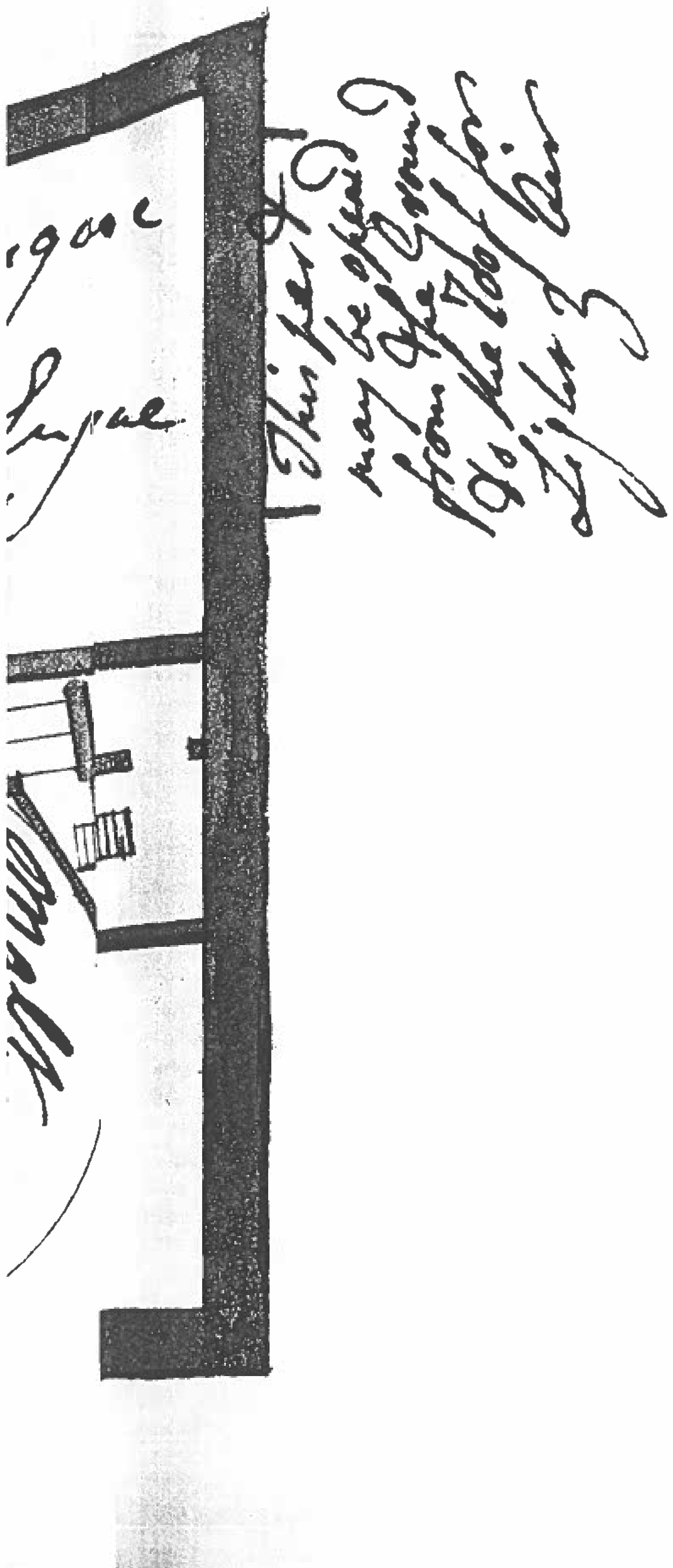
The Development

of the Factory

Jennifer Tann



Cornmarket

Designed by Nichelas Jenkins

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Printed in England by Kingprint Limited, Richmond
ISBN 0 7191 2134 5

Introduction

The change to the factory system of production which took place in Britain between the middle of the 18th and the middle of the 19th centuries posed a series of new and difficult problems for the entrepreneur. The most immediate ones were associated with building the factory and were of two kinds, technological and managerial. Technological problems included the choice of a site for the factory, the layout of the factory, the type of machinery to be used, the form of construction to be adopted, the methods of lighting and heating to be employed, the choice of a power system, an estimation of the amount of power required and the application of that power to the best advantage.

The managerial problems were wide ranging. Capital was required, overlookers and perhaps a manager had to be found, a labour force had to be recruited and kept and discipline had to be maintained. In the water power phase of the Industrial Revolution factories were often built in remote places for an adequate labour force and the entrepreneur was forced to build housing, an inn, a shop and possibly a chapel and school in order to attract labour. In other words he not only had to build a factory but a village as well.[1] The school and chapel did not bring a direct financial return but many entrepreneurs made a fair profit from the rents of housing. However the provision of school and chapel and 'superior' housing was regarded as a means of improving the moral character and hence the discipline of the working population so that they were often regarded as a useful investment in an indirect sense. As Ure said 'It is . . . excessively the interest of every mill-owner to organise his moral machinery on equally sound principles with his mechanical, for otherwise he will never command the steady hands, watchful eyes, and prompt co-operation essential to excellence of product.'[2] The way in which this was done depended upon the individual entrepreneur: 'Thus Quakers showed some fine feeling for their workers but made high demands of moral conformity on them;' philanthropic masters like Owen or the Fieldens attempted to humanize not only their works, but also those of others; 'and the hypocrites employed clergymen, sometimes paid with the workers' pence, to teach their hands how to suffer starvation wages without protest.'[3]

Discussion of the recruitment of labour, of factory villages and factory discipline and of the far reaching social implications of industrialisation is beyond the scope of this book. In the following pages discussion centres on the development of the factory as a physical structure in the late 18th and early 19th centuries.

This study is based to a large extent on the Boulton and Watt Papers. Although this collection has been used for some excellent studies of the firm of Boulton and Watt it has not been used anything like so extensively for a study of other firms. It is hoped that by using letters and drawings of firms both large and small, ones that survived and ones that collapsed, a balanced view of factory development can be achieved. One of the themes which emerges from the following pages is that it was the same few manufacturers who adopted the costly innovations such as fire-proof buildings, who installed gas lighting, steam or warm air heating and fire extinguishing apparatus; they were the giants, the ones who are most likely to have left some record of their activities behind, yet in many respects they were uncharacteristic. They appear to have found little difficulty in recruiting capital yet there were many smaller manufacturers who found difficulty in obtaining long-term loans, to whom a fire-proof factory or gas lighting would have seemed an unobtainable luxury. In this respect some of the most valuable letters are from those manufacturers who decided against buying a Boulton and Watt steam engine which was a good deal more expensive than an atmospheric engine or a simple water wheel.

About 20,000 drawings exist amonst the Boulton and Watt papers. Most of these are drawings of steam engines and engine parts but scattered amongst the drawings are some uncatalogued plans, sections and elevations of factories. Their survival is fortuitous for most of them were prepared by the entrepreneur's millwright or engineer and were loaned to Boulton and Watt to obtain their advice on the placing of the engine house. The standard of draughtsmanship varies greatly from the fine detailed drawings of John Sutcliffe the Halifax millwright (page 18) or the workmanlike drawings of Boulton and Watt's agent Creighton (page 19) to the rough sketch plans prepared by unknown millwrights (page 12). The drawings in this book were selected for their importance as historical documents but they also have aesthetic appeal for a functional drawing, like a functional building, can have high visual quality. They have been grouped by subject although in some cases the grouping is arbitrary.
There are few elevations of factories amongst the Boulton and Watt drawings so these have been supplemented where appropriate by contemporary engravings and a measured elevation.

A date after the title of a drawing is the date of the drawing and not necessarily the date of the erection of the factory.

On the majority of drawings the dimensions of the buildings are written in; some also have a linear scale. On others the scale is indicated in words and since most of the drawings have been reduced, the written scale is meaningless. In these cases an approximate scale has been noted in the description of the drawing.

One of Boulton and Watt's methods of copying a drawing was to take a press copy of it. This was called a reverse drawing and was a mirror image of the original. Where one of these drawings has been reproduced the word 'reverse' appears on the drawing or by the portfolio number in the description.

1. W. Ashworth,'British Industrial Villages in the Nineteenth Century, *Econ. Hist. Rev.* 3 1950-1; Sidney Pollard, 'The Factory Village in the Industrial Revolution,' *English Historical Review*, 89, 1964; 'Industrial Monuments at Milford and Belper,' *Archaeological Journal* 117, 1961 (1963).
2. Andrew Ure, *The Philosophy of Manufacturers*, p.417.
3. Sidney Pollard, 'Factory Discipline in the Industrial Revolution,' *Econ. Hist. Rev.* 16, 1963.

7. Factory Heating

There were obvious humanitarian motives for the provision of factory heating by the entrepreneur. At Samuel Oldknow's Mellor Mill it was noted that 'the place is merely wanted to be a comfortable temperature for the workpeople'. Hick's woollen mill at Stonehouse was to be heated to about 60°, a reasonable temperature to work in.[1] The pessimist might consider the provision of heating from another angle for no doubt there was an optimum temperature at which child apprentices and the rest of the labour force could achieve their highest output.

But leaving aside the human dimension, the heating of some part of the factory was necessary in a number of industrial processes. In the pottery industry, for example, slip had to be dried in buildings known as stoves. Stove buildings were required in the bleaching, dyeing and printing of cotton and also in the woollen and worsted industries. A temperature in the 70s was necessary in sugar refining and for drying paper in paper mills. A certain amount of moist heat was required for cotton and flax spinning. 'Until the machinery acquires a certain degree of warmth, the spinners find it nearly impossible to keep their work in order; and this is most felt on Monday mornings, when every thing has become cold and adhesive, through being a longer time at rest. It is an evil because in addition to producing bad work, it too frequently occasions the children employed to be treated with unmerited severity.'[2]

Until the latter part of the 18th century the open fire was the only source of heat available and this was unlikely to raise the temperature greatly in a large room. It was costly to have a separate fire on each floor and inconvenient too. Shute's Silk Mill at Watford was heated by thirteen separate stoves in 1816.[3] Nevertheless, the smaller firms continued to use this method of heating throughout the 19th century. But during the 18th century experiments were conducted on other forms of heating, notably on warm air and steam. As early as 1745[4] steam was suggested as a medium for warming rooms although it does not seem to have been applied to the purpose until the end of the 18th century. Count Rumford asserted that 'this scheme has frequently been put to practise with success in this country, as well as on the continent',[5] but there is little evidence to support his view. Patents were granted to John Hoyle in 1791 and to Joseph Green in 1793[6] for methods of warming buildings by steam and Matthew Boulton became interested in the possibilities of steam heating. In 1794 he assisted the Marquis of Lansdowne in improving the steam heating apparatus erected by Green for warming the Marquis's Library. But the scheme was abandoned because of the defective jointing in the pipes. In 1795 Boulton superintended the erection of a similar system in Dr. Withering's library. But this system was also dispensed with because the pipes being made of copper and softly soldered together emitted 'a most disagreeable effluvium which rendered it unpleasant to Dr. Withering who was then in an infirm state of health and suffering from a disease on his lungs.'[7] These setbacks probably account for the time lapse between Boulton's domestic experiments and Boulton and Watt's first steam heating installation in a factory in 1802.

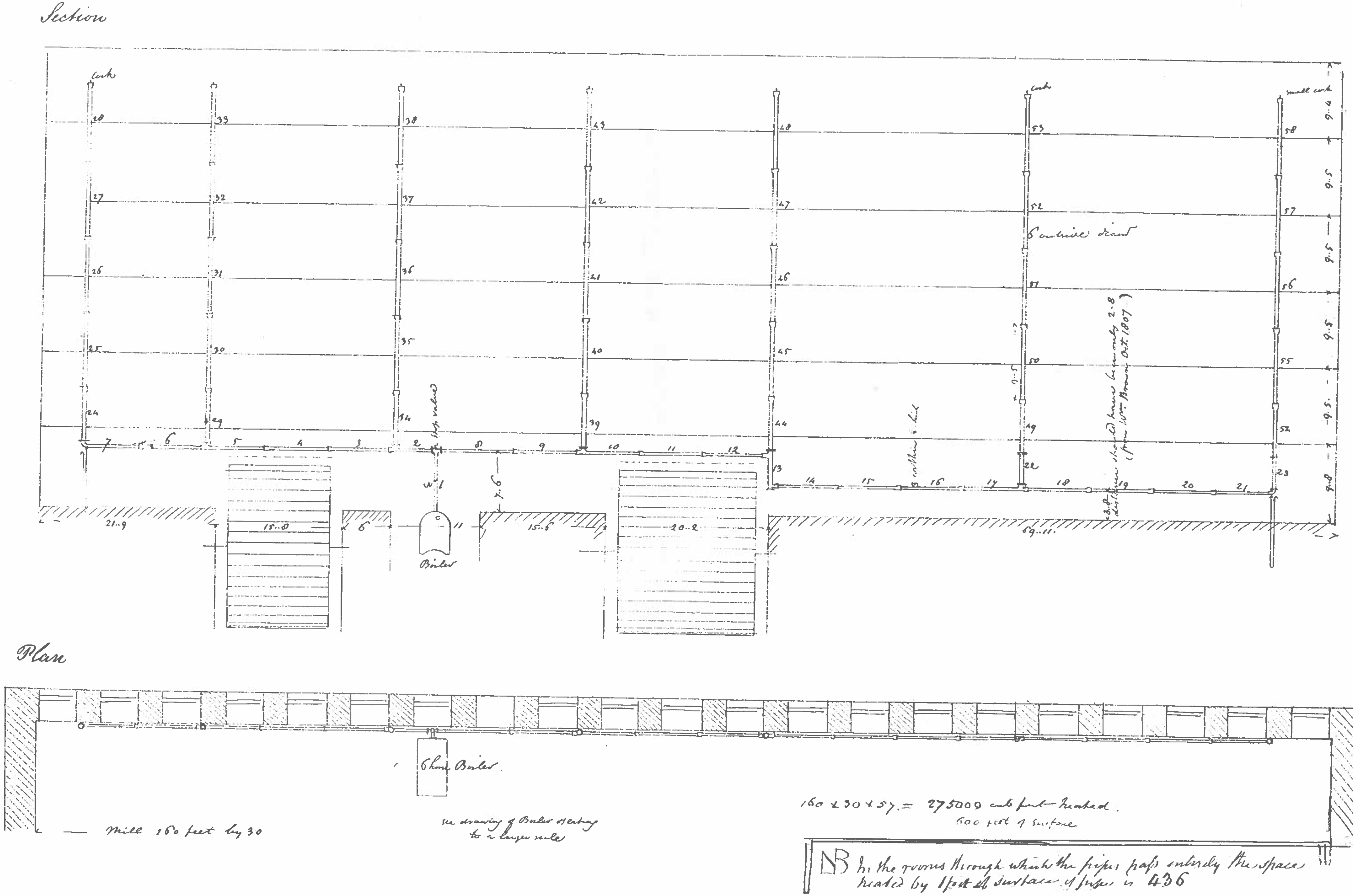
During the 1790s experiments were conducted on warm air heating in factories, and by 1792 William Strutt had designed a system for Belper Mills. Air was conducted into the building and brought in a current to the external surface of an iron 'cockle', a cubical vessel inverted over a fire. The warmed air rose in ducts to each floor of the building and was admitted to the rooms through hatches. Ventilators ensured that there was an adequate circulation of air.[8] This system was installed in the Derby Infirmary designed by Strutt, and Sylvester used it at the Wakefield Lunatic Assylum.[9] In 1796 George Salvin wanted to heat his Durham factory with warm air but wrote to Boulton and Watt saying, rather pitifully that he was at a loss to know how to set about it.[10] Charles Bage of Shrewsbury was obviously impressed by this method of heating although, characteristically, he subjected it to tests and altered Strutt's plans to suit his own requirements. In the first instance Bage was interested only in warming his drying rooms for 'bleached yarn, dyed thread and yarn brought wet from the reels'.[11] 'But', he added 'I fear I may not fall on the best and most economical plan of constructing the warming parts.' He asked Strutt about the best means of conveying smoke away as he was concerned about the possibility of smoke percolating into the drying room and spoiling newly bleached yarn. The other problem which concerned Bage was the best means of diffusing warmed air to all parts of the room. 'Is any contrivance necessary for dashing and diffusing the heated air to every part of the room?' He enclosed a plan of the proposed bleach house and stove 'on your plan about 8 by 9 feet'. It is interesting to speculate why Bage, considering his knowledge of heat transfer – he was using steam to heat the dyeing and bleaching vessels – did not apparently consider using steam to heat the stove building. Three boilers to be used for supplying a small steam engine and for heating the dyeing and bleaching vessels are shown on his diagram. It is hardly likely that he was unaware of the possibilities of steam heating. In the absence of other evidence one must suppose that he had heard unfavourable reports of it. In November[12] he wrote again to Strutt 'I have annexed a scheme for warming a drying stove, the best that has occurred to me, and will thank you to fulfill your promise of finding all the faults you are able, and also to send me a sketch of your latest improvement which I am fully prepared to expect is much superior.'

The iron cockle in Bage's stove was six feet in diameter, surrounded by a dome of brickwork which terminated at an opening to allow the warm air to ascend. The cockle rested on firebricks and was inverted over a grate. Cold air was admitted through the walls at the four corners of the room and was conveyed in cast iron pipes to the edge of the cockle. Warm air was diffused from the opening in the brickwork which surrounded

1. Box 1334. For a brief introduction to the history of heating see A. F. Dufton, 'Early Application of Engineering to the Warming of Buildings,' *Trans Newcomen Soc.* 21. 1940-1.
2. Thomas Tregold, *Principles of Warming and Ventilating Public Buildings, Dwelling Houses, Manufactories, Hospitals, Hot Houses, Conservatories, etc.* 1824, p. 167.
3. ibid p. 289.
4. *Philosophical Transactions* 1745.
5. *Journal Royal Institution*, vol. 3.
6. Patents nos: 1816, 1968.
7. Box 30. un-named pamphlet p. 173.
8. *Rees Cyclopaedia*, art 'Manufacture of Cotton; M.C. Egerton, 'William Strutt and the application of convection to the heating of buildings,' *Annals of Science*, 24, 1968.
9. C. L. Hacker, 'William Strutt of Derby,' *Journ. Derbys Arch. and Nat. Hist. Soc.* 80, 1960, pp. 57-9.
10. G. Salvin to Boulton and Watt 26 March 1796.
11. Shrewsbury Library, Bage Papers, Bage to Strutt, Oct. 15, 1802.
12. Ibid, Nov. 11, 1802.

Factory Heating
Gardom Pares and Co, Calver Mill, Derbyshire, 1807
This drawing shows one of the earliest methods of heating factories by steam. As this was a water powered mill only a small 6 hp boiler was required. It is interesting that Gardom and Pares chose steam heating rather than hot air heating for it was generally considered more economical to install the latter in a mill that was not driven by a steam engine.
Portf: 1334

Sketch of the heating pipes. 1/10 Inch to the foot May 1st 1807. Messrs Gardon Pares & Co.



the cockle and from four earthenware ducts which led up into the drying room. Shortly after sending his plan Bage wrote again[13] 'you said you would find as many faults with my stove as you could . . . I hope you will not only do this but send me a better. The final arrangement of our plans is delayed till we have your approbation or censure.'

