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Possible efficiency improvements in residential, gas fired furnances

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POSSIBLE EFFICIENCY IMPROVEMENTS IN RESIDENTIAL, GAS FIRED FURNACES

BY

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A PROJECT

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ABSTRACT

This project examines the problem of how to improve energy utilization in a residential space heating environment. Techniques for lowering unit energy consumption are developed and the feasibility of their implementation is discussed.

The project development first establishes the magnitude of the energy wastage problem for the individual consumer and its impact on the national scale. It must be emphasized that these represent two, sometimes distinctly different justifications for reducing energy use in the home. What may be considered only a small personal waste of $50 to $100 per year may indeed--when viewed in aggregate--represent a significant burden on the rapidly worsening United States crude oil import situation.

Having established the incentives for reducing inefficiency in residential furnaces the project concentrates on developing various techniques for recovering the waste heat. The technical feasibility and economic viability of implementing the energy recovery ideas is then discussed.

The project concludes that about $50 to $100 per year could be saved in a typical residential furnace by waste heat recovery. This amounts to the equivalent of reducing crude oil imports by nearly one million barrels per day. In the author's opinion; however, it is unlikely that the individual consumer would invest to recover this waste heat unless governmental pressure--perhaps in the form of tax credits--is vigorously exerted.

APPROVAL OF PROJECT

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FOR

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The author would also like to acknowledge his employer, Exxon Research and Engineering Company for their commitment to professionalism and technical excellence; and my wife Susan for her commitment to me.

DEDICATION

This project is dedicated to my mother and father--their love is an inexhaustable source of energy.

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INTRODUCTION

Conservation of our national energy resources is now perhaps the most important engineering challenge facing the nation. Both industry and government projections[5] indicate that, at our current rate of consumption, the non-regenerative energy sources will become critically scarce by the end of the century. This serious decline in available energy impacts on the society and economy in both the ability to maintain industrial growth, and by corollary, to maintain current standards of living. The first problem that will be encountered by the individual will be the increased out of pocket costs for his direct energy needs.

The individual consumer, in direct energy consumption such as space heating, transportation, etc. accounts for some 20% of the national energy usage.[12] This paper deals with reducing one aspect of this energy requirement. By the shear magnitude of this energy consuming sector one can see that a great potential exists therein for reducing the overall national energy demand. The role of the individual must; therefore, be significant if any credible energy policy is to survive.

It is necessary to provide the ideas and tools to allow the individual to easily, and with little net cost, help reduce the gross amount of energy being unnecessarily wasted. This statement defines one of the major engineering challenges facing the nation--and it will continue to do so until the non-depletable energy sources such as fusion, solar, geothermal, etc. are commercially developed.

The objective of this study is to define incentives and to suggest capital improvement projects that can be implemented by the homeowner to reduce his heating energy needs. The national space heating bill[4] is some 20 billion \$/year at present. The average fired fuel home heating unit operates at only 65% thermal efficiency. The resulting waste--2.4×10^{15} Btu/year--represents enough energy to reduce crude oil imports by over 1 million barrels per day.

SUMMARY

The entire energy issue is far too broad and is beyond the scope of this study. This project has been limited to examining potential efficiency improvements in gas fired, home heating furnaces. Even in this very restricted sector of the energy problem, significant savings have been defined.

Several ideas that can be implemented to improve existing home units are discussed. Many of these ideas are associated with directly improving thermal efficiency, such as:

- Recovering waste energy in hot flue gas by intermediate heat transfer fluid.
- Flue gas waste heat can be used to supplement space heating requirements.
- Improved thermal efficiency can best be realized by using a combustion air preheat system.
- Additional efficiency credits are possible with reduced excess oxygen usage. Implementation would be difficult at the homeowner level.

Additional ideas are discussed that are concerned with eliminating other wasteful practices associated with residential heating. Primarily, these equipment related items are:

- Replace continuous gas pilot lights with electrical ignition device.
- Timed sequence thermostats can realize energy savings with minimal personal discomfort.

These ideas are surveyed in the remainder of this report. Emphasis throughout is placed on technical feasibility at the consumer level, expected personal savings if the idea is implemented, the impact of these changes on the national energy picture and lastly, is it justified for the consumer to invest in the needed equipment.

Study Demonstrates That Major Energy Savings Are Possible

The following table summarizes many of the savings that can be accrued from improvements in home heating. These figures reflect efficiency credits as calculated in this project for implementing the various energy recovery measures. The national savings are based on 6.23 x 10^6 Btu per Fuel Oil Equivalent Barrel (FOEB). The savings shown are directly additive.

	Consumer Level	National Level
Typical Efficiency	65%	65%
Savings Due Air Preheat	50 $/yr	643,000 FOEB/Day
Savings Due Reduced O_2 Content	20 $/yr	257,000 FOEB/Day
Savings Due Electronic Ignition	10 $/yr	100,000 FOEB/Day

This study has been restricted to gas fired units--but similar projects could be attractive in oil burner service.

The final conclusion of this report is that although major national energy savings are possible, government support will probably be required to have any significant number of homeowners undertake the expense of modifying their furnaces.

BACKGROUND

The current energy crisis has been caused by both the rising demand and the reduced availability of fossil fuels. Since this report deals with techniques to reduce demand, some background information is required to quantify the scope of our national energy requirements.

U.S. Energy Consumption Patterns Define Incentive For Study

In Figure 1 it can be seen graphically that there is a rising trend in energy consumption. The data, compiled by Exxon Company, U.S.A.[5] shows that the United States energy demand has increased from 44.7 Quads (1 Quad = 10^{15} Btu) in 1960 to some 73.0 Quads in 1975--almost a 65% rise in 15 years. Exxon projections indicate that little relief is in sight; estimating that an additional 10% per year increase in energy demand to the year 1990 will be realized.

Of this staggering requirement of 113 Quads in 1990, it is estimated that about 25-30 Quads would be needed for space heating. In perspective, this energy is equivalent to some 12-15 million barrels of crude oil per day! Table 1[4][11][10] itemizes the national energy distribution for the years 1960 and 1972 (the last full year prior to the OPEC crude oil embargo), and Table 2 shows the distribution of energy resources by type. The rate of growth in space heating requirements is not as large as the overall increase in energy demand due primarily to the stabilized housing situation in the U.S.

TABLE 1

NATIONAL ENERGY USAGE
BY SECTOR

	Total Energy Usage In Year 1960 (1): 10^{12} Btu	1960 (1): % Total	1972 (2): 10^{12} Btu	1972 (2): % Total
Residential				
Space Heating	4,848	11.3	6,826	12.3
Water Heating	1,159	2.7	1,522	2.7
Air Conditioning	134	0.3	296	0.5
Refrigeration	369	0.9	288	0.5
Lighting	-	-	200	0.4
Cooking	556	1.3	470	0.8
Other	902	2.1	852	1.5
Total	7,968	18.6	10,454	18.9
Commercial				
Space Heating	3,111	7.2	4,431	8.0
Water Heating	544	1.3	527	1.0
Air Conditioning	576	1.3	540	1.0
Other	1,511	3.4	1,062	1.8
Total	5,742	13.2	6,560	11.8
Industrial				
Total	15,779 (3)	36.6	20,293	36.7
Transportation				
Total	13,624 (3)	31.6	18,054	32.6
Total Energy Usage	43,113	100.0	55,361	100.0

Notes:
(1) Data taken from Stanford Research Institute's Patterns of Energy Consumption in the United States (Nov., 1971). (11)
(2) Data published in Conserving Energy by Joel Darmstadter. John Hopkins University Press, 1975. (4)
(3) Estimated distribution by trends shown in: Energy, Environment and Building by Philip Steadman. Cambridge University Press, 1975. (10)

TABLE 2

DISTRIBUTION OF ENERGY RESOURCES[1]

	Coal	Natural Gas	Petroleum	Hydro & Nuclear	Total
• Residential and Commerical, %[2]	0.6	10.7	9.2	-	20.5
• Industrial, %	8.1	15.3	7.4	-	30.7
• Transportation, %	-	1.0	22.9	-	23.9
• Electric Power Generation, %	11.4	5.8	3.3	4.1	24.7
• Total, %	20.0	32.8	43.0	4.1	100.0

Notes: (1) Distribution of Energy Consumption by use in 1970 from Towards an Energy Policy by Keith Roberts. Published by the Sierra Club, San Francisco. (10)

(2) Approximately 2/3 of the residential and commercial energy requirements are for space heating. See also Table 1.

