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Charles E. Peterson, F.A.I.A., Editor

CHAPTER
10

An Historical Sketch of Central Heating: 1800-1860

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Charles Peterson, who invented and organized the symposium and edited this volume, once wrote that he did not believe that Philadelphia is the only place in the world worth writing about.[1] Much as I may agree with Mr. Peterson, I nevertheless find myself being led back to Philadelphia, far more frequently than even the piety of the native would require, whenever I look for origins of some aspect of American technology. For example, my story of central heating begins a few blocks from The Carpenters' Company, in that remarkable section of early nineteenth-century Philadelphia that was leveled a few years ago by the landscapers of Independence Hall.

One branch of central heating in the United States started, of course, with Benjamin Franklin's Pennsylvania fireplace in 1744. That is the branch that uses a fire to heat air directly, now used largely in domestic heating systems. The other branch of central heating, which uses steam or hot water as an intermediary between the fire and the space being heated, springs in a curious way from a Philadelphia shop near Market and Seventh Streets. Very briefly, in 1815 Jacob Perkins came to Philadelphia from Newburyport, Massachusetts. Perkins, who was then nearly fifty years old, already had established his reputation as a prolific inventor of nail-making machines and fire-engine pumps, and he was now working on important innovations in printing and engraving. In Philadelphia he joined a community of active and innovative mechanics that included Oliver Evans, Charles Willson Peale, Pat Lyon, Matthias Baldwin, and many others. Perkins was easily the most active of the lot: he was a man obsessed where inventions were concerned. Visitors to his little shop were treated to a succession of novel ideas delivered in his quick, enthusiastic manner; he could be aroused instantly by the excitement and challenge of a new technical problem.

When one of his regular visitors suggested to Perkins the notion of making steam at very high pressures (far higher than those used by

Note: I am indebted to Robert Bruegmann for guiding me to a number of sources that he had located earlier in his work on eighteenth and nineteenth century prisons and hospitals. His suggestions and comments have been most valuable.

Oliver Evans in his high-pressure steam engine), he seized the suggestion and developed it in several directions over the next two decades, particularly after he emigrated to England in 1819.[2] One of those directions was to a very high-temperature hot water heating system. It was this system, developed in England and brought back to the United States around 1840, that was installed in the White House in Washington and the Custom House in New York.[3] Through Joseph Nason, an American who learned heating and ventilating practice from Perkins and his son in London, the Perkins influence extended to the heating and ventilating system of the new wings of the United States Capitol building, one of the most extensive and advanced systems of its time.

It is hardly necessary to say that the history of technical details of heating systems is a complex affair, with many strands intertwined and overlapping. Most of what I have learned of such details I have placed in footnotes, not because the details are not interesting or exciting—at least *I* can get excited over finding a perfectly practicable steam trap in a book published in 1824 (Fig. 10.1)—but because I want to emphasize two things that I didn't expect to find in the history of central heating before 1860: the first was the vigorous if confused response of the technical community to new scientific information on human respiration; the second, the unconscious subordination of human criteria to the requirements and limitations of mechanical equipment. Finally, I shall want also to suggest a tendency at work in heating systems as in all other complex technical systems: a tendency, over a considerable period of time, of technical virtuosity to defeat itself and collapse. You may recall the Tacoma Narrows bridge of 1940, which exhibited the most advanced design in the world just before it fell into Puget Sound. This is the phenomenon I shall call the Vogel effect after Robert Vogel, the author of Chapter 7, because a chance remark of his brought home to me the fact that the tendency is a universal one.

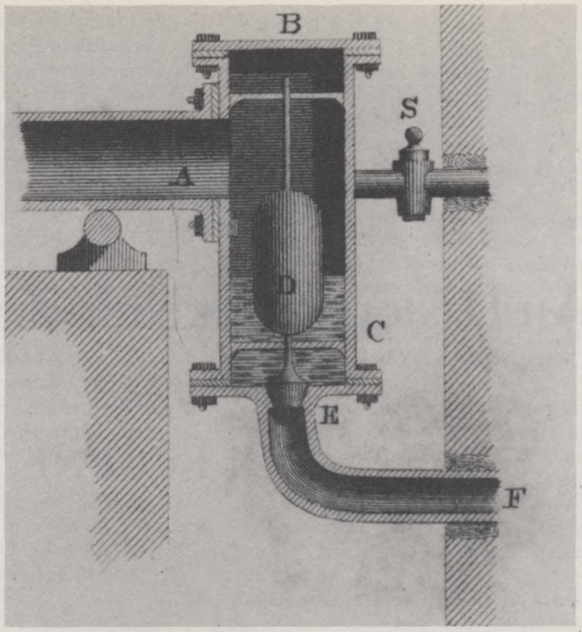

Fig. 10.1 Steam trap, 1824. The purpose of a steam trap is to remove, automatically, water from a steam space. Increments of condensate from pipe A collect in reservoir C. When sufficient water accumulates, float D rises and opens conical valve E. Internal pressure blows water out of trap (through drain pipe F); the valve E recloses and the trap cycle is repeated. Air is bled as necessary through cock S. Thomas Tredgold, *Principles of Warming and Ventilating Public Buildings* (3rd edition, London, 1836) plate III.

Before proceeding to my arguments, I will sketch in, with some names, dates and places, a minimum context for the thesis that follows.[4]

The English have for centuries favored fireplaces for heating.[5] The cheerful blaze and ventilation of an open fire have been frequently extolled by English writers. Thomas Tredgold, an early nineteenth century English authority on heating, pointed out the advantage of a "common fire"—that is, an open fireplace: it provided a "genial warmth" for one's body and at the same time permitted one to breathe cool air. The radiant heat from the fire provided a feeling of warmth even though the air of the room might be in the fifties (as Tredgold and others thought it should be).[6]

Austrians, Russians and Scandinavians have used stoves for space heating at least since the fifteenth century, although most surviving examples are of the eighteenth century and later.[7] Freestanding wood or coal-burning stoves of cast iron, which once again became popular a few years ago as insurance against massive power failures and even more recently to supplement uncertain oil-fired heating systems, were very widely used in the United States from around the time of the Revolution until well into the twentieth century.[8]

Benjamin Franklin's response to the English fireplace was to improve it without shutting up the cheerful blaze. By conducting fire and smoke over and around an air box before discharging them into the chimney, his Pennsylvania stove of the 1740s introduced fresh, heated air into the room, which the unaided common fireplace was unable to do (Fig. 10.2). Franklin thus reduced substantially the general complaint regarding fireplaces that he had put in the words of Everyman: "A man is scorch'd before," he wrote, "while he's froze behind."[9] The Pennsylvania stove was superseded before 1800 in the United States by freestanding cast iron stoves, which permitted the heat source to be placed well out into the room, requiring only a simple stovepipe connection to a chimney.[10]

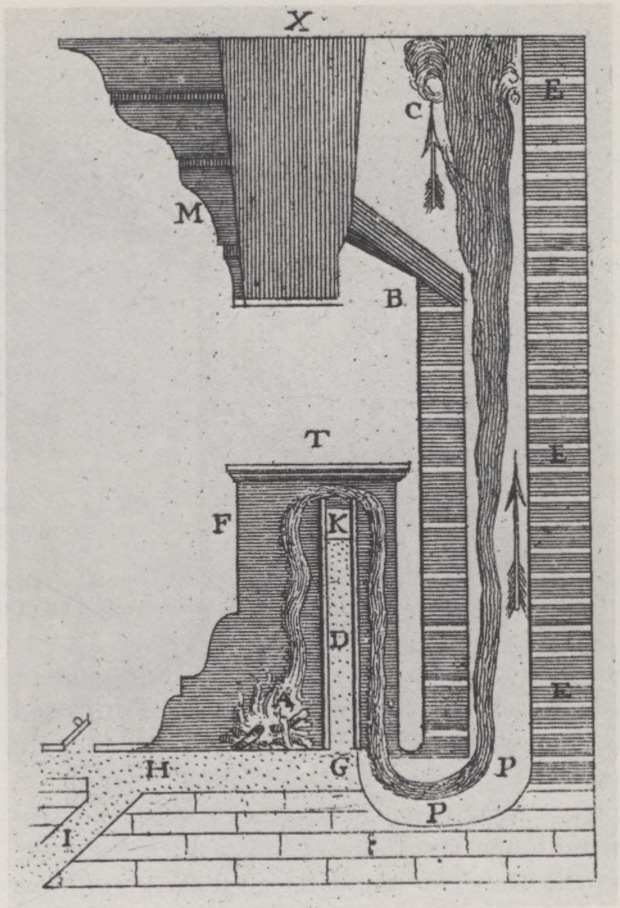

Fig. 10.2 Pennsylvania Fireplace, 1744. Designed by Benjamin Franklin, the Pennsylvania fireplace permitted the discharge of fresh heated air into the room through opening K in the fireplace casing. Fresh air, brought in through passage IHG, was warmed in box D by the hot products of combustion as they made their way toward the chimney. The flap valve at the left admitted cold outside air to the hearth. Benjamin Franklin. *Descrizione della Stufa di Pensilvania* (Venezia, 1791) fig. X.

Before 1820, numerous examples of hot air and steam central heating systems were to be found both in the United States and in England. Hot water systems came a little later, the ubiquitous rotating fan to propel air through ducts later still, although of course centrifugal fans were well known in the eighteenth century.[11]

Between 1802 and 1810, the historic Birmingham firm of steam engine builders, Boulton and Watt, installed fifteen extensive steam heating systems in cotton and paper mills, a sugar house, two warehouses, Lowther Castle in Westmorland and Covent Garden Theatre in London. A typical early mill installation, shown in Figure 10.3, carried low-pressure steam from a boiler throughout the building in cast iron pipes about 4 inches in diameter, which served as virtually a continuous radiator.[12] Probably the first system in the world to use exhaust steam from a high-pressure steam engine (there was no usable exhaust from the condenser of a Watt engine) was to heat a factory in Middletown, Connecticut, in 1811. The engine was one of Oliver Evans's. Another mill, near Baltimore, was similarly heated a year later.[13]

Central hot-air systems were being used in English mills by 1792. William Strutt's installation in his Belper Mill was copied soon after in the Derby Infirmary and in the Wakefield Insane Asylum.[14] In both England and the

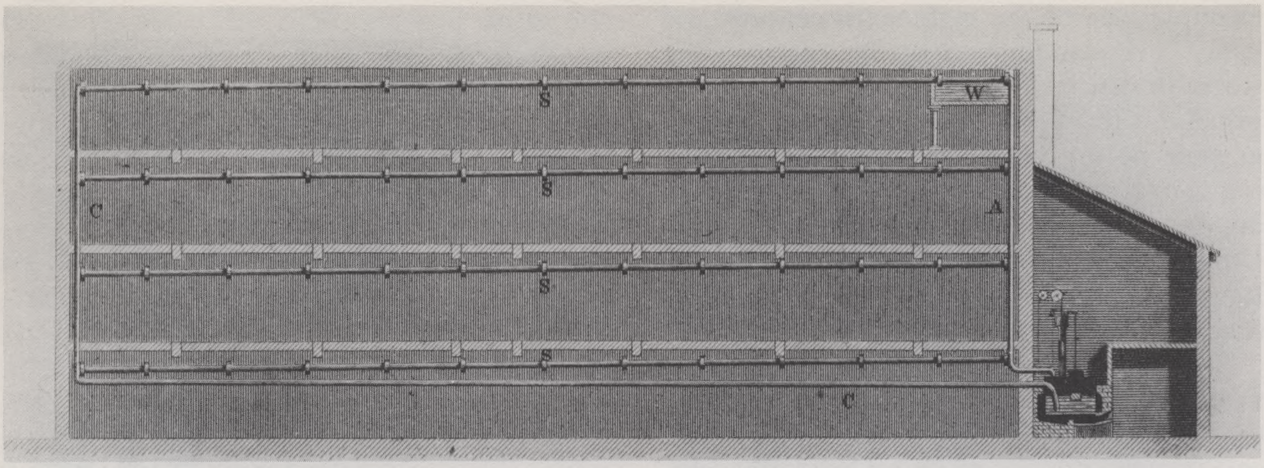

Fig. 10.3 Steam heating system in silk mill, 1817. Cast iron pipes, about 4 inches diameter, conducted steam through mill rooms just below the ceiling. Condensate was returned to the boiler through pipe C. This mill, in Watford, Herts., formerly was heated by thirteen individual iron stoves. Thomas Tredgold, *Principles of Warming and Ventilating Public Buildings* (3rd ed., London, 1836) plate VIII.