Strutt apparently approved the plan but it was not altogether successful for Bage wrote in March 1805[14] 'For warming your inverted pots [cockles] were adopted with tolerable success. Though I think with most effect when the internal brickwork is carried up some height. You have experienced the same inefficiency of this mode of warming for the room on the same level as the pot', and Bage adopted some kind of fan system to diffuse the warm air to lower levels. When Marshall visited the mill he noted 'I have long thought that our present stove was very improper for drying thread in and too small – steam heat would be far better.'[15]

Strutt's warm air system received the approbation of several noted industrialists of the day. After consultation with Strutt in 1808[16] Boulton and Watt installed the apparatus in the Hunterian Museum, Glasgow in *c.* 1810; and Boulton's house was heated in a similar way. David Dale with his manager, William Kelly of New Lanark Mills, had tried out three warm air systems by 1796.[17] The first mill built at New Lanark had a simple stove in the cellar at each end of the building and from each stove warm air was conducted up an iron pipe which passed through each storey at the end of the mill. At each storey there was an aperture which could be opened and closed at will. But it was quickly found that 'owing to the propensity of the rarified or warm air to rush to the top; and the smallness of the body of heated air in the pipe; we found it impracticable to warm more than one room at a time.'

This system was modified in the next mill. In this case the warm air was conducted in a brick passage enclosed in the end gable of the mill. Smoke, contained in an iron pipe, was also carried up this passage. A damper across the passage at each floor controlled the ascent of the warm air and another vent controlled the admission of warm air to each room. This system made 'a very good stove' according to Kelly but it had the disadvantage of the vents and dampers having to be regulated manually 'which the hands in the room are always disposed to alter as suits their inclinations'.

In the third and most satisfactory heating system at New Lanark a much larger column of heated air was carried up through the end of the building, the column diminishing in size towards the upper storeys. Only one stove was found necessary to heat a building 150 ft by 30 ft. The apertures to each room remained constant but diminished in size storey by storey. By this means 'the heated air is so regulated as to warm all the rooms at once'. This method, Kelly noted, 'we find answers most completely'. He added that the systems that he had described 'are the only kinds [which] have been seen fit for warming large houses upon a safe principle'. George Rennie had no doubts about which method of heating he considered the best: 'ventilation by warm air is now preferred to steam in most of our public Establishments here. Its superiority consists in a constancy & equability of Temperature which can be regulated to any proper intensity & in its salubrity & economy & from what information I have obtained I should be inclined to recommend the mode adopted by the London Institution as best adapted to your purposes. But then it is necessary to make such arrangements in your Building as shall answer the end required. 1st by placing the Apparatus on the basement storey or below it which is preferable . . . 2nd That the current of Air over the surface of the Stove Cockle should be so copious that the Cockle should not exceed 280 or 300 degrees Fah^{t}. lest the Air become burnt & vitiated.'[18]

Not only was the stove system safe but it was also cheap to run. It was certainly cheaper than having open fires in each room and George Lee told William Edgeworth in 1811 that Strutt's method of heating was 'the best and cheapest'.[19] For the manufacturer who used water or animals for the motive power in his factory there seems little doubt that a hot air system was the most suitable. But if steam power was used in the factory it was cheaper and effective to use steam for the heating system also, and for cotton mills 'it is found greatly superior to other methods'.[20]

Buchanan claims[21] that a Mr. Snodgrass was the first person to heat a factory by steam when he installed a heating system in Dale and McIntosh's Speyside cotton works in 1799. George Lee followed shortly afterwards by installing a heating system whilst building the Salford Twist Mill. The structural cast iron pillars of the mill also served as heating pipes and steam was conveyed from storey to storey through them. In January 1802 Lee told James Watt jun. 'Please to acquaint your father and Mr. Southern that we have admitted steam into the building and the elongation was as expected 1/10th of an inch per 10 feet nearly.'[22] T. Houldsworth of Glasgow followed suit when building his mill. Richard Gillespie, a calico printer, introduced steam heating to his warehouse and then gradually to other parts of the works. Messrs Orr installed heating in their Stratford upon Slainy (Ireland) works and were shortly followed by other Irish cotton spinners and manufacturers.[23] After the successful heating of Philips and Lee's mill in 1802 Boulton and Watt received a slow but steady flow of orders for steam heating apparatus. Some but by no means all of the orders came from owners of Boulton and Watt steam engines. Pooley, owner of a Boulton and Watt engine, installed a steam heating system in 1804. He was followed in 1805 by Radcliffe and Ross who needed it for drying ground flint. Boyes and Carlill, sugar refiners of Hull, also installed steam heating in 1805. Stevenson and Houston, cotton spinners, installed their heating system in 1806 and Wedgwood

13. Ibid, no date.
14. Ibid, March 5, 1805.
15. Brotherton Library, Marshall MSS 37 p. 10.
16. James Watt Jun. to J. Mylne, May 11, 1808, Misc. Mills Box.
17. Southern to Lawson 10 March, 1796, Foundry Letter Book. Southern remarked that as Lawson was acquainted with Dale's engineers B. and W. would like him to find out what method Dale employed to warm his mills. The following paragraphs are based on W. Kelly's reply. 24 March, 1796, pf. 1334.
18. Brotherton Library Gott MSS. G. Rennie to B. Gott 22 July 1819.
19. R. S. Fitton and A. P. Wadsworth *The Strutts and the Arkwrights* p. 215.
20. T. Tredgold pp. 166-7.
21. Robertson Buchanan, *An Essay on the Warming of Mills and other Buildings by Steam*, Glasgow 1807, p. 8.
22. G. A. Lee to J. Watt Jun., 17 Jan 1802, M IV L. This is the only evidence that B. and W. were at all involved in the heating of the Salford Twist mill. There are no drawings of heating systems for this firm.
23. Buchanan op. cit. p.8.

Robert Arkwright, Bakewell Mill, Derbyshire, 1813
Two methods of steam heating are shown; the main block was heated by steam rising in vertical columns whilst in the wing the steam travelled in horizontal pipes at ceiling level.
Portf: 1334

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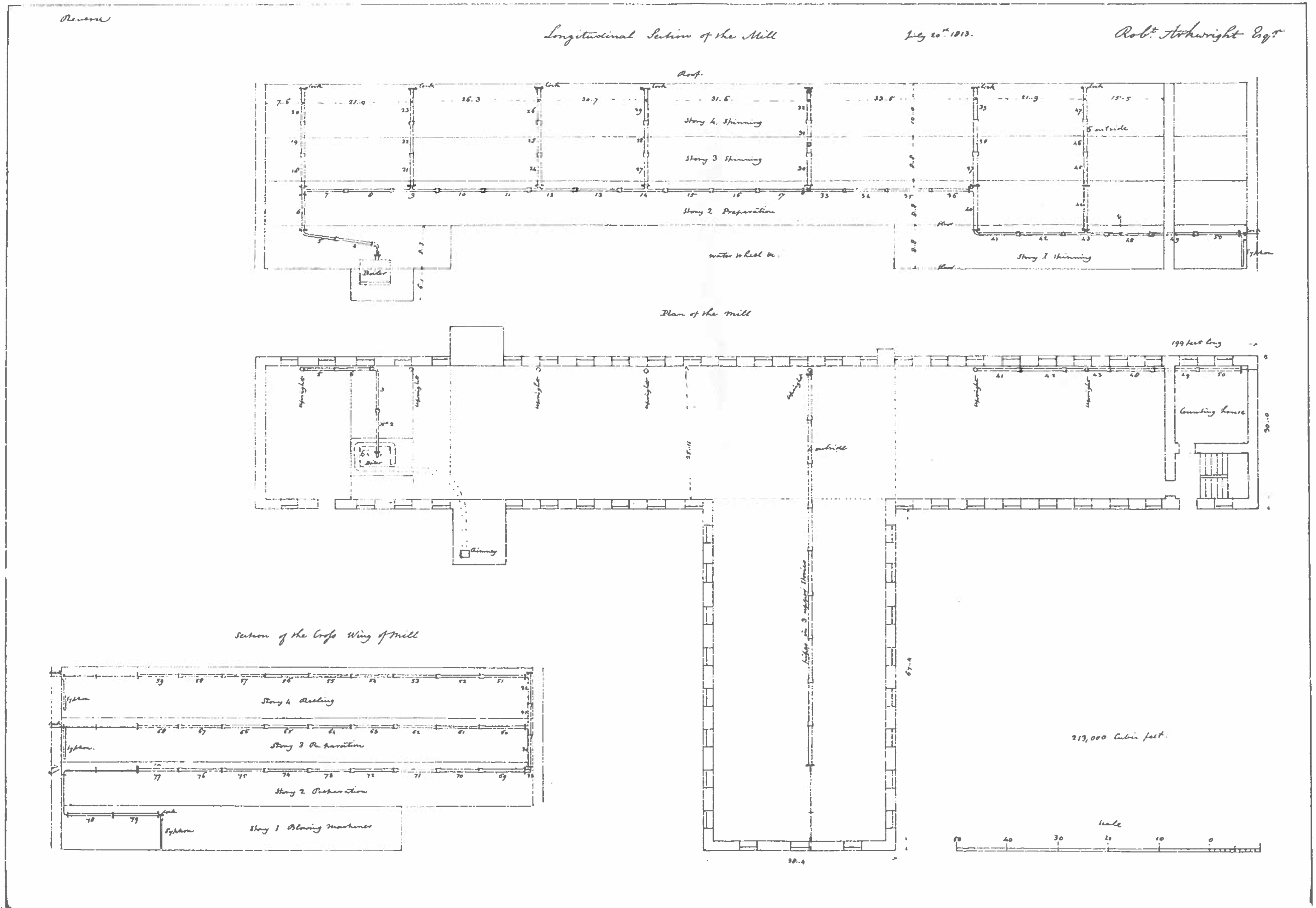

Reverse
Longitudinal Section of the Mill
July 20th 1813.
Robt. Arkwright Esqr.
Roof.
Story 4 Spinning
Story 3 Spinning
Story 2 Preparation
Water wheel &c.
Story 1 Spinning
Boiler
Syphon
Plan of the Mill
199 feet long
Counting house
outside
Chimney
Section of the Cross Wing of Mill
Story 4 Reeling
Story 3 Preparation
Story 2 Preparation
Story 1 Blowing machines
213,000 Cubic feet.
Scale

and Byerley, owners of a steam engine, employed steam heating in their stone drying house in 1807. Gardom and Pares, owners of a large water driven cotton mill at Calver, installed steam heating in 1807 and they were followed by Samuel Oldknow at Mellor in 1809. In 1810 Boulton and Watt undertook the heating of two important non-factory buildings – Covent Garden Theatre and Lowther Castle.[24]

Steam Heating Apparatus ordered from Boulton and Watt

Firm	Building	Date
Philips and Lee	Cotton Mill	1802
John Pooley	Cotton Mill	1804
Radcliffe and Ross	Stone Drying	1805
Boyes and Carlill	Sugar House	1805
John McCracken	Cotton Mill	1805
Stevenson and Houston	Cotton Mill	1806
Wedgwood and Byerley	Stone Drying	1807
Gardom and Pares	Cotton Mill	1807
Williams Cooper and Boyle	Paper Mill	1808
S. Oldknow	Cotton Mill	1809
Birley and Hornby	Warehouses	1810
Cardwell	Warehouse	1810
Duffy Byrne and Hamill	Print Works	1810
Covent Garden Theatre	Theatre	1810
Lord Lonsdale	Lowther Castle	1810
J. Spode	Stone Drying	1812
Davis	Hat House	1813
R. Arkwright	Cotton Mill	1813
Budgein	Paper Mill	1813
Gardom and Pares	Cotton Mill	1814
H. Hicks and Son	Woollen Mill	1816
La Compagnie d'Ours camp		1823

Source: B. & W. MSS Pf. 1334.

Technical problems were solved in a characteristically empirical fashion. Boiler size and the length of steam piping required to heat a factory were arrived at by a comparison of the efficiency of the heating systems in the first factories to be heated by steam. If a boiler was to be installed solely for the purpose of supplying steam to heat the factory the rule of thumb used was that one cubic foot of boiler would heat approximately 2000 cu ft of space in a factory, assuming that the temperature required would be between 70° and 80° F, 25 cu ft of boiler per 1 hp was allowed for a steam engine boiler in the early 19th century so that only a small boiler was required to heat the average sized factory. For cotton factories it was assumed that in most cases 'one superficial foot of exterior surface of steam pipe will warm two hundred cubic feet of space'. Nevertheless a larger allowance was usually made. H. Houldsworth allowed 1 ft of piping to about 179 cu ft, while Kennedy and Watt of Johnston allowed 1 ft to 168 cu ft. At Catrine 1 ft of piping was allowed to about 200 cu ft and a small chapel at Glasgow was adequately heated by allowing 1 ft of piping to 400 cu ft of space.[25]

Data of some steam heating systems

Factory	Steam Pipes	Cu ft Building	Cu ft Boiler	Space Warmed By 1 Cu ft Boiler	Cu ft Space Warmed By 1 ft. Steam Piping	Temperature F
H. Houldsworth & Co, Anderston Old Mill	Cast iron	250,000	–	[illegible],000	178	85°
Linwood	Cast iron	300,000	120	2,500	168	70°
Kennedy & Watts Johnston	Cast iron	289,000	160	1,180	160	75°
Catrine	Tin Plate Not Painted	–	–	–	200	–
T. Houldsworth Manchester	Cast iron	–	–	–	195	–
Chapel of Port Glasgow	Cast iron	60,000	10	6,000	400	–
Pt Adelphi Cotton Works	Cast iron	49,140	–	–	182	65°
Tambouring Mill, Anderston	Cast iron	–	–	–	240	60°
W. King & Sons, Johnston	Cast iron	244,583	180	1,303	200	70°

Source: Buchanan P.24.

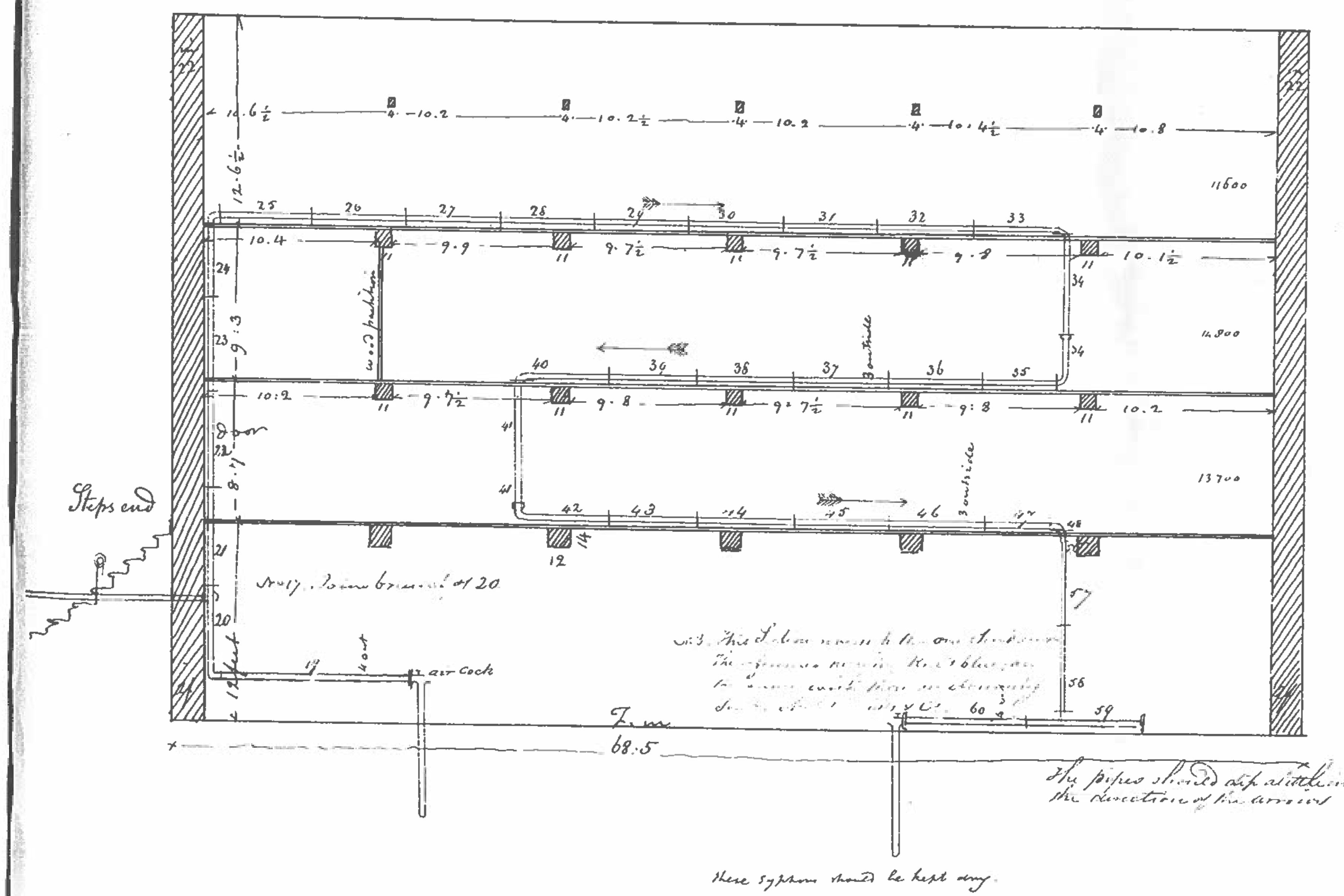
The main item of expense was the cast iron piping. Several manufacturers experimented with tin plate and copper pipes but cast iron was found to give out more heat than either of the others. H. Houldsworth made some experiments to ascertain the difference between tin plate and cast iron as radiating materials and found cast iron superior in a ratio of 2½ : 1. The arrangement of the piping was an important consideration. Metal expands on heating and this expansion was particularly difficult to manage when pipes had to be joined at different angles. A copper steam pipe 160 ft long became 2 in longer when filled with steam and the expansion of cast iron was found to be about 1/10 in per 10 ft. It was this expansion factor which led to the abandonment of the early plan whereby hollow cast iron structural pillars served as heating pipes too. When a vertical pipe was filled with steam it expanded equally and continued to be straight but there were problems with horizontal pipes for they tended to bend as the upper side became hotter and joints were endangered.