FIGURE 1

NATIONAL ENERGY CONSUMPTION
PROJECTION TO 1990

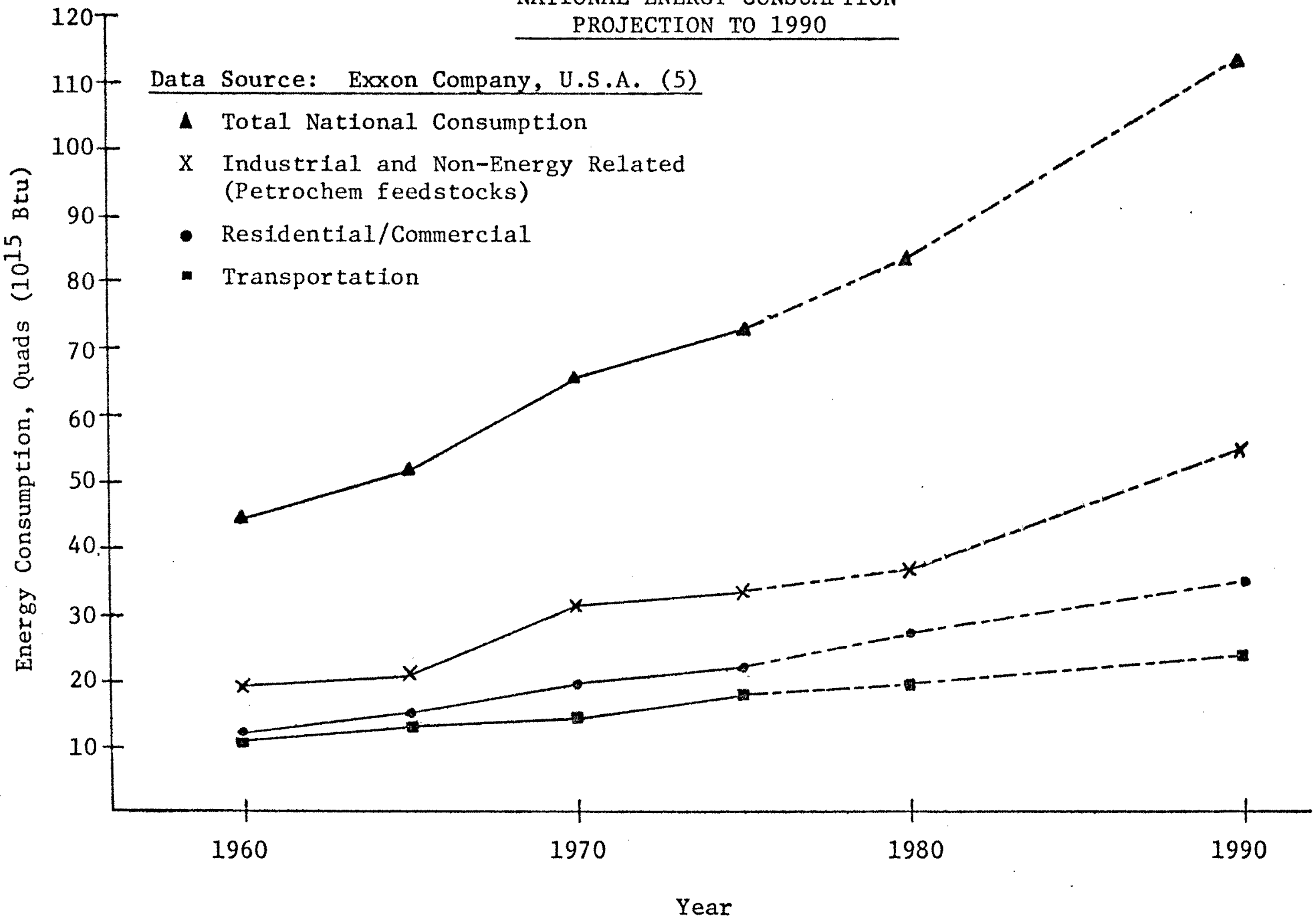
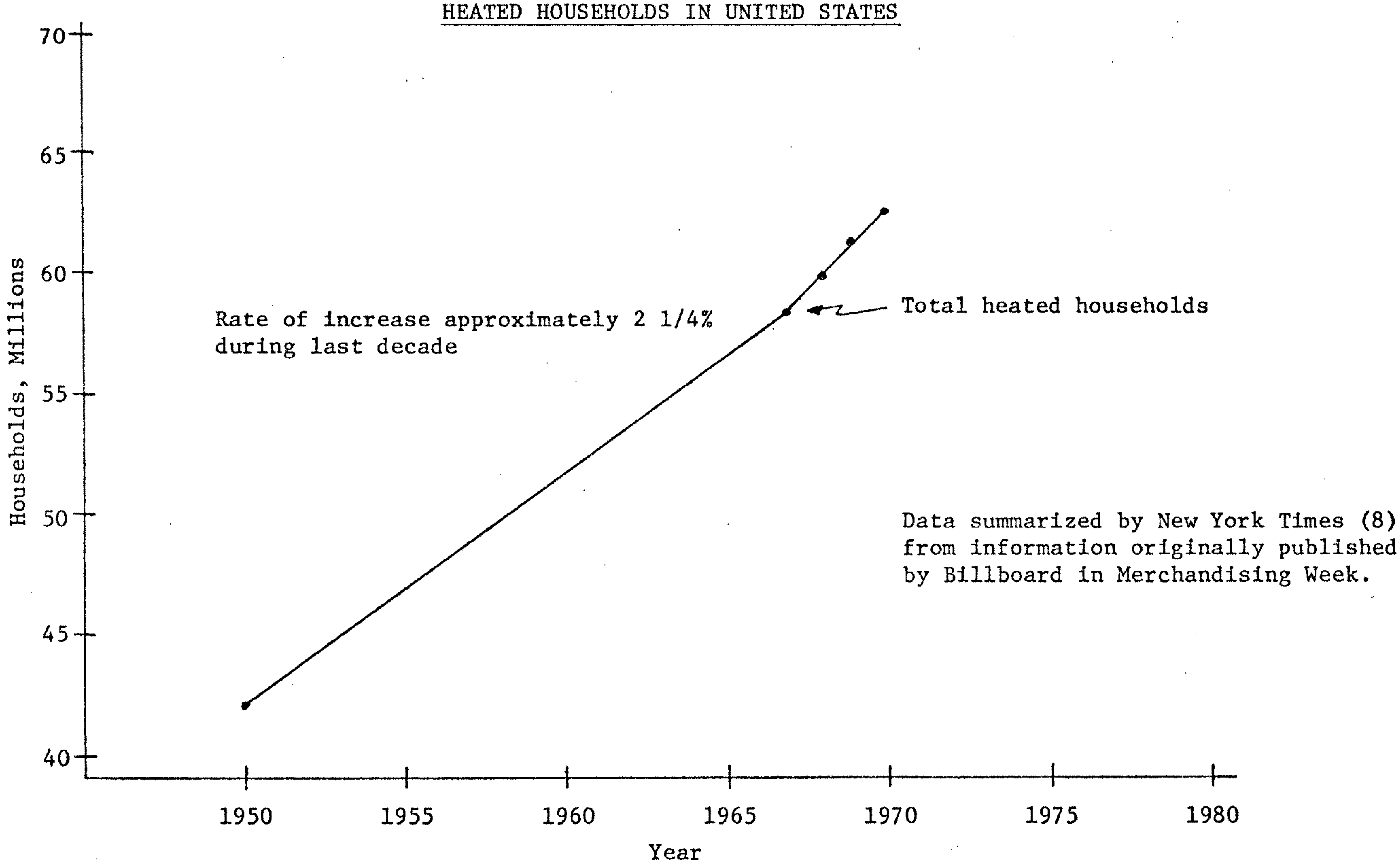


FIGURE 2

HEATED HOUSEHOLDS IN UNITED STATES



over the last decade. The New York Times,[8] see Figure 2, has shown that the number of U.S. households have increased at an annual rate of only 2% in the past decade, reaching some 62.5 million households in 1970. From the data in Table 1 and the energy forecasts in Figure 1, the following space heating energy needs can be developed.

	Space Heating Demand, Quads		
Year	Residential	Commercial	Total
1960	4.8	3.1	7.9
1970	6.5	4.2	10.7
1980	9.2	6.0	15.2

Using 1980 as the base, the total national heating requirement is therefore 15.2×10^{15} Btu/year or about 35 billion dollars per year when considering the 1980 fuel costs to likely be about 15$/Barrel. Even a small percentage reduction in this demand will have a large impact on the general energy picture in the United States.

