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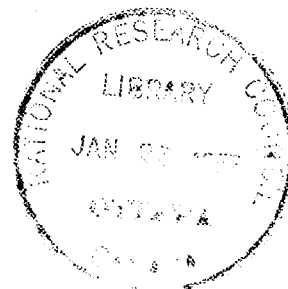
# BUILDING WORK

ANALYZED

## HOUSE HEATING EQUIPMENT

by

A. Grant Wilson



DIVISION OF BUILDING RESEARCH • NATIONAL RESEARCH COUNCIL • OTTAWA, CANADA

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## HOUSE HEATING EQUIPMENT

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### FUNCTION OF HEATING SYSTEM

The heating system operates in combination with the building enclosure, that is, the walls, windows, doors, floor and ceiling, to provide thermal conditions inside a building differing from those outside during the heating season. Thus the degree to which these inside conditions are "comfortable" depends on both the performance of the heating system and the thermal characteristics of the building.

Although thermal comfort is a subjective reaction and depends on all external factors affecting the body heat balance, in practice the performance of a house heating system with respect to comfort in Canada and the U.S. usually refers to the uniformity of temperatures that is produced in the living zone, including floor surface temperatures, and the degree to which the living zone is free from objectionable drafts. Thus, in these terms, the smaller the variations in temperature vertically and horizontally, and from room to room, regardless of outside temperature conditions the greater the general level of comfort provided by the heating system.

A heating system should not only provide an acceptable level of comfort during the coldest weather conditions, but it should function economically, both with respect to first and operating costs; it should be reliable and it should not constitute a health or fire hazard.

### TYPES OF HEATING SYSTEMS AND THEIR SELECTION

There are many different ways of classifying the heating systems available for house heating. Heating systems vary with respect to such factors as the type of fuel burned (solid, liquid, or gaseous) with respect to the type of heating medium (air, water, or steam) and its method of circulation (gravity or forced) and with respect to the type of distribution system. Details of all these variations in type will not be dealt with in this note but it might be useful to look very briefly at some of the factors as they may influence the selection of the system.

In selecting the type of fuel, availability and reliability of supply are naturally of first concern. Under special circumstances consideration of this factor may lead to the selection of a unit which can burn more than one fuel. Usually, however, reliability of supply is not a problem and the main factors to consider are convenience and economy. Considerations of convenience are largely personal. The matter of economy, however, is subject to calculation.

The method of calculation most often used utilizes degree-day data. The degree-day is a climate factor which correlates with the heat requirements of buildings and is used, for example, by fuel suppliers to determine when fuel deliveries are necessary. The degree-days for any one day are obtained by taking the difference between the average temperature for the day and 65°F. The degree-days for any period are obtained simply by cumulating the degree-days for each day.

The calculation to obtain the fuel consumption for a house for any period is relatively simple and normally provides an estimate sufficiently accurate for purposes of comparison. In order to make such a comparison it is necessary to know, in addition to the degree-days for the period, the efficiencies of the heating units, the heat content per unit of the fuels, the cost per unit of the fuels, and the hourly heat loss of the house under design temperature conditions. The formula then becomes:

$$\text{Fuel cost for period} = 24 \times \frac{\text{hourly design heat loss of house}}{\text{design temperature difference}} \\ \times \frac{\text{degree-days for period}}{\text{efficiency of heating unit}} \times \frac{\text{cost per unit of fuel}}{\text{heat content per unit of fuel.}}$$

The relative costs of heating with different fuels may be known from local experience. However, when new fuels or sources of energy are suggested or become available for house heating in an area there are often conflicting opinions as to costs relative to fuels in common use, which can be resolved by calculation using this relationship.

All of the information required for the calculation is readily available except the hourly design heat loss at the design temperature difference. This requires a separate calculation and is generally considered independent of the type of heating system or fuel used. The design heat loss of the house in British thermal

units (B.t.u.) per hour can be readily determined by a heating engineer. The trade associations in both the warm air and steam and hot water heating industries have published manuals covering this type of calculation and it is carried out regularly by many of their members.

