DOMINION OF CANADA

THE HONORARY ADVISORY COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

BULLETIN No. 6

THE HEATING OF HOUSES, COAL AND ELECTRICITY COMPARED

BY

A. S. L. BARNES

Assistant Engineer of the Staff of the Hydro-Electric Power Commission of Ontario

(With the collaboration of the Technical Staff of the Commission.)

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HEATING OF HOUSES.

Coal and Electricity Compared.

During the past few years and, perhaps, more particularly since the fuel problem has become acute in Canada, an idea appears to have been gaining ground that the immense water-powers of this great country (which by many people are vaguely considered as being illimitable) will amply suffice to meet all heating requirements; and that, in the provinces of Ontario and Quebec, especially, where water-powers are so abundant, the fact that little or no coal is ever likely to be found is of no consequence.

Electric heating has so many advantages over other methods that probably "the wish is father to the thought" that it may some day replace coal, gas, etc.

The fuel problem to-day is so serious that technical men all over the country are looking at it from every aspect; the more efficient use of coal in furnaces, the manufacture of gas from coal, peat, etc., the briquetting of lignite coal and peat, and the possibilities of electric heating have all been receiving careful attention for some time.

Unfortunately, some engineers and a few other persons, who ought to know better, have been giving out hints that sooner or later electricity would come to the rescue and solve the heating problem completely. Unquestionably, in some of the more temperate regions of the world such comparatively small amount of heating as is required may be supplied through the medium of electricity, but the situation in Canada is altogether different.

The climate of the greater part of this country is so severe in the winter that even the immense potentialities of its water-powers, if fully developed, would be altogether inadequate to cope with the demand for power for electric heating if this were fostered to any considerable extent.

An attempt is here made to eradicate, if possible, from the popular mind, this idea that electricity is destined to take the place of coal or other fuels for the heating of houses, offices, etc., on an extensive scale; and, at the same time, to indicate in what manner electric energy may be most usefully and economically applied for heating purposes.

Advantages of Electric Heating.—Undoubtedly electric heating approaches more nearly to the ideal than that obtained by any other means. Electric heaters can be designed for operating at any desired temperature, i.e., they may be arranged to work at a high temperature and give off radiant heat like a fire, or they may be designed for operation at a low temperature like a hot-water or steam radiator, and give up their heat by convection, that is, the heat is convected (or conveyed), by setting the particles of air in motion, to various parts of a room. There is no dust, smoke, smell, or noxious gas from an electric heater, no soot, ashes, or dirt of any kind, and it does not vitiate the atmosphere by using up the oxygen; the heating can be under complete and ready control by the turning of a switch, thus decreasing or increasing the number of heating elements in service or shutting off the current entirely; automatic control by means of thermostats is, of course, possible. Electric heaters can be obtained in portable form, and there is less risk of fire from electric heating than from any other method.

Difficulties Preventing the Adoption of Electric Heating on a Large Scale.

No other system of heating can claim all these advantages. What, then, are the difficulties in the way of utilizing electricity for this purpose on a large scale?

The difficulties are two, viz.:—

(*a*) The enormous amount of energy that would be required and which could be more efficiently applied to other purposes.

(*b*) The high cost of electric energy for heating as compared with other sources of heat energy.

Explanation of the difficulties.—It is necessary, in order that this bulletin may fulfil its purpose, to enter into some explanation as to the reasons why these two difficulties exist, and to show that they are by no means imaginary or insignificant.

We are here concerned with energy in three well-known forms, viz.:

(*a*) Mechanical energy.
(*b*) Thermal energy (heat).
(*c*) Electric energy.

Any one of these forms of energy is convertible into either or both of the others, i.e., under certain conditions, (*a*) may be transformed into either (*b*) or (*c*) or both; (*b*) may be converted into (*a*) or (*c*) or both; and similarly with (*c*).

A familiar illustration of the conversion of mechanical energy into heat energy is the primitive one of rubbing two sticks together to produce fire, and every one knows that hammering a bar of iron will make it warm; the mechanical energy put into the rubbing or hammering is converted into heat energy, thus raising the temperature of the wood or iron as the case may be.