This study will be limited to gas fired home heating units. The typical residential unit is about 120,000-180,000 Btu/hr fuel fired;[11] according to the American Gas Association,[7][1] in 1975 there were about 40 million housing units heated by gas in the United States. This would therefore represent some 60% of the total residential heating load.

RESULTS

The typical home heating furnace has a thermal efficiency of between 65% and 75%.[3] Efficiency is defined as the quantity of heat transferred to the heating objective as a percentage of the total fuel fired, e.g.:

$$E = \frac{Q_{ABS}}{Q_{fired}}(100)$$

where E = Thermal efficiency

Q_{ABS} = Heat transferred to the objective (space heating), Btu

Q_{fired} = Higher heating value of fuel fired in Btu.

By examining Figure 3, it can be seen that there are two parameters that effect the thermal efficiency of any furnace: the flue gas temperature and the excess oxygen. Note that the flue gas temperature shown is that of the gas after all useful heat has been absorbed, i.e., it is the temperature level of the waste heat. Inefficiency is thus caused by either wasting energy by heating too much inert gas (excess combustion air) or letting useful energy escape to the atmosphere in an inordinately hot flue gas. We will address both of these issues further on in this report.

An additional source of waste is the energy lost due to the nearly universal use of continuous gas pilot lights on residential gas furnaces. It has been estimated[13] that 223 billion cubic feet of gas (0.22 Quads) are wasted annually in this fashion. In Table 3 an efficiency calculation is shown for a typical home furnace. The

TABLE 3

TYPICAL RESIDENTIAL FURNACE
ENERGY LOSS ANALYSIS

Basis

Furnace Duty, Btu/Hr	150,000
Fuel Gas	Natural Gas
High Heating Value, Btu/SCF	1,000
Molecular Weight, lbs/mol	17.4
Flue Gas Temperature, °F	650
Excess Oxygen, mol %	100
Pilot Gas Rate, SCF/Season(1)	5,575
Heating Period, hours/year(2)	1,200

Calculate Thermal Efficiency

- From Figure 3 at 650°F flue gas with 100% excess oxygen heat available is 677Btu/SCF Fuel
- Heat input 1000 Btu/SCF High Heating Value
- Efficiency = $\frac{677}{1000} \times 100 = 67.7\%$
- Energy Loss = (1 - 0.677)(150,000 Btu/Hr) = 48,450 Btu/Hr fired

Total Energy Loss

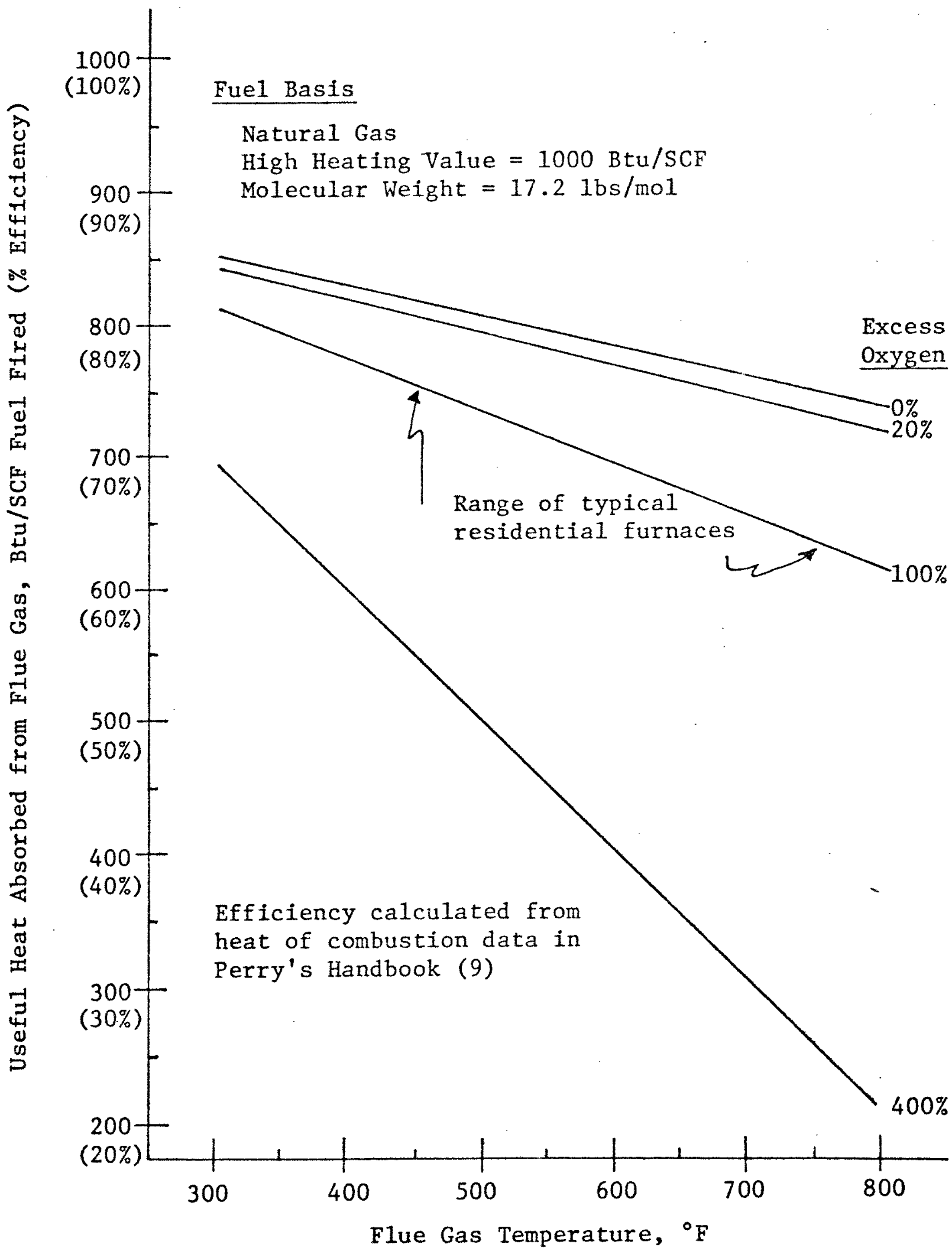
- Loss Due Efficiency $48{,}450 \frac{\text{Btu}}{\text{Hr}} \text{ fired} \times \frac{1{,}200 \text{ Hrs}}{\text{Season}} \text{ fired} = 58.1 \times 10^6 \text{ Btu}$
- Loss Due to Pilot $\frac{5{,}575 \text{ SCF}}{\text{Season}} \times \frac{1{,}000 \text{ Btu}}{\text{SCF}} = 5.6\ 10^6 \text{ Btu}$
- Total Heating Loss 63.7×10^6 Btu/Season
- Total Fuel Fired $150{,}000 \frac{\text{Btu}}{\text{Hr}} \times \frac{1{,}200 \text{ Hr}}{\text{Season}} = 180 \times 10^6 \text{ Btu}$
- Overall Efficiency $\left(1 - \frac{63.7}{180}\right) 100 = 64.6\%$

Notes: (1) Based on estimated national pilot gas waste of 223×10^9 SCF/year, and the American Gas Association estimate of 40 million gas furnaces in America.

(2) Heating period will vary from region to region. A 1200 hour/year firing period is typical of a moderate heating zone.

FIGURE 3

TYPICAL FURNACE EFFICIENCY
FOR NATURAL GAS FIRING



The basis is a conventional 150,000 Btu/hr unit firing natural gas with 100% excess oxygen and a flue gas temperature of 650°F. The thermal efficiency (67.7%) is calculated using the information in Figure 3.

The overall energy loss analysis is summarized below:

	Btu/Year
• Loss Due To Thermal Inefficiency	58.1
• Loss Due To Continuous Pilots	5.6
Total	63.7

When the 40 million home units are considered, this amounts to an incredible waste of 2.5 x 10^{15} Btu/year. This project is geared toward recovering this 2.5 Quads of energy. If all of this waste were recoverable, crude oil imports could be reduced by 1.1 million barrels per day and our balance of payments would be credited with nearly five billion dollars per year!

Several Practical Energy Saving Ideas Available to Homeowners

The gas fired furnace has the potential to be one of the most efficient space heating devices for home use. However, as discussed in the previous section, this potential is not currently being realized. There are two basic heat recovery possibilities that can be exploited by the homeowner:

- Reduce waste by eliminating the energy losses that occur due to high flue gas temperatures. That is, increase each unit's thermal efficiency.

- Reduce waste by improved firing cycles.

The remainder of this report discusses energy conservation ideas pertaining to these two areas, suggests capital improvements that can be made to implement these energy conservation measures, and lastly, highlights some of the economic considerations that the homeowner should evaluate.

