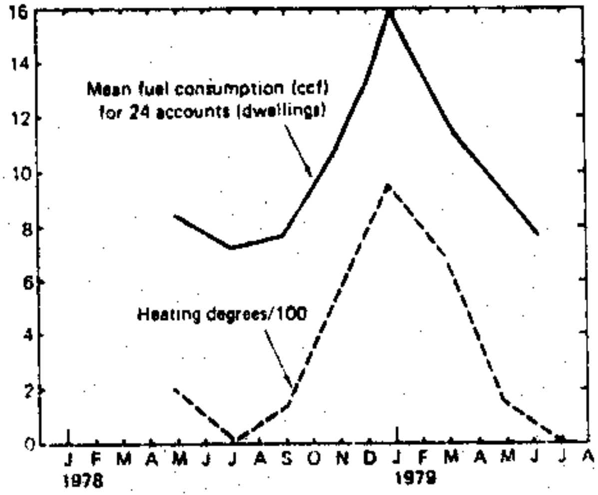


Figure 3. Metered gas consumption vs temperature

Pollution levels due to use of gas range emmissions may be alleviated somewhat by good venting and mechanically ventilated hoods. However, Sterling and Kobayashi (1981) found that large proportions of hood fans did not work or were not used. Hoods often are lacking entirely.

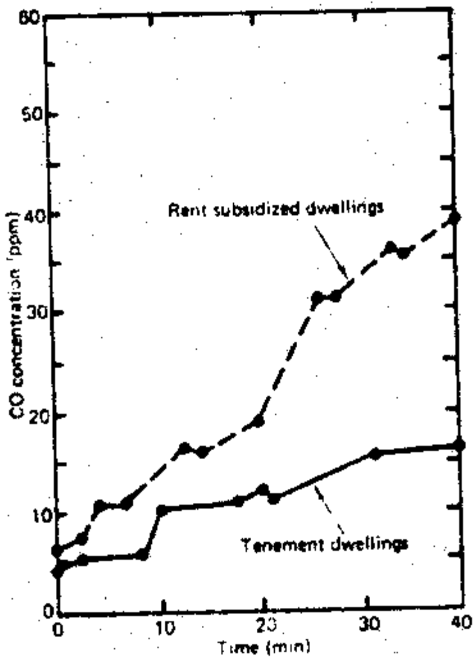


Figure 4. Comparison of average carbon monoxide build-up during simulated cooking in four tenement and eight rent-subsidized dwellings.

In summary then, excessively large pollution burdens may be produced by gas cookers which become serious health hazards when houses are tightly insulated and ventilation is purposefully decreased to save on energy.

One solution to this problem may be to remove the gas range from indoors entirely. This would permit a very high level of home insulation while reducing costs of increasing ventilation and heating ventilated air or of designing and installing heat exchangers. The natural gas so preserved could be used to produce additional electricity for cooking (but with the loss of energy entailed in conversion from gas to electricity).

We are now examining various models balancing costs and gains for the case of not using natural gas for cooking. Costs are mainly of loss of energy during conversion and of initial investment, while gains are reduced costs for heating homes, for lessened needs to design, install and maintain very effective heat exchangers, cleaner household air, and possibly decreased health costs. (The model does not cover cooling homes.) In the remainder of this paper, we describe a simple model which considers a few of the relevant variables and discuss the conclusions which can be drawn using this model.

THE MODEL

To quantify the effect on energy consumption of switching from gas to electric cooking, a simple model has been developed which can estimate the energy consumption and costs under the following sets of circumstances:

1. Cooking with gas with no forced ventilation.

2. Cooking with gas with sufficient ventilation to maintain acceptable air quality.

3. Cooking with electricity with minimum recommended level of ventilation (to remove cooking odors, heat).

The model expresses energy consumption in terms of total energy used in a year for cooking alone or for cooking plus an assumed level of ventilation necessary to remove combustion by-products, heat, and odors due to cooking. Costs are expressed in terms of dollar cost to the consumer for energy used in the home or in terms of total resources removed from the environment to provide the energy consumed in the home.