United States, a number of independent stoves, located throughout a mill, were used long after the idea of central hot-air heating was well known. A long horizontal run of stovepipe from stove to chimney helped to distribute the heat more evenly, as, for example, in the Duplanty and McCall textile mill, now the Hagley Museum, near Wilmington, Delaware.[15] A number of central hot-air heating systems, in hospital, almshouse, insane asylum, factory and medical college, had been installed in the United States before 1820; all were similar in principle to the system built by Oliver Evans and illustrated in 1795 in the first edition of his *Young Mill-Wright and Miller's Guide* (Fig. 10.4).[16] A closed stove or furnace, located in the cellar of a building, was surrounded by a brick or metal chamber (Fig. 10.5). Heated air, issuing from the top of the heating chamber, was led through air ducts to the respective rooms to be heated.

American stoves and hot-air central heating systems were perennial subjects for indignant comments by nineteenth-century British itinerants. Swedish visitors might complain that American houses were generally too cool, with bedrooms often not heated at all,[17] but the British could agree that an American heating system was "a terrible grievance to persons not accustomed to it, and a fatal misfortune to those who are. Casual visitors are nearly suffocated, and constant occupiers killed." And so forth.[18]

The idea of the hot-water heating system was quite as obvious as steam and hot-air systems to the early English and American writers on heating, but it is difficult to point to even one large hot-water system anywhere before the 1830s. The Marquis de Chabannes, in his book of 1818, illustrated a hot-water heating system for a hot house (Fig. 10.6) but not until 1836 do we find published a drawing of an actual installation, when the orangery of the royal palace at Windsor was so heated.[19] Tredgold, in his standard work on warming and ventilating, first published in 1824, said that water could not be circulated through pipes unless it was converted to steam, because the difference in densities of hot and cold water was insufficient to induce circulation.[20] Tredgold was wrong, of course, but domestic heating systems in the United States were generally steam systems until about 1880, when a massive shift to hot water occurred.[21] I suspect that a vast amount of tinkering with heating systems that should have worked but didn't was required to prove Tredgold wrong. A sampling of early radiator types is shown in Figures 10.7 – 10.9.

This brings us back to Jacob Perkins, who by

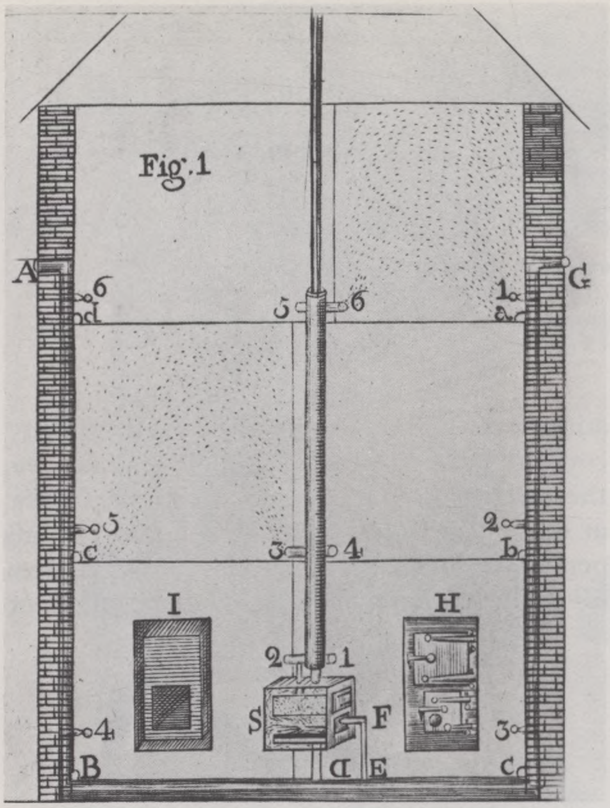

Fig. 10.4 Central hot air heating system, 1795. Hot gases, produced by combustion of fuel in furnace S, are conducted to chimney through the smoke pipe, shown extending into the attic. Heated fresh air is carried from top of furnace casing through T-shaped pipe 2–1 to annular passage surrounding the vertical smoke pipe. Warm air flows into rooms at 1, 2, 3, 4, 5, 6, near the central trunk. Exhausted air enters vent pipes which discharge outside at A and G. Oliver Evans, *Young Millwright and Miller's Guide* (Philadelphia, 1795) plate X.

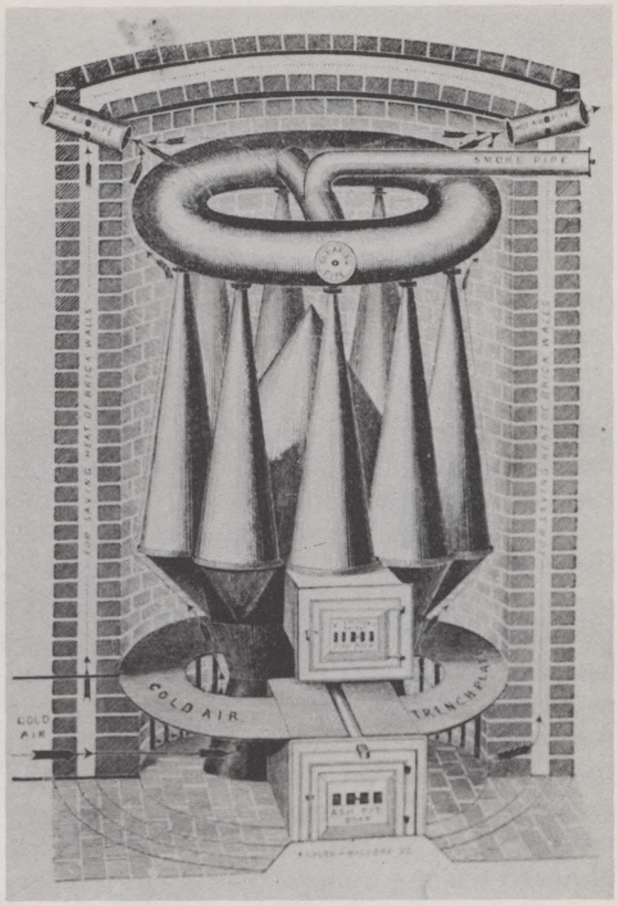

Fig. 10.5 Central hot-air heating furnace, 1857. This coal-burning furnace was to be located in a basement in a brick chamber. Fresh cold air enters at the bottom, flows over the conical heating surfaces of the furnace, and is conducted through "hot air pipes" *(upper left and right)* to rooms of the house. The annular space between inner and outer brick walls permits recovery of heat otherwise lost through the walls. David Bigelow, ed., *History of Prominent Mercantile and Manufacturing Firms in the United States* (Boston, 1857) p. 15.

the 1830s was the impressario of the Adelaide Gallery in London, a gallery of popular science and museum of "objects blending instruction with amusement." The Perkins steam gun, periodically discharging a terrifying fusillade of lead down the length of the "Long Room," was one outgrowth of Perkins' obsession with high pressure steam that had its origins in Philadelphia. Perkins, you will recall, had been in London since 1819. In 1831, his son, Angier Marsh Perkins, took out an English patent for a high-pressure hot-water heating system; in 1835 the younger Perkins' apparatus was heating the Long Room and its gallery in the Perkins emporium in Adelaide Street.[22]

The novelty of the Perkins system lay in the way water was used to convey heat from fuel in the furnace to the space to be warmed. A continuous, relatively small-bore pipe—about ¾-inch inside diameter, as compared to the usual 3½-inch inside diameter of other hot-water systems—formed a coil in the fire box of the furnace and a coil, not unlike a modern radiator, in the rooms to be heated; these coils were connected by supply and return lines. As just mentioned, the pipe was continuous throughout the system: no valves or other constrictions interrupted a free

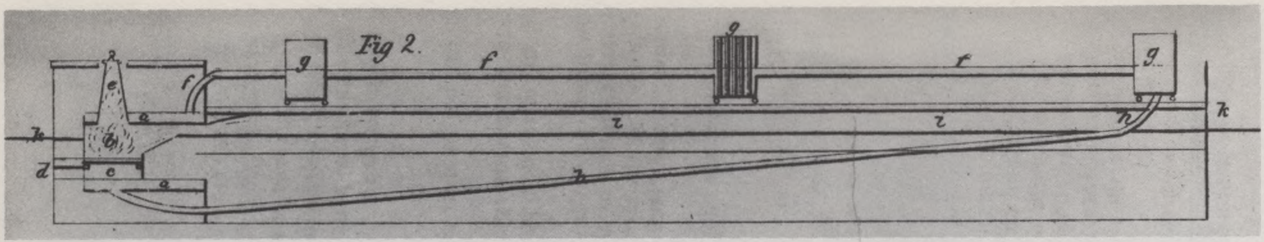

Fig. 10.6 Gravity-type hot water heating system, 1818. The furnace at left (e, b, c) supplies warmed water to large-diameter pipe f, f, f. Air is heated by the pipe and by "patent cylinders" g, g, g a rudimentary form of convector. Return pipe is marked h, h. Marquis de Chabannes, *On Conduction of Air by Forced Ventilation* (London, 1818) plate XIII.

gravity flow and the entire length of pipe formed a continuous, closed loop. Because the loop was closed and full of water, the water temperature could be raised well above 212°F, the boiling point of water at atmospheric pressure. When the water reached 212°F, there was no space for steam, so both the pressure and temperature in the system increased as heat was added. Perkins intended that the normal water temperature would be 350°F; the pressure in the system would then be about 125 pounds per square inch above atmospheric or, stated another way, a pressure of nearly ten atmospheres. Having no temperature controls, both temperature and pressure could rise precipitously; at 500°F, for example, the pressure was close to 50 atmospheres; at 636°F, 135 atmospheres or 2,000 pounds per square inch.[23] Even today, these figures will cause a normally conservative engineer

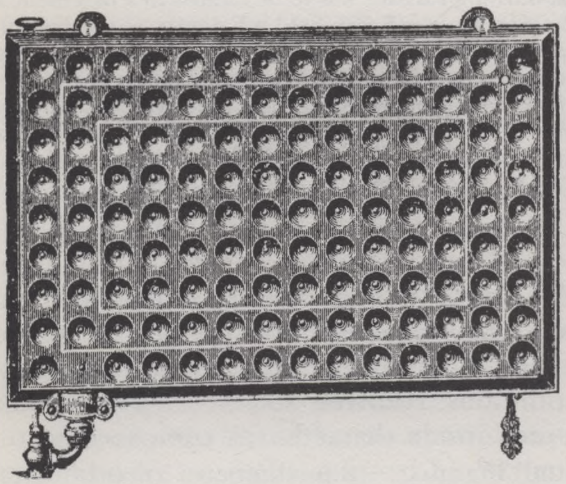

Fig. 10.7 "Mattress type" radiator, patented in 1854 by Stephen J. Gold, of Connecticut, inventor of a very popular home heating boiler. This radiator, in which two embossed iron sheets were fastened together by rivets, was similar to James Watt's steam radiator of 1784. Susan R. Stifler, *The Beginnings of a Century of Steam and Water Heating* (Westfield, Mass.: 1960) ff p. 64.