The reverse action is demonstrated when the steam in a kettle of boiling water raises the lid; in this case the heat energy in the steam, which has been received from the fire, is changed into the mechanical energy required to raise the weight of the lid; all steam engines are based on this principle.

That electric energy can be converted into either mechanical or heat energy is apparent to everybody in these days through the electric motors which drive our factories and run the street cars, and in the heat generated in electric heaters, toasters, smoothing irons, etc. The electric energy for these purposes is itself derived from the mechanical energy of falling water, or from a series of transformations of the energy in fuels, such as coal, oil, etc., this series being the change, during combustion, of chemical energy in the fuel into heat energy, heat energy into mechanical energy, and this last into electrical energy.

Mechanical energy is measured by the foot-pound (ft.-lb.) that is, a pound weight raised, against gravity, through a vertical height of one foot; e.g. 35 ft.-lb. may be 35 lb. raised 1 ft., 1 lb. raised 35 ft., 7 lb. raised 5 ft., etc., so long as the weight expressed in pounds is multiplied by the height through which it is lifted, expressed in feet, the product is called foot-pounds. The horse-power (h.-p.) is a rate of doing work, and is equivalent to the performance of 33,000 ft.-lb. of work in one minute of time—whether the duration of time in which the work is performed *at that rate* be a fraction of a second, or a period of years, makes no difference to the rate; a train may go at the rate of 60 miles per hour for half a minute, at 45 miles per hour for 4 hours, and so on, and in like manner work may be performed at the rate of 7½ horse-power for 12 months or at the rate of 1,000 horse-power for two minutes, etc.

Heat energy is measured by the British Thermal Unit (B.T.U.) which is the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit (this statement is not scientifically exact but it is quite near enough for all practical purposes).

Without entering into full details here it may be stated that the fact has been established that one B.T.U. or heat unit equals 778 ft.-lb. of energy, therefore $\frac{33000}{778} = 42{\cdot}4$ B.T.U. or heat units per minute=1 horse-power. Also it has been ascertained that a pound of coal will yield from 9,000 to 15,000 B.T.U. or heat units according to the kind and quality of the coal, although in practice the whole of this energy cannot be utilized.

For anthracite, 12,500 B.T.U. may be taken as a reasonable value. Now we are in a position to calculate the heating of, say, a house, on the basis of horse-power, and so to compare it with electric energy.

Assumed Case of Heating a House by Coal, and the Horse-power Equivalent to the Coal Used.

Let it be assumed that an 8-roomed house uses 9 tons of anthracite per season of 7 months, at a cost of $10 per ton.

Assuming that a fire is burning during the whole of this period, the coal is burnt in 7 x 30 x 24 = 5040 or say 5,000 hours, which is at the rate of $\frac{9 \times 2000}{5000} = 3{\cdot}6$ pounds per hour or 0·06 pound per minute.

Since 1 pound of coal will yield 12,500 B.T.U., 0·06 pound burnt per minute will yield 750 B.T.U. and 750 x 778 = 583,500 ft.-lb. per minute;

and since 33,000 ft.-lb. per minute equals one horse-power, coal is here burning continuously at an average rate equivalent to $\frac{583,500}{33,000} = 17 \cdot 5$ horse-power.

Note that this 17·5 horse-power is the *average* rate for the season; naturally on the coldest days coal will be burnt at a much higher rate than the average.

Assume, therefore, that the maximum rate is 50 per cent greater than the average rate (it is probably appreciably more than this), then coal will be burnt at a maximum rate equivalent to 26 horse-power.

In burning coal or any fuel there is a certain unavoidable loss of heat, up the chimney, and in other ways, and tests have shown that in an ordinary house, even with the best attention, the average loss is not less than 35 per cent of the total heat energy in the coal, and it may be 50 or 60 per cent if the fire be carelessly handled. Let us say that 40 per cent is lost, then the "efficiency" of the furnace would be stated at 60 per cent, i.e. of each 100 heat units put in, in the form of coal, 60 are made use of in actually heating the house. Hence it may be said that the *useful* average power rate is not 17·5 horse-power but $17 \cdot 5 \times \frac{60}{100} = 10 \cdot 5$ horse-power, and the *useful* maximum rate is not 26 horse-power but $\frac{26 \times 60}{100} = 16$ horse-power, approximately.