By implementation of these ideas, gas fired furnaces can be the most efficient fossil fuel fired heating plants for individual use.

The first area to be considered is the improvement of thermal efficiency by reduction in flue gas heat loss. It is in this regard that gas fired units offer a distinct advantage over oil fired furnaces. Natural gas, being as clean a fuel as is available--particularly with respect to sulfur content--produces the least corrosive flue gas of any commercially available fuel. Tables 4 and 5 list some typical properties for natural gas and home heating oil, respectively.[9] Since sulfuric acid condensation is not a major problem when firing natural gas, very low flue gas temperatures can be maintained without fear of corrosion in the stack. A practical minimum temperature of 350°F should be used for household flues thus ensuring that condensation will not occur.

Summarized below is a table of furnace efficiency versus flue gas temperature at a constant 100% excess air. In addition, the impact of wasted energy is shown both as Btu/hr wasted and dollars

TABLE 4

PROPERTIES OF NATURAL GAS

Gas Source[1]	Texarkana	Cleveland	Oil City, Pa.
Composition, mol %			
Carbon Monoxide	-	-	-
Carbon Dioxide	0.8	-	-
Hydrogen	-	-	-
Nitrogen	3.20	1.30	1.10
Oxygen	-	-	-
Methane[2]	96.00	80.50	67.60
Ethane[2]	-	18.20	31.30
Sulfur	Nil	Nil	Nil
Molecular Weight	16.2	18.5	20.2
High Heating Value, Btu/SCF	967	1131	1232
Low Heating Value, Btu/SCF	873	1025	1120
Adiabatic Flame Temperature, °F	3580	3600	3620

Notes: (1) Data from Perry's Chemical Engineering Handbook, 4th Edition. (9)

(2) The following combustion properties are for methane and ethane. Natural gas, being comprised of >95% CH_4 and C_2H_6 will have similar properties.

	CH_4	C_2H_6
Ignition Temperature, °F	1202	986
Lower Flammability Limit, % in Air	5.0	3.2
Upper Flammability Limit, % in Air	15.0	12.5

TABLE 5

PROPERTIES OF FUEL OIL[1]

Fuel Oil Grade	No. 1 Fuel Oil	No. 2 Fuel Oil
Gravity, °API	35-40	26-34
Specific Gravity	0.826-0.851	0.855-0.899
Flash Point, Minimum °F	100	100
High Heating Value, Btu/lb	19,800	19,250
Low Heating Value, Btu/lb	18,600	18,100
Sulfur, wt.% Maximum[2]	0.5	1.0

Notes: (1) Data from Perry's Chemical Engineering Handbook, 4th Edition. (9)
(2) Since publication of this data, the fuel oil industry regularly markets low sulfur fuel oil in the 0.1 to 0.3 wt.% sulfur range.

per year.

Flue Gas Temp °F	Thermal Efficiency, %	Wasted Energy 10^6 Btu/Year	$/Year
750	63.3	66.1	127
650	67.4	58.7	113
550	71.1	52.0	100
450	75.2	44.6	86
350	79.0	37.8	73

This table is based on an average furnace size of 150,000 Btu/hr, a moderate climatic zone with a 1200 hour/year furnace firing requirement and a deregulated energy cost of $12.00 per fuel oil equivalent barrel (6.23×10^6 Btu). Furnace efficiency calculations are based on the data in Figure 3.

In addition, there will be a further improvement in thermal efficiency if the amount of excess air can be reduced. Assume that a stack operates at 650°F and 100% excess oxygen--a typical home unit. By reducing the excess oxygen to 20% we improve the thermal efficiency from 67.4% to 75.7%. For the typical case as indicated above this efficiency increase would result in a savings of some 15 million Btu/year or nearly 30 $/year additional cash return. To not lose sight of the real objective--the national energy picture--this savings would amount to 0.6×10^{15} Btu/year or an equivalent reduction in imports of some third of a million barrels of crude oil per day.

To reduce the flue gas temperature, one must recover this waste heat in some useful fashion. The three basic techniques applicable to recovering heat are:

- Recover energy by heating an intermediate heat transfer medium for use elsewhere.
- Recover energy directly to space heat.
- Recover heat internally, i.e. combustion air preheat.

These items are discussed in detail in the following section of this report.

The second technique for reducing energy waste in a home furnace is to improve the firing cycle. This area covers all other items not directly related to thermal efficiency improvements. There are two techniques that will be discussed under this objective:

- Reduction of wasted fuel by elimination of the continuous gas pilot light.
- Improved energy utilization by use of a timed sequence thermostat.

Detailed purchasing information is not included since it is beyond this scope of this survey to determine which commercially available devices can be directly installed onto the myriad of different furnaces in operation. Sufficient information is given, however, to establish the incentive for development of home use sized, universal equipment of this nature.

Flue Gas Energy Recovery By Transfer to Intermediate Medium Rejected

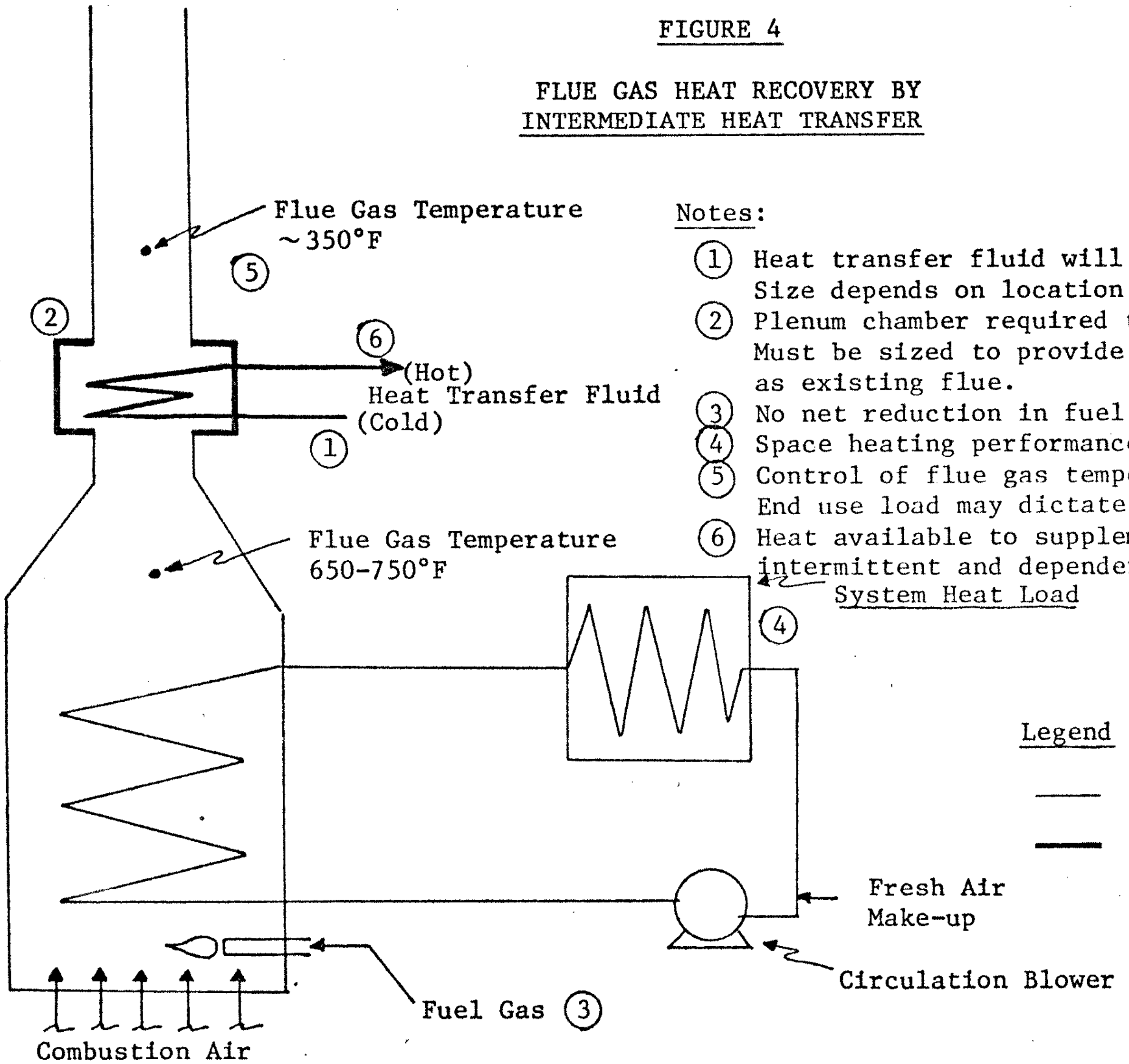
One technique for recovering the energy in the hot flue gas is to transfer it to an intermediate heat transfer fluid. A schematic diagram of such a system is shown in Figure 4. A standard, natural draft gas fired furnace is still used. The burner, combustion air registers, circulation air system etc. are unaffected. A heat transfer coil housed in an expansion plenum would be installed in the flue.