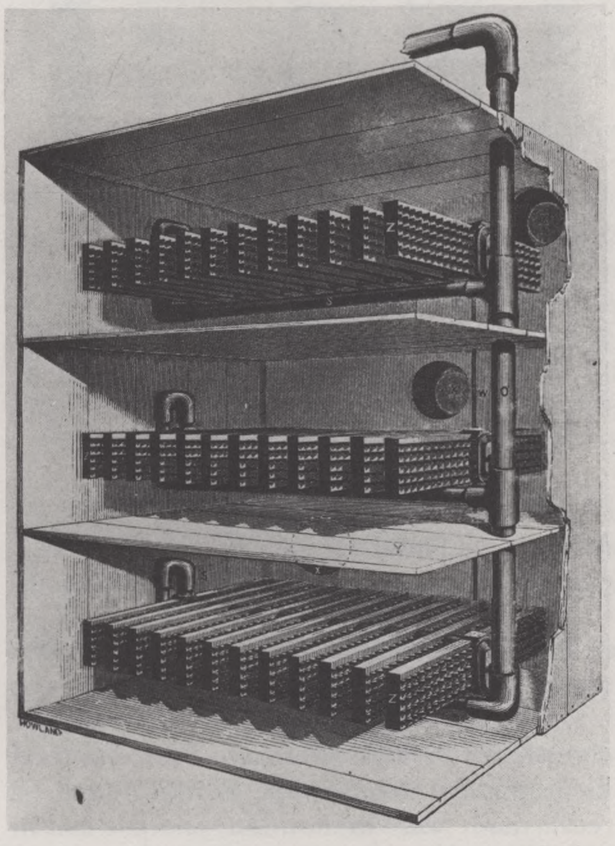

Fig. 10.8 "Pin-type" radiators (actually convectors), patented by Samuel Gold, Stephen's son, in 1862. Air was heated by the steam radiator sections as it passed through the wooden chambers adjacent to the heating boiler. Massachusetts Steam & Water Heating Co., trade catalogue, 1861. *(Eleutherian Mills Historical Library.)*

Fig. 10.9 Joseph Nason's steam radiators, ca. 1870, employed wrought iron return tubes fastened with ferrules into a cast iron base. The iron casting at the top of the radiator acted as a decorative diffuser and protective guard against contact with hot tubes. *(Broadside, n.d. Smithsonian Institution, Warshaw Collection, National Museum of History and Technology.)*

to turn slightly green, and not with envy.

While the low-pressure hot-water system was only slowly being adopted, the Perkins high-pressure system won astonishingly prompt acceptance. I can only guess that promotion rather than intrinsic merit was the secret of its commercial success. In November, 1835, two Perkins systems were installed in the British Museum for the architect Sir Robert Smirke: one system to heat the reading rooms and one to heat the Bird and Print Rooms (Fig. 10.10).[24] Before 1839, three Perkins high-pressure hot-water heating systems had been installed in Edinburgh; others were in the Duke of Wellington's country seat "Strathfieldsaye," the London Patent Office and the Atlas Insurance Office, Cheapside, Charles Babbage, designer of the noted calculating engine, heated his residence on Dorset Street with a Perkins system, placing one coil in an upstairs cistern that held enough water for two and one-fourth hot baths.[25] In the New York Custom House, a Perkins system was installed in 1841 despite the determined opposition of the Building Commissioner. The system was successful; the architect was delighted; eventually, even the Comissioner pronounced it satisfactory.[26]

A disturbing characteristic of the Perkins system was the tendency of the hot water pipes to char and sometimes ignite adjacent wood. In some tests made by the Manchester Assurance Company, blocks of wood in contact with Perkins pipes were charred, matches were lighted, gunpowder fired, and lead melted (which required a temperature of 612° F). Sir

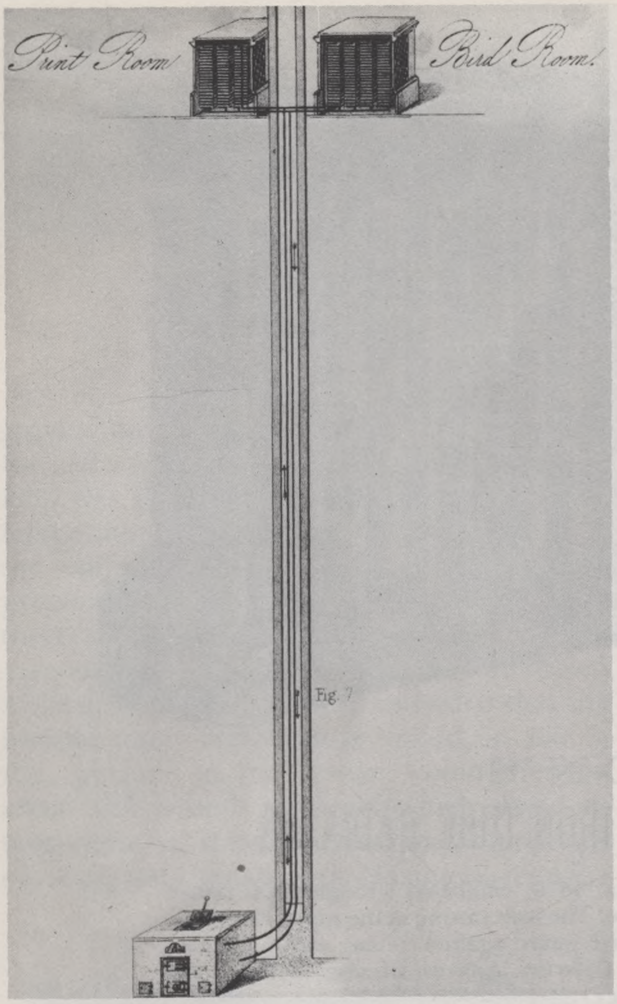

Fig. 10.10 Perkins high-pressure hot-water heating system in the British Museum. The furnace, at bottom of illustration, was about 50 feet below the heating coils, at top. Charles J. Richardson, *A Popular Treatise on the Warming and Ventilation of Buildings* (2nd ed., London, 1839) plate 2.

Robert Smirke reported that he had seen a red-hot water pipe some twelve feet from the furnace and that he would not consider installing a Perkins furnace in any but a fireproof room. Being less dogmatic than Perkins, Sir Robert also placed a safety valve near the furnace on the systems he had installed, thus limiting both pressure and temperature.[27]

Sharing the excitement of the Perkins invasion of Great Britain was Joseph Nason, a native of Boston; in 1837, when he went to work for Angier Perkins in London, Nason was 22 years old. He returned to America about 4 years later, bringing with him the knowledge

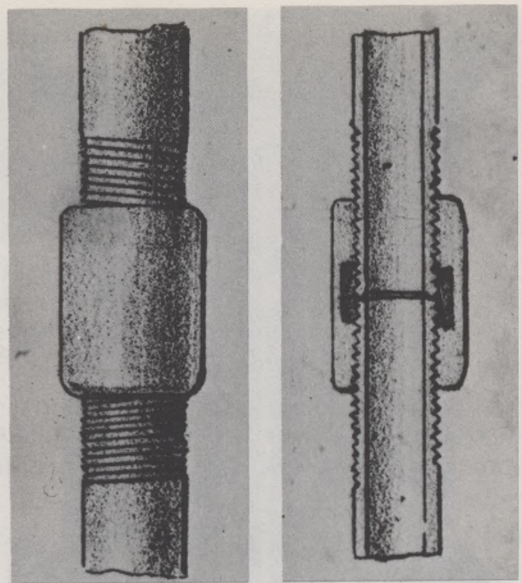

Fig. 10.11 Pipe coupling, used in the Perkins system. The end of one tube is sharpened, the other flattened. When the coupling, with left- and right-hand threads, is pulled up tight, the sharpened pipe-end is indented in the flattened surface of the other. Charles J. Richardson, *A Popular Treatise on the Warming and Ventilation of Buildings* (2nd ed., London, 1839) plate 1.

and experience gained from his association with Perkins. By the time he was 40, Nason was easily the most knowledgeable person in the United States on matters pertaining to heating and ventilating.[28] In that year—1855—he was the designer of the system for heating and ventilating the House and Senate wings of the Capitol in Washington, which I shall describe a little later. First, it is necessary to turn from developments in systems to a revolutionary incursion of science into traditional ways of thinking about the rooms we inhabit and the air we breathe.

Building on the work of a group of experts on ventilation who were active from about 1830 onward, a pure air movement rose to a crescendo right after the Civil War, when the Philadelphia lecturer and self-styled "heating and ventilating engineer," Lewis W. Leeds, coined and gave currency to the slogan, "Man's own breath is his greatest enemy."[29]

The facts of human respiration had been established in the late eighteenth century by Priestley, Lavoisier and others. Priestley demonstrated that in the lungs dephlogisticated

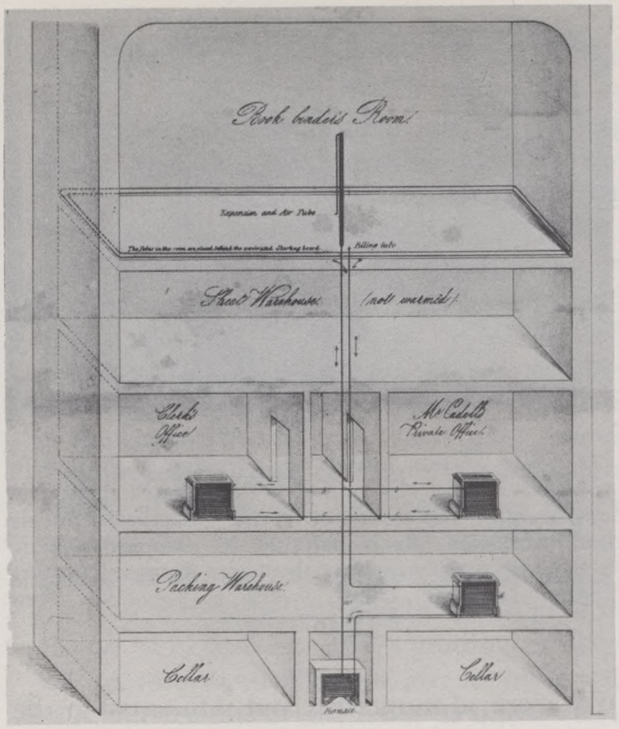

Fig. 10.12 Perkins high-pressure hot-water heating system, 1833. This installation was in the bookbinding establishment of Robert Caddell in Edinburgh. Charles J. Richardson, *A Popular Treatise on the Warming and Ventilation of Buildings* (2nd ed., London, 1839) plate 2.

air (Lavoisier would call it oxygen) changed blue blood to red while the air picked up phlogiston; part of the exhalation from the lungs was thus fixed air, now known as carbon dioxide, in the early nineteenth century also known as carbonic acid gas. Carbonic acid gas would not support life; oxygen would.[30] When, in the nineteenth century, the facts of respiration were translated into a need to have sufficient oxygen in the air one breathes and to avoid breathing the carbonic acid gas that was exhaled by oneself or by others, an embargo was placed on folk wisdom and common sense.

The entrepreneurial experts who jumped into the imaginary void mapped out a mechanism of hygienic ventilation which in the next generation became a powerful dogma. An adult inhales and exhales a third of a cubic foot of air per minute; but Dr. Arnott says that "air expelled from the lungs is found to vitiate, so as to render unfit for respiration, twelve times its own bulk of pure air." ($1/3 \times 12 = 4$ cu. ft. per min.) Not less dangerous than the carbonic acid of exhalation are the miasma, or effluvia, and vapor of animal matter, exuded from the whole surface of the body. This will require replacement by another 3½ cubic feet per minute of fresh air. Added to this is the vitiation of air by gas used for lighting.[31] Dr. Reid, an Edinburgh doctor of medicine who turned to the theory and practice of ventilation, made a series of tests, as careful as most, on human subjects. His conclusion, "given with much diffidence," was that 10 cubic feet per minute of fresh air should be supplied for every person in a given space.[32] Needless to say, other practical men were not so diffident and prescriptions of requisite fresh air varied widely. More importantly, a general underlying assumption was that the fresh air must be swept up through a room in order to avoid any possibility of having the same air "breathed over" or breathed twice; vitiated air was a terrible menace that must be avoided at all costs.[33]

In 1850, the American architect A. J. Downing, in his *Journal of Rural Art and Rural Taste,* deplored the prevalence of what he named "the national poison," which was "nothing less than the vitiated air of *close stoves,* and the unventilated apartments which accompany them."[34] In 1866, Lewis Leeds told an audience in Franklin Institute that although Philadelphia was one of the healthiest cities in the United States, he was "forced to the conclusion that about forty percent of all deaths that are constantly occurring are due to the influence of foul air."[35]

Leeds illustrated his lectures, using a magic lantern to show the way air currents behave with various arrangements of heating apparatus. In the little domestic scenes on the screen, the audience could observe how the people sat in clouds of purple air that had been vitiated while robust, pink, fresh warm air clung to the ceiling because of faulty design of the heating system (Figs. 10.13 through 10.15). The pictures are delightfully amusing, but two aspects of them are worth noting: first, they provide the graphic foundation for the fresh-air fads