On converting electricity into heat there is no loss such as takes place with coal, and the efficiency is said, therefore, to be practically 100 per cent. It follows, then, that if a house be heated by electricity we shall only require to meet the net maximum demand of 16 horse-power, as there is no lost power to be supplied. This sounds encouraging, but disappointment is in store.

Horse-power required to heat the homes of Toronto.—For example, there are about 80,000 homes in the city of Toronto; if each of these is to be heated and a demand of, say, only 12 horse-power per home must be met (probably a very conservative figure as an average for large and small homes) no less than 960,000 horse-power must be supplied for homes alone—no factories, no offices, no works, no street cars, no houses, even, will get any lighting or power from this, it is all required on the coldest days for heating homes alone, and more will be needed in proportion, as the population increases. The great Chippewa scheme at Niagara Falls only contemplates developing 300,000 horse-power for the present, and the total generated at Niagara 780,000 horse-power, and the entire maximum demand of all Toronto at present, including all power, lighting, and traction purposes is only in the neighbourhood of 125,000 horse-power.

It may be added that the 6,000,000 h. p., which represents the estimated total possible development of Ontario water-powers, is not sufficient to supply merely the existing *homes* of Ontario with electric energy for heating alone, exclusive of all other domestic, commercial, and industrial requirements.

Energy for heating required only in the winter.—A still further difficulty in supplying electric energy for heating on an extensive scale lies in the fact that all the heating is required in the winter only, and assuming that a maximum demand of 1,000,000 h. p. had to be met for supplying a city like Toronto, the load on the plant required for this purpose, throughout the summer months, would be practically nothing. In other words, for five months every year this enormous plant would be idle. Suggestions have been made that use might be made of it to supply certain industries which could be operated mainly during the summer months, but here there are two difficulties: (1) What are the industries on a large enough scale to be of any use? (2) How could such enormous undertakings afford to lie idle during the winter months when power was unavailable? The situation in this case would be just about as bad for the industries in the winter as for the electric stations, without the industries, in the summer.

Figures and statements such as the foregoing, which are based on incontrovertible facts, should once and for all answer the question in the negative as to whether the great water-powers of Canada will ever entirely solve the fuel problem in a climate such as that of Ontario and Quebec.

Cost of Heating a House Electrically at Lowest Domestic Lighting Rates.

Turning to our second difficulty, it was found above that power at an average rate of 10·5 h.-p. would be required throughout the entire season—this means that the horse-power hours (h.-p. hr.) needed are 10·5 x 7 x 30 x 24 = 52,920 h.-p. hr.

Electricity is sold by the kilowatt-hour (kw. hr.) and a killowatt equals 1·34 h.-p.; therefore, if the price per kilowatt hour be, say, 1 cent, the price per h.-p. hr. would be practically 0·75 cent, so that the season's bill on this basis, if electricity were used would be 52,920 x 0·75 = $397, the net amount would be 10 per cent less, viz., $357. People would not care to pay so large a bill for heating an 8-roomed house for a single season if they could do it for 9 x $10 = $90 by means of anthracite, even if they had the satisfaction of eliminating dust, dirt, ashes, labour, etc. The price per kilowatt hour (1 cent) assumed above is the lowest domestic rate of the Hydro-Electric Power Commission of Ontario at present available in Toronto; were it reduced to ½ cent, heating by coal would still be very much cheaper.

It has been assumed in the foregoing that the service charge for the house, at the standard Hydro-Electric Power Commission's rate of 3 cents per 100 square feet of floor area has been already paid for by the person living in it for his lighting service, and is not therefore charged against his heating account; but undoubtedly it would cost more to supply him with a maximum demand of 15 horse-power instead of, say, 1 to 5 horse-power for lighting, cooking, etc., and therefore an increased service charge would be essential; this, however, has not been reckoned in. This is very evident when it is considered that, to supply such an extra load for a large community, much larger meters, heavier overhead wires, stronger construction, bigger substations, more powerful generating stations, and increased size of equipment in every way would be required.

