

December 3, 1878.

JAMES ABERNETHY, Vice-President,  
in the Chair.

The following Candidates were balloted for and duly elected :

WILLIAM BAXTER, LESLIE CLARK, GRANVILLE CARLYLE CUNNINGHAM, GEORGE EDWARD GRAY, JACOB HIGSON, JOHN HIGSON, ALEXANDER MACNAB, ALFRED PENNY, Jun., JOHN RALPH REES, WILLIAM RUSS, WILLIAM HENRY STUBBS, and JOHN SWINBURN, as Members.

It was announced that the Council, acting under the provisions of Sect. III., Cl. 8 of the Bye-Laws, had transferred HENRY BANCROFT, EDMUND SCOTT BARBER, HENRY PURDON BELL, JOSEPH BRADY, JOHN WILLIAM JOHNSON, EDWARD HENRY KEATING, CHARLES BENJAMIN KNORPP, ROBERT REYNOLDS, and LIONEL HENRY SHIRLEY, from the class of Associate to that of Member.

Also that, under the provisions of Sect. IV. of the Bye-Laws, the following Candidates, having been duly recommended, had been admitted as Students of the Institution :—JOSEPH ARMSTRONG, FRANK WILLIAM BELFIELD, VALENTINE JOHN STUART BLOMFIELD, WALTER LONGLEY BOURKE, ALEXANDER BREMNER, NORRIS BRETHERTON, FRANK CHAUNTLER, WILLIAM HENRY WALTER COLEY, WILLIAM HENRY EDINGER, ARTHUR SCUDAMORE EMERY, HANS DITLER FABRICIUS, GEORGE SEPTIMUS FIRTH, ROBERT VINCENT GLOVER, LLOYD HASSELL, EDWARD BERESFORD HEARNE, WILLIAM FIELD HOW, REGINALD GRANT JACKSON, GEORGE KAY, JOHN LATIMER, WILLIAM MACLEOD MACKINNON, RAYNES LAUDER MACLAREN, CHARLES PERCIVAL METCALFE, ALBERT MOODY, SAMUEL HALL PARKER, HENRY ATWELL PURDON, GEORGE WILLIAM DENNISTOUN SCOTT, WALTER SHELLSHEAR, WILLIAM DICKSON SKRINE, FREDERICK WILFRID SCOTT STOKES, WILLIAM THORBURN, FRANCIS DAVID TOPHAM, EDWARD HENRY TOULMIN, HERBERT TULK, RICHARD WADDINGTON, and ALFRED RALPH WATSON.

No. 1,465.—“On the Heating and Ventilating Apparatus of the Glasgow University.” By WILSON WEATHERLEY PHIPSON, M. Inst. C.E.<sup>1</sup>

GENERAL MORIN, in his well-known “*Études sur la Ventilation*,” has insisted upon a fact that appears to have escaped numerous

<sup>1</sup> The discussion upon this Paper occupied portions of two evenings.

observers. In spite of the lightness of the atmosphere, like all other bodies it obeys the laws of gravitation, and is subject to those laws of inertia in virtue of which no body can change its state of repose or motion except by obeying the forces which act upon it. These elementary principles are frequently lost sight of by persons who occupy themselves with the ventilation of buildings.

It is not uncommon, indeed, to hear announced, as incontestable axioms, that "Air has a tendency to rise;" that "Cold air cannot rise;" that "Warm air cannot fall;" that "Air must not be conducted horizontally;" all of which are errors of judgment based upon false notions, and lead to uncertainty and confusion. In reality, air tends neither to rise nor to fall; it merely obeys the action of the forces by which it is solicited. Thus, in certain places, where warmer than the adjacent air, it rises, and gives place to the heavier cooler air. In this manner the flame of a candle or lamp, or a stove, incites motion in the air adjacent, causes it to rise, and the cold air around to flow towards the heated object. Thus, again, the air in contact with cold walls or windows becomes heavier than that around it and falls, while the latter moves to its place. Now, if slight variations of temperature produce such effects as these, slight variations of pressure or suction will produce similar results.

In the year 1864, when the building of the new University of Glasgow was determined upon, a sub-committee of the professors, amongst whom were Sir William Thomson, Dr. Allen Thomson, Professor H. Blackburn, and the late Dr. W. J. M. Rankine, considered the general principles which should form the basis of the operation to secure for the new building the most efficient system of ventilation and warming. After a lengthened investigation they came to the following conclusions:

1. That the foul air should be removed through outlets as near as possible to the place where it is produced, *e.g.* passages under desks or seats.

2. That the total area of the orifices of such outlets should be about  $\frac{1}{2}$  square foot per sitting, or 28 square inches.

3. That the total area of the orifices of the inlets for fresh air should be about double the area of those of the outlets for foul air, or  $\frac{2}{3}$  square foot per sitting.

4. That the inlets for fresh air should be at a high level and distributed round the circumference of the rooms.

5. That fresh air should be supplied both hot and cold, and each class-room be provided with means for mixing it.

6. That the total supply of air to the class-rooms should be  $\frac{6}{10}$  cubic foot per sitting per second.

7. That the sectional area of the channels or conduits for carrying away foul air should be  $\frac{1}{20}$  square foot per sitting.

8. That the final outlets of the foul air should be so placed that none of it should return to the building.

9. That the fresh air should be drawn from some place where the air is always pure.

10. That the fresh air should be forced in by one or any required number of suitable machines.

11. That the foul-air conduits should lead to chimneys in suitable positions, provided with furnaces capable of being lighted, the area of the furnace grate being  $\frac{15}{1000}$  square foot per sitting.

12. That the hot part of the fresh air should be heated by hot-water tubes, and that the most efficient position for such tubes was in the vertical passages in which the current of air ascends.

These resolutions were forwarded to the late Sir George Gilbert Scott, R.A., the architect, who selected three engineers to submit to the Committee suggestions in a practical form. The plans adopted by the Committee (Plate 6) represent the work carried out under the Author's directions.

In working out these suggestions, it was found that the allowance of  $\frac{6}{10}$  cubic foot of fresh air per second per sitting for class-rooms, if the class was only of one hour's duration, was too much, and that the vertical air shafts necessary to supply this large volume of air assumed such proportions that the walls would not admit of their construction. According to well-known authorities, a supply and extraction of 700 cubic feet of air per hour per sitting is ample in this case. The Author, therefore, based the calculations of the sizes of all air passages, &c., for both the outlet and the inlet of the air, on a supply equal to six times the cubical space of the class-rooms in the hour as a minimum, or about 750 cubic feet per hour per sitting; thus bringing up the total volume of air to be passed through the apparatus per hour to 1,800,000 cubic feet.

