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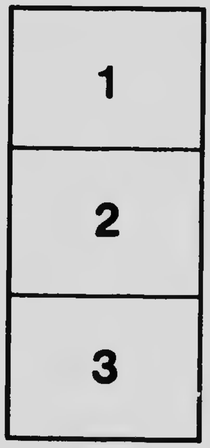

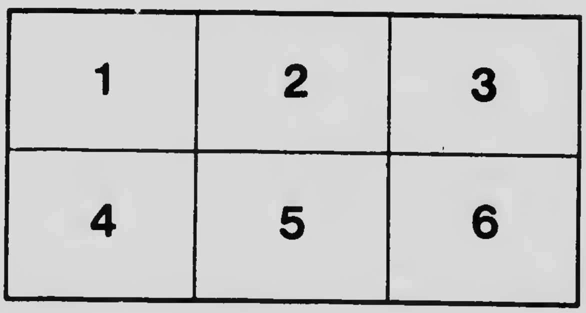

Central Heating and Power Plant
University of Toronto

FIG. 1. MAIN BUILDING OF THE UNIVERSITY OF TORONTO, NORTH OF AND FACING THE CAMPUS

Central Heating and Power Plant, University of Toronto

By L. M. Arkley, M. Can. Soc. C.E.*

The operation of central heating plants for the supply and distribution of heat over comparatively large areas has been successfully accomplished in certain instances by progressive municipalities. The private installation of such systems, however, is somewhat infrequent, due probably to absence of opportunity. Such an enterprise as that featured in the present article possesses exceptional interest not only because of magnitude and distances involved, but because of the consistent results which are justifying the wisdom of the undertaking.

THE buildings which comprise the University of Toronto are situated in extensive grounds, on west side of Queen's Park, in the city of Toronto. Bounded on the north by Bloor street, the west by St. George street, and the south by College street, the 21 buildings, as shown in plan, Fig. 5, present a problem of considerable magnitude and interest as regards the provision of a suitable heating system.

Previous to the year 1911-12, the widely scattered buildings were heated by several separate plants, the most of which were old and inefficient. Electric current for light and power was partly generated in these plants and partly purchased from supply companies. Conditions, therefore, were such that the possible economies which could be effected through the installation of a central heating and power plant warranted such a procedure, and the gradual reduction of costs ... the plant was put in operation is submitted as amply justifying the centralization arrangement as well as that of the equipment installed.

FIG. 2. INTERIOR OF POWER HOUSE ENGINE ROOM SHOWING CURTIS TURBO-GENERATOR IN FOREGROUND WITH ALLEN HIGH-SPEED UNIT IN REAR.

Power House

The location selected for the central plant was to the east of the Medical Building (4), and adjacent to the western end of the Ontario Legislative Building in Queen's Park. The power house building is for the most part underground, its flat roof being practically level with the pavement in the adjacent driveway in the park, from which the ground slopes down so that the west wall of the building is about eight or ten feet above ground level.

The main object in providing such a location was to facilitate the installa-

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tion of a gravity return heating system. An additional, though minor advantage, was that it has ' en possible, by placing ornamental balustrades on roof of the coal bunkers, and the judicious overheated bunkers. These have a capacity of 600 tons, are built of concrete, and, as shown in Fig. 7, overlap the furnaces so that a suitable angle is obtained for the delivery pipes which are fit-

FIG. 3. KNOX COLLEGE. THIS EDIFICE ALSO FACES THE CAMPUS, AND IS ONE OF SEVERAL RECENTLY COMPLETED BUILDINGS.

planting of shrubbery, to almost entirely disguise the location of the plant so that the scenic surroundings of the Legislative Building suffer no detraction whatever.

The ground space occupied by the building including the coal bunkers, is 82 feet in length by 107 feet in width. The sectional view, Fig. 7, shows the relative position of the engine room, boiler room and coal bunkers. The boiler room is 58 feet wide, with a total height of 26 feet and contains four Babcock and Wilcox water tube boilers, each of 403 nominal horse-power, and one boiler of the same make with a rating of 516 horse-power, giving a tot l of 2,128 boiler horse-power.

All of the boilers operate at a pressu-e of 165 lbs. per sq. in., without superheat, and each unit is equipped with a Murphy automatic smokeless furnace to which coal is fed by gravity from the ted with sluice valves at their upper end for regulating the supply of coal. The bunker is 25 ft. wide and 12 ft. high, and the roof forms part of the roadway by which the coal is brought to the plant, the sidewalk, along with the balustrades referred to, being indicated thereon.

An induced draft system is operated in conjunction with the boilers—two 78-in. American Blower Co. fans coupled to Robb fan engines drawing the waste gases from a smoke breeching extending along the back of the boilers (see Figs. 6, 8, and 10), and discharging them into an underground concrete tunnel leading to a brick stack which is built into a corner of the Medical Building (4).