The design of such a system is simple. The two important design criteria are the heat transfer coefficient in the transfer section and the increased flue pressure drop caused by inclusion of the secondary recovery device. There are; however, many drawbacks to this system.

First, the heat transfer media will require a pump or blower for circulation, the size of which would depend on the location of the end use heat sink. Secondly, the flue gas temperature would, in all likelihood, be required to "float" depending on the demand of this external load. However, the biggest drawback is in terms of the end use for this waste energy. For a system such as this to be worth anything to the homeowner (and to the national energy picture) this extra heat would have to allow a reduction in some other energy consumer. Since this waste heat is not available on demand but is subject to the energy needs of the main heat sink, it cannot be used in any service relying on a constant energy source.

FIGURE 4

FLUE GAS HEAT RECOVERY BY INTERMEDIATE HEAT TRANSFER



Notes:

1. Heat transfer fluid will require pump or blower. Size depends on location and end use.
2. Plenum chamber required to house transfer surface. Must be sized to provide as much unrestricted flow as existing flue.
3. No net reduction in fuel gas will be realized.
4. Space heating performance unaffected.
5. Control of flue gas temperature may not be possible. End use load may dictate heat transfer needs.
6. Heat available to supplemental heat sink will be intermittent and dependent on space heating demands.

Although a system such as this may well be justified for any individual who has a use for this heat--it is felt to not be universal enough to make a significant contribution to the overall objective of reducing the national space heating fuel requirements. This system would result in more energy being available to a given environment but would not necessarily reduce the consumption of fuel.

Flue Gas Energy Recovery By Heat to Space Viable But Not Optimum

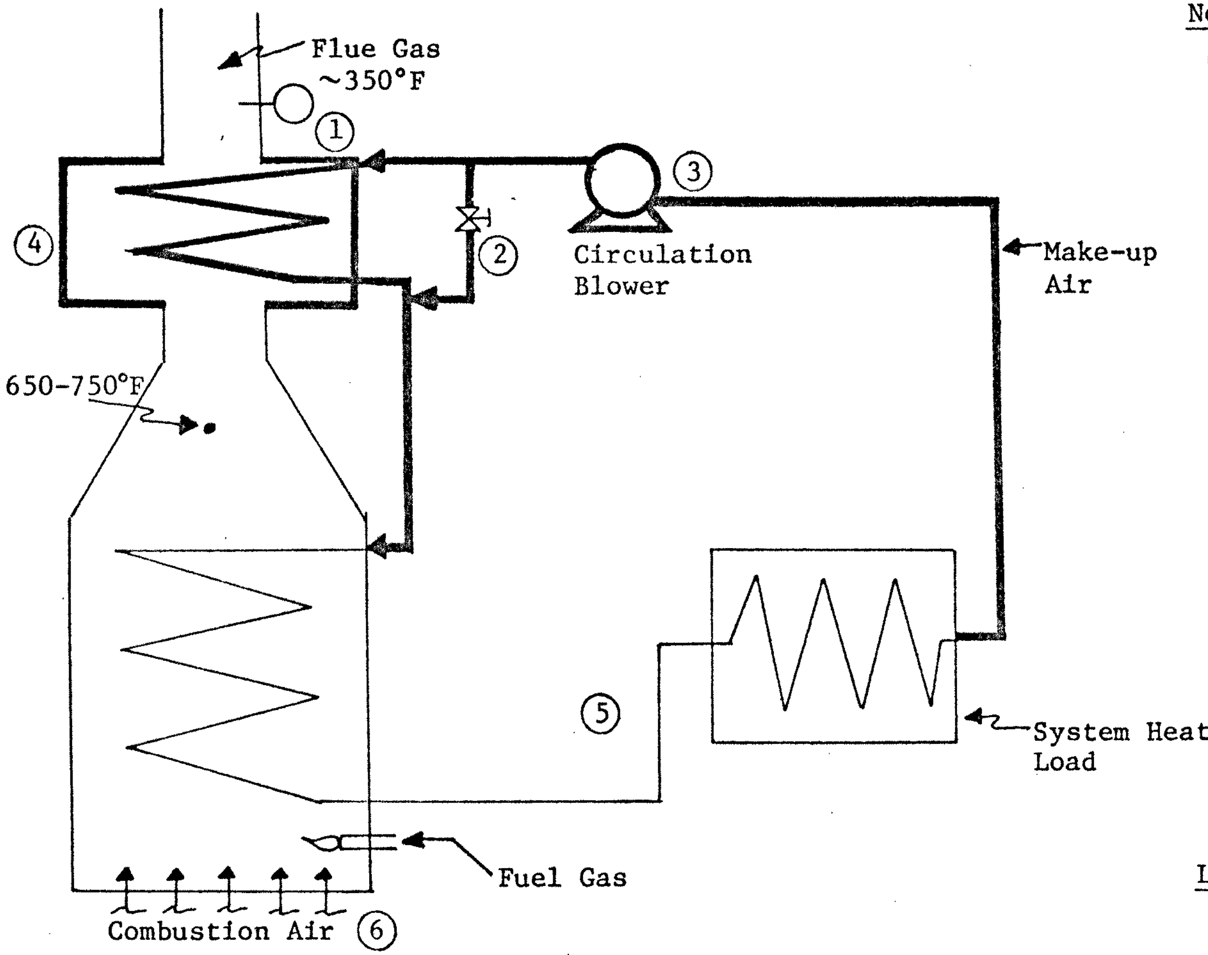
The most straight forward technique for recovering the waste energy in the hot flue gas is to transfer it directly to the space being heated. For a given heating requirement, this system will reduce the consumption of fuel. There are a variety of ways in which this additional space heating can be accomplished including a totally separate heating zone being operated from the wasted heat or incorporating the waste heat into the existing heating system. It is this latter scheme that is depicted in Figure 5.

In this scheme the secondary heat transfer section is linked in series with the primary (existing) heat transfer section. The circulating air first passes thru the stack section to absorb sufficient heat from the flue gas to reduce the stack to about 350°F. The air is then brought into its normal heating zone prior to circulation to the house.

A bypass will be required around the secondary transfer section to balance the system. A temperature indicator should be installed

FIGURE 5

FLUE GAS HEAT RECOVERY BY
HEAT TO SPACE



Notes:

1. Temperature gage required to set up optimum air flow.
2. Small diameter bypass duct with control flapper to balance flow/heat load for optimum stack temperature.
3. Existing blower and driver may be adequate. Systems with central air conditioning will already have over-sized driver.
4. Plenum chamber to provide adequate unrestricted Flue gas flow area.
5. Hot air to heating system will contain more heat than prior to modifications. Sufficient flexibility should be included during design to permit trade-off between temperature and volume of transfer air.
6. System does not reduce excess air requirements.

Legend

——— Existing Equipment

▬▬▬ New Equipment

in the flue and the bypass diversion valve set to minimize this temperature. Whether or not a new circulation blower driver would be required would depend on the specific installation. The heat transfer coils (see next section) can be designed to minimize pressure drop. Furthermore, the system should be designed with sufficient flexibility to permit a trade off between the temperature and volume flow rate of the circulation air.

Although this system will reduce the total energy requirement for a given space heating load, it still does not realize the full potential thermal efficiency credits since excess oxygen is not reduced. As will be seen in the following section, the final scheme has all the advantages of this system plus a reduction in excess air. As such, it will be reviewed in more detail.

Flue Gas Heat Recovery By Air Preheat Gives Positive Control

By recovering the waste heat in the hot flue gas by preheating combustion air, many of the disadvantages of the two previous systems can be eliminated. In contrast to the first system--heat to an intermediate transfer medium--no supplemental heating requirement is needed to justify the waste heat recovery. The air preheater will directly reduce fuel input for any required heating load. When compared to the supplemental space heating option, we find two distinct credits. First, since the home heating side of the system is totally unaffected by the changes--no home load rebalancing will be required and no problem can occur with the circulating air/stack gas temperature relationship. Secondly, since the combustion air system will be modified--the opportunity presents itself to more closely monitor, and therefore reduce, the excess air to the system.