By way of illustration Table 1 gives the degree-days per year for some Canadian cities, Table 2 gives a range of typical efficiencies for different heating units and Table 3 gives the heat content per unit for some fuels. Data in Tables 1 and 2 have been taken from the A.S.H.A.E. 1956 Guide. The data in Table 3 on oil and gas have come from the same source while those for coal were obtained from the Dominion Coal Board. With direct electrical heating an efficiency of 100 per cent can be assumed. There are 3415 B.t.u. per kilowatt-hour.

Table 1  
Average Yearly Degree-Days

Vancouver, B.C.	5,230	Ottawa, Ont.	8,830
Victoria, B.C.	5,410	Montreal, Que.	8,130
Edmonton, Alta.	10,320	Quebec City, Que.	9,070
Calgary, Alta.	9,520	Fredericton, N.B.	8,830
Regina, Sask.	10,770	Saint John, N.B.	8,380
Saskatoon, Sask.	10,960	Halifax, N.S.	7,570
Winnipeg, Man.	10,630	Sydney, N.S.	8,220
Churchill, Man.	16,810	Charlottetown, P.E.I.	8,380
Toronto, Ont.	7,020	St. John's, Nfld.	8,780

Table 2

Approximate Seasonal Efficiencies (per cent)

Gas, designed unit	75-80	Anthracite, hand fired	60-80
Gas, conversion unit	60-80	with controls	
Oil, designed unit	65-80	Anthracite, hand fired	50-65
Oil conversion unit	60-80	without controls	
Bituminous coal, hand fired		Anthracite, stoker fired	60-80
with controls	50-65	Coke, hand fired with	60-80
Bituminous coal, hand fired		controls	
without controls	40-60	Coke, hand fired	50-65
Bituminous coal, stoker		without controls	
fired	50-70		

Table 3

Approximate Calorific Values of Heating Fuels

<u>Oil</u>	Number 1	138,800 to 132,900 B.t.u. per U.S. gallon *
	Number 2	144,300 to 135,800 B.t.u. per U.S. gallon *
<u>Gas</u>	Natural gas	1129 B.t.u. per cu. ft.
	Propane commercial (natural gas)	2558 B.t.u. per cu. ft.
	Butane commercial (natural gas)	3210 B.t.u. per cu. ft.
<u>Coal</u>	Maritime bituminous	13,500 B.t.u. per lb.
	U.S. Anthracite	13,200 B.t.u. per lb.
	Drumheller bituminous	10,000 B.t.u. per lb.
	Edmonton bituminous	9,000 B.t.u. per lb.
	McLeod River bituminous	11,000 B.t.u. per lb.

\* To obtain heating value in B.t.u. per Imperial gallon multiply by 1.2

In choosing the heating medium, (air, water, or steam) cost is usually the major factor, since there need be little difference in convenience or comfort attributable to the heating medium. When proper design procedures are used it is now possible to achieve a relatively high degree of refinement in comfort conditions regardless of heating medium. Other things being equal the choice of heating medium then depends on the relative cost of the level of comfort desired.

Whether a system uses forced circulation or gravity circulation is a matter of balancing cost versus comfort, other things being equal, more refinement in comfort can be achieved when positive circulation is employed. There may be other factors influencing the choice of heating medium - for example forced hot water systems may provide lower noise levels than forced warm air systems while forced warm air systems readily permit humidification. However these factors are generally subordinate to cost.

As stated previously, heating systems are sometimes classed as to distribution system - that is, the manner in which the heat is transported and given to the room. The type of distribution system to use to achieve a given level of comfort possibly depends more on structural details than on other factors. Conversely, the degree of comfort attained with certain types of structures depends to a large extent on the type of distribution system used. For example, with a slab on grade structure it becomes necessary to introduce heat into the slab, particularly at the perimeter of the building, if reasonably good comfort conditions are to be attained. This suggests a panel or a perimeter type of distribution system. Similarly, with a house built over a crawl space it becomes necessary to introduce heat to the floor and at the perimeter of the building to produce relatively good comfort conditions. In the cases just cited other types of heat distribution may provide a much lower level of comfort and in balancing cost against comfort the choice may be between very good and very poor comfort conditions. In a house with heated basement and well insulated walls, on the other hand, the manner in which the heat is introduced to a room may not be so critical with regards comfort. If the walls are poorly insulated or if there are large window areas, however, the manner of heat distribution again becomes critical with respect to comfort and for relatively good comfort conditions the heat must be introduced at the source of high heat loss.