The different velocities per second which this volume of air should travel at different parts of the apparatus, to ensure the amount required at the several points with a given area of channel, form the most important item in all plans for ventilation and warming, as regards simplicity of construction, minimum resistance to the flow of air, and cost of the application. No general rule can be laid down with a view of fixing these

velocities, as they depend entirely upon the size, situation, and requirements of each building.

As a guide, however, General Morin gives the following velocities:

	Feet.	Feet.
For main inlets or outlets . . . . .	5.9	to 6.6 per second.
„ 1st series of channels . . . . .	4.3	4.6 „ „
„ 2nd „ „ . . . . .	3.3	3.9 „ „
„ final inlets or outlets . . . . .	2.3	2.9 „ „

Considering the number of experiments and reliable observations made by General Morin on the different systems of ventilation and warming in actual operation, these will be found of great help in determining the area of the channels for any apparatus, but more especially so when exhaustion of the air alone is adopted.

The Author believes that these velocities are too low to produce a practical and economical application, in any extensive system of ventilation and warming. For this reason, in computing the different velocities for the building under notice, he fixed as a basis for calculation that the air should travel through the apparatus as follows:

	Feet per Second.
1. Fan . . . . .	12
2. Distributing channels from fan to air-chambers . . . . .	6
3. Distributing channels from warm air-chambers to vertical flues . . . . .	5
4. Remaining parts or vertical flues to rooms . . . . .	4

The velocities for the vitiated air channels and flues were calculated in a similar manner, assuming the ascending velocity in each extracting shaft to be 7 feet per second. The different velocities of the air in motion having been fixed, the requisite size of any flue or channel was obtained by dividing the volume of air supplied per second by the velocity per second. This will be found in practice sufficiently accurate. Thus, for a supply of 750 cubic feet of air per hour per sitting, or  $\frac{1}{2}$  cubic foot per second per sitting, the area of the inlets from the apparatus to the class-rooms, calculated at the velocities above-named, should be  $\frac{1}{18}$  square foot per sitting, or 8 square inches; and the area of the exit  $\frac{1}{20}$  square foot, or 7 square inches per sitting. For a class-room of two hundred sittings, to receive a supply of 150,000 cubic feet of fresh air in the hour, 11 square feet of opening would be required for inlet, and  $9\frac{3}{4}$  square feet for outlet. Although this difference in the area of inlet to that of the area of escape works

well in practice, authorities do not all agree; and whilst some would rather that the area of outlet should be larger than the area of inlet, on account of increase of volume in the vitiated air, Professor Pettenkofer states, from a series of experiments on the ventilation of different buildings, that, provided ample provision is made for the inlet of fresh air, the vitiated air will find its way out of any ordinary occupied space. The Author is of opinion that these remarks apply more to small rooms or private apartments, where but few sources of vitiation of the air exist, and that in such cases Professor Pettenkofer's views may be correct. However, the disposition of the inlets and outlets of the air for ventilating and warming any given space evidently forms an important matter for consideration. For the building under notice it was determined by the Committee of Professors, but this by no means decides the question for all kinds of buildings.

Experience obtained in different classes of buildings, where various positions of inlets and outlets have been adopted, shows that the best solution of this problem consists in having all inlets of fresh air, either warm or cold, at a mid-level of the space to be ventilated; and that the extraction of the vitiated air should be both from a high and a low level simultaneously. The mid-level disposition is more effective than the higher level distribution, besides being of more economical construction; it has great advantage over the low-level distribution in being capable of delivering the air in larger volumes, and at higher velocities, without fear of draughts being felt. Where the height of the space to be warmed is very great, as in the Royal Albert Hall of Arts and Sciences, South Kensington, a mid-level distribution would not have been so effective; the air is therefore distributed at different levels, to lessen the cooling influence whilst in motion over so great a vertical space.

In considering the best form of channel, or air passage, it should be borne in mind that the resistance to the air in motion increases as the square of the velocity of the current, and is directly proportional to the perimeter of the channel, and inversely as the area of the transverse section perpendicular to the axis of the current. As stated by Mr. Hawksley, Past President, Inst. C.E.,<sup>1</sup> it follows essentially the law which regulates the flow of inelastic fluids through tubes. The circular or oval form of channel would suggest itself as the best shape to reduce to a minimum this resistance to

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<sup>1</sup> *Vide Minutes of Proceedings Inst. C.E., vol. xxxiii., p. 53.*

the flow of the air. But, as passages of this form entail more labour and expense in their construction than any other, the Author, in many of his applications, has been led to adopt channels having their height nearly equal to their width, with straight sides of an even or smooth surface, flat bottoms, and semi-circular or segmental arches for covering. In the particular application which forms the subject of this Paper, the covering of the channels from all the air chambers is formed of plates of corrugated iron with a layer of about 6 inches of concrete over them; but the channels from the fan to the different air chambers have semi-circular arches formed in two  $4\frac{1}{2}$ -inch rings of brickwork.

When constructing the flues in the thickness of the walls, the Author prefers that all the joints be struck fair, and the flues lime-whited, as the resistance to the flow of the air is thus more reduced than if the flues are pargeted in the usual way. For the channels in the roofs for conveying away the vitiated air, sheet-iron, zinc, lath and plaster, or matched boarding, lined outside with canvas, and painted, are often adopted. The question of economy frequently decides the materials to be used in the construction of the air passages; but in no case should the desirability of a smooth surface—with as few sharp angles, sudden enlargements or contractions, as possible—be overlooked.

The details concerning the levels, the directions of the air channels, and the position of the vertical shafts, should be accurately laid down on the architect's working drawings previous to the works being commenced.

As to the shape of the fan for supplying 1,800,000 cubic feet of air in the hour, the Author was governed to a great extent by the successful employment of similar fans previously in buildings ventilated under his direction. His reason for adhering to the form hereafter described is, that whilst screw fans are of no more complicated form of construction than the ordinary rotary fans, they are less liable to get out of order. They appear also, when moving at low pressure, to afford the same effective power, provided the minimum of resistance is given to the inlet and outlet of the air, and the delivery passages are of large dimensions.

