Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

SEASONAL EFFICIENCY STANDARD: A REQUIREMENT FOR OIL FURNACES

A.C.S. Hayden
Canadian Combustion Research Laboratory

December 1984

Prepared as a Background Paper for the Executive Committee, CSA Standards Steering Committee on Fire Safety and Fuel Burning Equipment

ENERGY RESEARCH PROGRAM
ENERGY RESEARCH LABORATORIES

SEASONAL EFFICIENCY STANDARD - A REQUIREMENT FOR OIL FURNACES

A.C.S. Hayden
Canadian Combustion Research Laboratory (CCRL)
ERL/CANMET/EMR

December 1984

INTRODUCTION

There is potential for significant reductions in energy consumption by improving in the efficiency of residential oil-fired heating systems. This potential has been only partially realized to date in Canada. Presently, residential oil furnaces in Canada are compared only on the basis of their steady state efficiencies. Such a measure neglects cyclic and off-cycle performance, as well as the effect of dilution air. It is possible to have two furnaces with the same steady state efficiency, yet with 10-20% differences in their actual seasonal performance, due to differences in technology.

Unless an equitable, accurate method to label their seasonal efficiency is developed, there may be little incentive for manufacturers to produce a truly more efficient product, one which may be safer as well as being compatible with the more energy efficient housing (i.e. R2000) now being built. In 1977, the Canadian Standards Association and the Canadian Gas Association, on meeting with the Senior Assistant Deputy Minister, Energy, Mines and Resources Canada, agreed to develop a seasonal efficiency standard for their respective central heating appliances. More recently, CSA has been requested by its Committee on Energy Use Evaluation and Labelling of Houses to produce such a standard for oil fired equipment, which might be referenced in its Labelling Standard.

The U.S. has developed such a standard (1), commonly known as the Annual Fuel Utilization Efficiency (AFUE). The Canadian Gas Association has recently developed a similar standard (2), with certain improvements that make it more accurate and more suitable to Canadian winter conditions. The latter standard could easily be adapted by CSA to produce a comparable seasonal efficiency standard for oil furnaces.

This paper discusses the controlling factors in furnace efficiency performance, and shows how some technologies can be significantly more efficient than others on a seasonal basis, emphasizing the need for rapid development of a seasonal efficiency standard for oil burning equipment.

FACTORS AFFECTING FURNACE PERFORMANCE

There is a close relationship between the house and the heating system, with the the relationship similar to the fundamental one of economics - demand and supply, as seen in Table I. On the left hand side are the demand factors - the reasons why heat is required; on the right hand side are the supply factors - the ability of the heating system to supply the heat.

Demand is controlled by the inside temperature requirement (the thermostat) and the colder outside temperature.

At the same time, the house is constantly losing heat in two basic areas, transmission losses and ventilation losses. Transmission losses are losses through the fabric of the structure. Ventilation losses are due to the passage of air through holes in the structure. The common ventilation loss is the infiltration/exfiltration through cracks (around doors, windows, etc.). A second component is directly attributable to a fossil fuel furnace. When the furnace is off, there is a large direct opening to the outside via the chimney, through which warm air from the house and the furnace heat exchanger can escape.

The supply, or performance, factors measure how well the heating system can supply the heat required. Three aspects must be considered:

(i) steady state efficiency is the measurement with which industry is most familiar. However, it takes furnaces 4 to 14 minutes to get to steady state from the time that the thermostat calls for heat and the burners begins firing. Until then the furnace is in the ...

(ii) transient state. In general, most physical systems work much more efficiently in steady state. Just imagine your car. You use much more gasoline per kilometer accelerating and decelerating around town than you do cruising on the highway. Similarly, a furnace is much more efficient at steady state than in the transient condition.

(iii) dilution air through the draft dilution device (barometric damper on oil) accounts for a much larger air requirement and heat loss than does the air actually required for combustion - anywhere from 2 to 10 times the latter. The main purpose of this device is to isolate the burner from outside pressure fluctuations. New technologies such as induced draft fans or very high pressure drop burners may eliminate the need for air dilution and the losses and problems entailed therein.

Figure 1 shows the effects of both the transient heat exchange and dilution for a furnace in a real house. The top two curves are for temperature and carbon dioxide (CO_2 - a measure of the excess air requirement) before dilution, and the bottom two are for the same two parameters after dilution. 8% CO_2 represents 100% excess air and 1.7% CO_2 represents about 800% excess air, a dramatic difference.