Cost of Electric Heating if Current be Supplied at "Power" Rates.

With a demand of such magnitude in houses as is indicated above, it is possible that supply authorities might be prepared to give service on a power schedule; hence the cost on this basis will be of interest also.

Taking, for the sake of illustration, the cheapest power rates of the Hydro-Electric Power Commission of Ontario, viz., that of Niagara Falls, Ont., the heating of a house, such as was assumed above, with a maximum demand of 12 horse-power (=9 kw.) and an average demand over the period of 715 hours per month (=5,000 hours per season) of 10·5 horse-power (=8 kw.) would work out as follows: —

Power rates:—

Service Rate—$1 per month per horse-power of maximum demand.

Consumption rates—2·2 cents per kw. hr. for the first 50 hours, monthly use of load; 1·5 cent per kw. hr. for the next 50 hours, monthly use; 0·15 cent per kw. hr. for all remaining consumption.

The gross bill subject to discounts of 50 per cent and 10 per cent.

The service charge will of necessity be spread over the entire 12 months; hence, per season, it will amount for 12 horse-power maximum demand, to $1 x 12 x 12=$144 gross. The average monthly consumption will be 8 kw. x 715 hours = 5,720 kw. hr.

The charge for electric current will be:—

450 kw. hr. at 2·2 cent..	$9 90	
450 kw. hr. at 1·5 cent..	7 23	
4,820 kw. hr. at 0·15 cent.	6 75	
Gross bill for current for one month..		$ 23 88
Gross bill for current for 7 months..		$167 16
Gross service charge (see above)..		144 00
Total gross bill for season..		$311 16
Less discounts of 50% and 10% (55%)		171 14
Total net bill for season..		$140 02

It will be seen that, while, reckoned on this basis and at the lowest existing power rates, the bill is considerably less than calculated above on the ordinary lighting rate, yet the cost of heating by electricity is, even so, more than one and one-half times that of heating with anthracite; the over-all net cost per kilowatt-hour in this case equals 0·35 cent as compared with the net lighting rate (used above) of 0·9 cent per kw. hr.

Cost of Developing a Million Horse-power.

The capital cost of furnishing a million horse-power to the city of Toronto, including hydro-electric development at Niagara Falls and all the switching and transforming equipment, together with transmission and distribution lines, etc., would probably be somewhere between $200 and $250 per horse-power to deliver electricity to the consumers' houses —this means a capital investment of from 200 to 250 million dollars. This enormous sum, owing to the fact that the plant would be idle for nearly six months out of every twelve, as already pointed out, would, during half of its existence, be earning nothing, and the services of a large number of men would, of necessity, have to be retained throughout the summer months during the non-earning period in order that they might be available when required in the winter.

Thus the capital charges and running costs of such a plant, compared with its earning capacity, would be heavy. Annual charges on such a plant covering interest, sinking fund, depreciation, maintenance and operation, would amount to from $22 to $27 per horse-power year. This plant would only be used for heating during a period of six or seven months, and the consumers would have to pay the charges for the whole year during this period.

Further, there would be no "diversity" factor enabling the supply authority to make any reduction on this cost, as is possible with ordinary existing electricity supply, since the power would be required practically continuously throughout the cold season.

By the word "diversity" is meant that condition of electricity supply whereby, owing to the diverse character of the loads and the times at which they come on and go off, the maximum load on a generating station in a given period, say, one day, is not the sum of the various maximum loads on the station during the day, *e.g.* the maximum load due to factories does not necessarily occur at the same time as the maximum load due to street car traffic, nor does the latter necessarily occur at times of maximum load due to lighting. Owing to this state of affairs, supply authorities are enabled to make their charges appreciably lower than they would be able to in the case of a winter heating load, in which the power, as already stated, would be required all the time and when one person needed extra power all the others would need it at the same time, for the same reason, viz., that the outside temperature had dropped.

Efficiency of Various Methods of Heating.

The ultimate efficiency of heating, by any method, depends on two factors: one is the efficiency of transformation of the energy in the fuel, or of electrical energy, into heat, and the other is the efficiency of application of the heat energy. For convenience, we will call these two efficiencies the physical efficiency and the efficiency of application, respectively.