The force necessary to propel air through any passage being equal to the square of the velocity into the total surface multiplied by the coefficient of friction, pressure of the air being uniform, and admitting the coefficient of friction in air passages as given by  
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Mr. Hawksley at 0·03, Mr. D. P. Morrison submits, as a practical formula for ventilation, the following expression<sup>1</sup>:

$$H = \frac{K V^2 P L}{A}.$$

H = the head of pressure, in feet of air of the same density as the flowing air.

L = the length of the pipe or passage in feet.

P = the perimeter of the cross section in feet.

A = the area of the pipe or passage in square feet.

V = the velocity in thousands of feet per minute.

K = the coefficient of friction taken at 0·03.

Taking D as the diameter for circular passages whose diameter is small in proportion to their length,

$$H = K V^2 \times \frac{4 L}{D},$$

and for irregular-shaped channels,

$$H = K V^2 \times \frac{P L + 200 A}{A}.$$

When this formula is applied for the calculation of the head of pressure, H, in an apparatus for heating and ventilating where the velocities and the area of channels have various proportions, it is found necessary to take a mean area, a mean perimeter, and a mean velocity for the whole length of the channels, without which too high a head of pressure would be given. Applying it, therefore, for the requirements in question, and assuming that—

V = the mean velocity through the channels = 6·75 feet per second, or 0·400 in thousands feet per minute.

A = the mean area in square feet = 26·83

P = the mean perimeter in square feet = 19·63

L = the length of air passage in feet = 810

K = the coefficient = 0·03

$$H = \frac{0\cdot03 \times 0\cdot400^2 \times 19\cdot63 \times 810}{26\cdot83} = 2\cdot85,$$

2·85 feet of air = 0·04 inch of water.

Taking into consideration the friction of the air through the channels, 1 inch or 5·2 lbs. of water on the square foot, would nearly represent the total head of pressure; and thus a volume

<sup>1</sup> Vide Minutes of Proceedings Inst. C.E., vol. xlv., p. 27.

of 30,000 cubic feet of air moved per minute with this head of pressure represents an effective HP. of

$$\frac{30,000 \times 5.2 \text{ lbs.}}{33,000} = 4.54.$$

At such a low pressure the effective power of the fan does not exceed 50 per cent. of the indicated HP. of the engine, so that about 7 HP. will be required for moving the air.

This method of calculating the power necessary to drive the air through passages bears a fair comparison with Table No. III. on Fans for Public Buildings<sup>1</sup> by Mr. Briggs. He gives, for a fan 7 feet in diameter, making from 140 to 280 revolutions per minute, and delivering from 20,000 to 40,000 cubic feet of air per minute,  $1\frac{1}{2}$  to  $11\frac{1}{2}$  HP. For the Glasgow University, the Author adopted the following method: Taking the velocity of the air at 12 feet per second, the diameter of fan to supply a volume of air equal to 1,800,000 cubic feet per hour, or 30,000 cubic feet per minute, will be 7 feet 6 inches. The amount of air put in motion per second would thus be 500 cubic feet, and the weight of air to be lifted per minute

$$= \frac{500 \times 60}{13} = 2,308 \text{ lbs.}$$

At three revolutions per second the velocity of the fan would be 70 feet, and the height traversed by a gravitating body to acquire this velocity per second is equal to 77 feet, then

$$\frac{2,308 \times 77}{33,000} = 5.38 \text{ HP.}$$

equivalent in actual practice to from 8 to 9 HP.

The volume of air evacuated by an extraction shaft increases in direct ratio to its area, and proportionately with the square root of the height, and the square root of the difference of the external and internal temperatures. It is found, experimentally, that, the internal temperature of a shaft remaining the same, an increased area has very little influence on the velocity of the up-current, though an increased resistance is given by the additional surface exposed to the air in motion. Also that, for an economical construction, when large volumes of air are to be exhausted, it is better to increase the area than to raise the temperature of the shaft. It must, however, be borne in mind, that to ensure a steady up-current of from 4 to 8 feet per second, a difference of temperature

<sup>1</sup> *Vide Minutes of Proceedings Inst. C.E., vol. xxx., p. 295.*



of 30° to 40° Fahrenheit must be maintained in the shaft, and that the termination of discharging openings should be well protected against the action of the wind. These remarks are applicable on the assumption that a uniform temperature is maintained in the whole height, and that no allowance need be made for any difference of temperature between the bottom and the top of the shaft.

Péclet's formula,  $U = 8.85 \sqrt{\frac{a D H (t - T)}{L + 4 D}}$  in which  $a$  = coefficient of friction, for the calculation of the velocities of the current in chimneys, having been found to lead to too high a result, several engineers have endeavoured to bring it to a more practical shape, and to make it coincide with experiments and direct observations. As the results of a series of measurements, the following formula has been prepared for calculating the velocity in any extracting shaft:

$$U = \sqrt{\frac{D H (t - T)}{L + 16 D}}.$$

$U$  = the velocity per second.

$D$  = the diameter of the shaft.

$H$  = the height of the shaft.

$T$  = the external temperature.

$t$  = the internal temperature of the shaft.

$L$  = the length of the evacuation channels.

General Morin remarks that this formula is nearly identical with the one he obtained by theoretical calculations, assuming the coefficient of resistance to be 0.01. The Author, when computing the proportion of the channels and extraction shafts in the apparatus to be described, used this formula, assuming the difference of temperature between the shafts and the external air to be from 20° to 25° Fahrenheit.

In determining the heating surface of an apparatus, consideration should be given to the climate of the place, the position and subsoil of the building, the materials and thickness of the walls, and the area and construction of the windows. When the subsoil is of clay, and the heating surface is placed in channels or chambers level with the foundations, great care should be taken to ensure that the drainage of the building is sufficiently deep to clear all water from these channels, or much loss of heating power will be caused by the evaporation of the surface water which collects in different parts of the apparatus.

The calculation of the heating surface to be fixed in a warming

chamber, when the air to be heated is put in motion by mechanical means, is much more complicated than that necessary for the power required when the heating surface is fixed in the space to be warmed.

In the apparatus about to be described, or in any other on a similar principle, allowance above the actual volume of air to be warmed must be made for the increased velocity of the air in motion, for the loss of heat from the distance traversed by the air to the space to be warmed, and for the loss of heat from the heating-surface being below ground and in chambers.