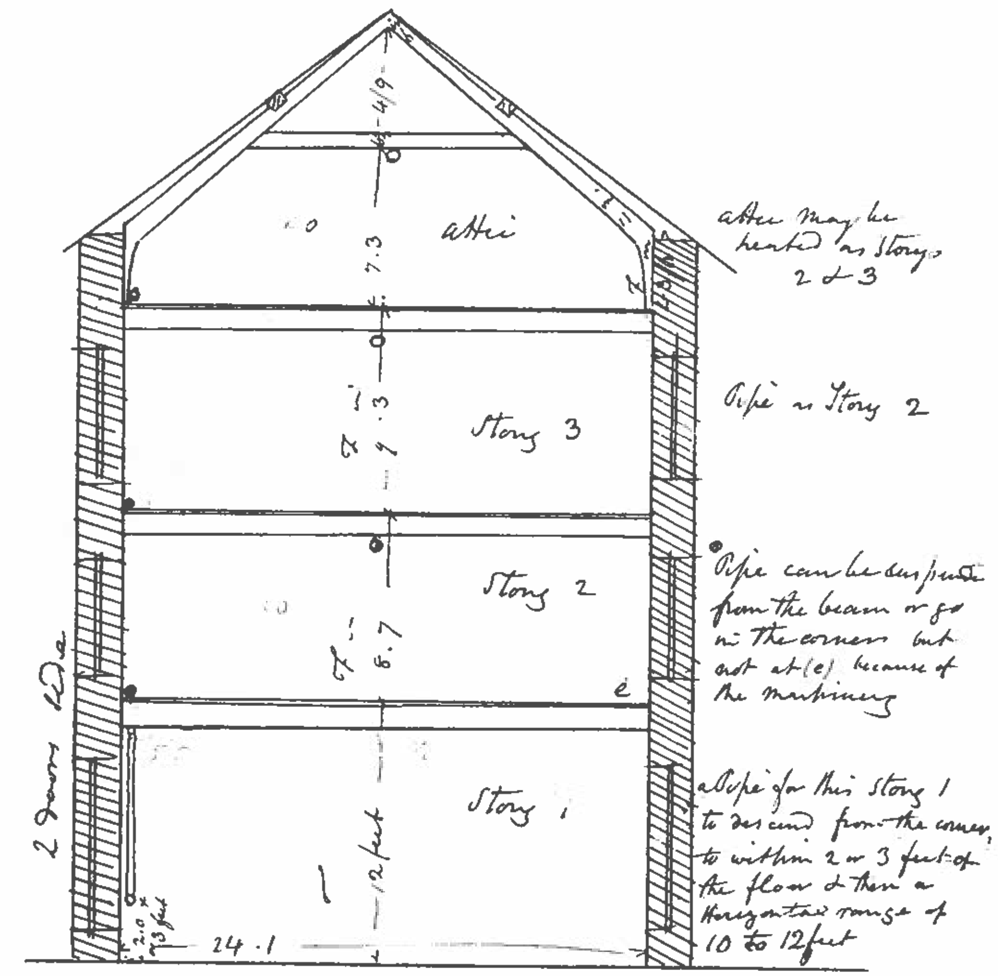
There were other important points. A convenient means of expelling air from the pipes while they were being filled with steam was required. And a small quantity of steam had to be

H. Hicks and Sons, Churching Mill, Eastington, Gloucestershire, 1816
This drawing illustrates a variation of the system of horizontal pipes for steam heating.
Portf: 1334

24. Notes and drawings pf. 1334.
25. Buchanan op cit. pp. 9-12.

Longitudinal Section of (A) (Churching Mill)
1/8 in. to the foot.





allowed constantly to escape so as to keep up the heat in the pipes. In a system using vertical pipes a cock was placed at the top of each pipe to allow for this (page 112). When horizontal pipes were used fewer cocks were necessary (pp 114,116). Water produced by condensation had to be removed from the pipes. Buchanan noted that 'when it can be done, it is better to make the water . . . to run in the same direction with the steam'. In a horizontal pipe the steam could drive the water before it. Care had to be taken to prevent water from remaining in any of the pipes after they became cool otherwise when steam was next let into the pipes 'some part of the pipe cracks, and a violent explosion takes place', an accident that had 'not unfrequently happened'. For this reason horizontal pipes were made to slope slightly 'by which means nearly all the condensed steam will collect again in the boiler'.[26]

In both Philips and Lee's and H. Houldsworth's mills the vertical pillars for supporting the floors also served as steam pipes for heating. Because of the expense of iron piping and the ease of installation while the factory was being built, this dual purpose system was often adopted by entrepreneurs building new factories in the early 19th century. Vertical pipes were favoured by Buchanan who noted that they had 'the advantage of diffusing the heat more equally;' and, notwithstanding the fact that they were more expensive to install in an existing building than horizontal pipes, Boulton and Watt used them in nearly all the early heating systems that they installed, whether or not the pipes also served a structural function. The practise of using structural pillars as heating pipes was discontinued after the early 19th century because of the expansion problem. Hot pipes in the centre of a factory could have been extremely dangerous and Boulton and Watt used a system of horizontal pipes in their later installations. The commonest and most simple arrangement (page 112) consisted of a main vertical pipe running up one end of the building with a horizontal pipe running off at each floor terminating at the further end of the building in a cock. A more effective system was that adopted by J. Houldsworth at Manchester and S. Oldknow at Mellor. At Oldknow's mill a boiler fed two central vertical pipes which conducted steam to the attic where from each pipe a branch led along the attic floor to the end of the building, down to the storey below, along that floor, down to the storey below and so on. (page 116) In the early systems, horizontal pipes ran just below the ceiling on each storey which must have greatly reduced the circulation of warm air. In later systems the pipes were laid at floor level.

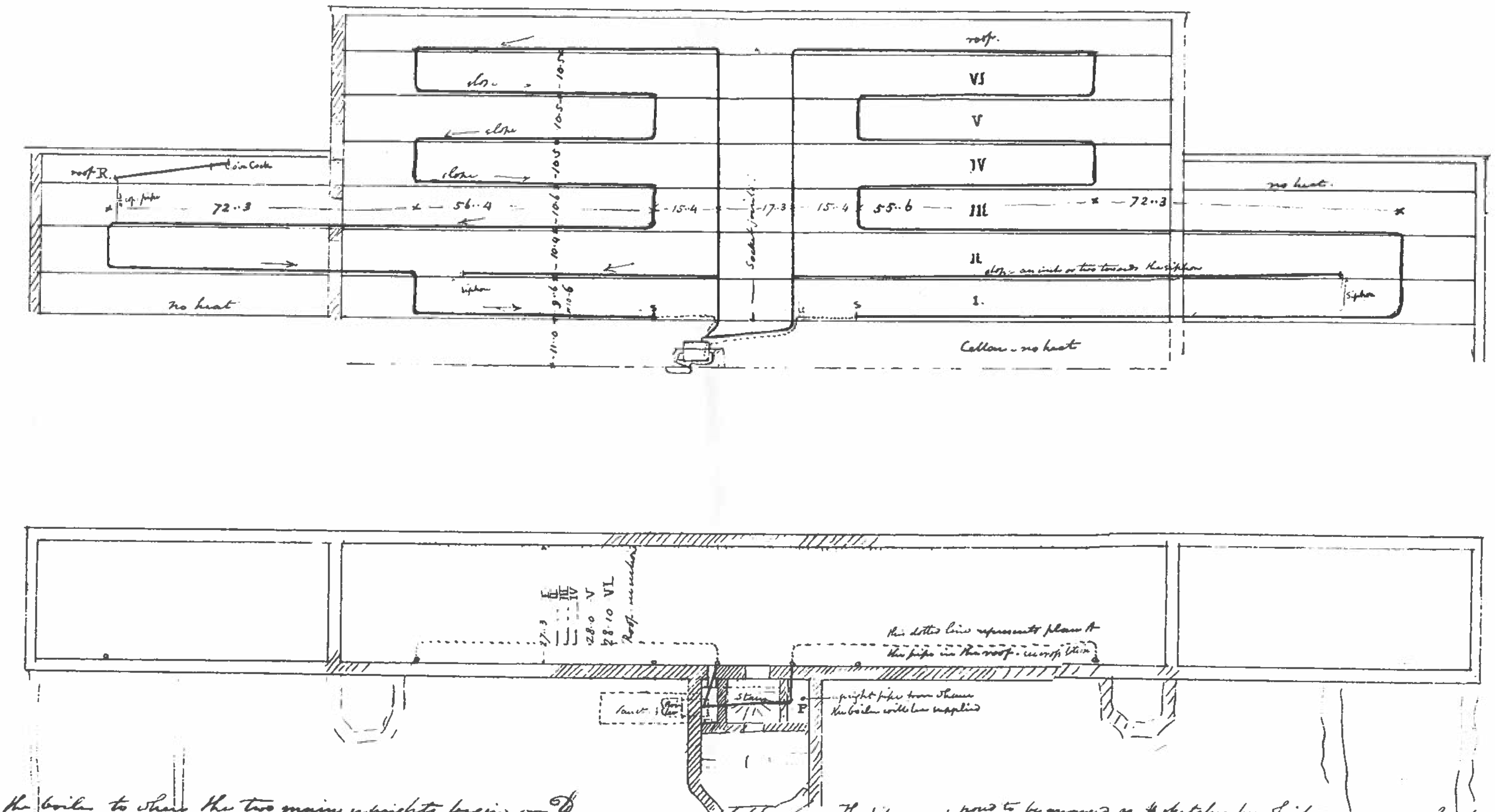
It is difficult to assess which was considered the better system of factory heating, steam or warm air. George Lee wavered and eventually decided that neither system had a distinct advantage over the other. Tredgold remarked wryly: 'I do not know how the comparison has been made by others, but he must be a novice in the science of heat, that cannot produce nearly the same effect by the one as by the other, all other circumstances being the same. I know that, in either method, it is easy to mismanage things in such a manner, that not more than half the heat will be effective in warming the intended space; and that, by selecting cases for comparison, you may make either appear to be the best method, as far as regards economy of heat.' Those manufacturers who did express a strong preference gave empirical reasons: 'If building a new fireproof mill would have only cockles at first and steam pipes in a year or two – Thought it best to have various means of regulating the heat and moisture: cockles: steam pipes: and steam', John Marshall of Leeds noted after a visit to John Kennedy of Manchester in 1829. He added 'I did not find that any of the cotton spinners had used the steam itself as we do.'[28]

Samuel Oldknow, Mellor Mill, Derbyshire, 1809
Buchanan considered that the system of steam heating illustrated here was the most effective method.
Portf: 1334

26. Ibid pp.. 14-17; pf. 1334.
27. T. Tredgold op. cit. p. 18.
28. Brotherton Lib, Marshall MSS, 37. p.l.

g illustrated

Saml. Oldknow Esq. Mellor Mills
July 8. 1809. —



The pipes from the boiler to where the two main uprights begin would perhaps be as well a little larger than the rest to let the water which will collect in them, more freely back to the boiler — Stop valves at the boiler will be unnecessary — The pipes for bringing back the water from S.S. to the boiler should I suppose not be less than 1½ inches diam. — possibly some of the 2 inch cast iron pipe would be as cheap & good as any thing —

The pipes are proposed to be arranged as pr sketches, by which means nearly all the condensed steam will be collected again in the boiler — the building being but abt. 28 feet wide & the stories 10f. high abt. clear — small cast iron pipes say 3 inches inside & as thin as convt. will I suppose give abundance of heat — the place is merely wanted to be of a comfortable temperature for the work-people — R abt. 3 lengths of pipe to warm this place will be suffict. & the water must run back. —
suppose all the pipes will be best with flanch joints except the 2 main uprights. —

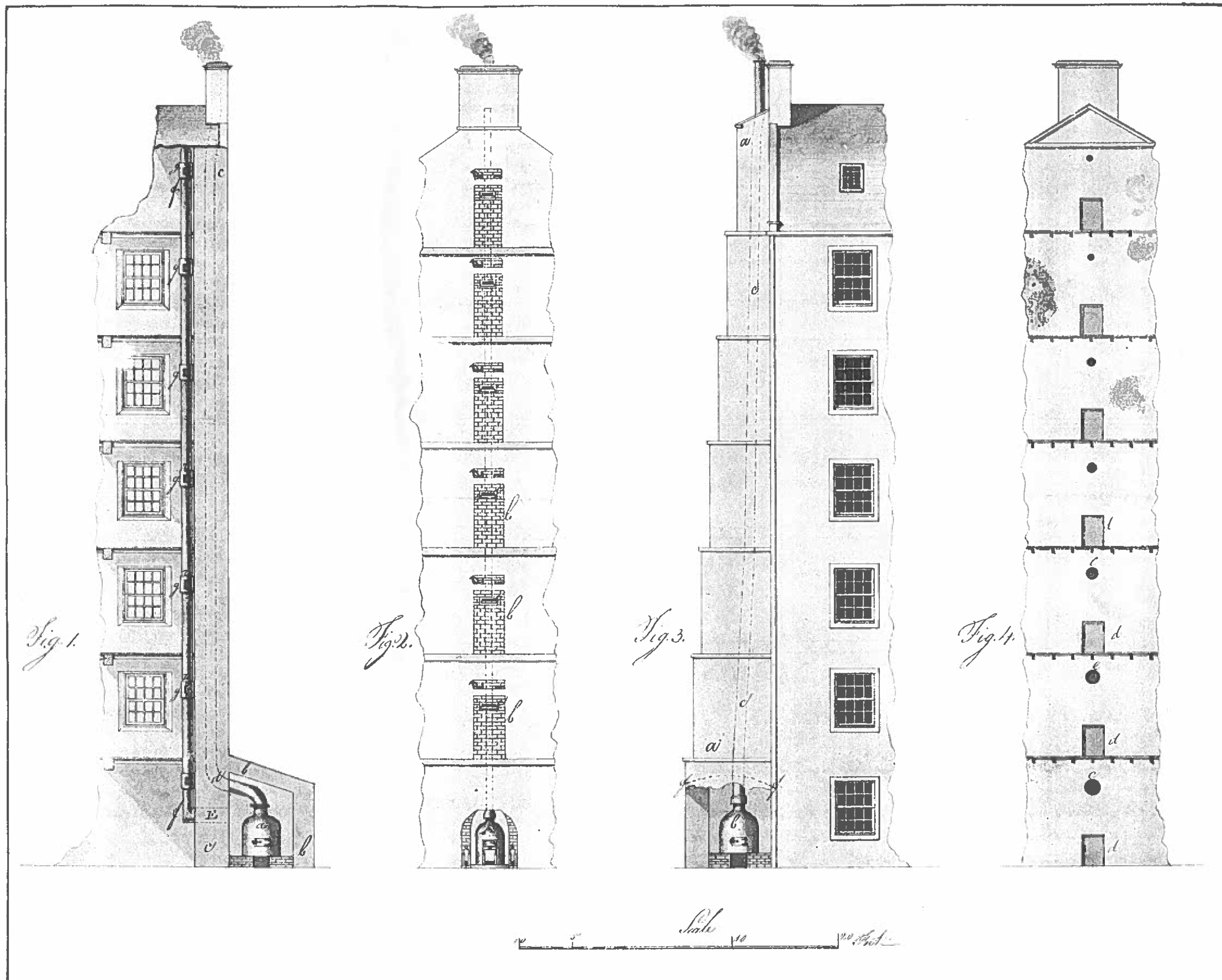


Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
Scale
10
20 Feet

David Dale, New Lanark Mills, Scotland, 1796

William Kelly, Dale's manager, sent this drawing and the 'Description of Cotton Mill Stoves' to Boulton and Watt in answer to their request in 1796.

'Fig. 1 is an edge view of the Gable of the mill, and represents the situation of the stove inclosed in the building b b. The smoke from the stove a, is introduced at d into the wall and carried up a vent and escapes at the top of the chimney. It is represented in the drawing as going directly from the stove into the vent, but it first takes a turn round the inside of the building b b.

The warm air is introduced into the mill at E, and conveyed into the rooms by the iron pipe ff. In each storey there is a hole or aperture g g, and a valve that shuts quite across upon the top of it at Z Z. The hole in the pipe at g is opened and shut similar to the manner of the Dark Lanterns; by turning round the socket or ferruie g g -.Our first built mill has a stove of this kind at each end of it; But subject to the following objections – Owing to the propensity of the rarified or warm air, to rush to the top; and to the smallness of the body of heated air in the pipe; we found it impracticable to warm more than one room at a time, and had to shut all the rest – When the warm air was admitted into the rooms above, we had to shut the socket g in those below, otherwise the bad air rushed up along with the heated air – It is also obvious the loss of fewel [sic] etc.

The next best way known to me, is that represented by Fig 2d, which is a fau [full] view of the stove as seen from the rooms. In the middle of the Gables of the Mill, there is an opening left in Building about 3 feet by 2 continued from bottom to top and terminates in the chimney heads; which our stone walls in this country easily admit of – At the bottom of said opening is placed the stove A inclosed in brick walls with an aperture on each side with dampers to regulate the admission of the external air to be heated. On the top of the stove are pipes of iron raised to carry off the smoke – these are placed in the middle of the above opening and terminates also in the top of the chimneys. The space round the pipes, serve for the ascent of the heated air which is to be distributed into the rooms. The space cc, in each room are originally left open towards the inside, for the convenience of putting in the pipes; and are faced or built up with brick. In each of these there is an aperture for the admission of warm air at c, which are fitted with an iron valve that can be opened or shut at pleasure. For the more effectual regulation of the ascent of the heated air; just above the aperture c, in each storey, there is an iron plate goes write [sic] across the opening in the gables, which is fitted also with a valve that can be moved up and down by a Quadrant or toothed-circular rack, similar to the moveable plates that arc placed in Chimneys above some of the new fashioned fire grates. By opening the above valve at the top storey, the heat is allowed to escape at pleasure to prevent any excessive degree of heat.

The above makes a very good stove; but is attended with some inconveniences, namely the necessity always regulating the admission of the warm air by the valves; which the hands in the room are always disposed to alter as suits their inclinations. There is also a Danger of the foul air below, escaping to the rooms above when the regulating valves are not properly set etc. –

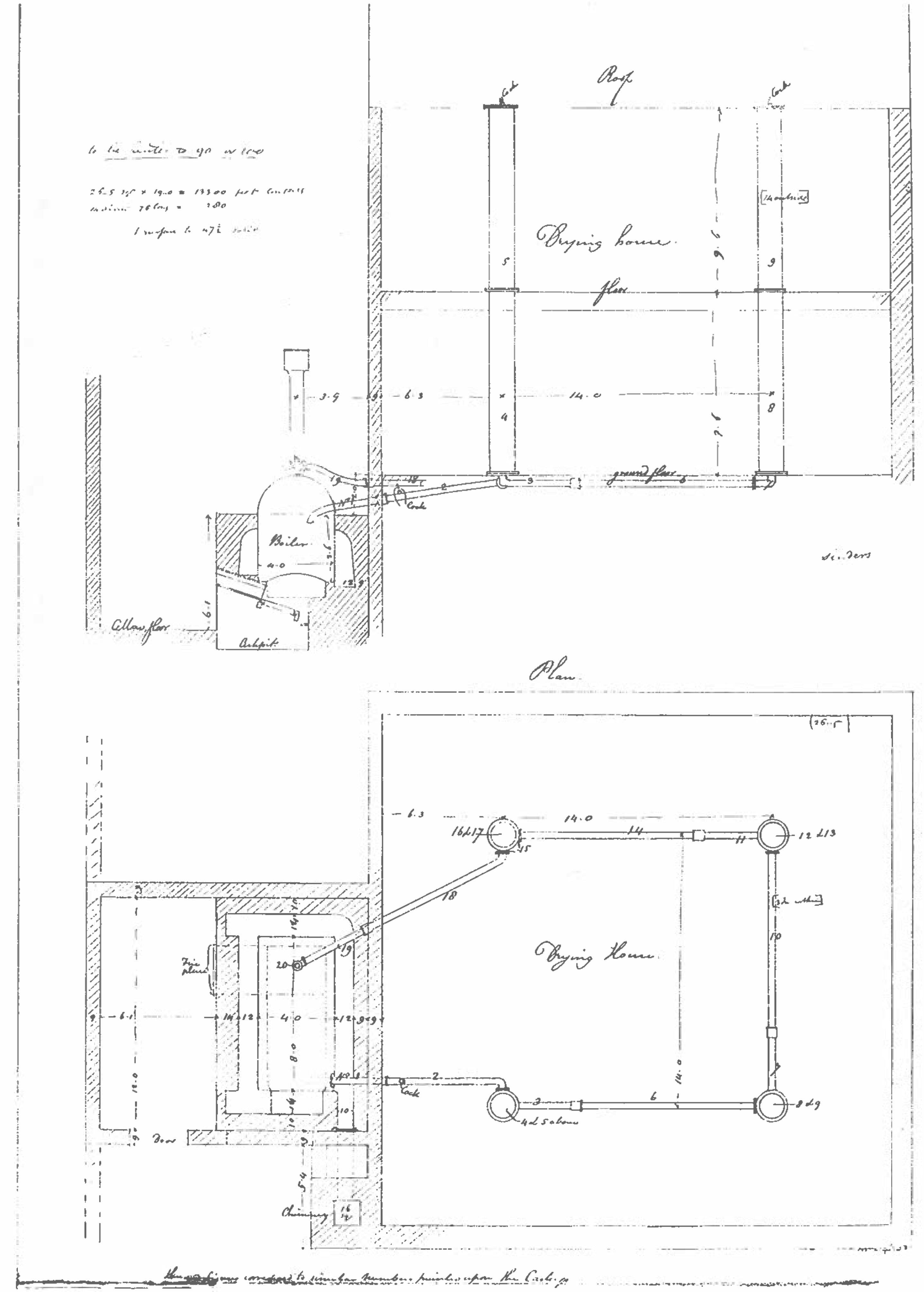
In our 3rd Mill we have a stove different from any of the two preceding ones, as shown by Fig. 3d, aa is a large building on the outside of the gable, taken in at every storey upwards. b is the Stove situated in the bottom, from which the pipe cc. goes up through the building to the top of the chimney; which carried off the smoke and increases the quantity of heated air. At each storey the pipes are supported by a strong cast-iron bar with a hole in the centre that receives the end of the pipe and which rests upon the flange, the ends of the bars being built into the wall. Besides these, there are small iron bars laid across like scantling; upon which a floor of thin rolled iron can be laid; And in which floors, a hole or aperture is made in each, of such dimensions as may be found necessary to check or regulate the ascension of the heated air.