Boiler feed requirements are taken care of by an installation of three Smart-Turner duplex steam-driven feed pumps. These are illustrated in Figs. 10 and 11, and are of the outside end-packed plunger type, 10 in. x 6 in. x 10 in., with pot valves. They are situated immediately behind the boilers, and are so piped that two independent methods are available for supplying water to the boilers. At the near end of the pump room, Fig. 10, is the sump, equipped with two small steam pumps for draining purposes, and one Bundy steam trap for taking care of the high pressure drips.

The coal used is a bituminous slack containing out 21 per cent. of volatile matter this is burned with very litt'e smoke While the coal is not bought on the B. T. U. basis, samples are taken regularly from the delivery waggons and tested for ash, volatile matter, carbon, moisture and sulphur. This procedure has resulted in the quality of coal received being uniformly high.

Engine Room

The engine room extends the full length of the building, i.e., '2 ft., and is 30 ft. wide by 23 ft. g', the floor level being 3 ft. above tha. c' the boiler room. It is separated fro. the boiler room by a 27-in. brick wall, and although not shown, a hand-operated ov -head traveling crane is provided, fitted with a 3-ton Yale triplex block, which enables all maintenance adjustments and repairs to be conveniently made.

The equipment contained in the engine room consists of four steam-driven generating units, switchboard, waterweigher and feed water heater, with feed water and vacuum pumps, the purpose of the latter being explained under heating section.

The generators are all direct connected to their engines, and are as follows:

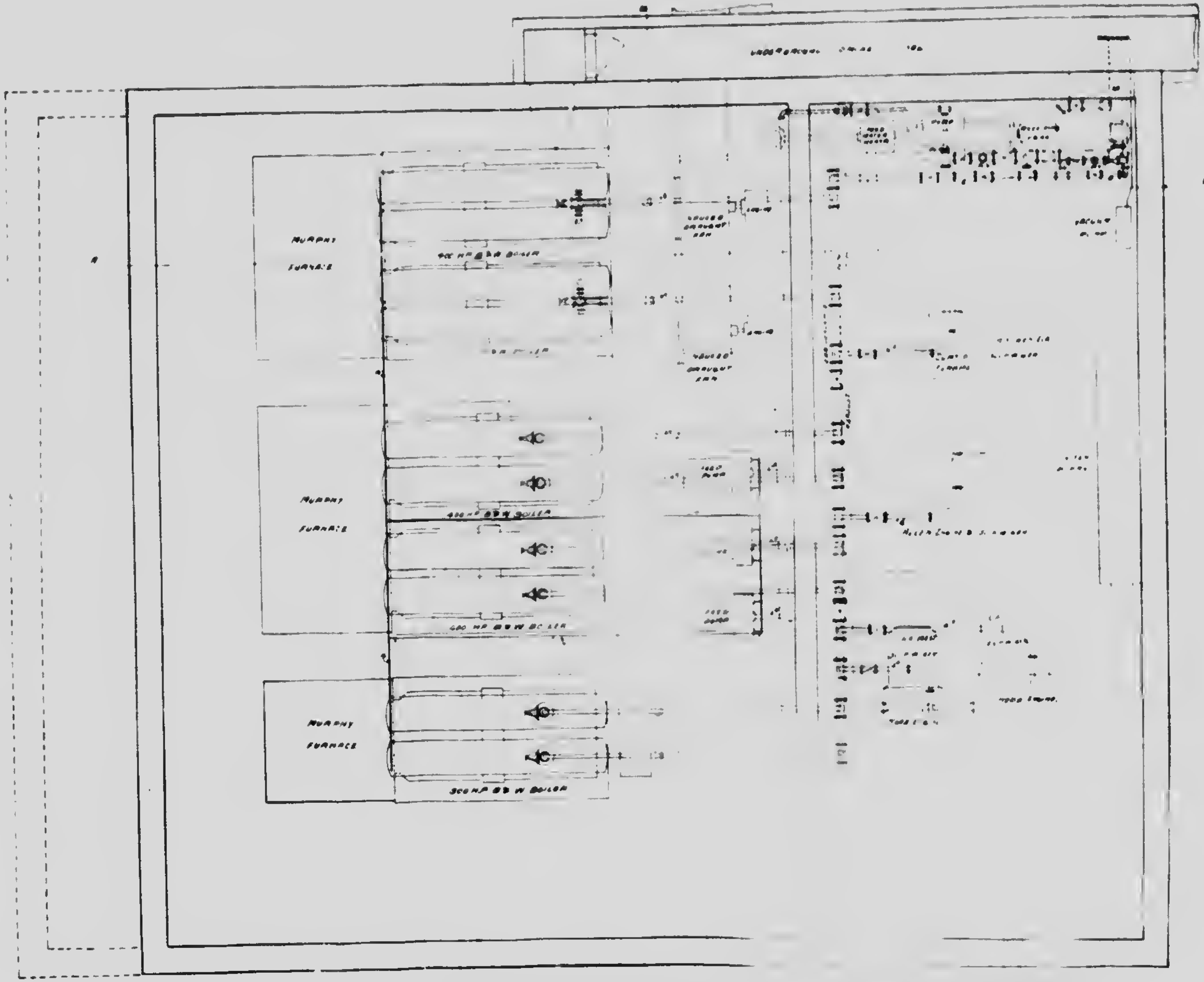

FIG. 6. PLAN OF POWER HOUSE SHOWING LAYOUT OF BOILER AND [illegible] ALSO LOCATION OF UNDERGROUND SMOKE TUNN[illegible]