The model depends on the following parameters:

Energy consumed by gas stove per unit of time. This parameter may be expressed directly as consumption per unit of time measured in cubic feet, cubic meters, BTU's or megajoules, or indirectly in terms of average consumption per hour and hours of use per unit of time for the oven and each top burner. Information on the energy requirements of gas stoves has been obtained from B. C. Hydro, (1981); American Gas Assosiation, (1974); De Werth, (1974); De Werth et al., (1976); and Deppisch and Irwin, (1974).

Energy consumed by electric stove per unit of time. This parameter may be expressed directly as consumption per unit of time measured in kilowatt hours or indirectly in terms of average consumption per hour and hours of use per unit of time for the oven and each top cooking element. Information on the energy requirements of electric ranges has been obtained from B. C. Hydro, (1981); American Gas Association, (1974); De Werth et al., (1976); and Dippisch and Irwin, (1974).

Increased ventilation required for gas stove. This parameter specifies the additional ventilation requirement in cfm. Information on minimum recommended ventilation levels has been taken from ASHRAE, (1981). The ventilation level required to maintain air quality in the presence of sources of pollution is discussed in Traynor et al., (1979).

Hours per unit of time ventilator is operated. Information comes from Sterling and Kobayashi (1981).

Annual degree days. This parameter is used to determine the average difference between indoor and outdoor temperature, which in turn is used to compute the amount of energy required to heat the outside air brought in by the ventilation system to room temperature. Tables of degree days for selected North American Cities are given in Carrier Corp, (1972) and McQuiston and Parker, (1977 - abridged from the ASHRAE Handbook-Systems, 1973).

Efficiency of heating equipment. This is the proportion of energy consumed by the heating device which actually shows up in the heated space. It is assumed at present that the heating equipment is gas fired although the model could easily be generalized to include other types of heating equipment. (An efficiency level of .7 is assumed for gas furnaces in DOE-2.)

Marginal cost of gas. This is the price of gas in dollars per megajoule. Since most homes which cook with gas also heat the house and water with gas the removal of the gas stove will not usually reduce consumption to the point that total consumption falls in one of the lower billing brackets for which a higher rate is charged.

Marginal cost of electricity. This is the price of electricity in dollars per kilowatt hour, and as for gas, is the rate charged in the lowest cost billing bracket. (Information supplied by B. C. Hydro indicates that roughly 25% of customers have no usage in the lowest cost billing bracket. These are mostly apartments with one or two occupants.)

Relative efficiency of cooking with gas and with electricity. Information comes from De Werth et al., (1976); Deppisch and Irwin, (1974).

These parameters are sufficient to compute estimates of the energy consumption within the home and the cost to the consumer for energy used in the home for cooking and heating ventilated air. To compute the total resource utilization the following additional parameters are required:

Efficiency of gas transmission. This is the efficiency of delivery of gas to the consumer but does not include losses in extraction and processing.

Efficiency of gas extraction. This is the efficiency of the extraction and processing of gas to the point where it reaches the utility.

Efficiency of generating electricity from gas.

Efficiency of electric transmission.

To compute total costs or savings to the social body as a whole would require expansion of the model to include (among others):

Number and types of illnesses associated with home use of gas ranges (including the excessive use of the gas range as a supplementary heater).

Economic costs due to gas range use related illnesses.

Most economical means of producing the needed additional electric capacity.

Economic benefit of using natural gas not piped to gas ranges for other purposes.

Costs of replacing existing gas ranges.

Consideration of additional refinements such as installation of heat exchanges to reduce heat loss due to ventilation.

Sufficient information is available now to permit first estimates of overall costs and benefits for entirely removing gas range from homes.

