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# Internal Economies: Airs, Bodies, and Building Technologies, 1832-1932

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# Internal Economies: Airs, Bodies, and Building Technologies, 1832-1932

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# Dedication

*to Ian, for making both the time and the space*

# Abstract

## Internal Economies: Airs, Bodies, and Building Technologies, 1832-1932

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In this dissertation, I posit that to fully understand the social, political, and economic valences of "air conditioning," this spatial practice must be understood as a body technology not a building technology. As such, I contend that this technology's form cannot be read separately from ideas of laboring bodies as constructed in classical liberal economic models and modes of production.

Drawing on Foucault's theory of "biopower," I interpret British and American space conditioning methods as emerging techniques of governmentality that presuppose a particular system of relations between bodies and indoor environments. In constructing explanations of bodily autonomy in *space*, scientific and medical experts could invalidate workers' demands for *time* and fulfil capitalists' needs for productive bodies while reducing costs of incapacity.

Within this investigation I challenge existing narratives that purport a decisive switch from the "failed" project of nineteenth-century ventilation to the triumphant ascent of twentieth-century refrigerated air conditioning. I argue that this shift from air to heat was not simply a matter of scientific "discovery" or the prerogative of equipment manufacturers, but rather a response to a material crisis in indoor industrial environments,

when new and old forms of aerial contamination exceeded the economic will for its removal.

Integral to this study is the discursive production of an individuated “modern” body based on a vitalist model that imagined a self-regulating and self-perpetuating unit that could maintain productivity and disease resistance with little support. Within this paradigm, the qualities of indoor air took on greater significance as preventive strategy. To trace this genealogy of airs and bodies, I examine the networks of political economists, chemists, physiologists, health administrators, engineers, and industrialists that looked first to botanical and then to thermodynamic models to further a vision of a society in which the state had minimal authority to regulate the interests of capital.

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## Introduction: Biopower, Bodies, and Environments

Around July, 2016, air conditioning became a human right. The context of this declaration was a federal class-action lawsuit brought by prisoners incarcerated at the Wallace Pack Unit, a state prison facility operated by the Texas Department of Criminal Justice.[1] The core of the plaintiffs' claim was that because the prison's living areas lacked air conditioning, they were regularly exposed to extremely high temperatures, a situation that constituted cruel and unusual punishment. In describing the case to a broader public, the plaintiffs' attorneys described the lack of thermostatic control as "a violation of a human right."[2] Against the legal backdrop of this case, this construction of a particular technology as an inviolable right seems crucial and linked to specific issues of vulnerability and justice, but since that time the discourse has expanded, positioning a right to air conditioning as a necessary and justified response to global climate change. This connection has been made, albeit by different means, by both the World Bank and *Jacobin Magazine*, a self-proclaimed "leading voice of the American left."[3] Given the variances in worldview between these two groups, if they agree on something, one should probably pay attention.

[1] The case, *Cole v. Collier*, Civil Action NO. 4:14-CV-1698 was heard in the United States District Court, Southern District of Texas, Houston Division. It was filed in June, 2014 and decided by federal district judge Keith P. Ellison in July, 2017.

[2] Jeff Edwards and Scott Medlock, "Air Conditioning is a Human Right," *Time.com* July 21, 2016, https://time.com/4405338/air-conditioning-human-right/. Edwards and Medlock were members of the legal team representing the plaintiffs.

[3] The World Bank's connection to this issue is through its funding and support of the United Nations program, Sustainable Energy for All (SE4ALL) initiative. The World Bank forms "a unique partnership" with the United Nations in this program. The founding chairs of the SE4ALL Advisory Board were the former UN Secretary General Ban-Ki Moon and then-president of the World Bank Group, Jim Yong Kim. The current CEO of SE4ALL, Rachel Kyte, was formerly the World Bank Group vice president for sustainable development. Thalif Deen, "Amidst Rising Heat Waves, UN says Cooling is a Human Right, not a Luxury," *Inter Press Service News Agency*, August 6, 2018, http://www.ipsnews.net/2018/08/amidst-rising-heat-waves-un-says-cooling-human-right-not-luxury/; Leigh Phillips, "In Defense of Air-Conditioning," *Jacobin Magazine*, Aug 30, 2018, https://jacobinmag.com/2018/08/air-conditioning-climate-change-energy-pollution.

Both the World Bank and the author of the *Jacobin* article frame the case for air conditioning's expansion in terms of equity; everyone in the world needs access to air conditioning, and they should not be judged for wanting it. For the World Bank, this is a matter of urgency, because as they put it in their report, *Chilling Prospects: Providing Sustainable Cooling for All*, especially for many in the "developing" world "a lack of access to cooling is increasingly impairing their ability to work, eat nutritious food, and lead healthy and productive lives."[4] The *Jacobin* author is more precise about what a right to air conditioning would look like. Precisely, it would be "free or cheap, reliable access to the thermal conditions optimal for human metabolism (air temperatures of between 18 degrees C and 24 degrees C, according to the World Health Organization)."[5] For this author, this controlled temperature range is not only "an essential, life-saving part of public health," but also critical for an everyday existence in which "we are comfortable, most productive, cozy."[6] In defense of this position, the author employs the authority of science. Foreseeing a critique, the author asserts that this particular prescription for a controlled indoor environment is no "aesthetic preference or cultural artifact." Rather, the author claims, it is the product of science, being "that same biological requirement to maintain as close to optimal metabolic conditions as possible."[7]

In this dissertation I make a case that this WHO-endorsed prescription for cooling, particularly its connection to human metabolism, is indeed a cultural artifact and that it is closely tied to the other critical term that appears in both the World Bank's report and the *Jacobin* article: productivity. In proposing this, I do not suggest that as humans, we do not

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[4] Sustainable Energy for All *Chilling Prospects: Providing Sustainable Cooling for All* (Vienna: Sustainable Energy for All, 2018), 4.
[5] Phillips, "In Defense of Air-Conditioning."
[6] Phillips, "In Defense of Air-Conditioning."
[7] Phillips, "In Defense of Air-Conditioning."

have bodies that react and respond to particular environmental conditions or that we do not experience or associate feelings of comfort or discomfort with them. Instead I want to complicate specific constructs such as “controlled environment should equal metabolism,” which at first glance may seem logical or even “natural.” I think it is critical to ask: Why would the standard for an environment be linked to a specific bodily process? What are the assumptions and ideologies embedded in this technology and the scientific research associated with it that made this construction seem correct? What are the historical links between air conditioning and productivity?

In the following pages I contend that this technologically mediated relationship between human bodies and indoor environments is a specific product of scientific, economic, and political discourses that reach as far back as the eighteenth century. In this, I share with Steven Yearly the point of view that human beliefs about the natural world, while shaped by evidence drawn from nature, are ultimately determined by humans themselves.[8] Thus, it is critical to recognize that within this historical discourse, the model human body at the center of it is itself predicated on particular relations of power that emerged in this period.

Therefore, before we accept the paradoxical situation suggested by *Cooling for All* in which the problems created in part by a particular technology are somehow addressed by more of that same technology, we should recognize how historical ideologies and conflicts have shaped the range of technological possibilities available today. Towards this end, I submit this dissertation as a resource for those organizations and individuals confronting the present dilemma of cooling in warming world. The examination of these types of future-facing challenges is the strength of the discipline commonly known as

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[8] Steven Yearly, *Making Sense of Science: Understanding the Social Study of Science* (London: Sage Publications, Inc., 2005), 183.

Science, Technology, and Society studies (STS). However, as Kristin Asdal has recently observed, the fields of STS and history of science and technology have, as a result of intra-disciplinary debates, drifted apart in recent decades.[9] STS went in one direction, studying contemporary actors with the tools of ethnography, and historians in the other, studying the past in the form of texts and contexts. While the shift in STS toward theorizing the active creation of realities has yielded much valuable scholarship and serves as a useful check to explanations that "reduce" or equate actors with broad generalizing themes, there is a downside in that in focusing primarily on the process of "becoming," the past may be neglected, sometimes to the detriment of full analysis and critique.[10] Instead, Kristin Asdal argues that historical context does not necessarily have to be reductive and advocates for a "philosophy of adding" that introduces *multiple* historical contexts into analysis.[11] Indeed, it can be particularly fruitful, she maintains, to trace contexts and past ways of reasoning that were deeply involved in shaping an issue in the past, but later became marginalized.[12]

A case where a multiplication of contexts is particularly relevant is to the analytical work of sociologist Elizabeth Shove, who with fellow sociologist Heather Chappells has carried out an extensive research program called *Future Comforts*, which investigates relationships among issues of climate change, the built environment, and thermal comfort

[9] Kristin Asdal and Ingunn Moser, "Experiments in Context and Contexting" *Science, Technology, and Human Values* 37, no. 4 (Jul 2012): 291-306. See also David J. Hess, "If You're Thinking of Living in STS....A Guide for the Perplexed," in Gary Downey and Joe Dumit, eds., *Cyborgs and Citadels: Anthropological Interventions in Emerging Sciences and Technologies* (Santa Fe: SAR Press, 1998), 143-164.Very broadly, the debates centered around issues of agency; does society structure individual actions or do individuals make society through their actions? More specifically, the debates in the 1970s and 1980s were between members of the "Edinburgh School" which called for studying the "interests" that shape the content of scientific study (e.g. class) and those more aligned with Bruno Latour's Actor-Network Theory, which proposes studying not what he saw as static contexts, but rather "worlds in the making."

[10] Kristin Asdal, "Contexts in Action—And the Future of the Past in STS," *Science, Technology, and Human Values* 37, no. 4 (Jul 2012): 379-403.

[11] Asdal, "Contexts in Action—And the Future of the Past in STS," 398.

[12] Asdal, "Contexts in Action—And the Future of the Past in STS," 397.

conventions.[13] In her 2003 book, *Comfort, Cleanliness, and Convenience*, Shove performs an astute analysis of what she calls the "social organization of normality," detailing how everyday practices, habits, and settings of daily life actively construct individuals' energy consumption patterns.[14] Shove dedicates a chapter of her book to a review of the historical construction of the idea of comfort, and for this she relies primarily on two key texts, John Crowley's *The Invention of Comfort* (2001) and Gail Cooper's *Air-Conditioning America: Engineers and the Controlled Environment, 1900-1960* (1998).

These two excellent histories mark essential inflection points in the social construction of comfort. John Crowley argues that a critical change in the idea of comfort occurred in eighteenth-century Anglo-American culture, when political economists such as Adam Smith reimagined the concept, erasing its former moral dimension and redefining it as a physical phenomenon.[15] A new social understanding of comfort proposed by Smith had distinct economic utility. As a middle ground between luxury and necessity, comfort simultaneously avoided the traditional (both classical and Christian) censure of indulgence and justified consumption of newly available consumer goods. Describing events in early twentieth-century America, Cooper maintains that the engineering profession's consciously effected autonomy relative to medical expertise supported manufacturers' efforts to realize air conditioning as a consumer product and established the foundation for contemporary engineering standards for thermal comfort.

The works of Shove, Crowley, and Cooper are fundamental in describing the construction and maintenance of middle-class comfort, but framed primarily as studies of

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[13] Elizabeth Shove and Heather Chappells "Future Comforts" https://www.lancaster.ac.uk/fass/projects/futcom/

[14] Elizabeth Shove, *Comfort, Cleanliness, and Convenience: The Social Organization of Normality* (Oxford; New York: Berg, 2003).

[15] John Crowley, *The Invention of Comfort: Sensibilities and Design in Early Modern Britain and Early America* (Baltimore and London: Johns Hopkins University Press, 2001), ix-x, 142.

consumption they leave a critical gap not only in the chronology—the nineteenth century is generally left unexplored—but also in perspective. In this dissertation, I present the case that there is an additional dimension, one that encompasses the social, medical, and technical shaping of the resilient bodies needed to produce the commercial goods newly available for personal consumption.

This is air conditioning viewed from the side of production rather than consumption, where comfort, health, and productivity are seen as more deeply intertwined than the current narratives suggest. Certainly these are not opposing perspectives—these matters overlap and intertwine in multiple and complex ways—but it is important to recognize that the particular relationship between bodies and air that we imagine today was not defined only by issues of leisure and consumption, but also by systems of labor and production. We should not ignore that in 1915 a particular group of physiologists, public health administrators, and engineers, supported by municipal bureaucracy and sponsored by newly available philanthropic funding, defined comfort as *an inclination to work*.[16]

Issues of productivity have not been neglected in the historical literature on air conditioning, but these have focused on geographical patterns and outdoor climates. For instance, Marsha Ackermann in her 2002 book *Cool Comfort: America's Romance with Air-Conditioning* describes the work of early twentieth-century geographer Ellsworth Huntington, who linked "progress" and "civilization" with temperate or cool climates (and often their "racially pure" inhabitants). In Huntington's view, "defective" and unproductive areas could be made productive with air-conditioning technology.[17] However, as Huntington's contemporary and colleague C.E.A. Winslow said of Huntington's

[16] C. E. A. Winslow, "Effect of Atmospheric Conditions upon Fatigue and Efficiency," *Monthly Review of the U.S. Bureau of Labor Statistics* 4, no. 2 (Feb 1917): 290.
[17] Marsha E. Ackermann, *Cool Comfort: America's Romance with Air-Conditioning* (Washington DC: Smithsonian Institution Press, 2002).

observations, these "relate to general outdoor conditions, not to those which exist in the factory itself."[18] Instead, Winslow wanted to call attention to "the great but commonly unrecognized importance of one of these environmental factors in efficiency—the physical condition of the atmosphere of the workroom."[19] Something more complicated was going on inside, and that is the subject of this dissertation.

My aim in this dissertation is to connect discourses on technology and space to narratives of science, health, and human productivity. As with most dissertations, this was not my original intent. I proposed to write a dissertation about ventilation in tall office buildings in the late nineteenth century, but as I got into the research I realized I might just be retelling Cooper's story of professional engineering entrepreneurship. The lucrative skyscraper market was the primary target of heating and ventilating engineers when they formed their professional society (American Society of Heating and Ventilating Engineers or ASHVE) in 1894. A few other questions kept nagging at me however, and these are the ones that inspired the direction of this dissertation.

1) Cooper argued that ASHVE consciously effected autonomy relative to medical expertise, and in fact went so far as to open their own lab to do their own science to get their own results. This lab was housed at the U.S. Bureau of Mines. While Cooper explains the relationship as one primarily of real estate and convenience, I kept wondering, what did the Bureau of Mines want from the engineers?

2) Cooper and others have argued that the story of air conditioning is one of humidity not of heat. This is accurate in the sense that the specific term "air conditioning" first applied to management of humidity in factories producing hygroscopic materials (swell and shrink with humidity), but it did not sufficiently account for the particular form

[18] Winslow, "Effect of Atmospheric Conditions upon Fatigue and Efficiency," 285.
[19] Winslow, "Effect of Atmospheric Conditions upon Fatigue and Efficiency," 283.

of air conditioning that emerged after 1923, when air conditioning meant refrigeration, or rather the addition of mechanical refrigeration equipment to the humidity control systems that were already in existence. What made refrigeration, the most costly element of air conditioning, necessary or important?

3) Engineering histories always noted that ventilation systems existed in the eighteenth century and earlier, but these were generally treated as failures. They just demonstrated the wrongheadedness and unenlightened status of earlier societies. But if moving air was never the "right" answer, then why would societies choose it again and again? What was going on in 1840 or in 1740 for that matter that made ventilation seem like a good idea?

Some scholars in architectural and engineering history have considered building environmental technologies such as heating and ventilation, but these have focused primarily on technical or aesthetic matters.[20] Central to this literature is Reyner Banham's 1969 work, *Architecture of the Well-Tempered Environment*, which is still cited as the "go-to" work in architectural history as well as many fields outside it. While Banham drew critical attention to a relatively overlooked subject, he did not seriously address nineteenth-century buildings. Rather, his chief concern was the effect of mechanical heating and cooling systems on aesthetics, and his comparatively techno-positivist work focused on demarcating the twentieth-century "modern" architectural canon.[21] In a critical 1978

[20] Sarah Landau and Carl Condit, *Rise of the New York Skyscraper, 1865-1913* (New Haven, London: Yale University Press, 1996), 30-33; Thomas Leslie *Chicago Skyscrapers, 1871–1934* (Urbana: University of Illinois Press, 2013); Thomas Leslie, Saranya Panchaseelan, Shawn Barron, and Paolo Orlando, "Deep Space, Thin Walls: Environmental and Material Precursors to the Postwar Skyscraper" *Journal for the Society of Architectural Historians* 77, no. 1 (March 2018), 77-96. James O. Ross, "The Impact of the Nineteenth-Century Public Health Movement upon American Architecture: Theories of Disease, Ventilation, and Sunlight, 1840-1944" (PhD diss., Brown University, 2006); Cecil Elliott, *Technics and Architecture: The Development of Materials and Systems for Buildings* (Cambridge, MA: MIT Press, 1992)
[21] Reyner Banham, *The Architecture of the Well-Tempered Environment* (Chicago: University of Chicago, 1969, second edition, 1984). Indeed, Banham was criticized at the time for his conclusions about turn-of-

article, Robert Bruegmann provided an unsurpassed description of major developments in heating and ventilating equipment and building configurations of the nineteenth century and documented the changing and sometimes fraught relationships between architects and newly self-identified ventilation experts.[22] Although both Banham and Bruegmann noted a need for a history of the medical and physiological dimensions of these technologies, both acknowledged that it was outside the scopes of their respective investigations.[23]

Two major engineering histories of building environmental technologies predictably eschew social context but do reveal a surprising difference in the basis for the equipment. Perhaps a product of differing geography or institutional setting, Neville Billington and Brian Roberts's *Building Services Engineering: A Review of Its Development* introduces the subject with a sustained review of "human requirements and comfort" (physiology, metabolism, and comfort), but Barry Donaldson and Bernard Nagengast's *Heat and Cold: Mastering the Great Indoors* begin their narrative with a lengthy review of scientific theory from 1600 to 1900.[24] However, as is typical with many histories sponsored by professional societies, these are generally characterized by presentism, seeking only to explain the origins of the currently dominant practice.

Thus, in order to approach these preliminary questions, I expanded my research into public health history, labor history, and environmental history. Many public health sources are complicated because their narratives of air are still formed around ideas

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the-century architects and buildings. Although he noted this critique in the second edition of the *Well-Tempered Environment*, Banham left the issue behind in later writing. [See Bruegmann, 144 note 2.]

[22] Robert Bruegmann, "Central Heating and Forced Ventilation: Origins and Effects on Architectural Design," *Journal of the Society of Architectural Historians*, 37 no. 3 (Oct 1978): 143-160.

[23] Banham, *Architecture of the Well-Tempered Environment* (1984), 301; Bruegmann, "Central Heating and Forced Ventilation,"149, note 21.

[24] Neville S. Billington and Brian M. Roberts, *Building Services Engineering: A Review of Its Development* (Oxford [England]; Boston: Pergamon Press, 1982); Barry Donaldson and Bernard Nagengast, *Heat and Cold: Mastering the Great Indoors: A Selective History of Heating, Ventilation, Air-Conditioning and Refrigeration from the Ancients to the 1930s* (Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1994).

disseminated by the early twentieth-century American "New Public Health" movement. Premised on the germ theory of disease transmission, the New Public Health priorities were promoted by Rhode Island state health superintendent Charles V. Chapin, who argued that cleaning hands was more important than cleaning air. Writing in 1907 Chapin proselytized, "we must teach those who have the care of the sick not to waste so much time on the invisible dry and dead micro-organisms of the air, but to use more soap and water on their hands."[25] Promotion of the new directives relied in part on denigrating past public health priorities, ventilation being one of the primary targets.[26] This determined rejection of earlier approaches echoed in later narratives. Historians of technology generally accepted that by the end of the nineteenth century germ theory had resolved—or made moot—problems of ventilation.[27]

The heroic narratives of the New Public Health movement also acted to muddle past distinctions. Many present-day urban, medical, and public health historians assume that ventilation efforts of the nineteenth century were exclusively dedicated to eliminating "miasmas"—bad air thought to cause epidemic diseases—and consequently merge them with major urban infrastructure projects to supply potable water, remove sewage, improve surface drainage, and remove refuse and other wastes from city streets.[28] Today most urban

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[25] Charles V. Chapin, "Contact Infection," *Public Health Papers and Reports* 33 (pt 1): (1907): 62, cited R.A. Hobday and Stephanie Dancer "Roles of sunlight and natural ventilation for controlling infection: Historical and current perspectives," *The Journal of Hospital Infection,* 84 (2013): 10.

[26] For example, George T. Palmer, "What Fifty Years Have Done for Ventilation" in Mazÿck P. Ravenel, ed *A half century of public health: jubilee historical volume of the American Public Health Association* (New York: American Public Health Association, 1921), 334-360.

[27] Bruegmann, "Central Heating and Forced Ventilation," 153; Landau and Condit, albeit writing prior to Cooper's book, claim that standards for ventilation were largely settled in 1885 and remained the same up to the time of their book's publication. Landau and Condit, *Rise of the New York Skyscraper,* 30-33,

[28] For example, Stephen Mosley, "Fresh air and foul: the role of the open fireplace in ventilating the British home, 1837–1910" *Planning Perspectives* 18, no. 1 (2003): 3. Here it may be useful to differentiate between "miasma" theory and "germ" theory as they emerged in the nineteenth century. Miasma theory, also called "filth" theory, were general terms for German organic chemist Justus von Liebig's zymotic theory, which he proposed in the 1840s. Based on models of chemical fermentation, Liebig's theory posited that the decomposition of organic matter (rotting garbage, human excrement) released certain damaging

and public health historians do not clearly differentiate between outdoor and indoor air, lumping together ideas about miasmas, outdoor nuisances (malodorous industries such as bone boiling and tanning), sewer gas (associated with indoor plumbing) with building ventilation (vitiation of indoor air), although many writers at the time saw them as unique problems.[29] John Duffy observes that from the 1870s on, interest in ventilation among public health advocates grew as earlier focus on epidemic disease declined, but assumes this was because "it was only logical that the sanitarians would worry about the concentration of fetid odors indoors."[30] Even Christopher Hamlin, whose revisionist reading of the British public health movement in part inspired the framing of this dissertation, does not engage critically with Chadwick's discussion of interior space.[31]

In many ways this dissertation is a history of occupational health, but this too tends to be neglected in labor history as well as histories of medicine and public health.[32] There

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gases that when inhaled or otherwise absorbed caused diseases like fever or cholera. The concentration of these aerial contaminants determined the relative salubrity of an enclosed space, and dilution of the air by ventilation was often a recommended preventive. This theory was not the only motivation for ventilation, but it certainly merged with or advanced other existing theories about air. Germ theory comprises the specific postulates laid out by German microbiologist Robert Koch in the 1880s. In Koch's construction, it was a live and self-contained organism that transmitted disease between people. It was a biological matter rather than a chemical matter.

[29] George Rosen *A History of Public Health*, rev. ed. (Baltimore: Johns Hopkins University Press, 2015; original published in 1958); Stanley K. Schultz, *Constructing Urban Culture: American Cities and City Planning, 1800-1920* (Philadelphia: Temple University Press, 1989); John Duffy, *The Sanitarians: A History of American Public Health* (Urbana: University of Illinois Press, 1990); Suellen M. Hoy, *Chasing Dirt: The American Pursuit of Cleanliness* (New York: Oxford University Press, 1995); Nancy Tomes, *The Gospel of Germs: Men, Women, and the Microbe in American Life* (Cambridge, MA: Harvard University Press, 1998); Dorothy Porter, *Health, Civilization and the State* (London: Routledge, 1999); Martin V. Melosi, *The Sanitary City: Urban Infrastructure in America from Colonial Times to the Present* (Baltimore: John Hopkins University Press, 2000). Much of the contemporary discussion of miasma theory in public health was influenced by Erwin H. Ackerknecht, "Anticontagionism between 1821 and 1867" *Bulletin of the History of Medicine* 22, no. 5 (Sep-Oct 1948): 562-593.

[30] John Duffy, *The Sanitarians: A History of American Public Health* (Urbana: University of Illinois Press, 1990), 132.

[31] Barbara Leckie, *Open Houses: Poverty, the Novel, and the Architectural Idea in Nineteenth-Century Britain* (Philadelphia: University of Pennsylvania Press, 2018), 29. Leckie makes this observation of Hamlin's work.

[32] Joseph Melling "An Inspector Calls: Perspectives on the History of Occupational Diseases and Accident Compensation in the United Kingdom," *Medical History* 49 (2005): 102; Paul Weindling "Linking Self

are multiple reasons for this, but some suggest that it follows the lead of the trade unions, who have traditionally focused on wages and job security instead of working conditions and worker health, and that it reflects the prerogatives and interests of the "New Labor History."[33] However, since the 1980s, a number of historians of medicine have undertaken to write critical histories of occupational health beyond the heroic narratives of earlier generations of historians.[34] Of critical relevance here is the work of historians David Rosner and Gerald Markowitz around industrial dust exposures and the long-contested disease silicosis.[35] It was in reading the compelling story they tell in their book, *Deadly Dust*, that I realized I was missing a crucial element in the story of air, and it was then that I turned my attention to issues of work and worker health. So many pieces began to fall into place, and it started to make sense why the Bureau of Mines would want to partner with ventilation engineers.

Some environmental historians have also taken an interest in labor history, primarily in issues of occupational health.[36] Christopher Sellers in his incisive book *Hazards of the Job: From Industrial Disease to Environmental Science* focuses on industrial diseases linked to long-term exposure to workplace contaminants, looking especially to the work of the medical and technical professionals who inserted themselves into debates. From this, Sellers argues that the early twentieth-century industrial (indoor)

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Help and Medical Science: The Social History of Occupational Health" in *Social History of Occupational Health*, ed. Paul Weindling (London; Sydney; Dover, NH: Croom Helm, 1985), 2.

[33] Paul Weindling "Linking Self Help and Medical Science," 10; Arthur McEvoy, "Working Environments: An Ecological Approach to Industrial Health and Safety" *Technology and Culture* 36, no. 2 supplement (April 1995), S156, note 45; Rosner and Markowitz claim that workers do indeed take an interest in health, David Rosner and Gerald Markowitz, eds. *Dying for work: workers' safety and health in twentieth century America* (Bloomington: Indiana University Press, 1987).

[34] Joseph Melling "An Inspector Calls," 102.

[35] David Rosner and Gerald Markowitz, *Deadly dust: silicosis and the politics of occupational disease in twentieth-century America* (Princeton: Princeton University Press, 1991).

[36] Gunther Peck, "The Nature of Labor: Fault Lines and Common Ground in Environmental and Labor History" *Environmental History*, 11, no. 2 (Apr 2006), 212-238

work of these professionals formulated a model for a mid-century environmentalism similar to Rachel Carson's *Silent Spring*, and its attention to low-level but persistent toxic exposures.[37] Michelle Murphy, in her book, *Sick Building Syndrome and the Problem of Uncertainty: Environmental Politics, Technoscience, and Women Workers* draws on similar themes beyond the industrial workplace to the environment of the post-WWII office building. From the perspective of tightly sealed and mechanically conditioned buildings, Murphy draws attention to the uneven consideration given to various groups' claims about indoor air quality and illnesses perceived as resulting from it.[38] Particularly helpful was Arthur McEvoy's proposal for an ecological method by which environmental historians can engage industrial and occupational health by attending to workers' bodies as the biological nexus of workplace technologies, processes, and ideologies.[39]

The work of these environmental historians and the critical tools of environmental history that complicate the boundaries between nature and culture were critical in shaping how I thought about a technology that essentially mediates between such natures and cultures, but by training, I am an architectural historian, and thus my fundamental frame of reference is architectural space. This perspective necessitates the question, what is the role of space in all of this?

First a brief explanation of the material form of this technology is useful. When asked to conjure an image of "air conditioning" technology, many might imagine the hum of a window unit or the hulking presence of a rooftop chiller, but the concept presupposes

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[37] Christopher Sellers, *Hazards of the Job, From Industrial Disease to Environmental Health Science* (Chapel Hill: University of North Carolina Press, 1997), 48-49, 235.

[38] Michelle Murphy, *Sick Building Syndrome and the Problem of Uncertainty: Environmental Politics, Technoscience, and Women Workers* (Duke University Press, 2006).

[39] Arthur McEvoy, "Working Environments: An Ecological Approach to Industrial Health and Safety" *Technology and Culture* 36, no. 2 supplement (April 1995), S145-S153; Michelle Murphy, *Sick Building Syndrome and the Problem of Uncertainty: Environmental Politics, Technoscience, and Women Workers* (Duke University Press, 2006).

not only an apparatus but also a process and a spatial configuration. The process embodies two conflicting operations, temperature control and ventilation. The first goal is to create a differential, to make indoor space different (warmer or cooler) than the other side of the boundary, the outdoors. The second goal, ventilation, assumes that this artificially created indoor environment is deleterious and attempts to make inside more like outside. Critically, these processes presuppose a defined space of varying porosity, a particular configuration of spatial boundaries, and it was this matter of *confined space* that absorbed the attention of scientists, physicians, reformers, administrators, and eventually architects as early as the seventeenth century.

Yet once the boundaries of this confined space were established, it was not just a matter of creating a particular ideal environment. This was not just a static space that contained static bodies, rather physiologists and others imagined a dynamic relationship between bodies and space. Although discussions of this issue sometimes centered on the supply of oxygen or cooling, the nature of the relationship between bodies and air was in fact almost always one of removal. Human bodies produced waste and the air removed that waste, whether exhaled or radiated.

## SPACE CONDITIONING AND THE CONTINUITY OF TECHNIQUE

In this dissertation there will be some talk of specific apparatuses—the fans, pipes, and sprayers that actually changed air—but that will be minimal. This is a not history of what air conditioning *can* do, it is a history of what different groups with different interests thought air conditioning *should* do. Thus, although the term "air conditioning" has specific present-day connotations (primarily as an apparatus for cooling and humidity control) and a commonly told early-twentieth century narrative origin, I posit that the concept is not specific to the twentieth century but rather continuous with medical discourses about heating and ventilation in the nineteenth century and earlier.[40] This longer perspective has multiple implications, but the most critical is that it casts into different light the critical inflection from ventilation to cooling that occurred in the first decades of the early twentieth century, describing it in the context of the labor disputes over work hazards that came to a head in this period. This conflict is the focus of chapter five of this dissertation.

Given this complicated and contentious relationship between air, space, and health, I propose to use the term "space conditioning" in this dissertation to stand in as a holistic accumulator of terms such as "air conditioning," heating, ventilating, cooling, filtering, and "air washing." In a practical sense, this makes it easier to account for the various methods of transferring or managing heat (radiation, convection, evaporation) as well as the various methods for achieving the same ends (windows, direct and indirect heating systems, heat-driven exhaust systems, fan-driven supply systems, cooling by evaporation, cooling by refrigeration).

However in a methodological sense, it connects the interests and aims of various groups not traditionally considered in connection to a specific technology. It can also establish longer narratives and trajectories within multiple contexts. Contemporary writers often treat "air conditioning" as either radically new, with no history, or as a continuous but non-specific practice founded in ancient medical theory (the *Airs, Waters, Places* of the Hippocratic canon) or ancient technique (Roman hypocausts). To a certain extent both are true. The technology of air conditioning in the twentieth-century did represent something new (applying refrigeration to an environmentally isolated space), but some

[40] There are two commonly told origin stories for the term "air conditioning." The first presents the origin as laying with engineer Stuart Cramer, who coined the term to describe the humidifying systems he was installing textile factories, mostly in the American South. The far more widely publicized origin story is that Willis Carrier, the founder of the Carrier Corporation, invented air conditioning in 1902, when the Carrier Corporation installed a humidity management system at the Sackett & Wilhelms printing plant in Brooklyn, NY.

ideas and constructs about the medical purpose of changing the air remained remarkably the same.

Certainly, this dissertation concurs with Merritt Roe Smith and Leo Marx's conclusion that historical narratives that subscribe to a "hard" technological determinism are rarely useful.[41] In allowing a technology to serve as the singular and primary variable these "hard" determinist narratives obscure human agency and the various social conditions that technologies may or may not reinforce. Smith and Marx's recognition that a "soft" determinism, which imagines technological practices as deeply embedded in complex social phenomena. Yet Smith and Marx are more concerned with a contemporary twist on instrumentality. Writing as they were at the end of the 1980s, they observed, with some concern, that "people seem all too willing to believe that innovations in technology embody humanity's choice for the future."[42] The extent to which various actors attribute problems or solutions to technology is a primary theme in this dissertation, but it is also a critical premise of the following chapters that actors make technological choices in view of what they categorize as either inevitable or controllable. This of course calls into question what, exactly, these historical actors wanted ultimately to control.

Some scholars suggest bluntly that air-conditioning technology is a means to discipline bodies "such that they have no excuse to stop working."[43] This is not the only purpose of space conditioning, but in this dissertation I argue that in view of the longer history of this technology, this was often the case. And yet this association is not so simple. An air conditioner is not a gun; it has no essential disciplinary features. It is here that the concepts of "biopower" and "governmentality" as suggested by sociologist Michel

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[41] Leo Marx and Merritt Roe Smith, eds. *Does Technology Drive History?: The Dilemma of Technological Determinism* (Cambridge, MA: MIT Press, 1994)
[42] Leo Marx and Merritt Roe Smith, eds. *Does Technology Drive History?*, xiv
[43] Gwyn Prins, "On Condis and Coolth" *Energy and Buildings*, 18 (1992): 251.

Foucault can help us understand the complex relationships between airs, bodies, and building technologies that emerged with the so-called industrial revolution.

## BIOPOWER

As Roger Cooter and Claudia Stein observe, many academics might feel that much of Foucault's thinking is now passé, but they argue this is not the case for his concept of biopower.[44] For our purposes, Foucault's theory of biopower offers a more subtle and effective reading of disciplinary power and how it operates through indirect means, particularly in the realms of bodies and health. Introduced in the first volume of his project *History of Sexuality* (1976) and outlined primarily in two consecutive lecture courses given at the Collège de France in the late 1970s and later published in English as *The Birth of Biopolitics* (2008) and *Security, Territory, Population* (2009), the concepts of biopower and its related ideas "biopolitics" and "governmentality" are rich, complex, and frequently debated among scholars, but Foucault's thinking in this direction emerged in part from further reflection on his earlier book *Discipline and Punish* (1975), in which he introduced as an exemplary model of disciplinary technology, Jeremy Bentham's panopticon, a 1791 proposal by the British legal theorist for a new type of prison.[45] The panopticon prison consisted of a radial arrangement of individual prison cells all facing inwards towards a central guard tower. The cells themselves would be backlit, such that the activities of the prisoner would always be visible to the guard tower. The opposite would be the case for the guard tower. It would be relatively dark such that the prisoners would never know whether the tower was occupied or not. The result would be that the prisoners, in this state of uncertainty, would begin to police their own behavior, a do-it-yourself model of prison

[44] Roger Cooter and Claudia Stein, "Cracking Biopower," *History of the Human Sciences* 23, no. 2 (2010): 109.
[45] Beverly H. Burris, *Technocracy at Work* (Albany, NY: State University of New York Press, 1993), 46.

discipline.[46] With this example, Foucault asserted that this demonstrated a way in which power could be embedded in a particular arrangement of space and knowledge, making unnecessary the continuous involvement of the prison guard or more broadly the state itself.

Foucault had already considered the rationalization of European institutional medicine in his 1963 work *Birth of the Clinic,* but in developing the idea of biopower in the 1970s Foucault began considering medicalization beyond the walls of the medical institution, weaving into the very fabric of society itself.[47] Biopower, Foucault argues, represents rationalized efforts "to intervene upon the vital characteristics of human existence" in the interest of predictability and productivity.[48] These interventions occur at two levels. At the level of "anatamo-politics" of the individual human body, biopower seeks to maximize the body's productive operations and to channel its forces into efficient systems. Biopower also simultaneously works at the level of the population, comprising methods to measure, monitor, and regulate vital characteristics such as birth, morbidity, mortality, and longevity.[49] As such, biopower is less concerned with the problems of epidemic disease that it is focused on illnesses that are persistent in a population and routinely whittle its numbers and its capacity.[50] In the realm of biopower, cholera is less a concern than consumption.

[46] Rarefied as it is in philosophical discussions of Foucault's work, the panopticon also reveals, recalling Hannah Arendt, some of the disquieting banality of Bentham's thinking; Bentham could congratulate himself for devising a *very cheap* way to run a prison.
[47] David-Olivier Gougelet, "The World is One Great Hospital," *Journal of French and Francophone Philosophy* 18, no. 1 (2008-2010): 43-66.
[48] Paul Rabinow and Nikolas Rose, "Biopower Today," *BioSocieties* 1 (2006), 195-217 (196); Burris, *Technocracy at Work*, 45.
[49] Rabinow and Rose, "Biopower Today," 196.
[50] Rabinow and Rose, "Biopower Today," 199; Gougelet, "The World is One Great Hospital," 51.

Critically, these interventions are not the activities performed by a centralized government or sovereign, but rather biopower operates diffusely in the undertakings of multiple and not necessarily coordinated state and non-state actors. Biopower exercises in 'micropower' relations, circulates in the form of social and scientific knowledge, and manifests in various disciplinary techniques and technologies. It is not the work of some shadowy ring of conspirators, but rather it is deeply rooted in what seems to be simply the rational conduct of society.[51] Biopower describes not the sovereign power to decide whether to kill or let live as much as collective social power to cultivate lives or neglect them to the point of death. In its operation is shares more in common with Adam Smith's "invisible hand" of the market than any set of health policy regulations.

In the context of this dissertation, the concept of biopower can both draw together and differentiate the situations in two eighteenth century factories. In the case of an outbreak of "fever" at Robert Peel's factory in 1784 described in chapter three, this was an epidemic requiring an inquiry by local government and eventually state intervention in the form of factory laws. This event, while not as well-known as others in conventional histories of public or occupational health, is often positioned as the origin story in a longer generally heroic narrative of direct governmental intervention in industry. The concept of biopower, in my interpretation, would not deny the importance of that event, but it would ask that the situation at the ceramics factory of Josiah Wedgwood in the 1780s also be considered within the same narrative. Wedgwood, growing despondent that "potter's rot" (now thought to be silicosis) was still the primary cause of death among his workers at Etruria, called upon his friend and scientific collaborator Joseph Priestley to estimate the

[51] Burris, *Technocracy at Work*, 45-46. See also Hubert L. Dreyfus and Paul Rabinow, eds. *Michel Foucault: Beyond Structuralism and Hermeneutics* (Chicago: University of Chicago Press, 1983).

cost to supply Priestley's new "eminently respirable air" (now known as oxygen) directly to his factory space.[52]

The dual nature of biopower—its focus on both the individual body and the population—can also illuminate the growing involvement of physiologists in matters of workplace environmental conditions. By studying physiological processes at the level of the individual body, both Stephen Hales in the eighteenth century (see chapter two) and John S. Haldane in the twentieth century (see chapters four and five) specified aerial conditions that could increase long-term productivity of populations, in Hales's case the populations of the army and navy, and in Haldane's case the populations of laborers in mines and factories.

In the interpretations of some philosophers, Foucault's theory of biopower is treated as totalizing and timeless, but others argue, I think correctly, that Foucault's concept of biopower is historically specific and embodies useful tools for political critique.[53] Read a certain way, Foucault could be seen as suggesting a radical doubt that precludes any worthwhile political analysis, but I find his theory of biopower helpful not only because his geographical and chronological periods of investigation overlap in certain respects with mine—Britain in the eighteenth and nineteenth centuries, America in the nineteenth and early twentieth centuries—but also because his method encourages efforts to look for power relations in unusual places.[54] Moreover, he was interested not just in the static conditions of power, but specifically in the mechanisms involved in the creation of that power; not so much in the *what* as in the *how*.

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[52] Brian Dolan, *Wedgwood: The First Tycoon* (New York: Penguin, 2004), 301-302.
[53] Rabinow and Rose, "Biopower Today," 199. Rabinow and Rose aim their critique at Italian philosophers Giorgio Agamben and Antonio Negri.
[54] Cooter and Stein, "Cracking Biopower," 110-111.

However, as some social historians have argued, many neo-Foucauldian perspectives tend to lose sight of the *what* in the pursuit of explaining the *how*. In other words, in their focus on the making of power and in their de-emphasis or outright rejection of social agency, some Foucauldian narratives downplay or ignore the persistent inequalities of power—between rich and poor, between capital and labor, and so on—making them less visible or seemingly less urgent. As historian Simon Gunn asks, "Why, if power is dispersed and multivalent, did it so often *appear* as unidirectional?" Or more specifically, "Why, for example, did all modern definitions of the social focus remorselessly on the bodies of workers and the poor while excluding the well to do?"[55] In this dissertation I take that question seriously. I do not forget that Edwin Chadwick's well-known 1842 report was not an inquiry into the sanitary condition of Great Britain, but rather an inquiry into the sanitary condition of the *labouring population* of Great Britain.[56]

In this work I aim to follow the guidance of environmental and social historians who propose a "middle ground" approach that borrows critical tools and ideas from Foucault, but does not try to replicate his philosophical approach in total. For both Christopher Sellers and Simon Gunn, this recommends paying attention to human bodies, not just landscapes and not just language.[57] I attempt to recognize in discourses of airs and bodies what David Montgomery saw accompanying changes in relations between

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[55] Simon Gunn, "From Hegemony to Governmentality: Changing Conceptions of Power in Social History" *Journal of Social History*, 39, no. 3 (Spring, 2006): 717.

[56] However, I do want to acknowledge that there is a critical narrative of space conditioning in the formation of the middle class. For an introduction to that subject, I point to for the eighteenth century: Vladimir Jankovic, *Confronting the Climate: British Airs and the Making of Environmental Medicine* (New York: Palgrave Macmillan, 2010), for the nineteenth century: Stuart M. Blumin, *The Emergence of the Middle Class: Social Experience in the American City, 1760-1900* (Cambridge: Cambridge University Press, 1989) and Nancy Tomes, *Gospel of Germs: Men, Women, and the Microbe in American Life* (Cambridge, MA: Harvard University Press, 1998), and for the twentieth century Marsha Ackermann *Cool Comfort: America's Romance with Air-Conditioning* (Washington DC: Smithsonian Institution Press, 2002).

[57] Christopher Sellers, "Thoreau's Body: Towards an Embodied Environmental History." *Environmental History* 4, no. 4 (October 1, 1999): 486–514; Gunn, "From Hegemony to Governmentality," 717.

employer and employee that came with extension of the freedom of contract as a legal doctrine. When all but monetary relations between these groups were essentially severed, Montgomery saw the emergence of less direct incarnations of discipline in the form of new work rules, public institutions, and police powers.[58] With the research in this dissertation, I attempt to describe how this shift to "free labor" was also accompanied by new ways of interrogating, describing, and recommending changes to relationships between bodies and confined air.

While the immediate subject matter of this dissertation is something most would identify as a technology, I examine it for the purpose of understanding the formation and reformation of webs of power woven by and between various groups. While I discuss positions taken by labor and management, I consider more closely the medical and technical experts who engaged in these debates. For as historian Christopher Sellers points out, these were the parties that often directed public attention to these issues, where they might be otherwise discussed only within the confines of the workplace itself.[59] Moreover, these were the individuals who shaped the frameworks within which questions could be asked and theories could be posited. This was far from a neutral activity, for as Sellers observes, in terms of industrial health, the boundaries of knowledge framed questions of responsibility.[60] As then mining consultant Herbert Hoover put it less impartially in 1909, "in these days of largely corporate proprietorship…the engineer becomes thus a buffer between labor and capital."[61]

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[58] David Montgomery, *Citizen Worker: The Experience of Workers in the United States with Democracy and the Free Market during the Nineteenth Century* (Cambridge: Cambridge University Press, 1993), 8.
[59] Sellers, *Hazards of the Job*, 48-49
[60] Sellers, *Hazards of the Job*, 8, also quoted in Vicky Long, *The Rise and Fall of the Healthy Factory*, 9
[61] Herbert Hoover, *Principles of Mining* (New York: McGraw-Hill, 1909), 167

In this dissertation, I describe the nature of that buffering, but I want to be clear that while the actors I describe in the following chapters often expressed that their work was in the interest of finding solutions that worked for both labor and capital, it was capital that benefitted the most from their activities. Some did this in part by constructing discourses of inevitability. For example, both Anthony Lanza of the U.S. Public Health Service and physiologist Frederic Lee (in chapter five) categorized the structural conditions of labor—payment by piecework, length of working days—as given, something that will not or cannot be changed. Instead, they turned attention to the body of the worker as something that could be improved or made more productive, often by an environmental enhancement. In prioritizing certain subjects as valid for scientific inquiry, they simultaneously invalidated the discourses of the workers themselves around shorter hours or better pay.[62]

However, in the face of a crisis, when enough evidence appeared to be mounting to suggest that workplace contaminants both old (silica dust now in high concentrations) and new (TNT and others) could indeed be causing workers' premature deaths and neither employers nor life insurance companies wanted to pay the high costs of consequences, physiologists not only changed the subject from air to heat, they also recast the nature of the body and the valid categories of inquiry. According to the "new physiology," scientists of the body were wasting their time trying to establish "causes" of bodily disruption, and instead should focus their attention on the "normals," the mechanisms by which the body regulates itself in everyday life. In doing this, they presented an image of the vitalist, resilient body that was exquisitely prepared by nature to survive in a range of inhospitable environments.

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[62] Larry Shiner, "Reading Foucault: Anti-Method and the Genealogy of Power-Knowledge," *History and Theory*, 21, no. 3 (Oct 1982): 384.

## CLOSED AND OPEN BODIES

Linda Nash, in her book *Inescapable Ecologies: A History of Environment, Disease, and Knowledge*, traces a distinct historical shift in the cultural construction of the human body's connection to the environment. What was once an "ecological" body, permeable to the environment, becomes a "modern" body, seemingly impermeable to environment. Nash's purpose is to emphasize that in isolating the body from the environment, it becomes possible to degrade the land and harm those who inhabit it without apparent human responsibility, because the human body is no longer a valid indicator of environmental health.[63]

With this dissertation, I wish to add another layer of interpretation to this concept of the "modern body." I propose that the modern body is also a vitalist body, one that is not only resilient, but also self-regulating, self-healing, and self-perpetuating. This model of the body requires little intervention, but it does have a particular relationship with its close environment. To thrive it must have a setting that "takes the load off," absorbing the waste products of the body that is seemingly at rest, but in fact working hard internally to maintain homeostasis. The primary waste product of the body here is heat produced in the metabolism of food. A space cooled by refrigeration can absorb that heat, guaranteeing the normal operation of the body. Hence, an environmental standard based on human metabolism.

I want to suggest that this model of the body accords with a final element in Foucault's theory of biopower, the emergence of a particular mode of subjectivity, the neoliberal *Homo Economicus.* This extends from Foucault's theory of liberal "governmentality" a particular mode of non-interventionist rule aligned with the free-

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[63] Linda Nash, *Inescapable Ecologies: A History of Environment, Disease, and Knowledge* (Berkeley: University of California Press, 2006).

market imperative of privatization and least government in which individuals are essentially self-watching and govern themselves.[64] It is the principle of Bentham's panopticon writ large; a body manages its own operation as an self-interested individual unit. No party must intervene to maintain its health or take responsibility for its damage. In its neoliberal incarnation, the body in an effacement of traditional divisions between labor and capital becomes "human capital." Everybody and every body is an entrepreneur in competition for scarce resources, and investments in the body, whether its health or its optimization, are critical.[65] I do not mean to suggest that we are all somehow trapped in a shadowy world of panopticon, but rather to invite reflection on ideas of air-conditioning as self-optimization, a mode in which consumption of air conditioning is linked to self-maintenance of a productive body, issues I will revisit in the epilogue.