Fig. 4 is an inside view of the Gable, dd are iron doors for admission into the stove when necessary, but always kep lockt. ee are round holes through the wall for the admission of the warm air – these are concentrated in each room upwards, in proportion to the influx of heated air; by which means, and, the apertures in the iron floors at each storey, the heated air is so regulated as to warm all the rooms at once.

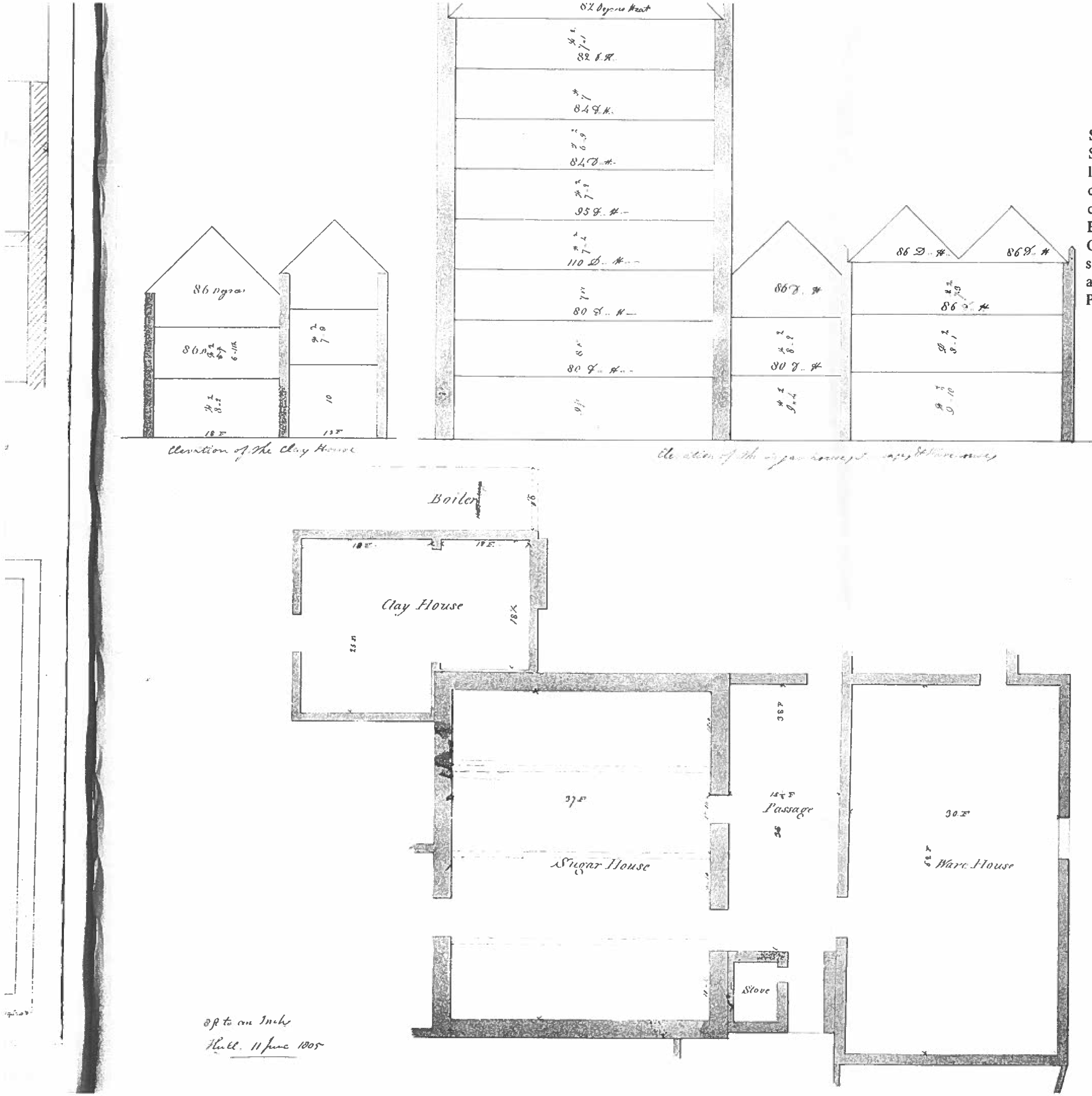
Another advantage of this stove, is, that owing to the largeness of the Column of warm air in the building aa, the air is in no degree burnt which is Noxious; but agreeably warm sweet air. The influx or springs of the air into the rooms, owing also I presume to the same cause I find to be more equal than the others. The last described stove we find answers most completely and one only at the end of the Building is sufficient to warm a mill of 150 feet by 30 or upwards. It is proper to add that there should be an arch thrown over ff, in order that the side of the wall may be taken down without injuring the rest of the building, in case of any accident happening to the Stove –

I should also notice that in place of opening a little of the tops of the windows, to let out the foul air in each flat; (which operates against the influx of the warm air) there should be at the farthest distant part of the room, a ventilator to carry off the bad air all the way to the top of the House. It is almost unnecessary to say, that the external air to be heated is admitted in all the stoves thro holes at the bottom of the Building; which must also be regulated by valves.'

Portf: 1334



Wedgwood and Byerley, drying house, Etruria, Staffordshire, 1807
Steam heating was employed in the pottery industry for drying slip.
Portf: 1334



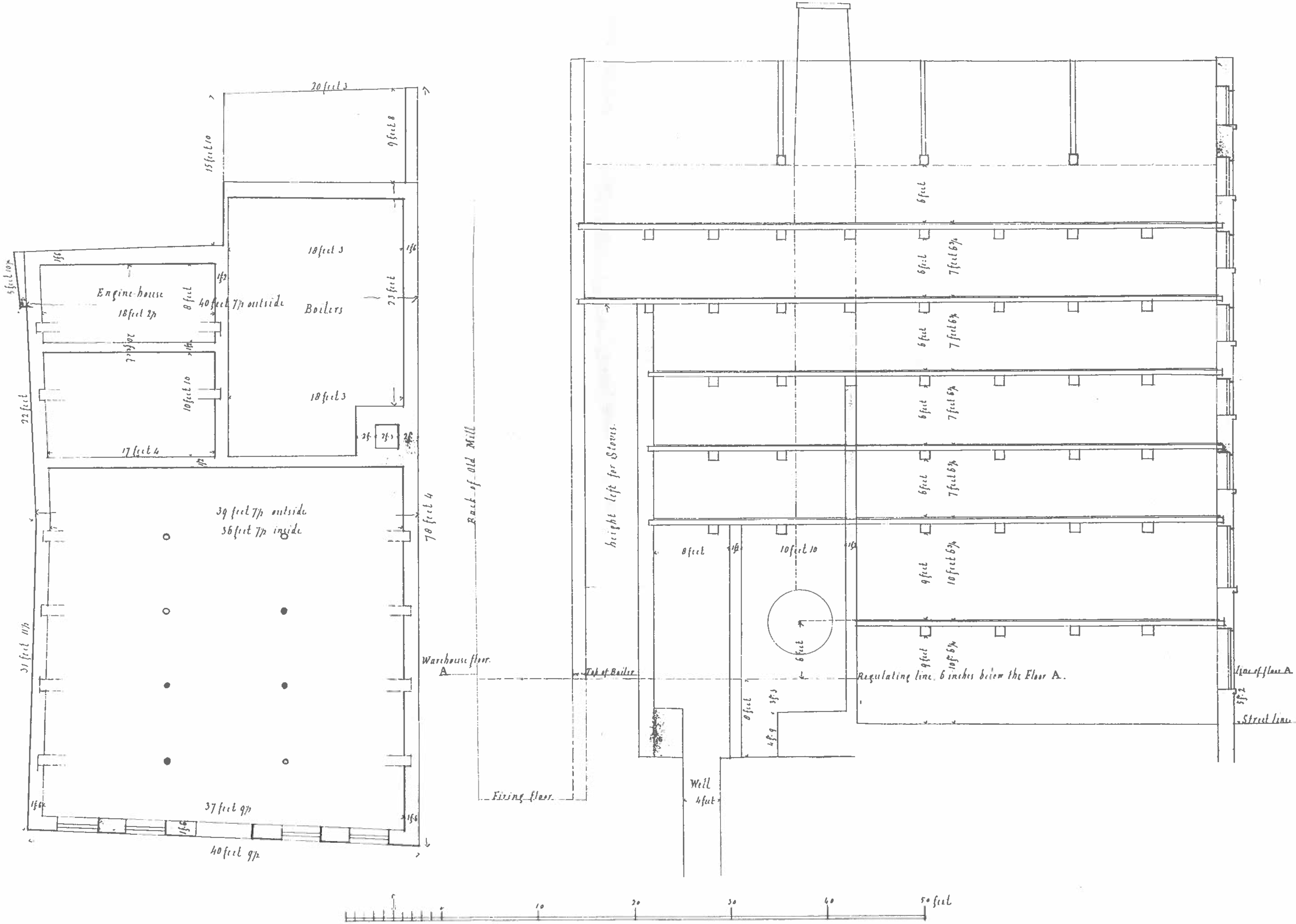
Sugar Refining

Sugar crushing and refining was a developing industry in the late 18th century. A number of London and Liverpool merchants invested in West Indies sugar plantations, and erected crushing mills in the West Indies and refineries in England.

Boyes and Carlill, Hull, 1805

Great heat was required in sugar refining. This drawing of an 8½ storey sugar house is an indication of the large scale of operations.

Portf: 1334



20 feet 3
15 feet 10
9 feet 8
Engine house
18 feet 2½
8 feet
40 feet 7½ outside
Boilers
18 feet 3
23 feet
10 feet 10
18 feet 3
22 feet
17 feet 4
39 feet 7½ outside
36 feet 7½ inside
78 feet 4
31 feet 11½
37 feet 9½
40 feet 9½
Back of Old Mill
height left for Stoves
Warehouse floor.
A
Firing floor
Top of Boiler
6 feet
7 feet 6¾
9 feet
10 feet 6¾
8 feet
10 feet 10
Regulating line, 6 inches below the Floor A.
Line of floor A
Street line
Well
4 feet
10
20
30
40
50 feet

Pe
Th
Pc

Peter Whitfield Brancker & Co, Liverpool, 1815
This refinery was on a similar scale to the one at Hull.
Portf: 824

8. Factory Lighting

For twenty years or so after Arkwright built his first mill at Cromford (1771) night work was common in the cotton factories – Arkwright himself used boy apprentices to work night shifts at Cromford.[1] In Robert ('Parsley') Peel's Burton-on-Trent mills 'the two spinning rooms work all night',[2] and even Sir Robert Peel's factories worked twenty-four hours a day. Mills and factories dependent on water power had to make up for time lost due to water shortages by working at night, for as one Gloucestershire manufacturer commented 'It sometimes happens that we do not get three hours work in the day.'[3] Although perhaps the majority of factories had ceased night work by the early 19th century, a number of mills, if not working all night, at least worked quite late into the night.[4]

The length of time during which artificial light was required each day varied considerably from factory to factory. Murdock estimated that it 'may upon an average of the whole year be stated at least at two hours per day of twenty-four hours. In some mills where there is overwork it will be three hours, and in the few where night work is still continued nearly twelve hours.'[5] Philips and Lee needed light from 6 am to 8 am and from 3 pm to 9 pm in the winter; Peter Marsland required light from 6 am to 8 am and from 4 pm to 9 pm and Radcliffe and Ross needed artificial light in the afternoon and evening only from 3 pm to 8 pm. Gott estimated that seven hours lighting was needed each day in the winter with lighting equivalent to 200 candles for nine hours or more. Wood, Daintry and Co. 'work sometimes until ten in the winter and have no morning work' whilst at W. Douglas's mill at Pendleton eighty-one lamps 'are used all night through the year'.[6]

In the textile factories less light was required in the preparation rooms, weaving shops, engine house and the staircase, than in the spinning rooms. Pooley had light equivalent to sixty-four candles in the carding rooms whilst in the mule spinning rooms between seventy-two and ninety-six candles were required. James Watt jun. reported that in the Salford Twist Mill 'in the upper rooms where they card it is only proposed to have about half the quantity of light'. Horrocks had nineteen candles in the preparation rooms of his new factory and twenty-eight in the mule rooms. Pollard used four candles per mule. Robert Peel of Burton had twenty burners in each weaving shop, twenty-eight in the preparation room and sixty-four in the spinning shop.

Lighting Required in Strutt's West Mill[7]

	Candle Equivalent
4 Mule rooms. 12 mules of 2 lights. Each = 3 candles.	288
1 carding room. 26 lights. Each = 2 candles.	52
Warping Room. 5 warping mills. 6 candles each.	30
Warping Room. 3 reels. 2 candles each.	6
1 cotton picker's lamp	12
3 winding machines. 4 lights. Each = 2 candles	24
1 light for opening machine, 1 for overlooker. Each = 3 candles	6
Sorting Room. 3 lights. Each = 3 candles	9
Staircase	6
Counting House	4
Engine and Boiler House	9
Joiners' Shop	6
	452

Factory lighting was an expensive problem for the entrepreneur. Between 1770 and 1798 there were two alternatives, either the factory could be lit by hundreds of candles or it could be lit by oil lamps. In either case the naked flames and oil, or wax dripping on to wooden floors constituted a severe fire risk. McConnel and Kennedy had approximately 1,500 candles which were lit for four hours per day during the winter half of the year. 125 pounds of tallow were burned each day and, not allowing for wastage, since tallow cost 10½d per pound, the annual cost in tallow was in the region of £681. 'But', James Watt jun. noted, 'it is probable that a considerable addition would require to be made to this for waste etc.' And he added 1/10th to the above mentioned cost. T. Houldsworth's lighting cost him between £310 and £350 a year. James Lees of Oldham had about 300 candles, James Kennedy about 1,000 of six to the pound. Pooley burned, in the depths of winter, two sixty pound boxes of candles a week which over the year came to about £131. Birley and Marsland spent about £187 per year on candles, while Peels at Burton spent about £168; Strutt's lighting at Milford cost approximately £360 per year.[8]

Those manufacturers who used oil lamps spent rather more on lighting their factories. William Douglas of Pendleton spent £255 on lighting 188 lamps in Pendleton Old Mill and his total yearly consumption of oil (including oil for the machinery) for the years 1803-5 was as follows:

	£
1803	777
1804	857
1805	639

Oil lamps were in use at Holywell and James Watt jun. noted that the firm 'state their present consumption of oil to be £800', reckoning their consumption of oil to be around ten gallons per

Gas Lighting

Philips and Lee, Salford Twist Mill, 1806

'The Old Mill' illustrated here was lit throughout by gas, whereas the 'New Factory', the famous fire-proof factory was only partly gas-lit at first.