METHODS OF COMPUTATION

The present computer model compares only the energy utilization and energy cost due to cooking and the ventilation associated with cooking and heating costs associated with ventilation needs. (Cooling costs are not yet included.) Obviously there are differences in capital investment costs associated with the cooking and ventilating equipment and other, less tangible costs and benefits associated with health and quality of life that the model does not consider.

Since the available sources present data on energy utilization, cost, etc. in different units and with respect to different time periods, the program has been designed to accept data in whatever units it is originally given to avoid the errors which would almost certainly result from converting to some standard unit and time period manually. As a first step, the program converts the energy requirements for gas and electric stoves to megajoules per year and kilowatt-hours per year respectively. (If the energy requirements of the individual burners and oven are stated separately, these are added to yield the overall requirement for the appliance.)

The input energy, in megajoules per year, required to replace the sensible heat loss due to ventilation is given by

$$.24 * .075 * F * 60 * H * N / 365.25 * D * .001055 / E$$

Where

$.24$ = specific heat of air(BTU/lb)
$.075$ = density of air(lb/cu ft)
F = flowrate(cu ft/min)
H = hours of operation of ventilation per time interval
N = time intervals per year
D = annual degree days
$.001055$ = conversion factor BTU to megajoules
E = thermal efficiency of furnace

We have chosen, at least for the present, to neglect latent heat loss since cooking generally adds considerable moisture to the atmosphere of the house and consideration of latent heat would require more-or-less arbitrary assumptions about indoor and outdoor humidity levels. Similarly, we have neglected the energy consumed by the ventilating fan since it represents only about one half percent of that required for cooking and for heating the ventilated air. (Typical ventilating fans used in domestic range hoods consume about 20 watts under normal operating conditions.)

Computation of energy used in the home under various conditions is a simple matter of adding the individual components that apply to each set of circumstances. To make comparison possible, all energy utilization is expressed in megajoules. (Note: 1 KWH = 3.6 megajoules.)

The consumer cost of the energy consumed in the home is obtained by multiplying the quantities of gas and electricity used by their respective costs and adding.

The total utilization of resources from the environment is obtained by dividing the amount of energy consumed in the home (in megajoules) by the gas transmission and extraction efficiency ratios in the case of gas and by the electric transmission and generation efficiency ratios and the gas extraction ratio in the case of electricity. The purpose of these figures is to permit a comparison of the total resource extraction required under each set of circumstances under the assumption that gas is used to generate the additional electricity required for conversion from gas to electric cooking. In practice, other methods of electric generation may well be employed to provide the additional electric capacity, but a comparison of resource requirements would then involve qualitative judgements of the relative importance and value of different basic resources.

RESULTS

The model depends on a large number of parameters and it would be of interest to examine the effects of many of them on the relative resource utilization and cost of gas and electric cooking. For the present report we shall focus attention on a few parameters which will be varied over a range of possible values while the remaining parameters are held fixed at typical values.

Specifically, the behavior of total resource utilization is examined for the following parameter values:

Amount of energy needed for gas cooking; 600, 900, or 1200 MJ/month. These figures are based on usage rates quoted by B. C. Hydro and are consistent with data given by De Werth (1974).

Relative thermal efficiency of gas stoves as compared to electric: .4 or .5. These figures are based on usage rates quoted by B. C. Hydro and results given by De Werth et al. (1976) and Deppisch and Irwin (1974). The relative thermal efficiency is used to calculate the amount of electrical energy that would be needed to do the same amount of cooking. For example 600 * .4 / 3.6 = 66.67 KWH would be required by an electric range to do the same cooking as is done with 600 MJ an a gas range if the relative thermal efficiency is .4.

Ventilation with Gas Cooking: 140 CFM for 14, 16 or 18 hours per week (depending on amount of gas used). Based on Traynor's (1981) finding of ventilation rate needed to maintain NO2 at less than .1 PPM in an average kitchen and Sterling and Kobayashi's (1981) results on time spent cooking.