**FROM ACUTE TO CHRONIC**

Two diseases dominated discourses about confined space in the eighteenth, nineteenth, and twentieth centuries, the acute affliction "fever" (what today we would call typhus) and the chronic but ultimately fatal condition "consumption" (then also called "phthisis," today called tuberculosis), and a shift in attention between these two diseases can inform our discussion of biopower. As a general chronological guide, the former disease was of more immediate concern from the early eighteenth century to the middle of the nineteenth century. The latter consistently produced high mortality, but the concern and attention given to it fluctuated in this same period. It became a primary focus of medical

[64] Gunn, "From Hegemony to Governmentality," 717.
[65] Jason Read, "A Genealogy of Homo-Economicus: Neoliberalism and the Production of Subjectivity" *Foucault Studies* 6 (Feb 2009): 31-32.

reformers in the second half of the nineteenth century as outbreaks of acute disease subsided.[66]

Needless to say, the term "fever" does not mean the same thing (a simple rise in body temperature) as it does today. Rather the term "fever" applied to multiple conditions or types of fever, including afflictions such as yellow fever, and medical theorists dedicated much time and effort to categorizing them and theorizing as to a potential unifying cause.[67] Many types of fever were familiar and well-defined for physicians by the eighteenth century, but after epidemics in 1720s doctors observed that a new type of fever seemed to be appearing, mostly among the poor.[68] This new fever was not responsive to traditional fever treatments, such as bloodletting and purging, so new theories and new treatments emerged. The spatial and technological implications of these will be the concern of the second and part of the third chapter of this dissertation.

Unlike typhus fever, consumption was not a new disease. Rather it was an ancient disease that always caused consistently high mortality rates.[69] Its appearance was persistent; it did not come in epidemic or seasonal waves, as so many other diseases did. Until late nineteenth century, the dominant model conceived consumption as hereditary, and because this made it essentially untreatable by physicians, most experts recommended

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[66] A quick note here about the plague and cholera. While both of these diseases were indeed of major concern in this period, many thought these diseases to be of foreign origin (hence "Asiatic" cholera, and common belief that the plague originated in Egypt or India). Fever and consumption were particularly troubling for the reason that they seemed to be home grown.

[67] The author of the most well-known nosology of fever in the eighteenth century was Edinburgh professor William Cullen. Cullen's unifying theory was that all fevers could be ultimately explained along a spectrum of stimulation and depression. Some fevers were characterized by a depression of vital energies, others by overstimulation. A physician could then choose an appropriate treatments (bloodletting, application of stimulant or depressant medicines) based on where a fever fell on this scale.

[68] Guenter Risse, "'Typhus' Fever in Eighteenth-Century Hospitals: New Approaches to Medical Treatment," *Bulletin of the History of Medicine,* 59, no. 2 (Summer 1985): 176.

[69] C.S. Breathnach, "Richard Morton's Phthisiologia," *Journal of the Royal Society of Medicine* 91 (Oct 1998): 551-552.

preventive measures such as improved hygiene, especially fresh air and proper nutrition, or travel to a more 'salubrious' climate to maintain one's constitution and resistance.

Because it was a disease that particularly affected the lungs, consumption was deeply tied to conceptualizations of air. Some of the disease's dramatic and recognizable symptoms were the persistent coughing and spitting of blood, but most recognized it as a wasting disease. This factor muddled theories about the definition of the disease and its precipitating factors. Experts and laypeople disagreed about whether consumption always ran the same predictable course or whether it manifested because of a basic lack of nourishment. This entered into the debates about the nature and conditions of heavy labor in the nineteenth century. Because miners and factory workers often had the highest rates of consumption—certainly it also affected the wealthy, but not in the same numbers—it was possible to imagine that the low wages (and consequent scarcity of food), repetitive work, long hours associated with these types of work could be the cause of the "disease" itself. These issues will be the concern of the third, fourth, and fifth chapters of this dissertation.

While attempting to maintain historical specificity and agency, in the broad arc of this dissertation I explore the emergence and expansion of biopower as it is embodied in theories and practices of airs and bodies from the middle of the seventeenth century to the beginning of the twentieth century. In the first chapter I describe how the theories of ancient medicine provided a basis for biopower that can work at both the individual and population level, and how those tools get refined and imagined in the service of expanded national productivity. In the eighteenth century, these tools and strategies get applied to large populations, first in the military and then as institutional reform of the poor in chapter two. In chapter three Edwin Chadwick takes up these ideas in the early nineteenth century and embeds them into his "sanitary idea," applied to the laboring population at large. In the "indoor" section of his program, Chadwick is particularly interested in the long-term productivity of working bodies, and with his "internal economy" proposes a method by which workers can maintain themselves self-sufficiently. These ideas transfer to the industrializing American northeast, where they extend to consider the maintenance of children's bodies and productivity within the schoolroom. In chapter four I explore a major shift, when the problem of ventilation was reframed from being one of the "chemical and respiratory" to one of the "physical and cutaneous," where overheating became "the most serious aspect of underventilating."[70] By following the references included in what many considered to be a pivotal scientific paper in this field, I connect this shift to concerns with worker health and worker productivity in the late nineteenth century amid growing labor unrest and revelations about the deadly nature of dust. In chapter five, I describe how by the early twentieth century, physiology becomes the nexus for research in improving workers' bodily efficiency at the intersection of body and environment, and engineers are recruited to both refine and guarantee these techniques. Following conflict over governmental involvement in industry and growing awareness of contamination in industrial workplaces, key scientists proposed a "new physiology" that circumscribed the domain of bodily inquiry and put new emphasis on the management of the close environment.

The chronological brackets of this dissertation, 1832 and 1932, represent specific events but they also reflect a broad trend in the trajectory of space conditioning medical science. The earlier date, 1832, represents the year in Britain in which the first (and controversial) Factory Commission was convened to examine the conditions of factories and factory workers. The later date represents the year in which Walter B. Cannon

[70] C.-E.A. Winslow, "Effect of Atmospheric Conditions upon Fatigue and Efficiency" *Monthly Review of the U.S. Bureau of Labor Statistics*, Vol. 4, No. 2 (Feb 1917): 284.

published his seminal book *The Wisdom of the Body*, which described a very particular relationship between and individual human body and its environment. Together these represent a categorical shift in envisioned political authority. The idea of the Factory Commission, if not the reality, meant broad governmental intervention in the space of industrial production. Cannon's book imagined a perfectly balanced world of individual self-regulation, reliance, and resilience, protected if not removed from the harsh conditions of factory life and resistant to external intervention.

That said, chapters one and two of this dissertation concern earlier periods. This was not my original intent, but research on the nineteenth century made clear that the actors of that period were both consciously and unconsciously looking to models from the earlier centuries, and that it was an incomplete story without consideration of earlier incarnations. In extending the study further back in time, Foucault's method of genealogy was an inspiration. Certainly I do not claim to achieve the level of depth and breadth that Foucault brought to his subjects, but his insistence on seeking not origin stories but rather patterns and interconnections shaped my research in numerous ways.[71] Although I followed a somewhat more traditional genealogy in that I traced networks of direct professional associations and scholarly exchanges, I deliberately sought out anomalies and unexpected connections. In the most mundane sense, it meant I paid closer attention to tables of contents, prefaces, and dedications, and tracked down seemingly obscure references that appeared more frequently than anticipated. In its analytical sense, it meant that I attended closely to subtle shifts in meaning and association in the interplay between airs, bodies, and building technologies. What I found was a technology that we purport to consume also in some ways produces us.

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[71] Peter-Paul Bänziger, Marcel Streng, and Mischa Suter, "Histories of Productivity: An Introduction" in *Histories of Productivity: Genealogical Perspectives on the Body and Modern Economy* edited by Peter-Paul Bänziger and Mischa Suter (New York; Abington: Routledge, 2017), 3.

## Chapter 1. Airs and Bodies, Ancient and Modern

For philosophers and physicians, air has long been an explanatory model by which to clarify or to muddle. In the Western philosophical tradition, air is one of Aristotle's four elements out of which all other matter is composed (the other elements are fire, water, and earth). Air's relationship to temperature and humidity are also deeply embedded in the Aristotelian thinking. Hot and cold along with wet and dry are qualities of the four elements, and within the Aristotelian model explain transformations in matter (Figure 1.1).[72] For medical thinkers and clinicians, air was both essential to and a potential enemy of life. Humans needed air for vital respiration, but that same air could also be deadly or debilitating. That said, theories about the exact role of air in human respiration and disease varied significantly, and when medical observers could not explain inconsistent patterns of disease transmission, for example why a caretaker did not fall ill or why a disease appeared in multiple locations without known contact, they most often blamed it on a quality of the air or something in it.

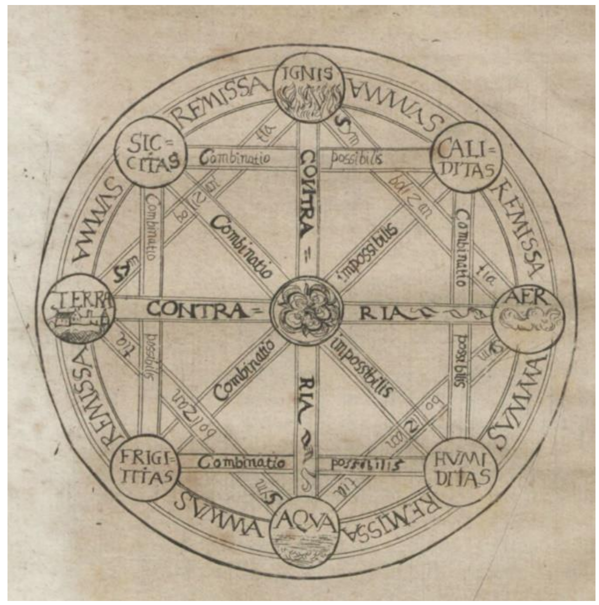


Figure 1.1 Aristotle's elements (air, water, earth, fire) and four qualities (hot, cold, dry, wet) represented in combinatory relationships. Frontispiece to Gottfried Leibniz De Arte Combinatoria, 1666

[72] Philip Ball, *The Elements: A Very Short Introduction* (Oxford; New York: Oxford University Press, 2004).

I am not suggesting that Foucault's theory of biopower extends back to ancient Greece and Rome, but it is important to understand that the conceptual tools for the management of bodies at the level of both the individual and the population existed in ancient medical theory. However, this knowledge was dispersed, partial, and located with individual medical practitioners, not with central bodies of government, institutions, or other networks of actors. Hippocratic writers certainly gathered and compiled information about climates and peoples over a relatively wide geography, but in its ancient form, knowledge about airs and bodies at the population level served primarily to help physicians make more informed decisions about therapies and treatments for individual patients. There were not efforts to apply this knowledge at the population level, nor ambitions to manipulate environments at a large scale.

That changed in the seventeenth century. Impressed by the wealth accumulated by the Dutch, mercantilist economic thinkers in England were casting about, trying to think of ways to increase national exports, the primary mode other than collecting bullion by which mercantilists believed wealth could be accumulated by a nation. The untapped resource that these thinkers came across was the "idle poor" of the nation. If only this resource could be put to work producing manufactures for export, England as a nation could prosper.[73] The health and working capacity of this population became a concern of the state itself. Figures such as physician and political economist William Petty surveyed this population and found it wanting of improvement, especially in terms of health. As a founding member of the Royal Society of London, Petty encouraged his friends to study subjects that could in some way effect this improvement by reducing mortality.[74]

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[73] Edmund S. Morgan, *American Slavery, American Freedom: The Ordeal of Colonial Virginia* (New York; London: W.W. Norton Co.), 320-322.
[74] Irvine Masson and A.J. Youngson, "Sir William Petty, FRS (1623-1687)," *Notes and Records of the Royal Society of London*, 15 (Jul 1960): 79-90.

## ANCIENT AIRS AND BODIES

In the Western tradition, notions of air have been long intertwined with ideas about human health and disease, and despite the passage of centuries and translation through multiple geographical and cultural contexts, conceptual models laid down by ancient Greek and Roman writers persisted and continued to influence thinking about the healthiness or unhealthiness of air into the nineteenth century and later.[75] Within classical medical theory, the concept of air played a critical role in the humoral model of human physiology, which dominated medical practice and theory until the seventeenth century and persisted in modified forms well into the nineteenth century.

It is useful to note that ancient medicine imagined multiple dimensions of air. What mattered was not just what was potentially carried in the air, but also the qualities of the air itself. This is not a purely esoteric distinction. Rather it points to a fundamental conflict that confounded all actors concerned with management of health and environment. Drafts (noticeable alternations of hot and cold) were as much, if not more, a concern as any contamination of air (e.g. miasma). Later commentators would see this as differentiation between mechanical and chemical models of the world and by extension models of the human body and mechanisms of disease. Again, this is not just an arcane categorization, it was the tension between chemical and mechanical models of human vitality that informed twentieth-century transformations in medical theory, space conditioning technology, and determinations of hazardous working conditions.

Looking back from the seventeenth century, medical practitioners saw two traditions operating in ancient medicine, broadly imagined as the Hippocratic and Galenic

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[75] Present-day scholars generally agree that the texts for many centuries attributed to Hippocrates as a historical individual are actually the work of several authors and thus are now typically referred to as the Hippocratic texts. Per Owsei Temkin "the works of Hippocrates, whose name was given to some seventy Greek medical writings of about 400 BC. Many of these writings [are] allegedly associated with Cos, the birthplace of Hippocrates" (Temkin, "Health and Disease" in *The Double Face of Janus*, 424).

models. As translated through Byzantine and Arabic medical theory, the Galenic model generally dictated practice, but for a number of reasons in the 1660s certain medical experts turned from an exclusively Galenic approach to a relatively Hippocratic one. This was embodied in the work of Thomas Sydenham, christened by later generations of medical theorists as the "English Hippocrates."[76]

**Hippocratic Airs (Populations)**

Although the numerous texts, theories, and practices of classical medicine were far from unified, three distinct models of the relationship between disease, miasma, air, and contagion endured in classical medicine (the magico-religious, the rational, and the elemental).[77] Yet while the models themselves are relatively succinct, it is critical to understand that they existed within the context of various physiological and ontological models, classifications of disease types and causes, beliefs about the interplay of individual health with both endemic and epidemic illness, and opinions about the most appropriate modes of ongoing and incidental medical treatment.

The "magico-religious" manifestation is not as critical to understanding medical ideas of the seventeenth century and later, but its ideas often persisted as subtext. This model relates to the original, non-medical meaning of the term "miasma," as derived from the Greek verb "miaino" meaning "to stain," as in "the stain of blood spilt in a crime." Here, disease is sent by the gods as punishment for sacrilegious behavior, and as such it does not differentiate between individual affliction and epidemic disease, although the

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[76] Peter Anstey, "The Creation of the English Hippocrates," *Medical History* 55 (2011): 457–478

[77] Jacques Jouanna, "Air, Miasma and Contagion in the Time of Hippocrates and the Survival of Miasmas in Post-Hippocratic Medicine (Rufus of Ephesus, Galen and Palladius)," in *Greek Medicine from Hippocrates to Galen* (Leiden, Boston: Brill, 2012), 121-136. Note that the first two terms "magico-religious" and "rational" are Jouanna's terms, but the third "elemental" is a term substituted by the present author for the model that Jouanna describes as the one found in the Hippocratic text "Airs, Waters, Places."

connotations of the term "miasma" connected with ideas of contagion and general pollution; "the disease is transmittable like the stain." The treatment engaged to counteract a disease within this model naturally included incantations and rituals of purification for the affected individual.[78]

In the "rational" model—the one most closely identifiable with "miasmatic theory" of the nineteenth century—miasma is not related to moral values and supernatural causes, as in religious medicine, but rather it is linked to a natural cause, material pollution of the air. It is now a relationship between human body and surrounding physical environment, not a relationship of humans and gods. The number, type, importance, and mechanism of various air-polluting agents varied from author to author, but some basic categories stayed relatively consistent over several centuries. In the Hippocratic text *On Breaths,* the sources of pollution were "fumes originating mainly from marshes or cadavers that are carried in the air and that enter men's bodies through respiration and cause general diseases or pestilences."[79] Other common sources were stagnant marshes and pools, vapors emanating from human or animal corpses, sick persons, excreta, spoiled foodstuffs, decaying vegetable matter, and "exhalations" from underground that came through ruptures or clefts. Although at least one significant Roman medical author mentions the contamination of "fresh air" of a city with "the smoke, the smells, the dust, and the other effusions,…and odours of the city," these explanations were not common. To this urban contamination they attributed the same noxious effects as those from non-urban causes such as "pits, mineshafts, holes in the ground, stagnant pools, marshes, or even clinging sea mist."[80]

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[78] Jouanna, "Air, Miasma and Contagion" 121-124
[79] Jouanna, "Air, Miasma and Contagion" 125, 128
[80] Caroline Hannaway, "Environment and Miasmata" in *Companion Encyclopedia of the History of Medicine*, W.F. Bynum and Roy Porter, eds. (London; New York: Routledge, 1993), 295; Vivian Nutton, "Medical Thoughts on Urban Pollution" in *Death and Disease in the Ancient City*, Valerie M. Hope and Eireann Marshall, eds. (London; New York: Routledge, 2000), 52

Although it is not as commonly articulated, a third model of disease causation appeared in ancient medical texts, one that explained diseases by way of environmental factors but one in which "miasmas" played no role. The Hippocratic treatise *Airs, Waters, Places* is the exemplar of this model. In *Airs, Waters, Places*, the writer differentiates between several types of diseases (individual, endemic, and epidemic). Individual diseases were caused by an unhealthy personal regimen, but endemic diseases and epidemic diseases had other etiologies. Endemic diseases could be explained by a city's orientation to the winds or sun or the nature and quality of its water. Epidemic diseases, on the other hand, were caused by changes in season, specifically by changes in the air's qualities (hot, cold, dry, wet), which had direct effects on bodies.[81]

Central to this third model is the assumption that the seasons and winds exerted a direct influence on the human body and its afflictions. The mechanism for this effect was explained as changes in the quantity of an individual's humors produced by the four possible qualities of a season: heat, cold, wetness, and dryness. Common belief held that the four seasons presented typical combinations of these qualities: winter was cold and wet, summer was hot and dry, autumn was dry and cold, and spring was a balance of all four qualities.[82] Thus, the winter's cold and wet character would produce a predictable increase in humoral phlegm, and diseases associated with an overabundance of phlegm were more prevalent. If the seasons had abnormal qualities, for example if a winter was dry instead of

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[81] Jouanna, "Air, Miasma and Contagion" 128-129; Jouanna is clear that the author does not blend the two explanations, for "at no time does the author of *Airs, Waters, Places* allude to miasmas or to pathogenic emanations originating from marshes. Although marshes are harmful to one's health, it is to the extent that one drinks their water."

[82] Meteorological phenomena were a subject of sustained study and consideration in ancient philosophy, for example, Aristotle's *Meteorologica* "The classical tradition of meteorology had grown up in close connection with philosophical ethics. Knowing about the weather was supposed to be morally improving, especially because a philosophical understanding of the reasons for atmospheric phenomena could dispel the fear they caused among the uneducated." Jan Golinski, *British Weather and the Climate of Enlightenment* (Chicago, University of Chicago Press, 2014), 30.

wet, and it was followed by a spring that was particularly hot or wet instead of balanced, inhabitants would suffer particularly from diseases thought to be caused by an excessive amount of humors such as fevers and dysenteries.[83]

A location's winds, like the seasons, could also predict the physical characteristics of inhabitants and the likely presence of certain endemic diseases. Common belief associated the winds with particular seasons and imbued in them combined qualities of hot or cold and wet or dry, depending upon their directional source. Like the seasons, the winds directly affected the relative quantities of the bodily humors. For example, a traveling physician, upon entering a town exposed regularly to hot, wet winds from the south would expect to find residents with "flabby physique" and "superabundance of phlegm," which would make them more likely to be epileptic or to suffer from chronic afflictions such as fluxes, diarrheas, and dysenteries.[84]

**Galenic Bodies (Individuals)**

Combining ideas recorded in Hippocratic texts with ideas delineated by Platonic, Aristotelian, and Stoic thinkers, Galen, the influential Rome-based Greek physician and scholar, in the second century CE proposed a systematic ideal of how the human body supposedly operated. This model consisted of four bodily humors: blood, yellow bile, phlegm, and black bile, which mirrored the four elements of the physical world (air, fire, water, and earth respectively) as well as the ages of man, the seasons, and the directional winds. Each humor-element pair in turn represented binary combinations of qualities: blood (air) was hot and moist, yellow bile (fire) was hot and dry, phlegm (water) was cold and moist, and black bile (earth) was cold and dry. The humors, imagined by Galen as the

[83] Genevieve Miller "'Airs, Waters, and Places' in History" *Journal of the History of Medicine and Allied Sciences,* 17, no. 1 (January, 1962): 129-140; 130-131
[84] Miller "'Airs, Waters, and Places' in History," 130-131

products of metabolized food, were a part of his larger anatomical and metaphysical model in which the liver, heart, and brain, served as the seats of a tripartite soul: the natural soul (human appetites and regulated nutrition), the vital soul (human passions and regulated body heat), and the rational soul (responsible for thinking, feeling, and willing).[85] The model also assumed that mental states had physical implications. The idea that a person could fall ill or even die as a result of persistent fear or grief was popularly accepted in Greek culture, but Galen claimed to be the first to bring the concept into a medical context and consequently to be a specialist in "stress diseases."[86]

Galen also maintained an Aristotelian explanation of respiration that still prevailed in the seventeenth century. Aristotle's construction, which embodied earlier religious and philosophical traditions, posited that respiration existed to bring air into the body for the purpose of creating "pneuma," a vital force essential for life. The heart, the Aristotelian "seat of vital heat," warmed inhaled air and converted it to pneuma, but the air had the secondary function of cooling the heart, and thus preventing the body from overheating. Galen's explanation added an additional dimension to this theory. He imagined that the blood acted in some way as the fuel for this vital heat and like an oil-burning lamp, the body created "sooty residue." Thus, another function of respiration, in Galen's view, was for the removal of these sooty wastes.[87]

In classical thinking, health and disease were the outcome of an interplay between the individual body and the environment, including the quality and conditions of the

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[85] Owsei Temkin, *The Double Face Of Janus And Other Essays In The History Of Medicine* (Baltimore: Johns Hopkins University Press, 1977), 423-424; Dorothy Porter, *Health, Civilization, and the State: A History of Public health from Ancient to Modern Times* (London ; New York: Routledge, 1999), 15; Vivian Nutton, Review of *Passions and Tempers: A History of the Humours* by Noga Arikha, *New England Journal of Medicine* 357, no. 22 (Nov 29, 2007).
[86] Nutton, *Ancient Medicine* (2004), 236
[87] Barbara Beigun Kaplan, *'Divulging of Useful Truths in Physick' The Medical Agenda of Robert Boyle* (Baltimore and London: Johns Hopkins University Press, 1993), 68; Michael Boylan, "Aristotle: Biology" *Internet Encyclopedia of Philosophy: A Peer-reviewed academic resource* http://www.iep.utm.edu/aris-bio/

surrounding air.[88] For physicians working in the Galenic tradition, health represented an equilibrium of the four humors, and conversely, an imbalance or excess of one of the four humors caused disease or a reduced state of health. Disruption of the humors could result from some change in local circumstances of air quality, food and drink, exercise, sleep, evacuations and emanations, sexual activity, and the passions of the mind, but the humoral balance was also affected by geographical location and climate.[89]

**Controlling Bodies, Not Environments**

Although the body-environment connection was essential to Greek and Roman medical thought, ancient medical practitioners focused their therapeutic energy on the individual body rather than the surrounding environment. As they saw it, endemic or epidemic diseases may share a common cause (e.g. a miasma), but a particular instance of illness is specific to an individual. Certainly, a few medical thinkers sought to explain specific mechanisms such as how air became diseased or how such air disrupted the body, but to the majority of doctors the question of why or how the air became bad was not as important as the challenge of how to reduce an individual's receptivity to a disease or increase that individual's resistance to it.[90] Knowledge of the environmental factors did not imply that Greek physicians could or should modify environmental circumstances, rather in the face of poor surrounding, an individual would take precautionary measures by

[88] "In view of the labile condition of the body, ideal health was rarely attained. But only when there was pain, and when a man was impeded in the functions of his personal and civic live, was actual disease considered to be present. There existed a borderland of relative health between perfection and actual disease" (Temkin, *The Double Face Of Janus And Other Essays*, 423-424)

[89] Golinski, *British Weather and the Climate of Enlightenment*, 140; Hannaway, "Environment and Miasmata," 293; Andrew Wear "The History of Personal Hygiene" in *Companion Encyclopedia of the History of Medicine*, W.F. Bynum and Roy Porter, eds. (London; New York: Routledge, 1993), 1283; but note that Nutton (*Galen, Problems and Prospects*, 1981, cited in Dorothy Porter, *Health, Civilization, and the State*, 16-17) differentiates between "innate constitutional" causes—such as sex, temperament, weight, age, pregnancy, sleep, awakening, ambient air-- and the 'non-natural' or optional causes, such as hot and cold baths, large meals, wine, and water.

[90] Nutton, *Ancient Medicine*, 26

changing one's lifestyle.[91] Ancient physicians and patients both saw the environment as a given, to be viewed fatalistically.[92] Indeed, even though some ancient authors both within and outside the medical discipline (e.g. Vitruvius) offered advice on the ways in which to achieve a healthy environment—by the siting of towns, the layout of streets, or the facilitation of ventilation within a house—there is no evidence this advice was followed. Rather, sanitation measures such as sewers and aqueducts were more often the result of concerns of aesthetics, prestige, and general orderliness.[93]

Responsibility for maintenance of health and the prevention of disease was thus laid squarely on the individual and, if one could afford it, one's physician. Here Galen proposed a division of labor between what he termed hygiene, "the art of staying healthy and preventing disease," and therapeutics, "the art of treating disease."[94] On the practical level, disease was present when a person was in pain, or when one was unable to perform the functions of personal and civic life. Thus there was a range of health conditions between "perfection" and actual disease.[95] On the theoretical level, the model of health as the balance of humors or elementary qualities (hot, cold, dry, wet) was fundamentally relative because the nature of that balance was peculiar to individual persons. Each person had a distinct "constitution" or "temperament," defined by the balance of one of the humors.[96]

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[91] Vivian Nutton, "Medical Thoughts on Urban Pollution" in *Death and Disease in the Ancient City*, Valerie M. Hope and Eireann Marshall, eds. (London; New York: Routledge, 2000), 55; Heikki S. Vuorinen "Ancient Greek and Roman Authors on Health and Sanitation" in *Evolution of Sanitation and Wastewater Technologies through the Centuries*, Andreas N. Angelakis and Joan B. Rose, eds. (London: IWA Publishing, 2014), 432

[92] James C. Riley, *The Eighteenth-Century Campaign to Avoid Disease*, New York: St. Martin's Press, 1987, ix.

[93] Nutton, *Ancient Medicine*, 27

[94] Wear "The History of Personal Hygiene," 1283

[95] Temkin, *The Double Face Of Janus And Other Essays*, 423-424

[96] Philip J. Van der Eijk, "Therapeutics," 298 (see Galen's *On the Preservation of Health* (San. Tu.); Robert C. Olby "Constitutional and Hereditary Disorders" in *Companion Encyclopedia of the History of Medicine*, W.F. Bynum and Roy Porter, eds. (London; New York: Routledge, 1993), 413

Some present-day authors suggest that for Greeks "health" and "hygiene" were synonymous, but this de-emphasizes the active nature of hygiene. Critical to the idea of hygiene was a person's regimen, matters of one's daily routines that today we might associate with "life-style" rather than medicine, involving choices of diet, exercise, sleeping patterns, bathing and hygiene, sexual activity, and other activities.[97] Individual diseases could be caused by an unhealthy regimen, and therapeutics often involved a physician's recommendations for a change in that regimen.[98] This change in regimen was typically preventive or corrective, for example by "making moister those conditions which are too dry, and making drier those which are too moist."[99] To create a corrective, a physician could apply a direct treatment such as bloodletting, but manipulations of diet were considered by Galen to be the most critical.[100]

These practices of hygiene remained embedded in Western medical thinking, but as we will see in later chapters, they took on greater importance as medical theory shifted toward a model of the self-healing body. In this model, "heroic" medical interventions such as bloodletting were positioned as doing more harm than good. Doctors should take a hands-off approach, and focus shifted to the surrounding environment as well as practices of diet and exercise. Control of Galen's non-naturals appeared to later thinkers as a means to manage individuals at the population level.

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97 Philip J. Van der Eijk, "Therapeutics," 298. Van der Eijk notes that there was sometimes competition between doctors and gymnastics trainers as to who was "the most competent expert to deal with" the prescription of regimens and whether health belong[ed] to the discipline of gymnastics or of medicine.
98 Jouanna, "Air, Miasma and Contagion" 128-129; Van der Eijk, "Therapeutics," 298, "Therapeia means 'care' as much as 'cure' and hence therapeutics was not concerned only with the sick body but also with the healthy body, and indeed not just with the body but also with the mind."
99 Van der Eijk, "Therapeutics," 299; Hynek Bartoš, *Philosophy and Dietetics in the Hippocratic on Regimen. A Delicate Balance of Health* (Leiden; Boston: Brill, 2015), 106
100 Nutton, *Ancient Medicine*, 240

## EARLY MODERN AIRS AND BODIES

The mid-seventeenth century work of the Royal Society and its intellectual circle embodied a growing conviction that humans might gain control over nature, that one's environment could and should be modified and managed for the purpose of reducing mortality. The method that could facilitate that control was measurement and quantification. The work of English physician and political economist William Petty was a critical source of this ideology. In the 1670s Petty undertook to study and quantifiably measure the resources of Britain, the Dutch Republic, and France in order to estimate the states' relative and potential strength. Towards this, Petty focused efforts in part on "demographic and medical matters," with the hope that he could accurately describe current mortality rates and predict future mortality and population trends.[101] Petty's encouragement was the sole inspiration for Robert Boyle's studies of air beginning in the 1660s, but working with colleagues such as Thomas Sydenham, Robert Hooke, and Christopher Wren, Boyle's thinking about air could be applied to matters of health at both the population and individual level.

### *Boyle's Redefined Air*

The very definition of air underwent a significant change beginning in the seventeenth century, as natural philosophers such as Robert Boyle (1627-1691) confined air within newly available laboratory instruments and subjected it to numerous and varied experiments, the method now so commonly known as "scientific." Within Boyle's experimental air pump (Figure 1.2), the unitary nature of Aristotelian air fragmented, as Boyle theorized new dimensions of it. Air was no longer just hot or cold, moist or dry, it had elasticity, a mechanical "spring" to it that, pointedly, could be harmed and made unfit

[101] Riley, *The Eighteenth-Century Campaign to Avoid Disease*, 5-6, 8

for respiration or combustion. Boyle's theory of air provided the foundation for many of the dominant explanations of disease transmission throughout the eighteenth century.

Although these new ideas came through the work of many investigators operating in multiple geographic and political contexts, the transformations in thought can be encapsulated in Boyle's work and publications. Boyle, the English aristocrat credited most often by historians as a founder of the Royal Society of London, was a persuasive promoter of Francis Bacon's natural philosophy and as an advocate for new trajectories in chemistry.[102] Boyle wrote extensively on many topics, but his work on the nature of air is dominant is both his experimental activity and epistemology. Boyle's motivations for the close experimental study of air and bodies were multiple, but essential was fulfilling Bacon's prescribed areas of study, and responding to practical challenges presented by the expanding industry of mining in Great Britain. Although a full discussion of Bacon's program is beyond the scope of this section, it will suffice to say that Bacon left a list of

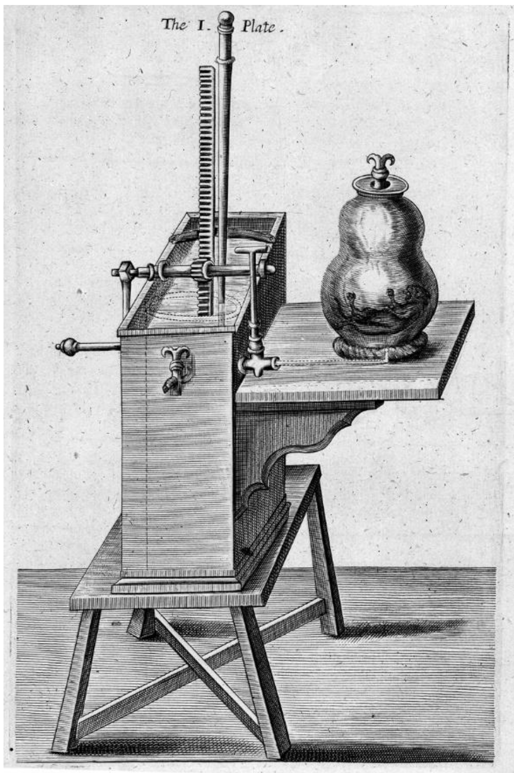


Figure 1.2 Boyle's second air pump, for experiments on the "spring and weight of air," 1669. Credit: Wellcome Collection, CC BY 4.0

[102] Common narrative often refers to the activities of Boyle and his colleagues at the Royal Society as the "scientific revolution." Although the nature of this periodization and characterization is the subject of much scholarly discussion, the primary shift in epistemology is away from the deductive logical reasoning characteristic of classical natural philosophy and toward an inductive approach based in controlled experiment. Historians of chemistry point out that Boyle's work is not a direct precursor to modern chemistry based in the idea of chemical elements but some argue that his promotion of the field as part of natural philosophy and his [advocacy] for corpuscular philosophy shifted chemistry away from the traditional practices of alchemy.

topics to pursue, two of which were a "History of Air as a whole, or in the Configuration of the World" and a "History of Humours in Man: Blood, Bile, Seed, etc."[103] Boyle's concerns in mining ranged from studies of "damps" (poisonous and explosive gases encountered underground) and their removal (essentially ventilation) to investigations of aerostatics as it applied to techniques for pumping water and lifting heavy loads out of deep mines.[104]

Boyle's theories of air were shaped by his particular "corpuscular" philosophy. This philosophy was essentially a post-Renaissance era cosmology based on a version of ancient Greek atomism. In the Greek version, proposed first by philosophers in the fifth century BC, atomism imagined the world as made up of minimal elements existing in a vacuum. These indivisible and "eternally unchanging" minimal elements combined through random chance to produce "all the different bodies in the world" and the various combinatory forms accounted for the various qualities of those "different bodies." In the fourth century BC, Aristotle debated this atomist viewpoint. Deeply concerned with matters of causes and purposes of things, Aristotle found the reliance on randomness and chance inherent in atomism an unsettling way to view the world, and claimed the theory was inadequate for really explaining anything. Instead, Aristotle's philosophy imagined a world made up of four terrestrial elements—water, earth, air, fire—occupying a plenum, not a vacuum.[105]

With the rejection of Aristotelian notions of elemental air came a need to define air more clearly in terms of corpuscular theory, especially its role in normal bodily function and disease. Up to the 1640s, natural philosophers gave air little attention. Textbooks of

103 Peter R. Anstey, "Locke, Bacon and Natural History" *Early Science and Medicine*, 7, no. 1 (2002): 73
104 Robert K. Merton "Science, Technology and Society in Seventeenth Century England" *Osiris* 4 (1938): 509-512
105 Trevor Levere, *Transforming Matter: A History of Chemistry From Alchemy to the Buckyball* (Baltimore: Johns Hopkins University Press, 2001), 15-16; Later Epicurean philosophy nonetheless embraced the atomistic view of the world as godless and governed by chance, arguing for an ethics "in which pleasure was the only good."

natural philosophy devoted very few pages to description of "air" and generally defined it in Aristotelian terms. The Aristotelians agreed that air was life-giving—no creature could survive without it—but it could have an adverse effect. Early seventeenth-century writers agreed almost unanimously with Aristotle's claim that nature abhorred a void, and thus a vacuum could not exist in nature.[106] This certainty about the nature of air was upended with the experiments of Italian mathematicians Evangelista Torricelli and Vincenzo Viviani that, contra Aristotle, demonstrated the existence of a vacuum. In response, natural philosophers concluded that air could have many "heretofore unexplained properties," particularly that it could have weight and possibly "spring."

In this context, 'air' and the 'airs' became a significant focus of investigation among natural philosophers.[107] Boyle was key among the experimentalists pursuing the questions of air, beginning with his book, *New Experiments Physico-Mechanicall, Touching the Spring of the Air, and its Effects*, first published in 1660. The text recorded a series of experiments undertaken with an improved piece of investigational equipment, the air pump. The critical function of the instrument was to carefully control the quantity of air in a small glass vessel, and Boyle's aim was "to compare the behavior of various processes both in rarified and normal air."[108]

In interpreting the results of his experiments with the air pump Boyle concluded, as many before him had, that air was in fact essential to life, but in following decades, Boyle puzzled over whether the life-giving nature of air was based in its *physical* dimensions (its effects as a whole, its ability to exert pressure, its "spring") or its *chemical* properties (the

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[106] Frank, *Harvey and the Oxford Physiologists*, 90, 115-117, "Air did have weight and substance, but only in comparison to the lighter element of fire, and the more dense and incompressible elements of water and earth."
[107] Frank, *Harvey and the Oxford Physiologists*, 115-117
[108] John B. West, "Robert Boyle's landmark book of 1660 with the first experiments on rarified air" *Journal of Applied Physiology* 98 (2205): 31–39

"virtue of its parts," namely chemical substances carried in it)."[109] Boyle's work, along with that of his colleagues and collaborators Robert Hooke, Christopher Wren, and Thomas Sydenham, applied to both the physiology of respiration and the causes of disease.

### *Boyle's Corpuscularian Bodies*

For Boyle, corpuscularian theory was a way to understand not only the relationship between the individual human body and the environment, but also the body's place within the divinely designed universe. Boyle, like Descartes, imagined the human body as a machine, but unlike Descartes, who described the body devoid of its context, Boyle asserted that the body interacted materially with its environment.[110] His definition of organic life imagined it as a particular corpuscular organization, with bestowed specific properties of motion and activity. Mechanical arrangement was key, for example, a fertilized hen's egg can form the new life of a chick simply because "there has been a transformation and reorganization of the egg-stuff into chick-stuff."[111]

Corpuscularian theory could also explain change from a healthy to a diseased state. Within the corpuscularianist view, health is a state of a particular "textural configurations" sustained a living being's function. Disease happened when something external impinged on the body and changed the motion and 'texture' of all or part of the organism. A departure from the healthy, functioning configuration equates with a diseased state. The body nonetheless had resilience in Boyle's view. A human body's "overall corpuscular texture" had an inherent elastic quality that allowed it, like a mechanical spring, to naturally regain

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[109] On Boyle's interest in both physical and chemical properties of air: Frank, *Harvey and the Oxford Physiologists*, 133; Caroline Hannaway, "Environment and Miasmata," 304; Kaplan, *'Divulging of Useful Truths in Physick'*, 68

[110] Also, for Descartes, the body was an automaton, for Boyle, the body was a 'manned boat' directed by divinely ordained human reason, which in turn made decisions to preserve life.

[111] Kaplan, *'Divulging of Useful Truths in Physick',* 62, 72, 74; Trevor Levere, *Transforming Matter*, 26.

its original healthy configuration after being altered by an external disturbance. For Boyle, this elastical quality replaced Galen's model of body-environment relationship, that of humoral equilibrium."[112]

**Internal Air: Respiration and Harvey's Physiology (Individuals)**

From his experimental investigations, Boyle concluded with confidence that air was indeed necessary for life, but he was less certain exactly how air and life intersected. A key experiment yielding critical physiological evidence was experiment forty-one, in which Boyle consecutively placed various small animals in the receiving chamber of the air pump and observed their behavior when he removed the air from the chamber. The animals would first "droop and appear sick" and then convulse and lose consciousness, but they would revive when the vacuum was released and air was returned to the chamber.[113] Similar experiments in which a candle placed in the receiving chamber extinguished soon after the air was removed suggested to Boyle that there was a "resemblance betwixt fire and life," some connection between combustion and the "vital flame."[114]

Quandaries about the role of air in supporting life had come in the years following the groundbreaking work of William Harvey, a prominent Oxford anatomist and physiologist. Harvey's work on blood circulation diverged significantly from traditional physiological models, and he suggested that the Galenic model of air as the raw material for creation of innate body heat (the "vital spirit" of animal life) was incorrect. The purpose of respiration and air as Harvey saw it was to cool the innate heat of the blood and remove its wastes. Nonetheless, at the end of his career Harvey, expressing some residual doubt about his conclusions as to respiration's cooling function, prompted his protégés and

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[112] Kaplan, *'Divulging of Useful Truths in Physick'*, 65, 74
[113] West, "Robert Boyle's landmark book of 1660," 37-38.
[114] Kaplan, *'Divulging of Useful Truths in Physick'*, 85

members of his intellectual circle (which included Boyle) to "consider a little more closely the nature of the air."[115]

Boyle took up Harvey's directive, and in a lengthy section of *New Experiments Physico-Mechanicall* he tried to reason out his ideas about air, heat, and respiration. Boyle and other Oxford-based researchers carried out further experiments and suggested that perhaps air had other qualities that supported life. One of these was qualities was chemical in nature; some element carried or contained in the air—many thought it was some nitrous substance—was the key to life.[116] Yet Boyle, who believed air's 'most genuine and distinguishing property' was not chemical but mechanical—its elasticity or 'spring'—speculated that combustion or respiration destroyed this elasticity of air and consequently made it unfit for further combustion or respiration.

Boyle's further experimental work made him doubt this mechanical explanation, but others continued similar research, and some did not lose faith. Boyle's close collaborator in the air-pump experiments, Robert Hooke, who was in fact responsible for the design and construction of the air pump, also built a human-scale version of the instrument in 1671. Hooke himself sat in what was essentially a decompression chamber and "blew out" a measured portion of the air thereby reducing the air pressure in the chamber. Hooke reported that the only effects of reduced pressure that he felt in the chamber was some pain in his ears and a temporary deafness, although a burning candle he brought into the chamber went out several minutes before Hooke felt any discomfort. Hooke believed that his experiment did not produce any conclusive results, but Hooke's

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[115] Frank, *Harvey and the Oxford Physiologists*, 2, 41-42, 115. Frank notes that in Harvey's time (early 1600s), physiology was not a well-defined field, "Few textbooks were strictly physiological. Rather explanations of function were woven into anatomical compendia and were assumed in works of disease and therapy."

[116] Frank, *Harvey and the Oxford Physiologists*, 145-146; Kaplan, *'Divulging of Useful Truths in Physick'*, 86

and Boyle's colleague John Mayow, in 1674, undertook a variation on their experiments with burning candles and concluded that air indeed lost its elasticity with combustion and that this loss was a loss of the 'force' that sustained both life and flame.[117]

**External Air: Effluvia and Sydenham's Epidemic Constitution (Populations)**

Boyle's later experimentation with animals and the air pump led him to propose a model of atmospheric air made up of various components, most importantly a compound of "perennial air" (the particles that have the quality of "spring") and "effluvia" (vapors or dry exhalations from earth, water, minerals, vegetables). Boyle's emphasis on the separability of atmospheric air into a perennial component and an effluvial component was key to Boyle's theories concerning environmental effects upon individual bodies. The effluvial components of air deserved special attention, especially from physicians, because not only were they imperceptible to humans, they could also pass directly into the human body due to their lightness and small size. This passing happened obviously through inhalation, but these effluvial elements were also able to insinuate themselves into the very pores of the body, where the larger 'springy' air corpuscles could not pass.[118] The effluvial elements had both acute and chronic effects. They could trigger epidemic disease, but they could also produce deleterious effects if a body was continually exposed to them over an extended period of time.[119]

Although the bad news was that effluvia were potentially dangerous and undetectable, the good news was that with the emerging tools of chemical analysis, various effluvial substances could be evaluated and their sources accurately located. A critical

[117] John B. West, "Robert Hooke: Early Respiratory Physiologist, Polymath, and Mechanical Genius" *Physiology* 29: 222–233, 2014 Kaplan, *'Divulging of Useful Truths in Physick'*, 90.
[118] Kaplan, *'Divulging of Useful Truths in Physick'*, 105-108
[119] Kaplan, *'Divulging of Useful Truths in Physick'*, 107

claim of Boyle's was that effluvial particles were "chemically identical to the gross bodies from which they emanated," and thus they could be qualitatively differentiated. This was a break from Aristotle, who recognized only two kinds of exhalations, terrestrial (called 'fumes') and aqueous (called 'vapors'). This categorization was too vague and simplistic to be useful for Boyle or for the physicians he thought would benefit from his analysis. Rather, with further investigation and analysis of the various effluvia, specific diseases could be linked to specific physically locatable causes.[120]

Boyle's theory of disease etiology was a complex combination of geological and meteorological action, and the sources of effluvia that Boyle thought most likely to cause disease were mineral and subterranean. Meteorological study became important when these subterranean mineral effluvia made their way to the surface because they could become toxic when combined with various corpuscles present in the aboveground air. Boyle assumed that celestial bodies were likely responsible for global meteorological phenomena, but local differences depended on an area's particular mineral effluvia. This relationship was reciprocal. Atmospheric humidity could change the characteristic motion of certain atmospheric corpuscles and thus their effectiveness, as in the case of a sudden cessation of the plague. Heat too had an effect. It could facilitate the emission of effluvia from substances that would not emit them at colder temperatures.[121]

Boyle's revision meant that the causes of epidemic disease, in this case the plague, could have a local rather than a foreign cause.[122] Diseases that had long been attributed to

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[120] Kaplan, *'Divulging of Useful Truths in Physick'*, 105-106, 111, 141

[121] Kenneth Dewhurst, "Locke's Contribution to Boyle's Researches on the Air and on Human Blood." *Notes and Records of the Royal Society of London* 17, no. 2 (1962): 198-206, 200 (see also discussion of Locke and Boyle's activities in mining and mineralogy); Hannaway, "Environment and Miasmata," 304; Kaplan, *'Divulging of Useful Truths in Physick'*, 117-119

[122] Kaplan, *'Divulging of Useful Truths in Physick'*, 112-113: "Boyle believed that his ideas of effluvial action, particularly in regard to subterraneal effluvia, offered a logical explanation for the regional outbreak and spread of plague as well as the varying severity of the epidemic between neighboring locales."

contagion—transmission of disease by an infected person or infected goods, especially at port cities—could now potentially be explained by a version of "miasmatic doctrine," although they did not call it that at the time. Boyle's ideas had resonance particularly in the work of his colleague and neighbor, physician Thomas Sydenham. In Sydenham's work a critical merging of concepts occurred, namely, he combined the miasma model and the elemental model of disease into a new theory of the "constitution" of places and diseases. Sydenham's theory, formed in the study of the several plague epidemics that occurred in London between 1661 and 1675, concluded that these epidemics broke out when an infective principle existing in the air (miasma model) was activated by particular weather conditions (elemental model), and that the transmission of disease occurred primarily through air, by inhaling "elements from the atmospheric and environmental constitution."[123] Sydenham thus united in one treatise ideas from multiple Hippocratic texts like *On Breaths*, which attributed disease transmission primarily to inhalation of the "fumes" emitted from marshes or cadavers, and *Airs, Waters, Places*, which attributed disease causation to characteristics of the seasons and the winds, namely the qualities of heat, cold, moistness, and dryness.[124]

## Reducible to Practice: Air Measured, Controlled, and Applied

Buttressed by Petty's call for quantification and Boyle and Sydenham's theories connecting disease, effluvia, and weather, members of the Royal Society, especially Christopher Wren and Robert Hooke, encouraged physicians to study the weather-sickness relationship. To facilitate this, Wren and Hooke developed a series of new instruments and

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123 Dewhurst, "Locke's Contribution to Boyle's Researches," 200; quoted text is from Riley, *The Eighteenth-Century Campaign to Avoid Disease*, 11-12

124 Jouanna, "Air, Miasma and Contagion," 128-129

tools that supported this distinctly quantitative investigation of weather.[125] Wren himself developed instruments such as a self-emptying rain gauge, an automatic wind recorder, and a self-registering thermometer. Hooke, curator of experiments at the Royal Society and an esteemed instrument maker, developed a barometer and a hygroscope.[126] This group at the Royal Society, later including John Locke, encouraged their fellow countrymen throughout the 1660s to acquire their new instruments and gather meteorological data from various geographical locations, with the goal of understanding broader weather patterns.[127]

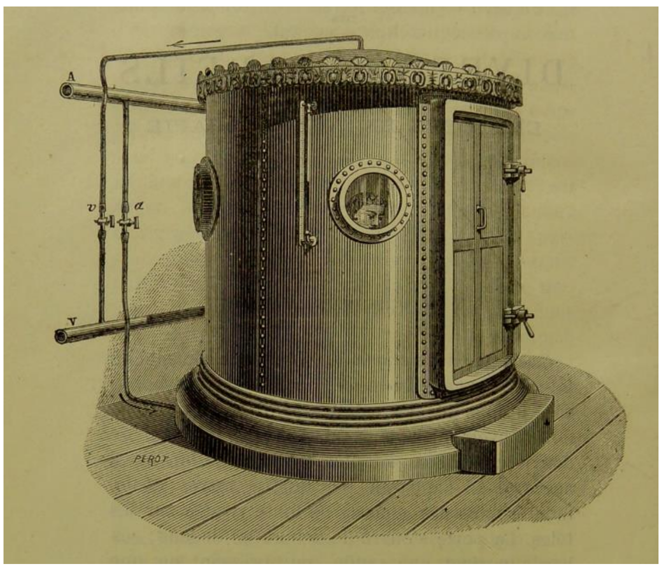

Figure 1.3 Compressed air chamber, Éstablissement d'aérothérapie of Dr. Fontaine, Paris. Therapeutic treatments with compressed air became popular in the nineteenth century. Image from J. A. Fontaine, *Effets Physiologiques et Applications Thérapeutique*

Boyle's experiments investigating the nature and characteristics of air led others not only to study air, but to apply Boyle's principles directly to human bodies. Nathaniel Henshaw, an English physician and an associate of both Boyle, proposed in his 1664 treatise *Aero-chalinos* (air chamber) how one might build an "air chamber" within one's house, in which a patient would be treated by increasing or decreasing the ambient air pressure in ways "conducive to longevity and good health" (Figure 1.3). Henshaw's proposed chamber was similar in theory to Hooke's

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[125] Conevery Bolton Valenčius, "Histories of medical geography" *Medical history*, Supplement, 20 (2000): (3-28) 12; Riley, *The Eighteenth-Century Campaign to Avoid Disease*, 7

[126] Dewhurst, "Locke's Contribution to Boyle's Researches," 198-206; J.A Bennett, *The Mathematical Science of Christopher Wren* (Cambridge: Cambridge University Press, 1982), 79.