Figure 2 presents consumptions over time for two similar-sized houses with nominally-comparable insulation levels, but with house A built with superior workmanship by the owner, having almost half the other's consumption. Both consumption rates follow outside temperature variations closely, effectively linearly. Expressed in another way, consumption rises in a straight line to the right when plotted against increasing degree days (decreasing outside temperature).

ENERGY CONSERVATION STRATEGIES

Thermostat Cutback

Thermostat cutback, an effective way of lowering heat demand, moves the consumption curve (straight line) parallel to the right, giving less consumption for any specific outside temperature (or inside temperature differential). A similar result occurs if insulation is added to the house to improve the thermal envelope.

Improved Furnace Performance

Just as for reduced demand, improving furnace efficiency moves consumption curve parallel to right, giving less consumption for any specific temperature differential. In a sample case, changing to a flame retention head oil burner resulted in an overall fuel saving of about 20% (3).

OIL FURNACE TECHNOLOGY

Conventional Oil Furnaces

Most conventional oil furnaces have a cast iron head-type burner, with fairly low pressure drop across it, operating at high excess air levels of about 100%, a flue gas temperature of 315oC (4) and a barometric damper with its large dilution air requirement. The latter is obviously a major loss of heated house air up the chimney, both when the furnace is running and when it is not. Over the heating season, a typical furnace will only be on for about 20% of the time.

Generally, conventional oil furnaces operate with a seasonal efficiency of 60% or less, although their steady state efficiency may be 75% or above.

Reduced Firing Rate

For a conventional furnace, lowering firing rate to make the furnace more in tune with home heat demands makes little effect at mild temperatures but has an increasing effect on fuel efficiency as the temperature gets colder, so that the consumption profiles diverge and savings increase with decreasing outside temperature. Fuels savings of as high as 10% have been measured in homes, even when the steady state efficiency was slightly decreased (3).

Vent Damper-Equipped Furnace

This type of furnace has a damper which is driven by a signal from the thermostat. It is located in the flue exhaust, downstream of the furnace heat exchanger and draft dilution device, closing the flue when the burner is not operating and opening before the burner ignites.

Contrary to effect of reduced firing rate, savings with the chimney damper are greatest when climate is mild and decrease as it gets colder, where the consumption profiles converge. However, the effect of the damper is almost negated if a fossil-fuel water heater also uses the same chimney, if the delay time on closing is too long or if the bypass opening is too large. Fuel savings are generally from 3% to 11%, with seasonal efficiencies from 62-68%, even though there is no difference in steady state efficiency.

Flame Retention Head Burner

This is a higher pressure drop burner which promotes better mixing of the fuel and air, allowing operation at lower excess air levels (typically about 40%). Aside from giving improved furnace steady state efficiency, the increased flow resistance it provides lessens the off-cycle air flow through the furnace, so that cycling performance is improved as well. The better mixing and range of heads available allows significant reductions in firing rate to further improve seasonal performance. CCRL has developed a retrofit flame retention head burner, and has produced a manual describing it and other conservation strategies (5). This manual describes in detail what makes heating systems efficient, with particular emphasis on the technology of oil-fired systems. It is recommended as background material for anyone concerned with designing or building homes with fossil fuel-fired heating systems.

OIL FURNACE ADVANCES

New developments are yielding more efficient oil furnaces with positive venting of combustion products and no dilution requirement, which will be safer and from 10% to 20% more efficient than even the flame retention head burner systems, or as much as 37% more efficient than conventional oil or gas furnaces.

Induced Draft (ID) Fan Furnace

The induced draft fan furnace has a fan downstream of the furnace proper which pulls the gases from the furnace and propels them up the stack. Downstream of the ID fan there needs only be a small opening (2 cm diameter) so the unit also operates as if it had a chimney damper on the off cycle. This system eliminates the barometric damper with its large air requirements and can improve the seasonal oil furnace efficiency to about 90%, without condensing. Fuel savings of the induced draft fan furnace relative to a conventional furnace would be from 15% to 25%, depending on the furnace design. Most of this type of appliance design should yield savings closer to the high end, and seasonal efficiencies on the order of 88%.

Compared to a flame retention head-equipped furnaces, savings would be at least 10%, even though the steady state efficiencies could be the same.

Additional benefits are powered exhaust, much lower air requirements and a safety shutoff in the event of flue blockage or reversal. Knowing the exact quantity and temperature of flue gas to be delivered to the chimney base allows proper sizing of the chimney to ensure adequate draft with no danger of condensation in the system.

