30 January, 1912.
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in the Chair.

(*Paper No. 3985.*)

"The Central Heating- and Power-Plant of McGill University, Montreal."

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It is perhaps difficult for those accustomed to a comparatively equable oceanic climate to realize how completely personal comfort may be dependent on the possession of efficient means for heating and ventilating buildings. This need makes itself strongly felt in places having the ranges of temperature which characterize climates of the Continental type, as in the cases of Central Europe, the inland districts of Canada, and the northern United States. In these countries, therefore, the question of economical and effective heating, especially for large public buildings, assumes considerable importance for the engineer; and the Author has thought that it may be of interest to describe some of the factors necessarily considered in the design, construction, and operation of a central heating-plant in a Canadian city where the yearly variation of temperature often exceeds 120° F.

Reasons for a Central Plant.

The pleasant but wasteful and ineffective open fire is, of course, out of the question in such climates, even for single rooms; its place was taken long ago by well-known and more efficient systems of distributing heat, using hot water or low-pressure steam supplied from a single source or furnace. Further, with very low winter temperatures, the problem of ventilation becomes inseparable from that of heating, because in such weather it is necessary to abandon the use of open windows or other means of directly admitting cold air from outside, since people will not submit to the violent draughts and rapid changes of temperature thus caused.

Recent progress towards efficiency and economy in heating has been along the lines of centralizing the heat-supply of groups of buildings, utilizing exhaust steam from electric generating-stations or from factory-engines, and burning cheaper kinds of coal than those suitable for individual heating-furnaces or boilers. The cost of heating in a climate like that of Canada may be judged from the fact that in well-constructed buildings having no air-supply other than that leaking through walls and window- or door-openings it is customary to provide for a maximum heat-supply equivalent to about 3 B.Th.U. per hour for each cubic foot of building. With heating-apparatus of the most efficient kind 1 to 1½ lb. of good coal is frequently used per heating-season for each cubic foot of building heated, and with poorly constructed buildings, or where the heating-system is inefficient, if air has to be warmed for ventilation, or if hot water is needed for domestic or manufacturing purposes, this quantity may be greatly exceeded. The heat required to warm air for an efficient ventilating-apparatus in a cold climate is often two or three times that taken by the direct-radiation system of the building—a point which is sometimes overlooked by owners and engineers in estimating probable working-expenses.

The central heating-plant described in this Paper belongs to the class in which economy and good service are aimed at by the combined operation of the heating and electric-light and power services of a group of buildings, the relation between the two demands being such that nearly all of the exhaust steam of the electric power-station can be condensed in the heating-apparatus of the buildings it supplies. Even if a certain quantity of boiler-steam has to be furnished to the heating-system at times of light load on the electric plant, considerable economy is often effected by combining heating with light and power service in this way, the total working-cost being very little in excess of that of the heating-system alone. Conditions favourable to the economical working of such a joint system will evidently be, first, a small demand for electric energy at times when the heating-system is not in operation, and secondly, a fairly uniform demand for electric current during the heating-season, such that the engines deliver enough or nearly enough exhaust steam to supply the heating-system.

Under such conditions only a very small part of the total steam generated is exhausted to the atmosphere, and the additional cost chargeable to the operation of the electric-supply system, over and above that needed in any case for the heating-service, will be but little more than the amount of interest and depreciation on the electric equipment. The operation of a combined heating and electric plant, however, when wrongly proportioned, worked under unsuitable conditions, or burdened by unnecessarily heavy fixed charges, may yield unsatisfactory financial results, the additional cost of the electric service being greater than is justifiable when compared with the cost of energy from the local electric-supply system.

Apart from the question of the supply of electric energy, it is often advisable to install a central heating system for a group of large buildings, or for a district in a town, in order to effect the saving due to the generation of the heat in the larger plant, as well as to secure a more reliable service.

HEATING AND ELECTRIC REQUIREMENTS OF McGILL UNIVERSITY.

The central plant of McGill University, while only of moderate size, was designed to replace a number of isolated heating-systems in the various university buildings, and also to furnish steam for laboratory and service purposes, as well as electric current for lighting, for laboratory work, and for the operation of the fans, motors, elevators, and other auxiliary machinery. Fig. 1, Plate 3, is a plan of the University grounds, showing the positions of the buildings.

The Arts building, which is the oldest of the group, was erected in 1862, and, like its successors, is substantially built of masonry and brick, but with wood floors and roof. In some of the later buildings also, a large amount of timber has been used internally; but all recent buildings have been built of steel and concrete, with masonry walls, wood being used only where absolutely necessary for furniture and fittings.

All the buildings are fitted with double windows, and the roofing, where of concrete or tiles, is wood-sheathed to diminish heat-loss as far as possible.

The heating-systems of the earlier group of buildings were all of the hot-water, gravity-circulation type, with cast-iron or pipe-coil radiators in the various rooms, and large heating-furnaces in the basements designed for burning the larger and more expensive sizes of anthracite coal. The Royal Victoria College and the Old Medical building were heated by low-pressure steam. These buildings had little provision for ventilation (except in one or two of the larger lecture-rooms where exhaust fans were installed), but their heating-systems were laid out economically and worked efficiently, as is seen from the fact that the fuel-cost for those buildings having only direct radiation averaged about 0·235 cent (0·1175*d.*) per cubic foot of building per heating-season.

The supply of electric current was obtained chiefly from the local lighting- and power-company, but a part was furnished by a small steam-power plant in the Old Engineering building, the exhaust of which was utilized for heating that building only. The steady growth of the aggregate demand for current, and the construction of new buildings, rendered it necessary in 1906 to consider the question of constructing a central heating- and power-plant for the University; and the destruction (in 1907) of two of the largest buildings[1] by fire, and their consequent replacement by larger and more commodious ones, led to the decision in 1908 to proceed with the installation of the plant, to which the various buildings were to be connected for heating and lighting as funds became available. Construction was commenced in May, 1909, and the plant was put in service in November of the same year, supplying heat to five buildings, and current to six. The lighting and power systems of five other buildings have been connected since 1910.

Some idea of the climatic conditions of Montreal during the heating-season may be obtained from the following figures, taken from the records of the University Observatory for the winter of 1908–1909, which was of about average severity :—

MONTREAL WEATHER-RECORDS, WINTER OF 1908–9.

Month.	Maximum Temperature.	Minimum Temperature.	Mean Temperature.	Snowfall.	Total Wind-Travel.
1908.	° F.	° F.	° F.	Inches.	Miles.
October . .	74·6	29·3	49·66	Nil	9,814
November . .	56·3	17·4	34·57	13·3	12,411
December . .	52·1	– 9·5	15·84	53·2	9,498
1909.					
January. . .	42·3	–17·2	14·60	22·1	11,118
February . .	41·2	–12·4	16·17	20·3	11,623
March . . .	41·8	3·6	25·78	20·9	12,125
April . . .	67·0	19·4	37·91	8·9	11,003
May	73·6	33·5	53·28	Nil	9,688

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[1] Old Engineering building burnt 5 April, 1907. Greater part of Old Medical building burnt 16 April, 1907.

From these and other figures it appears that the heating-season in an average year in Montreal lasts about 200 to 230 days, and that a possible minimum temperature of – 20° F. has to be provided for, which occurs sometimes (although not often) at the same time as a high wind. Temperatures as low as – 27° F. have been observed in Montreal, but such very cold weather occurs only once in several years and then is likely to last only for a few hours. Temperatures as low as – 10° to – 15° F., however, are often maintained for some days without much rise or fall.

Montreal is in nearly the latitude of Geneva, and during the shortest days artificial light is rarely required before 4.30 p.m., while fogs are practically unknown.

The buildings of the University are grouped upon an irregularly-shaped plot of ground about 26 acres in extent, and measuring about 1,800 feet in its longest dimension, as shown in Fig. 1, Plate 3. The surface rises from south-east to north-west, the site of the New Medical building being about 100 feet above the level of Sherbrooke Street.

The University grounds afford room for a considerable number of additional buildings in the future, and it was necessary to arrange the new power-station so as to allow of easy extension.