Ventilation with Electric Cooking: 40 CFM for 14, 16, or 18 hours per week. Based on ASHRAE recommendation of 20 CFM per person with minimum rate of 30-50 CFM.

Annual Degree Days: 1500, 3000, 5000, 7500, 10000, or 15000. Based on data on outdoor design conditions published by Carrier Corp. (1972). Table 1 shows the normal number of annual degree days for typical North American cities.

Thermal Efficiency of Furnace: .7. Based on DOE-2

Transmission efficiences: .93 for gas, .90 for electricity. Based on Sullivan, et al. 1980.

Extraction efficiency for Gas: .97. Based on Sullivan, et al. 1980.

Electric Generation Efficiency from Gas: .305. Based on Sullivan, et al. 1980.

Table 1. ANNUAL DEGREE DAYS OF SELECTED NORTH AMERICAN CITIES
(Source - Carrier Corp., 1972)

Phoenix	1441	Flagstaff	7242
Tallahassee	1463	Green Bay	7931
Mobile	1566	Minneapolis	7966
Birmingham	2611	Burlington	8051
Sacramento	2680	Montreal	8130
Little Rock	3009	Havre	8416
San Francisco	3137	Marquette	8745
Washington	4561	Ottawa	8830
St Louis	4596	Bismark	8937
Seattle	4815	Quebec City	9070
Vancouver	5230	Sault Ste. Marie	9307
New York	5280	Prince George	9500
Reno	5621	Duluth	9723
Boise	5678	Grand Forks	9871
Denver	5839	Devils Lake	10104
Hartford	6113	Edmonton	10320
Cleveland	6144	Winnipeg	10630
Chicago	6282	Regina	10770
Spokane	6318	Anchorage	10864 *
Detroit	6560	Saskatoon	10960
Toronto	7020	Goose Bay	12140
Eugene	7197	Dawson	15040
		Churchill	16810

* (From McQuiston, F.C., and Parker, J.D., 1977)