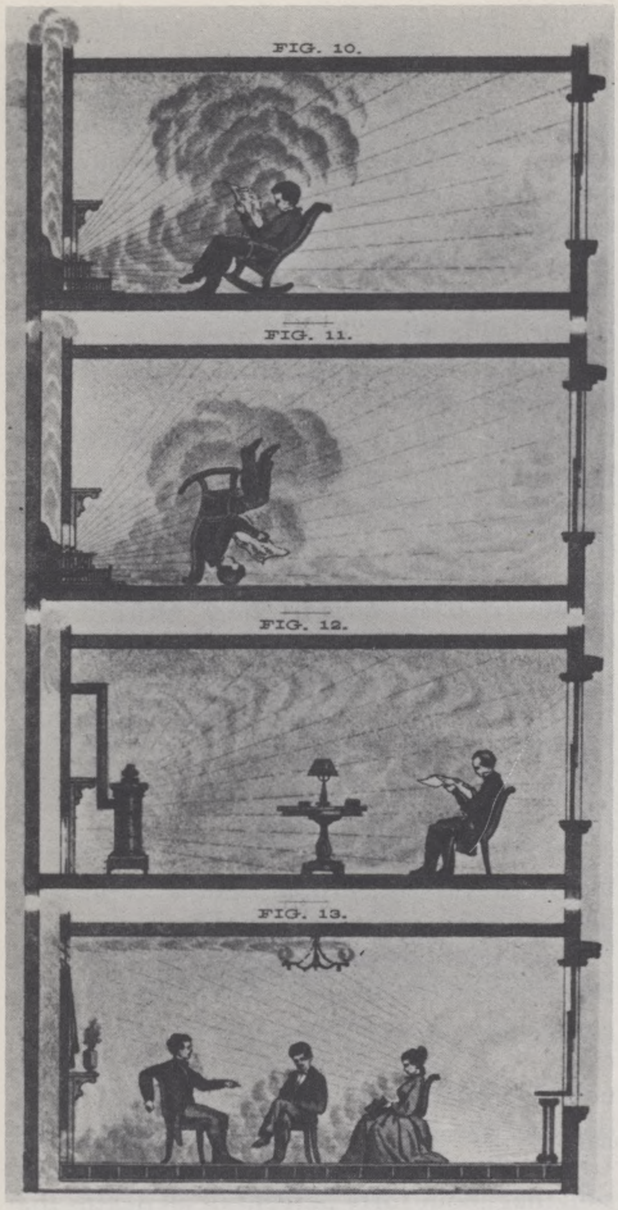

Fig. 10.13 Popular exposition of the principles of warming and ventilating. These illustrations were projected onto a screen by Lewis W. Leeds during his 1866–67 lecture series in the Franklin Institute, Philadelphia. They appear in his *Treatise on Ventilation* (New York, 1871). The clouds represent air exhaled and thus vitiated. The straight lines represent radiated heat. *Fig. 10* shows how feet are chilled by cold current from the closed window while reader breathes warm but vitiated air. *Fig. 11* shows how, with the given heating system, one may "keep the feet warmer than the head, and the back warmer than the face." *Fig. 12* notes the radiation from the man's back to the cold window, chilling his back and legs. The room's air is totally vitiated. *Fig. 13* depicts an optimum condition. Some fresh air is admitted to the room just above the radiator at right. Vitiated air is removed at floor level *(left)* and from the gas lighting fixture near the ceiling.

Fig. 10.14 Fresh, heated air, admitted at lower left, rises and flows across ceiling to the exhaust register at upper right. The clouds of heavily vitiated air, purple and unpleasant, which surround the man and woman, are nearly undisturbed by the badly designed heating system. Lewis W. Leeds, *Treatise on Ventilation* (New York, 1871) fig. 2.

that were so numerous and influential in the early twentieth century; second, they are technically quite accurate. Leeds understood very well the mechanisms of heat transfer, recognizing, for example, that the cold walls of a room can make the inhabitants uncomfortable even though the air temperature is at a comfortable level. He was also full of slogans. If you would be healthy, he admonished, "always keep your feet warmer than your head, and your back warmer than your face."[36]

Fig. 10.15 The open window, at left, permits cold air to enter, but the air flows across the floor and up the chimney while the sleeping victims are surrounded by the air that they have vitiated. Lewis W. Leeds, *Treatise on Ventilation* (New York, 1871) fig. 6.

In 1869, Catharine Beecher and her sister, Harriet Beecher Stowe, told the numerous readers of their *American Woman's Home: or, Principles of Domestic Science,* that "tight sleeping-rooms, and close, air-tight stoves, are now starving and poisoning more than one half this nation." Carbonic acid, they wrote, is a fatal poison; even a small amount, when mixed with pure air, is "a slow poison, which imperceptibly undermines the constitution."[37]

The rapid advances in ventilating practice, tried out in England and brought to fruition in the Capitol building in Washington, should thus be seen against the rapid rise of a shrill dogma of ventilation. The tendencies of heating and ventilating practice in England in the first wave of new knowledge are epitomized in the system installed in 1836 by Dr. Reid in the House of Commons. Reid's guiding principle was to control the flow of air. In his words, "The movement of air, from its ingress to its egress, was regulated as in a pneumatic machine, the house, in this respect, being treated as a piece of apparatus."[38] The entire basement was devoted to air filters and sprays, heating coils and air ducts. After being drawn in from the Old Palace yard, the air passed through a "suspended fibrous veil," 42 by 18 feet, for excluding mechanical impurities, through steam coils (which might also in summer contain cold water to cool the air),[39] and through ducts that spread the air evenly under the floor. The floor was pierced by nearly a million holes, drilled with gimlets, and the entire floor was covered by a loosely woven hair carpet. Reid expected that the air would be perfectly diffused and rise imperceptibly but uniformly throughout the House, making impossible the "breathing over" of vitiated air (Fig. 10.16). Spent air was removed from the top of the hall, being directed into a large duct which descended, outside the building, to the base of a huge chimney. In the center of the chimney, a brisk coke fire was maintained to produce a constant draft and, hopefully under full control, conduct the air through Reid's huge pneumatic machine.

Seldom is any complex machine under full

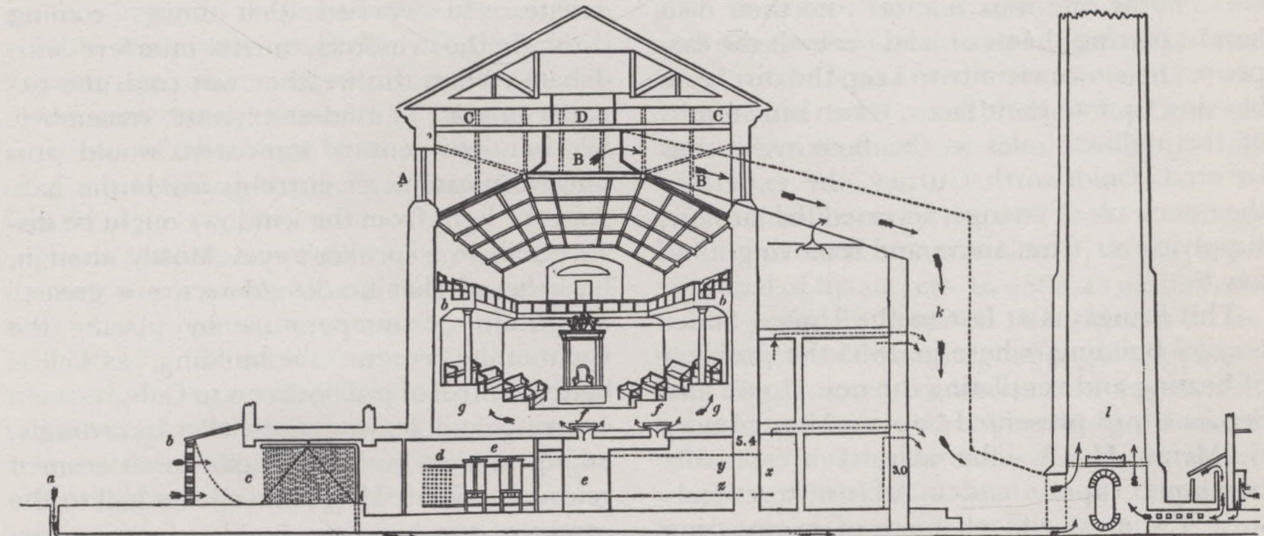

Fig. 10.16 Warming and ventilating system, House of Commons, 1836. Outside air was drawn in through wall b, at left. Screen c removed large dust particles; the air, heated as it flowed through coil D, was distributed under the House floor and balcony in chambers f, g, and b before it entered the chamber through a million small holes in the floor. Spent air was drawn through vent B and descended to the base of large chimney at right. A coke fire at l maintained a brisk draft in the chimney. David B. Reid, *Illustrations of the Theory and Practice of Ventilation* (London, 1844) p. 283.

control; this heating and ventilating system of the House of Commons was no exception. External conditions sometimes intruded. The smell from gasworks on both sides of the river occasionally reached the air inlets; "emanations" from the graveyard of St. Margaret's Church were occasionally very offensive; a barge laden with manure produced "extreme complaints"; in calm weather, even the smell of a crowd of coachmen smoking their pipes might enter the system. Internal conditions were controlled to the best of the ability of operators on duty. Every complaint was acted upon and in a single sitting of the House from fifty to a hundred changes might be made in quantity or quality of the air supplied.[40] Reid opined that if Members would dress more uniformly, particularly around the ankles and feet, "a greater unity would prevail as to the state of the air demanded."[41] Nor could much be done by Reid about the complaint that dirt in the carpet was blown into Members' eyes and noses, except to install boot scrapers at the entrances.[42] It was reported years later, perhaps with some exaggeration, that the Members one by one took matters into their own hands, placing sheets of lead beneath the carpet in their own vicinity to keep the dirt from blowing up into their faces. When nine tenths of the million holes in the floor were thus covered, Goldsworth Gurney, the expert of the next wave of change, reversed the air flow, supplying air from above and removing it below.[43]

This brings us at last to the United States Capitol building, where in 1855 the problem of heating and ventilating the new House and Senate wings presented Captain Montgomery C. Meigs, U.S.A.—the able, if occasionally pompous, superintendent of construction—with "the most difficult piece of engineering and construction that I have yet to undertake."[44]

The present Senate and House wings were added to the Capitol Building in 1855–61. Because the older parts of the building were inadequately warmed by sixteen hot-air furnaces,[45] it was clear to Captain Meigs that the haphazard approach to heating and ventilating which had gotten the Capitol through its first fifty years was inadequate for the future, particularly in view of the heightened importance of ventilation and the accepted need to avoid vitiated air in any form. The tide of best practice was setting hard toward complete control of air flow. The zeal with which Meigs approached the problem of complete and continuous control of the atmosphere hastened the day when architectural textbooks would leave unmentioned the principles or even the possibility of natural ventilation.[46]

In 1853, after visiting public buildings in Boston, New York, Brooklyn and Philadelphia, in company with Secretary Joseph Henry of the Smithsonian Institution and Alexander Dallas Bache, chief of the Coast Survey, Meigs modified plans of the new wings that had been made earlier. In the plans, the hall of the House of Representatives was located at the western end of the south wing—that is, overlooking the present Mall. Windows were to be provided on three sides of the room. Meigs reasoned that the primary purpose of the hall was to provide an effective setting for debate. He worried that noise, coming through the windows, might interfere with debate. When the weather was cold, the expanse of glass (a modest expanse, remember, by twentieth century standards) would produce unpleasant air currents inside the hall. And the light from the windows might be disagreeable in a speaker's eyes. Mostly, though, he believed that he "could secure a greater uniformity of temperature by placing the room in the center of the building," as well as better control of public access to Congressmen entering and leaving the hall. Accordingly, taking into account the factors that seemed relevant to him, Meigs moved the hall to the center of the building, making for posterity the choice that a controlled situation was more important than, say, a glimpse of the western sky as gas lamps were being lit overhead. Testifying in 1865, twelve years after he had made the decision to move the hall to the center of the building and to eliminate all windows, Meigs said, "It seems to me that members, occupied in the business of legislation, did not need, and would not have time to enjoy, any external prospect."[47]