## SYSTEM DESIGN

In the foregoing an attempt has been made to deal very generally with some of the factors that may influence the selection of one type of heating system or another. Regardless of how carefully the system is selected there will be no guarantee of achieving the desired results unless the system is properly designed. The proper engineering design of house heating systems cannot therefore be over-emphasized. This is usually the responsibility in the first instance of the heating contractor, unless a qualified engineer is employed, but ultimately the performance of the system becomes the responsibility of the house builder. This does not mean that the house builder need know the details of heating system design procedure but he should know what is generally involved.

There is no longer any reason to accept anything but a properly designed system since the trade associations in both the warm air and hot water and steam heating industries have made available to their members design manuals that are based on sound engineering principles. Further courses are given to the membership on the proper use of these design manuals and on the latest developments in the trade.

The design of the system, once it has been selected as to type involves certain other definite steps. The heat losses of each room, for the winter outdoor design temperature of the locality, must be calculated. To do this the construction of the outside walls, roof and floor and the details of windows and doors must be known so that the proper heat loss factors for the determination of heat losses by both heat transmission and air leakage can be selected. The sizes and locations of the registers, radiators, convectors or other means of introducing heat to the rooms must then be selected. The calculated heat loss for each room is then used in properly sizing the other components of the heat distribution systems so that each room will receive the proper amount of heat. This is the only way to ensure that each room can be adequately heated.

The total calculated heat loss for the house is then used in selecting the proper size of heating unit. Here again proper sizing is most important. The results of under-sizing are obvious. The unit if operated normally will fail to bring the house to the desired temperature during periods of cold weather. This will often result in forcing or over-firing of the unit, with consequent reduction in service life, increase in fuel and repair costs, and



the creation of a fire hazard. The results of over-sizing of units within limits are not usually so serious, particularly if the rate of firing can be made correct for the house. The major disadvantage may be a higher than necessary first cost and, in general, less satisfactory comfort conditions than with a properly sized unit.

#### UNIT CAPACITY AND EFFICIENCY

The size or capacity of a unit in general refers to the quantity of heat available for space heating, usually at the outlet from the unit. The capacity rating of a unit is determined in some cases from empirical rating equations as with solid fuel-fired warm air furnaces and some hot water boilers. In other cases the capacity rating is determined by test. With oil and gas fired warm air furnaces there is such a variety in design that each type must be tested to obtain a proper rating.

At present, in Canada, there are no generally accepted standards for the rating of warm air furnaces although work has been done toward the development of such standards. In any test for capacity there are various criteria used to determine the maximum permissible fuel input. For example limits may be placed on the maximum allowable temperature of furnace components and of flue gas temperature or on the maximum temperature rise of the heating medium. Test conditions under which these are obtained must be carefully specified and, if comparisons are to be made, standardized. The heat output obtained at the firing rate which results in any of these limiting temperatures might be considered the rated capacity. For example, 1000°F. is considered the maximum allowable operating temperature of the steel often used in manufacturing furnace bodies. The rated capacity then should be no higher than that which is obtained at a firing rate which results in this limiting temperature being reached. If the firing rate were increased beyond this point the unit would provide more heat but safe operating temperatures for the furnace components would be exceeded. It is thus important that the unit should have specified a maximum firing rate and that it should not be exceeded.

Another factor commonly referred to, and sometimes not altogether understood, by the home owner is the efficiency rating of a heating unit. Efficiency is merely the percentage of the total heat content of the fuel burned that is available for heating the home. Because there are different ways of defining

what heat is available for heating the home there are different kinds of efficiency. Two efficiencies commonly referred to in the case of warm air units are combustion efficiency and bonnet efficiency. The combustion efficiency considers that only the heat in the flue gas entering the smoke pipe is not available for heating. The bonnet efficiency considers that heat escaping from the furnace casing is also not available for heating the home - in other words, that only the heat in the air leaving the bonnet is available for heating the house. Furnace casing loss is often of the order of 3 to 5 per cent, in which case the combustion efficiency would be that much higher than the bonnet efficiency.