The Author has worked out several formulæ, and finds one which meets his requirements, and which has been used in proportioning the present apparatus, in which

$$L = \frac{(P - t) \times (T - t)}{P - T} \times 0.0045 C.$$

$L$  = the length of 4-inch hot-water pipe fixed in the chamber.

$P$  = the temperature of the 4-inch hot-water pipes taken at 180° Fahrenheit.

$T$  = the temperature to be maintained in the class-rooms, 57°.

$t$  = the temperature of the external air taken at 20° Fahrenheit.

$C$  = the volume of air to be warmed per minute.

0.0045 = the coefficient for 4-inch hot-water pipes.

The volume  $C$  of air in the building under consideration is obtained by multiplying the cubic space of the class-rooms to be warmed per minute by the velocity of the air in motion in the chambers, taken at 3 feet per second. The value of  $C$  for the different chambers is:

	Cubic Feet.
In the south-west chambers . . . . .	12,300
„ south-east „ . . . . .	10,500
„ east „ . . . . .	15,800

To the quantity of 4-inch hot-water piping calculated, about one-third more was added, on account of the pipes being placed below ground. Thus the proportional heating surface fixed in each chamber was as follows:

	Feet.
In the south-west chambers . . . . .	3,500
„ south-east „ . . . . .	3,000
„ east „ . . . . .	4,500

Besides this amount of heating surface, 4-inch flow and return pipes were fixed in all channels conveying warm air over a distance of more than 60 feet from the main source of heat.

According to General Morin, 12 square feet of heating surface are required for every 1,000 cubic feet of space to be warmed, when the pipes are in chambers; and for efficient work, the warm air must not be conveyed horizontally more than 60 to 70 feet. Monsieur Grouville allows from 4 to 5 feet of heating surface per 1,000 cubic feet of space, when the pipes are in the rooms to be warmed, this allowance being calculated on the assumption that the temperature of the pipes is 176° to 194°. Mr. Anderson, in his valuable experiments on the heating power of hot-water pipes,<sup>1</sup> estimates that about 15 square feet of heating surface are necessary for every 1,000 cubic feet of air to be warmed when the pipes are concealed, assuming their temperature to be about 160°. Mr. Hood deduced from numerous experiments that from 5 to 12 square feet of heating surface are necessary per 1,000 cubic feet, according to the requirements of the building; but that, when the pipes are in trenches, an additional 5 to 7 per cent. must be allowed to make up for the heat lost by this arrangement. From experiments by Tredgold, water contained in an iron pipe of 4 inches diameter internally, and 4½ inches externally, loses 0°·851 Fahrenheit of heat per minute, when the excess of its temperature is 125° above that of the surrounding air. From these data Mr. Hood estimates that 1 foot in length of 4-inch pipe will heat 222 cubic feet of air, 1° per minute. According to Mr. D. K. Clark, however, this estimate is too low, as it is based on too high a value for the specific heat of air, 0·2767. If the quantity be increased in the inverse ratio assumed, and with the actual specific heat of air, the volume of air raised 1° by 1 foot in length of 4-inch pipe, when the excess of temperature is 126° Fahrenheit, will be—

$$222 \times \frac{0\cdot2767}{0\cdot2377} = 258 \text{ cubic feet.}$$

The proportional heating surface adopted by the Author bears a fair comparison with the usual practice. It maintains the different air chambers at the temperature of 100°, even in severe weather.

The selection of the proper form of boiler for an extended apparatus of this kind is of great importance, as upon it depends the efficient and economical working of any application. Mr. Hood remarks, in his 'Treatise on Warming Buildings,' &c.,<sup>2</sup> that "it is no recommendation of a boiler" "to say that it contains a certain number of square feet of heating surface in a given

<sup>1</sup> *Vide Minutes of Proceedings Inst. C.E., vol. xlviii., p. 257.*

<sup>2</sup> Page 81.

space; for unless this surface can be acted upon by the radiant heat of the furnace, a boiler of less than one-half the superficial measurement, if judiciously contrived for this object, may greatly exceed it in power." The conditions of a good hot-water boiler are "that it shall expose the largest surface to the fire in the smallest space; that it shall allow free circulation of the water through its entire extent;" and that it shall be of simple form in its construction. No boiler, in the Author's opinion, meets these requirements in a more economical manner than the Cornish type, when the power of the apparatus exceeds 2,000 superficial feet of heating surface. In this application Cornish boilers have been adopted, their size having been determined by assuming 35 superficial feet of pipe to 1 square foot of effective boiler-heating surface. The whole of the internal flue has been calculated as effective, and the side flues as one-half effective, heating surface.

In an apparatus for heating the air artificially, its hygrometrical state should be considered, and means adopted, when found necessary, to restore the air to its proper degree of moisture before leaving the heating chamber. Surgeon-Major de Chaumont, M.D., in a Paper read before the Royal Society,<sup>1</sup> gives the following data as the standard of good air for ventilation: Temperature of dry bulb 63° to 65° Fahrenheit, of wet bulb, 58° to 61°; in any case the difference between the two thermometers (wet and dry bulbs) should not be less than 4°, nor exceed 5°, the temperature never being much below 60°. Vapour should not exceed 4·7 grains per cubic foot at a temperature of 63°, or 5 grains at a heat of 65°. Humidity should not exceed 73 to 75 per cent.. Carbonic acid (respiratory impurity) should not exceed 0·0002 per cubic foot, or 0·2000 per 1,000 volumes. Taking the mean external air ratio at 0·4000 per 1,000, this would give a mean internal air ratio of 0·6000 per 1,000 volumes. Of the several arrangements for moistening the air, the best are those that present a large and shallow evaporating surface. When the air in circulation is heated by hot water apparatus at low pressure, and when its temperature is not above 100°, little difficulty is experienced in maintaining the proper interval between the wet and dry bulb thermometers in any warming chamber, or to ensure to the incoming air its proper degree of moisture.

The apparatus consists of a fan, 7 feet 6 inches in diameter, worked by an 8-HP. steam engine, fixed near the main tower of

<sup>1</sup> *Vide Proceedings of the Royal Society*, vol. xxiii., p. 199.

the building. The fan draws its supply of air from four shafts, 5 feet deep by 3 feet wide, formed in the wall of the tower, terminating in a chamber, into which the external air is admitted. By this means a supply of fresh and pure air is obtained from a height of 100 feet, far from all local causes of contamination. The fan then forces the air through a series of subterranean passages leading into five distinct air chambers. (Plate 6, Fig. 1.)