[127] Hannaway, "Environment and Miasmata," 298

experimental decompression chamber, but where Hooke's machines was "death-dealing," Henshaw saw his as "life-giving." Henshaw's scheme was based on a variation of Boyle's theory of air's elasticity; air's "spring," could affect the quality of respiration. Henshaw was adamant that theory was meant to be directly applied. As he put it in his text, "because contemplations of this kind, are, in their own Nature, very unprofitable, if not *reducible to practice*: 'I have, as well as I could, applied the same to the cure and prevention of most diseases.'"[128]

Perhaps a better known application of new theories of air and respiration is Christopher Wren's ventilation scheme for the House of Commons. Wren, as Surveyor of the King's Works, was responsible for maintenance and alterations all of the Crown's buildings, including the remodeling between 1692 and 1707 of the meeting place of the House of Commons, which before the fire 1834 was in a former chapel of St. Stephen's at Westminster Palace. Begun as an inspection of the chapel's crumbling roof, the remodeling project expanded to include the removal of the medieval clerestory, replacement of the roof, installation of a new ceiling to obscure the church vaulting, and "making the chamber more comfortable," which together essentially rationalized the medieval buildings of the Palace.[129]

Wren's scheme to make the chamber more comfortable consisted of modifications to this new ceiling, but it unclear whether they were intended to address temperature or ventilation.[130] Later commentators such as J.T. Desaguliers described it as the latter, "At

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128 Henshaw quoted in Mark Jenner, "The Politics of London Air John Evelyn's Fumifugium and the Restoration" *The Historical Journal*, 38, no. 3 (Sep 1995): 546 emphasis added; Frank, *Harvey and the Oxford Physiologists*, 156-157

129 "The House of Commons Remodelled, 1692-1707: The Role of Sir Christopher Wren" https://www.virtualststephens.org.uk/sites/virtualststephens.org.uk/files/panoramas/1707/tour.html; "The House of Commons Remodelled, 1692-1707" https://www.virtualststephens.org.uk/explore/section4

130 Email communication with the Commons project indicated that no records currently known that describe the purpose of Wren's system in the time of Wren.

each Corner of the House in the Cieling (sic) there is a Hole which was the Bottom of a truncated Pyramid going up six or eight Feet into the Room over the House" (Figure 1.4). In Desaguliers's view these modifications were set up by Wren, to "let the Air (made foul by the Breath of so many People, and the Steam of the Candles when used there) go out."[131] However, Wren had worked on other projects to make the chamber more temperate. In 1693, a committee of Members of Parliament asked Wren to exclude the cold air that would often rush into the chamber through large windows at the end of the debating chamber. Wren ordered double sashing and double glazing of these windows.[132] However, when as part of the larger remodeling project, the height of the ceiling was lowered from 45 feet to 30 feet, complaints were of heat rather than cold, at least on crowded occasions.[133]

Figure 1.4 House of Commons showing Wren's ventilating system, c. 1709. The two dark rectangles at the rear of the ceiling appear to be the openings to which Desaguliers refers. Painting by Peter Tillemans, *The House of Commons in Session* © Parliamentary Art Collection, www.parliament.uk/art

Wren's system was ultimately deemed ineffective, but his and his colleagues' theories, practices, and ideologies of airs, bodies, and building technologies persisted

[131] J. T. Desaguliers, *A Course of experimental philosophy* Vol. 2 (London: printed for W. Innys, 1744), 560; Among others, those who repeat Desaguliers's description are Bernan, 1845; Wyman, 1846; Tomlinson, 1850, 1864; and Edwards, 1868.
[132] Bryan D. G. Little, *Sir Christopher Wren: A historical biography* (London: Hale, 1975), 178-179
[133] Peter David Garner Thomas, *The House of Commons in the eighteenth century* (Oxford: Clarendon Press, 1971), 2

through the following centuries.[134] They established methods by which air could be studied and used to address matters of health at the level of the body and the level of the population. They made biopower a possibility, but not a reality, for these ideas were not applied to indoor or confined spaces on a large scale. This changed in the eighteenth century, when Stephen Hales, John Pringle, Joseph Priestley, and Antoine Lavoisier, and others interrogated air's properties and its function within human physiology. From the laboratory, they suggested new uses for air to prevent the morbidity and increase the productivity of large populations, first in the changing British military and then among the growing factory workforce.

[134] D. Hayton, E. Cruickshanks, and S. Handley, eds. *The History of Parliament: the House of Commons 1690-1715* (Cambridge; New York: Cambridge University Press, 2002), 343

# Chapter 2. Close Places and Enlightened Air

## CLOSE PLACES: DISEASE AND MOVING AIR IN THE EIGHTEENTH CENTURY

In September 1740, the English clergyman Stephen Hales wrote to the physician reporting to Major General Lord Cathcart, who was facing a serious outbreak of "ship fever" among his soldiers, with advice on how to make the air of Cathcart's assigned ships more wholesome.[1] Hales's counsel did not entail anything out of the ordinary. He suggested only a small variation on the typical practice of sprinkling vinegar between decks of the ship: one could hang cloths soaked in vinegar between decks to prolong the effect. If an "infectious distemper" did break out, Hales recommended a cure to the infection by fumigation with burning brimstone, a custom that had long been used to contend with epidemic disease. But Cathcart's problem stayed in Hales's mind for many months, and in the following March it occurred to him that "large ventilators would be very serviceable, in making the air in ships more wholesome."[2] By May, Hales had written up an account of the idea, distributed it to "many persons of distinction," and presented his ideas to the members of the Royal Society, of which Hales was an active member.

Conventional technological histories often cite Hales as the father of modern space conditioning or point to these ventilators proposed by Hales as evidence of a natural and perhaps inevitable desire for ventilation. Yet even if they mention the particular setting for Hales's technological recommendation, they typically omit any discussion of the prevailing scientific and medical ideologies and the particular political and administrative circumstances that made Hales's suggestion seem at all reasonable as a medical

[1] Because of a shortage of able sailors, soldiers from the army were being deployed on ships.
[2] Stephen Hales, *A Description of Ventilators: Whereby Great Quantities of Fresh Air May with Ease be Conveyed into Mines, Gaols, Hospitals, Work-Houses and Ships in Exchange for their Noxious Air*, (London: W. Innys, 1743), ix-x

proposition—he was after all not a physician—and that made a large and complex organization such as the mid-eighteenth-century British Royal Navy seriously consider implementing it, which after some deliberation they did.

New forms of governmental administration emerged in the eighteenth century by nature were concerned not with the traditional focus of medical theory—the bodies of affluent individuals—but rather with the general health of large, relatively impoverished populations. A good deal of this arose in growing urban centers, but much of it was codified in the management of expanding military's personnel. The chosen strategy of these administrative bodies was prevention rather than treatment, for as they argued, it was cheaper to avoid disease than to cure it. Essential to this approach were theories of air, but not only the open, atmospheric air that had defined prior theories, but the cloistered and confined air that characterized the spaces these groups managed, the ships, prisons, and hospitals of an expanding empire.

Acute instances of epidemic disease such as the plague and "fever" concerned these administrators, but because their aims (a strong standing military, a robust and competitive nation) extended beyond the end of any specific instance of epidemic disease, they looked to theories that could address health maintenance and improvement in the long term. For this, they turned to the persistent and most frequent killer of civilian populations, consumption. This concern became particularly critical at the end of the century, when those in power began to recognize that those who were most often the victims of this affliction (the poor) could also potentially rise in revolt.

The technologies and practices requisitioned for this new approach to medicine were not innovations. The apparatuses and techniques typically already existed, most often in mining practice, where the spaces were exceedingly confined and the air indeed quite dangerous. Mine shafts accommodated only minimal dimensions for bodies and infrastructure, and various airs or “damps” were known by tragic experience to explode or suffocate miners. Although information about mining ventilation technology was known to eighteenth-century medical thinkers, they did not adopt it directly from such sources.[3]

Following the modes of technological adoption in the eighteenth century can provide insight into the complicated relationships between private and national interests in a particular location. In the case of the ventilators proposed by Hales to Lord Cathcart, the military administrators may have been among the first to test and consider their broad adoption, but they were testing it at the urging of Parliamentary officials, who had installed a mechanical ventilation device just a few years prior. The military architects were often conservative, however, and it was merchants and slave traders who adopted Hales’s ventilators first. The army and navy eventually adopted the idea, given the testimony of so many in private trade. Positive promotion by military experts, however, in turn fed back into decisions by public and private charitable organizations to adopt particular disease theories and prevention practices in their programs addressing the parish poor and eventually factory workers. This overlapped with efforts by manufacturers of new heating and ventilation systems in the 1780s to position their technologies as particularly beneficial to health.[4]

While Hales’s technological system is fairly familiar to present-day readers, the scientific reasoning he used to justify it likely is not. Although there have been historiographical shifts in the past few decades, many twentieth-century historians of medicine tended to dismiss medical theory from pre-germ eras as a uniform, undifferentiated block. This was often tinged with pity—how sad that they could not know

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[3] For example, through Agricola’s *De Re Metallica* (1556).

[4] For example, Boulton and Watt promoted steam heating in factories that already had one of their steam engines to power machinery; Strutt provided his warm-air heating system for the Derbyshire hospital.

what we now know—but attention to their specific reasoning and implementation can tell us something about how and why particular technologies were applied to them. This is critical, because many of these practices and apparatuses persisted beyond the useful life of the theories that motivated their original adoption.

Certainly, many aspects of ancient and early modern theories of air and medicine persisted, but the role of air in medicine and society changed meaningfully in the eighteenth century. While it may seem arcane to follow air so far back in time, I found it critical to understand at least provisionally why air-moving practices and technologies achieved and maintained such prominence in the nineteenth century, and why even with major changes in scientific and medical theory these ideas and habits persisted. There are many parallel stories to be told, but the one I find most convincing in terms of the large-scale material and ideological investment in air hinges on the year 1739, when British medical theory met British military administration at the beginning of a naval war of choice. In turn, this manifestation of air-medicine theory had been shaped by events also contingent on British merchant maritime expansion in the 1720s, news that an outbreak of the plague was visiting a French sea port and, separately, the imprisonment of numerous formerly wealthy debtors ruined by the South Sea bubble. A particular interpretation of an event in Calcutta in 1754, known as the "Black Hole" incident, gave rhetorical power to an aerial explanation of sudden acute death, and John Pringle's widely published military hygiene manual made this aerial theory official. With the endorsement of Pringle, the Enlightenment ontologies of Joseph Priestley and his fellow Dissenters pushed ventilation ideologies into the civilian sector, where air became morally instrumental and economically productive. The revolutions in France at the end of the century refocused French chemist Antoine Lavoisier's models of aerial physiology on understanding the vital relationship of air and food to heat and work, the "animal economy" as many called it.

This chapter explores the confined air of an expanding empire. As the flows of people and goods swelled in the eighteenth century, commercial interests, administrators, physicians, and scientists grappled with what seemed to be new types of diseases, many of which they attributed to a British person's exposure to unpredictable climates and geographies. Certainly, theories drawn from colonial experience wove into theories of medicine in the home country, but writers at the time often differentiated between diseases common to "tropical" climates (or a change thereto) and those encountered in the climate of one's birth.[5] However, I want to be clear that although the ideologies of "tropical disease" are equally critical and complicated, in this dissertation I am discussing what individuals at the time generally considered matters of the "home country," the diseases of *confinement* rather than those of exposure.

**Of Plagues and Plants: Newtonian Theories of Life and Death**

Despite variation in their subjects of study, both university-trained physicians and natural philosophers were influenced by overarching ideologies of scientific inquiry. In studies of airs and bodies, the beginning of the eighteenth century saw a clear Newtonian influence, with its emphasis on quantified mathematical precision and an optimism that experimental investigation would result in the establishment of a few, overarching natural laws by which all other phenomena could be explained. These were heady times. Those working in Newton's wake hoped to find the physiological equivalent to the law of gravity. By mid-century many had rejected the Newtonian approach as too rigid or perhaps not applicable to something as complex as human life (for example, Richard Mead), and

[5] Suman Seth, *Difference and Disease Medicine, Race, and the Eighteenth-Century British Empire* (Cambridge: Cambridge University Press, 2018).

adopted a more open-ended experimental method.[6] This too had its faults. The tentative theories drawn from a small run of experiments were often extrapolated to broad medical certainties (as with Lavoisier's work), which in turn became embedded in the material world. The drift away from Newtonian theory also encouraged a shift from mechanical to chemical models of the world and by extension models of the human body and mechanisms of disease.

James Riley argues that one of the ideas that characterized the dominant eighteenth-century "public health" movement was that air itself became the cause of disease rather than simply its vehicle. Riley points to the 1733 medical text of physician and mathematician John Arbuthnot (1667-1735), *An Essay Concerning the Effects of Air on Human Bodies* as the critical document representing a shift in which air became central to disease theory rather than peripheral.[7] Conversely, Vladimir Janković argues that Arbuthnot's *Effects of Air*, in the context of its 1731 companion *An Essay Concerning the Nature of Aliments* represents a shift toward an active private regimen, and that Arbuthnot advocated a turn from the unique and rare to the common and mundane. His ideal medical practice devoted its energies to deterring mundane risks, not to curing their effects.[8] This seems like a contradiction. How could Arbuthnot's theory turn outward as preventive public health, but at the same time inward as preemptive private fitness?

Part of the reason for this dual identity is that such theories of air came from the laboratory as well as from more traditional modes of medical practice such as clinical observation and treatment. Arbuthnot says as much. His primary concern in his essay is that the science of air and the "physiology of its effects" receive more thorough

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[6] Theodore M. Brown "From Mechanism to Vitalism in Eighteenth-Century English Physiology" *Journal of the History of Biology*, Vol. 7, No. 2 (Autumn, 1974): 179-216, passim
[7] Riley, *The Eighteenth-Century Campaign*, 9-10, 19
[8] Vladimir Jankovic, *Confronting the Climate: British Airs and the Making of Environmental Medicine* (New York: Palgrave Macmillan, 2010), 21

consideration from physicians than it had received in the past. Physicians had fallen behind "philosophers, mathematicians, chymists [chemists], [and] professors of agriculture and gardening" in the study of air, and they were the worse for it. Giving some credit to the physicians, Arbuthnot reasoned that perhaps physicians considered the study of air futile because air, although it was recognized as significant in traditional medicine, was both unavoidable and not amenable to being measured in doses. How could it be, Arbuthnot reasoned, that there were copious studies of various drugs, "which we take but seldom." but so few about the "effects of a substance that we take inwardly at every moment." This was especially perplexing because Hippocrates, the "first founder of our art," had recognized air as the "mysterious something of epidemical causation."[9]

Although Arbuthnot praised the few physicians who had followed Hippocrates' counsel to study the connection between seasons and "changes in human bodies," and expressed hope that if the recording of season-bodily change connection continued, it could one day "reduce the physiology of the air to a science."[10] Yet the body of Arbuthnot's text does not follow the same trajectory as those of other weather-disease recorders of the period. Rather, the content of Arbuthnot's book builds on theories derived from experimental activities, primarily those of Stephen Hales, and to a lesser extent those of Robert Boyle and Dutch medical professor Hermann Boerhaave.

While Arbuthnot's book was widely read, it did not suggest a particular technological approach. This section thus explores how ideas and theories established in

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[9] John Arbuthnot, *An Essay Concerning the Effects of Air on Human Bodies* (London: Printed for J. Tonson, 1733), vi-vii; Arbuthnot uses a Greek term for Hippocrates's definition of air. Charles Creighton in *A History of Epidemics in Britain*, Volume 2, (1894) p 403 translates the Greek term as the "quid divinum or mysterious something of epidemical causation"

[10] Arbuthnot, *An Essay Concerning the Effects of Air*, vii-ix. The physicians that Arbuthnot praises are Sydenham, some physicians in Italy, Germany, and Edinburgh who have imitated Sydenham, and Clifton Winteringham, whose book recording seasons and disease in York from 1715-1725 had just come to the attention of Arbuthnot.

the laboratory made their way into the material world, and specifically how ideas about bodies and air translated into material practices and technologies at a large scale. The key figures that guided this process were all defined by their dedicated Newtonism, in particular the socially prominent physician, Richard Mead, the clergyman, scientist, and reformer Stephen Hales, and the physicist and engineer John Theophilus Desaguliers. The ideas and techniques predicated by these three actors received broad promotion in the widely published guide of military physician John Pringle (1707-1782), who was essential in defining military medicine for the British nation, and who later as the president of the Royal Society of London, promoted the work of Joseph Priestley, the philosopher of airs and society described in the following section. Although there were certainly other significant characters in this drama of air in the early eighteenth century, focus on these four actors allows a clearer delineation of changes in ideas about nature of the air, the prevailing physiological model of the body, then in flux between a Newtonian mechanical model and a vitalist model, and the needs of commercial and state interests.

### *Against "shutting up": Richard Mead's Disease Theory of Confined Air*

In 1720, Dr. Richard Mead asserted, contrary to both custom and law, that it was wrong to keep houses closed up during an outbreak of plague. This was not the primary point of Mead's 1720 *A Short Discourse Concerning Pestilential Contagion and the Methods to be used to Prevent it*, but the theory of disease transmission he built around it had implications for ideologies of air and air-moving technologies for several future generations. Highly detested orders in place in England since the sixteenth century directed the "shutting up" of houses of those exposed to a spreading plague. What made the order so controversial was that the Privy Council order required both sick *and* well household members to remain isolated indoors with windows and doors shut for forty days. Against this, Mead argued that such spatial confinement of air was in fact a critical element contributing to the lethal strength of the disease.[11] Most historians of medicine (both Whiggish and otherwise) recognize Mead for proposing a contagion theory in a time when the concept was unpopular, but Mead's propositions, in concert with the experimental work on air carried out by Stephen Hales in the following years, had perhaps a longer-lasting influence on spatial practices for managing airs and bodies.

Mead's discourse on the plague was one among many written during a severe plague epidemic that struck Marseilles beginning in 1719 (Figure 2.1), but Mead's was the official comment commissioned by the king's representatives. That the king turned to Mead for an opinion on what should be done to avoid or manage an outbreak of the plague in Britain is not surprising. He was a learned physician, having first studied botany and "physick" at the University in Leyden under Archibald Pitcairn (1652-1713), who proselytized a distinctly Newtonian "mathematical physick," and then receiving a Doctor of Philosophy and Physick degree at Padua in 1695, and an established practitioner.[12] He had been a medical consultant to the royal family for some years, having inherited the active practice of King William III's personal physician,

Figure 2.1 View of Marseilles at the time of the plague, 1720. Etching by M. Serre. Credit: Wellcome Collection, CC BY 4.0

[11] Charles F. Mullett, *The Bubonic Plague and England: An Essay in the History of Preventive Medicine* (Lexington: University of Kentucky Press, 1956), 44; Margaret DeLacy, *The Germ of an Idea: Contagionism, Religion, and Society in Britain, 1660-1730* (New York: Palgrave Macmillan, 2016), 153

[12] Theodore M Brown, "Pitcairn, Archibald," *Complete Dictionary of Scientific Biography*, vol. 11. Charles Scribner's Sons, 2008. Gale Virtual Reference Library, 2

and he enjoyed much institutional recognition, with status as a fellow in both the College of Physicians and the Royal Society.[13]

Mead summed up his plague theory in the 1720 discourse concisely. As Mead saw it, a contagion (in this case the plague) was "propagated by three causes, the air, Diseased Persons and Goods transported from infected Places, and thus advised a new rule for the quarantine of goods and people coming from plague-afflicted places.[14] Much has been made by medical historians of this quarantine order and Mead's seeming endorsement of "contagionism," but his theory of air and its spatial implications have not been fully explored.[15] Certainly, in the cause of promoting the controversial idea of a contagious element, Mead himself downplayed the role of the air and its "disposition" to promote disease.[16] Indeed, Mead argued that the air in and of itself was not the immediate cause of the disease, but nonetheless a "corrupted State of Air is without doubt necessary to give these Contagious Atoms their full Force." The evidence for this came from an exercise in logical reasoning. If it wasn't in the air, how could one explain the eventual cessation of the plague, once it had broken out, without the death of every single inhabitant? Mead was

[13] C.-E.A. Winslow, "A Physician of Two Centuries Ago: Richard Mead and His Contributions to Epidemiology," *Bulletin of the Institute of the History of Medicine* 3, no. 7 (Jul 1935): 511; DeLacy, *Germ of an Idea*, 154

[14] Richard Mead, *A Short Discourse Concerning Pestilential Contagion, and the Methods to be used to Prevent It* (London: Sam. Buckley, 1720), 3, 10. These were often the places from which England imported cotton and other "spongy substances" such as silk. Mead blamed these substances, both in bulk and as clothing, particularly for plague transmission of contagion. By "Orientalist" I mean carrying out the ideological practice per Edward Said in *Orientalism* (1978).

[15] Historiographical note: Mead is often invoked by historians specifically as an early proponent of contagionism, sometimes in the context of modern germ theory (Winslow) but also more recent historians of medicine trying to understand the historical concept of contagion without the Whiggish intent (DeLacy). That said, the practice of ventilation is most often associated with the "anti-contagionist" movement of the early nineteenth century, as described in the heavily cited 1948 article by Erwin Ackerknecht ("Anti-contagionism between 1821 and 1867"). In Ackerknecht's interpretation, the contagionists want to continue quarantine practices, while the anti-contagionists—also called the sanitarians—want to locate disease locally and clean/ventilate the urban environment.

[16] Richard Mead, *A Discourse on the Plague* 9th ed. (London: A. Millar, 1744), 42

certain that the plague abated with an "Emendation of the Qualities of the Air, and the restoring of it to a healthy State capable of dissipating and suppressing the Malignity."[17]

Mead's theory of air's role in plague was a variation on Hippocratic theory, but it was highly localized and critically dependent on a spatial confinement of air. He argues that all the "shutting up" practices resulted in is a yet more concentrated pestilential poison that, upon re-opening of the windows, would like Pandora's box just spread the disease and then some.[18] Mead's proposition was a subtle shift, but one that was deeply informed by the "shutting up" practices maintained in England at the time. This can be surmised from the lengthy discussion of this issue Mead undertakes his discourse. He describes the practice as lacking all compassion. Upon the discovery of plague infection at any house, the magistrate required the house to be "shut up, with a large red cross, and *Lord have mercy upon us* on the door; and watchmen attending day and night to prevent any one's going in or out."[19]

This was an unreasonable burden to the family confined to the house, and in an appeal to empathy, Mead was likely influenced by the earlier plague experience and clerical status of his father. Matthew Mead was a nonconformist (Puritan) minister who was forced out of the country several times in the Church of England's efforts to maintain uniformity and conformity among its clergy. In 1665, the elder Mead had stayed in London during the plague outbreak of that year, and in a 1666 treatise *Solomon's Prescription for the Removal of Pestilence* criticized conformist ministers' heartless habit of abandoning the sick and needy during a plague. Part of a larger campaign among non-conformist ministers, Mead argued that the truly compassionate stayed in town. In the younger Mead's

[17] Mead, *A Short Discourse* (1720), 13-14
[18] Mead, *A Short Discourse* (1720), 34-35
[19] Mead, *A Short Discourse* (1720), 31

proposition was a way to make that easier.[20] Instead of "imprisonment" in their own homes, Mead recommended removing both the sick and the well from an afflicted house and taking them to separate "clean and airy" locations specifically designated for this purpose. The well would then be allowed to return to their house after only a short removal. In a revised 1744 edition of the *Discourse on Plague*, Mead discussed alternatives to "shutting up" much more extensively, but noted sustained resistance to such a measure.[21]

Mead only hints at a theory of confined air and disease in the 1720s, but by the 1740s it is well developed. In a communication to the Royal Society in 1742, Mead reasoned that because the air's "elasticity or springiness" is what made it "so useful to our life," that "when any part of it is enclosed…it expands itself, and, *in proportion to the closeness of the place*, loses its spring; and if any heat or moisture comes to it, the elastic force may be quite lost and destroyed." This situation could be fatal in the long run, but if the air "happens to be impregnated with noxious effluvia, either from unwholesome substances…or from the infectious breath of diseased bodies, it will become quite poisonous and deadly."[22] The refinement of Mead's theory resulted not only from his own theoretical reasoning or clinical experience, but from his interaction with natural philosophers and their experimental work in regular society and at the Royal Society. In

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[20] Patrick Wallis "Plagues, Morality and the Place of Medicine in Early Modern England" *The English Historical Review*, 121, no. 490 (Feb, 2006): 15

[21] A parliamentary measure to instate Mead's recommendations had been passed in December of 1720, but it had soon been repealed. As Mead explains it, parliamentarians opposed to the court (meaning the king), objected that "the Ministry were not to be intrusted with such powers," for they were prone to abuse them, choosing to "either remove or confine Persons not favoured by the Government, on Pretence that their Houses were infected." Mead, *A Discourse on the Plague* (1744), xxxvi

[22] Italics added, Richard Mead, "An Account of Mr. Sutton's Invention and Method of Changing the Air in the Hold and other close parts of a ship" (Read to Royal Society on Feb 11, 1741/2) *Philosophical Transactions* 42, no. 462 (1744): 42-45. Also quoted in Allan and Schofield, *Stephen Hales, Scientist and Philanthropist*, 87-88, who believe that Mead's "explanation of the effect of air in disease clearly derives from the work of Hales."

particular, the experimental work and reasoning of the Stephen Hales, allowed Mead to imagine and describe a specific mechanism underlying his medical theory.

Mead's embrace of Hales's science was part and parcel of his enthusiasm for a new Newtonian medicine. In an early work, Mead expressed aspiration for an improved medicine, one that introduced "Mathematical Studies, that is, Demonstration and Truth, into the Practice of Physick." Mead thought this type of reformation critical, for "all other Methods of Improving Medicine have bin found Ineffectual, by the Stand It has bin at these Three or Four thousand years." The purpose of the reformation follows the Newtonian intent to replace Cartesian mechanical philosophy with the discovery and establishment of a deep and meaningful order of natural laws. As Mead argues "the Animal Compages is not an irregular Mass, and disorderly jumble of atoms, but the Contrivance of Infinite wisdom, and Masterpeice of that Creating Power, who has bin pleased to do all Things by Established Laws."[23] Mead's Newtonian *bona fides* must have been convincing. On the basis of this research and publication, Mead was admitted as a fellow of the Royal Society, then presided over by Newton himself, and later became Newton's personal physician. The general enthusiasm for Newton's mathematical approach to medicine eventually wore thin, especially after Newton's death in 1727, but in the intervening years, when Mead was developing his medical theory of confined air, it seemed as if it could provide some real answers.

### ***Newtonian Physiology: Stephen Hales's Bodily Airs***

In formulating the broad outlines of his scheme, Mead followed logical reasoning and a loose epidemiological method typical of physicians of the time, observing patterns of who does and does not die. In contrast, the clergyman Stephen Hales, devised specific

[23] Richard Mead, *A Mechanical Account of Poisons in Several Essays*, 1702, preface (pages unnumbered)

experimental apparatus and procedures to study air and performed experiments on animal subjects using (controversially) vivisection techniques.[24] Yet Hales's science did not remain secluded in his home laboratory. Rather through his connections in the Royal Society, particularly its experiment demonstrator John T. Desaguliers, his involvement as a founding member of the Georgia Trust and the Society for the Encouragement of Arts, Manufactures and Commerce, he promoted his science to utilitarian ends.[25] Knowledge of his physiological and chemical studies traveled far in place and time through his publications *Vegetable Staticks* (1727) and *Haemastaticks* (1733) informed his mechanical proposals in *A Description of Ventilators* (1743) and *A Treatise on Ventilators* (1758).

Even at the outset Hales's research was aimed toward enhancing the productivity of living things. At first this applied to English agriculture, where methods of agricultural intensification were of keen interest in a time of land enclosures. Indeed, Hales's first book, *Vegetable Staticks,* was contributing to a larger debate within this context about soil fertility within England. Hales experimental approach in this area was novel in that it focused less on the anatomy and structure of plants than on their physiology, particularly the agents (water, soils and air) that encouraged root growth and sap production. His first purpose was to offer practical guidance to husbandmen in matching plants to soils and

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[24] Hales was of the same generation as Mead, and although the two men were ostensibly rivals in the technological application of confined air theory, Mead would have been familiar with Hales's work, if not through presentations at the Royal Society, then through John Arbuthnot, who was a close associate of Mead's.

[25] The Georgia Trust is the organization that established the American colony of Georgia. Hales was a founding member of Society for the Encouragement of Arts, Manufactures and Commerce, established in 1754. The Society of Arts, as it was later called, issued premiums for inventions and ideas the Society thought beneficial for economic development. The society divided their eighteenth-century premiums into six categories: "agriculture," "chemistry," "colonies and trade," "manufactures," "mechanics," and "polite arts." D. G. C. Allan, "The Society of Arts and Government, 1754-1800: Public Encouragement of Arts, Manufactures, and Commerce in Eighteenth-Century England," *Eighteenth-Century Studies*, 7, no. 4 (Summer 1974): 434-452, list on 435.

improving soil productivity.[26] Hales eventually extended this physiological approach to human bodies, and while it was not his noted intent to increase the individual productivity of people, his laboratory methods focused on individual bodies and systems yielded theory that he thought could apply to the maintenance of large populations of humans.

Under Newton's philosophical influence, Hales's science was premised on the minute and quantitative measurement of living processes. Hales had been deeply influenced by Newtonian mechanical philosophy during his education at Cambridge, and this inspiration was multi-dimensional.[27] At the largest scale, Hales admired the profound potential in Newton's mathematical approach. Newton had arrived at his magisterial conclusions about planetary movement through careful measurement and calculation, giving hope to his followers that this method could result in other such breakthroughs. This method indeed aligned with Hales's theology. As he put it, "the all wise Creator has observed the most exact proportions, of number, weight and measure, in the make of all things," and thus "the most likely way therefore, to get any insight into the nature of those parts of the creation, which come within our observation, must in all reason be to number, weigh and measure."[28] For Hales, Newton's mechanistic world view was reassuring in that it imagined the living organism as a "self-regulating machine," a clear sign of the benevolence of the Divine Architect "in framing for us so beautiful and well-regulated a world."[29]

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[26] Peter M. Jones, "Making Chemistry the 'Science' of Agriculture, c. 1760-1840," *History of Science* 54, no. 2 (2016): 179.
[27] D. G. C. Allan and Robert E. Schofield, *Stephen Hales, Scientist and Philanthropist* (London: Scolar Press, 1980), 11
[28] Stephen Hales, *Vegetable Staticks or an Account of Some Statical Experiments on the Sap in Vegetables* (London: W. and J. Innys, 1727), 1.
[29] Henry Guerlac, "Hales, Stephen," *Complete Dictionary of Scientific Biography*, vol. 6, (Charles Scribner's Sons, 2008), 43. First quote is Guerlac, second is Hales quote from *Vegetable Staticks* (1727), Dedication to Prince of Wales, A3-4.

At the smaller scale, Hales absorbed Newton's version of corpuscular theory.[30] Like Boyle's corpuscular theory, Newton's philosophy posited that all matter consisted of small, indivisible particles that could combine into more complex aggregations, but where Boyle explained change in terms of the shape, size, motion, and arrangement of atoms, Newton emphasized the "powers of attraction and repulsion."[31] This perspective resonates in many of Hales's explanations of plant and human physiology. Substances affected human bodies and the qualities of air through their attractive and repulsive properties.

For Hales, the physiological model was similar to the Newtonian-inspired one imagined by Archibald Pitcairn, Richard Mead's former instructor. Hales's exposure to Pitcairn's physiological theories as well as Newton's philosophy came through the anatomist and physiologist James Keill, who was a lecturer at Cambridge during Hales's time and an author of several well-known publications on anatomy and physiology. With Newton's influence, Keill's medical outlook as 'iatro-physical' or 'iatro-mechanical' and part of a particularly British 'iatro-hydrodynamicist' school of thought.[32] This group, including Keill, imagined the human body as consisting of a mix of solids and fluids, with particular focus on the tubes and vessels that transported blood and other fluids within the body. They explained physiological function and dysfunction primarily by the movement and qualities of body fluids, especially changes in "quantity, texture or velocity of motion" of those fluids. For example, in this view body heat was thought to arise from friction between blood particles in circulation. Fevers occurred when the blood became viscous as a result of some kind of hindrance to its motion. At the systems level, this point of view was concerned especially with issues such as blood pressure, velocity of the blood in

[30] Allan and Schofield, *Stephen Hales*, 11.
[31] Trevor Levere, *Transforming Matter: A History of Chemistry From Alchemy to the Buckyball* (Baltimore: Johns Hopkins University Press, 2001), 28; Allan and Schofield, *Stephen Hales*,15
[32] The prefix 'iatro' meaning medical.

various parts of the body (e.g. in arteries versus capillaries), the strength and elasticity of various blood vessels, and various other pressures and movements within the body. At the corpuscular level, the mechanical interactions (attraction and repulsion) of blood and air were of particular interest.[33]

Three key dimensions of Hales's experimental work are essential to understanding how his results translated into medical theory and technological practice. For one, Hales's statical model of the human body saw bodily processes as continuously in motion and communication with the surrounding environment; the air must be changed and replenished in order to prevent "stagnation" and disease. Additionally, Hales's work extended the potential sources of bad air from Boyle's effluvia from deep inside the earth to aboveground sources and to living human bodies and human exhalations. Although there was a long tradition that assumed noxious fumes from dead bodies, Hales's propositions seem to be the first time that live bodies, healthy or unhealthy, were assumed affect the air.[34] Finally, his rebreathing experiments made a quantitative case for the danger of confined spaces.

Hales emphasized a model of the relationship between body and environment as coupled, sometimes called the "animal economy" or a statical approach to physiological function. This method, previously articulated by Paduan physician Santorio Santori  in his 1614 text *Ars de statica medicina* (On medical measurement), focused on the quantitative measurement bodily input and outputs. In formulating his approach, Santorio used himself as a medical subject, recording for nearly thirty years the quantities of his daily inputs (food and drink) and outputs (urine and feces), his activities (eating, sleeping, working, sex, fasting, drinking, and excreting), and associating these with changes in his bodily weight.

[33] Allan and Schofield, *Stephen Hales*, 18-19, 49.
[34] For example on the Roman battlefield.

In the results of his study, Santorio found that the amount of his outputs (excreta) were less than the amount of his inputs (food and drink) and thus concluded that he must lose the difference through some other process than urination and defecation. The process Santorio proposed to account for difference was "insensible perspiration."[35] Hales's instructor Keill followed Santori's method in his 1718 publication, *Medicina statica Britannica*, but he added measurements of motion and environment: pulse rate and atmospheric conditions (wind direction, air temperature, and barometric pressure).[36]

In the tradition of Keill and the iatro-physicists' analogies between plants and animals, Hales set out to understand human physiology through the physiology of plants, specifically a plant's "bodily fluid," its sap. In this he posited a significant statical relationship between a plant and its surrounding environment. Hales noted that when a plant imbibed water at its roots, this moisture travels up fine capillary vessels to the leaves where it is carried off in perspiration. If this perspiration was blocked in some way by environmental conditions, say damp weather that prevents or slows transpiration, the sap would stagnate in the plant's vessels and become corrupt, causing in turn various rot and mold diseases. Hales took this as a direct analogy with the iatro-physical theory of human fevers, which assumed that stagnant blood caused various diseases and conditions in humans.[37]

Although Hales began his work on plant physiology with the study of fluids, he ended up emphasizing the importance of air. In the course of his experiments Hales's work on air began somewhat accidentally, when he noticed repeatedly that there were often

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[35] Kate Kelly, *Scientific Revolution and Medicine: Scientific Revolution and Medicine, 1450-1700* (New York: Infobase Publishing, 2010), 36-37

[36] F.M. Valadez and C.D. O'Malley, "James Keill of Northampton, physician, anatomist and physiologist" *Medical History* 15, no. 4 (1971): 331

Allan and Schofield, *Stephen Hales*, 32, 34-35; Henry Guerlac, "Hales, Stephen," 39; Hales quote is from *Vegetable Staticks*, 56 bubbles of air rising through a plant's sap. From this observation, Hales began to wonder whether plants somehow imbibed air as well as water. Some additional experiments using an air pump proved to Hales that plants did in fact "inspire" a considerable quantity of air. If plants took in air in large quantities, Hales posited that it was important to know more about that air, and as such spent the next two years performing what were essentially chemistry experiments, submitting various substances (e.g. hog's blood, tallow, oyster shell, amber, honey, coal, oak wood, peas, and a variety of other materials) to fermentation (mixing with acids, alkalies, water, etc) or distillation (heating) to determine how the effects of these processes on the elasticity of air.[38]

Hales understood atmospheric air in way a similar to Boyle, but layered it with a Newtonian proposition. Following Newton, Hales posited that there was a significant insensible exchange between bodies and the atmosphere. Air "fixed" within "dense bodies" (human bodies included) could by fermentation rarify into "several sorts of Air," and by the same mechanism, return to the same dense body. Thus, after these two years of experimentation, Hales drew conclusions that would resonate throughout the rest of the eighteenth century, namely that "there was such a thing as 'fixed air' and that it abounds in all sorts of animal, vegetable, and mineral substances," and that such air was "very instrumental in the production and growth of animals and vegetables."[39]

In terms of disease transmission, Hales's conclusions meant an expansion of Boyle's theory of effluvial influence. Now it was not only mineral emanations from the deep earth that could provoke an outbreak of epidemic disease, but also emanations of the

[38] Henry Guerlac, "Hales, Stephen," 41-42; Allan and Schofield, *Stephen Hales*, 32, 38-39, 42; Hales quotes are from *Vegetable Staticks*, 56, 87. Although Hales did not consider himself a chemist, "he had performed some chemical experiments during his Cambridge days, when he had read or consulted George Wilson's practical compendium, *A Compleat Course of Chemistry* (1699)"

[39] Allan and Schofield, *Stephen Hales*, 39; Henry Guerlac, "Hales, Stephen," 41, 43; Hales quotes from *Vegetable Staticks*, 85, 314-315; A.E. Clark-Kennedy, *Stephen Hales, an Eighteenth Century Biography* (Cambridge: Cambridge University Press, 1929), 96.

formerly "fixed air" of a much wider range of local, aboveground, and even living sources, such as diseased people rotting corpses and vegetable matter. Arbuthnot and other medical writers amended this theory to their observations of various epidemic diseases following in the tradition of Sydenham. If Boyle's causal theory of epidemics (underground effluvia combined with particular meteorological or atmospheric conditions) could not explain the occurrence of widespread disease in a particular location, then there must be something else in the mix, and this something else was animal or vegetable effluvia.[40]

Having explored the respiration of plants, Hales turned to the analogous process of human respiration. After repeating a set of Mayow's experiments on candles and mice in an enclosed chamber, Hales took the method a step further and performed a series of "rebreathing experiments" on himself that convinced him that animal respiration "vitiated" the air. By this he meant that regular human respiration *released* something damaging into the air that destroyed the air's elasticity. This conclusion differed from Mayow, who assumed that respiration *absorbed* a life-giving element from the air.[41]

Critical to Hales's approach was not just experimentation, but also calculation and quantification. It was not enough for Hales to describe the process by which he believe air became vitiated. He also attempted to quantify the amount of air made inelastic by respiration. This quantity he extrapolated from his experimental equipment and elaborate measurements of human anatomy. Hales rebreathing his own breath via a sealed bladder fitted with a breathing tube, calculated numerically what he thought to be the amount of air that lost its elasticity during respiration (Figure 2.2). These numbers did not stay in the laboratory. Arbuthnot includes these calculations in his book extrapolating that with "20

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[40] Riley, *The Eighteenth-Century Campaign to Avoid Disease*, 18-19
[41] Guerlac, "Hales, Stephen," 43

inspirations for 1 minute, and 20 cubical inches of air for every inspiration, this would make 24000 cubical inches of air in an hour [would be made unfit for respiration]."[42]

Despite Arbuthnot's promotion, Hales's ideas perhaps would have faded with the general decline in enthusiasm for Newton's methods in the 1740s had there not been purposes and institutions to implement them *en masse*.[43] Instead they aligned with what historian James C. Riley identifies a newly ambitious medicine arising at mid-century. In the past, doctors and administrators had been reactionary, attempting to manage or cure a disease after it had already struck. In contrast, the doctors and administrators of the mid-eighteenth century aimed to be proactive. They would *prevent* or *avoid* illness and disease by treating the environments where a person might become sick rather than treating the people themselves.[44] In a material sense, this meant ventilation instead of fumigation. If one ventilated a space consistently, disease would presumably never show up. Monetary investment in a ventilation system would ostensibly be less than the costs of disease and illness in terms of loss of life and time spent evacuating and fumigating a space to rid it of the disease once it had taken hold. This is the insight that struck Hales in 1741, when thinking about the health problems then besieging the Royal Navy.

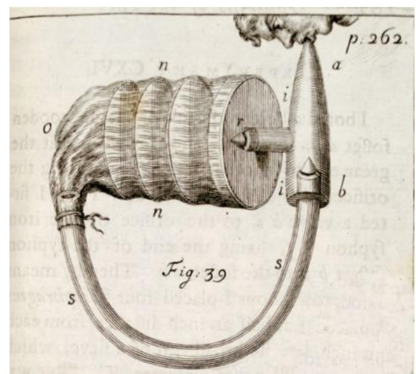

Figure 2.2 Stephen Hales's rebreathing apparatus from *Vegetable Staticks*, 1727.

[42] Hales, *Vegetable Staticks*, 234-235; Arbuthnot, *An Essay Concerning the Effects of Air on Human Bodies*, 103

[43] Theodore M. Brown, "From Mechanism to Vitalism in Eighteenth-Century English Physiology," *Journal of the History of Biology*, Vol. 7, No. 2 (Autumn, 1974), pp. 179-216. Brown comments on the general decline in Newtonian optimism. It is my assumption that Hales's ideas would have faded.