FIG. 1. DEPARTMENT OF HOUSEHOLD SCIENCE BUILDING, SITUATED ABOUT FIVE EIGHTHS OF A MILE FROM THE CENTRAL HEATING PLANT.

One horizontal C.. steam turbine, driving a 300 kw. General Electric D. C. generator, running at 1,500 rev. per min. (see Fig. 2).

One high speed vertical compound reciprocating engine, with generator built by W. H. Allen, Son & Co., Bedford, Eng., cylinder 16 in. and 24 in. x 11 in. stroke, developing 300 kw. at 400 revs. per min. This unit can be seen behind the Curtis outfit in Fig. 2.

Two Robb, Armstrong-Westinghouse units of 100 kw. and 50 kw. capacity respectively—these engines are of the single cylinder vertical type, the former having a 15 in. x 14 in. cylinder, and speed of 275 revs. per min., and the latter a 12 in. x 10 in. cylinder, with a speed of 265 revs. per min. shown in Fig. 12.

All of the engines operate under a steam pressure of 160 lbs. per sq. in. at the throttle, while the generators supply direct current at a pressure of 220 volts, each unit having an individual panel on the switchboard, which has seven panels in all, two being for distribution purposes and the seventh coupled up to one of the local supply companies.

The auxiliary apparatus in the engine

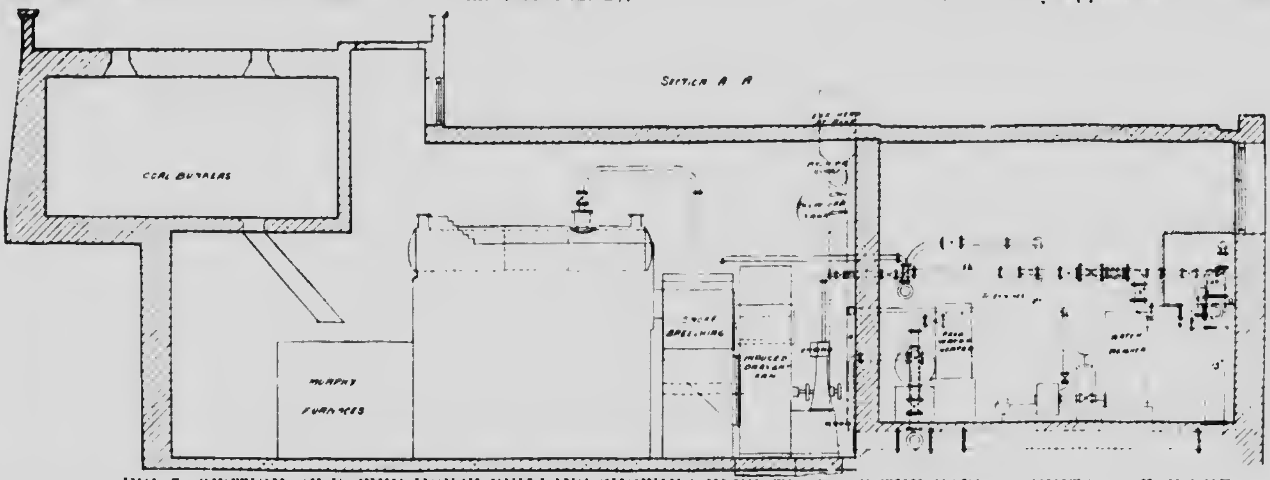

FIG. 7. SECTION OF POWER HOUSE BUILDING SHOWING ELEVATIONS OF THE VARIOUS UNITS OF EQUIPMENT.

FIG. 10. PUMP ROOM, SHOWING ALSO SMOKE BREECHING IN UPPER LEFT HAND CORNER AND FAN CASINGS IN BACKGROUND. HOT WELL IS IN IMMEDIATE FOREGROUND

room is illustrated in Fig. 13. At the left of the photograph is a Webster open type feed water heater, which receives part of the exhaust steam from the generating units, and is supplied with feed water by two Smart-Turner 6 in. x 5¾ in. x 6 in. duplex pumps, located next to it. Further to the right is a Kennicott water weigher with a maximum capacity of 65,000 lbs. per hr. Immediately above the water weigher is the entrance to the tunnel which carries the distributing pipes and cables referred to later, the 20 in. main being clearly discernible as it enters. At the extreme right is an 8-in. x 12-in. x 12-in. Warren vacuum pump, referred to above.