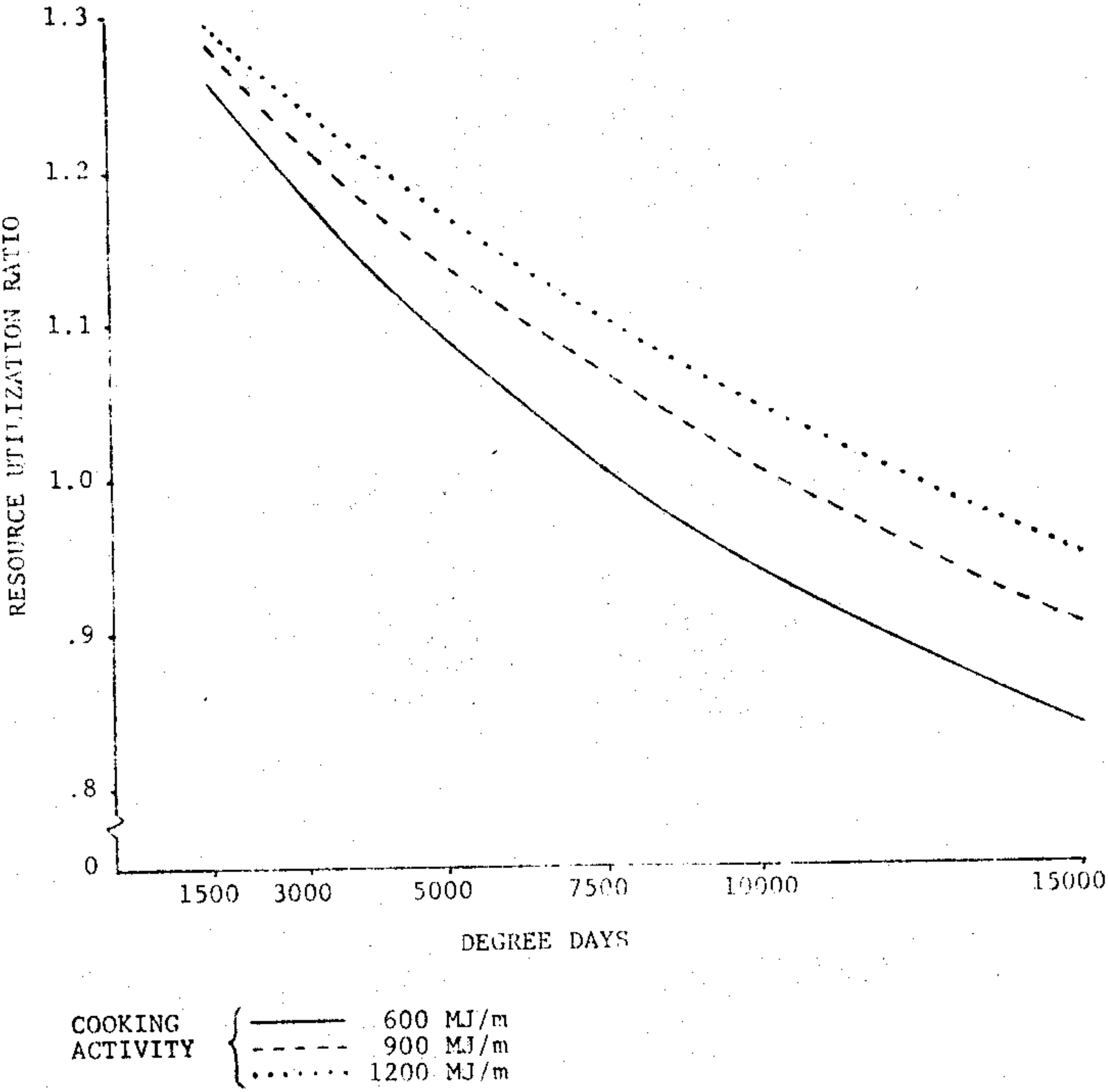
Table 2. TOTAL ENERGY UTILIZATION

TOTAL RESOURCES USED AND RATIO OF ELECTRIC TO GAS

STOVERATIO	.4			.5		
GAS_USE	600	900	1200	600	900	1200
DEGREE_DAY						
1500						
GAS	7981.4	11972.1	15962.8	7981.4	11972.1	15962.8
GAS+VENT	8739.2	12838.2	16937.1	8739.2	12838.2	16937.1
ELEC+VENT	11032.8	16471.9	21910.9	13736.9	20528.0	27319.1
ELEC/GAS	1.262	1.283	1.294	1.572	1.599	1.613
3000						
GAS	7981.4	11972.1	15962.8	7981.4	11972.1	15962.8
GAS+VENT	9497.0	13704.2	17911.5	9497.0	13704.2	17911.5
ELEC+VENT	11249.3	16719.3	22189.3	13953.4	20775.4	27597.5
ELEC/GAS	1.185	1.220	1.239	1.469	1.516	1.541
5000						
GAS	7981.4	11972.1	15962.8	7981.4	11972.1	15962.8
GAS+VENT	10507.5	14859.0	19210.6	10507.5	14859.0	19210.6
ELEC+VENT	11538.0	17049.3	22560.5	14242.1	21105.4	27968.7
ELEC/GAS	1.098	1.147	1.174	1.355	1.420	1.456
7500						
GAS	7981.4	11972.1	15962.8	7981.4	11972.1	15962.8
GAS+VENT	11770.5	16302.5	20834.5	11770.5	16302.5	20834.5
ELEC+VENT	11898.9	17461.7	23024.5	14603.0	21517.8	28432.6
ELEC/GAS	1.011	1.071	1.105	1.241	1.320	1.365
10000						
GAS	7981.4	11972.1	15962.8	7981.4	11972.1	15962.8
GAS+VENT	13033.6	17746.0	22458.4	13033.6	17746.0	22458.4
ELEC+VENT	12259.8	17874.1	23488.5	14963.8	21930.2	28896.6
ELEC/GAS	0.941	1.007	1.046	1.148	1.236	1.287
15000						
GAS	7981.4	11972.1	15962.8	7981.4	11972.1	15962.8
GAS+VENT	15559.7	20633.0	25706.3	15559.7	20633.0	25706.3
ELEC+VENT	12981.5	18699.0	24416.4	15685.6	22755.1	29824.6
ELEC/GAS	0.834	0.906	0.950	1.008	1.103	1.160