Preliminary calculations based on the dimensions of the various buildings, on their exposed surfaces of glass, roof, and wall, and on their original heating- and ventilating-equipments, gave the following figures (in round numbers):—

Total volume of eleven buildings	7,570,000 cub. ft.
Total direct-radiation heating-surface in buildings (steam)	10,600 sq. ft.
Total direct-radiation heating-surface in buildings (hot water)	71,000 ,,
Total air-supply of ventilating-systems . .	185,000 cub. ft. per min.
Total heat-loss from buildings per hour per degree difference between inside and outside temperature	200,000 B.Th.U.
Total heat per hour required to warm air for ventilation service (in buildings having mechanical ventilation) per degree difference between inside and outside temperature .	120,000 ,,

It was therefore estimated that the demand for heat (exclusive of steam used for laboratory or domestic purposes) when the temperature outside is – 10° F., and the temperature inside the buildings is 70° F., would be about 25,600,000 B.Th.U. per hour, and that a site capable of accommodating a boiler-plant evaporating 30,000 lbs. of water per hour would be needed, with possibilities of future extension to about double this capacity. The possible winter peak load on the electrical equipment was estimated at about 475 kilowatts with all existing buildings connected, this figure including the demand for laboratory purposes, as well as for light and power.

Two sites were available not far from the buildings of maximum demand, and the one selected finally was decided upon for reasons of University policy rather than on account of its immediate engineering advantages.

The choice of fuel was determined primarily by the necessity for avoiding smoke, having regard to the fact that the scale of the proposed installation was scarcely large enough to warrant the provision of mechanical stokers and coal-conveyors. A study of the various coals available indicated that good economic results would be obtained from small-sized anthracite, which could be delivered at the power-house for about $4·00 (16*s.*) per ton (of 2,240 lbs.), with a guarantee that the ash would not exceed 15 per cent. Preliminary tests showed that this coal could be burned satisfactorily with a good chimney-draught on plain grates, when mixed with one-fifth to one-third of good bituminous screenings; and the boiler-installation was accordingly designed with this end in view.

The site chosen was such that refuse had to be carted away, but during a large part of the year good boiler-room ashes are in such demand in Montreal for building purposes that they are readily disposed of to contractors. Ash-cartage, therefore, has only to be paid for during about 3 months in the winter, when building work is not very active. The scheme of electric distribution presented no special difficulty, but the heating and ventilation requirements were not so readily met, as the installations to be supplied were of several different types.

The necessity for mechanical ventilation-equipment capable of furnishing a proper supply of warmed air in winter has already been mentioned, and such apparatus is now nearly always installed in Canada in large buildings having public or semi-public rooms. It is, of course, possible to utilize such an equipment for heating purposes. For instance, direct radiating surfaces in the rooms themselves may be done away with, and the heating of a building may be effected by supplying sufficient heated air to each room, a method now very usual in schools and other buildings made up of a large number of similar rooms each containing about the same number of inmates and therefore requiring about the same quantity of air. In practice, however, this method suffers from the disadvantage that while the air-supply necessary for the ventilation of a room depends primarily on the number of people it contains, the quantity of heat required depends more particularly on the exposed wall- and window-area. Thus, taking the case of two rooms, one of which has a large heat-loss and a small number of inmates, while the other has a small exposed wall- and window-surface but contains many people, the first would need a comparatively small quantity of air introduced at a high temperature, while the second would require a much larger quantity of cooler air. With this system, therefore, it is necessary to have a different temperature of the air-supply for each type of room, and the building is completely dependent on its fans for heating, becoming (in severe weather) practically uninhabitable if these are not in operation.

On the whole, wherever the additional outlay is permissible, it seems best, in the Author's opinion, to install a moderate amount of direct heating-surface in the various rooms, calculated in each case to make up for the heat lost through walls and windows (but not sufficient to warm any of the air passing through the building), and, in addition, to install a ventilation-system supplying to and exhausting from each room a quantity of fresh air (warmed by suitable coils to about the desired room-temperature) proportioned to the number of occupants. The quantity of air required by the School Laws of Massachusetts (30 cubic feet per minute for each person) has been found in most cases to be amply sufficient for satisfactory results when properly distributed. All the newer buildings of the University are equipped in this manner, and most of them have also air-cleaning and humidifying apparatus. The radiators in the existing buildings are in all cases but two supplied with hot water, and forced-circulation hot-water heating will probably be adopted for all future buildings.

In Montreal the necessity for air-cleaning appliances is not great, but the air-washers in use in the Students' Union, Engineering and Medical buildings are found to remove a large quantity of dust and dirt, and they have the further advantage of humidifying the air in the buildings in the winter time to any desired extent. Air at zero temperature, having a fairly high relative humidity but, of course, a very low absolute moisture-content, when admitted to a building and there heated to 60° or upwards, is extremely dry, and in order to avoid the injurious action of such air on the noses and throats of the occupants as well as on the furniture and woodwork of the building, humidifying appliances aiming at a constant relative humidity of 30 to 50 per cent. are now quite commonly in use.

The amount of radiating surface installed and the ventilation requirements of the various University buildings are given in the following Table :—

ESTIMATED DEMANDS FOR STEAM FOR HEATING AND VENTILATION IN ZERO WEATHER AND FOR LABORATORY PURPOSES.

Buildings originally connected.	Approximate Cubical Contents.	Direct radiating Surface.	Steam or Hot Water.	Air supplied for Ventilation.	Steam for Heating and Ventilating.	Steam for Laboratory, etc.	Total Steam.
	Cub. Ft.	Sq. Ft.		Cub. Ft. per Min.	Lbs. per Hour.	Lbs. per Hour.	Lbs. per Hour.
New Medical .	1,650,000	16,000	H.W.	80,000	10,000	1,000	11,000
Old Medical .	650,000	4,100	S.	..	1,200	..	1,200
Engineering and Workman .	1,450,000	15,000	H.W.	55,000	9,000	Separate boilers	9,000
Chemistry and Mining . .	670,000	10,000	H.W.	20,000	2,000	2,500	4,500
Physics . . .	530,000	6,000	H.W.	..	1,200	1,000	2,200
						Total .	27,900
For Future Connection.							
Arts building .	480,000	6,500	H.W.	..	1,200	..	1,200
Museum . .	350,000	2,000	H.W.	..	500	..	500
Library . . .	500,000	8,000	H.W.	..	1,500	..	1,500
Students' Union	350,000	5,000	S. & H.W.	20,000	1,500	1,500	3,000
Conservatorium of Music .	130,000	2,500	H.W.	..	500	..	500
Royal Victoria College . .	810,000	6,500	S.	10,000	2,000	1,000	3,000

For buildings of the class considered here, the supply of air required for ventilation corresponds in most cases with between three and four changes of air per hour, taking the capacity of the whole building—laboratories as well as lecture-rooms; that is to say, between 50,000 and 70,000 cubic feet of air per minute should be supplied per million cubic feet of building. The demand for heat (including that required for warming the air-supply), with the temperature outside 0° F. and the temperature inside 65° F., ranges from about 2,500 lbs. of steam per hour in the case of buildings having no ventilation, to as much as 8,000 lbs. of steam per hour in buildings which have a large air-supply, per million cubic feet of building in each case. The heating demand is very nearly proportional to the difference in temperature between the air inside and outside the building, and is perceptibly increased when there is a high wind. These figures illustrate the large additional cost of working imposed by modern requirements as to ventilation; but of course they apply only to buildings of one particular class, and in the climate of Montreal.

The direct radiating surface of all the new buildings of the University has been calculated for the actual losses from walls, windows and roofs in accordance with the German Government heat-loss coefficients, which have been found to give very uniform and reliable results.

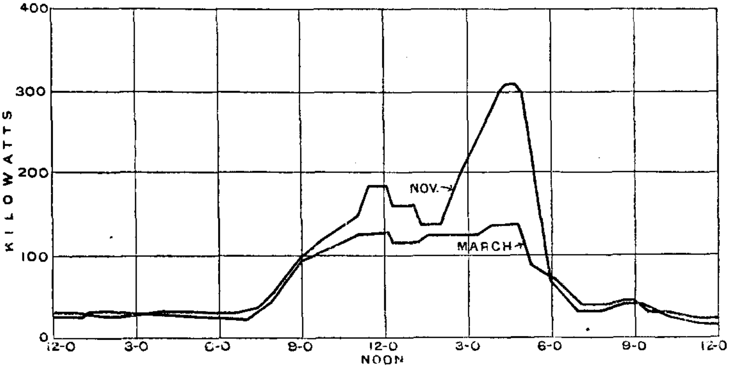
Steam is, of course, required for laboratory purposes, for which a pressure of 60 lbs. per square inch is sufficient.