After the basic decisions as to arrangement of rooms in the new wings of the Capitol had been made, Constructor Meigs called Joseph Nason to Washington to discuss the requirements of the new buildings. Meigs told Nason that he wanted "something more than a mechanic—one who has some scientific knowledge, so as to be able to appreciate the scientific discussions of the subject which have been published abroad, and to apply the principles they unfold with mechanical skill and practical knowledge, enough to lay down his system of pipes without error."[48] Nason proposed to supply all necessary pipe and fittings at fifteen per cent discount from printed list prices, to furnish an engineer and draftsman for six dollars a day, and first and second class workmen at proportionate rates. Nason's services, as consultant, were supplied at no extra charge to the purchasers of his pipe. Meigs promptly accepted Nason's proposal; design of the intricate system of steam boilers, steam coils, brick-masonry ducts and huge centrifugal fans began in the fall of 1855. Because no reliable data were available to determine power requirements of the fans, Meigs ordered immediately the making of a model fan, on a scale of 10 to 1, to be driven by a weight on a cord, falling through a distance of 50 feet.[49]

Nason's general approach to the heating of the new wings was to blow air across nests, or coils, of pipe containing steam at low pressure (Fig. 10.17). The heated air was then carried through ducts, divided and subdivided to reach every part of the rooms to be heated and ventilated. Pipe for the coils was wrought iron, slightly larger in size but otherwise the same as that used in the Perkins high pressure system.[50] In the House of Representatives wing, twenty-two heating coils were provided, each comprising over a thousand lineal feet of pipe. Four boilers supplied steam to the coils and steam to drive the two fan engines; two enormous fans—the larger some 16 feet in diameter—were required, one for the House chamber and one for all the other rooms in the wing (Fig. 10.18). An equivalent system was installed in the north, or Senate, wing.[51]

The detailed design of the fans was based on a study by Robert Briggs, Jr., of the data collected from the model fan and dynamometer, mentioned earlier.[52] Briggs was the "engineer and draftsman," furnished as part of the piping contract, who was to become a recognized authority on heating and ventilating, reinforcing in the next generation the Nason approach.[53]

The apparatus of the House wing was thoroughly tested during the winter of 1857–58, while the House was in session; the Senate system was completed soon after. In the Senate chamber, warm air was initially introduced through registers in risers just behind the Senators' chairs. Complaints by the Senators forced Meigs to change the duct locations immediately, and he also added deflectors to wall registers because drafts annoyed visitors sitting on sofas nearby.[54]

In 1861, nevertheless, Meigs noted that the new wings, having been in use for some time, had "realized all that I undertook to accomplish in regard to light, warmth, ventilation, and fitness for debate and legislation. The health of the legislative bodies has been better, [he asserted, and] more business has been accomplished in the same time than in the old halls."[55]

The inhabitants of the new halls would not have consented unanimously to Meigs' own appraisal of his success. In 1865 an inquiry, no doubt politically inspired (for there is a tangled history of wrangling amongst appointed and disappointed architects and engineers), led at length to a general diatribe by a number of Senators on the miserable conditions under which they worked. Suffice it to say that some Senators could see advantages in natural ventilation, perched on a hill as they were; Senator Charles Sumner of Massachusetts observed that "there is no public edifice in the world which enjoys the advantages of sight equal to that of this Capitol. . . . Now, Sir," he continued, "when we voluntarily shut ourselves up in this stone cage with glass above, we renounce all the advantages and opportun-

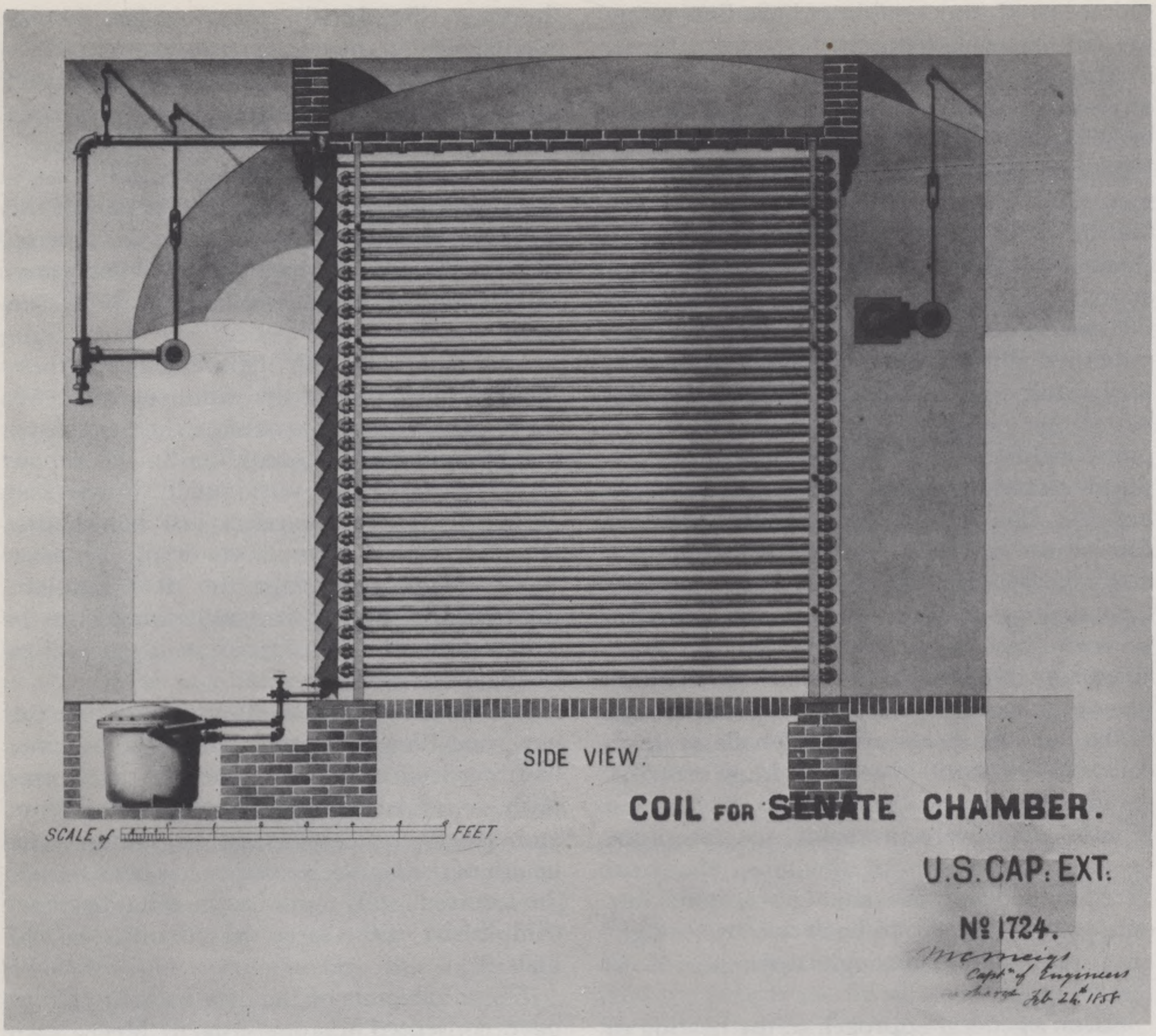

Fig. 10.17 Heating coil, U.S. Capitol, 1858. Wrought iron pipe, assembled with return bands, formed a continuous steam coil to heat air that was blown across it. Note the large pot-type steam trap at lower left. *(Photograph, kindness of the Architect of the Capitol.)*

ities of this unparalleled situation. Unless changed by legislature," he concluded, "this room will continue uncomfortable as it now is for centuries."[56] The charges and counter-charges of the inquiry served chiefly to highlight the differing perceptions of technical triumphs by those who build them and by those who merely use them.

Lewis Leeds, the popular lecturer, expressed in his discussion of the defects of the House and Senate heating and ventilating system a bit of folk wisdom that was, I presume, drowned out by the whoosh! of the great fans. Leeds said:

> It appears to have been originally designed to exclude the main halls as much as possible from all external influences, and to have all the currents, the heating and the lighting, under perfect artificial control.
>
> But if the whole nation could be taught the valuable lesson, of the great folly of attempting to produce artificial light, artificial heat, and artificially mixed air, that shall

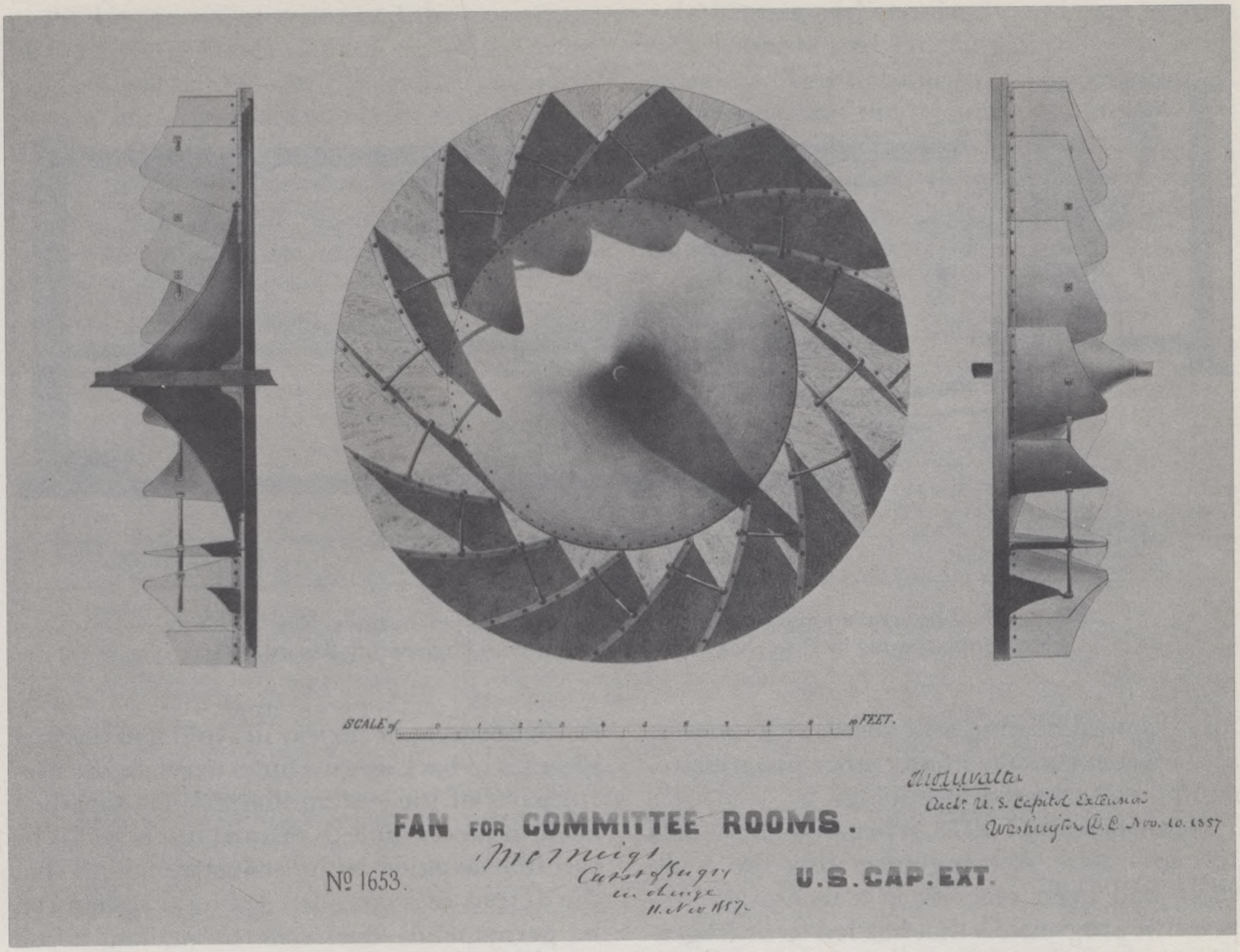

Fig. 10.18 Fan rotor, U.S. Capitol, 1857. The passages in which were located the large centrifugal fan rotors, designed by Robert Briggs, were so shaped that no fan casing was required. The central cone of the fan was of cast iron; the vanes were of wood, stiffened and fastened with metal angles and rods. This rotor was 14 feet in diameter. *(Photograph, kindness of the Architect of the Capitol.)*

equal to that which our Creator has provided for us, that knowledge would be cheaply bought at the great price paid for these buildings.[57]

I have no wish to use Montgomery Meigs as whipping boy, but the enormity of his decision, as viewed from my perspective (I hasten to say), not his, should, I think, give us pause. Here was an important, perhaps crucial, step in the direction of designing buildings whose internal conditions depend entirely on machines. Over the years I have been grateful to the maverick architects who put windows in the committee rooms in several places (not in the Capitol) in which I've spent uncounted hours. I did need, and I did have time to enjoy, the external prospect. My point is simply that Meigs' choices, made from the perspective of a man impelled to avoid imponderables and to embrace only the predictable and controllable, are the kinds of decisions that appear to a conditioned mind so right and natural, but which make a perceptible difference in the tone of a civilization. To complete my little soliloquy, I say simply that we would do well to hire poets as building commissioners in order to face the large issues before they are decided by small choices.