[44] Clark-Kennedy, *Stephen Hales, an Eighteenth Century Biography*, 90

**Of Fevers and Timbers: Moving Air for the Royal Navy**

In 1739, the British Royal Navy had big problems. After much controversy, the British Parliament had voted to go to war against Spain to settle disputes over maritime trade with its colonies, and the navy, which had not seen serious conflict in twenty-five years, was not prepared for the quick mobilization the administration required. The ships they had been keeping in reserve seemed to be decaying with rot more quickly than usual, and more critically, they simply could not find enough competent seamen to crew them.[45] The challenge was compounded at first by the fact that the primary agitators for the war, the major colonial trading companies (e.g. the South Sea Company), were resistant to contributing their trained seamen to the war effort, although their merchant-sailor fleet was often a source for personnel for the navy in wartime.[46] This shortage of crews lead the Lords of the Admiralty in June 1739 to issue warrants for impressment, meaning the navy could forcibly recruit any merchant seamen currently in port or on land.[47] Given that "pressed men" were even more prone to desertion than typical recruits, captains and

[45] Clive Wilkinson, *The British Navy and the state in the eighteenth century* (Woodbridge, Suffolk, UK; Rochester, NY: Boydell Press, 2004), 75
[46] Daniel A. Baugh, *British Naval Administration in the Age of Walpole* (Princeton: Princeton University Press, 1965), 19.
[47] Baugh, *British Naval Administration*, 150

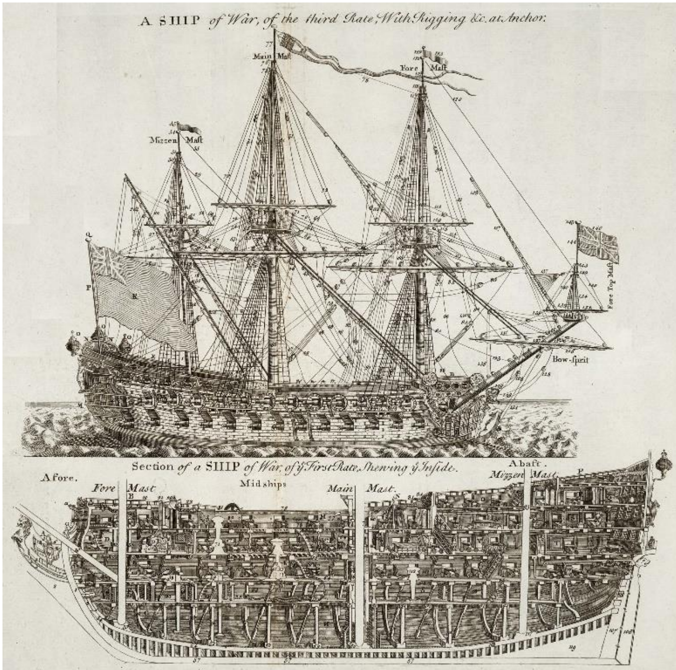


Figure 2.3 Exterior and interior of third- and first-rate war ships, British Royal Navy, 1728. The stagnant conditions in the confined spaces of the lower decks became more pronounced when the deck hatches had to be sealed while in rough waters.

commanders often kept their crews confined to the ship before departure, sometimes for weeks or months at a time (Figure 2.3).

The crew-shortage situation became even more acute in 1740 with a major outbreak of a "violent and malignant fever" on the vessels being made ready for battle in the West Indies. This eruption of sickness disturbed the naval administrators because its symptoms seemed to resemble closely a type of "fever" then relatively common in England, but not typically fatal. The men on ships, however, were dying from it in droves. Moreover, unlike the plague and many other diseases, this fever outbreak did not abate in the winter, but rather it increased in intensity in the winter months. Most blamed recently arrived crewmembers impressed directly from prisons for bringing it on board, but opinions differed as to what was making it particularly deadly. A group of ship captains, called to meet in Portsmouth by their commander thought the cause of the outbreak was a combination of factors: the spaces where sailors were "kept so very close," the particularly severe winter, lack of adequate clothing, and bedding "stuffed with nastiness." The naval surgeons, on the other hand, claimed the primary cause was the severity of the cold weather.[48] Addressing the Lords of

[48] Christopher Lloyd and Jack L.S. Coulter, *Medicine and the Navy 1200-1900, vol. 3 1714-1815*. (Edinburgh and London: E. & S. Livingstone Ltd, 1961), 109.

the Admiralty, both Richard Mead and Stephen Hales aimed to convince the naval administrators that the cause was confined air (Figure 2.4).

Given the numerous possible causes of the fever, there were equally numerous ways to address it. One could treat the patient directly with specialized medicines or bloodletting, but given the scale of the outbreak, a shortage of medicines, and limited clinical success with bloodletting for this fever, these were not the most viable strategies. One could try fumigation of the space (as Hales was originally suggesting), but that required emptying a ship and risking more delay and desertion. The navy could issue new clothing and bedding, or supply better food, but changes to naval supply processes were not speedy. Thus, in 1740, with reasoning endorsed by the Royal Society, the navy decided to try moving air for the health of seamen. With much persuasion, the navy considered two different devices for this purpose, a hand-driven bellows apparatus proposed by Hales and a heat-driven extraction system by Samuel Sutton, a London brewer and coffee-house proprietor who had the full support and advocacy of Richard Mead.

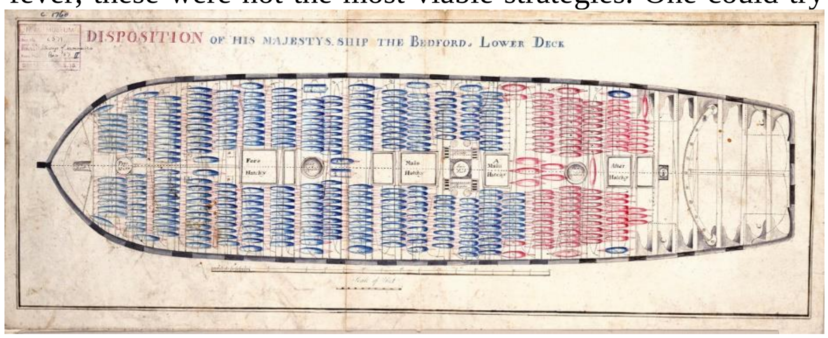


Figure 2.4 Crowded sleeping arrangements for sailors (blue), marines (red) c. 1790. Seamen slept on hammocks slung between the ship's rafters. © National Maritime Museum, Greenwich, London.

That Hales would presume to give medical and technical advice to the Royal Navy is not so surprising, as he had gained prominence in scientific circles following the publication of his *Statics* books, but by 1740, Hales was also familiar with the complications of sea voyages from his role in the Georgia Trust.[49] The efforts Hales made towards fitting out the Georgia-bound emigrant ship "Ann" in 1732, encouraged him to study the problems of sea travel.[50] Hales documented his research and work on these sea-faring problems first with his 1739 treatise *Philosophical experiments: containing useful and necessary instructions for such and undertake long voyages at sea,* in which he proposed methods for making "unwholesome" distilled seawater "sweet" and drinkable, for preserving grain provisions from pests (by fumigating with brimstone), and for salting whole animals to prevent spoilage in hot climates.[51] This work did not go unnoticed. The Royal Society awarded Hales the prestigious Copley medal for this work and for his work on kidney stone cures.

Hales developed his ventilating apparatus originally for drying and preservation of grain, but in his 1743 text, *Description of Ventilators* Hales prioritizes health issues (Figure 2.5).[52] In this book dedicated to the Lords of the Admiralty, Hales emphasized the problems of confined space where "the great quantity of rancid vapours that incessantly exhales from human bodies," that destroy the elasticity of the air and make it unfit for respiration. Moreover, they not only degrade the air, but they can cause disease as well, for "it is well known, that the Vapours which arise from human live Bodies, are extremely corruptible; hence it is, that the Air of Prisons often produces mortal Distempers," and "doubtless…the Air in Ships is much more rancid than in Prisons, on account of great Numbers of Persons

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[49] The newly established Georgia Trust at the time was working towards James Oglethorpe's vision to establish a colony in America for former inmates of London debtors' prisons.

[50] Jocelyn Thorpe, "Stephen Hales," *Notes and Records*, 3 (1940), 61.

[51] Stephen Hales, *Philosophical experiments: containing useful and necessary instructions for such and undertake long voyages at sea* (London: W. Innys and R. Manby, 1739).

[52] Stephen Hales, *A Description of Ventilators: Whereby Great Quantities of Fresh Air May with Ease be Conveyed into Mines, Goals (sic), Hospitals, Work-Houses and Ships in Exchange for their Noxious Air,* (London: W. Innys, 1743). Allan and Schofield say that the ventilator was originally designed to provide fresh air on ships, but to me it seems like they take Hales too much at face value.

on Board."[53] Hales supports his claim by quantifying the amount of vapors on a ship, equating the amount of vapors respired and perspired with "the Quantity of half the Meat and Drink which we take in daily, which is estimated to be about thirty-nine Ounces in England," a quantity that Hales calculated "by experiment."[54] Multiply that by the number of persons in a confined space, and (yikes!) the problem seems very serious. To avoid such a buildup of these vapors, the air must be refreshed and changed, and an hour or two of ventilation a day will not be adequate. The change of air must be constant.

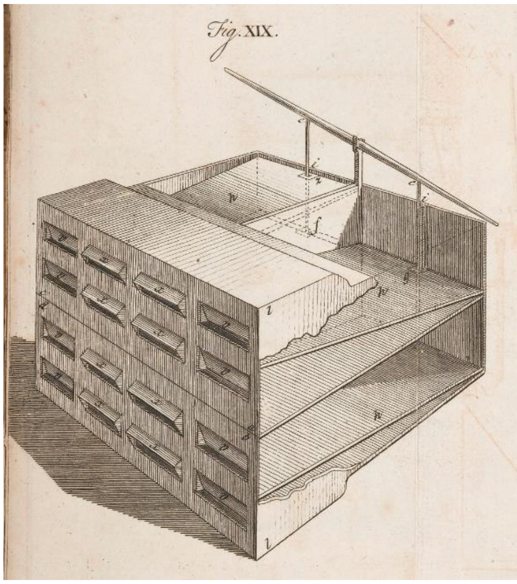


Figure 2.5 Stephen Hales's bellows ventilator, 1743. The apparatus, operated by the lever bar at the top right, both pushed air into and pulled air out of the ship's lower decks.

Hales's rival in this endeavor, Samuel Sutton, was not a member of the Royal Society's scientific elite, but by frequenting a "coffee-house near the Admiralty" and actively pursuing naval officials he was able to make connections enough to obtain permission for an installed test of his device aboard a ship. Sutton's efforts were thwarted, but "being no stranger to the character of Dr. Mead," Sutton appealed to Mead for assistance.[55] Mead intervened and secured another test of Sutton's system and delivered an account in support of it at the Royal Society in February 1742.[56]

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[53] Hales, *A Description of Ventilators* (1743), 41-42; also referenced in Allan and Schofield, *Stephen Hales*, 89

[54] Hales, *A Description of Ventilators* (1743), 43

[55] Samuel Sutton, *An Historical Account of a New Method for Extracting the foul Air out of Ships* (London: J. Noon, 1745), 9.

[56] Richard Mead, "An Account of Mr. Sutton's Invention and Method of Changing the Air in the Hold, and other close Parts of a Ship" *Philosophical Transactions* 42, no. 462 (Jan-Feb, 1741/2): 42. "Mead opens

In the following April, another fellow of the Royal Society, William Watson, also spoke in support of Sutton's scheme, particularly for its economy. Unlike Hales's bellows device, Sutton's did not require any manpower to operate, and it relied mostly on existing infrastructure. Every ship already had a stove installed for cooking; Sutton only had to add a system of pipes that allowed the heat of the stove to draw air from below decks.[57]

One of Watson's purposes was to defend Sutton's device against perceived conservatism on the part of Sir Jacob Acworth, the Surveyor of the Royal Navy. Acworth had voiced resistance to any new device for ship ventilation, claiming that the traditional system of ship ventilation, the windsail, was perfectly adequate. Certainly not, argued Watson. Not only did the windsails take a long time to deploy, they could not be used during storms, and they did not function when winds were calm. Moreover, they did not penetrate down to the lowest levels of the ship, where "stinking water" frequently collected and subsequently drove "offensive Air into the Cabin, and more airy Parts of the Ship."[58]

Given this pressure, the navy ordered some limited tests of Sutton's system, but the stakes increased further in 1742, for all had learned that a ventilating device, very similar in design to Hales's bellows, had recently been adopted by the Swedish and French navies. The designer of the ventilating system, Martin Triewald, military architect to King of Sweden, had also been rewarded materially and professionally by this acceptance. He was granted a lifetime patent on his design by the King of Sweden, and a description of his work printed by the king and distributed widely in the Swedish navy and transmitted to the Royal Academy of Sciences in Sweden and in Paris (Figure 2.6).[59]

this account with "It is found by daily experience that air shut up and confined in a close place, without a succession and fresh supply of it, becomes unwholesome, and unfit for the use of life."

[57] William Watson "Some Observations upon Mr. Sutton's Invention to extract the foul and stinking air from the well and other parts of ships, with critical remarks on the use of windsails" *Philosophical Transactions* 42, no. 463 (Mar-Apr 1742): 67-68.

[58] Watson, "Some Observations upon Mr. Sutton's Invention," 65-66.

[59] Clark-Kennedy, *Stephen Hales, an Eighteenth Century Biography*, 152-153

The navy was also contending with a ventilation problem of their own, unrelated to the health of its crews. At the end of the 1730s, the navy's shipbuilders were finding that the large timbers that formed the core structure of their ships were decaying much more rapidly than in the past. This was in part because the ships themselves were getting larger in order to keep up with similar increased the size of French naval ships.[60] The decay was exacerbated by an order in 1729 for a number of ships to have their interiors shut in so they could be made ready for sea at a short notice, given the increasing tensions between Britain and Spain that eventually led to the war in 1739. Thus, ventilation could address two problems with one solution.[61]

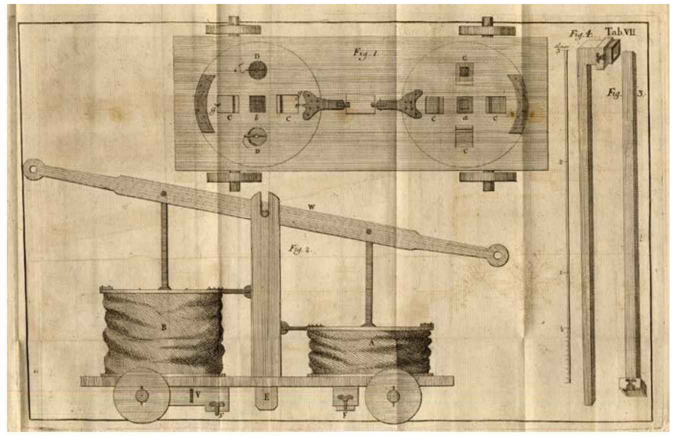

Figure 2.6 Martin Triewald's ventilator, 1742.

Hales and Sutton continued to promote their ventilation systems. Hales published his *Description of Ventilators* to defend his case, and used his connections as a Trustee for the colony of Georgia to get merchant and slaver ships to install his system. Hales was successful in this effort, when in 1749 the Board of Trade and Plantations officially adopted their use.[62] Although he lacked the social connections that Hales had, Sutton continued to petition for his system among the Lords of the Admiralty. Sutton's efforts were provisionally successful, when in 1744 Acworth finally accepted Sutton's system for

60 In the 1733 "Establishment" (giving standard designs for naval ships built at the many naval dockyards), Sir Jacob Acworth had suggested a way to make bigger ships to keep up with the French, see Peter Hemingway, "Sir Jacob Acworth and Experimental Ship Design During the Period of the Establishments," *The Mariner's Mirror: The International Quarterly Journal of The Society for Nautical Research,* 96, no. 2 (2010): 157.
61 Clive Wilkinson, *British Navy and the State,* 81-84
62 Allan and Schofield. *Stephen Hales,* 83

installation on several naval vessels. By 1751, however, the Admiralty was giving Hales's system a second chance, in part due to the system's seeming effectiveness in reducing disease and death on slave and merchant ships, but also specifically for its utility in preventing decay of a ship's timbers.[63] By 1756, the navy adopted Hales's system for all His Majesty's ships.[64]

**Of Health and Hygiene: Prevention Cheaper than Cure**

Mead's and Hales's association of confined space, disease, and ventilation reached a much wider audience through their promotion by John Pringle, a Scottish physician and author of the much republished and translated *Observations on the diseases of the army in Camp and Garrison*. Pringle's involvement with the army began in 1742, when the Earl of Stair, the commander of the British army in Flanders then engaged in the War of Austrian Succession, appointed Pringle as his personal physician. Within a year, Pringle's responsibilities had expanded to the running of the army's garrison hospital at Ghent and to a certain extent to consultation on the overall health of the army.[65]

When Pringle encountered it, the British military already had a particular shape and medical philosophy, which had its origins in the years following the "Glorious Revolution" in 1688-1689. The then-new ruler, King William, opted to enlarge significantly the standing army and navy (as opposed to a military called up only when there was a looming conflict) that the deposed ruler, James II, had started, and this expanded military force required a new type of physician and a new medical infrastructure. Traditional medicine focused on the unique constitution of individuals and imagined disease as a dynamic state

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63 Clark-Kennedy, *Stephen Hales, an Eighteenth Century Biography*, 159-168.
64 Allan and Schofield. *Stephen Hales*, 83; Clark-Kennedy, *Stephen Hales, an Eighteenth Century Biography*, 108.
65 Stephen C. Craig "Sir John Pringle MD, Early Scottish Enlightenment Thought and the Origins of Modern Military Medicine," *Journal for Eighteenth-Century Studies* 38, no. 1 (2015): 104.

reflecting the relationship of a specific body in a specific environment. Military doctors did not have this luxury. Rather they had to devise methods to treat large numbers of patients in a short amount of time. In doing this they shifted focus to specific diseases rather than specific patients and took an empirical approach, observing multiple cases in order to identify predictable patterns of symptoms and disease progression that would allow them to devise one-size-fits-all treatments that could translate into many different settings. The restructuring of military forces by King William also called for new medical staffing regimes. Doctors advising on medical care for soldiers and sailors now had permanent rather than temporary appointments. This corps of physicians addressed problems "affecting the supply of manpower" with a view toward the long-term, developing practices of military hygiene that eventually translated to the civilian population.[66]

Pringle remained in the service of the army until 1748, and during that time he recorded observations on the diseases and medical practices of the British army in the field. The outcome of that documentary effort was the 1752 publication of his *Observations on the Diseases of the Army*, which received wide audience through seven English-language editions before 1775, was translated into German, French, and Italian within fifteen years of its original publication, and influenced American medical writers as well. Pringle's book, in his view as well as that of many contemporary and future physicians and historians, was the origin of military medicine told for the benefit of the commanding officers. Certainly, there were other books on the subject written prior to Pringle's, but Pringle found all of them wanting for their lack of attention to preventive measures. Curative medicines and surgery were not enough; commanders must act in advance to

[66] Harold J. Cook, "Practical Medicine and the British Armed Forces after the 'Glorious Revolution.'" *Medical History*, 34 (1990): 1-3, 7, and 25.

maintain soldiers' health and avoid disease.[67] It is easy to see why Pringle's book gained such wide acclaim. Although it can be somewhat dense in the areas intended for medical practitioners, its structure and organization are laid out clearly for those involved in large-scale logistical planning. The structure of the book focused on disease classification, prevention, and troop forecasting.

Pringle recorded his observations on the diseases he encountered throughout his service and found the summer season to be most deadly. He theorized that these "summer" diseases were caused by an undefined "septic principle" in the air that caused putrefaction (essentially rotting or decomposition) throughout the body and manifested as the outward symptoms of disease. Pringle legitimized his rather novel theory first by connecting it to Galenic and Hippocratic notions of the corruption of the bodily humors, and later by carrying out a number of laboratory experiments on "putrescence."[68] Pringle's experiments, which he completed after settling in London at the close of his army service, consisted of placing various materials in sealed vessels, keeping them at the temperature of the human body, and observing them as they rotted. Pringle's observations on putrefaction of these materials "analogous" to human bodily fluids and flesh shaped the basis for his theories about putrid (summer) fevers."[69] Although Pringle's experimental work was aimed at determining which substances might arrest or reverse putrefaction—many now credit Pringle as originating or advancing the idea of antiseptics—the outcomes of his research lent experimental evidence to the idea that the air could be poisoned specifically by human exhalations of "putrid effluvia."[70]

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[67] Craig, "Sir John Pringle MD," 99, 105

[68] Margaret DeLacy, *Contagionism Catches On: Medical Ideology in Britain, 1730-1800* (New York: Palgrave Macmillan, 2017), 58; Riley, *The Eighteenth-Century Campaign*, 98

[69] Erich Weidenhammer, "Air, Disease, and Improvement in Eighteenth-Century Britain Sir John Pringle (1707-1782)" (PhD diss, University of Toronto, 2014), 102

[70] Allan and Schofield. *Stephen Hales*, 122; Riley, *The Eighteenth-Century Campaign*, 98

***Pringle's Confined Spaces***

One of the boldest declarations in Pringle's *Observations* was his statement, "among the chief causes of sickness and death in any army the reader will little expect that I should rank, what is intended for its health and preservation, the Hospitals themselves," and much of this was due to "bad air" in the hospital.[71] This idea went against conventional practice in the army, where medical officers typically sought temporary hospital quarters in the "close and warm houses" of the locals where the army was campaigning. Pringle felt convinced by his experiences in the field "that it is air, more than heat" that was necessary for an appropriate hospital setting. He felt strongly enough to declare it as a rule "that the more fresh air we let into hospitals, the less danger there is of breeding the distemper." For this reason he recommended recruiting "not only barns, stables, granaries and other out-houses, but, above all, churches" for hospitals "from the beginning of June to October."[72]

For Pringle as it was for Mead, the deadly strength of the hospital was a result of spatial confinement. A disease acquired in the field may be communicable but not fatal, but when patients were placed in a confined space, their unhealthy emanations became concentrated enough that they could essentially mutate into a more deadly disease, the familiar "hospital fever." An affliction that had not originally been contagious became so within the walls of the institution. This had consequences beyond the walls as well. If the middle classes neglected the conditions within the institution, the trapped and concentrated disease matter could transmute into an even deadlier form that might ultimately escape and afflict those in the surrounding area.[73]

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71 John Pringle, *Observations on the diseases of the army in Camp and Garrison* 2nd edition (London: A. Millar, D. Wilson, T. Durham, T. Payne, 1753) viii, also quoted in Craig, "Sir John Pringle MD," 109.
72 Pringle, *Observations on the diseases of the army*, 109
73 Christopher Hamlin, *More Than Hot: A Short History of Fever* (Baltimore: Johns Hopkins University Press, 2014), 116-117.

Although the medical officers attempted to comply with Pringle's advice in *Observations* on "disposition of hospitals, with regard to preserving the purity of air," to keep patient densities low (admit fewer patients to a ward that one would think it could accommodate) and make ceilings higher if they are found to be low, it was "near impossible" in operation of these converted hospital buildings to convince the nurses or the patients of the necessity to keep doors and windows open, allowing air to circulate. Pringle figured fireplaces with adequate chimneys might make up for this intransigence, but "when fireplaces are wanting, the greatest preservative would be had in the use of the reverend Dr. Hales's ventilators." Pringle had consulted Hales on this matter, and even includes specific directions from Hales on the placement and configuration of ventilators in such hospitals (Figure 2.7).[74] Hales was a natural reference for Pringle because Hales, during the years that Pringle was in the field, had been successful in convincing the administrators of various military and civilian hospitals to install his ventilators. They were installed at Hyde Park Corner hospital (1744), Middlesex smallpox hospital (1747), and naval

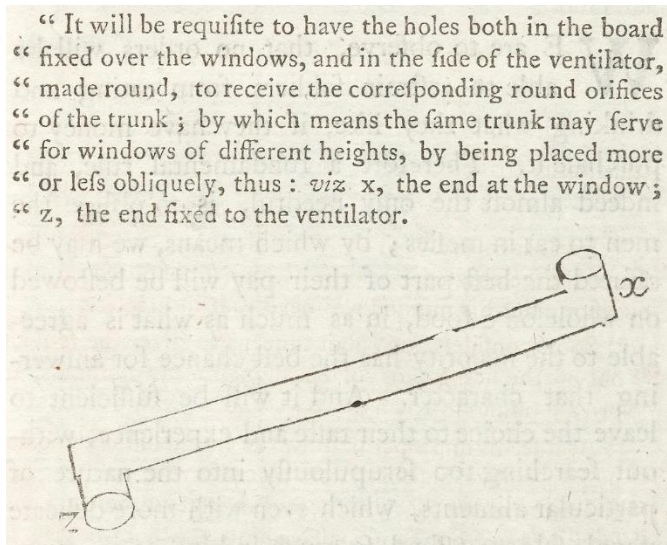
" It will be requiſite to have the holes both in the board
" fixed over the windows, and in the ſide of the ventilator,
" made round, to receive the correſponding round orifices
" of the trunk ; by which means the ſame trunk may ſerve
" for windows of different heights, by being placed more
" or leſs obliquely, thus : *viz* x, the end at the window ;
" z, the end fixed to the ventilator.


Figure 2.7 Hales's instructions, Pringle's *Observations on the Diseases of the Army*, 1752.

[74] Pringle, *Observations on the diseases of the army*, 109

hospitals at Portsmouth, Gosport, and Plymouth, and by Hales's 1758 publication of his *Treatise on Ventilators,* his devices were installed in many London and county hospitals.[75]

Yet in the time that Pringle was working in his lab, a fatal incident occurred at the "Old Bailey," the criminal court of England, that clarified Pringle's thinking and expanded the purview of Hales's ventilators. Following a court session, several prominent members of the court fell ill with the malignant fever and died. The cause was thought perhaps to be the presence of the defendants, prisoners who had been held at the Newgate prison, where, like other "gaols" crowded with criminals or debtors, outbreaks of the so-called "gaol fever" were common.[76] Called in to consult on the incident, Pringle concluded that the cause of the outbreak had been the stream of air from the only open window in the courtroom that "directed the putrid steams" from the prisoners' holding area to the seats of those presiding over the court.

Outbreaks of "gaol fever" may have been common, but it was Pringle's assertion about it in 1750 was uncommon. He asserted that this disease was the in fact the same one that he had observed in hospitals during the recent war.[77] By equating the cause of the disease with its location, Pringle could thus enlist similar strategies to prevent the disease, and in the case of Newgate prison, this included Hales's ventilators. Such a proposal to install ventilators at Newgate did not seem farfetched to prison administrators because

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[75] Allan and Schofield. *Stephen Hales*, 84; There were complaints about the conditions created by Hales's ventilators from hospital patients and doctors. For example, at St. George's Hospital, the quantity and speed of air movement created by Hales's bellows device brought resistance from those exposed to it. "Neither patients nor doctors knew whether the freshness of the incoming stream justified the lower temperatures and subjective feeling of chill. Many argued that ventilation made sense only if it guaranteed freshness without discomfort."

[76] Riley, *The Eighteenth-Century Campaign*, 100; Clark-Kennedy, *Stephen Hales, an Eighteenth Century Biography*, 189

[77] Sydney Selwyn, "Sir John Pringle: Hospital Reformer, Moral Philosopher and Pioneer of Antiseptics" *Medical History* 10, no. 3 (Jul 1966): 266–274. (quote 268); Pringle did this in a published 52 page letter to Richard Mead on *The Hospital and Jayl-Fevers*.

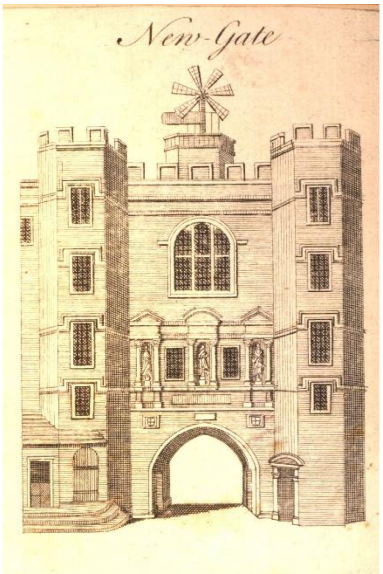


Figure 2.8 View of Newgate prison showing windmill-driven ventilator, c. 1760

Hales had already had some success convincing prison officials in outlying areas to install his ventilators before the 1750 incident at the Old Bailey.

After the installation of the windmill-driven ventilator in one ward at Newgate in 1752 (Figure 2.8), Hales and Pringle returned to the prison to observe its effects. They found these wards "much less offensive than the rest," and in interviewing some prisoners learned that although sickness at first increased, "general healthiness" soon improved. These preliminary findings gave Pringle and Hales the confidence to recommend installation of ventilators in all wards. Other installations soon followed at Gate-House, Westminster, Clerkenwell, and New Prison, and at some prisons in France.[78]

***Command Has Its Limits***

Yet some remained skeptical about the cure-all seemingly promised by ventilating devices. One such skeptic was James Lind, a physician to the navy assigned for most of his career at the Haslar Naval Hospital near Portsmouth. In his 1757 text, *Essay on the Most Effectual Means of Preserving the Health of Seamen,* Lind suggested that disease now known collectively as "ship," "gaol," or "hospital" fever was not likely caused or spread

[78] Riley, *The Eighteenth-Century Campaign,* 106; Allan and Schofield. *Stephen Hales,* 85; Clark-Kennedy, *Stephen Hales, an Eighteenth Century Biography,* 189-191; As with many early installations of Hales's ventilators, the first adoption of his system was in an institution where Hales had some existing authority. As Proctor for the clergy of the diocese where Winchester prison was located, Hales could put pressure on the local authorities to install a ventilator there. In turn, this influenced other decision-makers. Hearing of the Winchester installation as well as those on numerous non-military ships (mostly slave and convict ships) convinced Henry Fox, then Secretary of State for War, to request the installation of Hales's device at the Savoy Prison. Installations at other "gaols" and county prisons soon followed.

through the air. Contributing to his disbelief was his observation that despite the claims of Hales and Pringle, ventilators did not appear to stop the spread of typhus in jails.[79]

Instead, Lind hypothesized that the sources and transmitters of this malignant fever were the dirty clothing and bedding of the sick. Lind did not outrightly contradict Pringle and deny completely the role of air and ventilation. He allowed that fresh air in itself might slightly abate the malignity of a fever, but he proclaimed that even the "purest air cannot cleanse rags from contagion" and thus not wholly useful. Ironically, some of Lind's reasoning came from observations of the incidence of typhus on non-military ships, specifically convict ships and slavers. Lind observed that typhus seemed to run rampant on convict ships (where the convicts were clothed and provided bedding), but was virtually absent from slave ships (where the enslaved were typically almost naked and provided no bedding). Thus, Lind reasoned, it must be the fabric that retained and transmitted the disease. The solutions that Lind thus emphasized concentrated on cleanliness (clean linens provided, special washing procedures and protective clothing for staff) and fumigation (by wood smoke, burning gunpowder, or sulphur added to coal fires), rather than ventilation.[80]

So why did air and ventilation become the focus of indoor public health in the nineteenth century instead of personal cleanliness, which did not triumph until the twentieth century? Part of this can be explained by the personal trajectories of Lind and Pringle. Lind's position at the Haslar hospital allowed him to devise and enforce explicit regimens and practices. Indeed some claimed that Lind's biggest achievement was the disciplinary structure at Haslar, despite his well-known role in conceiving the common lime-juice cure for scurvy. Pringle, on the other hand, held the presidency of the Royal

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[79] Riley, *The Eighteenth-Century Campaign*, 108; Graham A.J. Ayliffe and Mary P. English, *Hospital Infection: From Miasmas to MRSA* (Cambridge: Cambridge University Press, 2003), 42
[80] DeLacy, *Contagionism Catches On*, 68; Ayliffe and English, *Hospital Infection*, 42-43

Society between 1772 and 1778, a position from which he endorsed further research on the properties of air, most significantly that of Joseph Priestley, whose work will be discussed in the following section.

A more critical difference is in the level of control required to effect each means. Lind, in his position at Haslar could exercise direct discipline. He aimed to control almost every aspect of the institution's routine as well as those of its inmates. Pringle, on the other hand, recognized the limits of command, even in the disciplined setting of the military. Generals could not control the weather or other things that "a soldier shall have in his power to neglect" (e.g. food, drink, sex, and thoughts), Pringle reasoned, but there was much that they could fix, particularly "accommodation (ventilation and density), sanitation, and the water supply."[81]

Now let me tell you who was right from the perspective of the twenty-first century. It was Lind. Although backwards mapping of disease categories is always fraught, present-day scholars generally agree that "gaol," "ship," and "hospital" fever was likely what we would today call typhus. This disease is caused by the organism *Rickettsia prowazekii*, spread by the feces of the human body louse, *Pediculus humanus*. The disease can transfer through skin abraded by the itching of louse bites, but it can also transfer through the mucus membranes via dried feces attached to clothing or bedding. The inability to change clothes or bedding and a lack of washing facilities in part explains the diseases common occurrence among inmates of prisons, hospitals, and ships. Yet because the limits of Lind's command lay within the walls of Haslar hospital, where he could enforce a particular regimen, his methods did not gain the wide acceptance that Pringle's ventilation did.[82]

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[81] Hamlin, *More Than Hot: A Short History of Fever*, 115.

[82] Something else happened in the 1750s that made a narrative of air compelling. On June 20, 1756, at the East India Company's Fort William in Calcutta, a group of 150 Europeans taken prisoner by Nawab Siraj-ud-daulah of Bengal were shut up overnight in small cell with only two small window openings. By the next morning, 123 of that group were dead. Although details were lacking, the cause of their demise was

Nonetheless, Pringle was disappointed that he could not figure out a method by which to apply his ideas for health improvement beyond the military to the wider British society.[83] Through his support of Joseph Priestley, however, Pringle forwarded his ideas to a setting where they met up with an emerging industrial economy and found resonance with those looking for ways to increase or manage human productivity in large civilian populations.

### ENLIGHTENED ECONOMIES OF AIR AND HEAT

Although historians typically interpret the work of the much celebrated late eighteenth-century experimentalists the Englishman Joseph Priestley and the French Antoine Lavoisier almost exclusively in terms of the history of chemistry, reflecting on their motivations and conclusions in terms of contemporaneous medical concerns yields a clearer picture of air's role in the political economy, and why air took on such significance at the time and in later periods. Although they were two among many figures working in pneumatic chemistry, Priestley and Lavoisier are exceptional in the scope of the theoretical formulation that they drew from their specific experimental evidence. Both men, the former a politically radical theologian and the latter a wealthy official employed by the monarchy, imagined air as part of a larger "economy" of material and political activity. In Britain, Priestley's *Experiments and Observations on Different Kinds of Air* not only complemented Pringle's aerial economy of fevers it also provided a key tool in Jeremy

deemed to be the confined air of the small chamber. The narrative certainly seems improbable, and as Partha Chatterjee has demonstrated, it has taken on multiple moral meanings in its telling, but in discussions of air from the 1770s on, this event, the so-called "Black Hole of Calcutta," is mentioned by almost every writer, medical or otherwise, in emphasizing the importance of ventilation for the next century and a half.[82] It is difficult to overemphasize the narrative persistence of this story; it was unfailingly used as a warning of the consequences of poor ventilation, even in wildly different settings and circumstances. Partha Chatterjee, *The Black Hole of Empire: History of a Global Practice of Power* (Princeton, NJ: Princeton University Press, 2012), xi.

[83] Morrice McCrae, *Saving the Army: The Life of Sir John Pringle* (Edinburgh: John Donald Publishers, 2014): 191-192.

Bentham's political philosophy of utilitarianism. For Lavoisier, it was an economy of air, food, and work that aimed to address political unrest brewing in pre- and post-revolutionary France. The two different angles from which the men approached their studies of air represent the situated and often conflicting representations of air in medicine and in the "laws of life."

The conventional story of Priestley and Lavoisier is often told as a rivalry between the two men, the end result being the so-called triumph of modern chemical theory (of which Lavoisier is often considered the "father") over phlogiston theory (of which Priestley is seen as a zealous and misguided defender). Yet this divergence signified a more critical difference, the two experimentalists disagreed on the fundamental definition of atmospheric air. Priestley followed the traditional view in which there was such a thing as "common air" that had its own defined qualities and properties.[84] Lavoisier, in a proposition that signaled a decisive change in chemical theory, declared that there was no such thing as a generic common air. Instead, he claimed, atmospheric air is actually a predictable and measurable mix of individual chemical components, oxygen and nitrogen. This conclusion along with a series of other suppositions undergirds the "chemical revolution" attributed by later historians to Lavoisier. The central tenet Lavoisier's theory, which persist to the present day, imagines a world of matter composed of combinations of irreducible chemical elements. For Priestley, there was an element called "water." For Lavoisier, there was a combination of hydrogen and oxygen.[85]

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[84] John G. McEvoy, "Gases, God and the balance of nature: a commentary on Priestley (1772) 'Observations on different kinds of air'" *Philosophical Transactions of the Royal Society A* 373 (2015): 8

[85] Today's periodic table of elements is an outcome of Lavoisier's thinking

### *Air in Reform and Revolution*

Historians have mined this rivalry between Priestley and Lavoisier to great effect, but to see the work of each experimenter within their own individual medical, institutional, and national contexts reveals two fundamentally different interpretations of the role of air in political economy that persist long into the nineteenth and twentieth centuries.[86] Articulation of these two themes is critical to understanding how and why later physicians, reformers, administrators, and politicians described aerial issues in particular ways and what solutions they posed for social and medical improvement.

For both experimentalists, the study of air had implications far beyond the laboratory. In Priestley's case, his "aerial philosophy" held promise for a better politics founded on expert knowledge of natural phenomenon, a perspective later adopted into Jeremy Bentham's philosophy of utilitarianism and vision for moral management through material means. His experiments and theories also formed the basis for a new technical instrument that allowed its user to claim the relative "goodness" of the air in a particular location. Lavoisier's early experiments with air influenced directly the reform building programs of the monarchical government, and his later studies of respiration addressed inequalities at the foundation of the political revolution in France. Although he was eventually executed for his association with the monarchy's tax collector, Lavoisier in the years leading up to and just after 1789 addressed his research toward the social crises emerging from food shortages and new modes of work. The tensions between two approaches would re-emerge multiple times in discourses of air and heat through the early twentieth century.

[86] John G. McEvoy, "Gases, God and the balance of nature," 8-9; Robert E. Schofield, "Joseph Priestley." *Complete Dictionary of Scientific Biography*, (Charles Scribner's Sons, 2008), 147

**Comfort, Necessity, Economy**

In his well-known 1776 treatise *Inquiry into the Nature and Causes of the Wealth of Nations*, Adam Smith suggested that for the newly consuming middle-class, necessity no longer had to be defined as the bare minimum required to avoid death, rather it could be determined by popular opinion. Any item, including fuel for heat, could be called necessary if its lack would bring shame to an individual. In turn, comfort "consisted in satisfying the necessities of life."[87] Smith linked comfort with the material world and thus emphasized physical surroundings. The eighteenth century's concomitant culture of sensibility encouraged reflection on one's own emotions and sensations, and the expanding material culture allowed one to acquire goods and to enhance pleasurable or reduce unpleasant sensations.[88]

Smith ran into difficulty though when extending the same reasoning to England's "laboring population." With a greater availability of goods formerly held as luxuries, critics complained that "the laboring poor will not now be contented with the same food, cloathing and lodging which satisfied them in former time." Smith countered that the material improvement of the lot of the laboring poor must be considered an overall good, for "No society can surely be flourishing and happy, of which the far greater part of the members are poor and miserable."[89] Indeed, Crowley argues that by the end of the eighteenth century physical comfort as an ideal and a right had "gained sufficient ideological force" that humanitarian campaigns to aid the poor, incarcerated, or the enslaved appealed to this

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[87] Crowley, *The Invention of Comfort*, 166

[88] Crowley, *The Invention of Comfort*, 166

[89] Adam Smith *An Inquiry into the Nature and Causes of the Wealth of Nations* [1776], ed. R.H. Campbell and A.S. Skinner, 2 vols. (Oxford, 1976; repr. Indianapolis: Liberty Classics, 1981), Book I, Chapter viii, 35-36 quoted in Crowley, *The Invention of Comfort*, 164; second quote is from *Adam Smith An Inquiry into the Nature and Causes of the Wealth of Nations* [1776] (London: T. Nelson and Sons, 1868), Book I, Chapter viii, 33.

concept when requesting assistance from better-off patrons. Entreaties to imagine the physical discomfort of those in need encouraged the propertied to act.[90]

Ideas and uses of comfort played a role the philosophies of political economists of the succeeding decades. Thomas Malthus, the controversial writer who espoused a rather unsympathetic position on population growth among the poor, reasoned that the desire for comfort might operate as an effective check on this expanding population. The poor would work hard and exercise the restraint Malthus thought necessary for population control (i.e. men and women would marry later in life and have less children), in order to earn enough to enjoy a basic level of comfort.[91] Agricultural improver Nathaniel Kent, writing in 1789 to his fellow reformer Coke of Norfolk suggested that landlords of large properties would be well served to build for their tenant laborers improved cottages for the tenants will then "have some Interest in their Dwellings and possessing comforts superior to those who have not the same advantages" and thus "will be the last men to risk them by joining occasional Tumults." Equally beneficial, the comfortable cottages would make these inhabitants "the least likely to become a burden upon the parish."[92]

**Dissenting Economies: Joseph Priestley's Air**

Although Priestley frequently claimed to be disinterested politically, his philosophy of science imagined radical social, political, and epistemological reform. In the context of an industrializing Britain, Priestley's science was a means by which to wrest power from the reigning aristocracy and to reimagine and realign English society toward the interests of the new bourgeois industrial class. As such, Priestley's prodigious scientific and philosophical work invoked a conflict between progressive and conservative elements in

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[90] Crowley, *The Invention of Comfort*, 143
[91] Crowley, *The Invention of Comfort*, 169-170
[92] Quoted in Crowley, *The Invention of Comfort*, 220.

British society. The conservative side, exemplified in the person and writing of Edmund Burke represented the established aristocracy, the inheritors of property and title in a Parliament whose power was closely tied to the Anglican Church. The progressive side, populated by natural philosophers and Unitarians like Priestley and industrialists such as Matthew Boulton and Josiah Wedgewood, called for numerous reforms, including the expansion of suffrage, the restructuring of Parliament to give greater representation to newly populated industrial cities like Birmingham, Manchester, and Leeds, and the repeal of the Test and Corporation Acts, which required anyone seeking governmental employment or admission to the universities at Oxford or Cambridge to pledge loyalty to the Church of England.[93]

For Priestley and his fellow travelers, the function of natural philosophy and experimental science was demystification, but not for the greater knowledge of God's design, as it had been for Bacon and Boyle, but rather for the obliteration of superstitions and mythical constructions that undergirded the power of the aristocratic class. In the reformist view, the aristocracy held a power tied to superstition emerging from "the mystery and awe of ancient institutions" (divine kings, titles, chivalry, and the like, played out in rituals and pageantry). In opposition, science would reveal the "real" picture of the natural world and the laws that governed it. The aristocracy would have no legitimacy to rule in this reimagined world.[94]

The reforming middle class believed they deserved such power because, unlike members of the aristocracy, who in the eyes of the reformers were lazy and unproductive, they were useful, hardworking, efficient, and would inevitably secure happiness, increase

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93 Isaac Kramnick, "Eighteenth-Century Science and Radical Social Theory: The Case of Joseph Priestley's Scientific Liberalism" *Journal of British Studies*, Vol. 25, No. 1 (Jan., 1986): 4.

94 Kramnick, "Eighteenth-Century Science and Radical Social Theory," 3, 9

comfort, and eliminate pain and disease for all in society. Indeed, the industrialists saw themselves as having already contributed more than their share to the power and wealth of the nation, and they had faith in their ability to effect through science unbounded progress toward the ultimate elimination of all pain and suffering.[95]

The dual projects of demystification and eradication shaped the questions that Priestley asked in his celebrated experiments with air in the 1770s and 1780s. The outcomes of this work were both pragmatic and metaphysical, and in some cases directly applied to medical problems. Although not a physician himself, Priestley's social and intellectual circles were populated with a "new breed" of physicians, who focused on the health of large populations, particularly those in the military and in growing industrial towns. Rhetorically, they positioned themselves in contrast to their predecessors in the seventeenth century who primarily served aristocratic clients.[96]

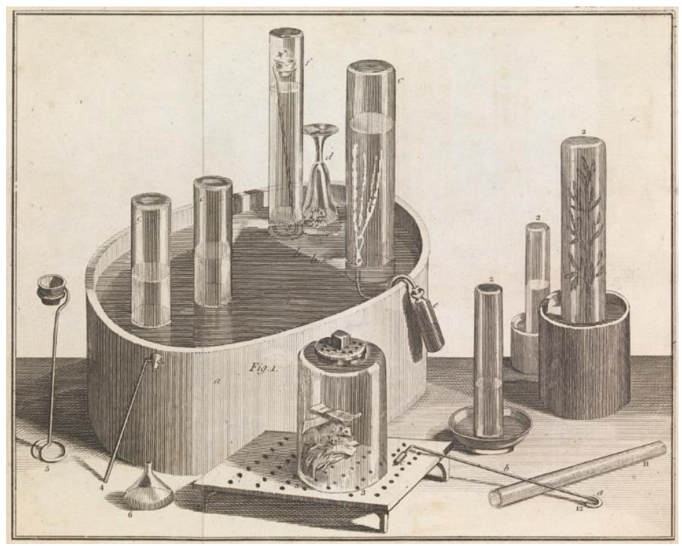

Figure 2.9 Priestley's chemical apparatus for his experiments on fixed air, 1790. Credit: Wellcome Collection, CC BY 4.0.

Priestley's work in pneumatic chemistry was clearly informed by his relationship with Sir John Pringle, whose influence in London's scientific community had expanded since the publication of his manual of army hygiene (Figure 2.9). Now the president of the

[95] Kramnick, "Eighteenth-Century Science and Radical Social Theory," 8, 12
[96] Christopher Lawrence, "Priestley in Tahiti: The Medical Interests of a Dissenting Chemist," in *Science, Medicine and Dissent: Joseph Priestley (1733-1804)* edited by R.G.W. Anderson and Christopher Lawrence (London: Wellcome Trust, 1987), 3

Royal Society, Pringle's support for the controversial selection of Priestley as the recipient group's prestigious Copley medal lent Priestley's work legitimacy and drew attention to specific elements that fit into Pringle's paradigm of air and disease.[97] In his address describing the work for which Priestley was receiving his Copley medal, Pringle emphasized three of Priestley's series of experiments with air. The first, a method to reliably dissolve "fixed air" into water, was eminently pragmatic and addressed directly Pringle's interest in treatments for putrid fevers. The second was more expansive, reimagining as it did human-nature relations. In attempting to determine a substance or action that could renew air "vitiated" by human respiration, Priestley found that plants "reverse the effects of breathing."[98] Pringle framed Priestley's results as a demonstration of the rationality of the natural world and the ultimate serviceability of nature to human, nothing, he assured his audience, grew in vain.[99]

### ***Nitrous Air, Good Air, and Eudiometry***

Yet it was the third series of Priestley's experiments that Pringle thought the "most brilliant." The results of this work was a tool, an air test by which one could, Priestley purported, judge the "goodness" of air. For Priestley, the goodness of air represented the extent to which a sample of air could support respiration or combustion.[100] By this test, Priestley claimed, he had established a "prodigiously large scale, by which we may distinguish very small degrees of difference in the goodness of air."[101] Priestley's test was

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97 Dorothea Waley Singer "Sir John Pringle and His Circle--Part III. Copley Discourses," *Annals of Science* 6 (1949-1950): 249.
98 Joseph Priestley, "Observations on Different Kinds of Air," *Philosophical Transactions* 62 (1772): 193
99 Christopher Lawrence, "Priestley in Tahiti," 8.
100 Simon Schaffer, "Measuring Virtue: Eudiometry, Enlightenment, and Pneumatic Medicine" in *The Medical Enlightenment of the Eighteenth Century*, eds. Andrew Cunningham and Roger French (Cambridge: Cambridge University Press, 1990), 286
101 Priestley, *Experiments and Observations* (Birmingham, 1790), vol 1, p 354-364, quoted in Schaffer, "Measuring Virtue," 287.

performed in his laboratory and required custom equipment and unique skills, but the test found its way beyond the walls of the laboratory with the development of a portable instrument called the "eudiometer" ("literally, the measurement of good weather") by Priestley and collaborators in Italy and Austria (Figure 2.10).[102] This new instrument, its promoters claimed, was an improvement on the traditional tools of medical meteorology. Not dependent on repeated observations and retrospective analysis, the eudiometer could give a reading of air's salubrity in real time, and the granularity of its scale made it possible to take measurements indoors.[103]

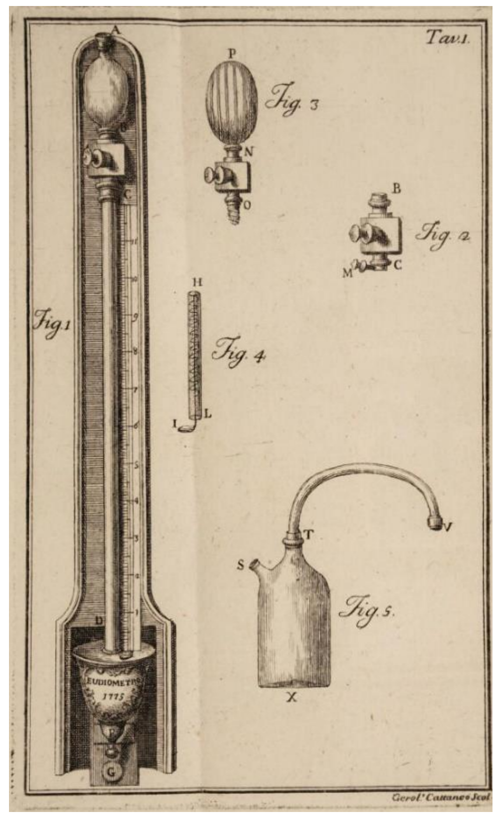


Figure 2.10 Eudiometer by Priestley's collaborator Marsilio Landriani, 1775. Published in Landriani's *Ricerche fisiche intorno alla salubrità dell'aria*. Credit: Wellcome Collection CC BY 4.0.