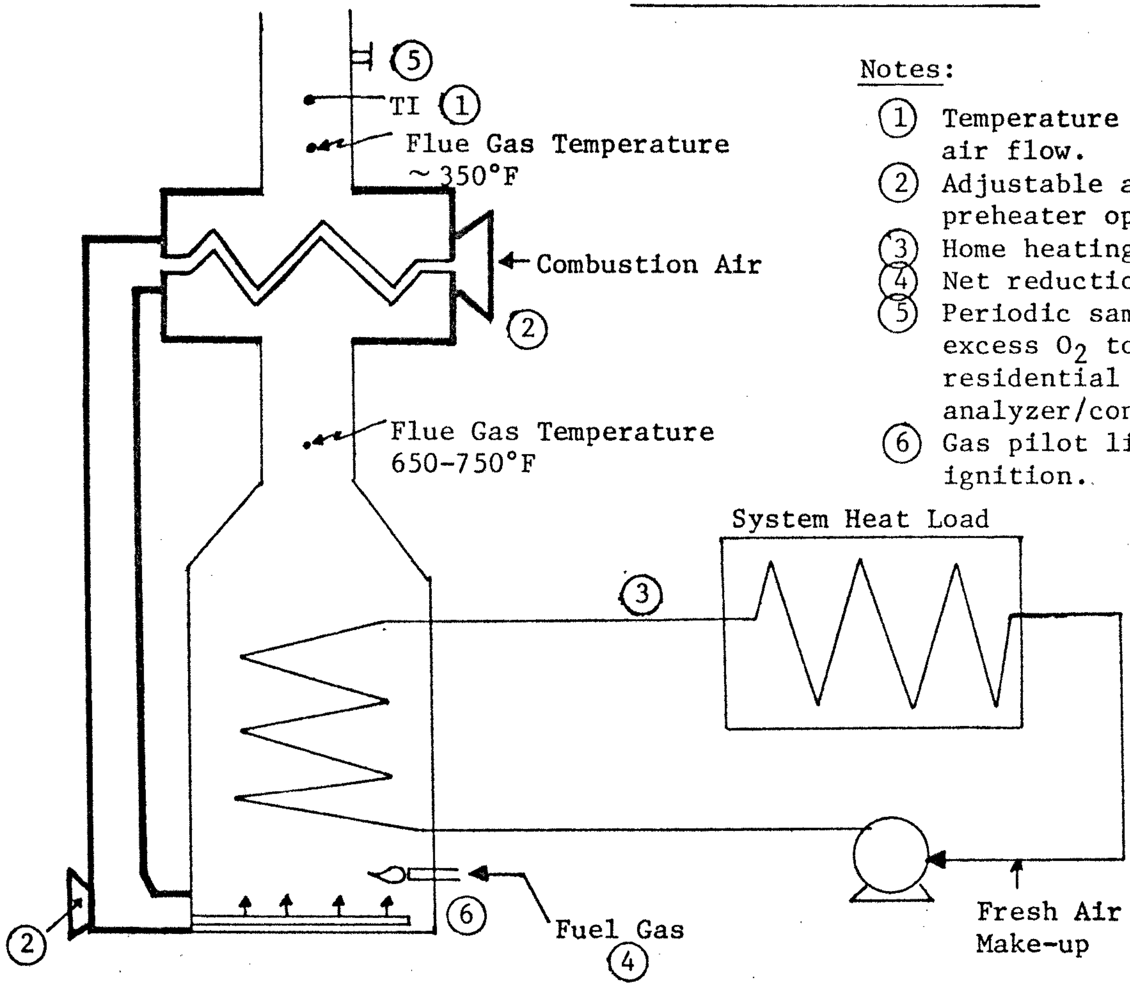
Figure 6 has been included to show, in schematic form, the proposed system. The secondary heat recovery section now contains heat transfer tubing to preheat the combustion air. With this configuration the stack temperature can be set to its minimum value (~350°F) independent of the heating load. Optimum furnace effficiency is thereby maintained. The combustion air system will have to be totally contained to eliminate any unpreheated air from leaking into system. Variable registers are provided to positively control the relative amounts of preheated and unpreheated air. By this technique it is possible to eliminate the need for an induced draft since the system can be balanced to minimize flow (and thus maximize the temperature) of the preheated air.

Some outline calculations pertaining to the design of such a system have been included in the Appendix for reference. These calculations serve only to demonstrate the feasibility of such a system and do not represent definitive design for any specific installation. Included in this Appendix are:

- Calculation basis
- Combustion air requirements
- Flue gas data

FIGURE 6

FLUE GAS HEAT RECOVERY BY
COMBUSTION AIR PREHEAT



Notes:

1. Temperature gage required to set up optimum air flow.
2. Adjustable air registers needed to balance preheater operation with available draft.
3. Home heating system unaffected.
4. Net reduction in fuel gas will be realized.
5. Periodic sampling of flue gas will permit excess O_2 to be minimized. If available in residential size and price range an automatic analyzer/controller could be used.
6. Gas pilot light replaced with electronic ignition.

Legend

—— Existing Equipment

▬▬ New Equipment

- Preheat calculations
- Heat transfer surface requirements
- Transfer section size outline

During definitive design, all these calculations have to be made in detail. In addition, the dynamics of the entire system must be evaluated to define pressure requirements and control functions.

With this basic air preheat system, the thermal efficiency of a home furnace can be increased from the 60-65% range to the 75-80% range. The remainder of this report deals with additional items that could further reduce the overall heating bill at the consumer level.

Reduce Excess Air

Modern, sophisticated industrial furnaces are typically designed to operate with 10-20% excess oxygen, while residential units are generally set at 100% excess oxygen and often drift much higher. What is the difference?

There are two breakthroughs that are required to permit the homeowner to significantly reduce his excess air usage. First, an industrial furnace will use a continuous oxygen analyzer located in the stack to monitor the performance of the unit; furthermore, the furnace will often be instrumented to directly control combustion air from this analyzer. The author has not been able to find a commercially available, small and inexpensive O_2 analyzer designed for home use. Without such a device (Beckman, Orsat, MSA, etc.)

positive control is impossible. However, it may be possible to rent or otherwise gain access to a portable "sniffer" unit on a twice per heating season basis. The flue gas oxygen content can be measured and the air register (see Figure 6) adjusted to give the best possible performance. In this way, it may be possible to maintain the average excess oxygen constant at 50-100% and prevent the costly drifts to 200-300%.

A second, critical equipment need must be filled to permit safe operation of a low oxygen home unit. Positive flame out protection is needed to ensure that the system safely shuts down should a loss of combustion occur due to oxygen starvation. Industrial flame scanners are again, not available on a consumer level. However, a thermostatically controlled system with a time delay relay can be used, much as are used in typical continuous gas pilot lights.

Even without using an air preheater, reducing the excess oxygen from 100% to 20% would increase the thermal efficiency of the unit from 60-65% to about 75%, an annual savings of nearly 50 $/year per individual and some 400,000 barrels of crude per day reduction in imports for the nation as a whole.

Pilot Light Losses Can
Be Eliminated Today

As indicated earlier, it has been estimated that continuous gas pilots cost this country some 223 billion cubic feed of gas per year. This can be eliminated by installation of an electronic ignition system. Capacitive discharge as well as solid state ignition devices are available and can be installed by a licensed electrician. Unless government subsidies are given, however, the individual homeowner would find it difficult to justify installation of such a device to replace an existing system since annual savings are in the 10-30 $/year range and the cost of the hardware alone may be as high as 50-100$. As this equipment becomes standard on new furnaces; however, both the nation and the individual will benefit.