Table 2 shows the results of applying the model to estimate total resource utilization for these parameter values. For each combination of parameter values, the table shows the energy required for gas cooking alone, for gas cooking with 140 CFM ventilation, and for electric cooking with 40 CFM ventilation under the assumption that the electric energy in generated by burning gas. The ratio of the energy used for electric cooking with ventilation to that required for gas cooking with ventilation is also given. These ratios are also shown graphically in Figure 5.

RATIO OF TOTAL RESOURCE UTILIZATION FOR ELECTRIC COOKING TO THAT FOR GAS COOKING VS DEGREE DAYS FOR THREE LEVELS OF COOKING ACTIVITY. *



* Relative thermal efficiency = .4

Cost to the Consumer is estimated for the same values (except that for relative thermal efficiency only .4 is used) for the following cost parameters:

Price of Gas: .0034 per MJ (The current cost of gas for residential customers of B. C. Hydro).

Relative Price of Electricty with respect to Gas: 2.5, 3, or 3.5. For example if gas costs .0034 per MJ and the relative cost of electricty is 2.5 then the price of electricty is 2.5 * .0034 * 3.6 = .0306 per KWH. The current price of electricty in B. C. is .03089 per KWH. Electric power in B. C. is almost exclusively hydro electric, thus electric power is relatively inexpensive with respect to gas; the other values are included to reflect the higher electric prices relative to gas that exist in much of North America.

Table 3 shows the corresponding results for cost to the consumer and the ratio of electric cost to gas cost is shown graphically in Figure 6. Observe that this ratio does not depend on the absolute level of the price.

DISCUSSION

Under the conditions we have assumed our results show that at least in terms of recurring costs and energy utilization it may be quite feasible to replace gas with electricity in cooking. From the consumer's point of view, operating costs are actually less, regardless of climatic conditions when the cost of electricity relative to that of gas is low (2.5) as can be seen from an examination of figure 6. On the other hand, when the relative cost of electricity is high (3.5) the consumer will pay more, but not all that much. Even a consumer who does a large amount of cooking (1200 MJ/month) in a warm climate (1500 degree days, where there is little equalizing effect due to savings on heat) and pays a high relative rate for electricity (3.5) faces an annual operating cost increase of only $17.45 (51.95 to 69.40) if he switches to electric cooking and reduces kithcen ventilation.