The possible electrical demand of the eleven buildings amounted to an equivalent of 8,060 16-candle-power carbon lamps and 478 HP. of motors. In some—as for instance the Royal Victoria College, a building containing lecture- and class-rooms and serving also as a residence for women students—it was estimated that about 60 per cent. of the total number of lights would be in use at any one time; in other cases, as in the Engineering building, where there are large rooms used as drawing-offices, a larger proportion of the total lights are in use at the peak of the load. A lighting peak of 248 kilowatts and a power peak of 227 kilowatts were assumed, making as already mentioned a total of 475 kilowatts.

The maximum distance for the transmission of current being about 1,300 feet from the site selected for the power-station, it was felt that there was not sufficient reason to depart from the voltage already in use in practically all of the university buildings for lighting, namely, 110 volts. For power purposes, however, the distribution was arranged to be on the three-wire system, with 220 volts between the outers, and with a maximum drop of 3 per cent. at the farthest point of distribution. Some of the existing motors had to be connected on the 110-volt circuits, but in practice this has led to very little trouble from want of balance. As far as possible the power-lines were arranged as separate circuits, so as to avoid difficulty due to the working of elevators, cranes, and other machines used only intermittently.

During the session the demand for electric power in the university buildings is fairly uniform from 8 a.m. to 5 p.m., as it is largely due to workshop and ventilating-fan motors: large fluctuations are unusual, unless some special work is being done with an electric furnace or other laboratory apparatus taking much current. In the afternoon somewhat heavier laboratory loads come on, followed and partly overlapped by the lighting load. After the session is over the demand is very much less, and of course no steam is used for heating in the summer. The actual load-curves for lighting and power for a November and for a March day are shown in *Fig. 2.* It will be noted that the economical operation of such a combined heating and electric plant as that described will depend almost entirely on the relation between the quantities of steam required for electrical and for heating purposes, and also on the quantity of electric energy which has to be supplied in the summer at a time when it is produced at a cost necessarily higher than the charge of a public supply. It was estimated that in the McGill plant, when supplying all the existing buildings, and assuming a total annual output of 700,000 kilowatt-hours, the output during the non-heating months of June, July, August and September would be only about 11½ per cent. of the total, a condition which is fairly favourable to economy. In the plant as actually operated during 1910 about 13 per cent. of the total electric output was generated during the non-heating months.

Fig. 2.



Typical Daily Load-Curves (Lighting and Power).

A report by the Author, based on the foregoing considerations, was submitted in 1908, together with detailed estimates, and it was decided to proceed with the power-house, installing boilers of sufficient capacity to deal with the electric supply of all existing buildings, but connecting at first only the New Medical, Old Medical, Engineering, Chemistry, and Physics buildings, and arranging for extension as funds became available, and as existing lighting- and power-contracts expired.

UNDERGROUND PIPING.

In designing a system of underground piping for heat-distribution, it is necessary to decide whether to install the pipes in a tunnel, where they will be accessible for repairs, or to employ some type of conduit, involving less first cost, but greater expenditure if any repair work has to be done on the pipes or joints. The advantage of ready access seems to be almost the only one possessed by a pipe-tunnel, its heat-efficiency being necessarily considerably lower than that of a well-designed and properly-drained conduit. Definite information as to the efficiency of heat-transmission by insulated piping in conduit as compared with that of covered pipes in tunnel seems to be lacking, but the Author hopes that, as the result of experiments now in progress, he will be able shortly to throw some light on this question.

The essential features of successful pipe-lines for heat-transmission are: (1) Small heat-loss in proportion to the amount of heat actually transmitted; (2) satisfactory arrangements for keeping the pipes and their covering clear of water, i.e., good drainage; (3) proper provision for expansion due to changes of temperature; (4) means for ready detection of leaks; (5) easy access for repairs and examination.

A well-designed and well-constructed conduit system has a smaller heat-loss than a tunnel carrying the same amount of piping—especially if two or more pipes can be carried within the same conduit—because the heated surface, from which loss to the surrounding ground goes on, is proportionately so much smaller in the former case than in the latter. It is difficult in bad ground, however, to keep a conduit perfectly free from ground-water, especially where the pipe-line is level or nearly so, and with wet pipe-covering the heat-losses are vastly increased. Expansion in tunnels may be allowed for by long-radius bends, by swivel joints, or by bellows joints in the pipe. A tunnel can usually be laid out so as to provide for these without incurring the additional expense of special expansion-pits or anchor-pits, which are a necessity with a conduit system. In conduit work expansion-pits must also be arranged so that any leakage will make itself manifest there, although in Canada in the winter a leak of any magnitude in an underground steam or hot-water line soon shows itself by the melting of snow on the ground above the pipe-line.

Having regard to these various factors, it would appear that tunnels should be used only where a considerable number of pipes are required along the same line, or where it is likely that more pipes will have to be installed in the near future. In these circumstances the expense of the tunnel, often amounting to $20 to $35 (£4 to £7) per lineal foot, will possibly be justified.

The Author has found that the expansion of long lengths of steam or hot-water piping can be allowed for most satisfactorily by installing long-radius bends at intervals of 150 to 250 feet, these bends, if on a conduit line, being placed in properly drained brick or concrete expansion-chambers, which should have double manhole-lids, with the space between the lids packed with non-conducting material. The walls should have an inner brick or concrete lining with an air-space, and the chambers should be just large enough to allow for the pipes and the space absolutely necessary for working at the joints.

The external corrosion of long heating-mains is not a serious matter when the conduit is kept dry, but in pipes carrying water of condensation from heating-coils or the like, where the warm water has an opportunity to dissolve air, severe internal corrosion often sets in. In such a case heavy wrought-iron (not steel) or cast-iron pipe should be used; in some installations so much trouble has been experienced that the water is wasted instead of being returned to the station. This is the practice of the American District Steam Company, the heat being taken from the water of condensation by means of special "economizer coils" before running it to the sewer. The Author has seen cases in which galvanized-iron pipe-lines carrying domestic hot-water supply from heaters in the boiler-room of a central plant to various buildings have had to be replaced after only about 12 months' use; for this reason it seems better practice to put in a separate steam heater for the domestic hot-water service of each building, and supply steam to these heaters from the central plant.

As far as corrosion is concerned, no difficulty arises in the case of hot-water lines carrying water to and from the direct radiation systems of buildings, because the piping-circuit is then a closed one, the water is freed from air, and the same water (except for any small loss due to leaks or alternate expansion and contraction of the water) remains in the system throughout the year.

Of the various types of underground conduit, the Author prefers a vitrified pipe (or similar incombustible material), such as is shown in Figs. 3, Plate 3 (the tunnel is shown in Fig. 4, Plate 3). Here the outer casing of the conduit is of hard-burnt vitrified pipe, each length being scored longitudinally before burning and split in halves, so that the lower part can be laid first, and the upper portion cemented in place after the hot-water and steam pipes have all been laid and tested in sight. The space between the pipes and the outer conduit is completely filled with asbestos-meal or other suitable heat-insulating composition, which has no corrosive effect on the outside of the pipes, even when wet, and is not affected by temperatures of 300° or 350° F. At the necessary intervals, inverted tile-pipe tees are placed, the lower leg being bedded in a mass of concrete which supports the frames and rollers for carrying the piping, or in which anchor fittings can be placed. Expansion is allowed for by long bends in expansion-pits, although other means might be adopted if desired. With this system it is possible and usual to carry more than one pipe in a conduit.

In all kinds of conduit construction for heating service the pipe is usually fitted with screwed joints, although in some special cases the pipe-lengths have been welded together in place by the oxy-acetylene process. Flange-joints, however, are used at the manhole pits, at special branches, crossings, and other fittings, and wherever necessary for the purpose of facilitating repairs.