The combustion efficiency is the most readily measured since it involves only a knowledge of flue gas composition and temperature, along with the chemical composition of the fuel. The former are readily measured and the latter is usually available in hand books. With oil or gas firing, combustion efficiency depends on these three factors only - the amount of air admitted to the furnace for combustion purposes in excess of that theoretically required, the completeness of combustion, and the amount of heat extracted from the flue gases before they leave the unit. The amount of air admitted should be such that essentially complete combustion occurs - under these conditions there will be little or no smoke in the flue gas. In order to obtain the combustion efficiency it is then only necessary to determine the extent of excess air admitted to the furnace and the degree to which the heat in the flue gases has been extracted before leaving the unit. The percentage of  $\text{CO}_2$  in the flue gas is commonly used as an index of excess air and the temperature of the flue gas is used as an index of heat extraction. Knowing these two factors along with fuel composition it is then possible to calculate combustion efficiency. Graphs of the relationship between  $\text{CO}_2$ , flue gas temperature, and efficiency are available to simplify the determination. These graphs will show that efficiency increases with increasing percentage  $\text{CO}_2$  (so long as combustion is complete) and with decreasing temperature.

There are definite practical limitations in the efficiency that can be obtained. For example, the theoretical maximum percentage  $\text{CO}_2$  in the flue gas for oil firing is 16 per cent. This is the  $\text{CO}_2$  that would occur if no excess air were required for complete combustion. In practice considerable excess air is required for complete combustion and a percentage  $\text{CO}_2$  of 10 to 12 per cent is seldom exceeded in oil firing without incomplete combustion, as indicated by the formation of smoke.

Similarly there are practical limitations in how much the flue gas temperature can be reduced. With modern oil and gas-fired units flue gas temperatures as low as 400°F. or 500°F. are not uncommon - some gas burning units and a few oil burning units may provide flue gas temperatures as low as 300°F. at rated capacity. However, even temperatures as high as these may sometimes lead to difficulties associated with low flue gas temperatures. These difficulties are usually with respect to venting of the flue gases and are thus associated with the chimney. Very low flue gas temperature may lead to conditions of inadequate or fluctuating draft and to condensation on chimney surfaces of the water vapour in the flue gas.

Reference to curves giving the relationship between CO<sub>2</sub>, temperature, and combustion efficiency for oil firing will show that with a CO<sub>2</sub> of 12 per cent and a flue gas temperature of 400°F. the loss in the flue gas is 15 per cent, corresponding to a combustion efficiency of 85 per cent - allowing 3 to 5 per cent for casing loss this corresponds to a bonnet efficiency of 80 to 82 per cent. Efficiencies higher than this are possible but would be unusual and, if quoted should be accompanied by substantiating evidence. It should be kept in mind that the efficiency of a unit will vary with the fuel input and the efficiency quoted should be that obtained at the rated capacity. Tests on several oil-fired furnace units manufactured and sold in Canada have shown that at fuel inputs corresponding to rated capacity some units will have flue gas temperatures of the order of 700°F. With a CO<sub>2</sub> of 12 per cent this corresponds to a combustion efficiency of 75 per cent and a bonnet efficiency of something less.

With warm air units fired with gun-type oil burners, efficiencies in general decrease with increasing firing rates. Thus it is possible to misrepresent the characteristics of a unit by quoting efficiencies for firing rates less than those corresponding to the rated capacity. Units fired with vaporizing burners often show an increase in efficiency with firing rate. At the higher firing rates vaporization of the oil is generally more complete with better mixing of air and oil so that less excess air is required for smokeless combustion. In this case it is possible to misrepresent the characteristics of a unit by quoting efficiencies for firing rates greater than those which will generally occur when the unit is installed. This indicates that only efficiencies obtained under standardized test conditions are useful for purposes of comparison.

## CHIMNEYS

In referring to the practical limitations in reducing the flue gas temperature of a heating unit reference was made to chimneys. The flue gas venting system, including the chimney is of course another important component of heating systems and a subject to which this whole discussion on heating systems could usefully be devoted.