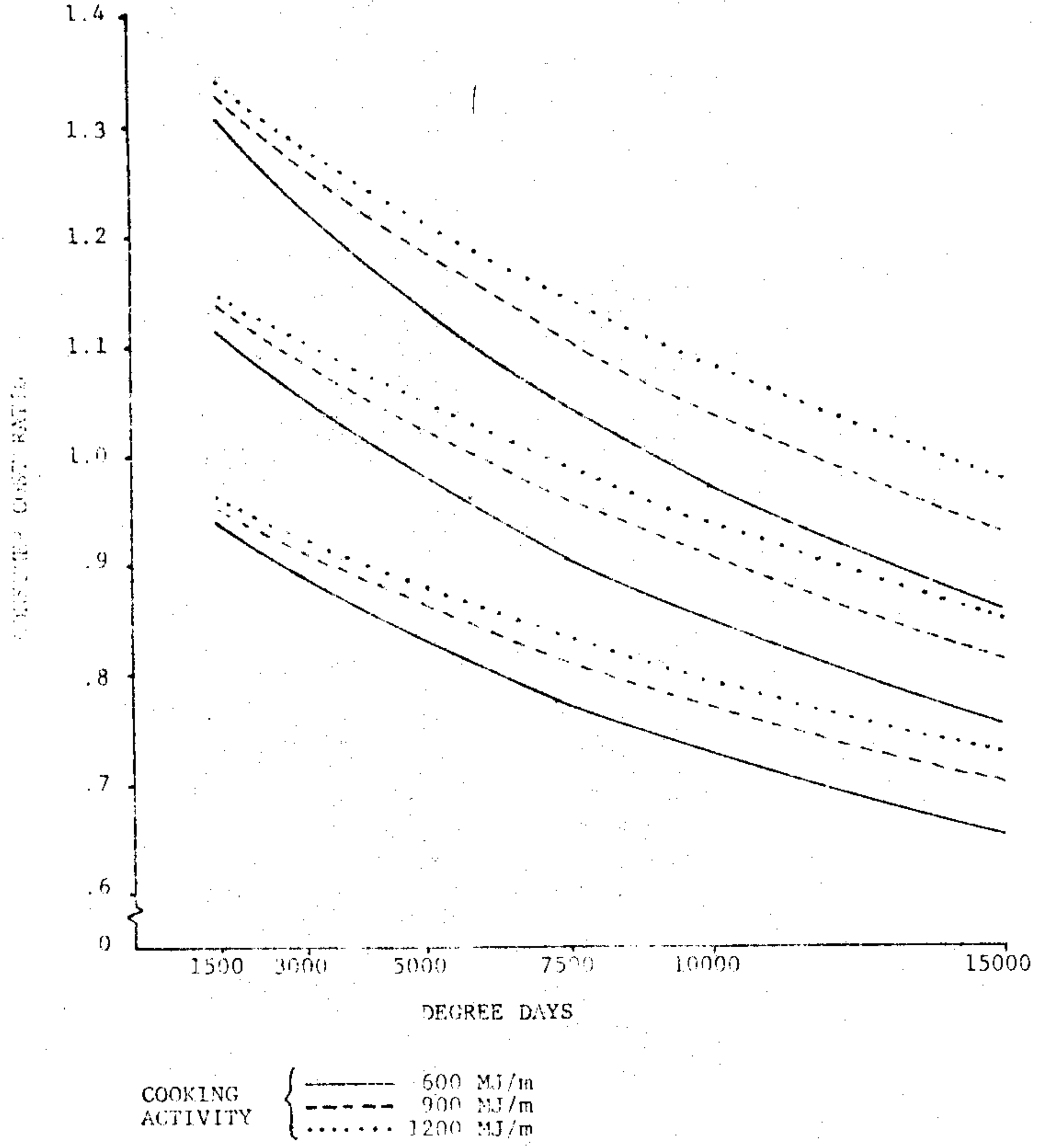
From the point of view of the entire society and only considering the need to heat but not to cool dwellings, Figure 5 shows that the overall use of energy is less for electric cooking than for gas cooking in cold climates while the reverse is true in warm climates. Thus the "loss" in warm climates would be offset by "savings" in cold climates. However, the majority of the population live in areas with less than 8000 degree days where there would be a clear loss, whereas only a relative handful live in areas with more than 12000 degree days where there would be a clear gain. At least from the point of view of resource utilization, there might be reason to recommend switching to electric cooking in colder climates and installing sufficient ventilation and using gas in warmer climates. But it is intuitively clear that when the outside air is warmer than the inside air, then by cutting down the ventilation, less of that warmer air is introduced, and less energy expended to cool it. The present computer model is being