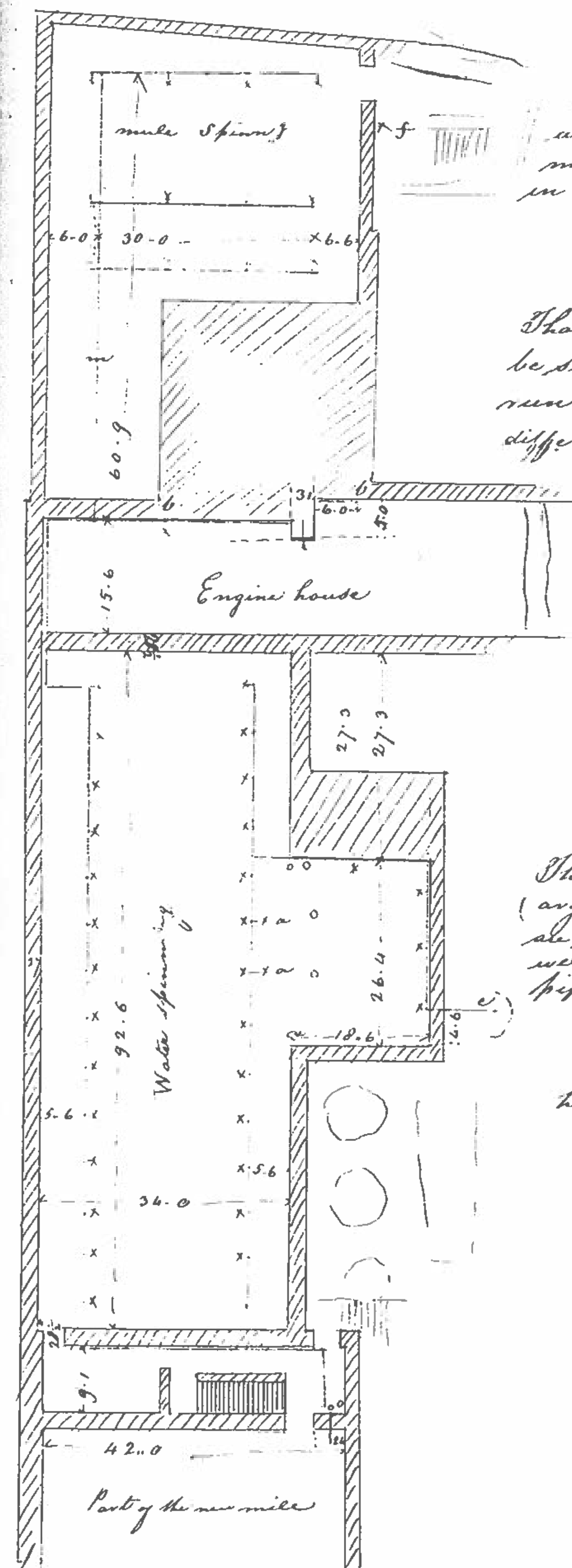
Portf: 242

1. S.C. on Children Employed in Manufactures, PP 1816, III, pp 280, 277, 134,
2. Notebook of James Watt jun. no pagination, Box 30.
3. Jennifer Tann, 'Some Problems of Water Power', *Trans Bristol and Glos. Arch. Soc.* 84, 1965, p. 70.
4. Stanley D. Chapman, *The Early Factory Masters,* p.175.
5. W. Murdock, *An account of the Application of the Gas from Coal to Oeconomical Purposes,* 22 Feb. 1808.
6. Watt Notebook op.cit.
7. Ibid.
8. Ibid.

s, where-
ıs only

Messrs. Philips & Lee June 1806

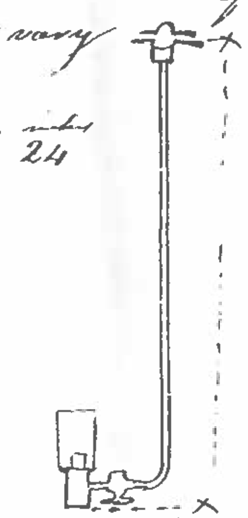
Plan of Story K, Old Mill



This mill is to be supplied with gas from a pipe already fixed in the staircase betwixt the old & new mills The burner pipes for the mule spinning in all the Stories will be similar

18 inches

Those for the water spinning in all the stories will be suspended from the horizontal pipes which will run close under the Beams but as the rooms are of different height their lengths will vary

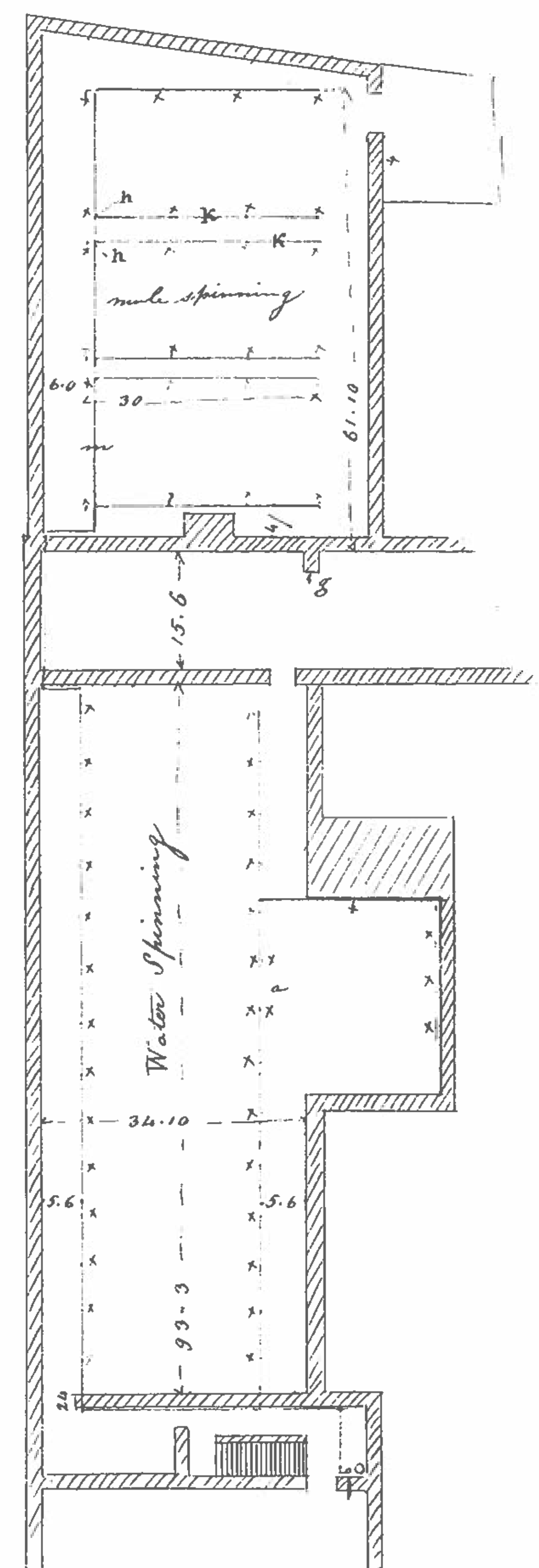


For Stories 1 & 2	length	inches 24
3		25
4		24
5		14

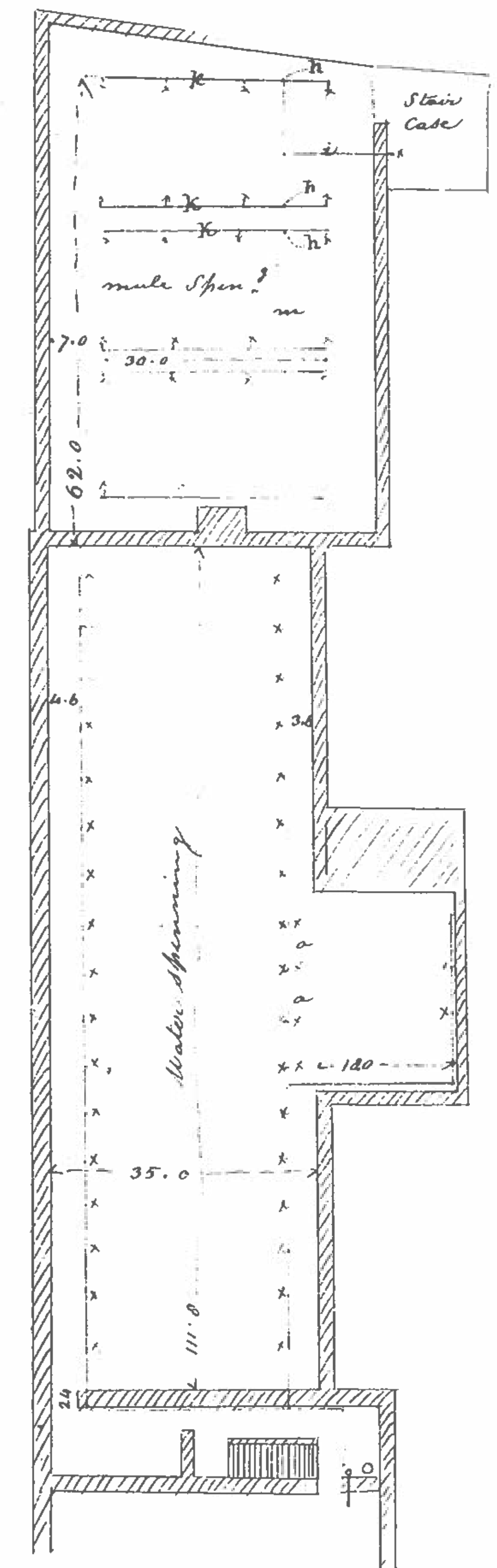
Those for the water Spinn.g are to have tube burners (argands with glasses & reflectors), some of them a, a, are double the two lights b.b. in the engine house will hang down 5.0 below the horizontal pipe & c, will be 18 inches below it

The pipe e, supplies the twist room mentioned hereafter the light f is supplied from above

Story L



Stories M.N.O.



9. Ibid.
10. *Phil. Trans. Roy. Soc.* 1667.
11. Ibid 1733.
12. William Matthews, *An Historical Sketch of the Origin and Progress of Gas Lighting*, 2nd ed, 1823, p.11.
13. W.H. Chaloner, *People and Industries*, p.125.
14. W. Matthews op cit, p.22. T. Wilson to Boulton & Watt, Jan. 27, 1808, Box 30.
15. Charles Hunt, *A History of the Introduction of Gas Lighting*, 1907, p.42.
16. Minutes of Evidence Taken Before the Committee to whom the Bill to Incorporate Certain Persons for Procuring Coke, Oil, Tar, Pitch, Ammoniacal Liquor, Essential Oil, and Inflammable Air, from Coal; and for other Purposes was Committed. 1809 (hereinafter Mins of Evidence Coke etc. Bill).
17. Ibid.
18. Ibid. Evidence of James Watt jun.
19. Aris's *Birmingham Gazette*, 15. April, 1802.
20. Samuel Clegg jun. *Treatise on the Manufacturing of Coal Gas*, 1841 p.6.
21. Soho Box.
22. Mins of Evidence Coke etc. Bill, evidence James Watt jun.
23. W. Matthews op.cit. p.24.
24. Southern to James Watt jun., 9 Mar. 1806, Box 30.
25. Watt Notebook.
26. W. Matthews op cit pp.37-39, 52. Trans. Roy. Soc. Arts XXVI, p.202.
27. Boulton & Watt to G. Lee, 31 Oct., 1800, Office Letter Book.
28. W. Murdock to Boulton & Watt, 23 Dec., 1805, Box 30.
29. W. Murdock to Boulton & Watt, 20 Dec., 1805, Box 30.
30. W. Murdock to Boulton & Watt, 1 Jan., 1806, Box 30.
31. G. Lee to Southern, Aug. 11, 1806, Box 30.
32. W. Murdock to Boulton & Watt, 5 Feb, 1806, Box 30.
33. G. Lee to Southern, Aug. 11, 1806, Box 30. Watt Notebook.

day. The introduction of fish oil had reduced their costs slightly – this was now mixed with seed oil 'and we may reckon it at 4/6d per gallon'. Experiments at Pendleton showed that in addition to being more costly oil lamps gave out less light than candles, one lamp being equal to only one candle of eight in the pound.[9] In view of these costs it is not surprising that when an alternative means of lighting factories was found the owners of the large cotton factories were the first to adopt it.

The burning properties of natural gas were known in the mid 17th century[10] and in 1733 it was noticed that coal gas could not be set alight except by a flame,[11] hence the flint steel which was used as a light by miners. Sir James Lowther sank a pit to drain a colliery of his near Whitehaven in the 1730s and discovered extensive deposits of natural gas.[12] In 1765 Spedding lit his office at Whitehaven with natural gas.[13] But in spite of these and other discoveries of the properties of gas it was not until the 1790s that William Murdock, an agent of Boulton and Watt's in Cornwall, demonstrated the commercial possibilities of gas lighting. In 1792 Murdock lit his office at Redruth and in 1795-6 he lit the counting house at Neath Abbey Ironworks.[14] Between 1797 and 1798 he travelled a number of times to Birmingham finally settling there in 1798. In that year he built a larger gas apparatus 'which was applied during many successive nights to the lighting of the building', and various new methods of washing and purifying the gas were practised.[15] The experiments were continued with some interruptions until 1802.

On his return to Birmingham, Murdock approached James Watt jun. on the question of a patent but was discouraged by Watt: 'I told him that I was not quite certain if it were a proper object for a patent, and I was induced to be rather nice upon the subject of patents, from being at that time engaged in carrying on the defence of a patent which my father had obtained for improvements on the steam engine, and which had then occupied more than four or five years, and which had been attended with a great expenditure of money.'[16]

In spite of the lack of encouragement from James Watt jun., Murdock continued to carry out experiments on his lighting apparatus at Soho Foundry. Gregory Watt went to Paris in 1801. What he heard there and reported back to Soho forced Boulton and Watt's hand 'if we intended to do anything with Mr. Murdock's light no time should be lost because he [Gregory] had heard that a Frenchman of the name of Le Bond [Lebon] was at the same period endeavouring to apply the gas obtained from the distillation of wood to similar purposes.'[17]

Murdock began to receive encouragement and to celebrate the peace of 1802 'a public display of these lights was made in the illumination of Mr. Boulton's Manufactory'.[18] From this description by Watt jun. and from other contemporary accounts one would be justified in assuming that the whole of the front of the Soho Manufactory was lit by gas but this seems highly unlikely bearing in mind the stage in his experiments that Murdock had then reached. Considering the novelty of gas lighting the local press could be expected to have devoted some space to a description of the source of light had it been gas, yet it is silent on this point although there is a lyrical account of the illuminations[19] as a whole. Samuel Clegg jun.[20] states that gas lights known as Bengal lights were placed at the ends of the building and were supplied by a retort placed in the room below whilst the rest of the Manufactory was lit by conventional oil lamps. The existence of a sketch of a Bengal lamp amongst the papers on the Soho Manufactory[21] in the Boulton and Watt Collection supports Clegg's assertion.

In 1803 the lighting at Soho Foundry was extended and between then and 1805 Murdock continued to experiment on the use of different types of coal and on retort design. 'The experiments were very long and attended with a great deal of expense.' Watt estimated that the expense in Murdock's time and the cost of the equipment amounted to £5,000.[22]

Between 1802 and 1805 Murdock altered his apparatus considerably. His first retorts were similar to the glass retorts commonly used in chemical experiments, then he tried cast iron cylinders placed perpendicularly in a common portable furnace – these contained about fifteen pounds of coal. In 1802 he tried horizontal retorts. In 1804-5 he constructed retorts with an aperture at each end, one for introducing the coal and the other for removing the coke but these were not successful and he tried a large retort shaped like a bucket with a cover to it which contained a loose grate to hold 15 cwt of coal. Later still, smaller elliptical retorts were designed.[23]

At first Murdock only lit the retorts shortly before a supply of gas was required. This meant that the retorts were cold each time and fuel was wasted in heating them up before the manufacture of gas could begin. It was John Southern, the faithful draughtsman, clerk and eventually a minor partner in the Firm, who first pointed this out and suggested that a great saving could be made by using fewer retorts continuously and storing the gas rather than by using a larger number of retorts intermitently.[24] At Philips and Lee's factory 1,400 cu ft per hour were required during the hours in which lighting was used. The total time of lighting during the winter was eight hours so that 11,200 cu ft of gas had to be made daily. If no means of storage had been provided about nine retorts would have been required to produce the necessary quantity of gas at the times it was needed. But Lee had five working retorts and one spare and stored the surplus gas made during daylight hours in gasometers. At McConnel and Kennedy's factory fourteen retorts would have been needed to provide the 2,250 cu ft per hour required during lighting times in their mill had there been no gasometers. Instead McConnel and Kennedy had five retorts and one to spare and needed either six gasometers 16 ft square and 5 ft deep or 12 ft square and 5 ft deep.[25]

Interest was shown in gas lighting by the chemists of the day, and Dr. Stancliffe gave a course of chemical lectures in Birmingham in which he 'exhibited and explained' the inflammable properties of coal gas. At the end of 1804 Dr. Henry gave a course of lectures on chemistry at Manchester in which he showed how to produce gas from coal and demonstrated the burning of it by argand lamp in Murdock's manner. The results of Dr. Henry's experiments on gas were published in Nicholson's Journal in 1805. Murdock communicated his discoveries in a paper presented to the Royal Society in 1808 for which he was awarded the Rumford Medal and in the following year Samuel Clegg sent a paper to the Royal Society of Arts[26] for which he was awarded the silver medal.

George Lee became interested in Murdock's experiments at an early stage, whilst Boulton and Watt were still sceptical. 'Murdock's countenance brightened upon my mentioning to him that his various schemes were shortly to be inspected by two such approved connisers [sic]',[27] they wrote in 1800. However, a firm order does not seem to have been placed until 1804 when Lee's house was lit by gas. The success of this experiment led Lee to place an order for a lighting apparatus for the Salford Twist Mill. Part of the apparatus was installed in late December 1805, but Murdock was obviously impatient with the slowness of both Soho Foundry and the communications system of the day for he wrote 'if materials cannot be forwarded in a more expeditious manner than they hitherto have done it is of no use to think of taking orders here, for your old servant Clegg is manufacturing them in a more speedy manner than it appears can be done at Soho.'[28]

From the start Lee took a keen interest in the installation of his lighting system. 'Mr. Lee enters into the spirit of the project and wishes much to have it lighted before Christmas but I think it impossible, however we may get it accomplished by New Years Day.'[29] On New Years Day fifty lamps were lit. Mrs. and Miss Lee visited the factory to inspect them 'and there [sic] delicate noses have not been offended'.[30] Lee carried out experiments on the efficiency of the lights, the relative brightness compared with candles and the cost of operating the apparatus. His was the final decision when the types of lamp were chosen: 'I propose to have Argands in all the water spinning rooms and no where else.'[31] Cockspurs were used elsewhere. But he left the design to Boulton and Watt: 'Mr. Lee thinks designing to be more in the way of the people at Soho than a cotton spinner therefore he hopes they will please their own fancy in his chandleers.'[32] When he tried to estimate the gas consumption of the two types of lamp he found that argands exceeded cockspurs by about one third. In February 1806 James Watt jun. noted 'Mr. Lee deduces from his Experiments that one hours consumption of a candle of six in the pound produces light equal to two thirds of a cubic foot of gas or that two cubic feet equal one cockspur burner of three issues for one hour.' 'These experiments', said Lee 'were made under my direction and inspection.'[33]

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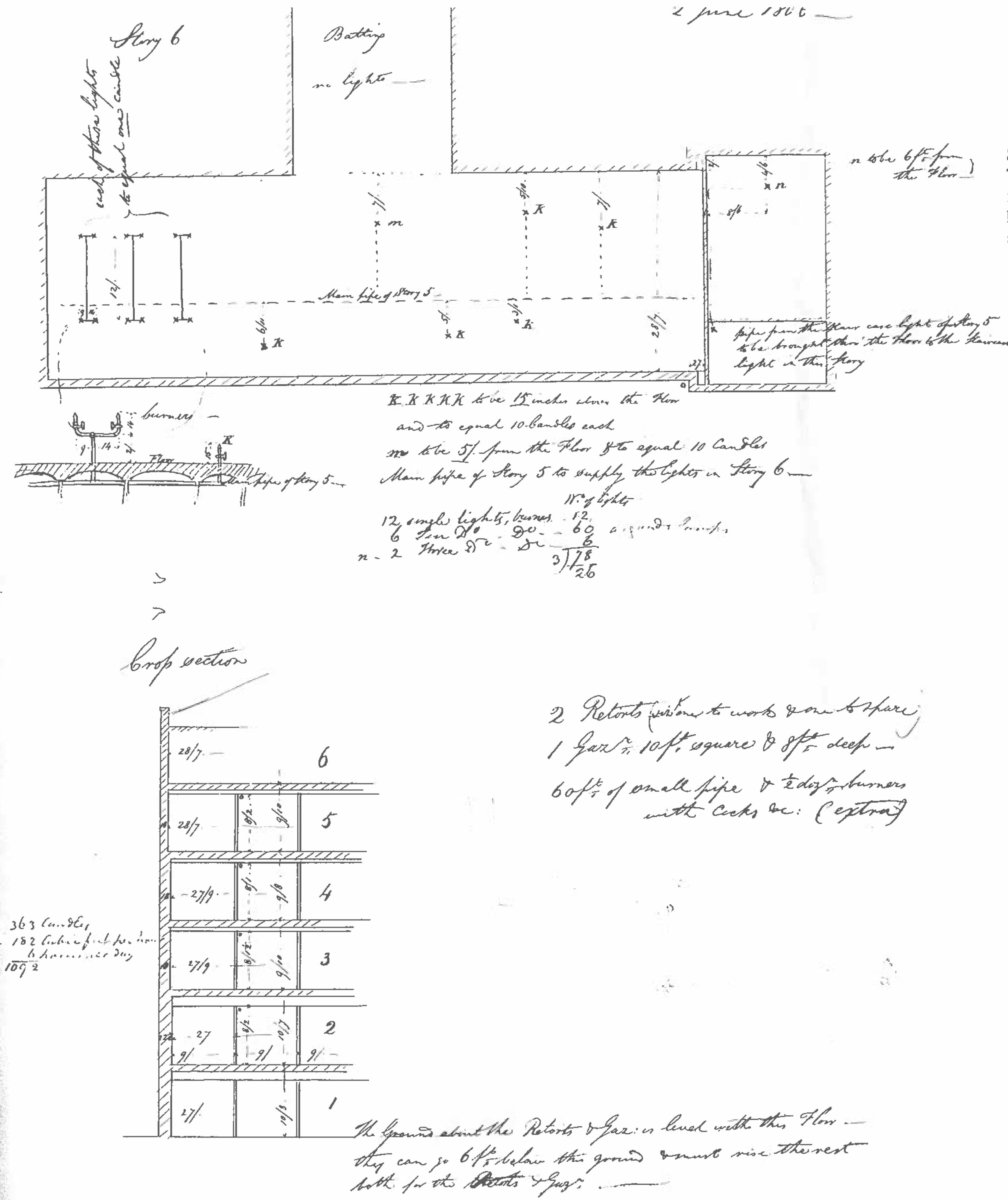