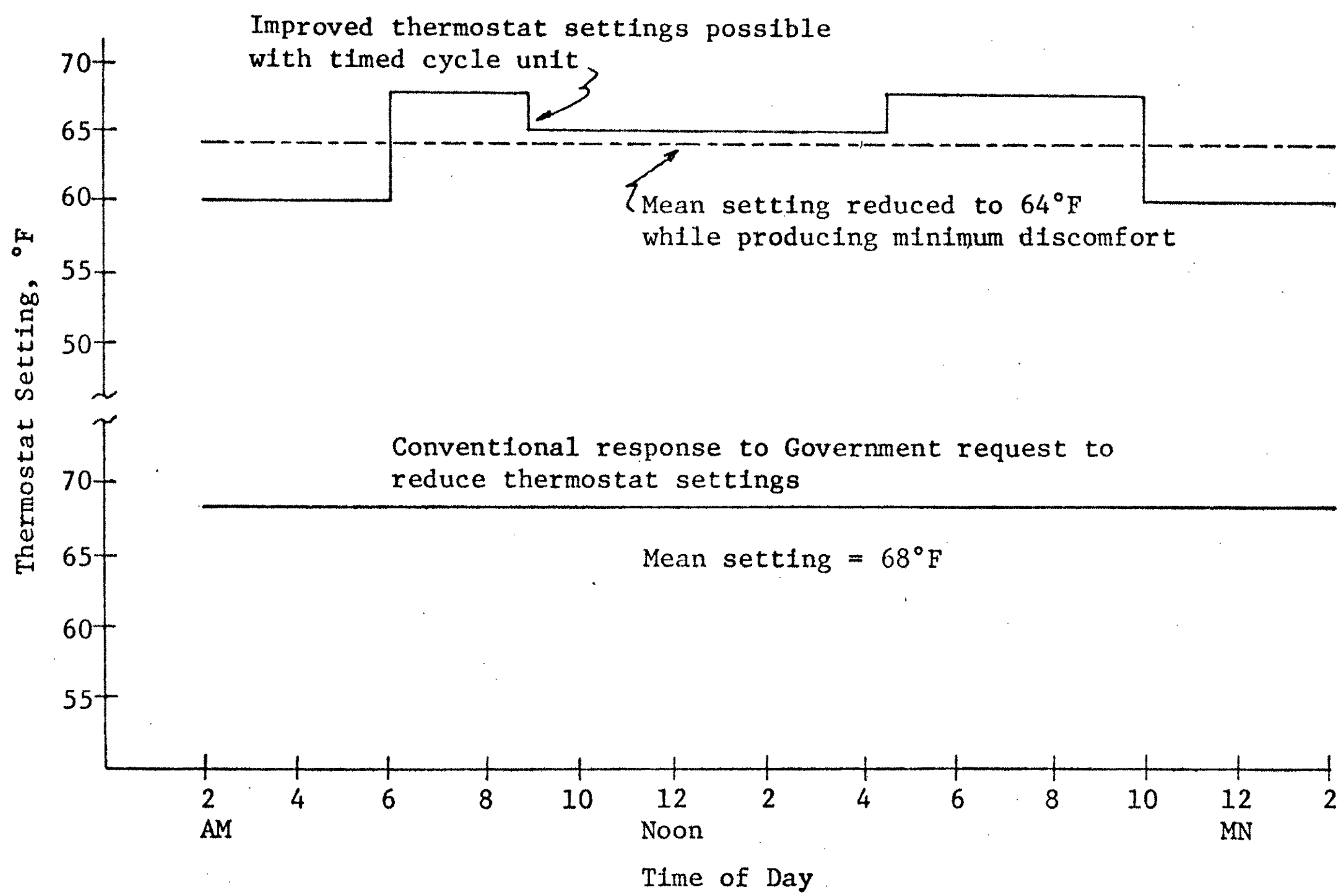
Timed Sequence Heating

The topic to be discussed relates to the heating cycles for most homes. Even if the homeowner has insulated his structure well and maintains the cleanlines of the furnace and associated filters--a great deal of energy is still being wasted. The standard on/off thermostat used in virtually all U.S. housing was perfectly adequate when energy costs were in the $1.50-$2.50 per barrel range. Today's $10-$15 per barrel prices have made it desirable to more optimally select a heating pattern.

During the winter of 1976-77, the nation was forced to "turn down" its thermostats to save energy. Many people were reluctant to make substantial temperature reductions, but did push their units down to 68°F. In the attached Figure 7 we can see that a significant reduction in mean thermostat setting (to ~64°F) could be accomplished while still maintaining a very comfortable 68°F during the morning and evening hours. Since this requires moving the thermostat setting

FIGURE 7

IMPACT OF
TIMED CYCLE THERMOSTAT



four times per day--plus the added discomfort of waking up to a very cold house it was very often not done. It is a simple matter to have a timed sequence thermostat installed. Devices such as these have been standard in Europe for many years but have just now become readily available to the U.S. consumer market. Prices range around $50 and can be installed easily.

CONCLUSIONS

In summary, this report has examined the contribution of domestic heating inefficiency to the national energy crisis and has found that perhaps as much as 1 million barrels of crude oil imports could be eliminated if the ideas developed above are implemented.

With respect to the individual homeowner, a savings of about 50 $/year could be achieved if a combustion air preheater were installed on a 150,000 Btu/hr furnace. The design of such a system is relatively simple and would probably cost about $100 to $200. An overall national savings of 600-700 thousand barrels per day of crude oil imports could be eliminated.

Better control of excess oxygen is possible with regular maintenance and periodic adjustment, especially if the combustion air preheat system is installed. An additional credit of about $20 per individual or a quarter of a million barrels of imports per day to the U.S. could thus be realized.

Continuous gas pilot lights needlessly waste 223 billion cubic feet of natural gas per year. Inclusion of electronic ignition systems available on the market today would result in a further savings of $10 per year or about 100,000 barrels per day of reduced imports.

RECOMMENDATIONS

Based on the results of this screening study it is possible to dramatically reduce the energy losses in residential, gas fired heating units. On average, nearly $100 per year or some 25% to 35% of the typical home heating bill is needlessly lost. This energy can be recovered by:

- Installing a combustion air preheater
- Reducing excess oxygen in the flue gas
- Replacing continuous gas pilot lights with an electronic ignition system

The total cost for implementing these modifications would probably be about $200 to $400 resulting in an attractive return on investment--particularly in view of the expected continual escalation of energy costs.

Unfortunately, in the author's judgement, a savings of even $100 per year will not be considered as very substantial by the public. Hence the prospects of realizing the potential million barrels per day crude oil import reduction are not very great.

To realize these potential credits the author believes that Governmental pressure must be vigorously exerted. Incentives, perhaps in the form of tax concession may be a workable option. Direct subsidy of furnace revamps could be considered or long term low interest loans may be made available to those homeowners interested in saving energy.

Finally, it is recommended that efficiency standards be established for all new furnace installations. The individual consumer is the largest source of energy waste in the United States and thus represents the target with the greatest potential for real progress in stemming the energy crisis.

APPENDIX

APPENDIX

CALCULATIONS FOR COMBUSTION AIR PREHEAT OPTION

Calculation Basis

Furnace Information prior to Modifications	
Fuel Fired, Btu/Hour	150,000
Heat Absorber, Btu/Hour (i)	101,150
Thermal Efficiency, %	67.4
Flue Gas Temperature, °F (ii)	650
Excess Oxygen, mol %	100
Firing Time, Hours/Year	1200
Fuel Information	
Type (iii)	Natural Gas
Molecular Weight, lbs/mol	17.2
High Heating Value, Btu/SCF	1000
Low Heating Value, Btu/SCF	905
Composition, mol %	
CH_4	95.0
C_2H_6	1.5
N_2	0.5
CO_2	3.0

Notes:
(i) Heat absorbed by circulating warm air to heat required space.
(ii) A major problem in residential furnace units is the lack of combustion air control. It is not uncommon for a furnace designed to operate with 100% excess air to be consuming twice as much air. This drift occurs since combustion air rates are rarely adjusted.
(iii) See also Figure 3 this report.

APPENDIX, CONT'D

Calculate Combustion Air Requirements

- Fuel Firing Rate $\frac{150{,}000\ \text{Btu}}{\text{Hr}} \times \frac{\text{SCF Fuel}}{1000\ \text{Btu}} = 150$ SCF Fuel/Hour

$$\frac{150\ \text{SCF Fuel}}{\text{Hr}} \times \frac{\text{Mol}}{379.5\ \text{SCF}} \times \frac{17.2\ \text{lbs}}{\text{Mol}} = 6.8\ \text{lbs Fuel/Hour}$$

- Air Requirements

	Fuel Rate SCF/Hr	Flue Gas Mols/Mol Fuel	O_2 Required SCF/Hr	Flue Gas Yield SCF/Hr	Flue Gas Yield lbs/Hr
CH_4	142.5	10.52(i)	285.0	1499.1	109.1
C_2H_6	2.25	18.20(i)	7.9	40.95	3.0
N_2	0.75	1.0	-	0.75	0.06
CO_2	4.50	1.0	-	4.50	0.52
	150.0		292.9	1545.3	112.7

- Combustion Air

$$\frac{292.9\ \text{SCF}\ O_2}{\text{Hr}} \times \frac{100.0\ \text{SCF Air}}{21.0\ \text{SCF}\ O_2} = 1394.7\ \text{Call}\ \underline{1395\ \text{SCF Air/Hour}}$$

$$\frac{1395\ \text{SCF Air}}{\text{Hr}} \times \frac{28.8\ \text{lbs Air}}{\text{Mol}} \times \frac{1\ \text{Mol}}{379.5\ \text{SCF}} = 105.9\ \text{Call}\ \underline{106\ \text{lbs Air/Hour}}$$