Heating System

The heating system was originally designed as a gravity return system, the hot well in the power house being the low point to which all condensed steam returned by gravity. Of the original buildings heated in this way, the Main and Mining Buildings have been changed to a vacuum system and the same method has been adopted for the recently completed Knox College and for Hart House. In this case the vacuum pumps located in these buildings discharge the returns from the [illegible] [illegible]tion to [illegible] head tanks, from wh[illegible] [illegible] flows by gravity into the main return line back to the power house.

The following table gives a list of the buildings heated, together with the number of square feet of radiation in each

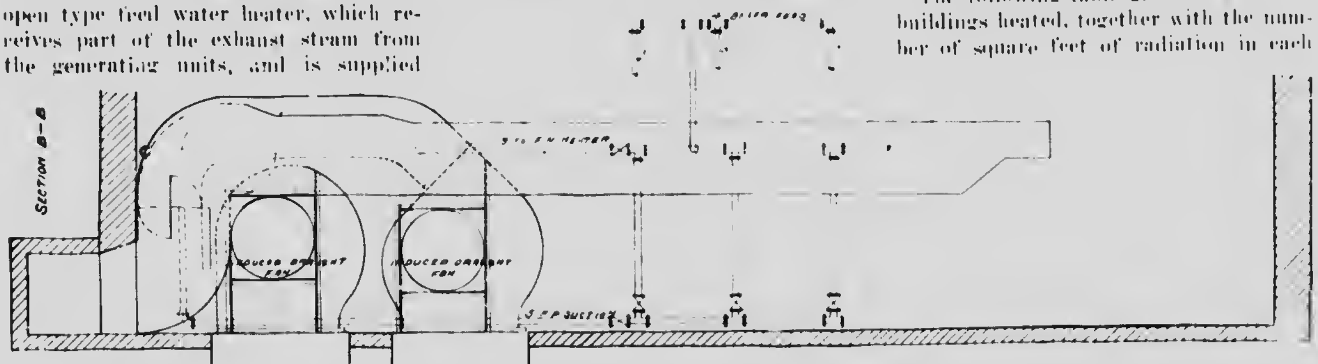

FIG. 8. ELEVATION OF INDUCED DRAUGHT EQUIPMENT SHOWING SMOKE BREECHING, FAN CASINGS AND SECTION OF SMOKE TUNNEL

for the heating season 1914-15:—

Name and No. of Building.	No. of sq. ft. of Radiation.
No. 1—Main	12,936
No. 2—Hart House (in course of construction)	5,000
No. 3—Library	10,829
No. 4—Medical	7,160
No. 5—Biological	8,271
No. 6 Engineering	9,084
No. 7 Thermodynamics	6,114
No. 8—Observatory	783
No. 9—Mining	13,721
No. 10—Chemical	6,595
No. 11—Physics	19,648
No. 12—Convocation Hall	6,689
No. 13 Men's Residences	9,336
No. 14 Household Science	10,137
No. 15—Museum	17,303
No. 16—Wycliffe College	12,371
No. 17—Victoria College	9,028
No. 18 Victoria College (Library)	[illegible]
No. 19 Annesley Hall	4,274
No. 20 Burwash Hall	4,300
No. 21—Knox College (not completed	15,000
Total sq. ft. of radiation	196,534

Note: No allowance made for indirect radiation.

Piping Distribution System

The main heating pipe as it leaves the power house is 20 in. dia., and continues of this size to a point west of the Medical Building (4), where it branches north and south in 16 in. mains, and gradually reduces in size towards the end of the line.

All engines, turbines and steam pumps in the power house exhaust into this pipe, but as the lighting and power load is normally small compared with the heating load required, live steam is introduced by passing it through a pressure reducing valve in the usual way. A pressure of from one to 4 lbs. per sq. in. is carried on the main heating pipe at the power house.

The question of expansion and contraction due to change in temperature is an important one in a steam line of this length, and it is taken care of by slip expansion joints, the pipe being securely anchored at the proper points. This form of expansion gives satisfactory service if the pipe is looked after and kept well in line, otherwise it leaks.