In considering the performance requirements for chimneys one important fact that must be recognized is that chimneys are an integral part of the heating system and particularly the heating unit. As further refinements are made in the development of furnaces and boilers it becomes increasingly necessary to think of the performance of one in relation to the other and it becomes increasingly important therefore for the heating contractor to be concerned with chimney design and location. The day may come when chimneys will be matched and sold with the heating unit.

Minimum constructional requirements for masonry chimneys are usually laid down in building codes and standards and even minimum flue sizes are sometimes specified. The location of the chimney however, is a matter of choice, one which unfortunately is often made solely on an aesthetic basis. Fortunately, due to the improvements in heating system design this does not often result in serious difficulty and perhaps the main factor regarding location which does give trouble is the placing of masonry chimneys on outside walls. Not only does this subject the chimney construction to all the stresses imposed on outside walls but in addition makes it difficult for the chimney to carry out its main function of providing adequate draft for the proper operation of the heating unit. The draft provided by the chimney is dependent on the difference between the average temperature of the flue gas in the chimney and the outside temperature. With chimneys on outside walls high heat losses from the flue gas to outside result and the average temperature of flue gas in the chimney is reduced proportionately. The Division has recently been involved in field investigations of venting difficulties being experienced with new coal-fired warm air systems, both here and in the Niagara peninsula. These difficulties were the result of poor draft conditions directly attributable to the locating of the chimneys on outside walls and occurred at low firing rates during relatively mild weather.

There is probably less likelihood of similar venting difficulties with liquid and gaseous fuels since, except for certain vaporizing burners, firing rates during "burner-on" periods are usually high regardless of weather conditions. However, as

mentioned, flue gas temperatures with many modern furnaces are already quite low and the heat losses with outside chimneys may be sufficient to produce condensation on the inside of chimney flues. This will be an increasing problem as the efficiencies of furnaces are increased. Condensation problems with the burning of gas are more acute than with oil and one can envisage some difficulties with outside chimneys in existing homes converted to gas firing when natural gas becomes available. Some of the problems experienced with masonry chimneys and fireplaces are known to result from poor workmanship. Bricks and chimney liners may be improperly mortared. Broken bricks and liners are sometimes used. Special care should be taken to avoid such practices since they may result not only in difficulties with heating system operation but in loss of life and property.

#### INSTALLATION OF HEATING SYSTEMS

If the heating contractor has used proper engineering design procedures in laying out the system and follows this design in his installation it is very likely that the system will provide satisfactory heating. However, seemingly small changes in the layout of a system from the original design during installation can cause real difficulties. As a simple example, suppose that in installing a warm air branch duct it was found necessary to go over a beam and down again with four 90° sharp elbows and that this had not been realized in the original design. The length of straight duct assumed in the design covering the same horizontal distance as the four elbows might have been only two feet whereas the four elbows would have a resistance to flow equivalent to 125 feet of straight duct. This might be of the same order as the equivalent length originally assumed for the entire branch. This doubling of the effective length of the branch would cause an appreciable reduction in air flow through the branch and might lead to underheating of the room being served. If the elbows were taken into account in the original design or if the design were corrected to meet job conditions the possibility of underheating from this cause would, of course, not arise.

Changes in construction from that assumed in calculating heat losses and sizing the distribution system can also lead to difficulties. For example, on site changes in size and type of windows could easily result in doubling of the heat loss of a living room with the possibility of underheating. Sometimes after construction has begun it is decided to build a room over an attached garage and it is not unusual for such rooms to be underheated as a result of failure to redesign the heating system.

This merely serves to emphasize the importance of a knowledge of engineering design principles by the heating contractor.

#### CLEARANCES TO COMBUSTIBLE CONSTRUCTION

Most municipal codes and CMHC standards have definite clearance and mounting regulations for components of the heating system. Clearance and mounting requirements have increased in importance and complexity with developments in heating equipment and the trend toward smaller homes with greater utilization of space.