Hydrogen Content of Fuels

Number 2 oil and natural gas both contain hydrogen which, on combustion, goes to water vapour, tying up energy in the form of latent heat. In comparison to oil, natural gas has twice the hydrogen content, resulting in a "hydrogen loss" of about 12%, making its flue gases much more moisture-laden than oil; hence the requirement for a chimney liner on conversion to gas in order to avoid condensation, damage and even ice bridging in masonary chimneys. This also accounts for the fact that conventional furnaces and boilers have a lower efficiency when fired with gas than with oil.

Condensing Oil Furnace

This type of furnace makes a conscious effort to recover some of the latent heat described above, by condensing some of the moisture from the flue gases in an additional heat exchange section.

Because the flue gas temperature is so low with any condensing furnace, no chimney is required. The flue gas is merely carried in a plastic pipe to a exhaust vent on the outside wall of the house.

Contrary to conventional furnaces, the shorter the cycle length of a condensing furnace, the more water is condensed (6), due to cold furnace walls, and the higher the efficiency. This type of furnace generally has a seasonal efficiency very similar to its steady state efficiency, with transient effects negligible.

With oil containing much less hydrogen, the potential for efficiency improvements by condensing the flue gas is much lower than for gas - the dewpoint is lower, so you have to work harder to condense less. Also, with much higher sulphur levels, the condensate is more corrosive, so that any condensing heat exchanger for oil must be even more resistant. The fact that oil combustion also produces a certain amount of soot, which can concentrate the acidic condensate at certain points on the heat exchange surface, makes things even more difficult. Thus a condensing furnace may not be the best way to achieve high efficiency with oil. However, both the induced draft fan and condensing oil furnaces offer major efficiency advantages over conventional existing appliances, much more than can be seen merely by the differences in their steady state efficiencies.

COMPARISON OF DIFFERENT TECHNOLOGIES

Table II presents the steady state and estimated seasonal efficiencies for the the different oil technologies discussed above. In particular, there is a significant difference between the two efficiency values for present technologies, the resulting in a serious overestimation of the real end-use efficiency. On the other hand, the newer technologies of induced draft fan and condensing bring these two numbers much closer together, while their large efficiency advantage in comparison to present equipment is not apparent when one looks only at the steady state numbers.

SUMMATION

As has been seen in this paper, the potential for major reductions in fuel consumption through research and development in residential oil heating system technology is high, with continuing efforts required to achieve the required goals.

On the other hand, the present technique to measure efficiency of oil furnaces in Canada is based only on the steady state performance, grossly overestimating the efficiency of older technologies in comparison to the ones now reaching the market.

In particular, oil furnaces which can operate at fairly low excess air levels and eliminate the draft dilution device may operate at seasonal efficiencies near to those of condensing gas furnaces, without the additional costs and complexities of actually condensing the combustion products. Using the steady state efficiency as the standard of comparison, such furnaces would not show their real fuel economy advantages. They would compete at an unfair disadvantage in comparison to conventional oil technology or to gas-fired equipment, likely suffering in the marketplace as a result. Realization of this might even prevent a manufacturer from placing such equipment on the market in the first place. This would be a shame, considering that such equipment is likely to be much safer in the event of chimney problems, and more suitable for tighter housing because of their low air requirements.

IT IS RECOMMENDED THAT CSA PROCEED AS SOON AS POSSIBLE WITH THE DEVELOPMENT OF A SEASONAL EFFICIENCY STANDARD FOR OIL FURNACES, USING THE RECENTLY DEVELOPED CGA STANDARD FOR GAS FURNACES (2) AS A MODEL, TO ENSURE CANADIAN COMPATABILITY AND EASE OF DEVELOPMENT.

REFERENCES

1. Kelly, G.E., Chi, J. and Kuklewicz, M.E.; "Testing and Calculation Procedures for Determining the Seasonal Performance of Residential Central Furnaces and Boilers"; National Bureau of Standards and U.S. Department of Energy; NBSIR 78-1543; October 1978.

2. CGA P.1 Committee; "Standard for Determining the Seasonal Gas Utilization Efficiencies of Gas-Fired Central Furnaces"; Canadian Gas Association; October, 1984.

3. Hayden, A.C.S., Braaten, R.W. and Brown, T.D.; "Oil Conservation in Home Heating"; ASME Journal of Engineering for Power, Vol. 99, Series A, No.3; July 1977.

4. Hayden, A.C.S. and Braaten, R.W.; "Domestic Oil Heating System Retrofit to Save Energy"; Proceedings, Symposium on New Energy Conservation Technologies; International Energy Agency; Berlin; April 1982.