A question of still greater importance than that of expansion is that of condensation of steam, as excessive condensation means not only a loss of heat, but also introduces the problem of tak-

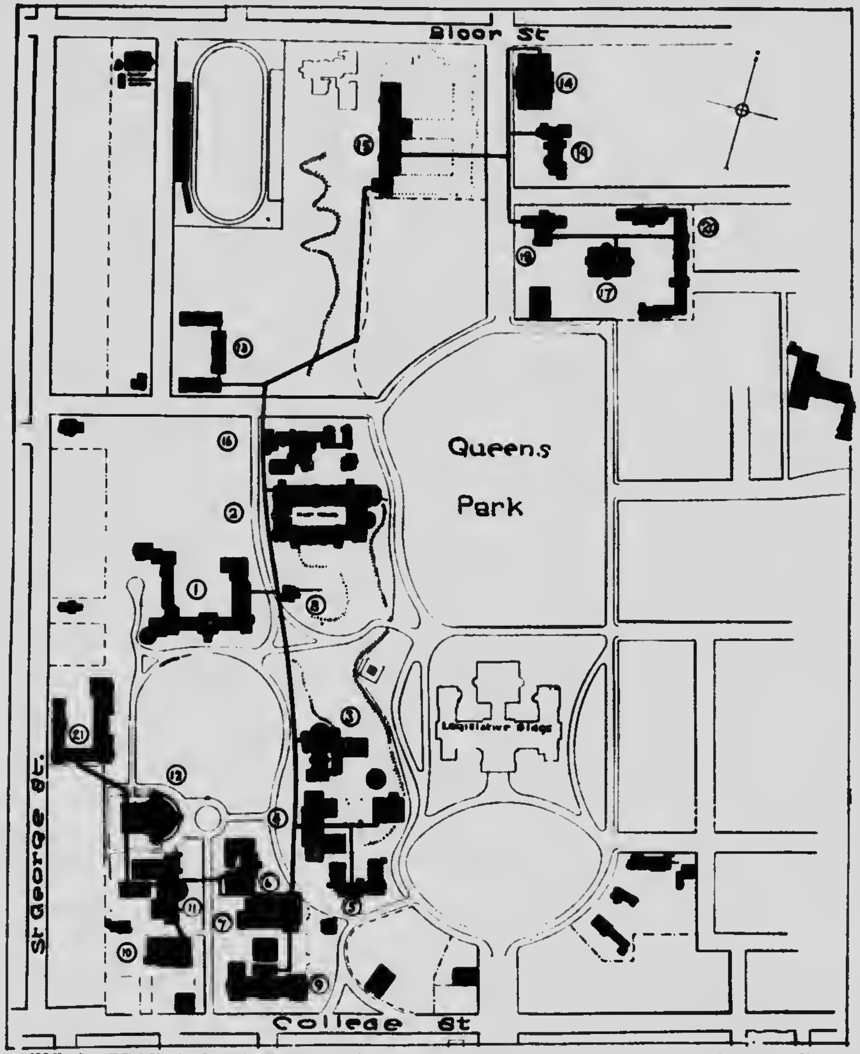

FIG. 5. GROUND PLAN SHOWING LOCATION OF VARIOUS BUILDINGS SERVED BY CENTRAL PLANT.

ing care of the water of condensation. The best method of reducing the loss from this source is, of course, to lag

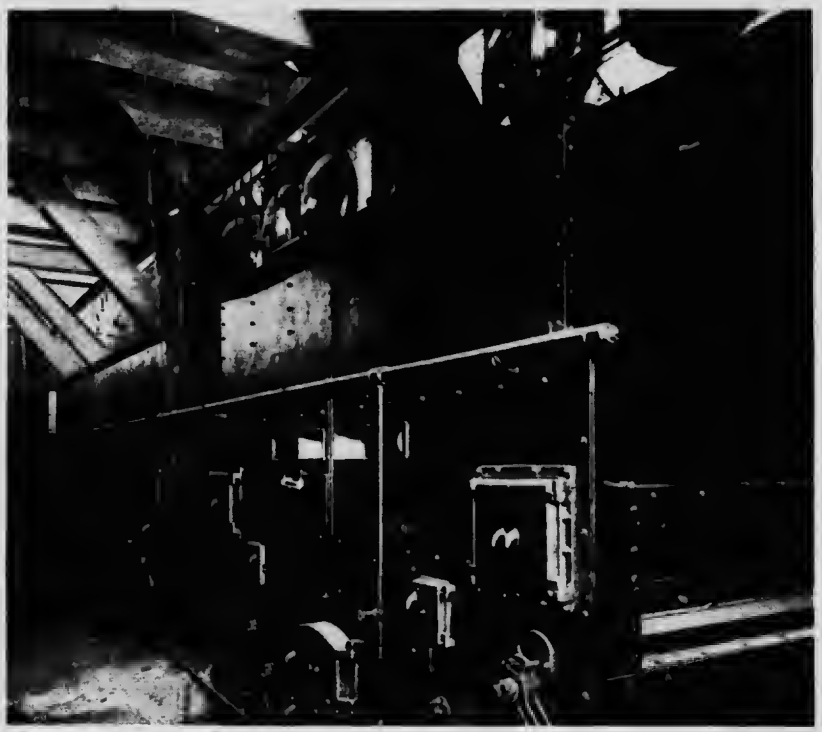

FIG. 9. BOILER ROOM SHOWING MURPHY FURNACE INSTALLATION.

the pipes well with some heat insulating material; this feature in the original layout was somewhat neglected resulting in a hot tunnel and large quantities of condensed steam in the main pipe, this condensation being drained from the pipe through traps to the power house. It was found necessary later to instal a vacuum pump in the power house to pump this condensation back and deliver it to the hot well, and with this addition the system works quite satisfactorily.