Priestley's work and its resulting instrument were of a piece with his reform philosophy. As the designer of a purportedly neutral technology by which a location's healthiness is supposedly measured, Priestley not only created the power to judge the "virtue" of a place, but he could also propose an alternative future in which England's productivity could be analyzed and managed by expert scientists and their instruments. Priestley's planned eudiometric survey of air in agricultural and manufacturing regions across England would give him and his reforming allies a tool by which to critique

102 Riley, *The Eighteenth-Century Campaign*, 50-51; Schaffer, "Measuring Virtue," 295.
103 Schaffer, "Measuring Virtue," 296

the existing social order. Similarly a eudiometer could be used to find "bad" air in public places and thus wielded as a disparaging assessment of "the old governing classes."[104]

Eudiometry was ultimately a failure, not only in the terms of natural philosophy, but also in its alignment with failed—at least for the moment—political reform efforts. At the level of data collection, eudiometric readings, claimed by Priestley to correspond to a sensitive scale of a place's goodness, varied wildly. Often readings taken at different times of day in the same place varied more than readings taken in two different place. More importantly, eudiometric scores did not seem to align with any mortality patterns. However, the decisive blow to eudiometry came with its political affiliations. Priestley's vision of progressive rational Dissent in England was directly challenged in 1791 by a conservative "church-and-king riot" in his home town of Birmingham that burned his house and laboratory and forced him to flee to America.[105]

### *A Philosophy of Air and Total Institutions*

The radical philosophy of Priestley and his circle imagined political, spiritual, and economic liberation of the new middle class from the tyranny of the aristocratic hierarchy and promised a better future for all with less sickness and suffering. But, as Kramnick points out, this required the simultaneous repression of the poor, served up under the guise of "improvement" and delivered through institutions they aimed to create or reform: hospitals, penitentiaries, and factories. The poor, they thought, had an unfortunate tendency toward idleness and must be taught both self-reliance and self-discipline. If they were to be the good, healthy workers that would make the new manufacturing ventures thrive, they must internalize a desire to be "methodical, clean, prompt, frugal, and industrious." This

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[104] Schaeffer, "Measuring Virtue" 290-291, 295

[105] Riley, *The Eighteenth-Century Campaign,* 50-51; Schaeffer, "Measuring Virtue," 309, 311, 314-315

could be achieved through the teaching and preaching of middle-class values, as some of Priestley's fellow travelers suggested, but Priestley was against state-sponsored education, on the grounds that it would likely "indoctrinate whatever authorities take as truth or whatever serves their interest" and thus hinder the "flourishing of truth, variety, and improvement."[106] Thus the solution to the problem of the poor must thus be physical, not psychological.

While this may seem like a strange proposition, it emerged through David Hartley's theory of associationism, which conjectured that the operations of the human mind were materially based and thus ultimately knowable and moldable. Following on the seventeenth-century theories of sensationalism posed by Hobbes and Locke, Hartley imagined the mind in terms of physiological processes that "associated" external sensations into an orderly consciousness. Unlike a philosophy that imagined mind (or soul) and body and wholly separate entities, Hartley's construction saw the activities of the mind as physical, determined by natural laws discoverable through experimentation and observation. This had two critical implications: people's minds were directly influenced by their circumstances and environments, and they could be shaped through education.[107] Contra a rigid social hierarchy, the world imagined by supporters of Hartley's theories was eminently open to change and improvement.

Because this philosophy erased the line between mind and body, its proponents envisaged a society in which social and moral behavior was managed through physical

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[106] Kramnick, "Eighteenth-Century Science and Radical Social Theory," 18-19, 30

[107] Kramnick, "Eighteenth-Century Science and Radical Social Theory", 15-16: "Hartley, without the evidence of the American or the French Revolution, read the history of mankind as one of inevitable progress. From its infancy, mankind, with its 'mind a blank, void of ideas, as children now are born,' had grown through the process of the association of ideas to an adulthood in which its knowledge and happiness would inevitably be paradisiacal. Presiding over the workings of the association principle was God and his providentially designed "system of benevolence," which would lead individuals in society "to promote the welfare of others." This moral sense was not innate, as the Scottish philosophers argued, but "generated necessarily and mechanically"

means, specifically “by disciplining…bodies via pleasure and pain.” This required expert knowledge and management. Some pictured this job falling on the shoulders of the scientist or medical doctor.[108] Others such as the political philosopher Jeremy Bentham, who credited Priestley's *Essay on Government* (1768) for the phrase that embodied his philosophy of Utilitarianism, “the greatest happiness of the greatest number,” argued that the figure of the legislator was required to enact such extensive change, for “the art of legislation is but the art of healing practiced upon a large scale. It is the common endeavor of both to relieve men from the miseries of life. But the physician relieves them one by one: the legislator by millions at a time.”[109]

The political and legislative target of both Priestley and Bentham was the English poor laws, which since the Elizabethan era had guaranteed charitable support for the needy. This beneficence not only encouraged idleness and dependency, Priestley claimed, but it also limited the mobility of the workforce, as poor-law distributions were made depending on one’s permanent residence in a particular parish. Institutional discipline, although in the short term limited some freedoms, would in the end make everyone ultimately more autonomous and independent, as the poor having learned to be industriousness and self-reliance were rewarded with middle-class freedom.[110]

Reformers in both Britain and France inspected institutions and institutional buildings and found them wanting.[111] In practice the reformers had economic imperatives as much as humanitarian ones. In order to discourage dependency (which made for high costs), reformed hospitals and like institutions had to heal or redeem the poor in order for

[108] Kramnick, “Eighteenth-Century Science and Radical Social Theory,” 24-25
[109] Bentham quoted in Dorothea Waley Singer, “Sir John Pringle and His Circle—Part I. Life,” *Annals of Science* 6 (1949-1950): 145, and in Schaeffer, “Measuring Virtue,” 317
[110] Kramnick, “Eighteenth-Century Science and Radical Social Theory,” 27
[111] The most well-known example of this inspection effort in Britain was John Howard’s *The State of the Prisons in England and Wales*, published first in 1777.

them to enter or return to the workforce. The confined environment thus had to be studied, understood, and improved in order to carry out the agenda of reform (Figure 2.11). In France this meant the application of Lavoisier's new theory of air directly to prisons, hospitals, and asylums.

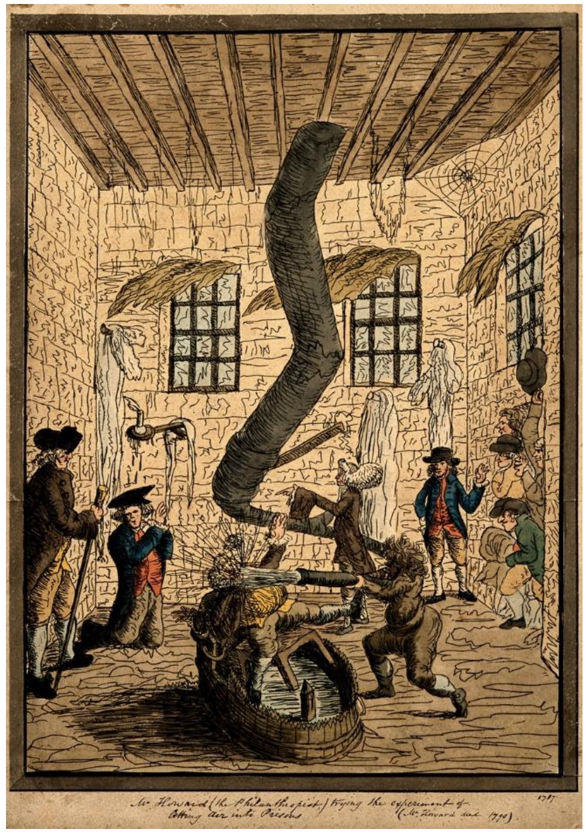

Figure 2.11 Mr. Howard trying the experiment of letting air into prisons, 1787. Clearly, reformers were not exempt from satire. Credit: Wellcome Collection CC BY 4.0

### Breathing Economies: Antoine Lavoisier's Heat

Antoine Laurent Lavoisier's most famous treatise, *Elements of Chemistry*, the text that first introduced the concept of the chemical element, was published in the year of the French revolution, but his theories of human respiration, work, and nutriment dealt more directly with the issues at the heart of the revolution itself. Lavoisier's first publication of this theory of respiration came in 1777, with the paper *Experiments on Animal Respiration*, delivered to the French Academy of Sciences. In this paper he laid out his theory of gas exchange in respiration in which an animal inhales "oxygine," (now oxygen) and exhales "carbonic acid" (now called carbon dioxide) in nearly equal volume.[112]

[112] J.B. West, "The collaboration of Antoine and Marie-Anne Lavoisier and the first measurements of human oxygen consumption," *American Journal of Physiology-Lung Cellular and Molecular Physiology* 305 (2013): L776

Lavoisier's experimental work on respiration carried forward Hales's and Priestley's conviction that humans could only survive for a limited time in a confined space, but his new theory of air's composition defined the qualities of vital air more narrowly, and it extended its purview beyond the boundaries of medical space. In Lavoisier's model respiration changed the composition of the air itself, and this happened "quite independently of the adverse effect on the air due to disease as a result of a mixture of contaminated secretions in the exhaled air." This deterioration of the air was caused as much by the healthy as the sick person.[113]

Lavoisier explained the spatial implications of this phenomenon. As the varying densities of the three components of air caused them to settle into layers in a given space, Lavoisier asserted that in buildings where many people have breathed, the products of respiration stratify. The heavier fixed air will sink to the floor, where the lighter "mophette" (nitrogen) will rise to the ceiling. Lavoisier claimed that he had confirmed this theory using Priestley's nitrous air test on samples taken at various heights in hospital wards and in public halls. These results should inform building design, Lavoisier maintained. Particularly in hospital wards, provision should be made for openings at the top and bottom of each ward (high windows and low doorways) to facilitate the escape of both the mophette and the fixed air.[114]

### *Balanced Airs, Guinea Pigs, and Crowds*

Lavoisier was not satisfied with leaving his work at the theoretical stage. He advocated its application to concurrent problems of the state, specifically the king's

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[113] Jacques Tenon, *Memoirs on Paris Hospitals* [1788] edited and with an introduction, notes, and appendices by Dora B. Weiner (Canton, MA: Science History Publications, USA, 1996), 179

[114] Frederic L. Holmes, *Lavoisier and the Chemistry of Life: An Exploration of Scientific Creativity* (Madison: University of Wisconsin Press, 1985), 94-95

quandary over the reconstruction of the Hôtel-Dieu, the hospital that had served the poor of Paris for several centuries. Part of the hospital, infamous for its overcrowded wards and high mortality rate, had burned several years before, and the public debate about the hospital's future was heated. Lavoisier bureaucrats to take advantage of the work of experimentalists such as himself.[115]

Although Academy members were not invited to comment officially on the Hôtel-Dieu project until almost ten years later, Lavoisier consulted on prison reform projects and continued to refine his spatial theory of air. The refinement was shaped in part through his close collaboration with physician and chemist on a potential treatment for asphyxiation. The problem of suffocation was not new to medicine, but the potential of Lavoisier's theory of air posed new possibilities for treatment. To explore this potential, Lavoisier and his associates in 1777 and 1778 performed approximately two hundred experiments with live animals, in which they asphyxiated various animals in different gases (fixed air, vapor from charcoal, inflammable air) and attempted to revive them with various agents.[116]

One particular case within the research regime caught Lavoisier's attention and significantly influenced his theory of respiration. In January 1778, the researchers placed a guinea pig in a bell jar filled exclusively with "eminently respirable air" (oxygen). After only two hours, the guinea pig fell over and died. To Lavoisier's surprise, upon testing the air remaining in the bell jar, he found that there was still a large quantity of respirable air remaining. The guinea pig had not died from a lack of respirable air, but rather from prolonged exposure to it. From this result, Lavoisier surmised that "eminently respirable air" alone was poisonous to animal life. Instead, animals needed a 'just proportion' of

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115 Holmes, *Lavoisier and the Chemistry of Life*, 95
116 Holmes, *Lavoisier and the Chemistry of Life*, 130-132

respirable air and mophette.[117] This conclusion had substantial implications for space conditioning. With previous theories of confined air it was adequate simply to move quantities of air through a space, replacing vitiated air with fresh, but with Lavoisier's construction of air, a much greater level of precision tuning was required to achieve what he defined as a salubrious balance of air in an enclosed space.

At the same time that his theory narrowed the definition of healthy air, Lavoisier suggested that attention to conditions of air was required for a broader population and a wider set of spaces. This became particularly clear in a paper he delivered at the Royal Society of Medicine early in 1785. The paper "Memoir on the alterations which take place in the air in the ordinary circumstances of society," as the title submits, asserted that the air was a problem not just for the spaces of the sick, rather it was now a problem for healthy people in "ordinary"—albeit crowded—spaces. A healthy well-to-do person attending the opera was as much in danger as a poor patient suffering in the confines of a hospital.[118]

As one of the few papers that Lavoisier presented at the Society of Medicine instead of the Academy of Sciences, this one interpreted his laboratory work for a medical audience. The central inquiries of the paper, addressed the concerns of doctors, not just scientists. He began with a restatement of the common understanding that animals will only live a limited amount of time in a confined quantity of air, but Lavoisier added a new twist.[119] He had determined that the typical composition of the atmosphere was 27 percent vital air (oxygen) and 73 percent mophette (nitrogen), but that if this proportion varied just a little bit, the air would become unrespirable. Ironically, respiration itself could cause the

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[117] Holmes, *Lavoisier and the Chemistry of Life*, 135-136

[118] Holmes, *Lavoisier and the Chemistry of Life*, 238.

[119] Denis I. Duveen and Herbert Klickstein, "Antoine Laurent Lavoisier's Contributions to Medicine and Public Health," *Bulletin of the History of Medicine* 29 (Jan 1, 1955), 168; The inquiries were "What are the alterations that this air undergoes during different conditions of society? What is their influence on the respiratory organs? What disorders in the animal economy can result from these alterations, and what methods are there for preventing or remedying them?"

dangerous proportional change. This was especially the case in confined spaces crowded with many people. As the group converted oxygen to carbon dioxide, the delicate proportion of oxygen to nitrogen shifted out of balance, creating a perilous environment.[120]

With this new theory, Lavoisier medicalized non-medical space, as the theory applied to the hospital and the theater alike. Lavoisier reinforced his point by collecting samples the air in both places, from the Hôtel-Dieu and the palace of the Tuileries, where the Comedie Française was performing to a crowded theater. At the hospital, he sampled air at the floor and ceiling of a ward, and at the theater, he gathered air samples from the orchestra pit and an empty upper-level box. At the lower levels in each setting, Lavoisier found that the air differed little from outdoor air, but at the upper levels, he found the proportion of oxygen was diminished by up to a fourth and the proportion of carbon dioxide increased. From this, Lavoisier defined salubriousness in volumetric terms, giving the example that in a theater with the dimensions thirty by twenty-five feet and a ceiling thirty feet high, an audience of a thousand people would make the air unrespirable within five to six hours, if not adequately ventilated. This was categorically different from the spread of disease by the "infectious exhalations" of the sick individual who happened to be present in a crowded space.[121]

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[120] Holmes, *Lavoisier and the Chemistry of Life*, 238-241; Duveen and Klickstein, "Antoine Laurent Lavoisier's Contributions," 168, footnote 25

[121] Duveen and Klickstein, "Antoine Laurent Lavoisier's Contributions," 168; Holmes, *Lavoisier and the Chemistry of Life*, 238-241; Of course, Lavoisier had to reconcile the fact that opera attendees did not drop dead in the way that his experimental animals did. He reasoned that the effect in a crowded hall was rather more subtle. As the air became less respirable over the course of two or three hours, the audience's attention would flag. Indeed, in his experience delivering papers to the members of the Academy of Sciences he observed at the end of long sessions an "*impatience machinale"* among the attendees. An unfortunate circumstance for the final speaker of the evening, but one that could be attributed to the deterioration of the atmosphere (Regarding the attention span of the audience at the Academy of Science Holmes seems to take Lavoisier in earnest; Duveen seems to take it as a joke).

The ideas that came from Lavoisier's laboratory were quickly extrapolated to medicine and architecture, even when Lavoisier himself thought his results were only preliminary. He acknowledged that the measurements taken at the hospital and theater "were not carried out with as much care as I would have wished," and that they really should be repeated many times, perhaps by an official government body, before any final conclusions could be drawn. Nonetheless, countless subsequent figures used his premise and evidence to argue for particular modes of ventilation in buildings.[122] What they did not immediately pick up, however, was Lavoisier's theory of respiration. The French revolution saw to that.

### ***Air, Food, Work, and Revolution***

Although he was eventually executed in 1794 for his long association with the king's tax collectors, Lavoisier in the years just after 1789 addressed his research toward the social crises emerging from food shortages and changing modes of work in France. As Dana Simmons suggests, Lavoisier's efforts to reimagine human respiration as combustion represented a model for a new social order, one in which the terms of work and wages would not be set by the market, but by a scientifically determined equivalence of human labor and sustenance.[123]

At the heart of Lavoisier's model was the animal economy, the quantifiable exchange between a human body and its environment (food and air in, heat and air out). Essential in this economy was a model in which respiration must be understood as

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[122] Holmes, *Lavoisier and the Chemistry of Life*, 238-241, 415. For example, Jacques Tenon applied Lavoisier's ideas to the determination of ward ceiling height in his *Memoirs on Hospitals*. Holmes attributes this tendency to "a typical eighteenth-century pattern of spinning broad systems of disease and treatment out of thin strands of empirical observations"

[123] Dana Simmons, *Vital Minimum: Need, Science, and Politics in Modern France*, (Chicago: University of Chicago Press, 2015), 2, 20.

combustion, a process “that consumes a portion of the individual’s substance at every moment.”[124] In his laboratory experiments, Lavoisier captured the exhalations of human subjects performing varying levels of physical or mental labor and measured what he saw as byproducts of bodily combustion (Figure 2.12). In doing this, Lavoisier quantified, ranked, and classified both manual and sedentary work based on the physical exertion required to perform such labor. In a fully rational world, Lavoisier imagined, each individual would be apportioned the exact amount of nutriment necessary to replenish the fuel performing a particular type of labor.[125]

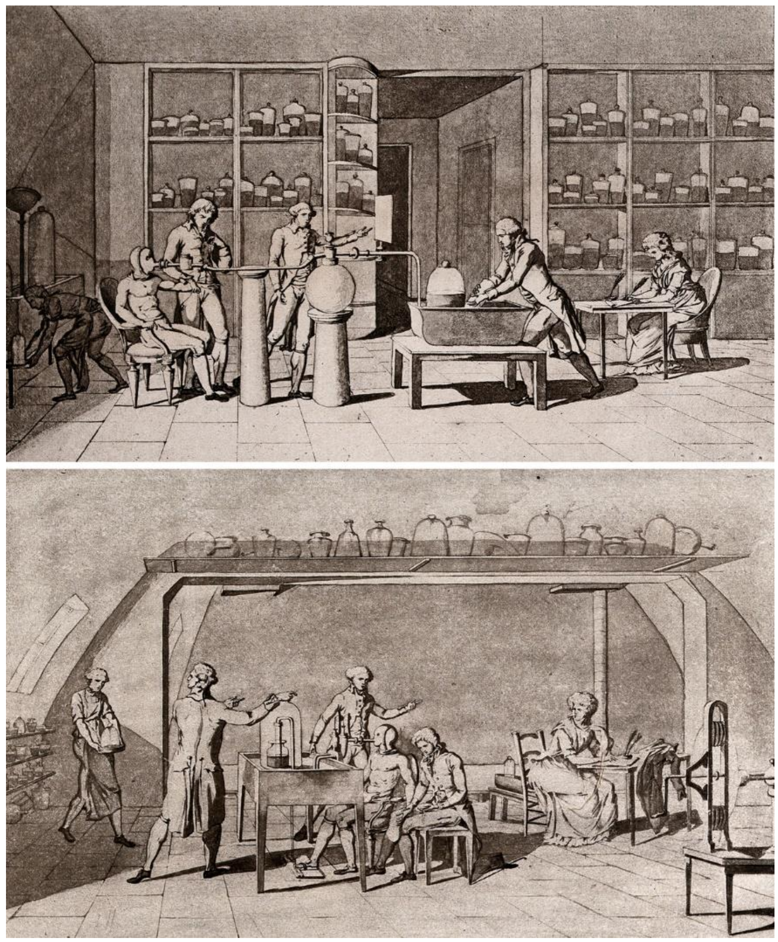

Figure 2.12 Lavoisier measuring respiration of man resting (top), at work (bottom), c. 1790. Credit: Wellcome Collection CC BY 4.0

These dynamics were brought into balance by what Lavoisier considered to be the three regulators of the ‘animal machine,’ respiration, digestion, and transpiration. Digestion provided the input

124 Antoine Laurent Lavoisier and Armand Séguin, “Premier mémoire sur la respiration des animaux,” 698, quoted in translation in Dana Simmons, *Vital Minimum*, 3.
125 Dana Simmons, *Vital Minimum*, 18-19

(nutriment/fuel) for combustion, and respiration signified combustion of that nutriment, which resulted in the production of heat (caloric). Transpiration managed the output (heat), by either retaining or released caloric, depending on environmental temperature.[126] "Compensations" among these three regulators allowed animals to maintain body temperature constancy despite differing environmental conditions. Conversely if conditions were too extreme, the body could not compensate, and disease might ensue.[127]

Lavoisier's model of respiratory equality and confidence in the redeeming power of science met a similar, if not as violent, end in France. Natural philosophers and medical experts of the early nineteenth century turned away from Lavoisier's all-encompassing formulas of environmental exchange and focused on individual bodies and organs in isolation. They left behind Lavoisier's mechanistic formulations in pursuit of a more vitalist approach.[128] This particular formulation of Lavoisier's thinking would not return to medical or scientific discourse until the latter part of the nineteenth century.

### Aerial Economies: Thomas Beddoes's Pneumatic Institution

Back in Britain, scientists and physicians struggled to resolve conflicts between Priestley's and Lavoisier's theories of air, but implicitly they struggled with the consequences of the revolution in France as it mutated into the Terror. This was the predicament of Thomas Beddoes, a physician and chemist and a member of Priestley's social and intellectual circle, who in 1798 opened the Pneumatic Institution in Bristol to pursue application of Priestley's theories to issues of both illness and poverty. Beddoes had adopted Lavoisier's new theory of chemical elements, but he maintained faith in Priestley's

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[126] Duveen and Klickstein, "Antoine Laurent Lavoisier's Contributions to Medicine," 168 note 21.
[127] Holmes, *Lavoisier and the Chemistry of Life*, 458
[128] Dana Simmons, *Vital Minimum*, 21; Anson Rabinbach, *The Human Motor: Energy, Fatigue, and the Origins of Modernity*, (Berkeley, Los Angeles: University of California Press, 1992), 64.

postulate that good air could directly ameliorate and improve human bodies. This was necessary, because although he had supported the revolutionaries in France early on, he saw it turn dark, and feared that the same pattern of events could play out in Britain.

With the support of Thomas Wedgewood and the technical assistance of James Watt, both also members of Priestley's circle, Beddoes constructed an apparatus for research and application of 'factitious airs' to patients in various stages of consumption (Figure 2.13).[129] These custom airs, nitrous oxide being the most infamous, could now be artificially produced using the knowledge and techniques developed by Lavoisier, and Beddoes in an unsettled society dreamed of a settled future made better by "pneumatic medicine." At first, Beddoes and his young assistant, Humphry Davy, did research on themselves and members of the "middling and affluent" classes that could afford courses of treatment, but as economic and social conditions in England worsened with a string of several bad harvests and a resultant rise in food prices Beddoes figured he could offer his treatments to the impoverished, even changing the name of his institution to the Institution for the Sick and Drooping Poor. Despite several years of research and a surprising finding that nitrous oxide

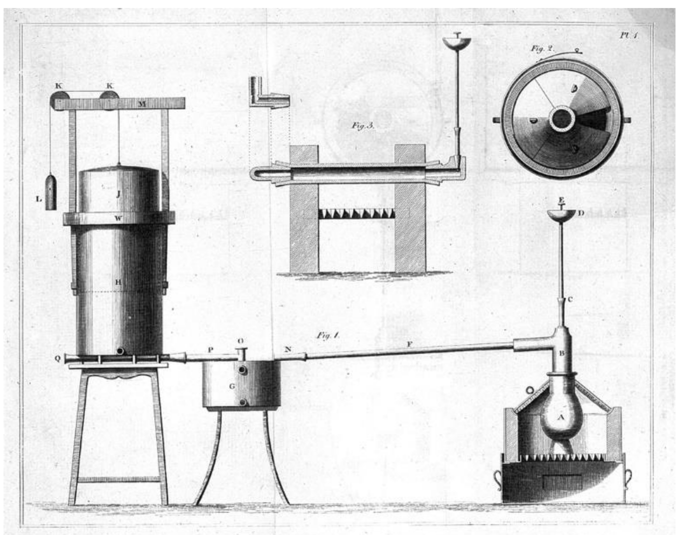

Figure 2.13 Apparatus for procuring air, 1794-6 from *Considerations on the medicinal use of factitious airs and on the manner of obtaining them in large quantities* by Thomas Beddoes and James Watt. Credit: Wellcome Collection CC BY 4.0

[129] James Watt also had a personal stake in the matter. His beloved daughter had been diagnosed with and eventually died of consumption.

could possibly be used as an anesthetic, Beddoes did not see the results he had hoped for. Humphry Davy left the Institution to join the staff of the Royal Institution of Great Britain, another organization aimed at applying research in chemistry to technical and social problems, but Beddoes up to his death in never lost faith in the redeeming possibility of air.[130]

Although the aerial tools of biopower were developed in preliminary form in earlier decades, in this chapter we observed the emergence not only of a theory of confined space that allowed air to take on new medical meanings but also a newly quantified theory of airs and bodies derived originally from a desire to increase the productivity of plants. This theory, applied *en masse* to bodies in confined spaces offered a method by which the health of a population, in this case military, could be managed. Through the advocacy of Stephen Hales and John Pringle, the idea of air as preventive medicine expanded to some non-military settings. These ideas were studied and refined in the labs of Joseph Priestley and Antoine Lavoisier and through their networks and connections, were applied as an instrumental tools of institutional reform, making institutions such as prisons and hospitals operate more efficiently to make the poor more healthy and more productive. In the following chapter, we will observe Edwin Chadwick and apply this idea to the "labouring population" at large.

[130] Trevor Levere "Dr. Thomas Beddoes The Interaction of Pneumatic and Preventive Medicine with Chemistry" *Interdisciplinary Science Reviews*, 7, no. 2 (1982): 137-147.

# Chapter 3. The Factory Question: Confined Air, Illness, and Industrialization

In the spring of 1833, when John Elliot Drinkwater, a barrister and civil officer for the Factory Inquiry Commission, asked Elizabeth Fowke, a "girl, turned fifteen," about her health and her experiences working at the spinning mill of Messrs. G. and J. Mills in Nottingham, she began with a reply quite like that of the other twenty or so workers whose statements had been abstracted for the Commission's report on the conditions of factory work, "been here since I was quite a child; health very good; the girls generally have very good health." But this young worker elaborated, "You see, sir, we have plenty of air. There's one bad thing here (*laughing*), we have no over-hours. I've heard of your coming and what it was about. I think it is a very good thing. I hope you won't make us work shorter hours though."[1] This testimony is exactly what Drinkwater hoped to hear, for the Commission had been formed earlier in 1833 by conservative Member of Parliament Wilson Patten to counteract the highly unfavorable evidence presented in a scathing parliamentary report on the conditions and health of factory workers presented the year before by Leeds MP Michael T. Sadler, the *Report of the Select Committee on the Bill for the Regulation of Factories*.[2] Sadler's purpose had been to encourage passage of a bill that would limit the number of hours that children, then a significant part of the factory

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[1] J.T. Ward *The Factory Movement 1830-1855* (London: Macmillan & Co., 1962), 88. Factories Inquiry Commission *Second Report of the Central Board of His Majesty's Commissioners appointed to collect Information in the Manufacturing Districts as to the Employment of Children in Factories, and as to the Propriety and Means of Curtailing the Hours of their Labor* (London: Ordered, by the House of Commons, to be Printed 15 July 1833), 1, italics in original. Elizabeth Fowke's full testimony is documented in the *First Report of the Central Board*, section C1, page 61.

[2] This title is from Clark Nardinelli, "Child Labor and the Factory Acts" *The Journal of Economic History*, 40, no. 4 (Dec, 1980): 739-755. A copy of the report, held by the University of California, shows as its title, *Report from the Committee on the Bill to regulate the labour of children in the mills and factories of the United Kingdom* (London: Ordered, by the House of Commons, to be Printed 8 August 1832). It is often commonly referred to as the "Sadler Report."

workforce, could work in a day. His aim was to rescue young people from "that over-exertion and long confinement," which was "utterly inconsistent with the development of their minds, the preservation of their morals and the maintenance of their health."[3] The hope of many of Sadler's supporters was that the limitation of children's workday to ten hours would by extension limit adults' working hours.[4]

This is not how it turned out. The Factory Commission's report, written by its ostensible chair Edwin Chadwick, devised a cunning inversion. It proposed to limit the workday hours of children under thirteen to nine hours, an hour less the opposition's ten-hour maximum, and to require that all children spend a certain number of hours in school. The recommendation, which became the basis for the subsequent (1833) law, had the opposite result for adult workers, however, because it allowed for two shifts of child workers, in effect extending or maintaining the adults' workday to around fifteen hours.[5] For any residual negative health effects for adults, Chadwick would blame the confined space of the factory itself, not the hours spent there. Although some Commissioners admitted that there was "much contradictory medical evidence," the report implied that a factory's temperature, ventilation, dustiness, and plumbing—its "sanitary" condition—should be the real concern, not its labor practices.[6]

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[3] Sadler quoted in Ward, *The Factory Movement,* 58

[4] Christopher Hamlin, *Public Health and Social Justice in the Age of Chadwick, Britain 1800-1854* (Cambridge; New York: Cambridge University Press, 1998), 97; Robert Hyde Greg Robert Hyde Greg, *The factory question, considered in relation to its effects on the health and morals of those employed in factories, and the "Ten hours bill" in relation to its effects upon the manufactures of England, and those of foreign countries* (London, J. Ridgway and Sons, 1837), 7.

[5] Hamlin, *Public Health and Social Justice in the Age of Chadwick,* 97.

[6] Hamlin, *Public Health and Social Justice in the Age of Chadwick,* 98, 101; Factories Inquiry Commission *Second Report of the Central Board* (Printed 15 July 1833), 2. The *Second Report* points specifically to the *First Report* on Glasgow submitted by James Stuart [which seems to be mistakenly written as Stewart in this instance], 83. Stuart notes that the factories was discussing had recently had disputes over the introduction of female workers, which resulted in the "violent resistance from the Glasgow Association of Spinners."

Although many were sympathetic to the idea that children were the most vulnerable workers, the Commission argued the drawing of spatial and temporal limits around age-limited labor with a specific physiological basis. This is why Elizabeth Fowke's age was particularly important for Commission inquirers to record, because it helped to establish the age at which "fatigue, drowsiness, and pain produced in young children by ordinary factory labour" began to diminish. Based on interviews with dozens of young factory workers, the medical commissioners determined that these negative effects lessened to the point of safety by "about the eleventh or twelfth year, and wholly or nearly cease at the age of adolescence or puberty."[7] The age limitation thus addressed questions of both productive and reproductive control, for "according to physiologists, both English and French," puberty began earlier for females than males, and it was important to protect the vulnerable health of young females such that it did not damage their ability to have large families when leaving the factory upon marriage.[8]

Workers wanted time, employers offered space. Workers believed it was the low pay and long hours that lead to so many workers' early demise. Labor activism demanded not only higher wages, but also shorter hours. Industrialists and civil administrators maintained that the answer was a question of space. Many argued that the bad condition of the air in factories was the true cause of worker illness. Others removed the cause even further from the factory, claiming it was the bad air of the workers' dwellings that were at the root of the problem. Powerful players in this dispute often drew on (or funded) new

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[7] Factories Inquiry Commission *Second Report of the Central Board* (Printed 15 July 1833), 1.

[8] Factories Inquiry Commission *Second Report of the Central Board* (Printed 15 July 1833), 1 in a starred footnote attributed to T.S.S. (Thomas Southwood Smith). The commissioners do not argue directly that girls need to be excluded from factory work until puberty because of reproductive issues, but it enters their line of argument: It must not be factory work itself causing the problems, because those girls "brought up in factories, and married from thence" are healthy, because they "have almost always large families of children, [but]…ventilation of factories will, [Southwood Smith is] persuaded, tend much to improve the health of the workers" *Second Report*, 2.

scientific explanations and new developments in technology to support their positions. Theories of respiration and the "animal economy" that emerged from late-eighteenth century studies in human physiology and pneumatic chemistry shaped approaches to diseases and "confined" space in the 1830s and later. An extension of these new theories was the idea that buildings and technologies that delivered more air could be a panacea. By treating the air, policy makers could avoid addressing workers' calls for shorter hours or a more equitable distribution of wealth.

This chapter explores how this use of air as a compromise and a framing device in early disputes over factory labor evoked technological resolution to questions of work, health, and space. Critical to this discourse is the displacement of specific worker demands for shorter working days by discussion of abstracted physiological relationships between human bodies and confined air. It will describe first the situation in Chadwick's London, as embodied in the recommendations in Chadwick's influential 1842 report. It then follows those ideas as they transferred to America, both to industrial Massachusetts and to urban New York in the first half of the nineteenth century. In the years following the American Civil War, public health attention followed children out of the factories into the schools, where a whole new set of relationships between physiology, air, and mental fatigue absorbed administrators, advocates, engineers, and now architects. These ideas were supported by new "oeconomical societies" as well as serial publications and professional societies that endorsed and promoted a new kind of "sanitary architecture."

### THE "FACTORY QUESTION"

The "illiberal spirit, misstatements, and calumnies" of an 1836 *Quarterly Review* article on the factory system motivated Robert Hyde Greg, proprietor of a major cotton manufacturing concern in Manchester, to push into publication his pamphlet, "The Factory

Question and the Ten Hours Bill," seemingly at his own expense. The situation was made more urgent by activities in Parliament that suggested a law restricting the working hours of adults might be soon passed.[9] The "evils of the factory system" had been "much exaggerated," Greg contended, but while the interference into private industry was not welcome, factory owners could live with it.[10] The problem was that the "ten-hours" advocates just kept coming back for more. Pretty soon, Greg claimed foreign competition from growing textile industries in France, Switzerland, America, and other places would soon overtake Britain's traditional dominance in the field.

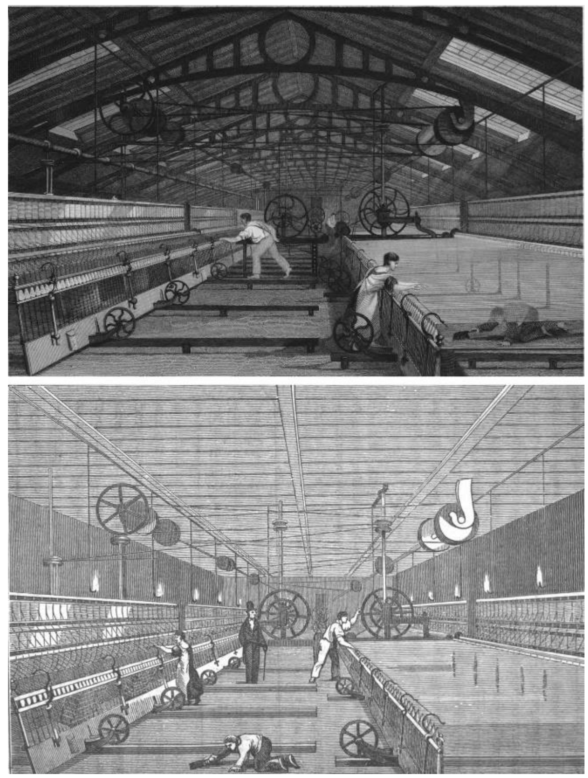

Figure 3.1 Two interior views of cotton mills, 1830s. Both images were produced by supporters of the factory system, Edward Baines (top) and Andrew Ure (bottom).

Greg never defines the "factory question" outright. It was not necessary at the time, for as he says, it "has been so long before the public."[11] The factory question essentially had two parts, however. The first posed whether the "factory system," as most called it at the time, was detrimental to the health or morals of the operatives who were employed in it (Figure 3.1). The second half of the question was contingent on the first. If the factory system was indeed damaging

9 Robert Hyde Greg, *The factory question, considered in relation to its effects on the health and morals of those employed in factories, and the "Ten hours bill" in relation to its effects upon the manufactures of England, and those of foreign countries* (London, J. Ridgway and Sons, 1837), Advertisement, np, 74.
10 Robert Hyde Greg, *The factory question* (1837), 23.
11 Robert Hyde Greg, *The factory question* (1837), 4.

to health or morals, and many claimed that it was not, the question was whether anyone should do anything about it. Although Greg's intimation that government would soon intervene to the point of industrial paralysis and decline was certainly exaggerated, he was responding to what appeared like an accelerated pace of new legislation and regulation of factories since the beginning of the century.[12] Yet while the factory itself seemed like a new type of spatial relations—activities like spinning that used to be carried out in individual homes were now performed collectively in one location—its health problems in the beginning were familiar to well-read physicians. Just like in jails, hospitals, and ships, it was the same fever, it simply broke out in a new form of confined space, the factory.

### Factory Fevers, Factory Air, Factory Acts

In 1784 an outbreak of "jail fever" occurred at Robert Peel's (1750–1830) Radcliffe cotton mill near Manchester. While the workers themselves claimed that the conditions in the large, hot mill caused the fever, Peel countered that the fever was contagious and had spread from a nearby town.[13] A group of physicians, led by Thomas Percival, was called in by the local magistrates to investigate the source of the fever. The physicians could not determine which party was correct as to the source of the disease, but they reasoned that the factory conditions likely aggravated it, following Pringle's confined-space disease-generation logic. They made nine recommendations for prevention of future outbreaks; the first three were aimed at improving the ventilation in the factory. The final

[12] Greg includes a joke attributed to Horace Walpole at the opening of his pamphlet that is indicative of his slippery-slope attitude: "My aunt, Mrs. Kerwood, reading one day in the papers, that a distiller had been burnt, by the head of the still flying off, said she wondered that they did not make an Act of Parliament against the heads of stills flying off."

[13] J. V. Pickstone and S. V. F. Butler, "The Politics of Medicine in Manchester, 1788-1792: Hospital Reform and Public Health Services in the Early Industrial City," *Medical History*, 28 (1984), 232.

recommendation suggested the “indulgence” of limiting hours for workers, particularly those under fourteen.[14]

This event that many claimed as the first of its kind recorded in England, repeated in various forms in the following years, and as steam power allowed factories to relocate closer to population centers they became a bigger concern for urban dwellers. Industrialists sought ways to mitigate the perception of health implications, protecting themselves against a key criticism of their rivals and workers. Medical advisors, typically aligned with industrialists, found ways to deflect attention through two strategies, by making quantifiable recommendation for increased ventilation at the factory buildings themselves and by shifting medical attention to non-factory spaces, namely homes and hospitals.

Towards this end, in 1796 Percival led the founding of the Manchester Board of Health. Although the Board of Health resolved that “large factories were generally injurious to the constitution of those employed in them,” they instead focused primarily on the living conditions of the workers. A medical inspectorate was established to police the whole community of the poor (doctors inspected homes and removed anyone suspected of fever to a specialized fever hospital). Taken at face value, this was a pragmatic direction; factories were privately held and often too remote from towns for regular inspection.[15] But it was also a skillful change of subject. Reformers could “fix” the housing issue and presume to solve the bigger problem without disrupting prevailing social and economic organization. That said, as more factories were built closer in to Manchester proper, physicians such as Dr. John Ferriar, an associate of Percival’s, began petitioning

[14] A. Meiklejohn, “Outbreak of Fever in Cotton Mills at Radcliffe, 1784,” *British Journal of Industrial Medicine* 16/1 (Jan, 1959), 68-69
[15] Pickstone and Butler, “The Politics of Medicine in Manchester,” 237

manufacturers to limit nighttime working hours and to "adopt other hygienic practices" especially during outbreaks of fever.[16]

In 1800, yet another fever broke out in Manchester, and in an effort to remain in control of potential regulation by the state, Peel himself proposed legislation, the *Health and Morals of Apprentices Act*, passed by Parliament in 1802.[17] At the time and later, most saw the law as primarily limiting the allowable working hours for all "pauper apprentices" under twenty-one years of age, but it also included regulation of the factory space itself. The law required that mills and factories whitewash their walls and "provide a sufficient number of Windows and Openings in such Rooms or Apartments, to insure a proper Supply of fresh Air in and through the same."[18] These rules, along with provisions for the summoning of a physician should fever break out, the arrangement for non-crowded sleeping accommodations, and the annual allotment of new clothing, comprised the "health" components of the law. The regulation of "morals" came through stipulations requiring separate sleeping arrangements for males and females, daily instruction in reading, writing and arithmetic, and regular church attendance on Sundays.[19]

As the application of steam power over the next decade allowed more factories to locate near urban centers, the employment of apprentices declined, but the employment of young children in general grew. At the urging of the progressive factory owner Robert Owen, Peel proposed a new law, the Cotton Mills and Factories Act of 1819, which

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[16] Joanna Innes "Origins of the factory acts: the Health and Morals of Apprentices Act, 1802" in *Law, Crime and English Society, 1660-1830,* edited by Norma Landau (Cambridge; New York: Cambridge University Press, 2002), 239.

[17] Joanna Innes "Origins of the factory acts," on the fever outbreak, 239, on Peel's motivations, 249.

[18] Text of 1802 Act quoted in W.R. Lee, "Emergence of occupational medicine in Victorian times," *British Journal of Industrial Medicine* 30 (1973), 119. Although the term "apprentice" recalls earlier forms of work in small shops, at the turn of the nineteenth century, an apprentice was essentially an orphan or other ward of the state who was contracted out from their home parish, often to a distant factory. This was a common employment practice at the time because early factories, as they had to be cited at sources of water power were often far away from urban centers had difficulty recruiting workers otherwise.

[19] Joanna Innes "Origins of the factory acts," 231.

excluded from employment all children under age nine and limited the working day of those under sixteen years to a maximum of twelve hours a day, with no nighttime work.[20] Peel left Parliament in 1820, but MP John Cam Hobhouse introduced a bill in 1825 to reduce the children's labor to 11 hours a day because even though some mills were well regulated, in others children were "daily suffering under an atmosphere, the temperature of which is warmer than the warmest summer days." Much debate ensued, with some arguing that such an act would result in mass layoffs, others that it was not limiting enough. Later in 1826 a less restrictive bill passed, restricting work during certain times of day, but not limiting the total number of hours worked.[21]

All this legislative action prior to the 1833 Factory Act occurred against a backdrop of increasing worker agitation over introduction of machinery, lowering of wages, and limited workers' representation in Parliament. The Combination Act of 1799 restricted union organization, although strikes over wages and other issues were fairly regular especially in Manchester, and the repeal of that law in 1824 saw much new union activity.[22] The jarring fluctuations of the international markets underlay much of the discontent and displacement. For instance, as Richard Guest, writer of the 1823 *A Compendious History of the Cotton-Manufacture*, saw it the reopening of trade with the Continent at end of the Napoleonic Wars in 1814 had caused a flood of unregulated exports and a significant reduction in workers' wages. This was certainly the cause for a subsequent increase in the Poor Rates, Guest contended, and most likely the reason for "much of the misery, tumultuous assemblages and riots, which took place in 1819," a reference likely to the "Peterloo" incident in Manchester, at which a number of laborers rallying for an extended

[20] Ward *The Factory Movement*, 27.
[21] Ward, *The Factory Movement*, 28-29
[22] Ward, *The Factory Movement*, 6

franchise were killed by authorities.[23] Workers' efforts to limit their own hours are less well documented than those of Parliamentary reformers, but J.T. Ward suggests that their motives were towards "spreading employment, to maintain children's wages and to restrict the age of entry, while retaining their traditional control over child workers."[24]

### Factory Constitutions, Factory Consumption

By the 1830s, fever was no longer so closely associated with factories, but barring a few industry cheerleaders most parties acknowledged that factory work was in some way damaging to health.[25] Some economists argued that despite some negative effects, factory work raised a worker's general standard of living relative to a life in agricultural labor. Others framed it as simply a trade-off. Workers tacitly accepted the health risks of factory labor when they accepted a certain level of wages as compensation for it. Those who met factory workers in dispensaries, infirmaries, and hospitals were not so sanguine. Many medical professionals spoke out about what they saw, scores of pale and sickly workers, not always presenting with acute, identifiable sickness, but rather with "a continual tendency to disease."[26]

But if there were no clear, distinguishable disease like fever associated with factories, what did health in the factory mean in the 1830s? Certainly, there were truly traumatic accidents that maimed and deformed factory workers, but concern about this was not always the focus.[27] Instead, medical theory precipitated around issues of constitution, a person's general state of health and capacity to withstand acute disease when exposed. In

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[23] Richard Guest, *A Compendious History of the Cotton-Manufacture: with a Disproval of the Claim of Sir Richard Arkwright to the Invention of its Ingenious Machinery* (Manchester: Printed by J. Pratt, 1823), 35.
[24] J.T. Ward, *The Factory Movement*, 28
[25] Hamlin, *Public Health and Social Justice*, 39.
[26] Hamlin, *Public Health and Social Justice*, 39.
[27] Hamlin, *Public Health and Social Justice*, 38

discussions of the state of factory workers, physicians posed a physiological explanation. The natural, healthy functions of workers' bodies were slowly but nonetheless insidiously undermined by their everyday work.