Strutt, Derby Calico Mill, 1806
This drawing is probably of greater interest in showing the first fire-proof factory in the world than in illustrating an early gas lighting installation. The brick arch floors can be seen in the small sketch beneath the main plan.
Box 30

Each of Lee's retorts produced from 160 to 200 cu ft of gas per hour and one hundredweight of coal produced about 370 cu ft In March 1806 further experiments were conducted. There were at this time three gasometers of 7 ft diameter and 5 ft deep, and a fourth was to be installed. Lee estimated that he would require 1,400 cu ft of gas per hour. It was found that Cannel coal was by far the best type to use in a lighting system and it was given 'a decided preference . . . over every other coal, notwithstanding its higher price'. Best Wigan cannel coal cost 13½d per cwt, 22/6d per ton at the factory. The annual consumption for 313 working days was 110 tons costing £125. Common coal was used to heat the retorts and 40 tons were used each year which at a cost of 10/- per ton amounted to £20 per year. The 110 tons of Cannel coal produced 70 tons of good coke which was sold on the spot for 1/4 per cwt and this over the year produced £93. 11 to 12 ale gallons of tar per ton were produced – about 1,250 ale gallons per year. This could be sold for 1/- per ale gallon. Without allowing anything for the tar the annual cost of running the apparatus was £52. To this cost had to be added the interest on capital plus depreciation which Lee estimated at £550. He estimated that the annual cost of candles to give the same light would have been approximately double although on re-examination before the Committee on the Coke, Oil, Tar . . . Bill he said that the difference in expense between oil and gas lighting was 50% and between candles and gas 70%.[34] Even this figure was far lower than Boulton and Watt's estimate. In 1807 Boulton and Watt drew up a memorandum concerning Philips and Lee's 'Photogenous Apparatus'. In this it was noted that 550 cockspur burners and 300 argands had been supplied to Philips and Lee. These produced light equal to 3725 candles and had candles been used the annual cost would have been in the region of £2,600 per year. The memorandum concludes with a detailed costing of Philips and Lee's apparatus:[35]

		£
Cost of metal materials of apparatus from Soho		3,670
Cost of gasometer pits, retort houses, putting up, pipes etc.		1,330
		5,000
Say 6 retorts £100 each	= £600 at 20%	120
8 gasometers £150	= £1200 at 15%	180
Pipes, burners, lamps	= £1800 at 10%	180
Buildings, etc.	= £1330 at 10%	133
		613

The high cost of Philips and Lee's lighting apparatus must be partly explained by the fact that when it was installed in the Salford Twist Mill Murdock's lighting system was still very much in the experimental stage. Later customers were to benefit from these experiments and their apparatus seems to have cost less. Estimates varied from about £800 for a medium sized order to £1,270 for 400 burners and 26 spare for Marshall Hives and Co in 1811. Two estimates were sent to Monteith Bogle and Co in 1814. In the first, the materials came to £1,161. 1. 0d and in the second they came to £1,710. 15. 11d.[36] Both James Watt jun. and George Lee gave evidence to the Committee on the Coke, Oil, Tar . . . Bill in which the cost of Philips and Lee's installation was set out and this may have deterred some smaller manufacturers from approaching Boulton and Watt to solve their problems of factory lighting.

Although Philips and Lee's factory was undoubtedly the first large factory to be lit by gas it was not the first factory (Soho apart) to be gas lit, for a former employee of Boulton and Watt, Samuel Clegg, successfully lit the cotton factory of H. Lodge near Halifax in 1805.[37] Clegg was one of a number of former employees of Boulton and Watt who branched out on their own and made valuable contributions to the design of machinery. In Clegg's case he was to improve gas lighting. In 1809 he introduced a paddle at the bottom of the tank to agitate the lime at a Coventry gas plant and in 1817 he invented the collapsing gas holder. Clegg was the first man to superintend the lighting of a town by gas. 'His active, ardent and enterprising disposition being united with many useful acquirements eminently qualified him for such large undertakings.'[38] Murdock was aware of Clegg's competition in Manchester as his letter to Boulton and Watt, quoted above, shows, and it was to Manchester that Bage went in 1808 when he wanted to see a gas-lit factory:[39]

'I am just returned from viewing some gas lights in a small factory near Manchester put up by Clegg. There are 28 splendid lights equal each to 10 or 12 candles of 6 in the pound; not nearly so offensive as candles or common oil; and what smell they have (in itself rather a pleasant one) might be diminished by ventilation, which seems very necessary where there is so much combustion. The expense according to the reports of Mr. Knight the proprietor and Mr. Clegg the Engineer is nearly as follows:–
Each retort holds 3 cwt of coals, and 2½ cwt is burnt under it. The gas supports the combustion of 28 lights 4 hours. The expense of an apparatus for 100 lights including fixing, brickwork and tin reflectors amounts to £500 which at 10 per cent is . . . £50 per an.

34. Watt Notebook. Mins of Evidence Coke etc. Bill. W. Murdock, An Account of the Gas from Coal to Oeconomical Purposes.
35. Memorandum Concerning Lee's Photogenous Apparatus, 2 June, 1807, Box 1 L.
36. Nearly all Boulton and Watt's estimates for gas lighting are now illegible. Box 30.
37. W. Matthews op cit p.40. Clegg probably obtained Lodge's order when he installed Lodge's steam engine in 1803, Southern to Clegg, 1 Feb. 1803, Foundry Letter Book.
38. W. Matthews, op.cit. pp.52, 83.
39. Shrewsbury Library, Bage MSS Bage to Strutt, 5 March, 1808.

Strutt, Milford Mills, Derbyshire, 1806
The cruciform building shown on the right hand side of the drawing was Strutt's second fire-proof building known as Milford Warehouse.
Box 30

the
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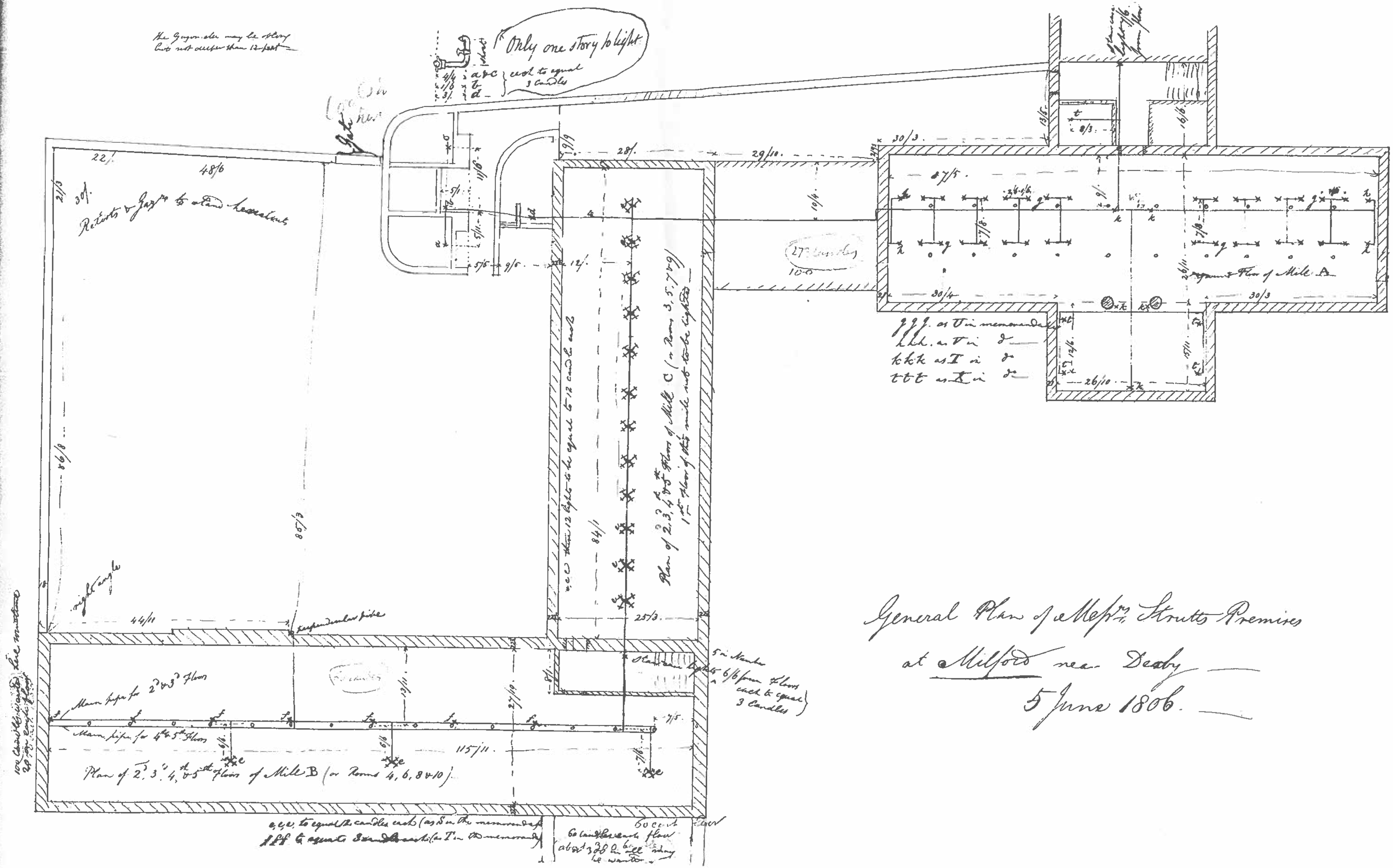

Only one story to light
each to equal 3 Candles
Retorts & Gazo to stand here
right angle
Main pipe for 2d & 3d Floors
Main pipe for 4th & 5th Floors
Plan of 2d, 3d, 4th & 5th Floors of Mill B (or Rooms 4, 6, 8 & 10)
Plan of 2, 3, 4 & 5th Floors of Mill C (or Rooms 3, 5, 7 & 9)
1st floor of this mill not to be lighted
Ground Plan of Mill A
ggg as U in memorandum
hhh as V in do
kkk as T in do
ttt as X in do
General Plan of Messrs Strutts Premises at Milford near Derby 5 June 1806.

40. W. Matthews op.cit. p.40.
41. Ibid. pp.39-42.
42. Ibid. p.43.
43. Charles Hunt op cit, pp.80-82.
44. W. Matthews op cit, 52, 83.
Charles Hunt op cit, p.69.
45. Watt Notebook. Boulton & Watt Engine Book.
46. Watt Notebook.
47. Mins of Evidence Coke etc. Bill.
48. Cusworth Hall MSS, B. Gott to B. Gott jun. 9 Jun, 1809.

Repairs Clegg says would be over estimated at £40 per an. as the chief source of expense is the burning of an iron saddle interposed between the fire and the retort; serving at once to preserve the retort and to equalise the heat, without which different gases would come over	£ 40
Attendance one man & an assistant whilst discharging and charging say	£ 40
Coals 5 cwt per hour for 100 lights. Suppose the season 400 hours, equal to 100 tons; of these one half are improved into coak and cost nothing, and half the remainder (they say the whole) is paid for by the tar. Say 25 tons	£ 15
Total expense (per an.)	£145'

Early in 1806 Josiah Pemberton, a Birmingham manufacturer and 'a very intelligent and ingenious man',[40] exhibited a number of different lights outside his Birmingham factory and began to install gas lighting apparatus for the smaller workshop/factories of the West Midlands. He designed a scheme for Mark Saunders, a button manufacturer, whereby the gas not only lit the premises but produced jets that could be used for soldering button shanks. Pemberton is said to have installed gas lighting for a number of Midland manufacturers including Isaac Spooner of Park Mill.[41] Another Birmingham manufacturer, Benjamin Cook, a brass tube and toy manufacturer, having seen Murdock's paper to the Royal Society, wrote a letter to *Nicholson's Journal* in November 1808 in which he stressed the economies to be made by using gas light in preference to other methods of lighting. Matthews suggests[42] that Cook's apparatus was made by Pemberton but this is not mentioned by Cook in his letter to the Journal. Cook described how, because of 'the present rupture with Russia and the northern powers the want of importation of tallow has increased to a very considerable height the price of candles.' What Murdock did for the large-scale manufacturer Cook attempted for the small manufacturer. 'Mr. Murdock's paper is on the great scale, therefore far above the circulation of the simple mechanic, and it is to the great number of these that the thing ought to be made clear. To them a small saving of ten pounds per annum is of as great consequence as to the wealthy their thousands.' Cook's apparatus consisted of a small eight gallon pot for the coal; and a gasometer holding about 400 gallons. He made about 600 gallons of gas from twenty to twenty-five pounds of coal. His former annual expenditure on candles amounted to £18. In addition to this he used to spend £30 per year on oil and cotton for soldering but found that in 'all trades in which the blow-pipe is used with oil and cotton the gas flame will be found more superior, both as to quickness and neatness in the work; for the flame is sharper, and is constantly ready for use.' His annual expenditure, including the wages of a man to make the gas amounted to £18. 4. 0d. 'The expense of putting up my apparatus was about £50.' Cook estimated the cost of a gas apparatus 'for the poor man who lights only 6 candles' at £10 or £12 'and if the pipes are made of old gun barrels, as mine are, and once a year, or once in two years, are coated over with tar to keep them from rusting, they will last half a century.' Cook modified his opinion regarding the use of old gun barrels on account of the number of joints which had to be made, notwithstanding this they were in general use for gas lighting in the Birmingham area for many years.[43]

In 1807 Alderman Wood attempted to light the Golden Lane Brewery in London and in the same year a weaving shed at Pollokshaws near Glasgow was lit by gas, the retort being the cylinder of an old steam engine. Two years later Clegg lit Harris's factory in Coventry, and in 1817 he was responsible for lighting the Royal Mint in London.[44]

Meanwhile, following the successful lighting of Philips and Lee's factory in Salford, Boulton and Watt received enquiries about gas lighting from a number of important manufacturers, many of them cotton spinners. But it was only the largest manufacturers who applied to Boulton and Watt, the others, probably put off by the high cost of lighting Philips and Lee's factory, either continued to use oil or candles or went to Clegg or one of the other firms competing in the artificial lighting market. Strutts were amongst Boulton and Watt's earliest customers and in 1806 details were drawn up for lighting the Derby Calico Mill (page 126). T. Houldsworth required approximately 600 burners which were expected to consume £45. 15. 0d worth of gas per year. James Kennedy ordered a lighting apparatus in 1808, and in the following year Greg and Ewart ordered theirs.[45] Creighton recommended one retort and one gasometer of 1,000 cubic feet capacity for the latter's seven storey building. There were to be twenty-six lights per storey with additional lights in the roof, staircase and boiler house providing altogether light equal to 1,200 candles. One of the most ambitious lighting schemes was McConnel and Kennedy's. They required 1,500 burners producing light equal to 4,500 candles. James Watt jun. computed that the cost of coal per year would be £106 or 1/21 of the cost of tallow to produce an equivalent amount of light.[46]

Benjamin Gott, woollen manufacturer of Leeds, stayed with George Lee and had 'regular access to the Salford Twist manufactory at all times. . . . I was induced to order the apparatus for one of the mills and when the engineer came to take the dimensions of that mill to order a drawing of two or three intending to apply a smaller apparatus to them so soon as it was ascertained whether the lights in the first were as advantageously applied for the convenience of the workmen as possible.'[47] Gott sent an enthusiastic report of gas lighting to his son: 'We have had Burley Mill illuminated by gas from coal for ten days past and a beautiful and interesting object it is, the shade of the light is so pure, ye quantity so great and at so small a price I have ordered similar apparatus for Armley Mill.'[48]

The two Shrewsbury flax mills were gas lit in 1811 and in 1814 plans were drawn up for the lighting of John Maberley's mill in Aberdeen (page 133).

It is noticeable that the owners of fire-proof mills were

Watson Ainsworth and Co, Preston, 1806

This drawing shows a large mule spinning factory. The 'machine shop' indicates that the company employed clockmakers, turners, carpenters and millwrights to make and repair machinery in the factory.