POWER-HOUSE.

The general arrangement of the power-house is shown in Figs. 5, Plate 3.

The building is of red brick, with a "mill construction" roof of 4-inch planks covered with felt, tar, and gravel, according to the usual Canadian practice. Steel was used for the framework wherever possible, and the temporary walls and partitions are of wire lath with cement plaster. The coal-bins are of reinforced concrete. The boilers discharge their waste gases to a brick stack 160 feet high and of sufficient size to take the gases from the additional boilers which will eventually be put in. The flue leading from the boilers to the stack is of reinforced concrete 4 inches thick, the mixture being 1 part cement, 2 of hard brick screenings, and 3 of hard brick broken to a $\frac{3}{4}$-inch mesh. A slip joint is provided about half-way along the flue, and the reinforcement consists of $\frac{3}{8}$-inch round rods 8 inches apart placed circumferentially, with $\frac{1}{2}$-inch rods 18 inches apart placed longitudinally. The flue has given very satisfactory service.

Under the boilers an ash-tunnel is provided, at the end of which the ashes are dropped into the boot of a bucket elevator; this discharges into a steel overhead ash-bin holding 15 tons, from which the ashes are shot direct to the carts outside the building.

The question of installing mechanical stokers was carefully considered, but they were not used, on the ground that in a plant of this size the saving in labour would not justify the additional expenditure, and also because the smoke difficulty could be met easily and economically by the use of the mixture of anthracite and bituminous coal to which reference has already been made (p. 216).

Economizers were not put in, because the local conditions (the station being placed on the slope of a hill rising 600 feet above the site and in a residential district) demanded a fairly high stack in order to avoid possible annoyance from dust and flue-gases carried down by baffling air-currents. As the height necessary for this purpose is only just sufficient to give the draught required for the small-sized coal to be burnt, and the boilers are not overloaded, the installation of economizers would probably have involved the provision of a fan equipment in addition to the high chimney, and would therefore have involved a considerable increase in the first cost. It was felt also that the whole plant should be as simple as possible, and that all unnecessary piping and connections should be avoided.

Similar considerations led to the decision not to fit superheaters to the boilers, although by their means some economy of steam might have been obtained during the summer months. The superheaters would have been of doubtful benefit in the colder portion of the heating-season, when the exhaust steam has in any case to be supplemented by live steam during the greater part of the day.

Having regard to the probability of considerable extension in the future, when these accessories may possibly become desirable, provision was made in the design of the boiler-settings for the easy erection of superheaters and of chain-grate stokers if required. In laying out the boiler-room, spaces were left for the necessary air-ducts, should it be desired to put in fans and forced draught, and room was also allotted for a conveyor-channel, so that coal- and ash-conveyors can readily be installed if needed.

The boilers are four in number, of the standard double-drum Babcock-Wilcox land type, built for 150 lbs. per square inch working-pressure, and each rated at 7,500 lbs. of steam per hour. Each boiler has 2,823 square feet of heating-surface and 59 square feet of grate-area. The grates have fixed bars with $\frac{1}{4}$-inch air-spaces. The furnaces are of the so-called Dutch-oven type, and have proved to be very satisfactory as far as absence of smoke is concerned, even when a considerable proportion of bituminous slack is mixed with the anthracite. The cost of maintenance has been moderate, although trouble was at first experienced with the roof of one of the furnaces, because the cross stays taking the thrust of the arch were too light. Since this was remedied each arch has lasted 2 years and is still fit for service.

The feed-pipe arrangement of the plant was purposely made as simple as possible. All make-up water from the City service carrying scale-forming materials is treated in an open feed-heater before entering the main feed-tank. A float in this feed-tank automatically controls the quantity of fresh water admitted. All steam condensed in the various heating-appliances, and all steam-pipe and other drips not contaminated with oil, are discharged by means of traps or pumps to the main feed-tank, which has a capacity of 1,000 gallons, and is placed in the boiler-room at a level well above the feed-pump suctions. After leaving the pumps the whole of the feed is passed through a closed feed-heater supplied with exhaust steam. Before passing into the feed-tank all the feed-water is metered by means of a tilting-tank weigher; in this way continuous records of the water-consumption can be obtained.

The 10-inch main steam-pipe line is of wrought steel, with wrought flanges and branches riveted on. A 4-inch line is also provided for supplying auxiliaries in the boiler-room, and is arranged so that in case of emergency the greater part of the main steam line can be cut out and one engine can still be used. Corrugated copper and asbestos gaskets are used for all high-pressure steam joints. The main feed-pipe is of brass (2½-inch iron pipe size), arranged so that any one boiler can be isolated for testing.

The boiler-room equipment also includes a set of standard tare-registering scales for weighing coal as filled from the bins into the barrows; 2,500 lbs. can be weighed at a time.

The main generating-sets are three in number. All are Belliss-Morcom two-crank compound engines of the forced-lubrication non-condensing type, direct connected to generators. Two sets have each a rated capacity of 150 kilowatts at 425 revolutions per minute, and the third can deliver 300 kilowatts at 350 revolutions per minute. The valves of all three are so set that a load 50 per cent. greater than the rated load can be carried when working with a steam-pressure of 150 lbs., and exhausting against back pressure of 5 lbs. per square inch.

The generators are all of the direct-current three-wire interpole type, compound-wound, and are provided with balancing transformers large enough to deal with a load 25 per cent. out of balance on the three-wire system with which the generators are connected.

These transformers, however, have actually carried for some hours loads which were unbalanced to a considerably greater extent than that specified. The machines will carry 25 per cent. overload for 2 hours immediately following a 24 hours' run at the rated load, without showing a rise in temperature of more than 60° C. (108° F.) above the temperature of the surrounding air. The transformers satisfy the same conditions as to rise of temperature. When working with full load and 25 per cent. overload on the two sides respectively of the distribution system, the difference in voltage between them does not exceed 2 per cent. of the normal. The normal pressure is 220 volts between the outers.

Each generating-set is mounted on a heavy concrete block, resting on a layer of teased-out coco-nut fibre, which isolates it completely from the concrete sub-foundation. This arrangement has proved very effective in preventing the transmission of noise or vibration, although the power-house is built on rock, and is not far from buildings containing sensitive instruments.

The switchboard has seventeen panels, of which five are for the power-circuits and seven for lighting-feeders. Each circuit has an integrating wattmeter and an out-of-balance ammeter, reverse-current relays and other protecting devices being installed where necessary. As far as possible, separate panels are provided for light and power to each building or group of buildings.

The arrangement of the engine-room piping, as well as of that in the boiler-room, is shown diagrammatically in Figs. 6, Plate 3.

The engine-room also contains the heaters and circulating-pumps for the forced-circulation, hot-water portion of the heating-system. The three heaters, being of the vertical type, are installed in a suitable pit commanded by the crane; the shells are of steel, the heads of cast iron, and the tubes through which the water is pumped are of brass. Two are supplied with steam at 5 lbs. per square inch pressure from the main exhaust system, and contain respectively 300 and 1,000 square feet of heating-surface; the third, having 300 square feet of heating-surface, takes its steam-supply through a reducing-valve at 60 lbs. per square inch pressure either from the main steam-line or from the auxiliary line, as may be desired. All three have their water-connections in parallel. The smaller exhaust heater has proved to be capable of supplying hot water to 30,000 square feet of direct radiating surface in the various buildings down to a temperature of 10° F. above zero; in colder weather than this the larger heater has to be put in service. The heater equipment was intended to deal with about 60,000 square feet of direct radiating surface and is actually able to condense 20,000 lbs. of steam per hour. The circulating-pumps are in duplicate, each being a 6-inch single-stage turbine pump directly connected with a 24-HP. motor, and capable of discharging 750 (Imperial) gallons per minute against 50 feet head when running at 1,200 revolutions per minute. Two Venturi meters and four thermometers enable the operating staff to take records of the quantity of water delivered and the drop in temperature between the flow and return, from which the actual quantity of heat supplied to the hot-water heating-system can be computed. Condensation-meters are provided on the various condensed-water return lines so as to measure the steam condensed in those buildings heated by steam, and in this way it was intended to keep an account of the whole heat-output of the plant. Unfortunately, however, it has not yet been found possible to obtain meters which are always reliable when dealing with the somewhat intermittent discharge of the traps on the condensed-steam lines; the meters tried have given good records for short periods, but have needed frequent adjustment and repair.