The physical efficiency of electric heating may be considered as 100 per cent, while that of heating by fuels, *e.g.*, coal, gas, oil, etc., may vary from 30 to perhaps 70 per cent. The efficiency of application of either method of heating is a difficult matter to determine, as its ultimate value is only to be measured by the degree of comfort experienced by the person or persons, subjected to the heating effect in any particular case.

The point, however, that it is desired to bring out here is this: In the case of heating by fuels, engineers have still from 70 to 30 per cent physical efficiency, according to circumstances, as room for improvement (it is not likely, however, that the whole of this will ever be utilized and possibly even under the most favourable conditions, 10 or 15 per cent will always be lost, leaving from 60 to 15 per cent as room for improvement) and in efficiency of application they have further scope, but of unknown extent. In the case of heating by electricity, however, there is no room whatever for improvement in physical efficiency as that is 100 per cent already, while in efficiency of application there is the same, or possibly somewhat less room for improvement than with heating by fuels.

The fuel-heating engineers, then, have a very great advantage over the advocates of electric heating, for, should the latter, by improvements in the efficiency of application, be able to make the cost of electric heating at all comparable with other methods, the men handling the fuel-heating problems have, in a modern system, a margin for improvement (and consequent reduction of cost) in the physical efficiency, of probably 15 to 20 per cent, and as much as, or more than, electrical men, in the efficiency of application.

Besides the effect which these two efficiencies have on the relative costs of heating by fuels and by electricity, there is to be considered the relative prices of these commodities. In the case of coal and electricity dealt with above, coal at $10 per ton is very much cheaper than electricity at 0·35 cent per kw. hr.

The cost of coal would have to rise to not less than $15.50 per ton before the cost of heating by means of it equalled that of heating by electricity even at the low rate of 0·35 cent per kw. hr. (See "Cost of Electric heating if Current be Supplied at Power Rates" above.)

It is, therefore, hard to conceive of a time when electric energy will compete successfully and on a large scale with coal, oil, gas, etc., for heating.

Electric Heating Auxiliary to Other Systems, or in Mild Weather.

The use of electric heaters, however, as auxiliaries to other systems to warm up an otherwise cold room, or during chilly periods in the spring and autumn when the furnace is hardly needed, will prove in very many cases a great convenience; and, provided that the periods of use be short, e.g., for an hour or two in the morning or evening, it will be almost as economical to use electric energy in this manner as to light a fire in the furnace, and very much less trouble.

Possibilities of Reducing Cost by Electric Heating.

Again, at present rates for electric current, it is likely that considerable reductions may be made in the cost of electric heating by the judicious use of electric fans to thoroughly circulate the air from the heater and bring all parts of the room to approximately the same temperature; the extra cost of current required for a fan is very small compared with the advantage to be gained.

In one case, it is reported that satisfactory results were obtained by placing a fan, pointed slightly downwards, behind the electric radiator and blowing the warm air across the floor of the room, the effect of this is to make the warm air first circulate around the feet of the occupants of the room and it is said to give a general sense of comfort which is entirely absent when the feet are cold although the upper part of the body may be warm. This scheme is, of course, applicable to steam, water, or hot-air heating.

Any method of improving the circulation of air in a room will result in greater comfort, provided that the creation of draughts is avoided, as the general tendency of comparatively undisturbed air is to arrange itself in strata of various temperatures, the higher temperatures being, of course, found near the ceiling. According to tests recorded in the *Electrical World* for February 22, 1918, the following temperatures were found at various levels in a room.

Distance above floor in inches.	Temperatures—Degrees F.
124	83
108	80
93	80
64	76
44	74
31	68
4	66
0	62

It will be seen from the foregoing that while the feet of a person sitting down would be at 62° F., which is too cool for comfort, his head would be at about 75° F., which is too warm, particularly so when his head is hotter than his feet, and also that the temperature at the ceiling is the excessive one of 83° F.

The writer of the article in question states that "the total amount of heat in the room was sufficient to make the whole room approximately 74 degrees—greatly in excess of what is necessary or desirable." In such a case, if the heated air at the ceiling were circulated throughout the room by means, say, of an electric fan, the quantity of heat required, and consequently the cost of heating, might be appreciably reduced.