Box 30

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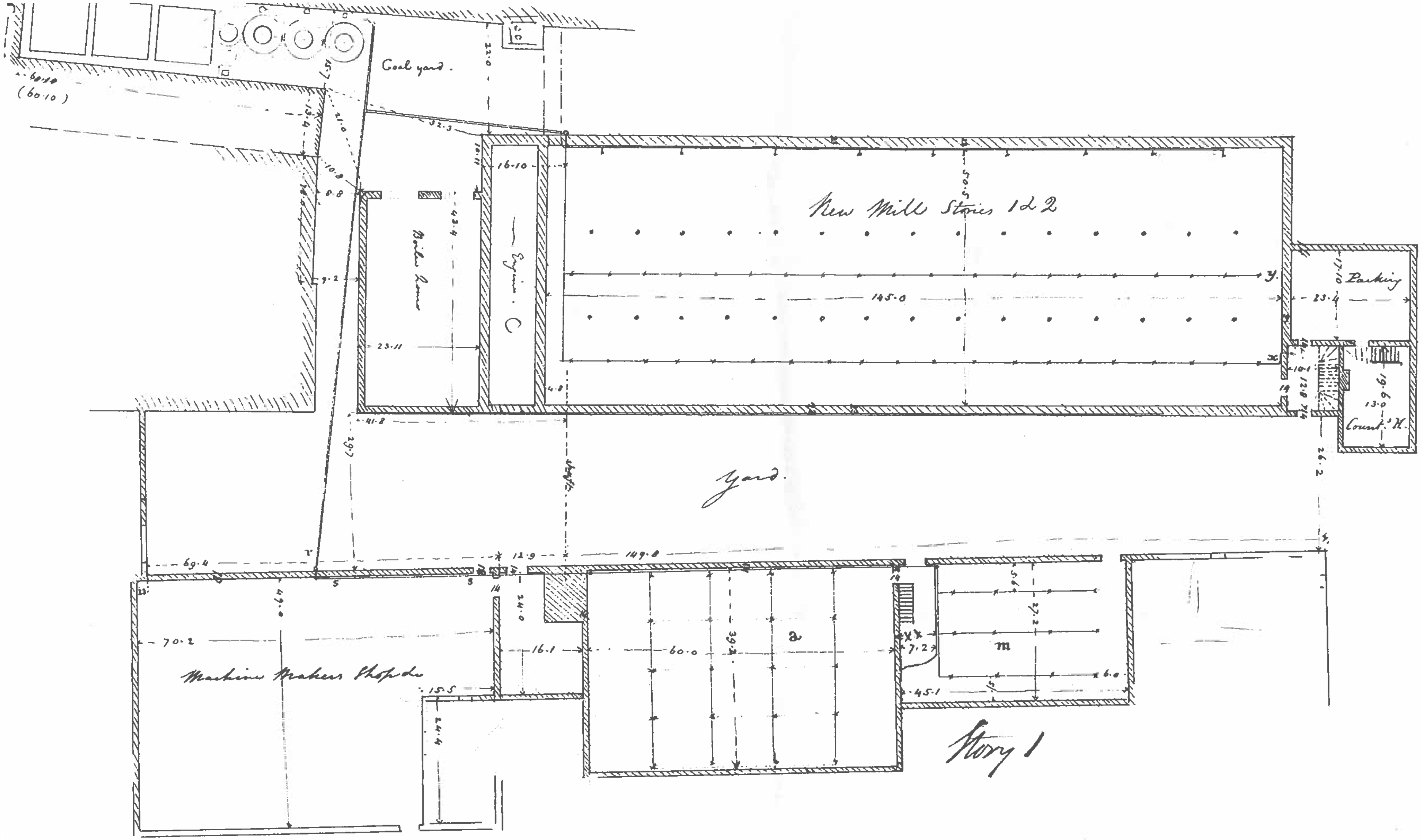
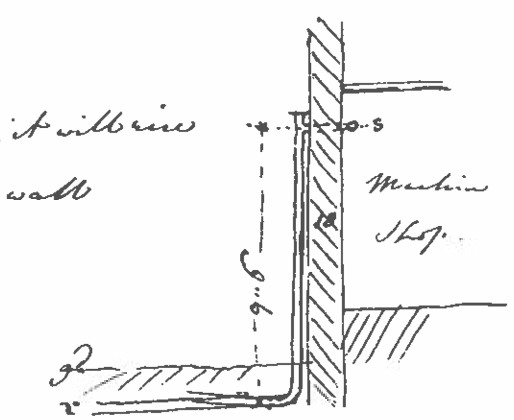


The pipe in the ground at x will be abt. 1 foot under the surface, it will rise up on the outside of the Machine makers shop & come thro' the wall



49. Mins of Evidence Coke etc. Bill.

amongst Boulton and Watt's first customers for gas lighting. George Lee said that the Sun Fire Office offered to insure the Salford Twist Mill for a third the usual premium and Warner Phipps, the secretary of the Albion Fire and Life Insurance Co, on being asked if he thought gas lighting was safe, commented 'It appeared to me to diminish the risk of fire very greatly.'[49] But just as fire-proof buildings remained exceptional until the mid 19th century, so did the lighting of factories by gas. For although there is no doubt that once installed it gave a better light than oil or candles and was also cheaper to run, with the exception of the cheap Midland type installations, the initial capital outlay was too great for all but the largest firms.

APPENDIX

Gas plants supplied by Boulton and Watt

No. on Portf.	Earliest date on Drawings	FIRM
804	1805	Philips and Lee, Salford.
818	1806	Strutt, Milford Mills.
816	1808	H. H. Birley & Co Manchester.
817	1808	James Kennedy, Manchester.
812	1808	Wormald, Gott and Wormald, Park Mill, near Leeds.
819	1809	Richard Gillespie & Co
809	1809	Neilson & Co
820	1809	Benjamin Gott, Armley Mills, Yorks.
811	1809	Marshall Hives & Co, Shrewsbury.
813	1810	Lister Ellis & Co, Burley near Otley, Yorks.
814	1810	T. Coupland & Sons, Leeds.
815	1810	John Thomas & Edward Lewis, Manchester.
810	1811	Marshall Hutton & Co, Shrewsbury.
805	1811	Benyon, Benyon & Bage, Near Shrewsbury.
806	1811	Huddart & Co Rope Manufactory, Limehouse.
808	1814	John Maberley, Broadford Mill, Aberdeen.
807	1814	Williams, Jones & Co, Birmingham.

The following drawings of crank engines show gas plants.

Greg & Ewart, Birley & Hornby, Huddart & Co, Heathfield, The Britannia Nail Co, McConnel & Kennedy.

James Watt jun. attempted to obtain orders from the following cotton spinners:

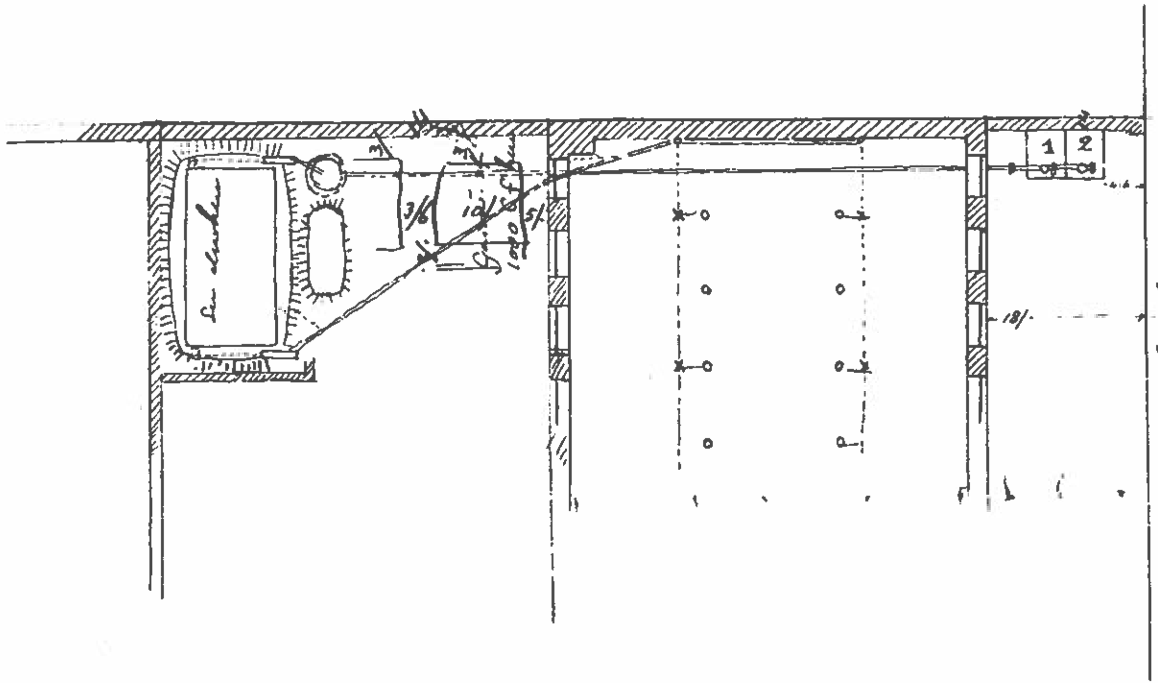
Houldsworth, Bury & Co, Radcliffe & Ross, Douglas (Pendleton), Douglas (Holywell), P. Marsland, J. Lees (Oldham), Pooley, Pollard, Wood, Horrocks, Peel (Burton).

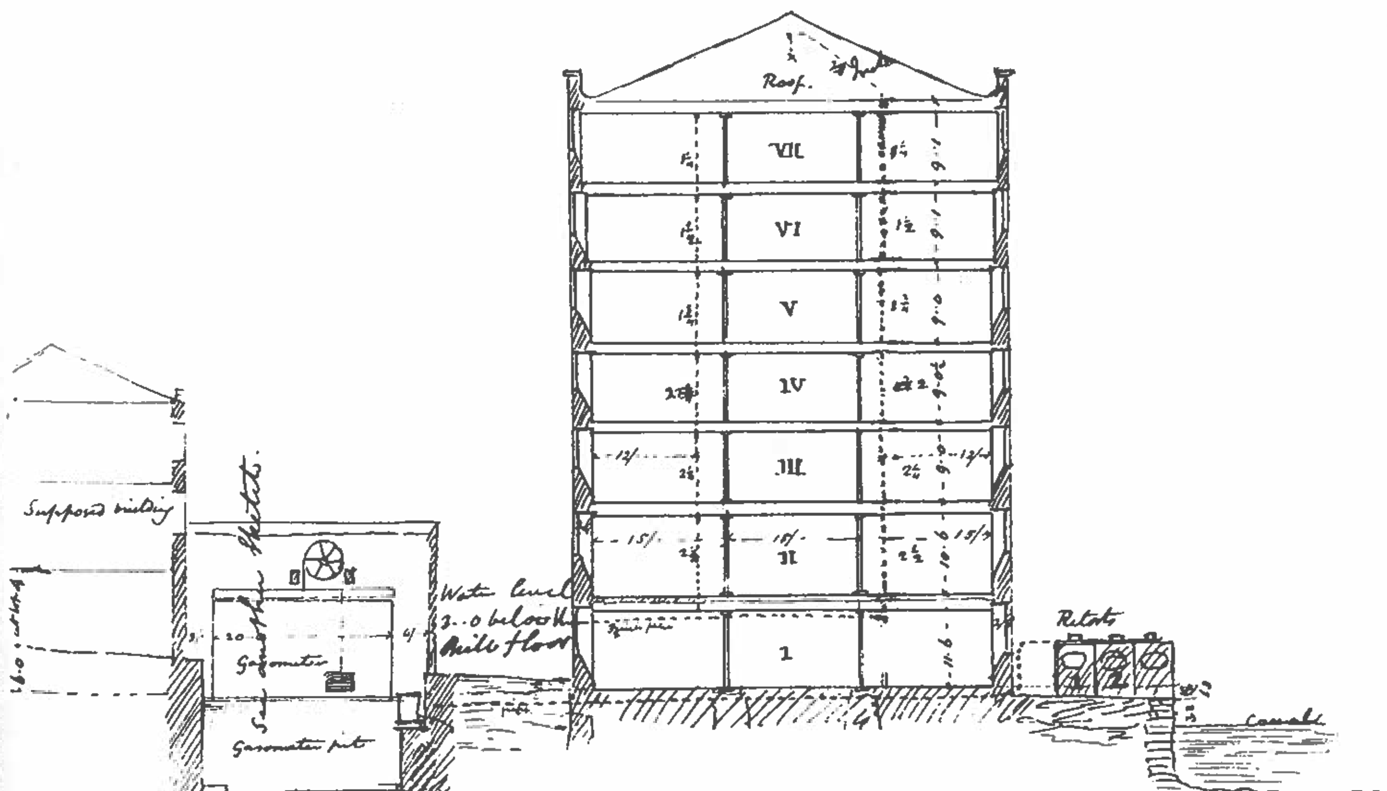
Source: Engine Book, James Watt Notebook, Box 30.

Greg and Ewart, Manchester, 1809

This was one of the new mule spinning cotton factories. It may have been iron framed for the pillars appear to be cast iron. Creighton's calculations indicate the hours during which light was required.
Portf: 307

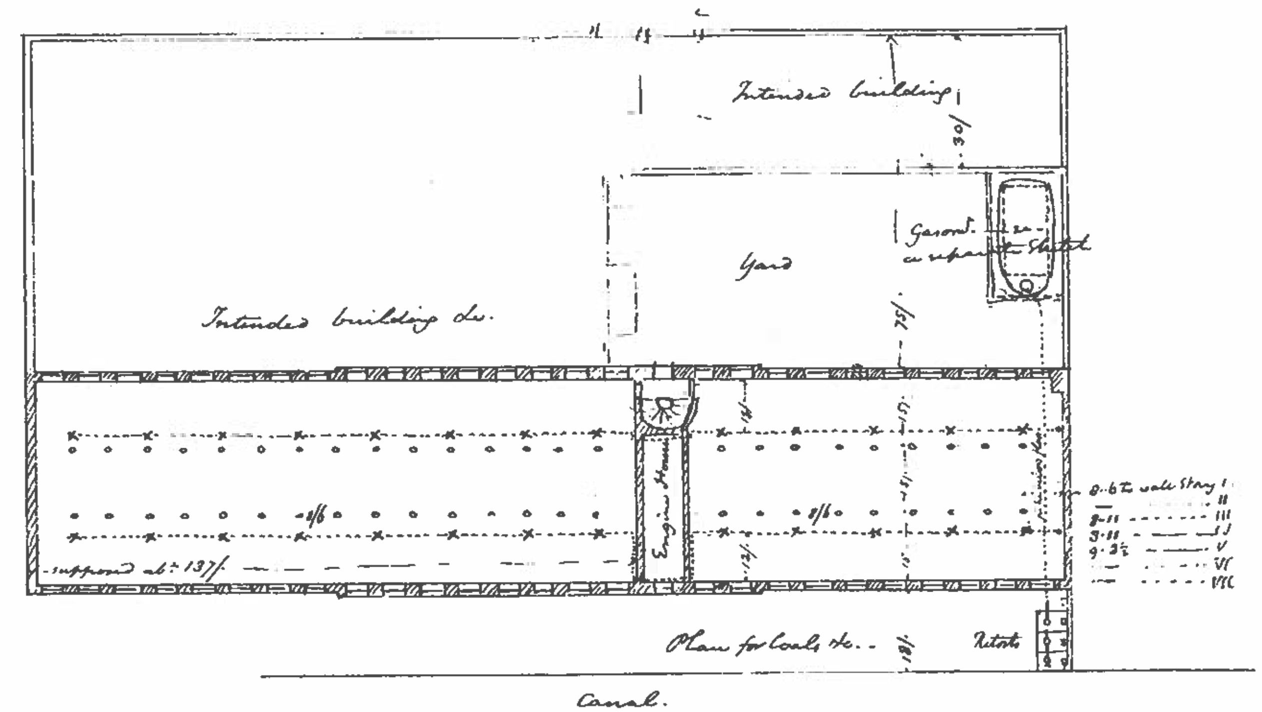
es. It may
iron.
ch light





Level of Canal is 4.4 below ground floor of Mill or 3.3 below the ground where the retorts stand.

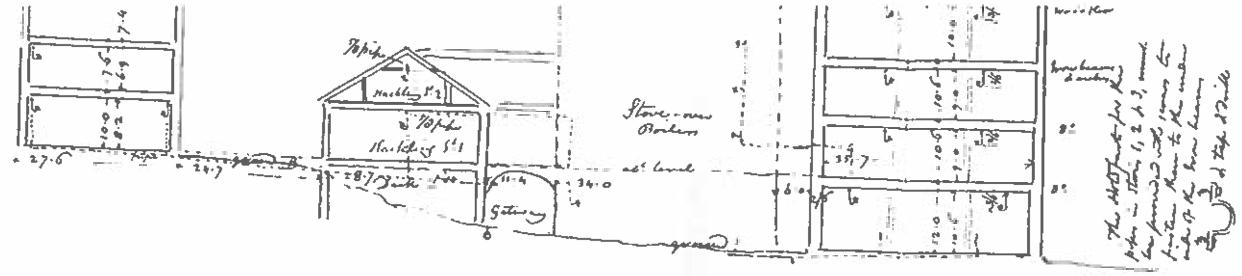
Messrs. Greg & Ewart. Manchester 30 June 1809.