The engine-room equipment also includes an overhead hand-crane of 5 tons capacity, and a 9-inch Westinghouse air-compressor supplying air at 100 lbs. per square inch pressure to a system of piping arranged for changing the crank-case oil of the engines, and also for delivering air for cleaning the commutators and generators and for cleaning tubes in the boiler-room.

DISTRIBUTION SYSTEM.

The method of heat-distribution by means of hot water warmed in the power-station and circulated by pumps was adopted for those buildings already heated by hot water, and will probably be employed for new buildings, for the following reasons. First, the initial expense for piping is very slightly more than with low-pressure steam, while the economy of working is considerably greater, especially in mild and variable weather; and secondly, regulation of the temperature can be conveniently effected by hand in the engine-room without having recourse to expensive thermostatic control systems on the direct radiation of each building: further, there is neither trouble in pumping condensed steam back from the lower levels, nor waste in allowing such condensed steam to run to the sewers.

In a winter climate such as that of Montreal, however, it was not considered advisable to use hot water, even with forced circulation, in the tempering coils through which fresh air is drawn by the ventilating fans of the buildings, because a careless operator, by closing off even one section of the heating-service, might cause serious damage from freezing. As steam was needed in practically all the buildings for laboratory or domestic purposes in any case, it was decided to use steam in the tempering and reheating coils in all the ventilating systems, as well as for the direct radiating surface of those buildings, fortunately few in number, which were already heated by steam. In this way the expense of changing from steam to hot-water heating in such buildings was avoided.

Heat, therefore, is distributed from the power-house partly by hot water, partly by low-pressure steam, and partly by live steam; the latter being adopted for the laboratory supply and also (in order to save the expense of 800 feet of large pipe) for heating the air for the ventilating system of the New Medical building. To accommodate the pipes for these services, and also to provide for certain additional pipe-lines which will probably have to be installed in the comparatively near future, it was decided to build a concrete tunnel about 400 feet long from the power-house to the Engineering building, and to lay the branch pipe-lines in the vitrified pipe conduit already described. This tunnel is illustrated in Figs. 4, Plate 3, which show the part leading to the Engineering building. The roof is reinforced and is waterproofed with felt and pitch, and in most places it is constructed at least 3 feet below the surface of the ground, in rock over which large quantities of water flow in the spring. The conformation of the ground is such that the course of the tunnel could be readily laid out to provide the bends necessary for pipe-expansion, and manholes for access were arranged at necessary intervals. The pipes in the tunnel are lagged with asbestos-sponge covering, protected with heavy roofing-paper wired on and tarred at the joints. The heat-loss was specified not to exceed 0·35 B.Th.U. per square foot per hour for each degree difference of temperature between the pipe and the air in the tunnel. The hot-water pipe-lines were proportioned for a drop in temperature of 20° F. between the flow and return mains when working at full capacity and with a water-velocity of 5 feet per second.

All piping for hot water and steam in the underground distribution system is of wrought iron with extra-heavy cast-iron flanges screwed on. The flanges are male and female, and the gaskets are of "rubber-bestos." Some consideration was given to the advisability of using cast-iron pipes for returning water of condensation to the boiler-room, a service very destructive to ordinary commercial wrought pipe, but it was finally decided to use wrought-iron pipe for this purpose also, in order to avoid the additional cost of heavy cast-iron piping.

As will be seen from Fig. 1, Plate 3, there are two main heating-circuits. The north circuit leaves the tunnel at the first bend, 70 feet from the power-house wall, and is carried thence in conduit, except where it traverses the basement of the Old Medical building. The south circuit passes along the whole length of the tunnel, then through the Engineering building, and is continued along the south conduit line.

The north conduit line (length 700 feet), which is a vitrified pipe 24 inches in diameter, supplies the New and Old Medical buildings, and contains the following pipes:—

Two 6-inch flow and return pipes for hot-water direct radiation in the New Medical building.
One 4-inch low-pressure steam line for direct radiation in the Old Medical building.
One 4-inch high-pressure steam line for laboratory and ventilation service in the New Medical building.
One 2-inch return line for water of condensation.

Alongside of this conduit is laid one set of nine-way electric duct.

The south conduit line (length 300 feet), also of vitrified pipe, is 20 inches in diameter; it supplies the Chemistry and Mining building and the Physics building, and contains:—

Two 7-inch (diminishing to 6-inch) flow and return pipes for hot-water direct radiation in the Chemistry and Physics buildings.
One 4½-inch (diminishing to 4-inch) high-pressure steam line for laboratory and ventilation service.
One 1-inch return line for water of condensation.

Where it leaves the power-house the tunnel carries all the foregoing pipes and the cables (Figs. 3 and 4, Plate 3), and also an 8-inch low-pressure line for the heating and ventilation of the Engineering building. The electric cables for these buildings (where not in tunnel) are carried separately from the heating-conduit.

The expansion-pits for the conduit are of the type already referred to (p. 222). The heat-loss from the piping inside the conduit was guaranteed to be not more than 0·15 B.Th.U. per square foot per hour, for each degree difference of temperature between the pipe and the ground outside.

The expansion-tank for the main hot-water distribution system is placed in the New Medical building, at a height of about

150 feet above the basement of the Physics building, and the heating systems in the Physics and the Chemistry and Mining buildings having been in use for upwards of 12 years, it was thought inadvisable to work these at the pressures corresponding with such head. The heat from the power-station distribution-system is therefore transmitted to the direct-radiation heating-systems of these buildings through secondary heaters having respectively 450 square feet and 250 square feet of heating-surface. These heaters are of similar design to the main heaters in the engine-room, and replaced the old furnaces in the basements of these buildings. The hot water of the main supply from the power-station passes through the tubes, the water of the secondary heating system of the building circulating outside.

In the Chemistry and Mining building the original gravity circulation was found to be sufficient, but in the Physics building, where complaints as to ineffective circulation in the lower floors had always been made, it was found necessary to assist the gravity circulation by the use of a small motor-driven centrifugal pump drawing from the return header of the building and discharging into the space outside the tubes of the secondary heater. In connection with each of the secondary heaters a by-pass was arranged between the main primary flow and return pipes, and was provided with a weighted by-pass valve of the butterfly type, the object being to prevent any considerable change in the rate of flow of the water through the main circulating-pumps should either of the secondary heaters be shut off for repairs, and in this way to arrange matters so that the relative quantities of water discharged by the main circulating-pumps to the north and south circuits respectively should not be subject to any appreciable variation from this cause. The whole system when once adjusted has been found to work with extremely little trouble, and if reasonable attention is given to the main-flow temperature in the engine-room the temperature in the buildings supplied will not vary by more than 5° F. during the winter.

OPERATION OF THE PLANT.

The staff comprises the following:—One superintendent and chief engineer; two watch engineers and switchboard men; one night engineer; three firemen and two trimmers in winter; two firemen in summer; one electrician; one steam-fitter for outside work; one labourer in winter.

This staff, with occasional unskilled assistance in heavy repair-work, looks after the regular working of the station and all outside heating and electrical plant, making necessary repairs and alterations in equipment.

In the working of a central heating-station such as the one here described the problem of temperature-regulation requires careful treatment. The arrangements for this purpose in the various buildings are designed to economize labour as much as possible, and in all the newer buildings of the University the temperature of the air supplied for ventilation is controlled by thermostatic apparatus, which needs only the occasional attention of a skilled man to give satisfactory service. In the older buildings, supplied with hot water directly from the station, thermostatic regulation of the temperature of the water in the radiators has not been found necessary. This temperature is adjusted by hand by the engineer on watch in the engine-room, who regulates the supply of steam to the heaters, and thus varies the temperature of the circulating water, in accordance with hourly observations of the outside temperature.

A scale of flow-temperature is adopted, varying from a hot-flow temperature of 210° F. at $-20°$ F. outside, to 105° F. with an outside air-temperature of 50° F. This scale is found to give good results as long as the weather is quiet, but in the event of a high wind it is necessary to raise the temperature of the water-supply in the proportion of 1° F. for each 2 miles per hour of wind-velocity. The direction and velocity of the wind are obtained by telephone from the neighbouring observatory.