Regarding the future outlook for the use of electric energy for heating, it may be said that to push the matter on an extended scale would be economically unsound in Canada, where such enormous amounts of energy would be required for this purpose alone, as all other fields of application for electric energy would suffer seriously thereby.

At existing rates for coal and other fuels, compared with those for electricity, electric heating is too expensive to be adopted extensively, but as an auxiliary its advantages are so attractive that efforts will undoubtedly be made to reduce the cost so as to make its use in this way more popular.

As electric heaters work at 100 per cent efficiency, no gain can be looked for so far as they are concerned, but by improving the methods of applying the heat, by storing electric energy, in the form of heat, during off-peak hours (e.g. by heating a large reservoir of water) thereby making use of electricity during part of the day when it is sold at a low rate, some reduction of cost seems to be feasible.

APPENDIX.

Since, as has been shown in this bulletin, we cannot look forward to using electricity for fully coping with the heating requirements in the cold Canadian winters, and must, therefore, continue to rely mainly on fuels, it will be of interest to consider the relation of these two commodities to the needs of the community for mechanical power for industrial and other purposes.

It can be readily demonstrated that, of the total energy in fuels, at the present time and under the most favourable conditions possible in the largest and most modern plants, a maximum of 12 to 15 per cent is obtainable in the form of mechanical power; this is only about one-third of the percentage obtainable in the form of heat in the average house furnace, and only about one-fourth of that obtainable in the form of mechanical power from the water-power of an hydro-electric plant. Moreover, it can be shown that there is no hope of ever getting more than perhaps 4 or 5 per cent greater efficiency than this 12 to 15 per cent in converting the energy in fuels into mechanical power.

This fact, taken in conjunction with those already given regarding electricity, leads to the conclusion, *that, so far as is practicable*, fuels should be used for heating, and electric energy for mechanical power.

This argument regarding electric energy applies whether in relation to motors in factories, etc., or on street cars, electric railways, etc.

True conservation, therefore, lies in using, to the fullest practicable extent, water-power for the generation of mechanical power and fuels for heating. Where no water-power is available, then the fuels must, of necessity, be used for mechanical power purposes, but this will preferably be done in large electric generating stations, the electric energy from which will be converted into mechanical power by means of electric motors, and again the fuels should preferably be used directly for the purposes of heating without converting their energy first into electricity and then into heat.

The question of using electric energy for mechanical power purposes has been taken up very seriously in England since the war broke out, as a means of conserving coal supplies. The Coal Conservation Sub-Committee of the Reconstruction Committee of Great Britain in a report presented to Parliament on April 17, 1917, on Electric Power Supply in Great Britain, states:—

> "Power may be most efficiently applied to industry by the medium of electricity.... The question which has been settled conclusively during the past fifteen years is that the most economical means of applying power to industry is the electric motor, which, on account of its high efficiency, has ruled out all rivals so far as the workshop itself is concerned. In the factories put

down for the production of munitions during the war, 95 per cent of the machinery is driven by means of electricity, and it is only a question of time for all power to be applied in this way."

It is shown in the report that a saving of some 60,000,000 (short) tons of coal could be saved annually in Great Britain by using it only in very large stations, and adopting electricity universally for the production of mechanical power.

The saving shows in that represented by the difference in efficiency of many isolated plants and a few very large ones, but, as has been stated above, the efficiency, even in the latter, is not more than 12 or 15 per cent, and cannot possibly be raised very much higher.

In Canada, however, fuels, instead of being used at 15 per cent efficiency for power, can be replaced by hydro-electric energy at four times this efficiency; thus, this would result in saving all the fuel so replaced for heating, under which conditions it can be utilized at three or more times the efficiency which it would yield for power purposes.

It must not be supposed that the foregoing statements apply to the use of electric energy for such special heating requirements as those of electric furnaces, electric welding, cooking and the like, in which the advantages of heat so obtained are very great and the aggregate power likely to be required will not run into millions of horse-power for any one purpose, nor the demand for such heating be confined specially to any one season.