Besides the main heating pipe, the tunnel contains a live steam main of 5 in. diameter, where it leaves the power house, also the main gravity return line of 8 in. diameter, and a 3 in. return line to the vacuum pump from the 20-in. main. The live steam is carried at 50 lbs. pressure and is used principally in the Main Building (1), Burwash Hall (20), Knox College (21), and the Household Science Building (14).

Besides these pipes all electric wires are carried on the walls of the tunnel.

Tunnel Construction

The main tunnel through which all steam pipes and electric wires are distributed to the various buildings, is of concrete and of 5 ft. x 6 ft., inside dimensions, where it leaves the power house. Its walls are vertical and 8 in. thick, while the roof slab slopes from 9 in. at the centre to 6 in. at the walls, and is reinforced where necessary.

The power house is indicated on Fig. 5 by a solid black circle.

Figure 14 shows a section of a piece of tunnel built recently by the Superintendent's Department to connect Knox College (21) with Convocation Hall (12). This shows a considerable improvement over the first tunnel built, in the arrangement of the piping and wiring. The main pipe rests on rollers which in turn are supported by substantial concrete piers securely bolted at the bottom of the tunnel; this point requires attention or the gradual movement of the pipe due to expansion, will work the piers loose in a short time.

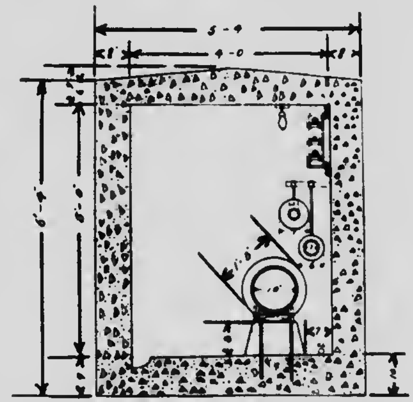

FIG. 14. SECTION OF TUNNEL CONNECTING KNOX COLLEGE WITH CONVOCATION HALL.

this trouble having actually developed in the original layout. The plant has been remodeled in many respects since first installed and this work has been done under the supervision of A. D. LePan, Joint Superintendent of Buildings and Grounds, under whose direct supervision the plant is operated.

Efficiency Test of Boiler Plant

The object of the test was to find the efficiency of the boiler plant under actual working conditions. While the boilers were cleaned shortly before the test, there was no special preparation made to insure anything but a normal efficiency.

The test was conducted by the writer assisted by J. D. Thompson, Demonstrator in Mechanical Engineering, and the members of the 1916 graduating class. A. D. LePan, Joint Superintendent, and W. H. Bonus, of the Superintendent's office, gave every assistance in preparing for the test. The operation of the plant was under the direction of C. Moseley. The accompanying table embodies in its detail the various factors entering into the test, together with the obtained results:

FIG. 11. THREE SMART-TURNER DUPLEX BOILER FEED PUMPS WITH OUTSIDE END-PACKED PLUNGERS AND POT VALVES.

1—Name of Plant	University of Toronto Heating and Lighting Plant
2—Number and kinds of boilers	Five Babcock and Wilcox water tube
3—Kind of furnace	Murphy Automatic
4—Grate Surface—Inclined grates—	
Projected area	328 sq. ft.
Actual area	454 sq. ft.
5—Heating surface— Total	21,264 sq. ft.
8—Date	Jan. 17th, 1916
9—Duration	11 hours
Average Pressures, Temperature, Etc.	
10—Kind and size of coal	Vinton, Slack
11—Steam pressure by gauge	153 lbs per sq. inch
12—Steam pressure absolute	167.6 lbs. per sq. inch
13—Temperature of feed water entering boiler	173° F.
14—Temperature of escaping gas leaving boiler	487° F.
15—Force of draft between damper and boiler	0.4" water
(a)—Draft in furnace	0.16
16—State of weather	Fair and cold (10° above zero)
17—Percentage of moisture in steam	1.5%
18—Factor of correction for quality of steam	98.5%
19—Total coal as fired	67,900 lbs.
19a—Total siftings weighed back and credited to furnace	6,130 lbs.
19b—Total net coal as fired	61,770 lbs

20—Percentage of moisture in coal as fired 3.51%
21—Total weight of dry coal fired .... 59,600 lbs.
22—Total ash, clinkers and refuse (dry) .... 5,372 lbs.
23—Total combustible burned .... 54,228 lbs.
24—Percentage of ash and refuse in dry coal 9%
25—Total weight of water fed to boiler .... 563,720 lbs.
26—Total weight of water evaporated corrected for quality of steam .... 555,250 lbs.
27—Factor of evaporation 1.088
28—Total equivalent evaporation from and at 212° F. corrected for quality of steam .... 604,112 lbs.