Finally, the Vogel effect was bound to show

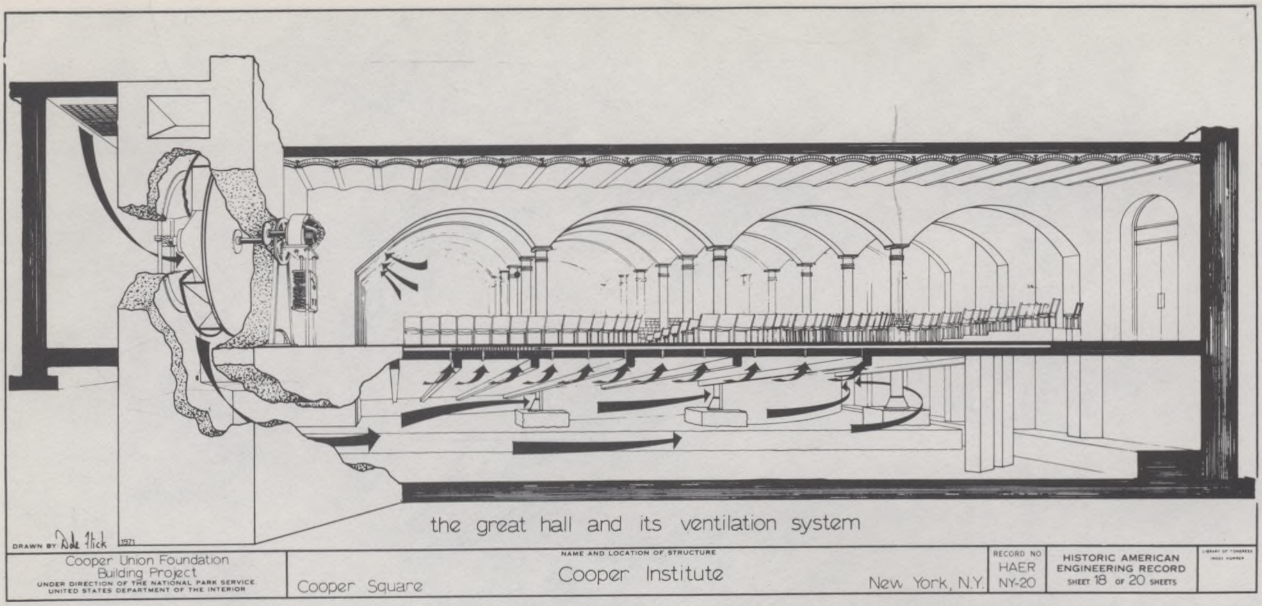

Fig. 10.19 The ventilation system of the Great Hall of Cooper Institute, New York City. Measured drawing by Dale Flick for Historic American Engineering Record, 1971.

up in central heating and ventilating systems, as it must eventually in any other progressive, equipment-oriented technology.

Near the end of 1973, it began to dawn on a few architects and engineers that the acute stage had been reached in a technically impressive progression that has led to overlighted, overheated and overcooled airtight boxes used for offices, stores and schools. The notion of the completely controlled environment, even if the systems actually operate as they promise to (and who does not have his own story of capricious failure of such systems?), requires acceptance of a cooling system that does battle with a lighting system, declares obsolete the use of spring breezes to produce a spring-like interior climate, and frustrates anyone who would turn off a light or otherwise upset the desperate balance of mechanism. Feature articles, appearing recently in newspapers and technical journals, explain that such buildings require at least twice as much energy—some closer to four times—as those making adequate but moderate use of heating, cooling and ventilating systems.[58]

Robert Vogel has told me that the way to overcome the aftermath of the Vogel effect (there seems to be no way to avoid it in the first place) is to back down a little, to retain the useful parts of the system that has just thrashed itself to pieces, and to discard the rest. To be carefully avoided is the seductive notion that the defects of a complex technical system can be permanently overcome by making it still more complex—by adding another layer of controls or other mechanism—rather than reducing its complexity. Yet it is this very notion that has propelled the winds of change since Reid and Meigs were at work.[59]

In closing, let me return to the beginning. We started with Jacob Perkins in early nineteenth century Philadelphia, thoroughly engrossed in the technical problems that he and his colleagues found interesting and solvable. We have seen how his enthusiasm and that of his son for technically advanced heating systems blossomed in England, was brought back to the United States by Joseph Nason and placed in the mainstream of American development through Nason's undoubted ability and professional connections. We have seen also how the new facts of science were given a twist in their interpretation that led to a new doctrine of ventilation as it affected public health. In the heating and ventilating systems of the House of Commons and the new wings of the United States Capitol, we found what can and will be done by the leading technical experts in the virtual absence of economic restraints. These great works provided the vision as well as the problems for following generations of experts, and those experts in turn advanced and modified their systems to incorporate new ideas and new enthusiasms.

In heating and ventilating, as in any technically sophisticated enterprise, the view from outside is likely to come to rest on an aspect of the subject that the technical community has considered neither interesting nor relevant. As I see it, that is precisely the justification for an historical review of a progressive, successful field of technology.

NOTES

1. In his piece on early house-warming; (*see* note 4).
2. The Philadelphia sojourn of Jacob Perkins (1766–1849) is described in Greville and Dorothy Bathe, *Jacob Perkins* (Philadelphia, 1943), pp 59–77; and in George Escol Sellers, *Early Engineering Reminiscences (1815–1840),* Eugene S. Ferguson, ed. (Washington, 1965), pp. 12–28.
3. U.S., Serial Set no. 1031 (see note 60) p. 8. The White House appears to have been warmed by hot air which was heated by twelve high-pressure hot water coils, operating above 212°F, in the basement. Louis Torres, "John Frazee and the New York Custom House," Society of Architectual Historians, *Journal,* XXIII, 3 (October 1964) 143–150.
4. A brief but comprehensive historical sketch is in John S. Billings, *Ventilation and Heating* (New York, 1893) pp. 26–41. A bibliography of 32 titles includes most of the significant historical and early technical works. More recent but much less satisfactory is Neville S. Billington, "A Historical Review of the Art of Heating and Ventilating," *Architectural Science Review,* (November 1959), 118–130; the references are cryptic, the information frequently wrong. A.F. Dufton, "Early Application of Engineering to the Warming of Buildings," Newcomen Society, *Transactions,* XXI (1940–1941) 99–107, pls. XVII–XX, written when libraries were being blitzed, is understandably very thin. Charles Peterson, in "American Notes," Society of Architectural Historians, *Journal,* IX, 4 (December 1950) 21–24, has supplied an astonishing amount of fresh information on "Early House-Warming by Coal-Fires." Benjamin L. Walbert, III, "The Infancy of Central Heating in the United States: 1803 to 1845," Association for Preservation Technology, *Bulletin,* III, 4 (1971) 76–87, another fresh article, demonstrates the existence before 1820 of a substantial number of central hot-air systems.

   Maurice Daumas, ed., *Histoire Générale des Techniques,* vol. 3 (Paris: Presses Universitaire de France, 1968) pp. 516–523, has a general review of French heating experience before 1850, following and borrowing from British practice, including the Perkins high-pressure system. Tredgold's 1824 book was translated into French in 1825.

   A review that tells how the earlier notions were revised after 1900 is George T. Palmer, "What Fifty Years Have Done for Ventilation," in American Public Health Association, *A Half Century of Public Health,* M. P. Ravenel, ed. (New York, 1921; reprinted, Arno, 1970) pp. 335–360. The manuscript history of heating by the stove designer and builder William John Keep (1842–1918), which was deposited in Baker Library by his daughter, is concerned chiefly with the internal details of stove design; it was of marginal interest to me in writing this paper. However, a section on the making of iron suitable for stoves refers to a series of technical papers by Keep and others, 1888–1905. Wiley appears to have published a book by Keep on cast iron. I am indebted to Mrs. Diana Waite for telling me of the existence of Keep's manuscript.

   Marshall B. Davidson, "American House-Warming," Metropolitan Museum of Art, *Bulletin,* N. S. III (March 1945), pp. 176–184, has an 1882 cartoon of Oscar Wilde on a red-hot American stove.
5. Fireplaces were present in castles in the fourteenth and fifteenth centuries. Viollet-le-Duc, *Dictionnaire raisonné de l'architecture française du XI. au XVI. siècle* (10 vols., Paris, 1854–68) vol. 3, p. 206, illustrates a spectacular fifteenth-century triple fireplace in Poitiers. He asserts (p. 207) that many small fireplaces were used in private rooms in castles. Lynn White, Jr., in "Technology Assessment from the Stance of a Medieval Historian," *American Historical Review,* LXXIX, 1 (Feb. 1974) 1–13, notes the tendency toward privacy and individualism that chimneys and fireplaces in northern Europe encouraged in the eleventh and twelfth centuries. He refers to a graduate dissertation on an aspect of the subject (pp. 8–9).
6. Thomas Tregold, *Principles of Warming and Ventilating Public Buildings,* (3rd ed., London. 1836) pp. 2, 4. The notion that cool air is healthier to breathe than warm air is examined by Billings, *op. cit.* (note 4), p. 213. Billings rejects the notion, but it turns up after 1900, intertwined now with comfort and industrial efficiency.

   Cf. Palmer, "What Fifty Years Have Done," *op. cit.* (note 4), pp. 344–346.
7. The great ceramic stove ca. 1500 in Hohensalzburg, Austria, is beautifully illustrated in William Anderson, *Castles of Europe* (New York: Random House, 1970) p. 223. A number of ceramic stoves of the eighteenth century are illustrated in Josephine H. Peirce, *Fire on the Hearth. The Evolution and Romance of the Heating-Stove* (Springfield, Mass., 1951) pp. 78–86.
8. Peirce, *op. cit.* (note 7), claims an earlier date for American stoves, but her data hardly support the claim. However, her book, a standard work, illustrates dozens of nineteenth century stoves and lists several hundred patents before 1860. See also the important article by Samuel Y. Edgerton, Jr., "Heating Stoves in Eighteenth Century Philadelphia," Association for Preservation Technology, *Bulletin,* III, 2–3 (1971) pp. 15–104. Many stoves of the mid-nineteenth century are illustrated and a checklist of makers is in John G. and Diana S. Waite, "Stovemakers of Troy, New York," *Antiques,* CIII, 1 (January 1973) 134–144. See also Marcel Moussette, "Quatre fabricants d'appariels de chauffage du Bas-Canada," Association for Preservation

Technology, *Bulletin,* V, 4 (1973) pp. 50–64, which notes a steam system in 1815 for house warming, cooking and washing.