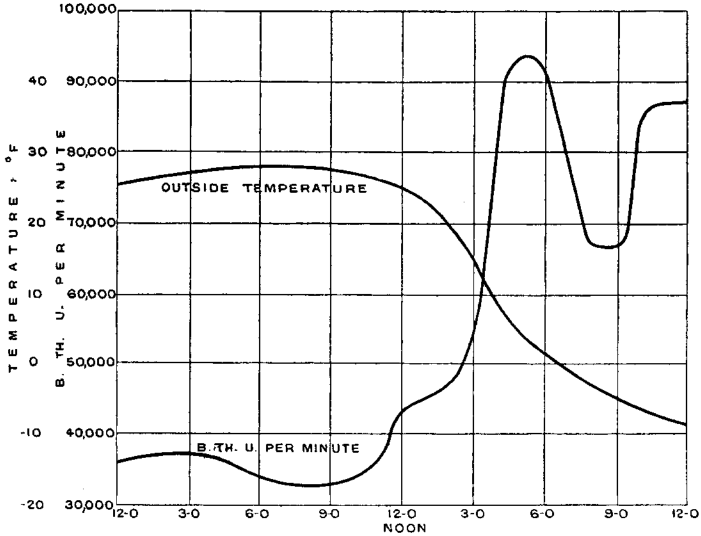
A load-curve of the heat-supply on the 30th December, 1910, to the direct-radiation heating-systems of the New Medical, the Chemistry and Mining, and the Physics buildings is shown in *Fig. 7*. The considerable variation in the outside temperature, and the corresponding variation in the heat-supply, will be noted.

The coal-consumption of the station for the year 1910 amounted to 7,850,000 lbs. (3,500 tons) and the coal used was a mixture of about 4 parts of small anthracite (“bird’s eye” size) with one of good-quality bituminous screenings, the cost being approximately $3·72 (15*s*) per ton delivered into the bunkers. This mixture had a calorific value ranging between 11,000 and 12,000 B.Th.U. per pound, and a proportion of ash varying between 12 and 15 per cent. The total electrical output for five buildings for the year was 299,483 kilowatt-hours.

The heat-distribution scheme of the plant being unavoidably somewhat complex, *Fig. 8* has been prepared, to show (for December, 1910) in diagrammatic form the various ways in which the total steam generated was used, and the quantities (in thousands of pounds) employed for each purpose. It will be noticed that a very small portion of the total steam was wasted in the atmospheric exhaust.

Taking similar figures for the whole year 1910, it is found that, of the total quantity of coal consumed, about 6,390,000 lbs. (2,852 tons) is chargeable to the production of the steam actually delivered to the pipe-lines for heating purposes and for the laboratories; that is, more than 6,000,000 lbs. of coal would have been burnt under the boilers if no electric generating equipment had been installed, and if the station had supplied heat only. The remainder of the coal consumed, approximately 1,460,000 lbs. (650 tons), therefore represents the quantity to be charged to the electric generating equipment, and corresponds with a fuel-cost of 0·81 cent (0·405*d.*) per kilowatt-hour generated. Evidently this figure does not represent the cost of the coal used in evaporating the total quantity of steam passed through the engines, but is really the cost of the coal consumed in generating that portion of the total steam which was either lost in condensation, or which passed through the engines without being afterwards utilized for heating purposes. This is, of course, approximately the quantity of steam actually exhausted to the atmosphere, and is about 18 per cent. of the quantity generated during the whole year. The coal expended for heating, ventilation, and laboratory purposes is

Fig. 7.



HEAT DELIVERED TO HOT-WATER HEATING MAINS: 30TH DECEMBER, 1910.

thus seen to be equivalent to about 1·29 lb. per cubic foot of building for the heating-season, and corresponds with an annual fuel-cost of 0·214 cent (0·107*d.*) per cubic foot, a figure which may be compared with the 0·235 cent (0·1175*d.*) already given on p. 214, for the direct-radiation heating of the older buildings when worked with their individual furnaces. Such a comparison, however, is hardly fair to the central plant, because the various isolated heating installations had to warm no air for ventilation, and did not furnish any steam for laboratory work or other purposes.

Two years' working of the new central plant has shown that the station-costs for steam (not including maintenance or fixed charges) have averaged about 36 cents (1*s.* 6*d.*) per 1,000 lbs. delivered to the buildings when combined with a station-cost of about 2·5 cents (1·25*d.*) per kilowatt-hour delivered. These figures are based on the assumption that heat is the main product of the station, and that only that portion of the steam not used for heating service is charged against electric generation.

Fig. 8.

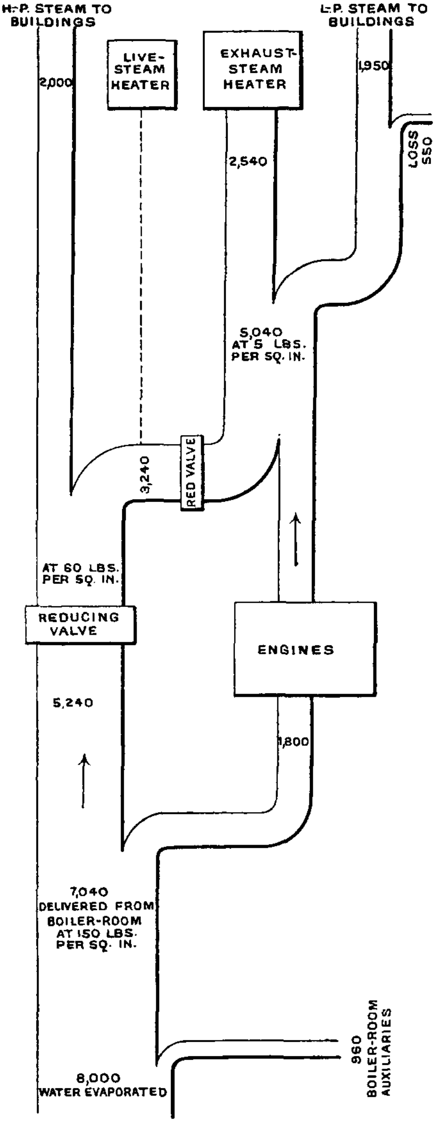


Diagram of Steam Distribution for Month of December, 1910: Thousands of Lbs.

It is, of course, possible to look at the question of economy from the point of view of charging all the steam used by the engines against the electric output, and debiting the heating-plant only with the live steam supplied directly from the boilers to the heaters and buildings. This would give a higher cost per kilowatt-hour, but a much lower figure for heating, although the cost of the combined services would evidently be the same as before. In whatever way the total costs are distributed, the economical performance of a combined plant such as the one described in this Paper must evidently be judged by the cost of the combined heating and electric services to the consumer, and not by taking the figures for either portion alone.

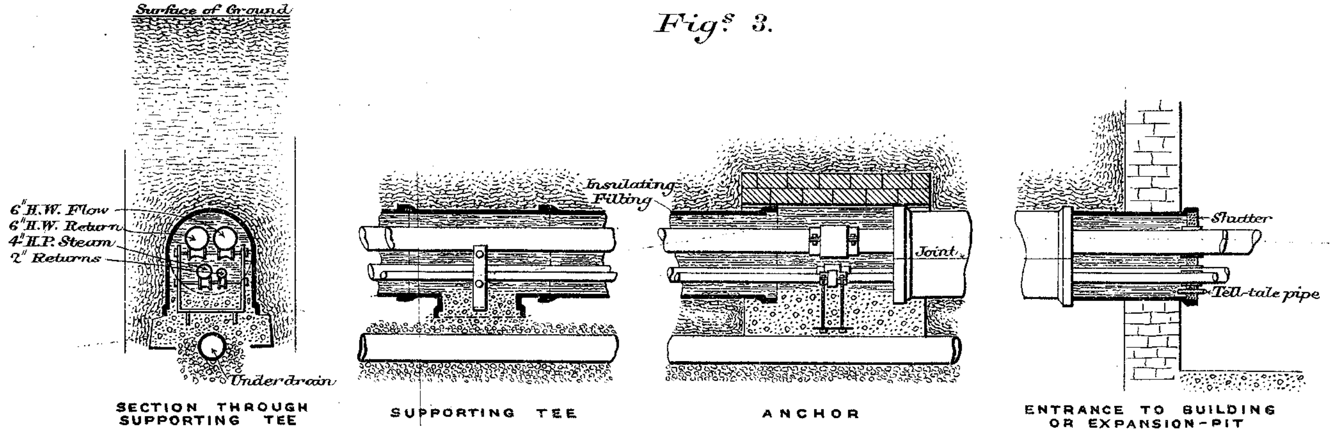
On the daily log-sheet of the McGill power-plant the various data required for cost-calculations are recorded. These include hourly readings of the steam, hot-water, and electric supplies, and daily records of the coal and water used and of the wattmeters and condensation-meters.