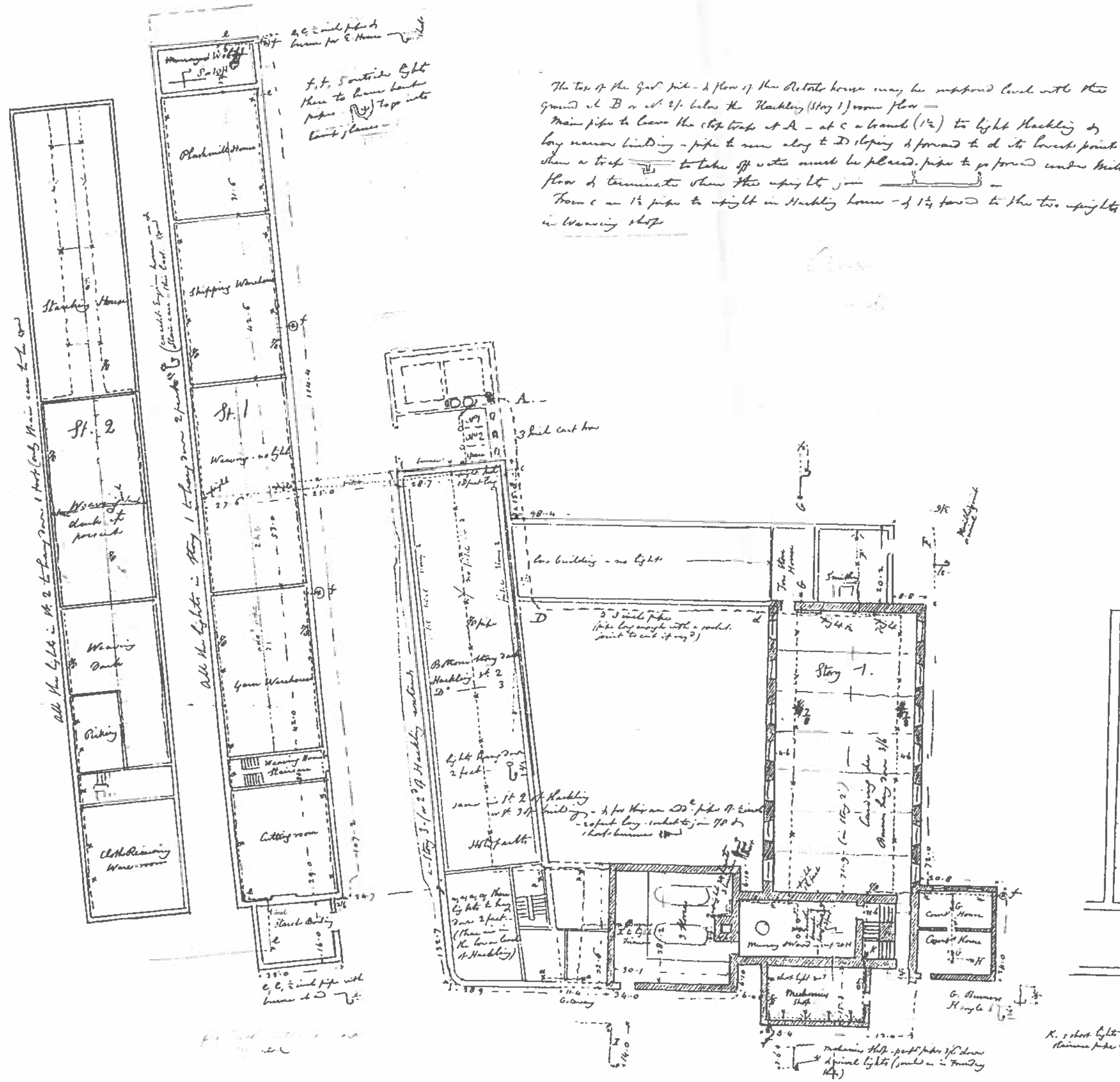


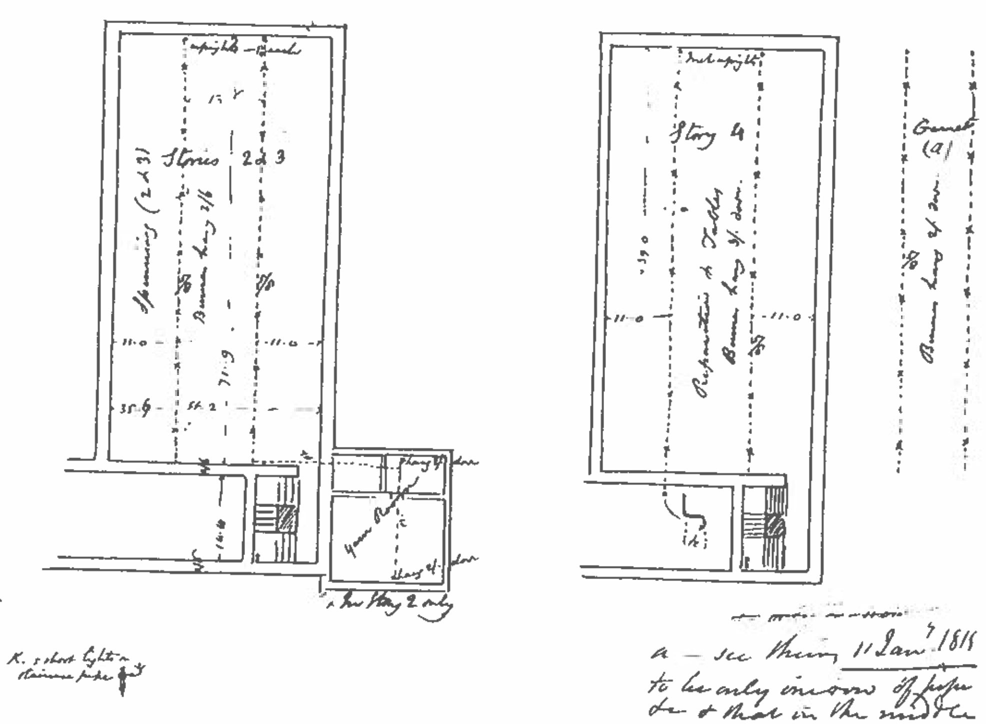
For a building of the above size there are supposed 26 lights in each story & 7 stories = (26×7) = 182 + 13 for roof = 195 & 4 over the Engine house in Stories IV.V.VI.VII. = 199. call 200 at 6 Candles each = 1200 C.
Staircase 7 lights = 14 C. & Boiler H say 6 Candles = 20
1220 Candles

which would require 600 C.f. of Gas ℘ hour & 7 hours ℘ day = 4200 C.f. which 2 retorts would supply working constantly — in 4½ hours (the longest time of burning at once) 2700 C.f. gas will be used & if the Gasom. contains 2000 C.f. the two retorts will make out the rest. — ~~the total quantity of light may however be = to 1600 Candles at one period or other & but at present the following will be a statement of what is required~~ —

One retort & one gasom. of 1000 C.f. will be suff. for the present building (taking the lights = 6 Candles) (79×6 =) say 80×6 = 480+20 = 500 Candles or 250 C.f. Gas ℘h. = 1750 C.f. ℘ day —





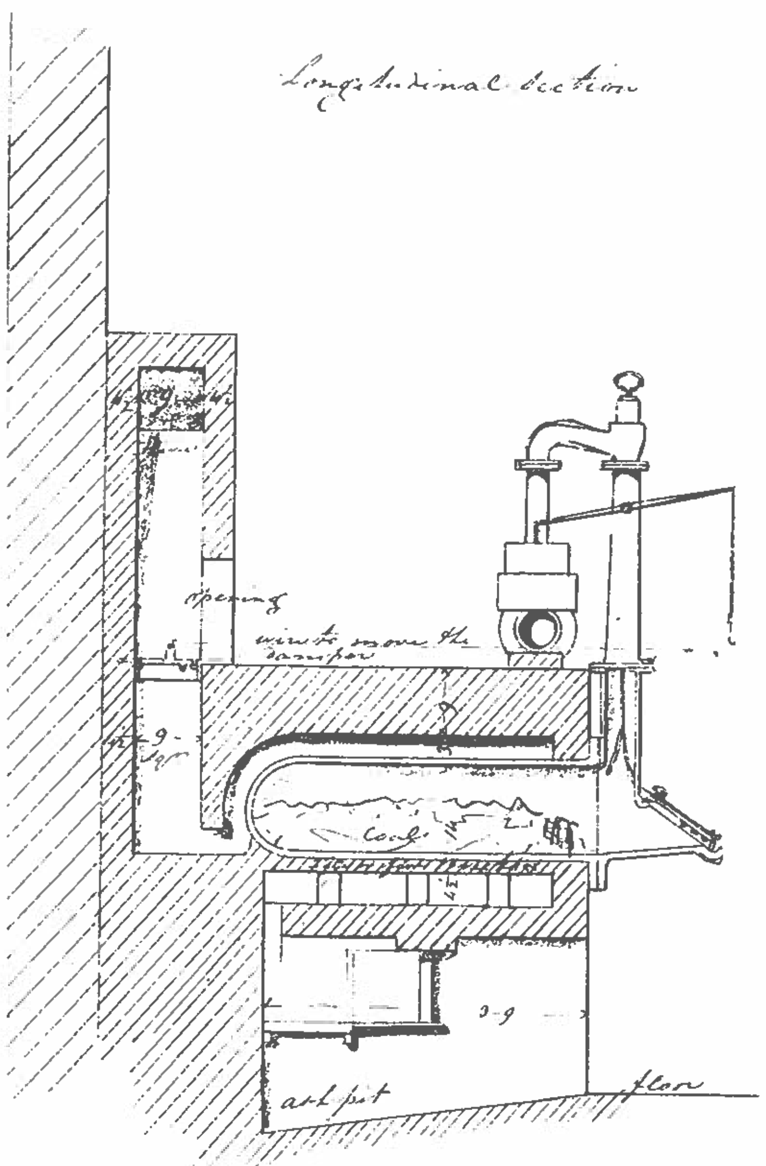


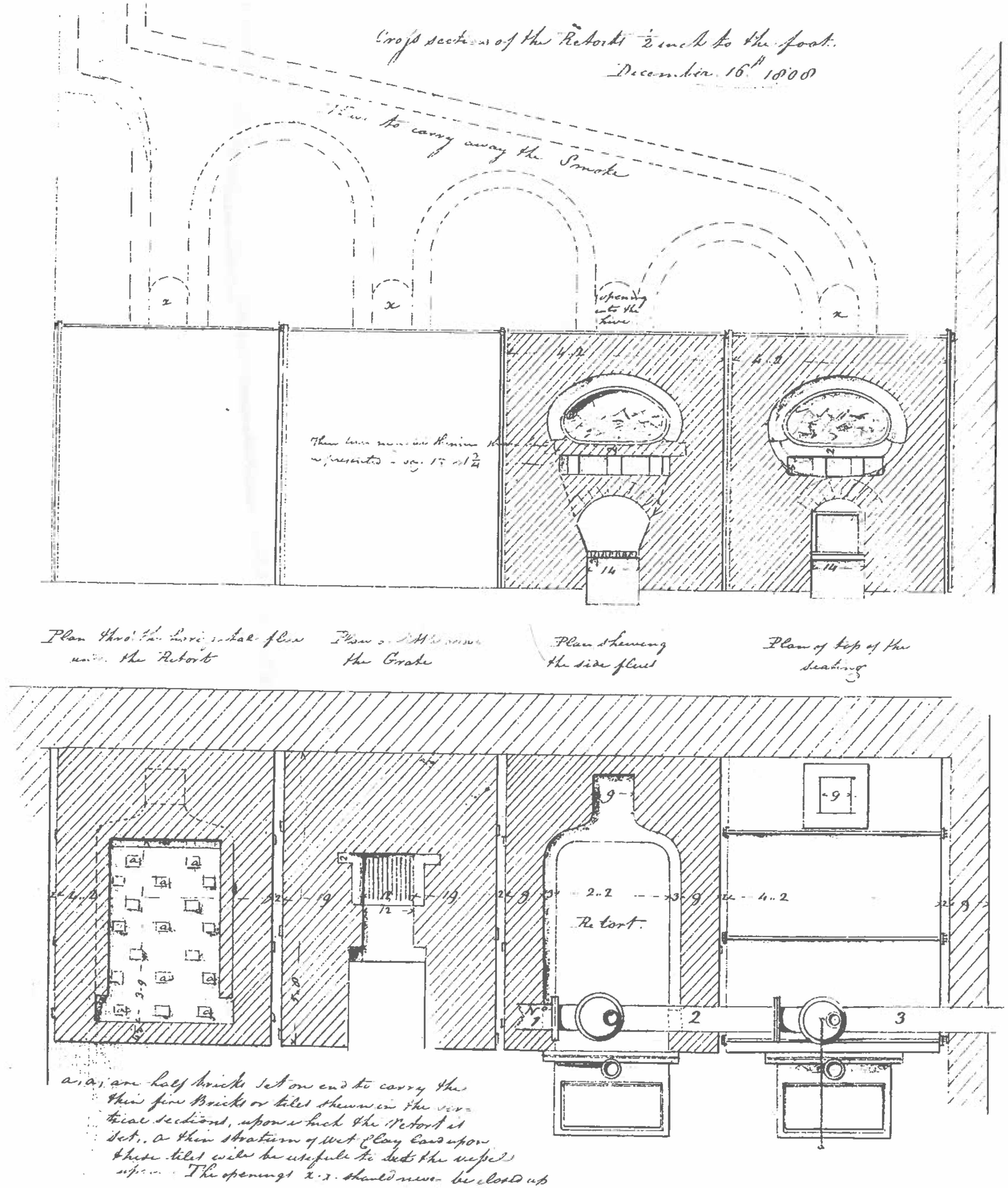
John Maberley, Aberdeen, 1814

This detailed drawing contains a number of interesting points. Maberley was a flax manufacturer at a vertically integrated plant containing carding, spinning, weaving, and printing shops with a smithy for making and repairing machinery. The section at the top of the drawing shows a part-iron framed building. The lower storeys had iron beams and columns whilst the roof was timber framed and the attic had a 'common wood floor.' Power was supplied by a Murray Fenton and Wood engine.
Portf: 808

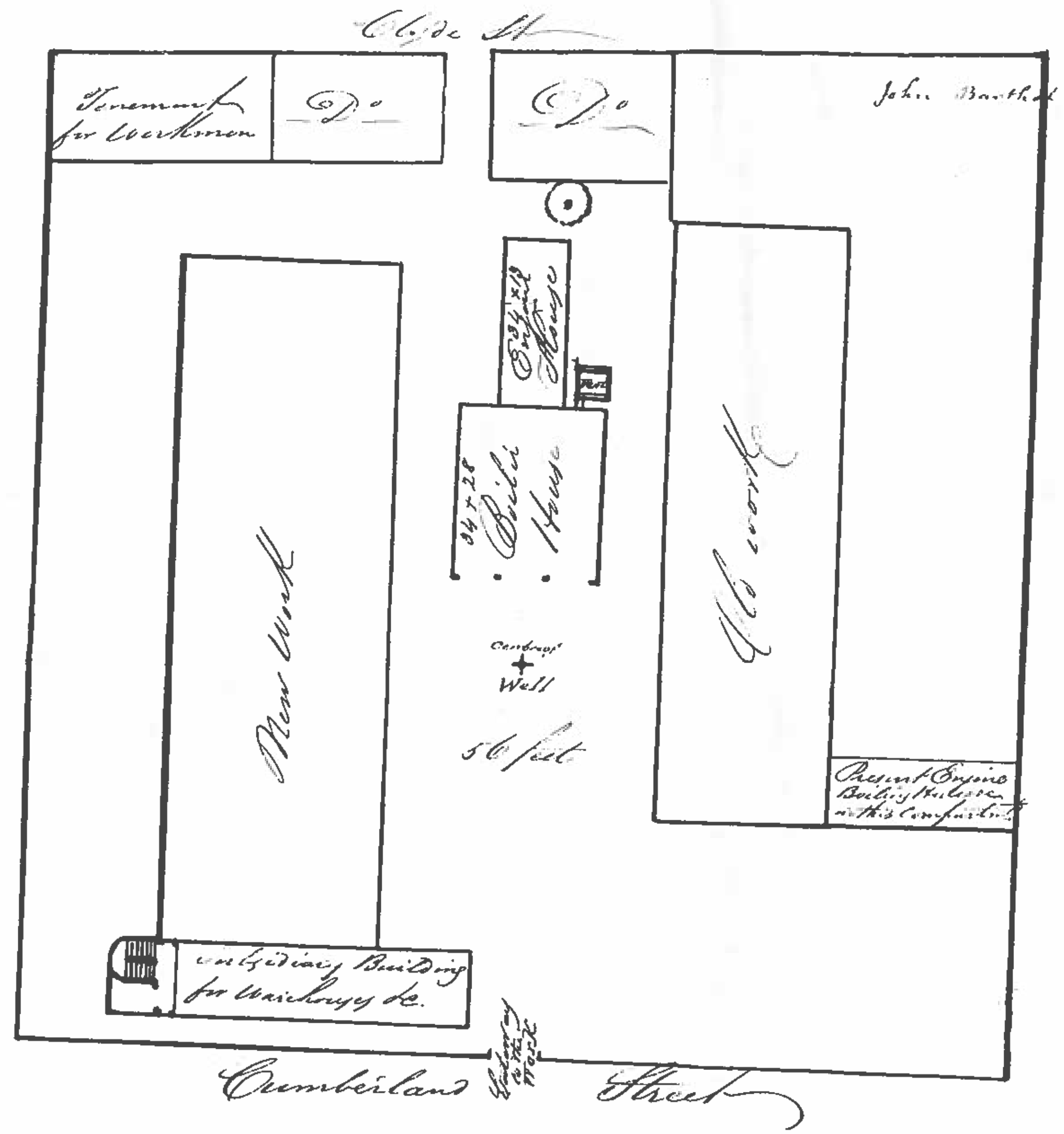
Messrs Wormald Gott & Wormald

Wormald, Gott and Wormald, Leeds, 1808
Murdock used vertical retorts in his earlier gas experiments but by 1808 had developed the horizontal retort as shown in this drawing. A similar retort was installed at the Salford Twist Mill in the same year.
Portf: 812



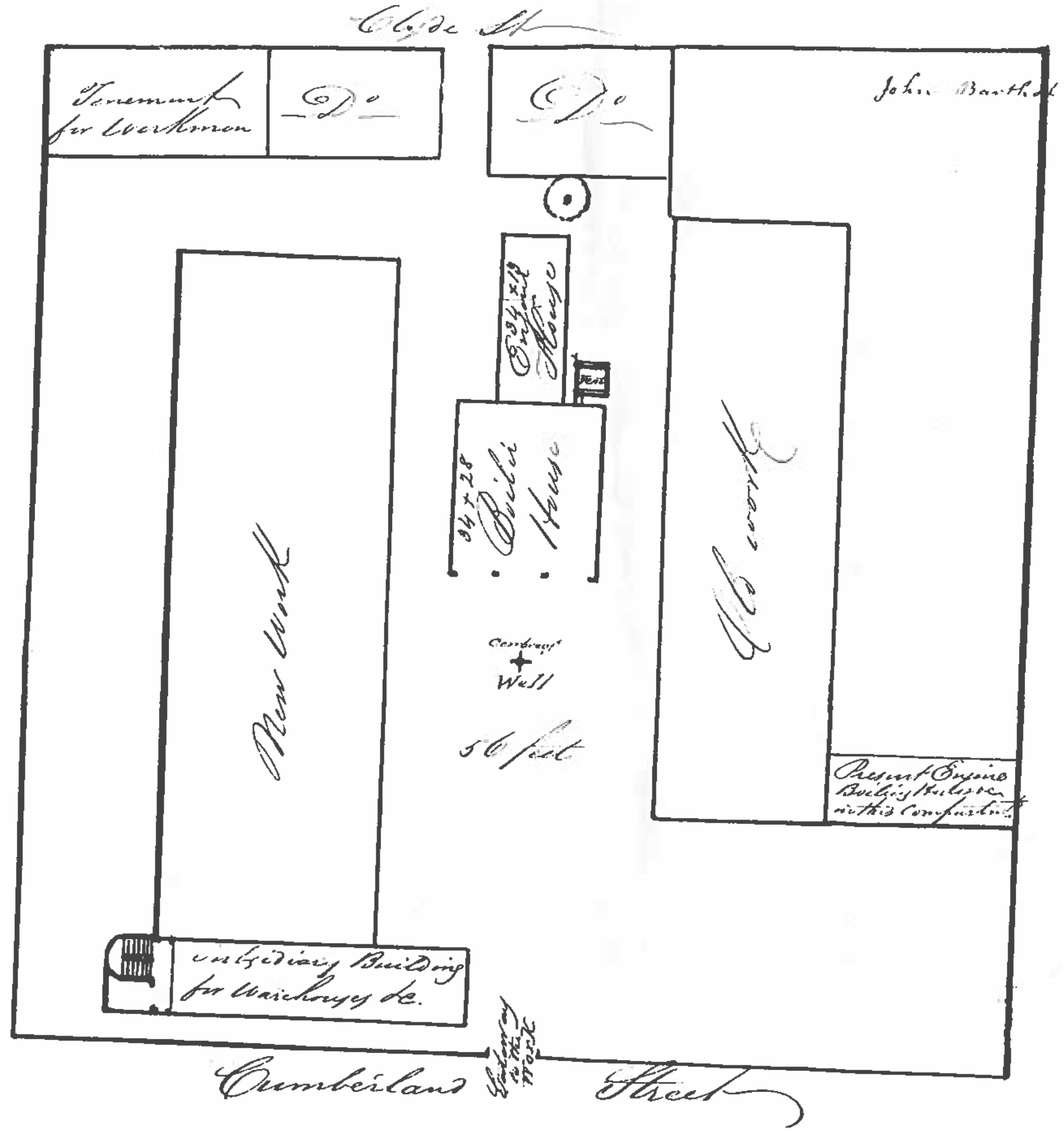


Mr Bannatine, Glasgow, 1790
A cotton spinning factory on Arkwright's principle.
Portf: Misc Mills



John Bartholomew and Co, Glasgow *c.* 1796
The drawing shows a large Scottish cotton works with industrial housing as part of the complex.
Portf: 464

Mr Bannatine, Glasgow, 1790
A cotton spinning factory on Arkwright's principle.
Portf: Misc Mills



John Bartholomew and Co, Glasgow *c.* 1796
The drawing shows a large Scottish cotton works with industrial housing as part of the complex.
Portf: 464