This explanatory model could account not only for higher rates of illness among workers, but also for what appeared to be a prevalence of consumption among factory workers. Clinical experience seemed to demonstrate that factory workers died more often from consumption than the general population. This complicated the debate because unlike fever which could arise and abate quickly, consumption was a slow degenerative disease, making it difficult to associate with a specific cause. Consumption had long afflicted many in the British population, but the general statistics put its menace in high relief. It was responsible for at least twenty-five percent of all deaths in the British Empire.[28] William Farr, the well-known medical statistician for the British General Register Office, asserted that "consumption is the greatest, the most constant, and the most dreadful of the diseases that affect mankind. It is the cause of nearly half the deaths that happen between the ages of fifteen and thirty-five years."[29]

Medical perspectives on consumption, were shifting with new etiological theories offered by physician James Clark, outlined in his 1835 book *A Treatise on Pulmonary Consumption*. Clark maintained that while consumption was indeed hereditary, he theorized it more as a predisposition (a "cachexia") rather than a fatal certainty. Given this model, Clark focused not on the health history of one's parents or other ancestors, but rather on the living and working conditions that might cause one's hereditary disposition to develop into full-blown consumption. In many ways, this was a variation on Clark's

[28] Hamlin, *Public Health and Social Justice*, 62.
[29] William Farr, "Letter to the Registrar General on the Causes Of Death in England in 1852," *Fifteenth Annual Report of the Registrar-General of Births, Deaths, and Marriages in England* (London: Longman, Brown, Green, and Longmans, 1855), Appendix, 66.

parallel work describing the beneficial effects of certain climates on chronic diseases, consumption in particular.[30] That work was clearly aimed at the travel-enabled wealthy classes, but the local conditions Clark identified as disease-provoking in the treatise were those characteristic of industrializing Britain, not only poor-quality food and inadequate clothing but also poor ventilation, bad lighting, and overwork.[31]

According to Clark, the risk was especially high for children, and "the earlier the causes of tuberculous cachexia are applied, the more speedily it will be induced." It would only take a few months for an infant, even if "born in perfect health and of the healthiest parents," to develop the cachexia if the infant "be confined to rooms in which free ventilation and cleanliness are neglected."[32] Although a number of circumstances promoted the cachexia, Clark's biggest concerns were food and air. Most beneficial to health, Clark maintained, were "the proper adaptation of food to difference of age and constitution, and the constant supply of pure air for respiration," but the general public were "at present most ignorant of them."[33]

## CHADWICK'S ANSWER

Many traditional histories recall Edwin Chadwick (1800-1890), the British civil servant and social reformer, as the heroic instigator of the first "modern" public health agency, the General Board of Health, established in 1848, but in his day he had a lot of problems. The underlying issue, of course, was the simultaneous growth and urban shift in population beginning in the closing years of the eighteenth century. Despite years of bad

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30 James Clark, *The Influence of Climate in the Prevention and Cure of Chronic Diseases, More Particularly of the Chest and Digestive Organs: Comprising an Account of the Principal Places Resorted to by Invalids in England, the South of Europe, &c* (London: Thomas and George Underwood, 1830). The third edition of the book is entitled *The Sanative Influence of Climate* (London: Murray, 1841).

31 Hamlin, *Public Health and Social Justice*, 62

32 Clark, *A Treatise on Pulmonary Consumption*, 174

33 Clark, *A Treatise on Pulmonary Consumption*, 178

harvests and frequent epidemics, there were more, not less, people in England and Wales, and industrial opportunity as well as exclusion through various rural enclosure acts drew many of these people as well as those from Scotland and Ireland to emerging manufacturing centers.[34] The dirty world of Charles Dickens emerged; poverty and sickness abounded.

Many proposed approaches to these problems, one of the most extreme being Thomas Malthus, whose ultimate do-nothing philosophy would have famine and disease do the dirty work of thinning the population. Others looking to France or Prussia supported proactive, centralized management, but this was not a good fit for the relatively loose and liberal form of government in England.[35] Chadwick, following his mentor Jeremy Bentham, brought a utilitarian philosophy to prevail on the situation. Yet a Benthamite ethic prescribing actions bringing the most good to the greatest number, did not automatically presume the material form of Chadwick's answer to the problems of poverty and premature death, namely the systems of urban drainage, sewerage, and water supply for which Chadwick is most often glorified. Chadwick made some specific and not necessarily intuitive decisions here, and this is where it gets interesting. As Christopher Hamlin reminds us, historians tend to take Chadwick's sanitary measures as a foregone conclusion, but rather than assuming that everyone just *naturally* needed drainage, water, and air, historians should ask what other avenues were possible and perhaps why they were not taken.[36]

At the heart of the problem for Chadwick was the relationship between poverty and disease. Chadwick's position at the time he managed the survey and writing of the 1842

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[34] Hamlin, *Public Health and Social Justice*, 2-3.
[35] Hamlin, *Public Health and Social Justice*, 5.
[36] Hamlin, *Public Health and Social Justice*, 10

report *The Sanitary Condition of the Labouring Population* was as the secretary to commission responsible for successful carrying out of the new Poor Law, which had gone into effect in 1834. English poor laws had been first codified during the reign of Elizabeth I, and they entitled all residents of a particular parish to direct monetary assistance if parish administrators approved. Motivations for poor law reform were multiple and complex, including the dislocations caused by the end of the wars with France in 1815, but its outcome was certainly controversial. The new law centralized many decision-making functions once allotted at the local parish level, and it banned "outdoor relief," namely the direct aid to families that allowed them to stay in their own homes within the parish. The only direct assistance now available was "indoor relief" to be given only to those willing to enter one of the newly organized workhouses. The theory was that this reform would assist only the truly poor, who had no other options than the workhouse, and eliminate assistance to paupers, individuals who, according to the Commission, chose not to work but rather to live in a state of indolence explicitly enabled by poor relief payments.[37]

Critics of the New Poor Law—and there were many—claimed that it offended notions of Christian charity and left far too many people destitute and hungry, for working wages and employment stability were often not enough to keep many families from struggling. More often than not, the critics asserted, this lead to near starvation, and in this weakened state disease easily took hold. One such critic was William Lovett, a former cabinet maker, trade unionist, and radical leader in the Chartist movement.[38] Lovett's response to the 1832 cholera epidemic is telling. Where religious leaders called for a penitential fast (a common practice), Lovett called for a feast, for the "ravages made by

[37] Hamlin, *Public Health and Social Justice*, 90.

[38] The Chartists aimed to gain the right to vote for working men left out of the suffrage expanding Reform Act of 1832, which had limited the expansion only to property-holding men (i.e. broadly, the middle class)

that dreadful disease were chiefly to be attributed to the want and wretchedness that prevailed there."[39] Another perspective was offered by the Scottish physician William Alison. In Alison's view, it was not any contagious element that should be a physician's primary concern, but rather the "misery" among the poor that provided a fertile ground for an invasion of sickness.[40] Misery's specific mechanism, that is exactly how "deficient nourishment, want of employment, and privations of all kinds, and the consequent mental depression favour[ed] the diffusion of fever," was still open to examination, Alison allowed, but "that they have that effect in a much greater degree than any cause external to the human body itself, is a fact confirmed by the experience of all physicians who have seen much of the disease."[41]

Chadwick's response to these types of criticisms was to invert them. It wasn't that poverty caused sickness, but rather that sickness caused poverty. Healthy workers did not need assistance, but when they got sick, they could not work, and consequently became destitute. Chadwick's proposal would take it one step further, premising an ounce of prevention for a pound of cure. He would prevent pauperism by preventing disease, for this was certainly cheaper than supporting paupers after they got sick.[42] As Chadwick put it, the "comparative ease and economy of measures of prevention rather than of relief."[43] Christopher Hamlin persuasively argues that Chadwick's project was not one of discovery,

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[39] Hamlin, *Public Health and Social Justice*, 86; Lovett quoted in Hamlin, but in the original *William Lovett, Life and struggles of William Lovett in his pursuit of bread, knowledge, and freedom, with some short account of the different associations he belonged to and of the opinions he entertained* (originally published in 1876, reprinted as New York: Alfred A. Knopf, 1920).

[40] For an expanded discussion of the medical theory of "misery," see Christopher Hamlin, "William Pulteney Alison, the Scottish Philosophy, and the Making of a Political Medicine," *Journal of the History of Medicine and Allied Sciences*, 61, no. 2 (April 2006), 163.

[41] William Pulteney Alison, *Observations on the Management of the Poor in Scotland, and Its Effects on the Health of Great Towns*, 2nd ed. (Edinburgh: Blackwood, 1840), 10-11, quoted in Hamlin, "William Pulteney Alison," 164.

[42] Hamlin, "Edwin Chadwick and the Engineers," 683

[43] Edwin Chadwick, *Report on the Sanitary Condition of the Labouring Population of Great Britain* (London: Clowes, 1842), 104.

of finding the right answer to a clear problem, but rather one of critical framing that allowed him to propose a simple technocratic solution to a complex social problem. As Hamlin sees it, Chadwick directs attention to epidemic disease and its promised removal by a sewering scheme, obscuring systemic problems contributing to disease rates, such as poverty and malnutrition, even though some members of the medical community advocated the latter.

**The Internal Economy**

When Chadwick sat down in the late summer of 1840 to interview fifty-two year old journeyman tailor Thomas Brownlow, his first questions were not about Brownlow's own health, the bodily demands of piecework, or the long hours spent with the needle, but rather about the space where Brownlow carried out his tasks. The room at the Messrs. Allen's workshop, where Brownlow had worked for eight years, was about sixteen to eighteen yards long and about seven or eight yards wide. Eighty men worked together in this room lit by skylights, but although the men sat "as loosely as they possibly could," the heat and closeness of the room in summer at times felt unbearable. It was worse in winter, Brownlow observed, when shorter daylight hours required the burning of more candles, and the men squabbled endlessly over the cold drafts that blew through the space when someone opened a window.

In his interview of Brownlow, Chadwick was gathering evidence for his seminal 1842 report, *The Sanitary Condition of the Labouring Population of Great Britain,* to support his theory of why so many workpeople of this "particular class" died inordinately young. Chadwick's spatial questions persisted. "What was the effect of this state of the work-places upon the habits of the workmen?" Chadwick asked. Brownlow responded with the reasoning of contemporary medical theory, "It had a very depressing effect on the energies…The natural effect of the depression was, that we had recourse to drink as a stimulant." And the effect on their health? "Great numbers of them die of consumption. 'A decline' is the general disease of which they die." How much longer could a man work in "a well-ventilated or uncrowded room, as compared with a close, crowded, ill-ventilated room?" Chadwick inquired (Figure 3.2). Brownlow estimated perhaps two more hours a day. Armed with this information from Brownlow (although one suspects that the answers may have been suggested in advance by his interlocutor), Chadwick offered a positive calculation. If proper ventilation was provided in the workshop, a man could accumulate the value of an additional 50,000 hours of productive labor over the course of his working life, allowing him to accrue at least 600*l* that could "maintain him in comfort when he is no longer able to work."[44]

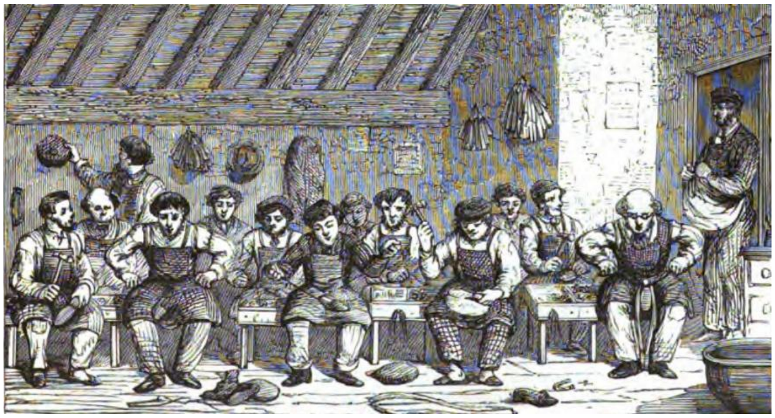

Figure 3.2 View of shoemakers' workshop from *Another Blow for Life*, 1864. The author, George Godwin, was an enthusiastic supporter of Chadwick's and translated many of Chadwick's concepts into practice through his journal *The Builder*.

This estimate represents Chadwick's calculation of the "internal economy," which attributed not only "the loss of healthful existence and happiness to the labourer, the loss of profit to the employer, and of produce to the community" but also more critical for Chadwick—then serving as secretary to the British Poor Law Commission—the "loss in expenditure for the relief of the destitution" to an "original cause," bad ventilation. Yet in Chadwick's calculation, bad ventilation was a good thing, because it represented an easily

[44] Edwin Chadwick, *Report on the Sanitary Condition*, 101

quantifiable factor that fit into an equation that could be solved, and more importantly, solved more cheaply and finitely than other, more boundless problems. In its explicit context, Chadwick's mathematical balance spoke to the immediate concerns of the Poor Law Commission, which had convened in 1832 to address increasing demands for relief payments to the poor, but in its finite, actionable nature, Chadwick's model provided implicit relief to those worried about the steeper economic and social costs of labor strikes, unrest, and possibly revolution.

Ventilation thus addressed not just a knotty administrative problem, but also a deep-seated dispute about industrializing society. By framing the issue in this particular way, Chadwick was able to claim that workers' bad health and shockingly early demise were due not to the arduous demands of newly industrial forms of work, but rather to the spatial conditions that accompanied them.[45] For Chadwick, regular health inspection of workplaces would function especially "to disabuse the popular mind of much prejudice against particular branches of industry." Many were mistaken, Chadwick claimed, in thinking that the causes of illness and shortened life were "*essential* to the employment itself," rather than simply "*accidental* and removable, and sometimes unconnected" to industrial work. Critically outside Chadwick's frame were the more systemic problems of industrialization. The laboring classes did not suffer more than others because they lacked adequate wages or sufficient food, as some were arguing, but rather because they lacked ample quantities of good air. All of the numerous problems consequent to the laboring classes—medical, moral, and otherwise—could be linked to "the operation of one

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[45] This revisionist reading of Chadwick's project was first suggested by Christopher Hamlin, *Public Health and Social Justice in the Age of Chadwick, Britain 1800-1854* (Cambridge; New York: Cambridge University Press, 1998).

predominant cause;—bad ventilation or overcrowding."[46] This was the *real* cause according to Chadwick.

To reassure his audience, Chadwick invoked "high scientific authority" as proof that such problems of air and ventilation could be "easily and economically controllable."[47] Although Chadwick does not provide a specific reference for this authority, David Boswell Reid, chemist, ventilation adviser for the new Parliament buildings, and investigator for Chadwick's supplementary report, pointed to the scientific inquiries of the nature and composition of air(s) made by Priestley, Scheele, Lavoisier, and Black as constitutive. Indeed, Reid claimed, without the work of those scientists "the term Ventilation could have had no distinct and definite meaning, such as is now attached to it."[48] Chadwick's other, even closer adviser on ventilation, physicist Neil Arnott, also carried forth a Newtonian faith in science, with its envisioned capacity to reveal the "harmonious laws of nature, mechanical, chemical, and vital."[49] Yet this was an instrumental knowledge. The more scientists knew about air, the more they could manage and control it.

The same held true for the study of human bodies and their operations, or as many called it, the "animal economy." Both Arnott and Reid were also trained as physicians, although their work represented the rising discipline of physiology, not clinical medicine (treating individual patients and their particular afflictions). Physiology, which many

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[46] Chadwick, *Report on the Sanitary Condition*, 98, 113 emphasis in original.
[47] Chadwick, *Report on the Sanitary Condition*, 98
[48] Reid, David Boswell. *Illustrations of the Theory and Practice of Ventilation, with Remarks on Warming, Exclusive Lighting, and the Communication of Sound*, London: Longman, Brown, Green, and Longmans, viii. Carl Wilhelm Scheele (1742-1786) and Joseph Black (1728-1799), were, respectively Swedish and Scottish chemists. The plural form "airs" is used to signify that until settlement of the "phlogiston" debate between Priestley and Lavoisier, most scientists (natural philosophers at the time) held that there were many different kinds of air, hence Priestley's six volumes entitled *Experiments and Observations on Different Kinds of Air* (1774–86).
[49] Neil Arnott, *On Warming and Ventilating; with directions for making and using the thermometer-stove, or self-regulating fire, and other new apparatus*. London: Longman, Orme, Brown, Green, and Longmans, 1838, 1.

described as the scientific examination of the normally functioning body, aligned with a new approach to health, critical to Chadwick's model, predicated on prevention rather than cure. The approach premised that the more one knew about how the body functions in health, the more one could maintain that healthy condition. Although Chadwick's concern was a civilian population, his method was deeply informed by military physicians' experiences maintaining the health of standing armies and navies. As in the military, the health of the "laboring classes" required both frugality and some form of evidence-based accounting. Dr. Southwood Smith, perhaps Chadwick's closest medical adviser, made clear this link in his retrospective *Philosophy of Health*, "a knowledge of the structure and functions of the human body…a most interesting branch of science, is necessary to a rational care of health."[50]

This combined knowledge of airs and bodies not only informed Chadwick's recommendation for an economical and environmental 'solution' to the Poor Law Commission's problems, but it also shaped how later policy makers, physicians, engineers, architects, and health advocates thought about buildings and building technologies. Although its construction and motivation have sometimes changed, the concept that one can most efficiently *maintain* the body by treating the air confined within a building's walls has persisted through time. Yet the 1840s mark a period when building experts began to think about buildings beyond shelter and symbol, as discrete containers for an artificially created and carefully controlled environment, and approaches that had previously been confined to institutional buildings made their way into common architectural discourse.[51]

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[50] Southwood Smith, *The Philosophy of Health; or, An Exposition of the Physiological and Sanitary Conditions Conducive to Human Longevity and Happiness* (London: Longman, 1865), vi. The 1865 edition is a revised version of the 1837 edition in two volumes.
[51] Robert Bruegmann, "Central Heating and Forced Ventilation: Origins and Effects on Architectural Design" *Journal of the Society of Architectural Historians*, Vol. 37, No. 3 (Oct, 1978): 160.

Chadwick's 1842 report is well known to historians of public health and urban planning. It is most typically cited as the inspiration for the heroic works of urban infrastructure that sewered and drained extensive sections of London and other towns Britain. Perhaps because its interventions were less visible, less attention has been paid to the parallel section of Chadwick's report, concerning the "internal economy and bad ventilation of places of work" as well as lodging-houses, dwellings, and "the domestic habits affecting the health of the laboring classes."[52] The indoor section (part III of the 1842 report), which Hamlin does not emphasize in his analysis, presents a second but equally important framing action carried out by Chadwick, this one addressing residual concerns from the Factory Act of 1833. In the face of an even more vocal Ten Hours movement, Chadwick performs a double recasting. The first and perhaps most crucial is a spatial relocation of the problem, declaring it more a problem of houses than of factories, an argument similar to that made in Manchester in the 1790s by Percival and Ferrier, who Chadwick cites in the report. As Chadwick put it in the report:

> The Factory Inquiry, and more recently on the cases of children of migrant families, that opinion is erroneous which ascribes greater sickness and mortality to the children employed in factories than amongst the children who remain in such homes as these towns afford to the labouring classes. However defective the ventilation of many of the factories may yet be, they are all of them drier and more equably warm than the residence of the parent; and we had proof that weakly children have been put into the better-managed factories as healthier places for them than their own homes.[53]

The second recasting was to put everything in the air. Reintroducing the issues that had come up in earlier debates over the Factory Act, Chadwick provided a resolution that invited action, just a very particular type of action.

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[52] Chadwick, *Report on the Sanitary Condition*, 98.
[53] Chadwick, *Report on the Sanitary Condition*, 158

While the two sections of Chadwick's share many similarities, there are some critical differences. The outdoor section is concerned with epidemic diseases, especially fever of the type that concerned John Pringle (see previous chapter). The indoor section is concerned with chronic diseases, particularly consumption. Chadwick's often quoted proclamation, "all smell is disease," certainly applies to the outdoor section, which deals with human waste and other "nuisances." But the converse, that all disease was not smell, is the concern of the indoor section, where many of the dangerous elements of air were thought insensible to humans.

The organizational models that provided Chadwick with his model of "prevention rather than relief" were military (especially naval) medicine and prison administration. These were theories and success stories that Chadwick's associates claimed had been neglected or overlooked relative to civilian non-prisoners. Indeed, Thomas Southwood Smith, one of Chadwick's chief medical advisors, cites Pringle as someone who had "given valuable lessons to the world, which have been forgotten, and to which it is a useful labour to recall the attention of the present age."[54]

**The Removal of Many Agents: Thackrah's Health and Longevity**

Yet while navies and prisons provided useful approaches, they did not offer models that could translate directly to populations neither conscripted nor imprisoned. For that Chadwick turned to the work of Charles Turner Thackrah (1795-1833), a Leeds-based physician, whose popular 1831 treatise, *The Effects of the Principal Arts, Trades, and Professions, and of Civic States and Habits of Living, on Health and Longevity,* provided medical model for addressing the laboring body. Thackrah had provided testimony to

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[54] Smith explains his theory of fever as an extension of Pringle's theory, i.e. that the immediate "exciting" cause of fever was decaying vegetable or animal matter in Southwood Smith, *A Treatise on Fever* (Philadelphia: Carey & Lea, 1830), 362.

Sadler's committee, and Christopher Hamlin suggests that Chadwick ignores Thackrah in his report, but even if Chadwick did not cite Thackrah directly, Thackrah's explanatory model and some of his recommendations suited Chadwick's case and are critically embedded in the 1842 report.[55]

Although a study of occupations and health was not a new form—the Italian physician Bernardo Ramazzini had published *De Morbis Artificum* (The Diseases of Artisans) in 1700—Thackrah's 1831 treatise exhibited a shift in perspective on the risks of industrial work since the late eighteenth century, when physician (and close associate of Joseph Priestley) Erasmus Darwin (1731-1802) enthused that industrial work had great benefit, as it was so much less demanding than traditional agricultural work. The experience of several generations of industrial workers left few able to argue that factory work was healthy, although some did so, and most commentators, especially physicians noted the detrimental effects of industrial occupations. Thackrah certainly did not share Darwin's optimism, but while Thackrah documented the ill effects of industrialization, he was confident that with his suggestions for preventing avoidable harm, industrial development could remain viable and profitable.[56] Thackrah emphasized this message of prevention in the preface to the second edition of his book, published in 1832. If anyone claimed that "the cure, not the causes or prevention of disease, is the business of the medical practitioner," he would counter "that the scientific treatment of a malady requires a

[55] Hamlin, *Public Health and Social Justice*, 45. In the indoor section, Chadwick cites M. Patissier, a French physician, who had also investigated the effects of occupations on health. Thackrah was known to have disputed many of Patissier's arguments about the negative effects of work. Ann F. La Berge, *Mission and Method: The Early Nineteenth-Century French Public Health Movement* (Cambridge: Cambridge University Press, 1992), 158

[56] J. Tim Carter and Anne Spurgeon "Historical Book Review: The Effects of Arts, Trades, and Professions on Health and Longevity" *Occupational Medicine* 67 (2017), 500-501.

knowledge of…the cause," and that a practice of medicine that "disregards the prevention of diseases, limits its utility and its honours."[57]

Pieces of Thackrah's text appealed to both sides of the factory debates, but as an affirmative compromise, it must have been particularly appealing to Chadwick.[58] Thackrah's credentials and experience made him a believable source. Trained first as an apprentice practitioner in his home city of Leeds, Thackrah continued his training under the well-known physician Sir Astley Cooper at Guy's Hospital in London from 1816-1817. Upon returning to Leeds, Thackrah was not able to set up a successful private practice, so he took a position with the Workhouse Board, where he was tasked with providing medical care to poor patients in the city, and later with the writing of a report on the state of lodging houses for the poor in Leeds.[59] This position did not dampen Thackrah's enthusiasm for the rapid industrial growth in his city, although in his introductory discourse to his fellow members in the newly formed Leeds Philosophical and Literary Society he expressed disappointment that "the energy and knowledge of Leeds people is too exclusively devoted to the acquisition of wealth."[60] In the year following, Thackrah expanded his influence in Leeds's medical circles with a popular series of lectures on physiology that he subsequently published in 1824. It was during the time that Thackrah was preparing his lectures that he supposedly began his "'series of inquiries' into the effects of various manufacturing

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[57] Charles Turner Thackrah, *The effects of arts, trades, and professions: and of civic states and habits of living, on health and longevity: with suggestions for the removal of many of the agents which produce disease, and shorten and duration of life*, 2nd ed, (London: Longman, Rees, Orme, Brown, Green, & Longman, 1832), Preface to the Second Edition, np

[58] Robert Hyde Greg, noted that Thackrah "is often quoted by the advocates of the Ten Hours Bill, and so far may be regarded as an impartial witness," but Greg emphasized Thackrah's conclusion that all people are generally not healthy, not just factory workers, so it must not be factory work that is causing the real problem (Robert Hyde Greg, *The Factory Question* (London: J. Ridgway and Sons, 1837), 27.

[59] J. Cleeland and S. Burt "Charles Turner Thackrah: a Pioneer in the Field of Occupational Health," *Occupational Medicine* 45, no. 8 (1995), 285-287.

[60] C.T. Thackrah *An Introductory Discourse Delivered to the Leeds Philosophical and Literary Society, 6 April 1821*, quoted in Cleeland and Burt "Charles Turner Thackrah," 288.

processes upon the health of workers" that resulted in the publication of his *Effects of the Principal Arts, Trades, and Professions* under a decade later.[61]

Thackrah was a supporter of the Ten-hour movement, speaking at one of its large assemblies in Leeds in January of 1832, but we will never know what he thought of Chadwick's approach because Thackrah died of consumption in 1833, shortly after the publication of the second edition of his treatise. Nevertheless, even if Thackrah's text was not the sole inspiration for Chadwick's claims in the indoor section, it certainly aligns with its premise of ventilation as a critical element. While the organization of Thackrah's text nominally divides between different "classes of persons" (operatives, dealers, merchants and master manufacturers, men independent of business and labor, and professional men) its focus is on operatives and its essential structuring premise depends on the location of work, whether workers are "men of active habits, whose employments are chiefly in the open air" or those "whose employments are carried on in an atmosphere confined and impure."[62]

After surveying the "principle employments" in series, Thackrah condenses his findings "a recapitulation or abstract of their effects." His first point of order is to proclaim that many of the "agents" commonly thought very dangerous were "comparatively harmless," namely humidity in the local atmosphere, changes in temperature, exhalations from vegetable matter, odors of manufactured vegetables (e.g. tobacco), changes in period of sleep (as in night work). Some of those agents were actually beneficial, such as animal exhalations (butchers were found to be surprisingly healthy and long-lived). A longer list of agents Thackrah found to be "decidedly injurious." Some of these concerned diet and digestion (typically the problem is overeating or improper eating, not a lack of food), level

[61] Cleeland and Burt "Charles Turner Thackrah," 288.
[62] Thackrah, *The effects of arts, trades, and professions*, 2nd ed (1832), vii.

of movement (employments too sedentary could be harmful), and intemperance (a worker's fault for lack of restraint, but also an employer's fault for not intervening), but many that cause the more fatal effects concern the air. A common atmospheric impurity was harmful enough, but "dust and gaseous impurity" could cause not only vomiting, loss of appetite, and impaired digestion, but also inflammation of the bronchial membrane and pulmonary substance, consumption, and asthma. Yet many workers perished from consumption who were never exposed to dust or other impurities, particularly tailors, but also shoe-makers, weavers, and printers. To this Thackrah attributes "confinement in a bad atmosphere" along with bad posture. The primary result of this situation was consumption.[63]

Thackrah agrees with many of the advocates for the Ten-hour movement in that he affirms that industrial labor had a slow, deleterious effect on workers' health. However, Thackrah suggests that this effect if much more likely caused by a lack of fresh air. As he explains it:

> Though health is directly attacked, and finally destroyed by many occupations, it is much more frequently undermined. By close attention, and continued labour, the nervous system is depressed; the digestive organs are disordered; the circulation and respiration are rendered irregular; in a word, all the systems become progressively impaired, and vitality seems at length exhausted. Life is worn out by excess of labour, as in the smith. More frequently it is reduced and shortened by the want of its natural food —an atmosphere pure and free.[64]

Thackrah closes his discussion with a "few other points important in preventing or diminishing the evils of our civic situations." The first on the list is "fresh air and change of air," but this applies primarily to workers with some relative level of control over their setting. A delicate clerk or pallid artisan could spend a month in a rural village or move

[63] Thackrah *The effects of arts, trades, and professions*, 2nd ed (1832), 192-198
[64] Thackrah *The effects of arts, trades, and professions*, 2nd ed (1832), 203

one's place of work to the outskirts of the city, but mills needed better ventilation. By Thackrah's guidance, the buildings needed to be loftier and less crowded, and air should be "freely admitted by openings at the *highest parts* of the rooms," for "workmen, slightly clad, are not willing, nor indeed able, to bear windows open close to their shoulders."[65]

**Economical Society: The Royal Institution and Technological Containment**

With so much riding on the appropriate levels of ventilation, there was great incentive to control the movement of air spatially and technologically. Granted new significance, ventilation technologies to address these problems had to be expertly designed and tightly controlled.[66] Chadwick implied this when he praised the ventilation system of a cotton factory and machine works he visited near Stirling. Other factories that depended on simply opening windows for ventilation were "generally found to be imperfect," but the Stirling factory had a system similar to the one found at the House of Commons.[67]

The designer of the House of Commons system, David Boswell Reid, was a chemist, physician and an inspector for Chadwick's later *Health of Towns* reports, but he also authored the influential treatise *Illustrations of the Theory and Practice of Ventilation* (1844). While earlier engineers and natural philosophers had considered building ventilation requirements, Reid advocated thinking not only in terms of a required volume of air but also in terms of the building enclosure as part of the ventilation system. Indeed, for Reid, a building is simply a container for an artificial indoor environment. His emphasis was thus on a closed, controlled system, in which air is not just introduced but also guided

[65] Thackrah *The effects of arts, trades, and professions*, 2nd ed (1832), 216-217
[66] Alain Corbin, *The Foul and the Fragrant, Odor and the French Social Imagination* (Cambridge, MA: Harvard University Press, 1986), 123.
[67] Chadwick, *Report on the Sanitary Condition*, 241.

through a building and carefully removed, for treatment of the air was also treatment for the body (Figure 3.3).

Yet because one of Chadwick's primary aims was to relocate responsibility for the ill health of workers from their industrial to their domestic settings, his 1842 report includes numerous appendices with specific recommendations for improving the domestic atmosphere as well. In this Chadwick drew indirectly on the methods and models of the Royal Institution of Great Britain, especially its conscious efforts to bring science into the domain of utility, its tradition of "improved" rural cottages, and its function as a central clearinghouse for material apparatuses deemed beneficial to the Institution's aim to achieve "the scientific treatment of scarcity."[68] The Royal Institution's utilitarian science aligned with Chadwick's compromise position, for unlike other scientific societies such as the Royal Society, its efforts were primarily "to contain problems, not erase them."[69]

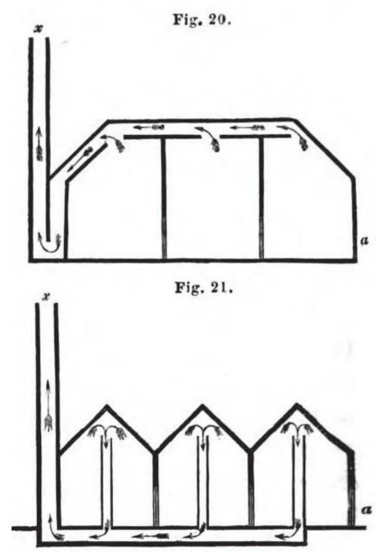

Figure 3.3 Reid's diagrams showing mode of ventilating air-tight manufactories, 1844, from his book *Illustrations of the Theory and Practice of Ventilation.*

The positive examples that Chadwick includes in the 1842 report are designs for workers' cottages proposed by horticulturalist and writer John Claudius Loudon in his 1835

68 Morris Berman, *Social Change and Scientific Organization: The Royal Institution, 1799-1844* (London: Heinemann Educational Books, 1978), 8.
69 Berman, *Social Change and Scientific Organization*, 110

*Encyclopædia of cottage, farm, and villa architecture and furniture* (Figure 3.4). That Chadwick would select a rural precedent is at first perplexing; in an urban setting where land is so scarce, the land requirements of a cottage seem impossible, but the early form of the Royal Institution provide some context for this selection. Although the Institution's founding vision came from Count Rumford the active membership of the Royal Institution at first were the landed aristocracy, as intent on managing the disruption caused by the Enclosure Acts as they were on improving and intensifying agricultural practices.[70] Loudon's cottage plans addressed numerous issues, particularly moral ones, but their facility for "good ventilation (windows that could open and close and fireplaces that were designed with ventilation in mind)" made them particularly appealing to Chadwick.[71]

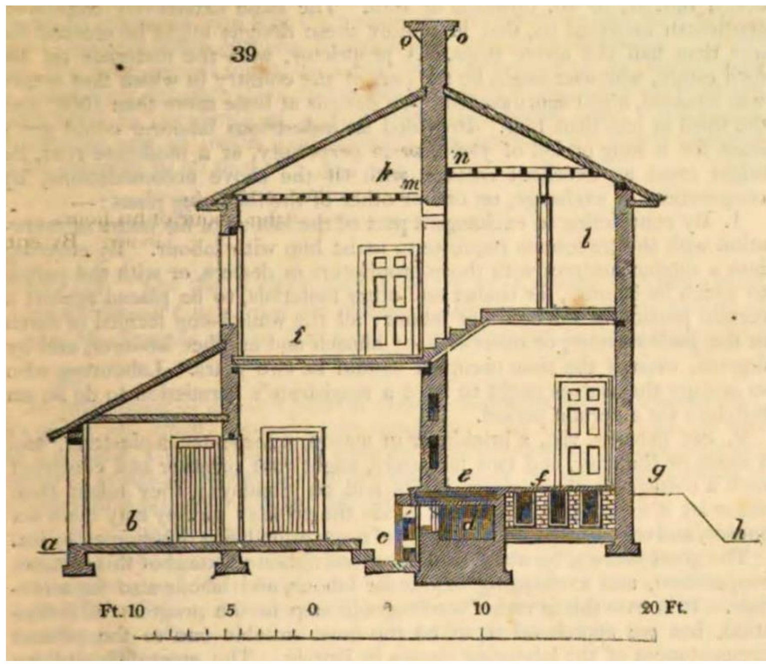

Figure 3.4 Design for a model cottage by John Claudius Loudon, 1830. The letter "l" indicates location of openings to a false flue for ventilation.

Although the founding members of the Royal Institution had come from the landed aristocracy, by the mid-1820s its leadership had shifted to a professional class of reformist Whig and Utilitarian members, including "improving physicians." Although the means

70 John Macarthur, *The Picturesque: Architecture, Disgust and Other Irregularities* (London; New York: Routledge, 2007), 115.

71 Barbara Leckie, *Open Houses: Poverty, the Novel, and the Architectural Idea in Nineteenth-Century Britain* (Philadelphia: University of Pennsylvania Press, 2018), 39.

were the same (science applied to social problems), the aim now was to address the destabilizing forces of industrialization not agricultural improvement. Morris Berman, in his critical history of the organization sees this as solidifying the ideological shift in the social construction of scientific pursuit that the Royal Institution embodied. For unlike the earlier Royal Society, where research was a matter of private, arbitrary interest and teaching and demonstration limited to small, well-connected private audiences, the Royal Institution was intent on making science public and bending it "to entrepreneurial and professional purposes."[72] The title for Rumford's original 1799 proposal for the formation of the Institution embodies this meaning. He envisioned

> The two great objects of the Institution being the speedy and general diffusion of knowledge of all new and practical improvement, in whatever quarter of the world they may originate; and teaching the application of scientific discoveries to the improvement of arts and manufacture in this country, and to the increase of domestic comfort and convenience.[73]

Thus it was not unusual to find Neil Arnott, one of Chadwick's closest medical advisors on the 1842 sanitary report, lecturing on the subject of warming and ventilation at the Royal Institution in March of 1836. The purpose of Arnott's lecture, which he expanded and published two years later as *On Warming and Ventilating*, was not only to describe the methods by which a person could maintain a healthy constitution by securing four "necessaries of life": air, warmth, aliment, and exercise, but also to describe his newly invented apparatus, the "Thermometer-stove, or self-regulating fire" (Figure 3.5).[74] Arnott

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72 Berman, *Social Change and Scientific Organization*, xxi

73 Benjamin Thomson (Count Rumford), *Proposals for forming by subscription in the metropolis of the British empire, a public institution for diffusing the knowledge and facilitating the general introduction of useful mechanical inventions and improvements, and for teaching, by courses of philosophical lectures and experiments, the application of science to the common purposes of life* (London: Printed for T. Cadell jun. and W. Davies, 1799), 25.

74 Arnott, *On Warming and Ventilating*, 1; Robert A. Bayliss and C. William Ellis, "Neil Arnott, F.R.S., Reformer, Innovator and Popularizer of Science, 1788-1874" *Notes and Records of the Royal Society of London*, Vol. 36, No. 1 (Aug., 1981), 110.

sought to describe his invention in public because, against the advice of his friends, he did not plan to obtain a patent for it. As explanation for his resistance to seeking patent rights, Arnott describes his technology in terms familiar to the supporters of the Royal Institution. Seeking a patent would be unrighteous "because the stove was originally planned as a means of preventing and curing diseases, purposes for which it will always be important."[75]

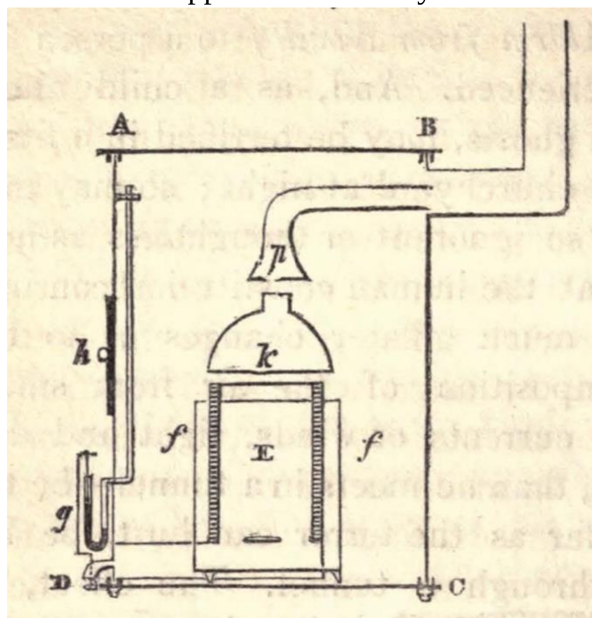

Figure 3.5 Diagram of Arnott's Thermometer-stove, 1838. Letter "E" indicates the coal-burning grate, as enclosed in the larger box ABCD. The thermoregulator is at letter "g."

Arnott's lecture at the Royal Institution was part of an organized research and teaching program in the organization's conscious effort to bring science into the domain of utility. In addition to hosting guest lectures, the Royal Institution from its founding retained a regular lecturer to deliver talks on subjects such as practical chemistry and physics, especially as applied to manufacturing processes and charitable enterprises. A special series of evening lectures for artisans on mechanics and construction of new models of chimneys, fireplaces, and boilers, emerged after an attempt to inaugurate a formal course in these topics.[76] In 1803, the organization established an in-house research laboratory for the public demonstration of experiments, commissioned analysis of materials, and the carrying out of the Institution's research agenda, for example early on the development of

[75] Arnott, *On Warming and Ventilation*, iv
[76] Berman, *Social Change and Scientific Organization*, 27.

improved chemical processes for the tanning industry, and later more medical topics (Figure 3.6).[77]

The orientation of the Royal Institution was not medical in its early years, but its influence on technological practices linking air and bodies is surprisingly significant.[78] This is especially the case for the second Professor in Natural Philosophy and full-time lecturer at the Institution, Thomas Young (1773-1829), a trained physician. Although Berman suggests that Young was not an effective lecturer and that his mode of science was old-fashioned, Young gave engineers access to medical and scientific knowledge.[79] Young's tenure at the Royal Institution was short (1801-1803), but he published his lecture material in several volumes in 1807.[80] While Young's teaching methods may have been less than inspiring, his work of knowledge dissemination was nonetheless influential. It merited him the formal dedication of the Thomas Tredgold's 1824 *Principles of Warming and Ventilating*, one of the most-cited works on this subject through the nineteenth century. Tredgold recognized Young as, "a Man Equally Distinguished for His Original Views in Natural Philosophy,

Figure 3.6 Laboratory at the Royal Institution, c. 1818. Credit: Wellcome Collection CC BY 4.0

[77] Berman, *Social Change and Scientific Organization*, 28, 53.
[78] Berman, *Social Change and Scientific Organization*, 48
[79] Berman, *Social Change and Scientific Organization*, 23-24
[80] Thomas Young, *A Course of Lectures on Natural Philosophy and the Mechanical Arts* (London: Printed for Joseph Johnson, 1807)

and for His Profound Researches in Every Department of Medical and Mechanical Science."[81] Perhaps under the influence of Young's lessons, Tredgold makes a critical shift in his method for calculating technological requirements. It was studies of human bodies rather than studies of air that were the only reliable source for guidance on ventilation. Introducing his chapter on the subject, Tredgold wrote, "the physiological chemists [studies of the body] have placed in our hands a more accurate means of measuring the deterioration of air in dwelling rooms, than by the best eudiometer [studies of the air]."[82] The Royal Institution's next Professor, Humphry Davy (1778–1829), perhaps even better exemplifies the organization's position on the medical instrumentality of air. Although Davy went on to make contributions in many fields, it is likely that Count Rumford recruited in Davy in 1801, despite being only twenty-three and without an established reputation, because he was the protégé of Thomas Beddoes's at the Pneumatic Institution, where Davy had been carrying out experiments in the medical applications of air since 1799.

### *Resolution not Revolution*

The passage of the 1847 Ten Hours Act and the 1848 Public Health Act signaled a provisional resolution to debates over time and space. The former law limited the workday of women and children to ten hours, and subsequent revisions in 1850 effectively limited the hours of factory operation and by extension the workday length of men.[83] Factory ventilation was not a part of these mid-century laws. The Public Health Act established central and local boards of health, and the primary activities resulting from this measure

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[81] Thomas Tredgold, *Principles of warming and ventilating public buildings: dwelling houses, manufactories, hospitals, hot-houses, conservatories*, &c. (London: J. Taylor, 1824), ii.
[82] Tredgold, *Principles of warming and ventilating* (1824), 69-70.
[83] B. L. Hutchins and A. Harrison, *A history of factory legislation* (Westminster: P. S. King & Son, 1903), 111.

was drainage, sewering, and the provision of water. Local boards had some domain over ventilation in residential buildings, but these were not clearly defined.[84] Issues of work and environment were certainly not settled in Britain, but the national laws provided some measure of resolution in the year of many revolutions in continental Europe.

In America, many of the problems of industrialization and worker health mirrored those in Britain. The emergence of large manufacturing enterprise in Massachusetts and the significant influx of new immigrant populations in northeastern cities created—in the eyes of administrators, advocates, physicians, and workers—situations quite in parallel to those in Britain. Despite tensions and a war between the two nations in the first decades of the nineteenth century, ideas began to flow, especially those about airs, bodies, and building technologies.

### AMERICAN AIR

In early 1849, Massachusetts physician Edward Jarvis (1804-1884) submitted an essay to the *American Journal of the Medical Sciences* reviewing the latest texts on ventilation. To Jarvis, the appearance of six separate publications, all published within the previous two years, demonstrated that there had been "a very great increase of interest in, and of attention to, this subject." Indeed, beyond the reviewed texts, the frequent newspaper and magazine articles, lyceum lectures, and inclusion in works of general hygiene and physiology on "the use of air in the animal economy, and the necessity of frequent supplies of this element," demonstrated to Jarvis that the topic was "becoming one of general interest" and that it was on the "high road to popular appreciation and acceptance." Jarvis wanted to be clear however, that he was differentiating between

[84] W.G. Lumley *The New Sanitary Laws: Namely, the Public Health Act, 1848, the Public Health Act 1858, and the Local Government Act, 1858, an Introduction, Notes, and Index* (London: Shaw and Sons, 1859), 114, 265.