Most codes and standards, including the National Building Code and Central Mortgage and Housing Corporation Standards, have followed published requirements of the National Fire Protection Association and the National Board of Fire Underwriters. These describe standard clearance and mounting arrangements which are acceptable. Responsibility for decisions with respect to non-standard arrangements, therefore, are usually left, in municipal codes, to the discretion of the building inspector or other authority having jurisdiction. This has placed a difficult responsibility on the building inspector in view of new developments in heating equipment and practice. This situation is being relieved somewhat by the development of equipment safety standards through both the Canadian Standards Association and the Underwriters Laboratories of Canada. Thus it will be possible for the building inspector to refer to these standards, when published, in determining the acceptability or otherwise of arrangements not presently covered in most municipal building codes.

The Canadian Standards Association Laboratory and the Canadian Underwriters Laboratory both carry out tests with respect to the safety of heating units and label these units as meeting their laboratory requirements. These labels thus do not indicate anything with respect to the efficiency of a unit. The significance of the labels of these organizations will be more apparent when the standards which they follow are published.

#### ADJUSTMENT OF HEATING SYSTEMS

Many of the potential advantages of careful selection, design and installation of the heating system will not be realized if the system is not properly adjusted by the heating contractor after installation. For automatically-fired forced circulation systems this should include both adjustment of the burner for efficient combustion and adjustment of the distribution system and controls for maximum comfort.

Adjusting burner operations for efficient combustion involves measurements of smoke,  $\text{CO}_2$ , temperature, and draft. Relatively accurate field instruments to make these measurements are now available and should be used by all heating contractors. As already noted, obtaining maximum combustion efficiency involves adjustment of combustion air supply to attain maximum percentage  $\text{CO}_2$  (i.e. minimum excess of air) but with complete combustion as evidenced by essentially smokeless combustion.

An important step in the adjustment of the distribution system with forced warm air heating involves balancing of the air flow in the branch ducts to the various rooms so that each receives its proper proportion of the heat supplied by the furnace. This is accomplished by setting of the dampers in these ducts in accordance with measured room air temperatures or measured air volumes at the registers. Comparable adjustments can be made with hot water heating systems. Where the supply registers have adjustable vanes for directing the air flow these should be set to provide the most satisfactory air flow pattern for the room.

It is generally conceded that with warm air heating the more continuous the blower operation the greater the degree of comfort achieved. One step in lengthening the blower-on periods is the adjustment of blower speed to limit air flow through the system to an optimum value. In a typical system used for winter heating only (not summer cooling) the blower speed should be set so that the rise in temperature of the circulating air passing through the furnace is approximately  $100^\circ\text{F}$ . Setting of the blower switch control is a second important step. The blower switch should be set to stop the blower at the lowest register air temperature possible without causing an uncomfortable feeling of air movement in the living zone. This may be as low as  $80^\circ\text{F}$  with some systems. The differential on the blower switch should be set so that the blower cut-in temperature is approximately  $15^\circ\text{F}$  higher than the cut-out temperature.

The trade associations in both the warm air and hot water and steam industries issue instructions on the adjustment of heating systems. Good heating contractors will therefore be familiar with proper adjustment procedures.

#### SUMMARY

It is the function of the house heating system to provide conditions of thermal comfort within the living space during the heating season. The ease with which it can overcome the heating loads imposed on it and provide conditions of comfort depends on the thermal characteristics of the building enclosure. In carrying out its prime function, the heating system should be economical, reliable and safe.

The proper selection of the type of system requires a knowledge of costs and performance characteristics since in general the selection of the type of system becomes a problem of balancing cost against comfort and convenience. To achieve an acceptable level of comfort the type of distribution system employed may be critical with certain types of construction.

In order to achieve satisfactory operation with any certainty, the heating system must be designed on an engineering basis. There is no reason to accept anything less since the trade associations in the heating field provide design manuals and courses of instruction based on engineering principles. The design of the system not only involves proper selection and layout of the system but also proper selection of the heating unit. A knowledge of the implications of heating unit capacity and efficiency is necessary. It should not be forgotten that the chimney too is an important part of the heating system to be considered in the over-all design.

Seemingly small changes in the layout of the system from that assumed in the original design which may be necessitated by job conditions can seriously affect system performance. These should be carefully watched and where necessary the design corrected to take these changes into account. Adjustment of the heating system for efficiency and heat distribution is a most important aspect of heating system installation and may mean the difference between satisfactory and unsatisfactory performance.