Average Hourly Quantities and Rates.

29—Dry coal per hour .... 5,418 lbs.
30—Dry coal per sq. ft. of grate surface per hour .... 11.93 lbs.
31—Water evaporated per hr. corrected for quality of steam .... 50,477 lbs.
32—Equivalent evaporated per hr. from and at 212° F. corrected for quality .... 54,919 lbs.
33—Equivalent evaporation per hr. from and at 212° per sq. ft. of heating surface 2.58 lbs.

Capacity.

34—Boiler horse-power developed (average) 1,592
35—Rated capacity per hr. (10 sq. ft. H.S. per boiler H.P.) 2,126
36—Percentage of rated horse-power developed 74.9%

Economy.

37—Water fed per pound of coal as fired 9.12
38—Water evaporated per lb. of dry coal 9.31
39—Equivalent evaporation from and at 212° per lb. of coal as fired 9.78
40—Equivalent evaporation from and at 212° per lb. of dry coal 10.14
41—Equivalent evaporation from and at 212° per lb. of combustible 11.14

Efficiency.

42—Calorific value of 1 lb. of dry coal by calorimeter .... 14,800 B.T.U.
43—Calorific value of 1 lb. of combustible by calorimeter .... 15,800 B.T.U.
44—Efficiency of boiler furnace and grate 66.5%
45—Efficiency based on combustible 68.3%
46—Cost of coal per ton of 2,000 lbs. delivered in boiler room $3.525
47—Cost of coal required for the evaporation of 1,000 lbs. of water under observed conditions .... 19.5¢
48—Cost of coal required for evaporating 1,000 lbs. of water from and at 212° F.... 18.02¢
49—Note on smoke: Very little noticeable during tet.
51—Analysis of chimney gases—

	Average.
CO_2	9.7
O	10.1
C O	0.1
N by difference	80.1

52—Proximate analysis of coal

	Per cent.
(a) Moisture	0.465
(b) Volatile matter	21.467
(c) Fixed carbon	71.358
(d) Ash	6,710
(e) Sulphur separately determined	2.00

As will be observed from these results, the plant possesses ample capacity for all heating requirements, and, being connected to local supply sources, occasional demands for lighting current in excess of the plant capacity in operation can be instantly met without having to force the boilers or start up additional generators. These conditions enable the plant to be run at a fairly steady load with no sudden or unexpected variations so that conditions of at least as great or perhaps greater efficiency than those indicated by the test results are doubtless constantly maintained under regular operation.

Operating Data

The cost of production for three successive seasons from 1912-13 are tabulated below, as well as tables showing the amount of coal used and the temperatures obtaining during the different months of these seasons:—

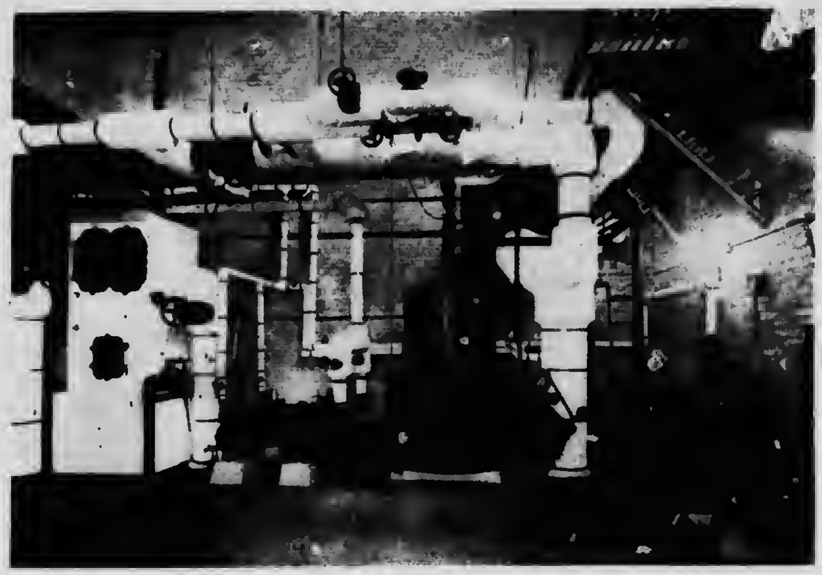

FIG. 13. AUXILIARY EQUIPMENT IN ENGINE ROOM.

COST OF PRODUCTION.