The south-west and south-east chambers are under the gateways leading to the quadrangles; the east chamber is in a sub-basement in the centre of the east wing; and the north-west and north-east chambers are constructed in each side of the main walls of the libraries and museums. In these chambers the fresh air is warmed previous to its distribution, by being passed over the surface of 4-inch hot-water pipes, arranged in coils, each chamber having its distinct hot-water boiler. The heating powers obtained in these chambers vary according to the amount of work they have to do. The combined heating surface throughout the building is equal to about 21,000 feet of 4-inch pipe, and the average temperature these chambers are maintained at is 100° Fahrenheit.

The air, having been sufficiently heated in the chambers, is then conveyed by branch channels to a series of vertical air shafts formed in the thickness of the walls, having their lower openings in the horizontal channels, and their upper apertures in the class-rooms. These shafts are 18 inches broad by 12 inches deep for the ground floor, and 12 inches square for the upper floors. The fresh air is admitted in all the class-rooms, with few exceptions, near the ceiling; but in the libraries and museum, which have distinct apparatus, the air enters at the level of the skirting. In some of the class-rooms used in the morning, in addition to the openings at a high level two extra openings are provided at the level of the skirting. The area of inlet to each class-room is equal to  $\frac{1}{8}$  square foot per sitting; and this delivers, at a moderate velocity, a supply of air equal to 750 cubic feet per hour per sitting. Valves of simple construction are fixed to each inlet-opening, and are regulated by the attendants.

For the extraction of the vitiated air from the class-rooms, three shafts have been provided at the south-west, south-east, and east angle towers, the size of each being 5 feet broad by 3 feet wide, and about 96 feet high. The extracting power of the shafts is increased by the waste heat from the hot water and steam boilers being carried inside them by a cast-iron flue or pipe, 2 feet 3 inches in diameter, thus maintaining a temperature of 25°, as a minimum,

above the external air. The extraction shafts communicate with the different class-rooms by a secondary system of horizontal and vertical channels. The sizes of these channels and their branches are calculated on the allowance of  $\frac{1}{20}$  square foot per sitting, and their respective sizes are graduated according to their distance from the main shafts. The exit of the air from the class-rooms is through perforations in the risers of the seats, as shown in Plate 6, Fig. 2; but, in the medical and other class-rooms, which are used in early morning when much gas-light is required, openings for exit have been provided near the ceiling, in addition to these perforations. In the libraries and museum buildings no mechanical extraction of the vitiated air is adopted; but ordinary air flues are carried up in the walls, with discharging openings to the external air over the roofs. In the anatomical department, in which there is a special warming apparatus, after various schemes had been proposed the only system of ventilation adopted was the open windows at a high level around the room. For the chemical laboratory an exhaustion shaft is provided for the removal of noxious vapours.

Cornish boilers, 10 feet long by 4 feet wide, with 2-feet 6-inch tubes, are used for circulating the water in the hot-water pipes in the different chambers, and are all set on the wheel draught, with every facility for cleaning out the flues. The steam boilers, of which there are two, one being supernumerary, are 10 feet long by 4 feet 6 inches wide, with 2-feet 4-inch tubes, set in the same way. They are made of the best Glasgow iron,  $\frac{3}{8}$  inch thick, with Lowmoor iron over the furnaces.

The fan, to propel the air through the passages, is on the principle of the Archimedean screw, having four blades set at angles of  $60^\circ$ , on a spindle parallel to the axis of the air channel. The blades are slightly twisted, to present in rotation an uniform resistance to the air in motion. The shaft of the fan is  $2\frac{1}{2}$  inches in diameter; it runs between two pillar blocks carried on two cast-iron girders, fixed across the centre of the chamber. The fan is driven direct off the fly-wheel of one of James Robertson's valveless steam engines, having a vertical cylinder  $8\frac{1}{2}$  inches in diameter and a 12-inch stroke, the whole forming a compact piece of machinery.

The 4-inch pipes fixed in the different chambers are ordinary hot-water pipes, weighing about 100 lbs. to the 9-feet length. They were all proved to 200-feet water-pressure before delivery. They are generally arranged in upright coils extending the whole length and width of the chambers, thus presenting to the incoming air a

large exposed heating surface. In the north-west and north-east apparatus, for the museums and libraries, the pipes are arranged in four chambers as continuous coils, running the whole length of the main walls.

The extent of heating surface exposed in each chamber is—

	Square Feet.
In the south-west chamber . . . . .	3,500
„ south-east „ . . . . .	3,000
„ east „ . . . . .	4,500
„ north-west „ . . . . .	4,500
„ north-east „ . . . . .	4,000
„ anatomical department . . . . .	645
„ chemical „ . . . . .	565
	<hr/> 20,710 <hr/>

In the Appendix will be found a register of the average monthly temperatures of the class-rooms, recorded by the engineer at 8 A.M. It will be seen that, whatever may be the external temperature, the rooms are maintained uniformly at about 54°, a temperature which meets all requirements at that early hour. The amount of fresh air supplied by the fan corresponds with the temperatures given, and is about 1,600,000 cubic feet per hour.

A series of experiments to ascertain the amount of air delivered by the fan, in which both Biram's and Casella's anemometers were used, gave the following results :

FIRST SERIES, OCTOBER 29, 1870.

HP. of steam engine . . . . .	8
Pressure of steam . . . . .	31 lbs. to square inch.
Strokes of the engine per minute . . . . .	91
Diameter of the fan . . . . .	7 feet 6 inches.
Revolutions of the fan per minute . . . . .	273
Velocity of air through the fan per } second . . . . .	10·83 feet.
Volume of air delivered per hour } through the fan . . . . .	1,722,600 cubic feet.

The volume of air, measured with anemometers at the mouths of the chambers under the same conditions, was, per hour—

	Cubic Feet.	Feet.
South-west chamber . . . . .	352,200	velocity = 6·30 per second.
South-east „ . . . . .	339,900	„ = 5·50 „
East „ . . . . .	468,000	„ = 6·50 „
North front „ . . . . .	402,000	„ = 5·00 „
	<hr/> 1,562,100	
Leakage and friction . . . . .	160,500	
	<hr/> 1,722,600 <hr/>	

## SECOND SERIES, OCTOBER 31, 1870.

HP. of the steam engine . . . . .	8
Pressure of steam . . . . .	32 lbs. per square inch.
Strokes of the engine per minute . . .	99
Diameter of the fan . . . . .	7 feet 6 inches.
Revolutions of the fan per minute . .	297
Velocity of air through the fan per } second . . . . .	11.60 feet.
Volume of air delivered per hour } through the fan . . . . .	1,845,000 cubic feet.