9. *The Papers of Benjamin Franklin,* Leonard W. Labaree, ed. vol. 2 (New Haven: Yale University Press, 1960) pp. 419–446. The common fireplace is purely a radiant heater; it heats no air that will be discharged into the room. In the Franklin system, cold air, from outside the room that contained the Pennsylvania stove, was heated in the stove's air box and discharged into the room. In order to reduce the amount of warm air drawn out of the room merely to supply the needs of the fire, unheated air could be introduced through a flap in the hearth just in front of the fire. Franklin mentioned his debt to Nicholas Gauger, whose *Mécanique de Feu* (1713) described a similar scheme of warming air in an air box set in a fireplace. An illustration of Gauger's fireplace is in A. F. Dufton, *op. cit.* (note 4), pl. XVII. A substantial analysis of Gauger's text is in John S. Billings, *op. cit.* (note 4) pp. 27–29. Franklin's later thoughts on heating and ventilation and his description of a new stove are in American Philosophical Society, *Transactions,* II (1786), 1–36, 57–74. See also J. Pickering Putnam, *The Open Fireplace in All Ages* (Boston, 1882), in which all the variations of "ventilating fireplaces" that one could wish for are illustrated (pp. 32–88).
10. "Franklin stoves," which may still be bought from Sears, Roebuck & Co., are simply cast iron fireplaces; the air box (the essential feature of the Pennsylvania stove) has been omitted. Substantial changes in the masonry of a fireplace were required to install the original Pennsylvania fireplaces.
11. A rotating positive-displacement fan, not centrifugal in its action, is described in Georgius Agricola, *De Re Metallica* (1556), Herbert and Lou Henry Hoover, eds. and trans. (London 1912, New York, 1950) pp. 203–207. A centrifugal fan is described and illustrated in J. T. Desaguliers, *A Course of Experimental Philosophy* (2 vols, London, 1734–44), II, pp. 563–568, pl. XLVI. Desagulier's fan, rotated by a man he called a "Ventilator," blew fresh air into and sucked foul air out of the House of Commons from 1736 until 1791, perhaps as late as 1819. Cf. Charles Tomlinson, *Cyclopaedia of Useful Arts and Manufacturers* (2 vols, London, 1854), II, 931. Incidentally, the Speaker of the House was the control device, giving orders to suck or blow, depending on conditions within the House.
12. Jennifer Tann, *The Development of the Factory* (London: Cornmarket Press, 1970) pp. 109–122. An 1816 installation in Samuel Oldknow's six-story Meller Mill (pp. 115–116), 28 feet wide by over 300 feet long, required over 1500 feet of pipe, whose surface area was about 1500 square feet. The cubic content of the mill was about 500,000 cubic feet. Essentially, the arrangement gave each running foot of each story (28 × 10 × 1 = 280 cu. ft.) a square foot of heating surface. Neil Snodgrass, whose system won a prize of the Society of Arts, in 1799 installed perhaps the earliest successful British steam heating system. *Ibid.,* p. 111; *Philosophical Magazine,* XXVII (Feb.–May 1807) 172–181.

    A paper by Mårten Triewald, of steam engine fame, on heating hotbeds with steam, published in 1739 in the *Transactions* of the Swedish Academy of Sciences, is listed in Mårten Triewald, *Short Description of the Atmospheric Engine* (Cambridge: Heffer, 1928) p. 56.
13. Greville and Dorothy Bathe, *Oliver Evans* (Philadelphia, 1935) pp. 184, 193. I am indebted to Ben Walbert III for these references. In his article, *op. cit.* (note 4), Walbert notices Benjamin Latrobe's claim that in 1807 he recommended steam heat for the hall of the House of Representatives in the Capitol.
14. Jennifer Tann, *op. cit.* (note 12), p. 109.
15. *Ibid.,* p. 109; Acc. 500 Add., Papers of Duplanty, McCall & Co., General file, Inventory, Sept 26, 1820, Eleutherian Mills Historical Library, Greenville, Delaware. An invoice for two stoves, 120 feet of stovepipe, and 6 elbows is in Correspondence, In-file, Nov. 29, 1817.
16. Oliver Evans, *Young Mill-wright and Miller's Guide* (Philadelphia, 1795), Appendix, pp. 5–7, pl. X. In the second edition, 1807, the text is unchanged, but appears on pp. 358–359. A footnote in the first edition (1795) indicates the actual construction of an example by Evans. The plate was reengraved without alteration and the description of the "philosophical and ventilating stove" was modified only slightly when Thomas P. Jones took over editorship of the Guide at its fifth edition in 1826; Walbert, *op. cit.* (note 4), identified central hot air installations in a hospital, an almshouse, an insane asylum, jail, and medical college. U.S., Congress, House Committee on Public Buildings and Grounds, *Report . . . relative to Daniel Pettibone's Petition,* Feb. 19, 1817, mentions the installation of Pettibone's system in 1815 in the Patapsco cotton mill: safe, economical, providing "an agreeable and pleasant heat," an improvement on the principle of the Russian stove.

    There are several contenders for the earliest U.S. central heating system. Zachariah Allen, in his manuscript autobiography, p. 29, Rhode Island Historical Society, believed his system of 1820 to be first in New England; I am indebted to Ted Z. Penn for this reference. Claims for Jacob Perkins and Solomon Willard are noted in Society of Architectual Historians, *Journal,* XII, 3(Oct. 1962), p. 145.
17. *Baron Klinkowström's America 1818–1820,* Franklin D. Scott, trans. (Evanston: Northwestern University Press, 1952) pp. 66, 68; Fredrika Bremer, *The Homes of the New World: Impressions of America* (2 vols., New York, 1853), I, 66, cited in Association for Preservation Technology, *Bulletin,* IV, 3–4 (1972) p. 60, n. 139.
18. Thomas C. Grattan, *Civilized America* (2 vols., London, 1859), quoted in Allan Nevins, ed., *American Social History as Recorded by British Travellers* (New York, 1923) pp. 254–255. There is also a minor professional literature on the health hazards of overheated stoves. Tredgold, *op. cit.* (note 6), pp. 2–3, thought that when metal surfaces exceeded 212°F, the air was burned, and "burnt air is neither healthful nor agreeable." Tomlinson, *op. cit.* (note 11), p. 909, said burnt air had a "sulphurous smell." No, Benjamin Franklin had said, *op. cit.* (note 9), p. 439, iron is a "sweet" metal; what you smell is evaporated grease and spittle. The *Scientific American,* n.s. XXIII (Dec. 3, 1870) 359, warned that overheated iron stove plates were "permeable to carbonic oxide, generated in the combustion of coal, a very poisonous gas." The sad case of an English cat, reduced to convulsions by air that had passed over a hot stove, was duly reported in the *Philosophical Transactions* and repeated in U. S., Serial set no. 545 (see note 60) p. 9.
19. Marquis de Chabannes, *On Conduction of Air by Forced Ventilation* (London, 1818), described hot air, hot water, and steam heating systems. His plate XIII shows details of a hot water system for a hot house. Daniel Pettibone, *Pettibone's Economy of Fuel; or Description of His improvements of the Rarefying Air-stoves . . . for Warming and Ventilating . . . with or Without the Application of Steam* (2nd ed., Philadelphia, 1812; 62 pp.) pp. 38–40. The Windsor Palace orangery installation is illustrated in the appendix (by T. Bramah), of Tredgold, *op. cit.* (note 6). Charles Hood, *A Practical Treatise on Warming Buildings by Hot Water*

(2nd ed., London 1844), p. 3, notes that in 1822 Atkinson designed what became the conventional hot-water apparatus. Cf. David B. Reid, *Illustrations of the Theory and Practice of Ventilation* (London, 1844) p. 244. I have not identified Atkinson or the other men mentioned there.

In the "number of recent conversations at the Institution of Civil Engineers," reported in Franklin Institute, *Journal,* XIV (Sept. 1832) 211–212, three or four hot water installations were mentioned by the members.

20. Tredgold, *op. cit.* (note 6), p. 12.
21. Susan Reed Stifler, *The Beginnings of a Century of Steam and Water Heating by the H. B. Smith Company* (Westfield, Mass, 1960) pp. 34, 68, 100–102. There were two crucial inventions in American domestic hot water heating systems. The first was the sectional boiler, invented in 1859 by Samuel F. Gold, of Connecticut, which simplified boiler construction and permitted a new boiler to be carried literally in pieces down narrow cellar stairs of old or new houses. The second was the cored, cast iron, sectional radiator, attempted unsuccessfully in the early 1870s and perfected by several makers in the 1880s. Billings, *op. cit.* (note 4), p. 238, in 1893 advised hot water radiator pipes no smaller than 3 inches in diameter, because "friction increases rapidly with the reduction in the diameter of the pipe, and thus impedes the circulation."
22. *Society for the Illustration and Encouragement of Practical Science, Gallery for the Exhibition of Objects Blending Instruction with Amusement, Adelaide Street and Lowther Arcade, West Strand. Catalogue for 1835* (11th ed., London, 1835;48 pp.) p. 14. Angier's patent, dated July 30, 1831, was noticed in Franklin Institute, *Journal,* XIV (July 1832) 45–49. A biographical sketch of Angier Marsh Perkins (1799?–1881) appears in the *Dictionary of National Biography.*
23. The best description of the Perkins system is in the promotional book by Charles J. Richardson, *A Popular Treatise on the Warming and Ventilating of Buildings* (2nd ed., London, 1839), *passim.*
24. J. Mordaunt Crook, "Sir Robert Smirke: A Pioneer of Concrete Construction," Newcomen Society, *Transactions,* XXVIII (1965–66), 5–22; see p. 5. Smirke employed other heating systems in the British Museum and elsewhere, but he heated his office with a Perkins system; he put one in the Custom House and one in the temporary houses of Parliament, following the fire of 1834.
25. Richardson, *op. cit.* (note 23), pp. 38–39, 42, 44, 45, 47, 119, 121. A Perkins system, installed in Kew Gardens, is illustrated in Derek Linstrum, *Sir Jeffrey Wyattville, Architect to the King* (Oxford: Clarendon Press, 1972) p. 208.
26. Torres, *op. cit.* (note 3).
27. John Davies and George V. Ryder, *Report on Perkins's System of Warming Buildings by Hot Water* (Manchester, 1841; 15 pp.). This report was the subject of a "conversazione" in the Royal Victoria Gallery of Practical Science, Manchester; the report and the ensuing discussion were published in Sturgeon's *Annals of Electricity,* VI (1841), 475–499.
28. *National Cyclopaedia of American Biography,* vol. 24 (1935) p. 150; portrait opp. The judgment on Nason's eminence is mine, hopefully supported in the present paper. Nason died in 1872.
29. Lewis W. Leeds, *Treatise on Ventilation: comprising seven lectures delivered before the Franklin Institute, Philadelphia, 1866–68* (New York: John Wiley & Son, 1871). His home in 1867 was in Germantown; he was addressed as "heating and ventilating engineer" in one of the solicited testimonials (p. 218); Leeds's slogan is displayed on the title page.
30. J. R. Partingon, *A History of Chemistry,* vol. 3 (London 1962) pp. 196, 253, 284–286 (Priestley on respiration), 471–479 (Lavoisier on respiration). Early and influential surveys of hospitals by Lavoisier are reported in Denis I. Duveen and Herbert S. Klickstein, "Antoine Laurent Lavoisier's Contributions to Medicine and Public Health," *Bulletin of the History of Medicine,* XXIX, 2 (March–April 1955) pp. 164–179.

The importance of pure air was well known to miners and sailors. Agricola, *op. cit.* (note 11), pp. 200–212, has a section on mine ventilation. Stephen Hales, the Englishman whose influence upon Lavoisier was traced in Henry Guerlac, "The Continental Reputation of Stephen Hales," *Archives internationales d'histoire des sciences,* IV (April 1951) pp. 393–404, was concerned with ventilation of ships. I was introduced to the windsail in a troopship in the tropics in World War II; it was and probably still is the most effective ventilator of troop spaces in a ship's hold.