“internal ventilation, or that of houses, halls, shops, &c.,” from “external ventilation, or that of streets, towns, &c,” because there was a separate problem of gaseous emanations from many recent drainage projects, but the technologies and approaches needed to manage those were quite different than those needed for providing fresh air indoors.[85]

Of the last book in his review, Jarvis wanted readers to take particular notice. Although the work had no author’s name attached, it was the beginning of a series of *Tracts for the People*, and more importantly “it described so well the subject of its title,” namely *The Uses and Abuses of Air*. The book was critical because most people were so ignorant of the “connection of life with air, and of the necessity of pure air for the support of health” Jarvis noted, that “the means by which fresh air may be secured within our places of abode, of labour, and of assemblage” were too often neglected. Yet this work was different than the others under review in that it was aimed specifically at the “hardy children of want and toil,” who had not yet learned that pure air was a necessity not a luxury. They did not yet realize just how much “their vigour and their productive power” depended on the “air they breathe both night and day” in their homes and their workshops. The connection between pure air and productive power was critical knowledge not only for the laborers themselves, but also Jarvis thought, it “cannot be urged too earnestly upon employers [and] contractors.”[86]

This last point had particular resonance for Jarvis, for just a year earlier he had argued in a petition to the Massachusetts legislature urging a state-wide sanitary survey in part because the state was quickly becoming a manufacturing center, it was critical to understand the effects on health of the population of the new occupations associated with

[85] Edward Jarvis, “Review, Treatises on Ventilation” *The American Journal of the Medical Sciences,* 35 (July 1849): 129-133.
[86] Jarvis, “Review, Treatises on Ventilation,” 146-147.

these industries.[87] Despite all the effort that has gone into calculating the exact costs and profits of manufactured goods in term of amounts of labor, wages, and board, Jarvis pointed out, no one has ever inquired as to "the cost of life and health—…the wear and waste of human strength and power—caused by the different employments."[88]

This was not entirely the case. In 1837, the New York Medical Society published an essay authored by young physician Benjamin McCready, *On the influence of trades, professions, and occupations in the United States, in the production of disease,* in the Society's journal. McCready's dissertation had been the prize-winning submission to an 1835 essay competition organized by the Society, requesting responses to their subject, which was the same as McCready's title. Like Jarvis, McCready maintained that such a topic had not been approached in the United States, and thus relied heavily on Charles Turner Thackrah's book, which had been published in a U.S. edition in 1831.[89]

Like Thackrah, McCready divided his analysis primarily into occupations carried on out of doors (agriculture, work on canals and railroads), those occurring indoors (generally unskilled textile workers), skilled trades (e.g. tailoring, shoemaking, printing, etc), and professional and literary pursuits (physicians, lawyers, clergy). The professionals suffered especially from mental disorders, due to relative inactivity and mental strain, but McCready concludes that in general for occupations "by which man obtains his bread by the sweat of his brow," a category that included the skilled trades, there was nothing *essentially* unhealthy about them, with the exception of a few occupations where the workers were regularly exposed to poisonous materials, as were painters exposed to lead,

[87] Barbara Rosenkrantz, *Public Health and the State, Changing Views in Massachusetts, 1842-1936* (Cambridge, MA: Harvard University Press, 1972), 24.
[88] Edward Jarvis *Massachusetts House Documents 1845, No. 16: Petition of the American Statistical Association* (Feb 9, 1848),
[89] Genevieve Miller, "Introduction," to Benjamin McCready, *On the Influence of Trades, Professions, and Occupations in the United States, in the Production of Disease* [1837] (Baltimore, Johns Hopkins University Press, 1943), 12.

or "inhalation which mechanically irritates the lungs." Any other "complaints" had causes that in some way could be actively prevented. Those secondary causes were 1) ignorance and bad habits, especially intemperance, 2) wages so low, leaving the worker "time insufficient for repose or recreation," or 3) "faulty construction of his dwelling or his workshop." The human body was so complex, however, according to McCready, it was impossible to know which of these had the "greatest agency."[90]

Yet the first of those three items to warrant further elaboration in McCready's text was "the necessity of pure air and of perfect ventilation of dwellings and workshops." Certainly, McCready allows, this issue had been emphasized in the past, but it was so important that he felt he could not avoid underscoring it himself. [91] For a "confined and impure atmosphere" was "one of the most active agents in the production and development of the tubercular diathesis [a constitutional tendency to consumption]"[92]

These effects of "foul air, at least in its more concentrated forms," destroyed the health of laborers especially, in McCready's opinion. This was an important point for McCready, for he followed Chadwick's reasoning in claiming that "the evils of factory labor…depend less upon any thing in the nature of the labor itself, than upon circumstances not necessarily connected with it." Of the many evils, which at least in England seemed inevitably to accompany industrial development, the primary problems were, 1) "the length of time which the operatives are employed," 2) "the confined and ill ventilated apartments in which they reside," 3) "their intemperate and inactive habits," and 4) "the bad quality of the provisions which they consume," but often too factory proprietors were ignorant of the

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[90] Benjamin McCready, "On the influence of trades, professions, and occupations in the United States, in the production of disease," *Transactions of the Medical Society of the State of New York* 3 (1836-1837): 143.
[91] McCready, "On the influence of trades, professions, and occupations," 144.
[92] McCready, "On the influence of trades, professions, and occupations," 108.

“importance of thorough ventilation” and were often careless of it, compelling the laborers to breathe “a deteriorated atmosphere.”[93] Of all of these principal problems, however, McCready discusses only air and intemperance at length.

Of course this is not exactly how the workers themselves saw the situation, but McCready did believe workers capable of such discernment. He found them “so little attentive to the causes which affect their health,” and their views “so often warped by prejudice or interest,” that their impressions could be little trusted.[94] Intemperance, the workers saw it, was not just an innate habit among laborers, rather it arose from both a lack of education and a lack of free time. Because free public education was not available to young men, they went to the saloon. An opportunity for education, the Working Men’s Party argued, would keep these youths occupied and out of trouble. For older workers, labor activists contended, drink was the preferred form of recreation only because the exceedingly long hours of the workshop and factory left little energy or time for any more active or wholesome pursuits.[95]

### Hygienic Relations: Factory Ventilation and the Ten-hours Movement

The factories and factory workers in America were supposed to be better. Numerous English authors, from factory critic Charles Dickens in *American Notes* (1842) to factory supporter Robert Hyde Greg in *The Factory Question* (1837), praised the conditions supposedly found at American factories, especially those in Lowell, Massachusetts. As part of his larger tour of the United States, Dickens traveled to Lowell

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[93] McCready, “On the influence of trades, professions, and occupations,” 109.

[94] Nonetheless McCready, in the absence of statistics, his preferred evidence, begrudgingly relied in part on the reports of the workers themselves. Benjamin McCready, “On the influence of trades, professions, and occupations,” 91.

[95] Genevieve Miller, “Introduction,” to Benjamin McCready, *On the Influence of Trades, Professions, and Occupations*, 23.

and visited several factories. The majority of factory workers in Lowell were women, and Dickens found them as well ordered as the rooms in which they worked. Factories were a veritable paradise, there were green plants and "as much fresh air, cleanliness, and comfort as the nature of the occupation would possibly admit of." There were few children working at these factories, and state laws forbade their working more than nine months of the year and required that they attend school during the other three months. Schools for this purpose abounded in Lowell.[96] Greg, quoting testimony given to the Factory Commission by an American cotton manufacturer, claimed that there had been some protests against child labor in the newspapers, probably made by workers who came from England, but that workers themselves did not want shortened hours. Americans considered British workers to be great drunkards, and their own workers "better educated, and more intelligent, and more moral, and refrain more from sensual indulgence." There were no jealousies between workers and masters, and more importantly no unions. American workers were stronger and healthier, although the witness couldn't draw a parallel with Britain because the American climate was just so different.[97]

The situation in Lowell was not as sunny as these British writers claimed. In their discourses, America was a foil, a means to criticize British factory conditions or factory workers. In the real America, not refracted through a British lens, between 1830 and 1850 growing labor unrest among women workers at the textile mills in Massachusetts invoked questions of factory environmental conditions' influence on worker health. Workers organized strikes typically in response to reductions in wages or increases in hours, but

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[96] Charles Dickens, *American Notes, for General Circulation* (New York : Harper & Brothers, 1842), 28

[97] Robert Hyde Greg, *The factory question, considered in relation to its effects on the health and morals of those employed in factories, and the "Ten hours bill" in relation to its effects upon the manufactures of England, and those of foreign countries* (London, J. Ridgway and Sons, 1837), 140-143.

health and factory conditions served as critical and complicated flash points in labor disputes.

Between 1834 and 1844, the conditions of work in the textile mills of Massachusetts had deteriorated. Gone were the now idyllic-seeming early days of the mills in the 1820s, when wages were high enough to attract women from lower-wage employment in teaching or domestic service, and when work days were long but manageable, each worker overseeing no more than one or two looms. By the end of 1836, Lowell mill workers had already gone on strike twice to protest wage cuts, unsuccessful on both counts. Also at issue were work "speed ups" that required factory operatives to take on the management of sometimes double the looms as before, but for the same wages. By 1844, a typical worker made the same wage as in 1834, but did twice the work. Workers were supposedly free to contract their own labor, but an owner-determined system of year-long contracts coupled with a blacklist among factory proprietors meant that workers functionally had little choice or control over the conditions of their labor.[98]

Early concerns about the health of women mill workers in Massachusetts were born out of paternalism and competitive angling by male trade unionists, but the female workers themselves also spoke out about the potential negative health effects of factory work. Speakers at conventions of the National Trades' Union in the 1835 and 1836 criticized the factory system, claiming it destroyed the health, specifically of female factory workers; wage-earning work in factories, they asserted was "a physical and moral injury to woman and a competitive menace to man."[99] The 1837 panic brought an end to the national trade union movement, but complaints about the detrimental health effects of the hot, humid, ill-

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[98] Frances Early, "A Reappraisal of the New England Labour-Reform Movement of the 1840s: The Lowell Female Labor Reform Association and the New England Workingmen's Association" *Social History* 13, no. 25 (May 1980): 35-36.

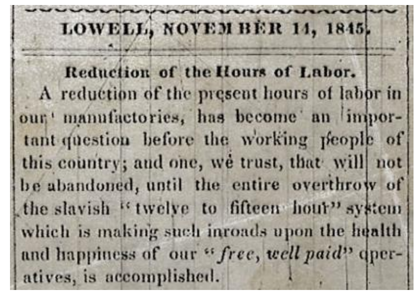
[99] George Rosen, "The Medical Aspects of the Controversy Over Factory Conditions in New England, 1840-1850" *Bulletin of the History of Medicine*, 15, no. 5 (May, 1944): 488.

ventilated, and lint-saturated factory atmosphere, some more radical figures claiming that "the great mass wear out their health, spirits, and morals" and are no better for it; the only reason the bills of mortality in the factory villages were so low was because "the poor girls when they can toil no longer go home to die."[100] The workers of Lowell did not necessarily disagree. In an 1842 petition to the Massachusetts legislature—a reform tactic alternate to striking—a group of Lowell operatives requested the passage of a ten-hour bill, for the reasons, "it would in the first place, serve to lengthen the lives of those employed, by giving them the greater opportunity to breathe the pure air of heaven, rather than the heated air of the mills." It would also allow them "more time for mental and moral cultivation" as well as time to attend to their personal affairs.[101] An appeal for a ten-hour workday was not a radical request, President Martin Van Buren had in 1840 issued an executive order that limited government workers' day to ten hours.[102]

The stakes were raised in 1845 with the formation of the Lowell Female Labour Reform Association (LFLRA), led by Sarah G. Bagley, a former mill worker turned labor organizer. The purpose of the organization was to advocate for the ten-hour day, arguing that "such unmitigated labor is to the highest degree destructive to the health…and serves to injure the constitutions of future generations."[103] Together with the New England Working Men's Association, the LFLRA submitted another petition for a ten-hour day to the legislature in 1845 (Figure 3.7). This time the legislature responded and formed a committee "to investigate the factory system, in particular the subject of hours in

[100] Orestes Brownson "The Laboring Classes," *Boston Quarterly Review* 3 (July 1840), 47-48.
[101] Text of petition quoted in Charles E. Persons, Mabel Parton, and Mabelle Moses, *Labor laws and their enforcement: with special reference to Massachusetts* (New York; London; Bombay; Calcutta: Longmans, Green, and Co, 1911), 26.
[102] Early, "A Reappraisal of the New England Labour-Reform Movement," 45 n63.
[103] Quoted in Rosen, "The Medical Aspects of the Controversy Over Factory Conditions," 491.

factories."[104] Success of the petition was unlikely, given that committee was chaired by William Schouler, a pro-industry publisher, but the process did allow several workers, including Sarah Bagley, to give testimony in front of the committee.[105] The committee's report writer did not temper their statements, recording, "the petitioners declare they are confined 'from thirteen to fourteen hours per day in unhealthy apartments,' and are thereby 'hastening through pain, disease and privation, down to a premature grave.'"[106]



LOWELL, NOVEMBER 14, 1845.

Reduction of the Hours of Labor.

A reduction of the present hours of labor in our manufactories, has become an important question before the working people of this country; and one, we trust, that will not be abandoned, until the entire overthrow of the slavish "twelve to fifteen hour" system which is making such inroads upon the health and happiness of our "*free, well paid*" operatives, is accomplished.

Figure 3.7 Notice in the worker-sponsored newspaper *The Voice of Industry*, 1845.

Not surprisingly, Schouler's committee determined that no legislative action was necessary. Among the arguments made by the committee was that the health of Lowell workers was not as bad as the petitioners argued, and indeed according to medical witnesses to the committee—albeit some of whom worked for mill owners—the health of operatives was rather better than residents of nearby non-manufacturing towns.[107] This case was repeated by the Reverend Henry A. Miles in his 1845 publication *Lowell, as it was, and as it is,* and much of the operatives health and comfort could be attributed to provisions of the mills themselves, which were "kept of a uniform temperature, being heated in cold weather either by steam, or by hot-air furnaces," and the rooms of the mill, Miles claimed, were "lofty…well ventilated, and…kept as free from dust as is possible."[108]

Members of the Massachusetts medical community expanded this argument, some maintaining that overwork was a problem not just factory workers but for all Americans.

104 Rosen, "The Medical Aspects of the Controversy Over Factory Conditions," 491.
105 Early, "A Reappraisal of the New England Labour-Reform Movement," 45.
106 "Report on the subject of Hours of Labor" Massachusetts *House Document* no. 50, March, l845, 1.
107 Rosen, "The Medical Aspects of the Controversy Over Factory Conditions," 491.
108 Henry A. Miles, *Lowell, as it was, and as it is* (Lowell: Powers and Bagley, N.L. Dayton, 1845), 116

In an address to the Massachusetts Medical Society in 1846, entitled "The Factory System, in its Hygienic Relations," Dr. John O. Green, argued that "no peculiar evils to health and life attach *necessarily* to manufacturing business." He admits that "among the most prominent perhaps of the adverse influences" was the "too long confinement by the protracted hours of labor." As such, workers did not spend enough time in the open air, but that said, the factory environment was good, and even possibly protective, for they were "kept of a uniform temperature, and are lofty and well ventilated." Rather Green explained away the problems of long hours for factory workers by making it a more generic American problem. This was an issue "by no means confined to our factory system." In fact, overwork resulted primarily when "the acquisition of wealth becomes the universal, the all absorbing concern." Moreover, the consequent fatigue, which represented "the deterioration and destruction of the living machine," could result from either mental or physical work. It was likely, Green argued, that fatigue of the mind might even be a worse predicament than fatigue of the body, because where bodily energy could be restored by good sleep, "thought and care cannot be discontinued or cast off." Perhaps wealthy doctors had it worse than factory workers.[109]

Still others reasoned that even if mill workers were not in the best health now, it could be improved, but not by a shortening of hours. Rather they would improve it by technological means, by improved factory ventilation. Lowell physician Dr. Josiah Curtis, suggested this in a report on the sanitary conditions at Lowell at the American Medical Association conference in 1849. In his report, Curtis concurred with previous writers that some of the general conditions of factory labor were good, "their hours of labour, and rest, and meals are regular, and this is highly conducive to health." Yet he could not agree that

[109] John O. Green, *The factory system, in its hygienic relations: an address, delivered at the annual meeting of the Massachusetts Medical Society, Boston, May, 27, 1846* (Boston: The Society, 1846), 12, 17-22.

the factories were well ventilated. Calculating the average amount of air space allotted to factory workers, Curtis found the quantity unacceptable; the ventilation in most prisons in New England was better than this! In Lowell, Curtis maintained, physicians saw inadequate ventilation as "the most prolific source of deteriorated health in the adjuncts of factory labor." Yet there was good news, "happily, this is an evil which admits of a remedy."[110]

The medical and technical communities in Massachusetts were already attending to this issue. A few years earlier the Boylston Medical Committee of Harvard University, which regularly posed questions to the medical profession and awarded prizes for the one deemed the best response, had proposed "ventilation of hospitals, churches, public halls, dwelling-houses, shops, &c." as one of the subjects to be addressed. The successful respondent for the prize was Dr. Morrill Wyman (1812-1903), whose prize dissertation expanded into the 1846 *A practical treatise on ventilation*, one of the first book-length publications on ventilation authored by an American.[111] Wyman's book was both medical and technological, beginning with chapters on human physiology and aerial chemistry and ending with chapters on various ventilating apparatus and techniques for moving air within different building types. Evidence of the close interaction of technical and medical communities in this matter appears in Wyman's dedication of the book to Daniel Treadwell, an inventor and, from 1834 to 1845, the endowed Rumford professor at Harvard University. Wyman also participated in a committee formed by the American Academy of Arts and Sciences in 1847 to "make experiments for testing the value of the principle kinds of ventilating apparatus now in use." The committee tested the airflow in eighteen various chimney-tops and ventilators, with the intention of influencing technical production, for

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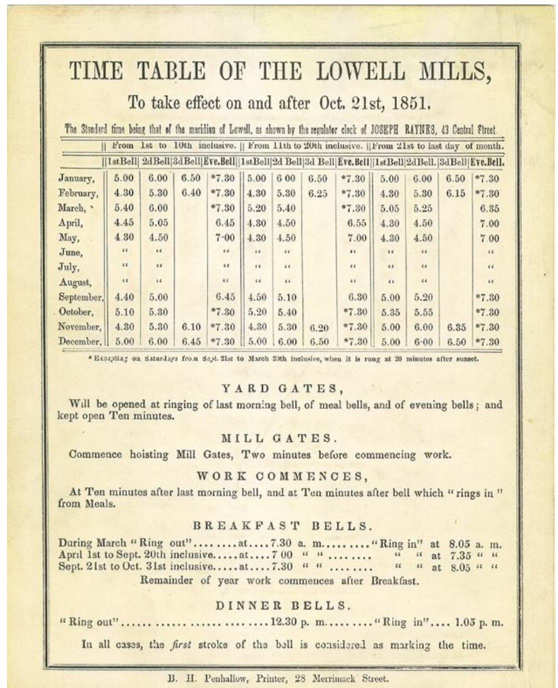
[110] Josiah Curtis, "Public Hygiene of Massachusetts," *Transactions of the American Medical Association* 2 (1849): 514, 531.
[111] Morrill Wyman, *A practical treatise on ventilation* (Boston: Munroe, 1846); Jarvis, "Review, Treatises on Ventilation," 129.

"the proportions of those forms of ventilators" that the committee found most efficient would be "placed in the hands of manufacturers."[112]

Ultimately a ten-hour bill passed, but not until almost thirty years later in 1874 (Figure 3.8).[113] The new Massachusetts law limited the labor only of women and minors (under eighteen years) to ten hours per day.[114] It is not clear just how many manufacturers responded to ventilation guidance, but presumably not enough in that an 1877 Massachusetts factory inspection law included a requirement that "all such establishments shall be well ventilated and kept clean," although that law was primarily concerned with fencing dangerous machinery.[115] Ventilation does not appear again in Massachusetts factory legislation until 1893, when the legislature amended



TIME TABLE OF THE LOWELL MILLS,

To take effect on and after Oct. 21st, 1851.

The Standard time being that of the meridian of Lowell, as shown by the regulator clock of JOSEPH RAYNES, 43 Central Street.

| | From 1st to 10th inclusive. | | | | From 11th to 20th inclusive. | | | | From 21st to last day of month. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1stBell | 2dBell | 3dBell | Eve.Bell | 1stBell | 2d Bell | 3d Bell | Eve.Bell | 1stBell | 2dBell. | 3dBell | Eve.Bell. |
| January, | 5.00 | 6.00 | 6.50 | *7.30 | 5.00 | 6 00 | 6.50 | *7.30 | 5.00 | 6.00 | 6.50 | *7.30 |
| February, | 4.30 | 5.30 | 6.40 | *7.30 | 4.30 | 5.30 | 6.25 | *7.30 | 4.30 | 5.30 | 6.15 | *7.30 |
| March, | 5.40 | 6.00 | | *7.30 | 5.20 | 5.40 | | *7.30 | 5.05 | 5.25 | | 6.35 |
| April, | 4.45 | 5.05 | | 6.45 | 4.30 | 4.50 | | 6.55 | 4.30 | 4.50 | | 7.00 |
| May, | 4.30 | 4.50 | | 7·00 | 4.30 | 4.50 | | 7.00 | 4.30 | 4.50 | | 7 00 |
| June, | " | " | | " | " | " | | " | " | " | | " |
| July, | " | " | | " | " | " | | " | " | " | | " |
| August, | " | " | | " | " | " | | " | " | " | | " |
| September, | 4.40 | 5.00 | | 6.45 | 4.50 | 5.10 | | 6.30 | 5.00 | 5.20 | | *7.30 |
| October, | 5.10 | 5.30 | | *7.30 | 5.20 | 5.40 | | *7.30 | 5.35 | 5.55 | | *7.30 |
| November, | 4.30 | 5.30 | 6.10 | *7.30 | 4.30 | 5.30 | 6.20 | *7.30 | 5.00 | 6.00 | 6.35 | *7.30 |
| December, | 5.00 | 6.00 | 6.45 | *7.30 | 5.00 | 6.00 | 6.50 | *7.30 | 5.00 | 6·00 | 6.50 | *7.30 |

* Excepting on Saturdays from Sept. 21st to March 20th inclusive, when it is rung at 20 minutes after sunset.

YARD GATES,

Will be opened at ringing of last morning bell, of meal bells, and of evening bells; and kept open Ten minutes.

MILL GATES.

Commence hoisting Mill Gates, Two minutes before commencing work.

WORK COMMENCES,

At Ten minutes after last morning bell, and at Ten minutes after bell which "rings in" from Meals.

BREAKFAST BELLS.

During March "Ring out"........at....7.30 a. m.........."Ring in" at 8.05 a. m.
April 1st to Sept. 20th inclusive.....at....7 00 " " ........ " " at 7.35 " "
Sept. 21st to Oct. 31st inclusive.....at....7.30 " " ........ " " at 8.05 " "
Remainder of year work commences after Breakfast.

DINNER BELLS.

"Ring out"..........................12.30 p. m.........."Ring in".... 1.05 p. m.

In all cases, the *first* stroke of the bell is considered as marking the time.

B. H. Penhallow, Printer, 28 Merrimack Street.

Figure 3.8 Time table of the Lowell Mills, 1851. Despite worker protest, hours at the mills remained long.

112 Benjamin Peirce, Joseph Lovering, Eben N. Horsford, Morrill Wyman, *Report of a Committee of the American Academy of Arts and Sciences on Ventilators and Chimney-Tops* (Cambridge, MA: Metcalf and Company, 1848), 3, 20.

113 Thomas Dublin attributes this lag in legislation changes in the labor force. Immigrant laborers arriving in the 1850s were not in a position to protest, but as they gained stability in the following decades they were successfully able to advocate for shorter hours. Thomas Dublin, *Women at Work: The Transformation of Work and Community in Lowell, Massachusetts, 1826-1860* (New York: Columbia University Press, 1979).

114 Sarah Scovill Whittelsey, "Massachusetts Labor Legislation, An Historical and Critical Study," *The Annals of the American Academy of Political and Social Science*, 17, Supplement 15 (Jan 1901), 12.

115 Whittelsey, "Massachusetts Labor Legislation," 120

laws regulating building permits to require that submitted plans include a system or method of ventilation.[116]

In schools, however, discussions of ventilation and heating took on new energy. More of the schooling process was coming under state control, and immediate concerns about incredibly high rates of child mortality as well as more existential worries about the viability of future generations and American society focused reformers on childhood health. Of course the story is not a two-dimensional debate about the salubrity or insalubrity of schools. Many competing parties used the conditions of ventilation in schools as a proxy in larger political, religious, and economic conflicts. Moreover, following the Civil War, during which the U.S. Sanitary Commission exposed many laypersons to the "sanitary idea" and American industrial capacity expanded significantly, new manufacturing interests joined the sanitary movement, actively shaping a concept of "sanitary architecture" with the participation of a formalizing architectural profession.

**Forcing Houses: School Ventilation in the Sanitary Age**

For American school reformers the nineteenth century, urban schoolrooms represented an explicit spatial alternative to the overly restrictive environment of the factory and the excessively unstructured city streets, where reformers imagined the children of the poor drawn into to moral degeneracy. Interest in schoolroom health was a concern also because physicians and reformers considered childhood a special category. Children were not only physically different from adults because they were in a period of growth, but they also held an existential value in that their state of health indicated the present or future success of a state, nation, or "race."

[116] Whittelsey, "Massachusetts Labor Legislation," 122

James Clark, the British consumption expert who we met earlier in this chapter, considered children particularly at risk, linking consumption, air, and childhood. In Clark's view, children were particularly at risk because the earlier in life a person was exposed to the causes of tuberculosis cachexia, the sooner full-blown consumption would develop. Even if a child was born to perfectly healthy parents—which seemed a guaranteed escape from consumption, because the disease was still considered essentially hereditary—if that child was "confined to rooms in which free ventilation and cleanliness are neglected, a few months will often suffice to induce tuberculous cachexia." In Clark's view, education in the effects of air on children's bodies was critical because the "constant supply of pure air for respiration" was, in addition to "adaptation of food to difference of age and constitution," were the two circumstances that influenced a growing body's health more than any others, but also the ones that the public generally most ignorant of. [117]

The pressure was high to achieve good air for children because many believed that their health status determined the long-term future of the nation. Certainly this is almost a truism, but in the nineteenth century this idea had a particular environmental mechanism. As Benjamin McCready, the author of *On the influence of trades, professions, and occupations in the United States, in the production of disease,* worried that if young people regularly continued to be employed "in a confined atmosphere, at a period of life when inclination, so often our best guide, calls for varied and free exercise in the open air," the negative effects may not be immediate, but they were nonetheless serious. Even if the first generation of child factory workers were not so greatly affected, it was likely that their children would be "more short lived and weakly."

[117] Clark, *A Treatise on Pulmonary Consumption*, 174, 178

McCready tied this idea into broader medical theories emerging in America at that time. Some medical thinkers proposed that because societal relations and conditions had changed so much that human diseases had changed as a result. As a consequence, there were many diseases in the "modern times" of the 1830s that would have been "unknown to our ancestors." Essentially, many of these new-fangled diseases had been brought about by changes in habits and modes of living, and one of those changes was the "extensive employment of young children in manufactories." This new way of living might bring about for future generations both "new and strange disorders," as well as more scrofulous (consumption-inducing) maladies, which were "already the great bane of our race."[118] In the following decades, medical writers speculated that human constitutions had in fact changed at the population level. Successive generations of Americans would be more susceptible than previous generations to diseases of all kinds. In addition to the conditions of factory work, to blame for this slow, generational degradation was the physical environment of the city, including the urban school room.[119] Where Pringle in the 1750s assumed that a confined space could transform a relatively harmless disease into a virulent one, medical theorists in the 1830s imagined that confined space might transform a strong constitution into a weak one.

Medical commentators also focused on air specifically in discussions of child health because unlike the case for adults, they could not attribute childhood disease to intemperance. McCready, like Thackrah, had explained many workers' early demise as resulting from a worker's own intemperance. Yet this could not explain the shockingly high mortality rate in children. Air was one of the only other equally prevalent yet

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[118] McCready, "On the influence of trades, professions, and occupations," 109-110
[119] Stanley K. Schultz, *Constructing Urban Culture: American Cities and City Planning, 1800-1920* (Philadelphia: Temple University Press, 1989), 124.

amorphous causes that advocates could turn to. Thus, McCready could reason that children often died early because “confined as they are to the house in early life” they were more affected than adults by “the privation of pure air and of the light of the sun.”[120] This reasoning made reformers to more likely to blame school ventilation for death or illness in children for the usual go-to, intemperance, could not explain it otherwise.[121]

The cases of school reform and school hygiene in Massachusetts and New York City demonstrate the contexts in which schoolroom ventilation took on particular significance. In Massachusetts, education was the political substitute for child labor, and many issues of ventilation followed children’s transition from the space of the factory to that of the schoolroom. Yet in the 1870s and 1880s, sanitarian reformers began to see the school environment itself as potentially dangerous, its vitiated air spreading disease, damaging constitutions, or contributing to an overworked student’s distraction.

### *Factory Work, Common School: School-House Air in Massachusetts*

The stakes were high in Massachusetts schoolrooms because schools themselves were a compromise put forward to quell social unrest. In response to the growing labor conflicts between factory owners and workers, political reformers (typically of the Whig party, improver types who favored a centralized approach) such as Horace Mann advocated for a system of publicly funded “common schools” that would provide education for children whose hours in the factory were limited by recently passed labor legislation such as an 1836 law that required children under fifteen working in factories to attend school at least three months out of the year.[122]

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[120] McCready, “On the influence of trades, professions, and occupations,” 143-144

[121] Robert D. Jamieson, “Towards a Cleaner New York: John H. Griscom and New York's Public Health, 1830-1870,” (PhD Diss., Michigan State University, 1972), 123, 138 n48, 139 n55.

[122] Wayne J. Urban and Jennings L Wagoner, *American Education*: *A History* (New York: Routledge, 2009), 90; Whittelsey, “Massachusetts Labor Legislation,” 107

This connection between factory and school goes back to the time of the time of Percival and the first factory acts in Britain. Thomas Percival, in his letter advising local magistrates on ways to move forward after "we deem this indulgence [limitation of hours in factory work] essential to the present health, and future capacity for labour, of those who are under the age of fourteen…that the rising generation should not be debarred from all opportunities of instruction at the only season of life in which they can be properly improved."[123] The British 1802 factory act included requirements for factory owners to provide some basic schooling (reading, writing and arithmetic) for their young workers, and this requirement continued in some form in subsequent British factory regulations.[124]

The connection continued through the 1830s, when Massachusetts began considering factory regulation. Reformers in Massachusetts and other northeastern states founded the influential American Institute for Instruction (AII) in 1830 with the purpose of advocating for educational improvements. In Massachusetts, the group lobbied the legislature for the appointment of a state superintendent of schools and the formation of a teachers' college. They were successful in both, in 1837 with the appointment of Horace Mann as Superintendent of Public Education, and the organization of a teachers' college in 1839.[125] Soon after the group formed, they sponsored an essay competition on the topic of school-house construction. The AII awarded the prize to William A. Alcott for his 1832 *Essay on the Construction of School-houses.*

In the space of his short essay, Alcott had to discuss many aspects of school construction, including their location, size, structure, internal arrangement and furniture,

[123] Cited in A. Meiklejohn "Outbreak of Fever in Cotton Mills at Radcliffe, 1784," 69
[124] Michael Sanderson "Education and the Factory in Industrial Lancashire, 1780-1840," *The Economic History Review*, new series 20, no. 2 (Aug 1967): 266-279; Marjorie Cruickshank "Factory children and compulsory education: The short-time system in the textile areas of north-west England 1833–64," *The Vocational Aspect of Education* 30, no. 77 (1978): 111-117.
[125] Richard B. Michael, "The American Institute of Instruction," *History of Education Journal* 3, no. 1 (Autumn, 1951): 27, 31.

but where he found problems with the external conditions of existing schools, much worse were their internal arrangements. In existing schools, students suffered from the alternation of heat and cold, and from smoke there with "little or no provision for free ventilation." School administrators, Alcott argued, must take students' health and comfort more seriously than their curricular progress. He communicates this need in economic terms, for as Alcott reasons *"health*, as well as *time*, is *money*; and it is a most mistaken economy which confines a child to those arrangements, and to that atmospheric impurity, which render him unfit for vigorous effort, and thus slowly, though surely, impair his constitution." By making the case for more air, Alcott could make an argument for space and more cost. Alcott anticipated objections to his proposed schoolroom layout, given that it would be "larger, and consequently more expensive than is necessary for common schools in country towns," but the negative health implications of a smaller space would be a "far greater tax on the parent."[126]

Alcott really leans into the ventilation argument. The rate at which "respiration alone contaminates the air" was astonishing enough to those not familiar with the subject, but add to that "the effluvia which are constantly escaping from the surface of all living bodies," Alcott warned. Indeed it was surprising there was not more "immediate injury sustained by the human constitution in confined rooms." Even prisoners in solitary confinement in the new Philadelphia Penitentiary were allocated more than 1300 cubic feet of space, in which ventilation, cleanliness, and temperature received the utmost attention. In contrast, Alcott claimed to know of many school rooms which were smaller and without ventilation, in one instance "the amount of space to each *school-room* prisoner" was almost

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[126] William A. Alcott, *Essay on the construction of school-houses, to which was awarded the prize offered by the American Institute of Instruction, August, 1831. With an appendix [by William C. Woodbridge]*. (Boston: Hilliard, Gray, Little and Wilkins, 1832), 6-7, 17.

thirty times less than that allotted to an adult prisoner. And people complained that the prisoners did not get enough![127]

Alcott's essay dedicates more than a quarter of its space to issues of heating and ventilation, but even then he thought it had not received enough attention. The AII thought so too and attached a separate appendix on the "Size and Ventilation of School-Rooms" by longtime educator William C. Woodbridge to their publication of Alcott's essay. The organization was clear to point out that it did not approve of the specific classroom plan that Woodbridge submitted to their essay competition, but they heartily endorsed the principles on which he based it (Figure 3.9). "The intent of all theoretical and practical education is, "to form the sound mind in the sound body," for it would be impossible to develop the "powers of genius" be in a sickly child. To these principles, Woodbridge attaches an extensive thesis reviewing not only how "diseases of the most dangerous character, are often produced by the want of ventilation, where no immediate injury is perceived," with evidence pointing back to the works of Ferrier and Pringle (and of course

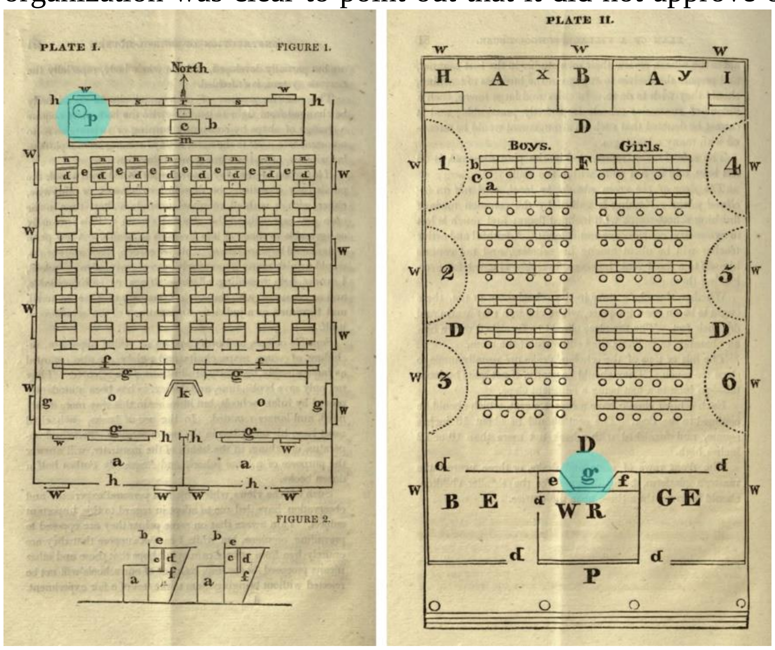

Figure 3.9 Plans, American Institute for Instruction *Construction of School-houses*, 1832. Alcott's prizewinning plan (left) was heated by a stove (at "p") and ventilated by windows only. Woodbridge's plan (right) included a ventilating fireplace (at "g").

127 Alcott, *Essay on the construction of school-houses*, 15, 18.

the Black Hole of Calcutta), but also "the recent authorities in Chemistry and Physiology within my reach" for specific quantities of air and configurations of windows and vents in school rooms.[128]

These same ideas were formally reinforced in state policy by Horace Mann, the first secretary to the newly formed Massachusetts Board of Education, in his 1838 report on the subject of school houses, a supplement to his first annual report. Like Alcott and the AII, Mann found existing schoolhouses "almost universally contracted in size…situated immediately on the road-side, and…without any proper means of ventilation," and dedicates several pages of his supplemental report to the topic. Mann's ideas about ventilation drew on those established for larger institutions, again including a reference to the Philadelphia Penitentiary. Mann also includes appendix with extensive advice from Dr. Samuel B. Woodward, Superintendent of another large institution, the State Lunatic Hospital in Worcester, on the deleterious but slow effects of inadequate ventilation on the brain. A heavily restricted airflow might produce death, but even a slightly restricted flow was likely to produce, "stupor, syncope, and other dangerous effects upon the brain and nerves. In still less quantity, it produces dullness, sleepiness, and incapacitates us for all mental efforts."[129]

### *Science and School Air*

In the second half of the century, public health reformers in Europe and America called for a new, scientific approach to problem of schoolchildren's health. In 1870, the U.S. Dept. of Education published a translation of Prussian physician and public health advocate Rudolf Virchow's "School-Room Diseases," in which he outlined such a program

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[128] Alcott, *Essay on the construction of school-houses,* 28, 30, 35.
[129] Horace Mann, *Report of the Secretary of the [Massachusetts] Board of Education on the Subject of School Houses* (1838), 6, 58.

of scientific investigation. Virchow noted that physicians and educators had since the beginning of the century called attention to the “detrimental influences of schools on the health of children” but these had not “until quite recently, been made the subject of thorough and scientific investigation.” For Virchow, diseases of the respiratory organs (primarily consumption) common among children were caused by bad air, alternating hot and cold, dust, and sitting too long in one position. Ironically, although Virchow was advocating for a new science, the source for his theory about air was based on an 1832 study carried out by none other than Chadwick’s associate Neil Arnott. In his study of the Norwood school, a London school for pauper children founded to absorb excess juveniles when workhouses were full, Arnott concluded that bad air, not too little or poor quality food, was the cause of high rates of consumption among the schoolchildren.[130]

Virchow’s call for a scientific approach to school health corresponded with a confidence in mid-nineteenth century American thought that science rather than religion could provide answers to social problems.[131] As early as 1850, promoters of the “sanitary idea” in Massachusetts were recommending establishment of “sanitary professorships” at medical schools, but it wasn’t until the establishment of the Massachusetts Board of Health in 1869 that anyone took action on this proposal. In that year, Charles W. Eliot became the new president of Harvard University, and intent on reforming the medical school, Eliot made science a priority. As part of this initiative, Eliot created a new position, that of professor of hygiene, and supported the establishment of experimental physiology within

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[130] U.S. Bureau of Education, translation of Rudolf Virchow "School Room Diseases" in *Circular of Information for August, 1870* (Washington DC: Government Printing Office, 1870), 20, 27; Ruth G. Hodgkinson, *The Origins of the National Health Service* (Berkeley and Los Angeles: University of California Press, 1967), 173; Richard A. Meckel, *Classrooms and Clinics: Urban Schools and the Protection and Promotion of Child Health, 1870-1930* (New Brunswick, NJ: Rutgers University Press, 2013), 26.
[131] Edward C. Atwater, “’Squeezing Mother Nature’: Experimental Physiology in the United States before 1870,” *Bulletin of the History of Medicine* 52, no. 3 (Fall 1978): 331-332.

the medical curriculum.[132] Two of the appointed faculty, George Derby and Henry P. Bowditch, organized research programs to scientifically study health and environment.

This optimism and faith in science shaped new approaches to consumption in America, especially that of physician George Derby, who in 1869 became the first lecturer in hygiene at Harvard with a simultaneous appointment as the Secretary of the Massachusetts Board of Health. Questions about the disease of consumption continued to absorb medical and popular thought because it remained one of the most intractable causes of mortality. Its seemingly inconsistent pattern of transmission urged medical writers to continually develop new theories about its cause and progression. They puzzled over whether death was primarily caused by heredity, environment, non-observance of hygienic practices, or some combination of those factors.

In the years following the American Civil War, however, George Derby expressed a growing confidence that consumption could be avoided or prevented, especially if physicians knew more about the disease.[133] A critical point in this shifting perspective was the appearance in 1869 of an article "Consumption in America," in the popular journal *The Atlantic.* Authored by prominent physician Henry I. Bowditch, the article summarized Bowditch's decade-long project researching the causes of the disease. Bowditch's primary conclusion was that although he still considered the constitutional predisposition to consumption as hereditary, it was possible that one could improve one's chances for resistance or recovery if one followed rules for personal and social behavior, namely the

[132] Jean Alonzo Curran *Founders of the Harvard School of Public Health, with biographical notes, 1909-1946* (New York: Josiah Macy, Jr., Foundation, 1970); W. Bruce Fye, "Why a Physiologist?–The Case Of Henry P. Bowditch," *Bulletin of the History of Medicine*, 56, no. 1 (Spring 1982): 19-29

[133] Barbara Rosenkrantz, *Public Health and the State, Changing Views in Massachusetts, 1842-1936* (Cambridge, MA: Harvard University Press, 1972), 51. For Derby knowledge of the disease was the critical determinant of prevention.

rules of hygiene.[134] Although Bowditch's conclusion that dampness was the primary influence on consumption did not necessarily address the indoor environment, Derby nonetheless praised his approach, writing that "these are the kind of discoveries which advance rational medicine, and prolong life. Not evolved from anybody's internal consciousness, which is good for nothing in the healing art, but deduced from observation."[135]

More common was the proposition that air, rather than damp, had a particular influence on the development of consumption. Much of this philosophy of air was influenced by the research of Munich-based chemist Max von Pettenkofer (1818-1901), the first professor of hygiene in the German principalities. Although Pettenkofer is best known today as the "loser" in a rivalry with Robert Koch, his publications and theories of heating, ventilation, and health were remarkably influential among American physiologists, sanitarians, and engineers in the second half of the nineteenth century.[136]

Pettenkofer undertook his first research in a hygienic topic in 1851, a study of differences in air of spaces heated either by stoves (the traditional German method) or by hot air furnace (the new British method), at the request of his sponsor, King Maximillian II of Bavaria.[137] Pettenkofer's research on air in buildings continued in the 1850s, and this

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[134] Barbara Rosenkrantz, *From Consumption to Tuberculosis: A Documentary History* (New York: Garland Publishers, 1994), xviii

[135] George Derby, "The Prevention of Disease" in *First Annual report of the State Board of Health of Massachusetts* (1870), 46.

[136] The specific rivalry between Koch and Pettenkofer concerned their assumptions about the causes of cholera. Koch promoted his germ theory, and Pettenkofer was skeptical of it, but their disagreement also had social resonance. Some saw Koch's germ theory as egalitarian. If it was a microorganism that caused disease, not one's morals or lifestyle, or race, class, or ethnicity, treatment or prevention could be applied unilaterally (of course, it wasn't). Others were less enthusiastic. If all resources went to eradicating the microorganism, then significant social and economic differences among disease victims could be ignored. This was the position of Koch's primary rival, German chemist and hygienist, Max von Pettenkofer. See Alfredo Morabia, "Epidemiologic Interactions, Complexity, and the Lonesome Death of Max von Pettenkofer" *American Journal of Epidemiology* 166, no. 11 (2007): 1233-1243.

[137] Edgar Erskine Hume, *Max von Pettenkofer, His Theory of the Etiology of Cholera, Typhoid Fever, and other Intestinal Diseases, a Review of his Arguments and Evidence* (New York: Paul B. Hober, 1927), 21

led him to propose a new theory of ‘vitiated air.’ Lavoisier’s theory of carbonic acid contamination had been essentially disproven by French chemist Felix LeBlanc in the 1840s, but Pettenkofer amended it to make it credible again. In Pettenkofer’s theory, people experienced physical discomfort in “stale” air not because it was too warm or too humid or that there was too much carbonic acid or too little oxygen. Rather, it was due to the presence in the air of some organic material emitted by the lungs and skin of people in an enclosed space. This bad air did not immediately cause disease, but repeated exposure would weaken one’s resistance to other disease-causing agents. In this model, carbonic acid was harmless, but its concentration level was an indicator of the concentration of the organic effluvia.[138]

Pettenkofer also followed Lavoisier in his research on the metabolism of respiration, but this work like Lavoisier’s research in respiratory metabolism was not generally referenced in discussions of hygiene. Like Lavoisier, Pettenkofer drew conclusions about the minimum standards for food intake and air exchange in an enclosed space, based on work with an elaborate piece of laboratory equipment, a “respiratory apparatus” that allowed him to measure precisely the content of the air taken in by a person occupying the apparatus and the content (carbon dioxide and water) released by them.[139] Rather it was Pettenkofer’s method for sampling air for various substances that George

[138] J. Sundell, “On the Association between Building Ventilation Characteristics, some Indoor Environmental Exposures, some Allergic Manifestations and Subjective Symptom Reports,” *Indoor air* 4, no. S2 (Dec 1994): 11-12.

[139] Didem Ekici “The Physiology of the House: Modern Architecture and the Science of Hygiene” in *Healing Spaces, Modern Architecture, and the Body,* edited by Sarah Schrank and Didem Ekici (London; New York: Routledge, 2016); Didem Ekici, “Skin, Clothing, and Dwelling: Max von Pettenkofer, the Science of Hygiene, and Breathing Walls,” *Journal of the Society of Architectural Historians* 75, no. 3 (Sep 2016): 281–298.

Derby utilized in reporting for his text, “Air and Some of its Impurities” (1871), which appeared in the *Second Annual report of the State Board of Health of Massachusetts.*[140]

### *Sanitary Schools*

In New York City, the public school system had its origins less as an alternative to factory work and more as a strategy of philanthropic social management. Against a deeply partisan political backdrop, the school environment, particularly its heating and ventilation, took on additional layers of meaning. School air was not just a means to prevent disease or maintain health but also an instrument to critique opponents’ credibility and to claim superiority. Ventilation and heating in this context were a mechanism in power struggles over control of schools and school funding. Critical to the promotion of this effort were manufacturers of “sanitary” equipment, as well as professionalizing groups of engineers and architects, who united to both construct and define new fields of practice as sanitary engineering and sanitary architecture.

Virchow’s proposition for a scientific approach to school diseases aligned easily with the scientific mentality of the philanthropic groups that influenced the early building campaigns of the New York Board of Education, newly formed in 1853. In that year, the Public School Society, a private philanthropic society associated with reformers of the Association for Improving the Condition of the Poor (AICP) had been subsumed by the elected Board of Education, but continued to consult on a subsequently launched school construction campaign.[141] The AICP philosophy of “scientific philanthropy,” the application of science and technology means to achieve economical and utilitarian end,

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[140] Derby also considered small particles in air in response to John Tyndall’s “Dust and Disease” (1871). Tyndall was then the Professor of Natural Philosophy at the Royal Institution of Great Britain.

[141] Edwin G. Burrows and Mike Wallace, *Gotham: A History of New York City to 1898* (Oxford: Oxford University Press, 2000), 620, 780; the Board also hired women as teachers in order to keep costs down.

was embedded in public talks on ventilation delivered at the hall of the Board of Education in November 1855 by John H. Griscom, Jr. (1809-1874), the formerly anonymous author of the *Uses and Abuses of Air* as well as an active member of the AICP, and in December of that same year by David Boswell Reid, the recently emigrated British ventilating expert.[142]

Griscom is a familiar figure to the traditional story of health reform in New York City. His work with the AICP was essential to the campaign for the passage of the Metropolitan Health Act of 1866. Griscom had been an early promoter of Chadwick's "sanitary idea," having made in 1842 during his tenure as a city inspector an extensive survey of the living conditions of the city's poor, which he published in 1845 as *The Sanitary Condition of the Laboring Population of New York*.[143] Several years of advocacy by Griscom and fellow campaigners and an extensive sanitary survey of the city (seventeen volumes!), paired with fears stoked in the reforming middle class by the Draft Riot of 1863, and the threat of another cholera outbreak in 1865, resulted in the eventual passage of the Metropolitan Health Act of 1866. While not a secret, the dimension emphasized less often in popular narratives is that the 1866 Act was passed by the State of New York, not the city government, effectively removing from New York City voters the responsibility for the city's health and turning it over to the State, which was a Republican administration, where the city was generally Democratic and represented many of the Catholic immigrant populations.[144]

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142 John H. Griscom was also the son of John Griscom, Sr., a founder of the earlier Society for the Prevention of Pauperism. There is much background here on the senior Griscom's activities with the SPP, the House of Refuge, and the Free School Society—its Lancasterian system and its conflict with the Catholic Schools—his travels to Europe and communication of scientific ideas from there, but that's too deep a cut for this section.