The volume of air, measured with anemometers at the mouths of the chambers under the same conditions, was, per hour—

	Cubic Feet.	Feet.
South-west chamber . . . . .	429,840	velocity = 7.83 per second.
South-east   "   . . . . .	360,720	" = 5.83   "
East       "   . . . . .	496,800	" = 6.90   "
North front   "   . . . . .	441,540	" = 5.50   "
	<hr/> 1,728,900	
Leakage and friction	116,100	
	<hr/> 1,845,000	

On both days there was a slight breeze from the south.

Not being satisfied with the foregoing experiments, the Author made another series of observations, to ascertain whether the difference between the amount of air measured at the fan and the amount of air measured at the mouth of each chamber could be an error of the previous series; but the new series of these measurements, of which the following is a mean, gives nearly the same result, and therefore this difference may be accounted for by leakage and friction through the channels.

## THIRD SERIES, NOVEMBER 19 to 23, 1877.

Wind, south west, strong.

External temperature . . . . .	43° Fahrenheit.
Pressure of steam in the boiler . . .	35 lbs. per square inch.
Strokes of the engine per minute . .	92
Revolutions of the fan per minute . .	276
Diameter of the fan . . . . .	7 feet 6 inches.
Area of the opening . . . . .	44.18 square feet.
Velocity of air through the fan per second	11.70 feet.
Volume of air delivered per hour } through the fan . . . . .	1,846,800 cubic feet.



The volume of air, measured at the mouths of the chambers under the same conditions, was, per hour—

	Cubic Feet.	Feet.
South-west chamber	. 502,200	velocity = 9.10 per second.
South-east     "	. 309,600	" = 5.80     "
East           "	. 419,760	" = 5.80     "
North front   "	. 488,000	" = 5.83     "
	<hr/>	
	1,719,560	
Leakage and friction	127,240	
	<hr/>	
	1,846,800	
	<hr/>	

A series of measurements of the volume of air entering and escaping from the class-rooms, indicated that the mean velocity of the incoming air was 4 feet per second, and of the outgoing air 5 feet.

In the south-west block the result of experiments in one class-room was as follows :

Capacity of the room.	. . . . .	32,000 cubic feet.
Area of inlet from the apparatus	. . .	7 square feet.
Area of outlet into the extraction shaft		4½ square feet.
External temperature	. . . . .	40° Fahrenheit.
Temperature of the class-room	. . . . .	57°     "
Temperature of incoming air at the	mouths of the openings . . . . . }	75°     "
Temperature of the outgoing air		
Temperature of the extraction shaft	. . . . .	64°     "
Mean velocity of the incoming air	. . . . .	5.88 feet per second.
"     "     outgoing air	. . . . .	7.50     "     "
Volume of air supplied per hour	. . . . .	148,536 cubic feet.
"     "     extracted     "     "	. . . . .	121,500     "     "     , to which must be added the air es- caping under the risers of the seats not measured.

Observations show that on account of the air being drawn by the fan from so high a level, the amount delivered varies somewhat according to the direction and force of the wind: the situation of the building on a high hill has also a great deal to do with this. The lowest delivery of air, when the average speed of the engine was 90 strokes per minute, was 1,350,000 cubic feet per hour. Valves are fixed in all the subterranean passages, so that the power may be increased, or otherwise, in any particular portion of the building.

The amount of fuel consumed in working the apparatus for six sessions has been as follows :

		Tons.	Cwt.
Session	1871-72 . . . . .	448	15
„	1872-73 . . . . .	427	10
„	1873-74 . . . . .	372	12
„	1874-75 . . . . .	458	18
„	1875-76 . . . . .	462	19
„	1876-77 . . . . .	404	4

In calculating the allowance for the heating surface contained in this building, assuming an average of eight hours' firing per day, and comparing the amount with the quantity of fuel consumed, it will be seen that the average consumption of 2 tons 3 cwt. per day bears a just proportion to the number of feet of heating surface, and to the cubic contents, 2,035,000 feet, of the building; but as an essential part of the apparatus is the regulated supply of fresh air, amounting to 1,800,000 cubic feet per hour, this must be added in order to give a fair estimate of the power of the apparatus. Thus the air moved and warmed by the average daily consumption of 2 tons 3 cwt. of coals is equal to 3,835,000 cubic feet per hour.

The staff consists of one engineer and one stoker, with the assistance of a supernumerary stoker during the winter months.

The cost of maintenance, with a sum set aside for occasional repairs, is about £500 per annum; the average cost of coals in Scotland being taken at 13s. per ton. The total cost of this application, including the construction of the air chambers, air channels, vertical flues, and extracting shafts, has been about £17,000.

In conclusion, the Author may, perhaps, be allowed to state that this application has given general satisfaction; and is, probably, the best arrangement that could have been adopted under the circumstances. The successful issue is certainly attributable, in a great degree, to the persevering labours of the eminent Professors who formed the Ventilating Committee, and to their Architect, the late Sir George Gilbert Scott, R.A.

The communication is accompanied by several diagrams, from which Plate 6 has been compiled.