Original documents of the sixteenth and seventeeth centuries illustrating discoveries that led to our current understanding of respiration are given and sensibly explained in Mark Grabaud, *Circulation and Respiration: The Evolution of an Idea* (New York, 1964).
31. T. Antisell, *Hand-Book of the Useful Arts* [Putnam's Home Cyclopedia] (New York, 1852) pp. 663–664. Calculations and conclusions are to be found in many places, e.g., Byrne and Spon, eds., *Spon's Dictionary of Engineering* (London, 1874) pp. 3024–3025, which summarized the findings of Péclet, Morin, Arnott, and others. For long term changes in quantities of air considered necessary, see Palmer, *op. cit.* (note 4), p. 344. A chemical solution to the problem of vitiated air was suggested in the 1820s by a chemist in Manchester. Where work rooms were too small and too crowded to be adequately ventilated, he wrote, one might obtain a "supply of oxygen from manganese." His method was not further elaborated. See C. Turner Thackrah, *The Effects of the Principal Arts, Trades and Professions . . . on Health and Longevity* (Philadelphia, 1831) p. 33.
32. Reid, *op. cit* (note 19), p. 176. Reid is noticed in *Dictionary of American Biography.*
33. *Spon's Dictionary, op. cit.* (note 31), pp. 3024–3025. The term "breathed over" appears in *The Horticulturist and Journal of Rural Art and Rural Taste,* V (Nov. 1850) p. 205.

It is easy to dismiss the fresh-air advocates as fools or charlatans, but the matter is not as simple as that. Epidemic diseases, such as yellow fever and cholera, were thought to be caused by a "miasma" that arose from swamps or other putrid sources. By 1849, the nature of the miasma was being debated—carbonic acid gas, electricity, ozone, fungi or animalculi—but of 146 physicians sampled in that year only four considered microscopic germs to be a possible cause of disease. Cf. Charles Rosenberg, *The Cholera Years* (Chicago, 1962) pp. 75n22, 164n31, 165–166. Andrew Ure, in his *Dictionary of Arts, Manufactures, and Mines* (4th ed., 2 vols., London, 1853) II, 890, assumed that stoves in the Custom House were the cause of "the malaria which prevailed there."
34. *The Horticulturist, op. cit.* (note 33), V (Nov. 1850) pp. 201–202.
35. Leeds, *op. cit.* (note 29), p. 13
36. Leeds, *op. cit.* (note 29), pp. 98, 155, 187.
37. Catharine E. Beecher and Harriet Beecher Stowe, *The American Woman's Home: or, Principles of Domestic Science* (New York, 1869) pp. 47–49.
38. Reid, *op. cit.* (note 19), p. 274
39. Precursors of cooling and "air-conditioning" will be found throughout the nineteenth century; that is a subject whose early history has not yet been traced. For a framework, see Margaret Ingels, *Willis Haviland Carrier: Father of Air Conditioning* (Garden City,

1952) pp. 107–170, a "Chronological Table of Events Which Led to Modern Air Conditioning 1500–1952."

40. Reid, *op. cit.* (note 19), pp. 270–299.
41. Reid, *op. cit.* (note 19), p. 297.
42. Tomlinson, *op. cit.* (note 11), p. 930.
43. U.S., Serial set no. 1211 (see note 60), p. 31.
44. U.S., Serial set no. 994 (see note 60), p. 96. Meigs was referring specifically to the heating and ventilating system.
45. U.S., Serial set no. 545 (see note 60).
46. Billington, *op. cit.* (note 4), p. 126. An earlier proposal for heating the House wing was made in 1843 by A. A. Humphreys, first lieutenant, Topographical Engineers. Humphreys reported that, until a few weeks earlier, heating and ventilating was a "subject upon which I have never bestowed any attention." Leaning heavily on Tredgold and Ure, he recommended steam coils and a "spiral fan," similar to one giving good service, according to Ure, in the Reform Club House, London. See U.S. Serial set no. 441 (see note 60); Ure, *op. cit.* (note 33), p. 890.
47. U.S., Serial set no. 1211 (see note 60), p. 50.
48. U.S., Serial set no. 1031 (see note 60), pp. 1–2.
49. *Ibid.*, pp. 3, 6, 7, 8. Although the services of consultants are frequently obtained in this way, at no extra charge, the implications regarding the kind of advice thus made available are seldom thought much about. It was not to be expected, for example, that Nason, committed as he was to a system employing pipe coils, would recommend an alternative system that would not require large quantities of the pipe he had for sale.

    Before the design was fairly under way, Nason's firm Nason and Dodge, in what appears to me to be a promotional puff, wrote a letter to Meigs informing him that Péclet, the French author of a standard work on heat and heating, had just published a new book, *Nouveaux documents relatif au Chauffage* (1854), which gave more fully than his earlier volumes the results of recent French experience. Furthermore, the letter continued, Mr. Nason had "added to his experience with further investigations at Utica," where the heating system in the Insane Asylum had proved more than adequate during the previous winter.
50. Wrought-iron pipe for the Perkins heating systems was supplied in England by the Russells of Wednesbury, Staffordshire, who, before 1835, were making lap-welded pipe by running formed skelp between grooved rollers; a supported spherical mandrel, inside the pipe, provided the pressure to complete the weld. The Philadelphia firm of Tasker, Morris, and Tasker, later Pascal Iron Works, made the first wrought iron pipe in the United States. In 1848–49, James Walworth (Nason's first partner), after visiting the Russells in England, organized and operated a tube mill near Boston. The consulting engineer to the tube mill was Nason. Five brief but useful articles on wrought-iron pipe making and early steam heating in U.S. are in *Valve World*, I, 1 (Jan. 16, 1905) 7; I, 2 (Feb. 1905), 5, 7; I, 9 (Oct. 1905), 5; I, 11 (Dec. 1905), 7; II, 1 (Jan. 1906), 7. Additional details are in Richardson, *op. cit.* (note 23), and in the biographies of James Walworth in *National Cyclopaedia of American Biography*, XVIII (1922) pp. 374–375, and Joseph Nason in *ibid.*, XXIV (1935) p. 150. Nason is credited here with the invention of the term "radiator." R. T. Crane, in the *Valve World*, I, 11 (Dec. 1905), 7, credits Nason with the present design of the globe valve, and also a most elegant invention: taper threads for pipe and fittings. The standard pipe thread assumed Briggs's name. See references in C. P. Auger, *Engineering Eponyms* (London: The Library Association, 1965), p. 18.
51. U.S., Serial set no. 1031 (see note 60), pp. 9–11; U.S. Serial set no. 1263 (see note 60), pp. 2–3. An apparently similar system was installed in 1859 to ventilate the Cooper Union building in New York City. The following description is quoted from *The Cooper Survey*, November 1859, in the Historic American Engineering Record (National Park Service) report of "The Cooper Union for the Advancement of Science and Art, HAER NY-20," page 59:

    "The basement contains a large hall which will seat 2500 persons. A steam engine in an adjoining room drives a fan 14 feet in diameter, by which warm or cold air may be thrown into the several halls at pleasure; the air being admitted to the large hall through small holes under each seat so that the most perfect ventilation is secured without disagreeable currents of air."

    Who designed this heating and ventilating system I do not know. The HAER report, p. 22, attributes it to Peter Cooper's son Edward; the source cited does not support the attribution.
52. U. S. Serial set no. 1263 (see note 60) pp. 15, 23. Briggs based his design upon methods suggested by E. Péclet, *Traité de la chaleur* (2nd. ed., 3 vols., Paris, 1843). He described and explained his design in Robert Briggs, "On the Conditions and Limits Which Govern the Proportions of Rotary Fans," Institution of Civil Engineers, *Minutes of Proceedings*, XXX (Session 1869–70), pt. II, pp. 278–308. Comments by prominent English engineers in his audience made clear their disdain for the rational approach to design employed by Briggs. Briggs's understanding of several aspects of vitiation of air and conditions for comfort are given at some length in his paper "On the Ventilation of Halls of Audience," American Society of Civil Engineers, *Transactions*, X (1881) pp. 53–106. He refers to other sources of further details of the Capitol heating and ventilating system. His obituary notice is in *loc. cit.* XXVI (1896) pp. 542–545. He died in 1882, aet. 50.
53. Billings, *op. cit.* (note 4), pp. 38–39, described Briggs as "a well-known American engineer, who died in 1882." Through his numerous papers, given before engineering societies, "as well as through those trained in the shops under his direction, he has exercised a very considerable influence on . . . heating and ventilating during recent years."
54. U.S. Serial set no 1211 (see note 60), p. 49. Billings, *op. cit.* (note 4), p. 198, noted the phenomenon as a sheet of air "swept across the ankles of the member just in front [of the register]. When it had passed his desk and reached the next riser, it was reinforced by a fresh stratum, and the honorable member next in front received the upper current on the calves of his honorable legs while the floor current swept his ankles, to his great discomfort and dissatisfaction."
55. U.S., Serial set no. 1118 (see note 60, below). Meigs, who was on the speakers' stand at the opening of the Philadelphia Centennial Exhibition, May 10, 1876, inserted a half-page "Note on the Direction of Currents in a Crowd in Open Air" in Franklin Institute, *Journal*, LXXII, 2 (Aug. 1876) p. 85. The key passage: "a striking example and illustration was observed of *the fact that a crowd lives only by the aid of the ascending current* of the persons composing it." [italics added].
56. U.S., Serial set no. 4585 (see note 60), p. 847. See also later comments by Henry Dawes and Benjamin Harrison in David J. Rothman, *Politics and Power: The United States Senate, 1869–1901* (New York: Atheneum Reprint, 1969), p. 143.
57. Leeds, *op. cit.* (note 29), p. 115. Discussions of proposed modifications of the Capitol heating and ventilating system were of widespread interest. Besides Leeds's study, pp. 114–127, I have noted an article in Edward H. Knight, *Knight's American Mechanical*

Dictionary, vol. 3 (Boston, 1876) pp. 2704–2705. Cf. also note 56, above.

58. Paul Goldberger, "Energy Crisis May Doom Era of Glass Towers," *New York Times*, December 6, 1973, pp. 45, 85; a similar article appeared in *VDI Nachrichten* [organ of the German Engineers' Society], XXVIII, 2 (Jan. 11, 1974) pp. 1–2.

59. It is well to read and ponder Reyner Banham, *The Architecture of the Well-tempered Environment* (Chicago, 1969), and the extended review of the book by John Kouwenhoven in *Technology and Culture*, XI, 1 (Jan. 1970) pp. 85–93. Banham notes (p. 17), "The history of the mechanization of environmental management is a history of extremists, otherwise most of it would never have happened." Amen. In another place he writes, the "arts of both ventilation and heating really waited upon the development of effective blowing fans."

60. Titles in the U.S. Serial set are arranged below by volume serial number. They are as listed in John R. Kerwood, *The United States Capitol; an Annotated Bibliography* (Norman, Okla., 1973).

Serial 441. Kerwood 1279.
U.S., Colonel of the Corps of Topographical Engineers, *Report*, Nov. 30, 1843 (28th. Cong., 1st. sess., H. Doc. 51, pp. 1–20).

Serial 545. Kerwood 1552.
U.S., Congress. House, Committee on the Public Buildings, *Report*, July 26, 1848 (30th Cong., 2d. sess., H. Rept. 90).

Serial 994. Kerwood 1682.
U.S., Congress. Senate, Committee on the Public Buildings, *Report*, Feb. 21, 1859 (35th Cong., 2d. sess., S. Rept. 388).

Serial 1031. Kerwood 1851.
U.S. President, *Message . . . Communicating . . . Information in Relation to the Heating and Ventilating of the Capitol Extension*, 1860 (36th Cong., 1st. sess., S. Ex. Doc. 20).

Serial 1118. Kerwood 1110.
U.S., Captain of Engineers in Charge of the U.S. Capitol Extension, "Report of Operations," Nov. 26, 1861 (37th Cong. 2d sess., S. Ex. Doc. 1, pp. 77–83).

Serial 1211. Kerwood 1641.
U.S., Congress, Joint Select Committee to Examine into the Present Condition of the Senate Chamber and the Hall of the House . . . , *Report*, Feb. 20, 1865 (38th Cong., 2d sess., S. Rept. 128).

Serial 1263. Kerwood 930.
U.S., Architect of the U.S. Capitol. To the Secretary of the Interior, 4 May 1866. *On Warming and Ventilating the Capitol: Letter from the Secretary of the Interior in Answer to a Resolution of the House of the 4th. Instant, Transmitting a Report of T. U. Walter Relative to Warming and Ventilating Both Houses of Congress* (39th Cong., 1st. sess., H. Ex. Doc. 100) 1866 95 pp.

Serial 4585. Kerwood 274.
Documentary History of the Construction and Development of the United States Capitol Building and Grounds, 1904 (58th Cong., 2d. sess., H. Rept. 646).