	1912-13 Total cost	1912-13 Cost per sq. ft. radiation in cents	1913-14 Total cost	1913-14 Cost per sq. ft. radiation in cents	1914-15 Total cost	1914-15 Cost per sq. ft. radiation in cents
Cost of coal	$29,429.52	17.23	$26,649.23	15.12	$25,135.64	12.80
Cost of city water ..	510.62	.30	265.90	.15	209.00	.11
Repairs and renewals	2,393.39	1.41	3,674.89	2.08	5,354.06	2.73
Salaries (Engineers, Firemen, Helpers),	8,713.81	5.12	7,992.47	4.54	7,972.25	4.05
Elec. cur. purchased	1,100.66	.65	1,424.24	.81	1,329.32	.66
Total cost of operat'n	$42,148.00	24.71	$40,006.73	22.70	$40,000.37	20.35
Additional Data—						
Total sq. ft. radiation		170,221		176,203		196,534
Total current generated (Kw. hrs.)		395,395		351,231		390,655
Total water evaporated		112,329,661 lbs.		121,657,911 lbs.		117,421,163 lbs.
Total cost of coal required for evaporating 1,000 lbs. of water under observed conditions		26.2 cents		21.9 cents		21.4 cents
Cost of evaporation per 1,000 lbs. steam		38 cents		33 cents		24 cents

Note:—1—The increased charge on repairs and renewals is accounted for by extensive alterations which have ultimately reduced the cost of operation.

2—In this distribution of cost no charge is made for light and power or high pressure steam service.

TEMPERATURES.

On a Basis of Average Taken from 1840 to 1898.

	1912-13. Degrees	1913-14. Degrees	1914-15. Degrees
October	50.6—4.05 above aver.	51.6—5.1 above aver.	52.75—6.20 above aver.
November	40.5—[illegible].54 "	42.2—6.3 "	38.13—2.17 "
December	32.6—.41 "	22.4—7.2 "	25.72—0.47 "
January	31.3—0.45 "	25.5—3.7 "	23.12—1.77 "
February	20.4—1.77 below aver.	15.5—9.7 below aver.	26.04—3.87 "
March	33.3—4.61 above aver.	20.8—2.1 above aver.	29.93—1.24 "
April	46.3—5.13 "	41.5—0.3 "	49.82—8.65 "
May	54.3—1.90 "	58.5—6.1 "	52.15—0.30 below aver.
Yearly average	4.29 "	2.85 "	2.80 above aver.

COAL USED.

Average daily consumption.	1912-13. tons.	1913-14. tons.	1914-15. tons.
Sept. 25-Oct. 31	17.0	14.2	13.2
November	36.5	31.4	29.1
December	49.0	35.7	41.5
January	43.8	46.0	44.5
February	58.2	57.4	41.9
March	42.8	37.6	28.6
April	23.6	24.2	18.6
May	10.1	10.1	7.0
Total consumption	8,584	7,700	7,146

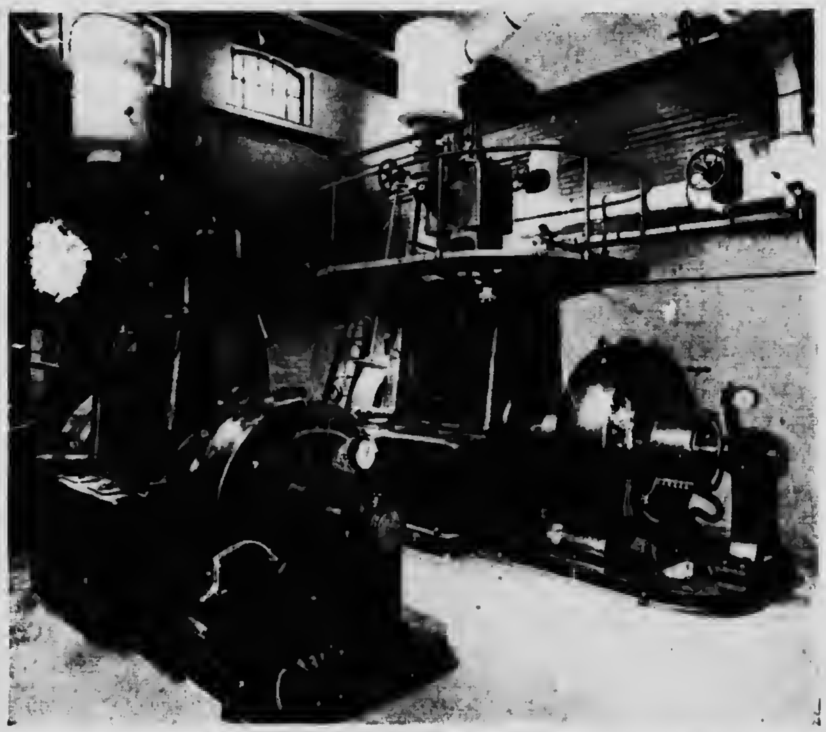

FIG. 12. ROBB-ARMSTRONG ENGINES AND WESTINGHOUSE GENERATORS.