## APPENDIX.

## GLASGOW UNIVERSITY.

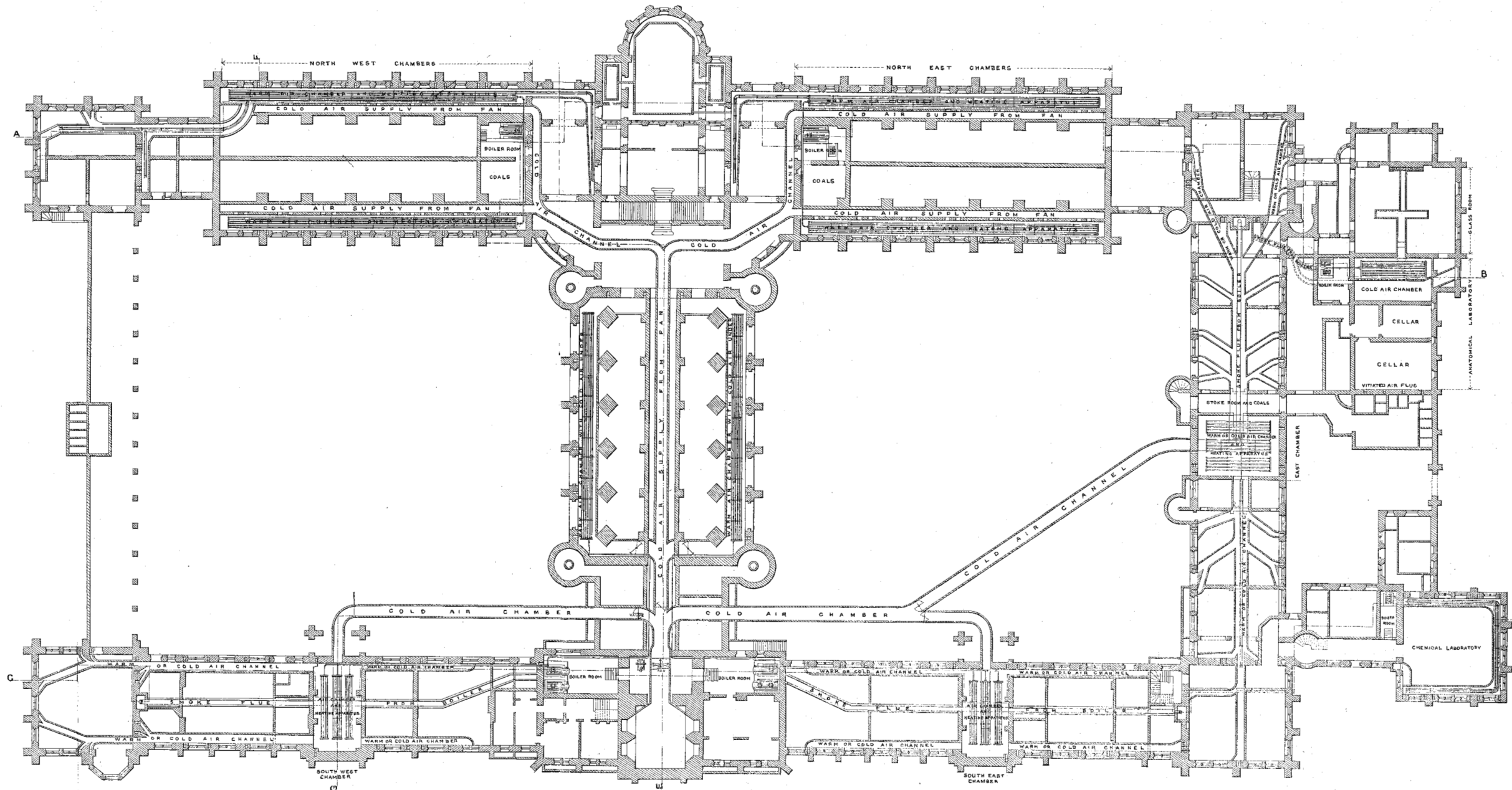
## I.—AVERAGE MONTHLY TEMPERATURES at 8 A.M. Session 1871-72.

Name of Class-rooms.	November.		December.		January.		February.		March.	
	Ex- ternal.	Class- rooms.	Ex- ternal.	Class- rooms.	Ex- ternal.	Class- rooms.	Ex- ternal.	Class- rooms.	Ex- ternal.	Class- rooms.
Humanity . . .	40	51	38	52	36	52	34	50	35	57
Greek . . . .	"	50	"	51	"	50	"	51	"	53
Logic . . . .	"	51	"	51	"	51	"	50	"	52
Moral Philosophy	"	51	"	52	"	53	"	51	"	54
Natural Philosophy	"	56	"	55	"	54	"	54	"	56
Physical Labora- tory . . . . }	"	54	"	54	"	54	"	54	"	54
Mathematics . .	"	50	"	51	"	52	"	51	"	53
Astronomy . .	"	51	"	52	"	52	"	50	"	53
Civil Engineering	"	50	"	51	"	52	"	50	"	53
English Literature	"	51	"	50	"	50	"	51	"	51
Natural History .	"	54	"	54	"	53	"	53	"	56
Divinity hall . .	"	53	"	53	"	53	"	54	"	57
Hebrew	"	55	"	55	"	54	"	53	"	55
Ecclesiastical His- tory . . . . }	"	54	"	54	"	54	"	54	"	55
Biblical Criticism	"	57	"	55	"	55	"	55	"	57
Scottish Law . .	"	53	"	54	"	53	"	51	"	54
Conveyancing	"	52	"	52	"	54	"	53	"	55
Chemistry Class- room . . . . }	"	56	"	54	"	53	"	52	"	54
Chemical Labora- tory . . . . }	"	53	"	54	"	51	"	54	"	55
Materia Medica .	"	50	"	53	"	54	"	50	"	56
Anatomy Class- room . . . . }	"	51	"	52	"	53	"	53	"	53
Anatomical Labora- tory . . . . }	"	48	"	49	"	51	"	50	"	52
Practice of Physic	"	53	"	54	"	53	"	52	"	54
Surgery . . . .	"	54	"	54	"	54	"	51	"	55
Midwifery . . .	"	51	"	52	"	52	"	51	"	55
Forensic Medicine	"	52	"	53	"	54	"	53	"	56
Physiology . . .	"	52	"	53	"	54	"	53	"	55
Library . . . .	"	53	"	55	"	54	"	55	"	55
Museum (Sunday)	"	50	"	52	"	51	"	52	"	53
Reading-room	"	52	"	52	"	51	"	50	"	52
Dr. A. Thomson's room . . . . }	"	57	"	57	"	56	"	56	"	56
Examination hall	"	51	"	52	"	55	"	54	"	54