Table 3. CONSUMER ENERGY COST

COST OF ENERGY USED IN THE HOME AND RATIO OF ELECTRIC TO GAS

COST RATIO		2.5			3			3.5	
GAS USE	600	900	1200	600	900	1200	600	900	1200
DEGREE DAY									
1500									
GAS	24.48	36.72	48.96	24.48	36.72	48.96	24.48	36.72	48.96
GAS+VENT	26.80	39.38	51.95	26.80	39.38	51.95	26.80	39.38	51.95
ELEC+VENT	25.14	37.48	49.81	30.04	44.82	59.61	34.94	52.17	69.40
ELEC/GAS	0.938	0.952	0.959	1.121	1.138	1.147	1.303	1.325	1.336
3000									
GAS	24.48	36.72	48.96	24.48	36.72	48.96	24.48	36.72	48.96
GAS+VENT	29.13	42.03	54.94	29.13	42.03	54.94	29.13	42.03	54.94
ELEC+VENT	25.81	38.24	50.67	30.70	45.58	60.46	35.60	52.93	70.25
ELEC/GAS	0.886	0.910	0.922	1.054	1.084	1.101	1.222	1.259	1.279
5000									
GAS	24.48	36.72	48.96	24.48	36.72	48.96	24.48	36.72	48.96
GAS+VENT	32.23	45.57	58.92	32.23	45.57	58.92	32.23	45.57	58.92
ELEC+VENT	26.69	39.25	51.81	31.59	46.59	61.60	36.49	53.94	71.39
ELEC/GAS	0.828	0.861	0.879	0.980	1.022	1.045	1.132	1.184	1.212
7500									
GAS	24.48	36.72	48.96	24.48	36.72	48.96	24.48	36.72	48.96
GAS+VENT	36.10	50.00	63.90	36.10	50.00	63.90	36.10	50.00	63.90
ELEC+VENT	27.80	40.51	53.23	32.70	47.86	63.02	37.59	55.20	72.81
ELEC/GAS	0.770	0.810	0.833	0.906	0.957	0.986	1.041	1.104	1.139
10000									
GAS	24.48	36.72	48.96	24.48	36.72	48.96	24.48	36.72	48.96
GAS+VENT	39.98	54.43	68.88	39.98	54.43	68.88	39.98	54.43	68.88
ELEC+VENT	28.91	41.78	54.65	33.80	49.12	64.44	38.70	56.47	74.24
ELEC/GAS	0.723	0.768	0.793	0.846	0.903	0.936	0.968	1.037	1.078
15000									
GAS	24.48	36.72	48.96	24.48	36.72	48.96	24.48	36.72	48.96
GAS+VENT	47.72	63.28	78.84	47.72	63.28	78.84	47.72	63.28	78.84
ELEC+VENT	31.12	44.31	57.50	36.02	51.65	67.29	40.91	59.00	77.08
ELEC/GAS	0.652	0.700	0.729	0.755	0.816	0.853	0.857	0.932	0.978

RATIO OF COST TO THE CONSUMER OF ENERGY USED IN THE HOME FOR COOKING WITH ELECTRICITY TO THAT FOR COOKING WITH GAS VS DEGREE DAYS FOR THREE LEVELS OF COOKING ACTIVITY AND THREE LEVELS OF THE PRICE OF ELECTRICITY (PE) RELATIVE TO THE PRICE OF GAS (PG). *



* Relative thermal efficiency = .4

expanded to include the enery saving or expenditure incurred when air conditioning needs are added to our model.

But we should bear in mind that these results are based on assumed values for several parameters which, while reasonable, may not be universally applicable. Further analysis of the effects of these and other parameters is needed. We should also remember that our present analysis is based on the assumption that the electricity used for electric cooking is generated by burning gas, an inefficient process. As we have already mentioned several times, there may be other, more efficient methods of electric generation available, and the gas saved may be either left in the ground or used for other purposes. Evaluation of such trade-offs awaits the detailed specification of the alternatives in each specific case; it is difficult to see how a simple, general statement can be made. What can be said is that it should always be possible to do better than shown by the present analysis.

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