The Paper is accompanied by nine tracings from which Plate 3 and the Figures in the text have been prepared; also by a copy of the log-sheet.

HEATING- AND POWER-PLANT AT McGILL UNIVERSITY.

PLATE 3.
HEATING- AND POWER-PLANT AT
McGILL UNIVERSITY.

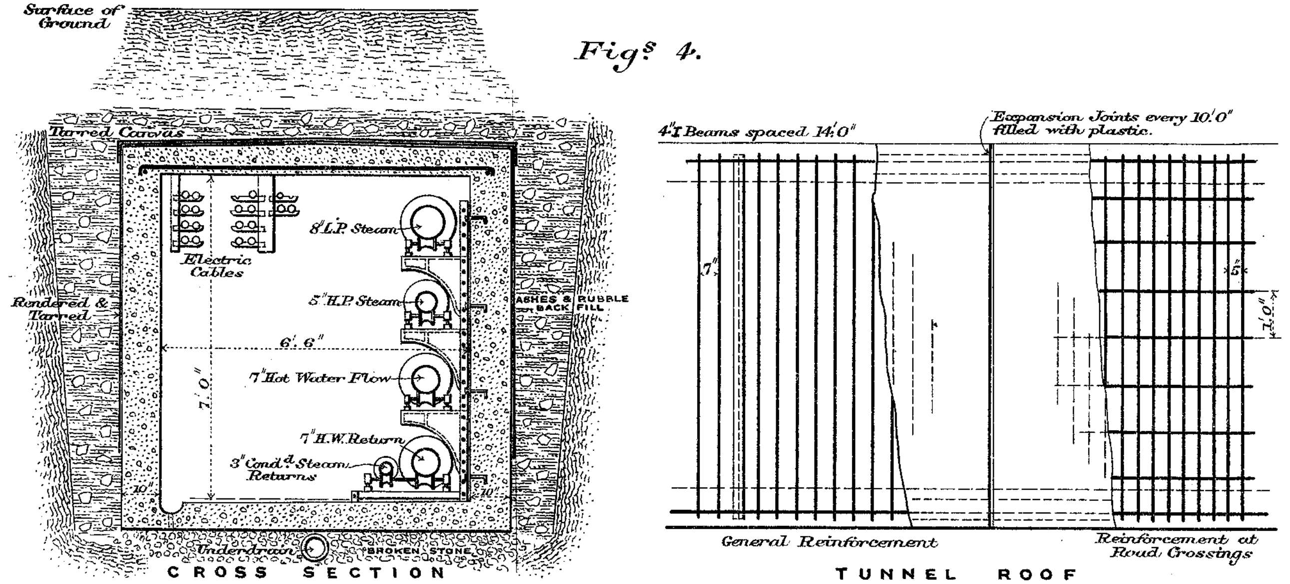
Figs 3.



SECTION THROUGH SUPPORTING TEE · SUPPORTING TEE · ANCHOR · ENTRANCE TO BUILDING OR EXPANSION-PIT

DETAILS OF PIPE-CONDUIT

Figs 4.