## II.—AVERAGE MONTHLY TEMPERATURES at 8 A.M. Session 1872-73.

Name of Class-rooms.	November.		December.		January.		February.		March.	
	Ex- ternal.	Class- rooms.	Ex- ternal.	Class- rooms.	Ex- ternal.	Class- rooms.	Ex- ternal.	Class- rooms.	Ex- ternal.	Class- rooms.
Humanity . . .	38	53	36	52	39	52	31	51	35	54
Greek . . . .	"	53	"	51	"	51	"	50	"	51
Logie . . . .	"	52	"	52	"	52	"	50	"	51
Moral Philosophy	"	55	"	53	"	54	"	53	"	52
Natural Philosophy	"	56	"	54	"	55	"	55	"	55
Physical Labora- tory . . . .	"	54	"	55	"	55	"	54	"	54
Mathematics . .	"	53	"	52	"	51	"	52	"	52
Astronomy . .	"	54	"	52	"	52	"	52	"	52
Civil Engineering	"	54	"	52	"	52	"	51	"	51
English Literature	"	51	"	53	"	54	"	52	"	54
Natural History .	"	54	"	51	"	53	"	53	"	54
Divinity hall . .	"	56	"	54	"	53	"	54	"	56
Hebrew . . . .	"	56	"	54	"	54	"	54	"	54
Ecclesiastical His- tory . . . .	"	56	"	54	"	54	"	54	"	54
Biblical Criticism	"	56	"	54	"	56	"	56	"	56
Scottish Law . .	"	54	"	53	"	54	"	53	"	55
Conveyancing . .	"	56	"	54	"	55	"	54	"	56
Chemistry Class- room . . . .	"	54	"	53	"	52	"	53	"	54
Chemical Labora- tory . . . .	"	54	"	55	"	51	"	53	"	54
Materia Medica .	"	54	"	53	"	53	"	52	"	55
Anatomy Class- room . . . .	"	53	"	52	"	54	"	54	"	54
Anatomical Labor- atory . . . .	"	50	"	51	"	51	"	50	"	52
Practice of Physic	"	55	"	55	"	53	"	53	"	54
Surgery . . . .	"	54	"	54	"	54	"	52	"	55
Midwifery . . .	"	53	"	53	"	52	"	51	"	53
Forensic Medicine	"	53	"	54	"	54	"	53	"	55
Physiology . . .	"	54	"	54	"	55	"	53	"	55
Library . . . .	"	55	"	55	"	54	"	55	"	55
Museum (Sunday)	"	54	"	53	"	52	"	52	"	53
Reading-room . .	"	52	"	52	"	51	"	51	"	54
Dr. A. Thomson's room . . . .	"	57	"	55	"	57	"	55	"	55
Examination hall	"	58	"	54	"	55	"	56	"	56

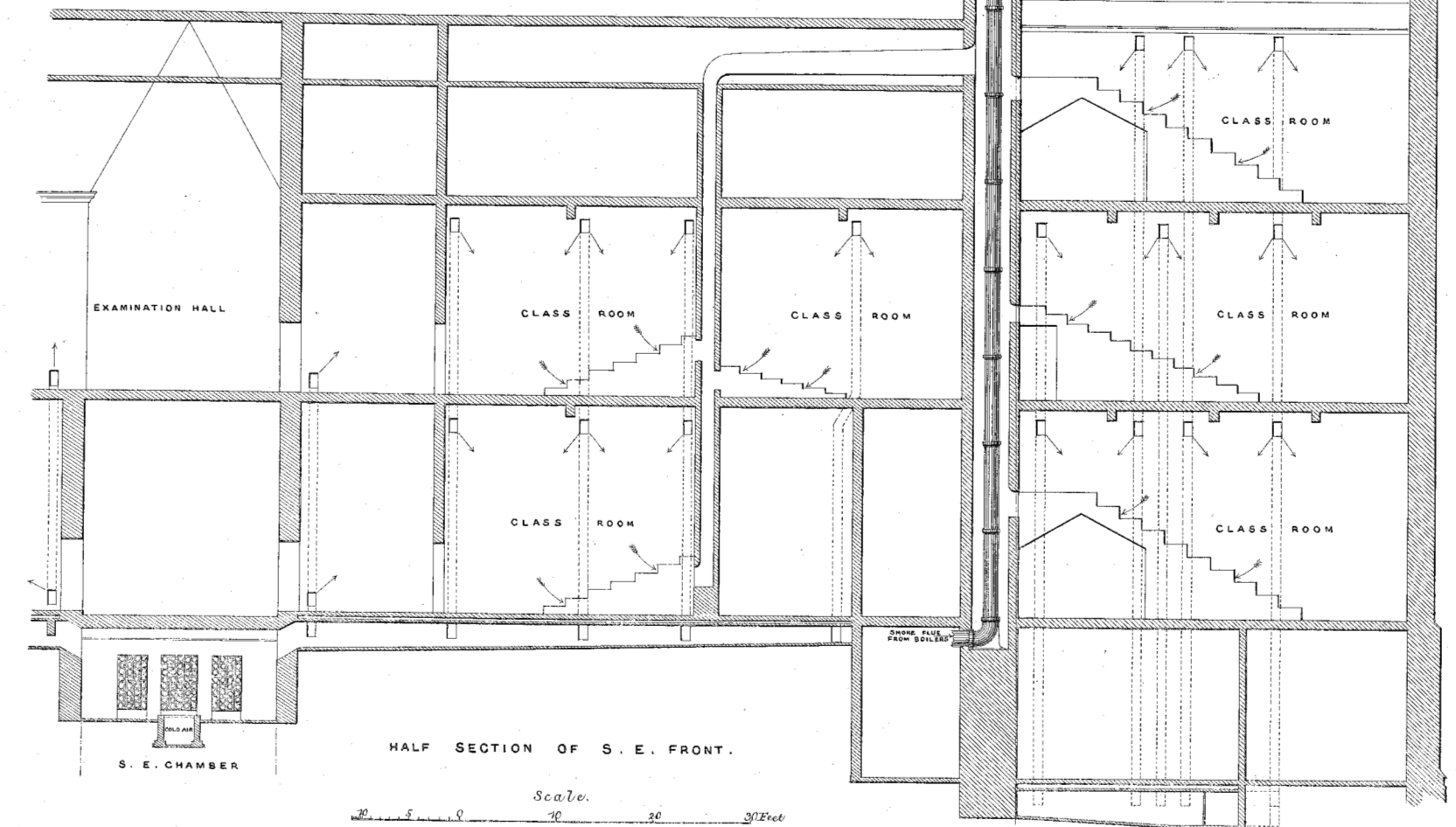
[Professor JAMES THOMSON,



PLAN OF APPARATUS.

Scale.

Feet 10 5 0 10 20 30 40 50 60 70 80 90 100 Feet



HALF SECTION OF S. E. FRONT.

Scale.

Feet 10 5 0 10 20 30 40 50 60 70 80 90 100 Feet