5. Hayden, A.C.S. and Braaten, R.W.; "Efficient Residential Oil Heating Systems - a Manual for Servicemen, Designers and Builders"; EL 79-8; Energy, Mines and Resources Canada; Ottawa, 1980.

6. Hayden, A.C.S., Palmer, C.E. and Braaten, R.W.; "Performance of Condensing Gas-Fired Systems"; Proceedings, International Symposium on COndensing Heat Exchangers; Atlanta, Georgia; March 1982.

Table I. Factors affecting furnace performance.

Demand Factors (House)		Performance Factors (Heating System)
Heat Requirements	Heat Losses	
- Thermostat	- Transmission	- Steady State Efficiency
	- Infiltration	- Transient Operation
	- Downtime Losses	- Dilution Air

Table II. Comparison of oil furnace technologies.

Furnace Type	Steady State Efficiency	Fuel Savings re Conventional	Seasonal Efficiency
Conventional	73%	base	60%
Chimney Damper	73%	3-11%	62-68%
Flame Retention Head Burner	78-84%	10-20%	67-75%
Induced Draft (ID) Fan	75-88%	20-32%	75-88%
Condensing Furnace	85-95%	29-37%	85-95%

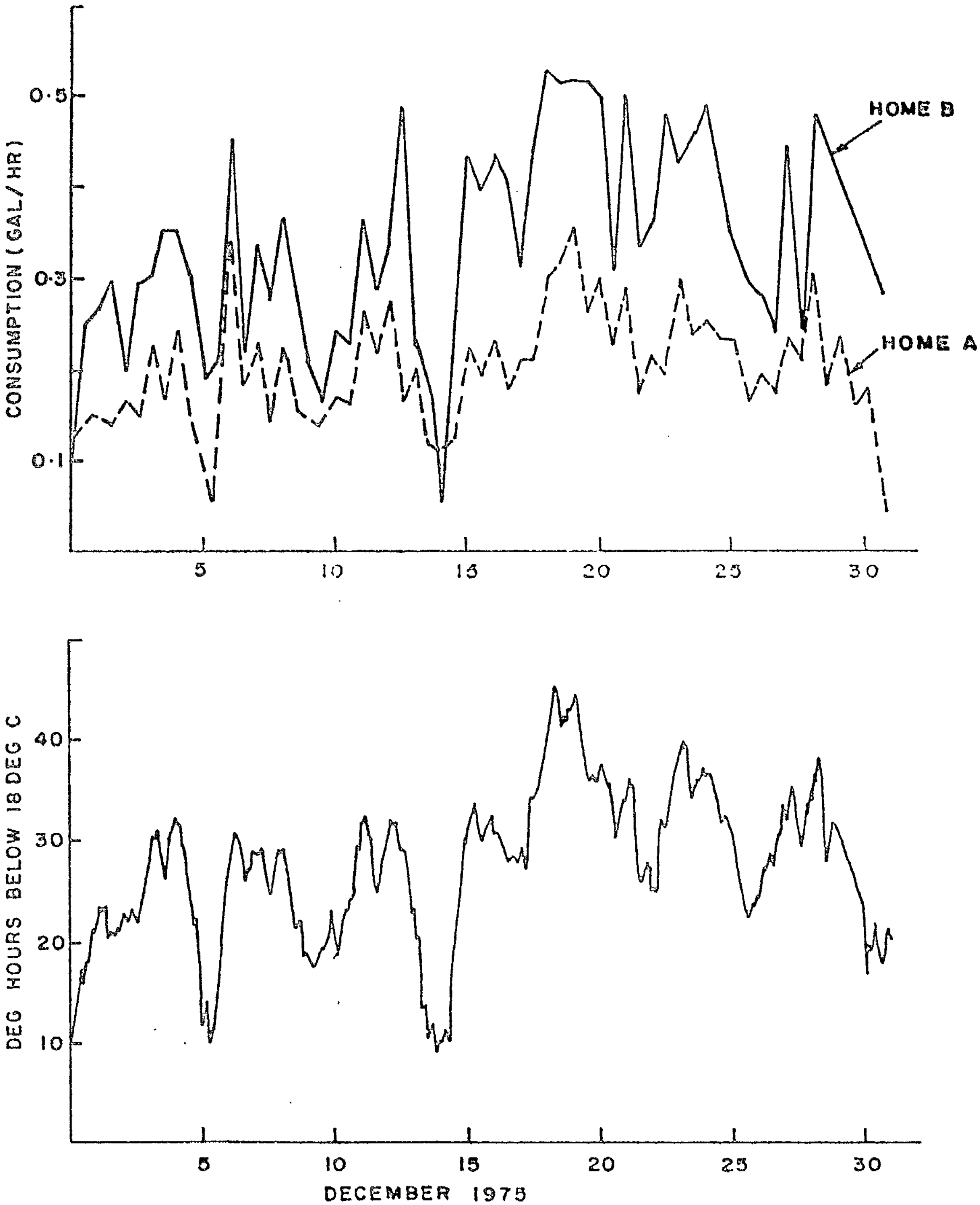

FIGURE 2 THE EFFECT OF EXTERNAL TEMPERATURE
ON FUEL CONSUMPTION
HOMES A AND B

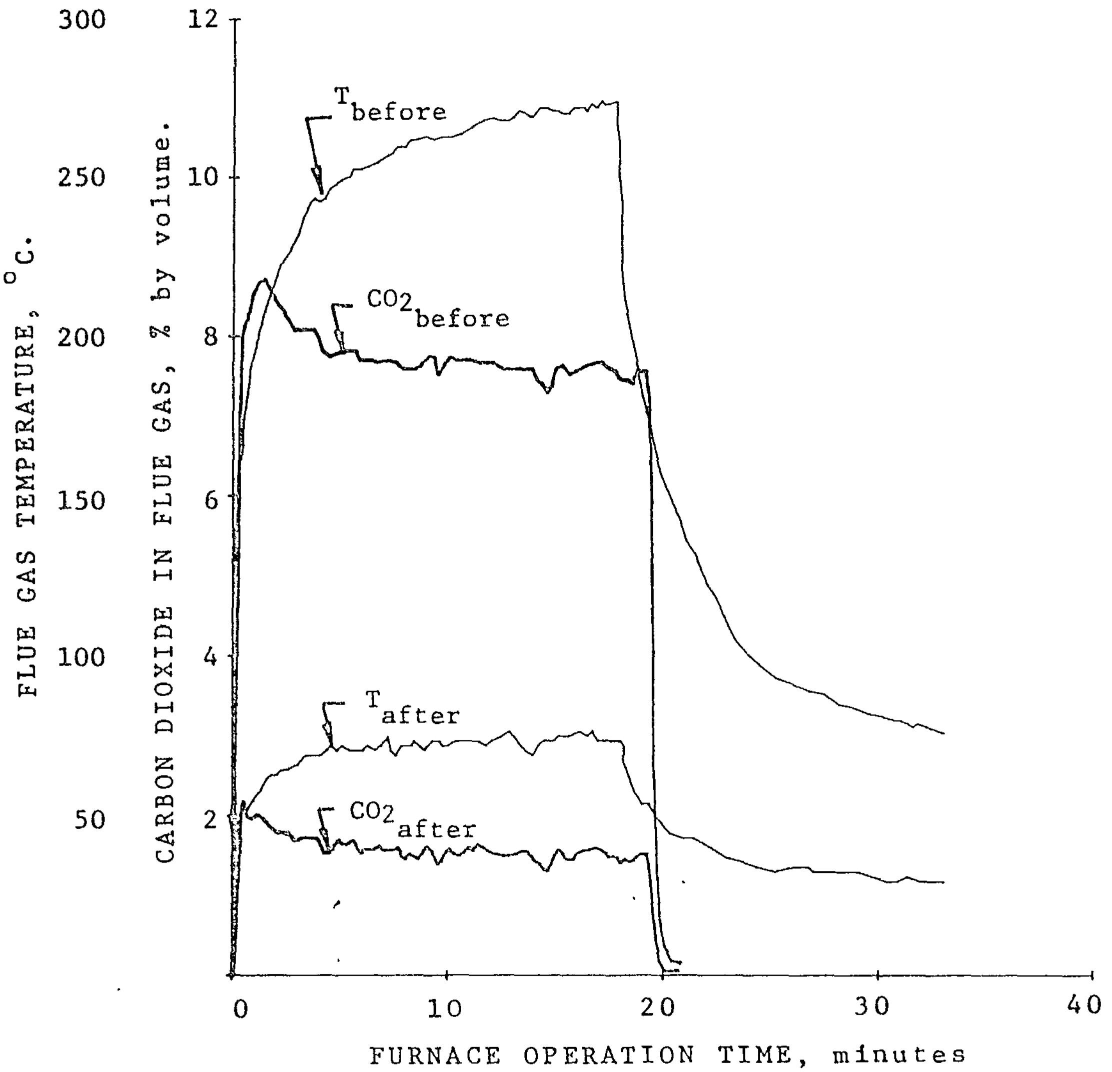

Figure 8. Effect of dilution on flue gas temperature and composition, House C.