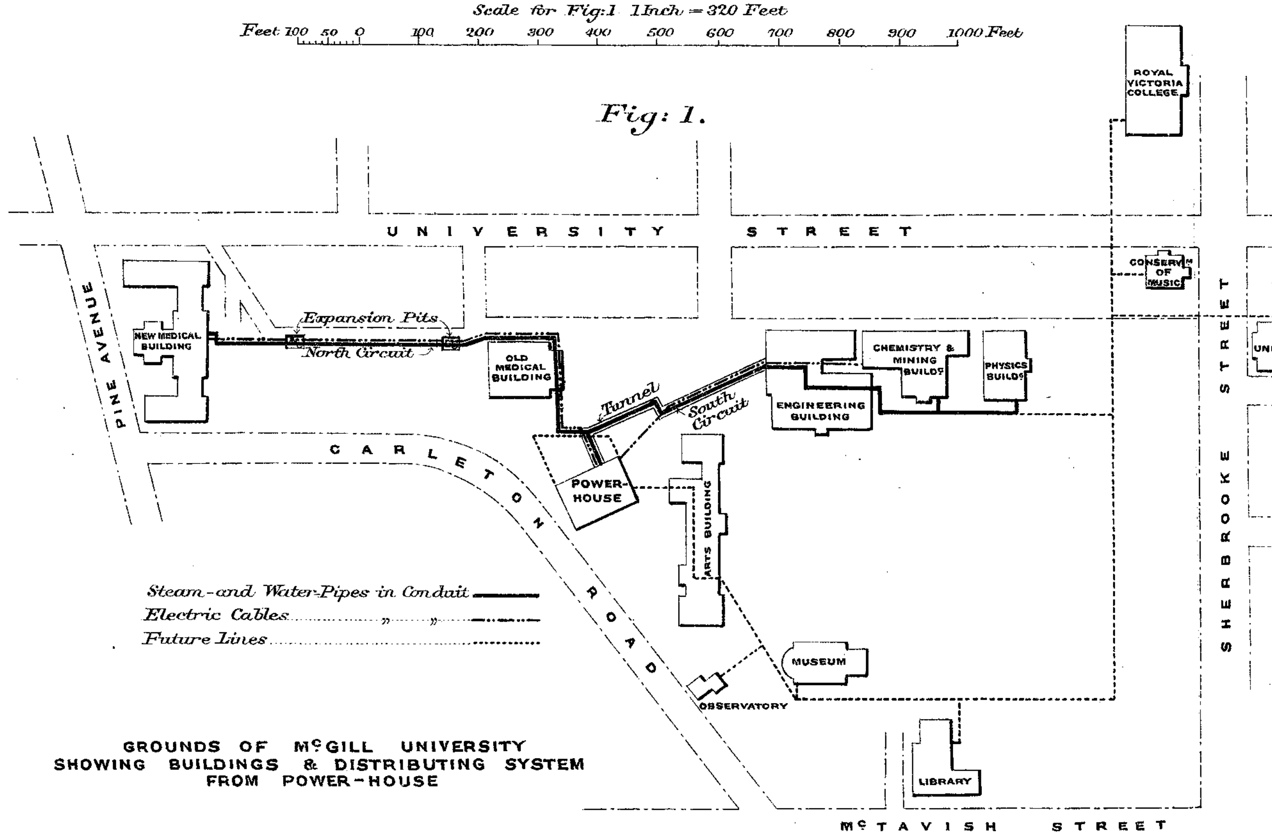


CROSS SECTION · TUNNEL ROOF

DETAILS OF PIPE AND CABLE TUNNEL

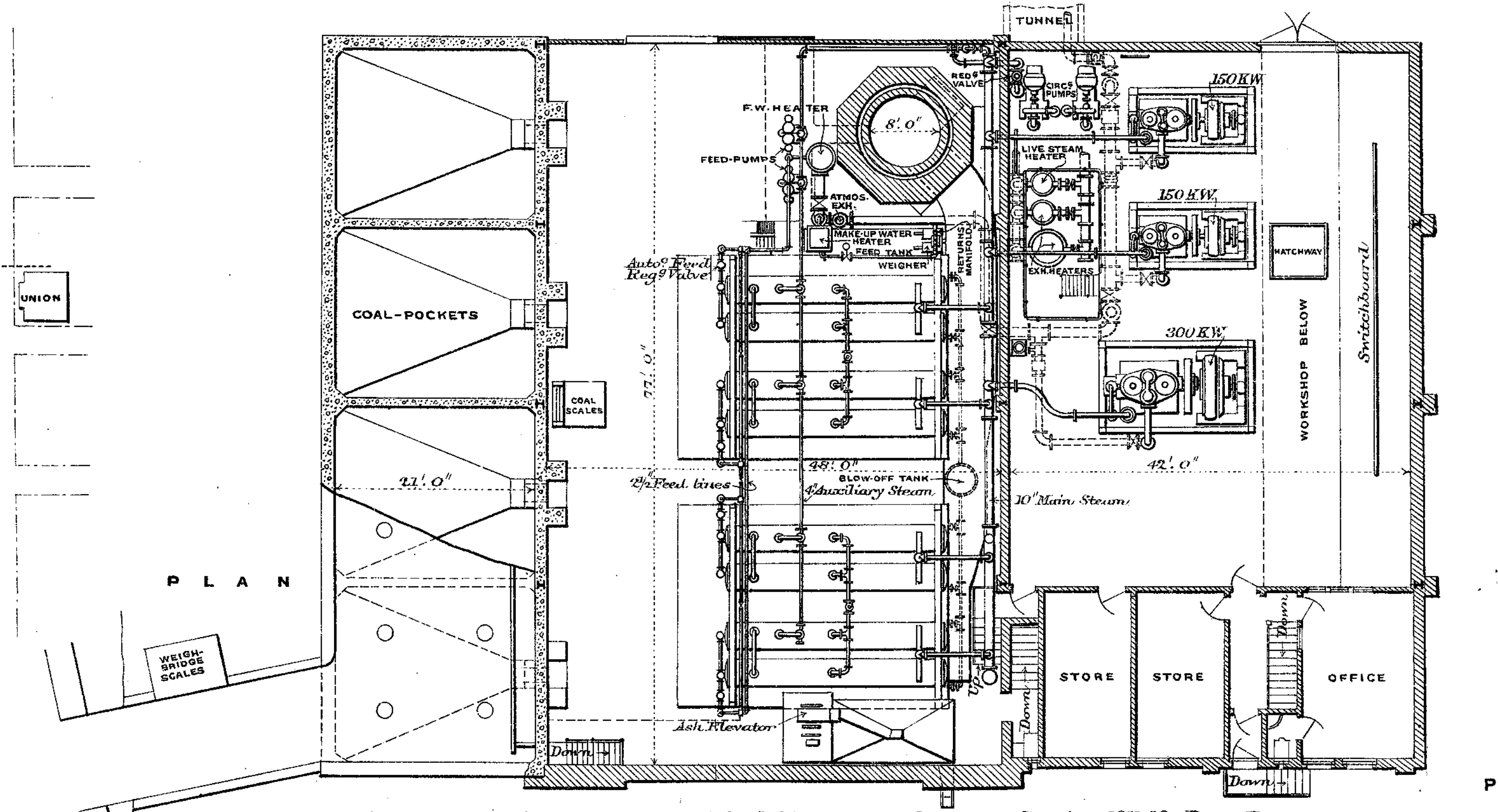
Scale for Fig: 1 1 Inch = 320 Feet

Fig: 1.

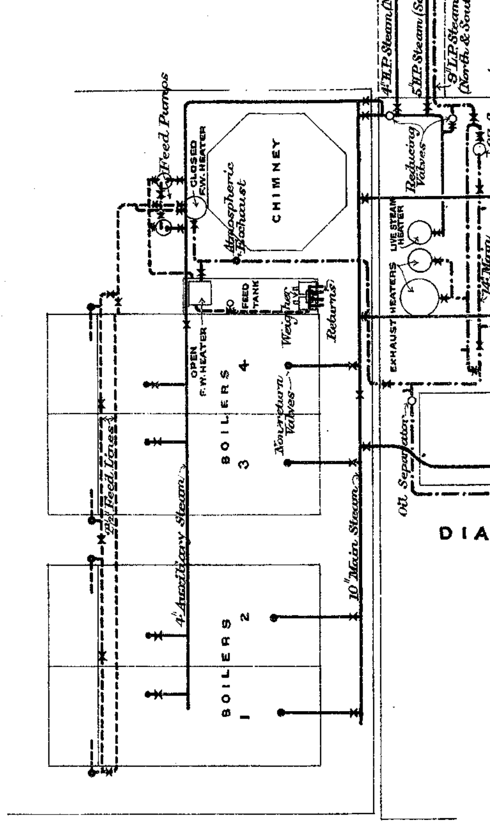


GROUNDS OF McGILL UNIVERSITY
SHOWING BUILDINGS & DISTRIBUTING SYSTEM
FROM POWER-HOUSE

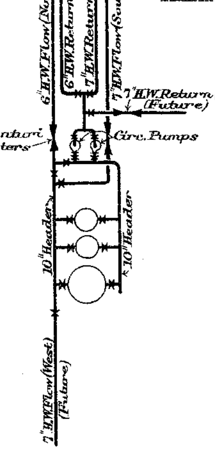
PLAN



Figs 6.



STEAM-PIPES



WATER-PIPES

REFERENCE

H. P. Steam	———
H. W. Circg	———
L. P. Steam	—·—·—
Boiler Feed	- - - - -

DIAGRAM OF PIPING.

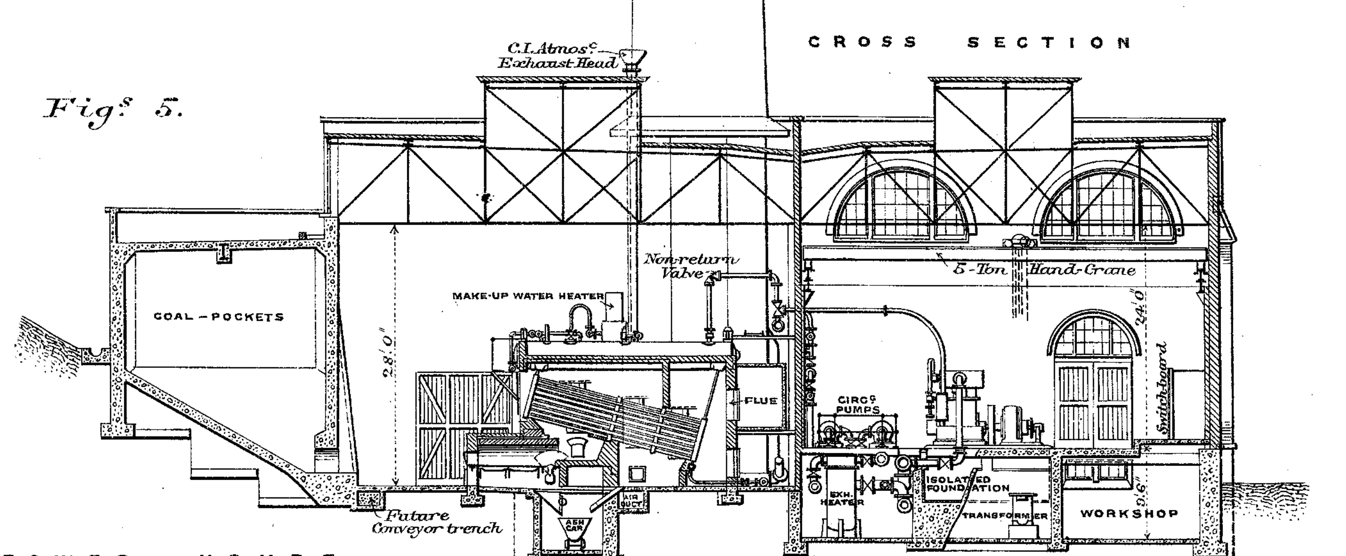
SCALES

Figs 3 and 4. 1 Inch = 4 Feet
Inches 12 6 0 1 2 3 4 5 6 7 8 Feet

Figs 5 and 6. 1 Inch = 20 Feet
Feet 10 5 0 10 20 30 Feet

CROSS SECTION

Figs 5.



POWER — HOUSE

R. J. DURLEY.

Minutes of Proceedings of The Institution of Civil Engineers. Vol: CLXXXVIII Session 1911-12. Part II.

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