Excess Air %	Combustion Air SCF/Hr	Combustion Air lbs/Hr	Total Flue Gas SCF/Hr	Total Flue Gas lbs/Hr
0	1395	106.0	1545	112.7
20	1674	127.2	1824	133.9
100	2790	212.0	2940	218.7
400	6975	530.0	7125	536.7

Notes: (i) Stoichiometric equations for methane and ethane combustion are:

$$CH_4 + 2\ O_2 + 7.72\ N_2 \longrightarrow CO_2 + 2\ H_2O + 7.52\ N_2$$

$$C_2H_6 + 3.5\ O_2 + 13.2\ N_2 \longrightarrow 2\ CO_2 + 3\ H_2O + 13.2\ N_2$$

APPENDIX, CONT'D

Combustion Air Preheat Calculation

- Combustion Air Heat Capacity: $C_{Pmean} = 0.2375$ call $0.24\ \frac{Cal}{9°C}$ (i)

  $= 0.24\ \frac{Btu}{lb°F}$

- Enthalpy Considerations

Heat Fired, Btu/Hr	150,000 (1000 Btu/SCF Fuel)
Heat Absorbed with 650°F Stack (ii)	
@ 0% Excess Air, Btu/Hr	116,970 (780 Btu/SCF Fuel)
@ 20% Excess Air, Btu/Hr	113,530 (756 Btu/SCF Fuel)
@ 100% Excess Air, Btu/Hr	101,150 (674 Btu/SCF Fuel)

- Flue Gas Composition

@ 20% Excess O_2	Mol %	C_p Mean	Wt.%	C_p Contribution
CO_2	8.30	0.24	13.1	0.031
H_2O	16.00	0.47	10.3	0.048
N_2	72.57	0.26	73.0	0.190
O_2	3.13	0.24	3.6	0.009
	100.00		100.0	0.278
@ 100% Excess O_2				
CO_2	5.15	0.24	8.03	0.020
H_2O	9.92	0.47	6.32	0.030
N_2	75.24	0.26	74.65	0.194
O_2	9.69		11.00	0.026
	100.00		100.00	0.270

Call Flue Gas $C_{p\ mean} = 0.27$ Btu/lb°F

Notes: (i) Perry's Chemical Engineering Handbook. (9)

(ii) Heat absorbed from circulating air.

APPENDIX, CONT'D

Air Preheat Calculation, Cont'd

- Case 1 100% Excess Air

$$650°F \xrightarrow{\text{Flue Gas}} ?$$

$$? \xleftarrow{\text{Combustion Air}} 70°F$$

Flue Gas Volume 2924 SCF/Hr = 218.7 lbs/Hr (see page 37)

Combustion Air 2790 SCF/Hr = 212.0 lbs/Hr (see page 37)

(1) Cool Flue Gas to 350°F

$$Q = m\ C_p\ \Delta T = \frac{218.7\ \text{lbs}}{\text{Hr}} \times \frac{0.27\ \text{Btu}}{\text{lb°F}} \times (650\text{-}350)°F\ \Delta T = 17{,}715\ \text{Btu/Hr}$$

Check using data in Figure 3

@ 650°F Heat Absorbed = 101,150 Btu/Hr

@ 350°F Heat Absorbed = 118,350 Btu/Hr

Δ = 17,200 Close Enough

(2) Heat Combustion Air

$$Q = m\ C_p\ \Delta T \quad \frac{17{,}700\ \text{Btu}}{\text{Hr}} = \frac{212\ \text{lbs Air}}{\text{Hr}} \times \frac{0.24\ \text{Btu}}{\text{lb°F}} \times \Delta T,\ °F$$

ΔT = 348°F $T_{Hot\ Air}$ = 70 + 348 = 418°F This is a feasible preheat temperature.

Flue Gas 650°F ⟶ 350°F

Air 418°F ⟵ 70°F

ΔT_1 = 650-418 = 232, ΔT_2 = 350-70 = 280 $\quad LMTD = \dfrac{280-232}{Ln\frac{280}{232}}$

LMTD = 255°F

APPENDIX, CONT'D

Air Preheat Calculation, Cont'd

- Case 2 20% Excess Air

Flue Gas	650°F	$\longrightarrow$	?
Combustion Air	?	$\longleftarrow$	70°F

Flue Gas Volume = 1827 SCF/Hr = 133.9 lbs/Hr (see page 37)

Combustion Air Volume = 1674 SCF/Hr = 127.2 lbs/Hr (see page 37)

(1) Cool Flue Gas to 350°F

$$Q = m\ C_p\ \Delta T = \frac{133.9\ \text{lbs}}{\text{Hr}} \times \frac{0.27\ \text{Btu}}{\text{lb}^\circ\text{F}} \times (300^\circ\text{F})\ \Delta T = 10{,}850\ \text{Btu/Hr}$$

(2) Heat Combustion Air

$Q = m\ C_p\ \Delta T$, Air Side

$$\frac{10{,}850\ \text{Btu}}{\text{Hr}} = \frac{127.2\ \text{lbs}}{\text{Hr}} \times \frac{0.24\ \text{Btu}}{\text{lb}^\circ\text{F}} \times \Delta T,\ ^\circ\text{F} \qquad \underline{\Delta T = 355^\circ\text{F}}$$

Air Preheat Temperature = 70 + 355 = <u>425°F</u>

Flue Gas	650°F	$\longrightarrow$	350°F
Air	425°F	$\longleftarrow$	700°F

$\Delta t_1 = 650 - 425 = 225$, $\Delta t_2 = 350 - 70 = 280^\circ\text{F}$

$$\text{LMTD} = \frac{280-225}{\text{Ln}\frac{280}{225}} = \underline{251^\circ\text{F}}$$

APPENDIX, CONT'D

Heat Transfer Section

- Determine heat transfer coefficient for Air/Flue Gas

  From Perry's(i)

  $$U = \frac{10\ \text{Btu}}{\text{Hr, ft}^2\text{, °F}} \quad \text{for low } \Delta P \text{ (0.1 to 0.5 psi)}$$

  $$U = \frac{20\ \text{Btu}}{\text{Hr, ft}^2\text{, °F}} \quad \text{for High } \Delta P \text{ (2.0 to 5.0 psi)}$$

  Use U = 10.0

- Calculate Required Transfer Area

	Case 1 100% Excess Air	Case 2 20% Excess Air
Duty, Btu/Hr	17,715	10.850
LMTD, °F	255	251
Correction Factor,(ii) F_N	0.91	0.91
Transfer Coefficient, Btu/Hr, ft^2, °F	10	10
Area,(iii) ft^2	7.63	4.75

Conclusion: Inlcude a 10 ft^2 heat transfer section for residential use--should provide adequate margin.

Notes: (i) Perry's Handbook, reference (9) page 11-21: heat transfer coefficients using bare aluminum tubing.
(ii) Perry's, page 11-17.
(iii) Based on $Q = UA\,F_N$ (LMTD)

APPENDIX, CONT'D

Tubing Requirements

- Tube Size 1 1/2 inch x 10 BWG

  Transfer Area 0.3927 ft^2 outside area/ft length

  $$\text{Length required} = \frac{10\ ft^2\ \text{Area}}{0.3927\ ft^2/ft} = \underline{25.5\ \text{Linear Feet}}$$

- To minimize pressure drop use 2.5 foot tubes (10 required)

  Check velocities in tubes (1 1/2" x 10 BWG Tube = 1.192 $in.^2$ inside area)

  Maximum Air Flow = 2790 SCF/Hr at 100% Excess Air

  $$\frac{2790\ SCF}{Hr} \times \frac{\frac{70 + 418}{2} + 460}{520}\ \frac{ACF}{SCF} = \frac{3780\ ACF}{Hr} = \underline{1.05\ ACF/Sec}$$

  Thus per tube flow rate = 0.105 ACF/Sec

  $$\text{Velocity} = \frac{0.105\ ft^3}{Sec} \times \frac{Tube}{1.192\ in.^2} \times \frac{144\ in.^2}{ft^2} = \underline{12.7\ ft/sec}$$

  $$\text{Mass Velocity} = \frac{212\ lbs}{Hr}\ \text{total} = 21.2\ \text{lbs/hour per tube} = 2561\ \text{lbs/hour-}ft^2$$

  Pressure Drop:(i) $\frac{\Delta P}{ft} = 0.0005$ psi/ft

  0.0005 psi/ft is reasonably low i.e., 0.00125 psi total

Notes: (i) From Perry's Handbook, reference (9): Pressure Drop Alignment Chart page 5-23.

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