143 John Duffy, *A History of Public Health in New York City* (New York: Russell Sage Foundation, 1968), 567.

144 Duffy, *The Sanitarians*, 120

It is not surprising then, that in the inaugural volume of *The Sanitarian* journal, one of the key public health journals of the late nineteenth century, when a debate broke out over ventilation in the public schools, those on opposing sides of the debate had differing political affiliations. With a less-than-subtle title, "School Poisoning," the first article, authored by the City Sanitary Inspector and published in April 1873, measured the carbonic acid levels in multiple schools and claimed them to be dangerous. The school board then called in Lewis W. Leeds as a ventilation expert to inspect the schools and offer a second opinion. Leeds reported similarly negative conditions (chickens roosting in the fresh air intake!) (Figure 3.10). The board never published Leeds's report, and the *Sanitarian* claimed it was suppressed. A third article in the same volume struck a more conciliatory tone, explaining the circumstances of the report's unpublished state, but nonetheless disparaged the state of the schools and those in charge of them.[145] Certainly

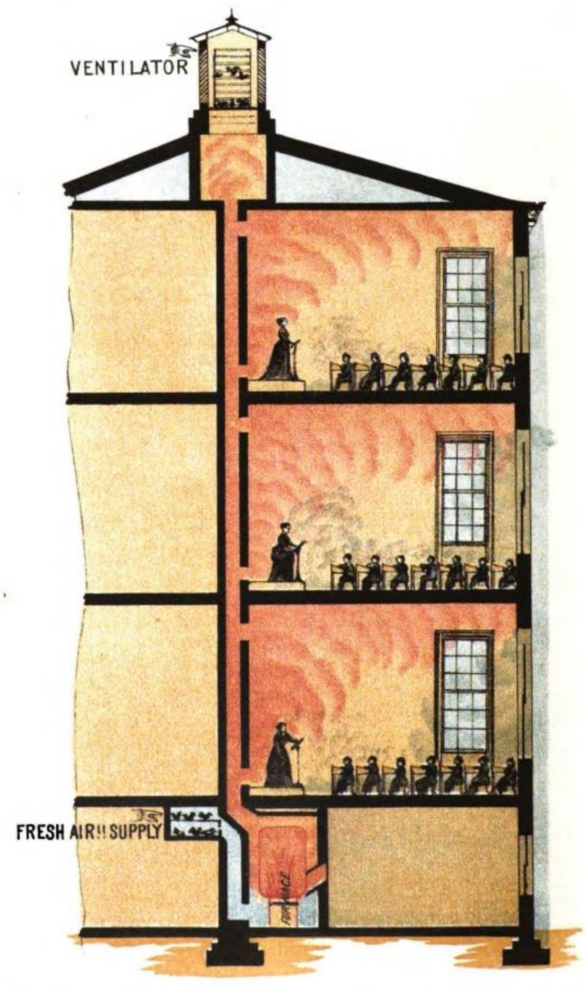

Figure 3.10 "Poisonous" school ventilation, Lewis W. Leeds, *The Sanitarian*, 1871.

[145] C.H. Janes, "School Poisoning," *The Sanitarian* 1, no. 1 (Apr 1873): 35-37; Lewis W. Leeds, "School Poisoning in New York.—A Suppressed Report," *The Sanitarian* 1, no. 5 (Aug 1873): 193-198; "Something More About School Poisoning in New York. — A Correction Corrected" *The Sanitarian* 1, no. 7 (Oct 1873): 308-312. Source for statement about Sanitarian being a primary journal, Duffy, *The Sanitarians*, 133

the medical professionals inspecting the schools and publishing the journal had real concerns about students' health, but the political context likely urged them to make the situation seem particularly dire, a way to cast aspersions on the newly established Board of Public Instruction, an organization formed by the Tweed-led Democratic city government following a political shift in power in favor of Tweed.

School-room health thus remained a controversial area. Because the Board of Education in New York City was highly politicized, it remained generally out of the purview of the City Health Department. Occasionally health inspectors might check on school buildings or encourage vaccination of school children, but in general they steered clear of the Board of Education's territory.[146] Sanitarians thus adopted other strategies to address school health.

One strategy was part of a larger effort to inculcate newly arrived immigrant as well as existing populations in "the laws of life" and behaviors observant of them. Reformers believed that education of the poor in physiology and hygiene was critical to the sanitarian project. They thought that if only the 'laboring classes' knew how the body worked and how to keep it healthy, they would of course want to observe prescribed sanitary practices. In the 1840s, educational reformer Horace Mann advocated for introducing the subject of human physiology into the public school curriculum.[147] John H. Griscom emphasized education as an essential mission in his writings, and this was the motivation behind his physiology textbook, *Animal mechanism and physiology; being a plain and familiar exposition of the structure and functions of the human system,* published in 1839.[148]

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[146] Duffy, *The Sanitarians*, 141

[147] James H. Cassedy, "The Roots of American Sanitary Reform 1843–47: Seven Letters from John H. Griscom to Lemuel Shattuck" *Journal of the History of Medicine and Allied Sciences* 30, no. 2 (Apr 1975): 136-147.

[148] John H. Griscom, *Animal mechanism and physiology* (New York, Harper & brothers, 1839)

***Sanitary Engineer, Sanitary Architect***

Manufacturers saw an opportunity to engage professionals in this discussion. Although they denied self-interest, they promoted ideas and methods that would both create a market for their products and establish an allied set of experts who would endorse them at a secondary level, once removed from the manufacturer's direct sponsorship. The professionals were likewise enthusiastic to gain new knowledge and skills that would allow them to present themselves as addressing "modern" problems with modern means.

Again, this is not to say that there were not genuine concerns about death rates from consumption among school children or real financial or administrative limitations, it is just that there were other factors influencing the tone and direction of the discourse about school health and environment. One of these factors was the development of what Robert Wiebe called a "professional technostructure." For Wiebe, this represents primarily the technocratic approach to social issues, as he puts it "thorny political issues" translated as simply "technical difficulties," matters for social engineering…government by 'science,' not by men."[149] We have seen this technocratic dimension among Chadwick's circle, Massachusetts medical advisors, and in the 'scientific philanthropy' of the AICP, but as Wiebe describes, there develops in parallel a new class of technical experts who absorb the directives of the technocratic framing and work to resolve the "technical difficulties." In the American context, this involved a self-conscious professionalization of technical expertise in sanitary architecture and sanitary engineering as well as the promotion of particular sanitary regimes by the manufacturers of apparatus that support such practices.

Many argue correctly that the U.S. Sanitary Commission during the Civil War exposed large populations to ideas about the sanitary idea, practices of hygiene, and the

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[149] R.H. Wiebe, *The Search for Order 1877-1920* (New York: Hill and Wang, 1968) quoted in Berman, *Social Change and Scientific Organization* xix.

importance of ventilation, making them amenable to sanitary regulation of their lives away from the battlefront.[150] This is true, new groups were primed to accept or even seek out hygienic directives, but existing professional groups and manufacturers also consciously took on the sanitary idea and translated it into new areas of expertise and new product lines. Numerous historians have demonstrated this movement in terms of the "wet" side of the sanitary movement, its pipes and its drains, but less attention has been paid to the "dry" side of this narrative. The concept of "sanitary architecture" emerged as an exchange between professional groups such as the fledgling American Public Health Association (APHA, formed in 1872), the American Institute of Architects (AIA, nominally formed in 1857), and trade and professional publications like the New-York based journal, the *Sanitary Engineer,* (launched in 1877), and *The Sanitarian* (launched in 1873). Heating and ventilating engineers did not organize as a professional group until the 1890s, but a number of individual civil and mechanical engineers developed their individual reputations as experts in the field and participated in the exchange with other groups and published frequently in the journals.

In the early years of the APHA, presentations at annual meetings focused primarily on epidemic disease, sewage, and urban refuse removal, but in later years, the group emphasized epidemic disease less and turned more often to other subjects, in particular the topic of ventilation. Historian John Duffy attributes this shift to sustained fears of miasma and worries about the "concentration of fetid odors indoors."[151] This is partially true. Newly available indoor plumbing did bring with it a fear of "sewer gas." While the gaseous emissions associated with urban sewers had been a public health concern for some time,

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[150] Suellen M. Hoy, *Chasing Dirt: The American Pursuit of Cleanliness* (New York: Oxford University Press, 1995), 57; Melanie Kiechle, *Smell Detectives: An Olfactory History of Nineteenth-Century Urban America* (Seattle; London: University of Washington Press, 2017), 106.
[151] Duffy, *The Sanitarians*, 132

private concern increased as householders installed newly available indoor plumbing. Indeed several popular books both cultivated and addressed this fear. Yet, although some commentators merged the concepts of sewer gas and "vitiated air" (confined air deteriorated by human respiration), most considered them as separate problems. Sewer gas was relatively easy to address. Self-declared experts advised that better plumbing and some modest ventilation would rid a building of sewer gas, although some cities went a step further and regulated the plumbing trade in the name of sewer gas fears.

The increasing interest in ventilation at the APHA might also be attributed to the growing confidence in America in the preventability of consumption. Duffy claims that within the APHA consumption "received little attention" relative to the more vivid and immediate epidemic disorders, but that does not appear to be the case in the ventilation discourse from the mid-1870s on.[152] Certainly, as physician and professor F. Donaldson of the University of Maryland, presenting at the American Public Health Association's 1875 annual meeting, noted that despite the advances in "Hygienic Medicine" that had occurred in the few years prior, "little has been written and still less done in regard to the prevention of Pulmonary Consumption, — the great scourge of the human race." But there was great hope, Donaldson felt he "could confidently assert that there is no chronic disease which can be so controlled in its development by sanitary and hygienic laws as pulmonary consumption." There were a number of possible causes of consumption beyond heredity, Donaldson claimed, but after considering all of these possible causes, he had concluded that ventilation was most important, followed by nutrition. This knowledge required proselytization, Donaldson averred, for "if we could only convince the community of the

[152] Duffy, *The Sanitarians*, 2

fact that vitiated air was so frequently a cause of consumption, it might supply a motive which would induce them to attend to the all-important requirements of ventilation."[153]

Henry C. Meyer, founder of the journal, the *Sanitary Engineer*, imagined it as just such a forum to convince and to supply motive. From the beginning, Meyer attempted to project an image of neutrality, even though he was the owner of a large plumbing-supply manufacturing operation, Henry C. Meyer & Company, with many products promoted to address sewer gas issues. For the first several years of publication, Meyer kept his identity as publisher a secret, acknowledging when he finally did reveal his connection that some would perceive self-interest.[154] From its first issues, *Sanitary Engineer* featured articles on heating and ventilation, which Meyer says was for the purpose of attracting interest from architects (Figure 3.11). The first series of articles were written by mechanical engineer Robert Briggs but from 1879-1883 the series was written by John S. Billings, a physician considered an expert in ventilation, and entitled "Letters to a Young Architect on Ventilation and Heating." Billings later consolidated these articles into his influential book *Principles of Ventilation and Heating*, published in three editions in 1884, 1889, and 1893.

Figure 3.11 Masthead for *The Plumber & Sanitary Engineer*, 1879. Meyer soon changed the name of the journal to *The Sanitary Engineer.*

Billings may have been writing to the private sector, but his expertise and knowledge emerged from his career in the public sphere. He had his beginning in the Surgeon General of the United States Army. The Civil War broke out soon after Billings

[153] F. Donaldson, "The Influence of City Life and Occupations in Developing Pulmonary Consumption" *Public Health Papers and Reports* 2 (1876): 95, 103, 112.
[154] Henry C. Meyer "An Announcement," *Sanitary Engineer* 7, no. 1 (Dec 7, 1882), 1; Henry C. Meyer *The story of the Sanitary engineer, later the Engineering record, supplementary to Civil War experiences,* (New York: privately printed, 1928), 8.

graduated from medical school in Ohio, and he joined the Union army as a field surgeon. Billings remained with the Army Medical Department until he retired from military service in 1895, and this allowed him to participate in many national-scale public health endeavors both governmental and professional, including management of the vital statistics portion of three censuses, involvement in the short-lived National Health Board (1879-1886), and active participation in the American Public Health Association.[155]

Billings's experience with ventilation as a health issue originated with a series of assignments given to Billings in the years following the war, a survey the hospitals of the U.S. Marine Hospital Service and a subsequent survey of the barracks, hospitals, andhygiene of the United States Army. Billings relied primarily on British military models for the structure and content of his surveys, particularly the sanitary surveys of the British Barrack and Hospital Improvement Commission of the early 1860s, and the popular military hygiene manual written by Edmund A. Parkes of Britain's Army Medical School. Yet unlike the British surveys, Billings did not consider closely the water-supply, drainage, and sewerage of the army camps, because these were not the responsibility of the field surgeons at the time. Rather he emphasized the perceived deficiencies of the soldiers' barracks, particularly their overcrowding and ventilation, which did not meet the standards laid out by the British authorities. Following these surveys, Billings participated in the design of Barnes Hospital, which was a functioning hospital as well as an unusual project to test 'all the most recent and improved appliances' for heating and ventilation.[156] With this experience, Billings became a specially selected consultant on the new Johns Hopkins

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[155] Fielding Garrison, "The Scientific Work of Dr. John Shaw Billings," *National Academy of Sciences of The United States of America Biographical Memoirs* 8 (1917): 385-416.
[156] James H. Cassedy, *John Shaw Billings: Science and Medicine in the Gilded Age* (Philadelphia: Xlibris, 2009), 42-43, 58-59, 63, 102-113.

Hospital competition and on ventilation in the U.S. Capitol in the 1870s, even traveling to western Europe to examine ventilation and heating systems there.

Meyer sought authors like Billings because his intended audience for the *Sanitary Engineer* was decidedly middle-class and professional. His vision was that it would be a "high-class paper" that would "enlighten architects, plumbers and physicians on these questions" of sanitary engineering. He consciously pursued "writers of experience and high standing" to discuss sanitary principles, not specific products, because if Sanitary Engineer was perceived as an "ordinary trade sheet" he could not "secure the cooperation of the class of contributors that I needed." Although Meyer disclaimed any objective to "create a demand for the articles made by [his] firm," he had no scruples about creating demand for "more careful plumbing and house drainage," but in order to do this, he realized it was critical to secure architects and physicians as subscribers more so than plumbers.[157]

Although Meyer was seeing some success in gaining architect subscribers, mostly as a result of his employing an architect to promote subscriptions among colleagues, he was anxious to retain their interest, which he feared would flag if the journal discussed only plumbing, heating, and ventilation. Thus, Meyer launched an architectural competition for a tenement house that would be "reasonably healthy to live in and yet pay as an investment." The results of the competition are well recorded in both architectural and public health histories—the "dumbbell" tenement design, despite receiving harsh criticism from architects and many others, became a basis for the 1879 Tenement House Act—but its secondary objective is not as frequently noticed. With the competition, Meyer hoped "to enlist the interest of the architectural profession" in architecture as preventive

[157] Meyer *The story of the Sanitary engineer,* 5-7, 9-10.

medicine.[158] As Meyer testified to the British Parliament in July, 1884, the Tenement House Act was aimed at building design, not remedial inspection, "because we find that it is much easier to control the character of the house before it is built, than after it is built and occupied."[159]

Although winning the tenement house design was criticized for its minimal modification of the frequently denounced double house plan, the competitions tactic seemed to be yielding some success. [160] In the next year, when the Sanitary Engineer announced its competition for a model public school house, it had a prestigious jury to judge the results. It included not only two physicians, John S. Billings and C.R. Agnew, and an education expert, John D. Philbrick, but also two prominent architects, George B. Post and William R. Ware, then a professor of architecture at the Massachusetts Institute of Technology. "The increased employment of my professional brethren in the building of tenement houses, is no doubt largely due to your competition last winter. I trust the one you have just instituted will also have the effect of opening up another field for their services."[161]

Throughout the 1870s and later, architects, physicians, and engineers participated in an exchange of knowledge, building a new dimension to each profession, a practice often called "sanitary architecture" by members of all three professions. This was a change from ante-bellum views. In 1848, John H. Griscom in *Uses and Abuses of Air* portrayed architects as ignorant of what he defined as healthy heating and ventilation principles. His

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158 Meyer *The story of the Sanitary engineer*, 10-11; Gwendolyn Wright, *Building the Dream: A Social History of Housing in America* (New York, Pantheon Books, 1981), 122.
159 Meyer *The story of the Sanitary engineer*, 37.
160 Richard Plunz, *A History of Housing in New York City: Dwelling Type and Social Change in the American Metropolis* (New York: Columbia University Press, 1990), 27.
161 "$500 Competition for a Model Public School House" *The Plumber and Sanitary Engineer* 3 (Dec 15, 1879), 44.

book includes a long exchange between an architect and a "stranger" in which the figure of the architect repeatedly reveals his ignorance, giving answers to questions about sanitary measures like, "Really, I cannot answer you. Your question puzzles me."[162] George Derby was more generous to the architectural profession. In observing that good ventilation was not often achieved even with ample funding because builders and architects did not really know how to realize it, but to a certain extent he could pardon their current ignorance, for "Architecture was a full-grown art two thousand years ago. Ventilation is modern."[163]

By the 1870s architects' professional associations and publications were inviting sanitarians and sanitary engineers to share knowledge about criteria and methods for "healthy" heating and ventilation. Although historian Annmarie Adams observes that the relationship between doctors and architects over sanitary concerns was contentious and adversarial in Great Britain, the exchange between the groups in the American context was generally collegial, and indeed architects saw acquisition of sanitary knowledge as a way to define and add value to their emerging profession.

The AIA regularly communicated with allied engineering societies and health organizations and invited engineers and physicians to deliver talks on heating and ventilation. For example, architect and then-AIA Secretary Carl Pfeiffer delivered the talk "Sanitary Relations to Health Principles of Architecture" at the first annual meeting of the American Public Health Association in 1873.[164] Consulting engineer Lewis W. Leeds addressed the attendees Thirteenth Annual AIA Convention in 1879 with a talk entitled "The Proportion of Inlet and Outlet Shafts in Ventilation" and held in the Directors' Room

[162] John H. Griscom, *The Uses and Abuses of Air; Showing Its Influence in Sustaining Life* (New York: Redfield, 1848), 209.
[163] George Derby, "The Prevention of Disease," *Annual report of the State Board of Health of Massachusetts* (1870), 52
[164] Carl Pfeiffer "Report on "Sanitary Relations to Health Principles of Architecture" *Public health papers and reports presented at the meetings of the American Public Health Association in the year 1873* 2 (1875), 147-156. Note that Pfeiffer's primary reference on ventilation is Max von Pettenkofer.

of the Equitable Life Assurance Society, a building which featured an extensive ventilation system designed by Leeds.[165] Civil engineer Robert Briggs, well known for his design of the fan-driven ventilation system at the U.S. Capitol, also often spoke at AIA chapter meetings and contributed several articles to *American Architect and Building News* (AABN) between 1876 and 1878. A short editorial appearing in second issue of AABN expresses both the new responsibility and ambition of the profession. Reporting on the high annual death rate in New York City, the writer observes, "There is hardly a class of the community who have a better opportunity to exert an influence for securing a lower death-rate than architects."[166]

### *School Heat and Mental Fatigue*

In December 1879, the *Sanitary Engineer* announced its competition for a model school building, the journal included some reflections from the president of the New York City Board of Education (Figure 3.12). President Wood hoped that the competition entrants would offer "a good and reasonable cheap system of automatic ventilation," one that would provide "an abundant supply of fresh air without draughts" and at the same time "get rid of the foul air expired by the schoolchildren." There had been much agitation in the press about ventilation in schools recently, Wood noted, and while he chalked this up to a "spasmodic excitement," he figured that there was probably a legitimate concern somewhere within the flurry, and he hoped that the competition would address it.[167] Much of that flurry was likely inspired by a recent monumental survey of the sanitary conditions

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165 Lewis W. Leeds "The Proportion of Inlet and Outlet Shafts in Ventilation" *Proceedings of the Thirteenth Annual convention of the American Institute of Architects held in New York November 19 and 20, 1879* (Boston: Committee on Library and Publications of the American Institute of Architects, 1880), 31-38.
166 *American Architect and Building News* 1, no. 2 (Jan 8, 1876), 10.
167 *The Plumber and Sanitary Engineer* 3 (Dec 15, 1879): 26

of the public schools in Massachusetts, sponsored by the American Social Science Association (ASSA), which of course had found the schools' conditions inadequate.[168] The ASSA, which had been founded in 1865 to "extend social knowledge and provide a more authoritative basis for dealing with contemporary social problems" took education as one of its four primary areas of reform activity, the public school system was a critical issue for the ASSA (the others were public health, social economy, and jurisprudence).[169]

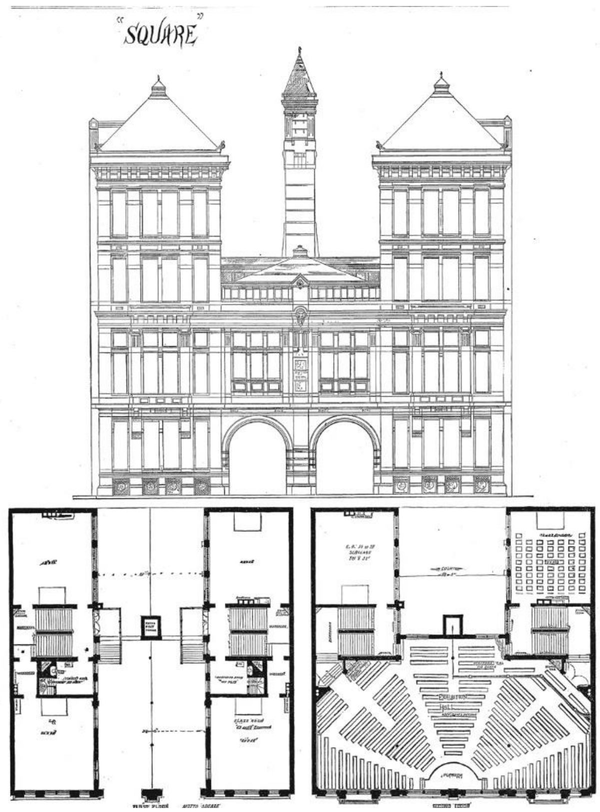


Figure 3.12 First-prize winner of the *Sanitary Engineer* model school competition, 1880. The competition jury noted that none of the submitted plans had fully met their requirements, but this plan by Arthur T. Matthews of Oakland, CA came the closest.

The opinions of the ASSA found their way into the Sanitary Engineering school competition both in the competition's jury and in the journal's series of articles on "sanitary school construction" published to accompany the announcement of the competition. On the jury, both Philbrick and Agnew were active members in the ASSA, and the articles were authored by D.H. Lincoln, the ASSA's Secretary of its Health Department and the author of the

168 Meckel, *Classrooms and Clinics*, 26.

169 Dorothy Ross, "The Development of the Social Sciences," in *The Organization of Knowledge in Modern America, 1860-1920,* edited by Alexandra Oleson and John Voss (Baltimore: Johns Hopkins University Press, 1979), 108-110.

Massachusetts school survey.[170] For Lincoln and the ASSA, however, the primary problem in American schoolhouses, even the well-built ones, was not the expired air of schoolchildren or the excessive cold that sometimes chilled students in the winter. Rather the critical problem was excessive heat, which as Lincoln put it was "doubtless a natural concomitant of that 'forcing-system' to which our schools seem to tend," alluding to the highly artificial environment of the greenhouse. For Lincoln, this was "a system implying an excess of mental strain (even more than excess of work), which induces a liking for bodily warmth in proportion as it discourages a liking for active sport."[171] The effects of the school environment were thus much more insidious. School afflictions would not appear like quick-acting "school poisoning," but rather as a slow yet persistent nervous decline.

Inspiration for this switch in attention to heat and mental fatigue in schools came from two different but related sources. In part this concern with mental fatigue was an extension of a concurrent "overpressure" debate in Britain that had its basis in disagreements over so-called half-time schools. Many argued that these half-time schools, which were established to provide part-time education for children concurrently employed in factories, should be made full-time, giving the students more time away from the factory. Others, in particular Edwin Chadwick, argued that this would be too costly, and it would limit the availability of child laborers to employers. Of course Chadwick and his fellow travelers did not articulate it this way. Rather they finessed the subject by shifting the conversation to school conditions. They argued that any more time in school would exceed both the physiological and psychological capacity of students, especially if the school's

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[170] Meckel, *Classrooms and Clinics,* 26.
[171] D. F. Lincoln, M.D., "School Hygiene," in *A Treatise on Hygiene and Public Health,* edited by Albert H. Buck (New York: W. Wood and Company, 1879), 599

space conditioning were defective. As Chadwick argued, "the confinement of the children for five or six hours in such conditions, overtasked mentally, and painfully constrained bodily, are surely evil conditions requiring active intervention for their relief."[172]

In America, the school debate was overlaid with a simultaneous preoccupation with the problem of nervous exhaustion and so-called "neurasthenia." Lincoln, a neurologist by training, shared this fixation with other American medical experts, particularly S. Weir Mitchell, a Philadelphia-based physician and physiologist whose 1871 text *Wear and Tear: or, Hints for the Overworked* on the topic was widely cited.[173] In terms of school life, Lincoln and this group claimed that school work, if performed in a "vitiated" or overheated classroom would over time produce "nervous fatigue, irritability, and exhaustion."[174] Yet while the efforts of figures like Lincoln Mitchell were often specifically aimed at the affluent classes, with its subset of white-collar "brain-workers," clerks, and office workers, their particular construction of "neurasthenia" as ultimately physical in origin meant that these discussions about school conditions could also carry a subtext about overwork and physical fatigue in industrial settings.[175] These debates about the physiological manifestations of overwork would come to the surface in the last decades of the nineteenth

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[172] Edwin Chadwick, "The Sanitary Principles of School Construction," *Journal of the Society of Arts* (Nov 3, 1871): 856

[173] S. Weir Mitchell, *Wear and Tear: or, Hints for the Overworked* (Philadelphia: Lippincott & Co, 1871). In this book, Mitchell proposes the "rest cure" made infamous by Charlotte Perkins Gilman in her book *The Yellow Wallpaper*. It is critical to note that Mitchell intended the "rest cure" and its recommendation for complete domestic isolation and inactivity only for women suffering from overstrain and "neuroses." For overworked men, Mitchell recommended the opposite, more physical activity and time outside in nature. Mitchell claimed later that he developed the rest cure originally during the Civil War as a treatment for battle fatigue. Ellen L. Bassuk, "The Rest Cure: Repetition or Resolution of Victorian Women's Conflicts?" *Poetics Today,* 6, no. 1-2 (1985): 247; Michael S. Kimmel, "Introduction," in *Wear and Tear: or Hints for the Overworked* S. Weir Mitchell [1871] (Walnut Creek, CA: AltaMira Press, 2004), ix-x.

[174] Meckel, *Classrooms and Clinics*, 30.

[175] Charles E. Rosenberg, "The Place of George M. Beard in Nineteenth–Century Psychiatry," *Bulletin of the History of Medicine,* 36, no. 3 (May-June 1962): 249; D.F. Lincoln, "Proceedings of the Department of Health, at Detroit, May 11, 12, and 13, 1875, Report of D.F. Lincoln, MD, Secretary of the Department of Health," *Journal of Social Science: containing the Transactions of the American Association* 8 (May 1876).

century and crescendo in the early twentieth century. The story of these debates and their technological implications are thus the subject of the following two chapters.

In this chapter we observed Chadwick applying aerial preventive medicine to the labouring population at large, invoking the authority of science to achieve his ends. With this, he could simultaneously deflect responsibility from "the factory system" and deflate worker demands for shorter hours. In his proposition of "internal economy," however, Chadwick elaborates an aspect of biopower in which he imagines the management of individual laborers' health and productivity in a way that makes them self-sufficient. These same ideas and conflicts transferred to industrializing Massachusetts in the 1840s. Here and in New York, discourses on ventilation also grew around the emerging public school system. While this was partly a means to critique political rivals, it can also be seen an extension of the practices of biopower, where officials acted to preserve and build the productive capacity of the next generation. In this process, both manufacturers and social science organizations recruited architects to carry forth the "sanitary idea" into more sectors of the built environment.

# Chapter 4. The Labor Question: Air, Heat, Consumption, Fatigue

Between June and November 1881 a team of investigators dispatched by Carroll D. Wright (1840-1909), Chief of the Massachusetts Bureau of Labor Statistics, interviewed nearly seven hundred residents of the Massachusetts cities of Fall River, Lowell, and Lawrence in order to answer a question the Bureau had received from a member of the state House of Representatives, “Why is it that the working people of Fall River are in constant turmoil, when at Lowell and Lawrence they are quiet?” The investigators began by interviewing mill operatives, mostly from textile mills, as this was still the pre-eminent industry in these towns (Figure 4.1). Making evening visits to the operatives in their homes, the Bureau’s agents tried to leave their inquiries open-ended. They asked “no uniform questions” in the effort to understand the operatives’ reasons “for being discontented, or for being contented, as the case might be.” With the operatives’ contents and discontents on record, the agents then set out to interview the manufacturers as well as members of the city government and others “conversant with the industrial life of the respective cities.” Meanwhile, accompanied by a member of the local board of health, they personally inspected numerous corporate boarding-houses and tenements. The Bureau rounded out the investigation with a circular seeking written statements from “leading citizens, in all callings.” With this effort, they

Figure 4.1 Carding room, Granite Mill, Fall River, MA, c. 1870. The J. Paul Getty Museum, Los Angeles, image courtesy of the Getty's Open Content Program.

received opinions from clergymen, grocers, lawyers, physicians, bankers, real estate agents, and "well-informed parties" in all three cities.[1]

The investigators heard a range of complaints and explanations, but few directly related to health or safety. They documented no concerns about machine guarding (shielding of moving parts to prevent injury), and only a few about heating or ventilation. Some respondents even praised the conditions, with plenty of heat in the winter and "perfect ventilation," and specific grievances tended to focus on overheating, particularly in textile weaving rooms, where windows were kept closed in order to trap the hot steam used to maintain thread flexibility.[2] Instead within the two-hundred plus page report, there were many more complaints in Fall River about overwork and low wages as well as high food costs and high rents demanded for poorly constructed company-provided housing. The report teased out that much of the discontent among operatives emerged from the practices of "driving" and "grinding," that were demanding ever higher output for the same or lower wages (Figure 4.2). Some informants argued that these practices resulted from many of the mills in Fall River, unlike

Figure 4.2 "New England factory life – 'Bell-time,'" *Harper's Weekly*, July 1868. Depicts Washington Mills, Lawrence, MA.

[1] Carroll D. Wright, "Fall River, Lowell, and Lawrence," *Public Document no. 15, Thirteenth Annual Report of the Bureau of Statistics of Labor* (Boston: Rand, Avery & Co, Printers to the Commonwealth, 1882), 195-197.

[2] Judson MacLaury *Government Regulation of Workers' Safety and Health, 1877-1917* (U.S. Department of Labor, Office of the Assistant Secretary for Policy, 2004), np; Wright, "Fall River, Lowell, and Lawrence," 222, 224. The operatives found the conditions insufferable in summer and wished that all weaving rooms were equipped with a "new device that was in operation in Granite Mill No. 2, where, it was said, the pipes throughout the room, in summer, emitted jets of cold vapor, which not only dampened the warp and made the work go easily, but kept the room cool."

those in Lowell or Lawrence, having been built "on speculation rather than on capital," and thus were struggling to repay debt after the downturn in early 1870s. The investigators could not prove these claims, they reported, but some evidence they gathered suggested that it may have been a factor.[3]

In closing the lengthy and detailed report, Wright and his Bureau colleagues concluded that non-intervention on the part of the state was the most effective response. In order "to remove discontent in Fall River, and prevent its growth in Lowell and Lawrence," they argued that legislation might be appropriate on some points, but that more could be done "by an awakening of honest public sentiment in these cities." Such an awakening would mean offering education, promoting thrift, insisting upon "clean, wholesome, healthy homes" for those willing to work, discouraging married women and children from working in the mills, preventing intemperance, and making available to the people "all the safeguards that science and inventive genius can supply." Most important was an "obedience to law and true moral principles" that would in turn encourage all, including employers, to deem "that the operative shall share more and more in the resulting wealth." This should be carried out on an individual basis, for it was "this individual work that makes moral revolutions easy." If one manufacturer built a model boarding house, it would naturally lead others to follow the example.[4]

Like Pringle and Chadwick before him, Wright circumscribed the role of the state to specific health matters amenable to a technical fix. Wright posed the question rhetorically, "What specific legislation can be instituted to remove any of the causes, either of discontent or unwholesome conditions?" His emphatic answer was, "Give a State Board of Health full power to clean out every tenement "rookery" in the State; especially give it

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[3] Wright, "Fall River, Lowell, and Lawrence," 229-230.
[4] Wright, "Fall River, Lowell, and Lawrence," 413-414.

power to enforce all the laws relating to health in our great manufacturing cities."[5] The state had the right to intervene in matters of life and death, but matters of wages, working hours, and rent should be left to the moral conscience of the employers.

***Maybe it is the Heat***

In the decades around the turn of the twentieth century, the medical definitions of air presented a number of seeming paradoxes. At the time that germ theory ostensibly refuted the long-standing aerial theories of disease transmission, medical attention to air significantly increased. Although Gail Cooper astutely summarizes the role that factory air conditions had long played in labor-management struggles, she focuses primarily on a conflict outside the factory, between open-air crusaders and professional engineers, and suggests that the "comfortable" conditions created by air conditioning for factory workers were incidental to industrial process objectives that they were primarily a value-added proposition. Certainly Cooper does not discount labor struggles. Rather she observes that the engineers were happy to stand outside the labor-management controversies and to provide a seemingly easy "technical fix" for these conflicts.

Yet by excavating deeper into medical theory and scientific practice, it is possible to capture more dimensions of "the labor question" and thus unpack some of the paradoxes implicit in the technological paths chosen not only by engineers but also by medical experts, reformers, and employers. Undoubtedly the engineers' story of "air conditioning" is critical—and indeed it is the one most frequently repeated in the popular press—but in following scientific and medical narratives more closely, this chapter reveals additional complexities and contingencies that informed the technology's material manifestation. By focusing on removal of bodily heat rather than the removal of respiratory or other airborne

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[5] Wright, "Fall River, Lowell, and Lawrence," 414.

contaminants, physiologists, laboratory scientists, and health administrators endorsed a technology that would simultaneously increase worker productivity (by reducing worker fatigue) and draw attention away from the increasing concentration of contaminants in the confined environment of the workplace. Although the majority of the benefits of increased worker productivity went to employers, I want to point out that medical experts often expressed that they thought they were doing the workers themselves a favor as well. Because many factory and mining operations paid by the piece, workers earned more wages if they could work more intensively. Thus, the medical experts believed they were creating a win-win situation: more work completed for the employer, more total wages for the employee with less immediate damage to health.

Cooper argues that the story of air conditioning is one of humidity not of heat. This is accurate in the sense that the term “air conditioning” first applied to management of humidity in factories producing hygroscopic materials (swell and shrink with humidity), but it does not sufficiently account for the particular form of air conditioning that emerged after 1923, when the American Society of Heating and Ventilating Engineers debuted the “comfort chart.” After 1923, air conditioning meant refrigeration, or rather the addition of mechanical refrigeration equipment to the humidity control systems that were already in existence.

Instead, issues of heat were more essential to the medical and scientific discourses at the turn of the twentieth century. In turn these were embedded in conflicts that erupted between employers, workers, and labor reformers over the concept of industrial fatigue in these years. Perhaps not incoincidentally, Lavoisier’s post-Revolution formulation of the animal economy was at the foundation of this new concept of fatigue, but now it was conjoined with newly outlined principles of thermodynamics.[6] The first law of thermodynamics, the law of conservation of energy, laid out in 1847 by German physicist Hermann von Helmholtz posited the myriad forces in nature should be conceived as unified concepts of energy and work. This was an optimistic account, it imagined nature as a boundless reserve of energy available for productive work. Then along came another German physicist, Rudolph Clausius, to rain on everyone's parade with the second law of thermodynamics. Clausius demonstrated that with the transformation of energy into work there was a predictable but unavoidable dissipation of force, which he called entropy.[7] Dreams about boundless productivity became fears about the heat death of the universe.

Physiologists were quick to apply these theories to human bodies, and with this new model of energy, they imagined the human worker not just as a Cartesian machine but also as a heat engine that produced a quantifiable amount of labor power. Yet, while quantifiable, this power source was neither perpetual nor boundless. Fatigue occurred when that measure of labor power had been expended without time for recovery and replenishment. It was a natural bodily limit to the amount of time a laborer could work. Labor reformers saw this concept of fatigue as means to argue for legislated limits on working hours. Employers resisted the biological definition of this phenomenon, framing fatigue instead as psychological manifestation, a simple lack of will or inefficiency, addressable through incentives and later scientific management.[8]

These new theories also inspired variations on Lavoisier's equivalence of food, heat, and work. To study these concepts, scientists constructed a complex new piece of

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[6] Simmons, *Vital Minimum*, 21; Anson Rabinbach, *The Human Motor: Energy, Fatigue, and the Origins of Modernity* (Berkeley, Los Angeles: University of California Press, 1992), 64.
[7] Rabinbach, *The Human Motor*, 47, 67.
[8] Robin Wolfe Scheffler, "The Power of Exercise and the Exercise of Power: The Harvard Fatigue Laboratory, Distance Running, and the Disappearance of Work, 1919–1947," *Journal of the History of Biology* 48 (2015): 392.

laboratory equipment, the respiratory calorimeter, a variation on Lavoisier's ice calorimeter that in its most elaborate form comprised a room-sized enclosure for human subjects. These were expensive and highly delicate machines, intended to detect slight variations in physiological function, especially changes in bodily heat emission. To accomplish this, the instruments had to be tightly controlled, especially the temperature mechanisms. In a sense this had the same effect it did in Lavoisier's work. Because he could detect and minutely measure the products of respiration with such certainty, the laboratory ideal became the rule in the outside world.

### THE "LABOR QUESTION"

By 1884, Wright considered many elements of the "factory question" provisionally answered, even if the answer had not yet been fully implemented. In his report of that year to the federal census bureau, *The Factory System in the United States*, Wright issued his prescription, "Let the children of factory workers everywhere be educated in the rudiments of sanitary science, and then let law say that bad air shall be prohibited, even in homes, and I believe the question of the health of the operatives will not so seriously trouble us." Wright followed Chadwick's reasoning in finding that "low health conditions in factory places, where such conditions exist, are not due to the factory system, but to negligence either on the part of the proprietors or the employees." The negligence that Wright found was that these parties simply weren't applying the knowledge now readily available to them. Wright argued that physiologists and scientists such as Pettenkofer had already determined how much air a person needed, and architects such as Carl Pfeiffer, who Wright also notes as a source, had translated the scientists' numbers into spatial terms. The situation in Wright's eyes was straightforward, now all factory owners had to do was apply these guidelines to their factory buildings. In many cases, Wright claimed, they were already doing as much. He found that in many recently built factories "the most careful attention is paid to their ventilation, and large sums are paid for improved methods of changing the air and for regulating its temperature." Indeed, he asserted, "The air of a cotton factory is better than that of a lecture-room."[9]

Also like Chadwick, Wright argued that the bigger trouble was "not in the air-space of the factories, but in that of the homes." This reasoning removed culpability from the factory system in both contemporary and historical terms. It allowed Wright not only to argue that housing conditions, not factory work were to blame for high rates of worker illness and mortality in 1884, but also to negate sentimental impressions of pre-industrial conditions. Those who argued that life before the factory system was better were wrong according to Wright, for when the first worker entered the factory, he "left the closeness of his home-shop for the usually clean and well-lighted factory" and experienced "an agreeable and healthful change."[10]

The federal administration in Washington approved of Wright's perspective. In 1885 Wright was appointed as the first commissioner to a new federal agency, the Bureau of Labor. This appointment appealed across political party lines—Wright was originally nominated by outgoing Republican president Chester Arthur, but formally appointed by incoming Democratic president Grover Cleveland—but to those in power it also represented a more "neutral" appointment than that of an earlier nominee, John Jarrett, a leader in the Federation of Organized Trades and Labor Unions and head of the Amalgamated Association of Iron and Steel Workers.[11]

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9 Carroll D. Wright, *Report on The Factory System in the United States* (Washington DC: Government Printing Office, 1884), 26-30

10 Wright, *Report on The Factory System in the United States*, 18, 28

11 James Lieby, *Carroll Wright and Labor Reform: The Origin of Labor Statistics* (Cambridge, MA: Harvard University Press, 1960), 70-71. Apparently President Arthur had formally nominated Jarrett in July of 1884 and the Senate quickly confirmed the nomination. Arthur then rescinded Jarrett's nomination because of his support for a rival of Arthur's. Leiby could not trace exactly how the nomination came to

The Massachusetts legislature also shared Wright's views and passed a law in 1887 that required cleanliness, general sanitation, and ventilation of manufacturing establishments, specifically for the "better health of operatives." A subsequent law passed in 1888 extended this obligation to mercantile and other industries. Unlike an earlier provision that required factories be "well ventilated and kept clean" attached to an 1877 law regulating dangerous machinery in factories, the later legislation had specific inspection and enforcement provisions.[12]

Surely partial resolution to the factory question was good news, but for Wright and many others there remained the more complicated "Labor Question." Of course, the terms "factory question" and "labor question" in the nineteenth century held multiple and diverse meanings to different groups—their variations implied quite different course of action for unionists as for factory owners—but in the context of this dissertation, we will attend to the meanings these terms had for reformers (both conservative and progressive) at the turn of the twentieth century.[13] In his 1902 essay collection, *Some Ethical Phases of the Labor Question*, Wright defined the term "labor question" as "representing the problem of working people in their struggle to secure a higher standard of living."[14] Yet while Wright figured that the problems of health embedded in "question" had been solved by the sanitary idea, others argued that industrial work still impaired bodily integrity, lifetime longevity, and one's own sense of mental capacity and opportunities for betterment.

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land with Wright, but he cites a letter written some months later purportedly documenting a conversation with Arthur expresses preference for appointing "some one known only as a statistician" rather than "any one of these Communists, agitators, and radicals."

[12] Sarah Scovill Whittelsey, "Massachusetts Labor Legislation, An Historical and Critical Study," *The Annals of the American Academy of Political and Social Science*, 17, Supplement 15 (Jan 1901), 23

[13] Joseph Reid, Jr. "Book Review of State of the Union: A Century of American Labor Nelson Lichtenstein," *Journal of Labor Research*, 24, no. 4 (December 2003), 734; see also Eric Foner *Nothing But Freedom: Emancipation and Its Legacy* (Baton Rouge: Louisiana State Univ Press, 1983)

[14] Carroll D. Wright, *Some Ethical Phases of the Labor Question* (Boston: American Unitarian Association, 1902), 26.

**The Three Miseries**

Although this debate was multidimensional, one such dimension played out in terms of airs, bodies, and building technologies. Hints of the complicated connections that workers, employers, physicians, and others made between factory work, work environments, and workers' health can be found in the observations of an operative that Wright's office interviewed for the Massachusetts report of 1882, "If a child of a certain age goes to work in the mill, constantly breathing a temperature of 90° both winter and summer, it is sure to grow up puny, and die early. I get so exhausted that I can scarcely drag myself home when night comes."[15] Here is the sense not only that the common conditions of factory work may prematurely end one's life, but also that it sapped one's energy and vitality on a daily basis.

Concurrent changes in scientific and medical theory shaped larger discourses emerging in the second half of the nineteenth century about the capacity and incapacity of the laboring body, most often imagined through the concept of "fatigue." Yet the scientifically defined theory of bodily fatigue, characterized as it was by references to the laws of thermodynamics, did not necessarily lead the discussions of worker health. Rather it followed, merging with already existing discussions of human work and over-work. One of the prominent early commenters on this phenomenon was British physician and Benjamin Ward Richardson, a sanitarian and protégé of Edwin Chadwick, perhaps best known to general audiences as the author of "Hygeia: A City of Health," which describes a utopian vision of the Chadwickian sanitary city.[16] In 1863 and 1864 Richardson published

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[15] Wright, "Fall River, Lowell, and Lawrence," 202.
[16] Benjamin Ward Richardson, *Hygeia: A City of Health* (London: Macmillan & Co., 1876); James H. Cassedy, "Hygeia: A Mid-Victorian Dream of a City of Health," *Journal of the History of Medicine and Allied Sciences*, 17, no. 2 (April, 1962), 221.

a series of articles on "work and overwork" and the "diseases of overworked men," which he then compiled into the 1876 book *Diseases of Modern Life.*[17]

Richardson's reflections on the idea of overwork expanded over time, but he always tied them back to the sanitary idea. Writing in response to sensational news stories reporting on the sudden death of a young seamstress, Mary Ann Walkely, Richardson draws a tri-partite set of circumstances that afflicted "needlewomen of all kinds," only one of which was overwork. For this class of workers, there were "three miseries—over-work, deficient air, and either deficient food or deficient digestion." Of these three, however, air was the dominant misery for Richardson. Certainly, he does not deny that needlewomen worked exceptionally long hours, being "engaged 15, 16, aye, even 18 hours out of the 24," but for him, it was the location of this work that caused the real trouble, being as these women worked "at home, in one room, starving or near to it…in an air that is scarcely tolerable and on food which even if it be good, cannot be digested in the absence of pure air." Death was typically not immediate in these cases, but rather, it was "on these victims, consumption, which is purely a disease of bad air, feeds."[18] A writer in the London publication *The Spectator* argued similar ideas in legislative terms:

> Parliament can abolish the most immediate cause of ill-health--the close packing in dormitories. It may apply the Lodging house Act to such places, and so bring them within supervision. Or it may make it a misdemeanor for a householder to leave any lodger or servant less than 700 cubic feet of air space, punish the offender with fine...That provision would not prohibit overwork, and no law can quite protect the victim from the effect of poverty, but it would at least secure rest after the work, and with it the health which could resist the most fatal of its

[17] Benjamin Ward Richardson, "Work and overwork" (lecture to the Ladies' Sanitary Association), *The Social Science Review*, 2 (1863): 475-481; Benjamin Ward Richardson, "The diseases of overworked men," *Social Science Review and Journal of the Sciences*, new series, 1 (1864), cited in Karl Figlio, "Chlorosis and Chronic Disease in Nineteenth-Century Britain: The Social Constitution of Somatic Illness in a Capitalist Society," *Social History* 3, no. 2 (May 1978): 185.
[18] Benjamin Ward Richardson, "Work and Overwork," *Social Science Review* (Jul 18, 1863), quoted in Karl Marx, *Capital; A Critical Analysis of Capitalist Production* (London: George Allen & Unwin Ltd., 1938), 239, note 2

> effects...Such a reform will be far less expensive than the limitation in the hours of work to which a repetition of such scenes will ultimately drive the Legislature.[19]

Yet not all saw air as the governing misery. In the view of more radical writers, in particular Karl Marx, the critical issue was indeed overwork. In Marx's view, a worker's "sole wealth" was that worker's own "labour power," which in many ways equated to a worker's health. However, this individual resource, Marx argued, was not unlimited. Rather it consisted of a finite amount of "human muscle, nerve, brain, etc.," that when expended, required restoration through rest, sleep, or other non-working state. In this formulation, an "unlimited extension of the working day," allowed an owner to use up in one day "a quantity of labor power greater than [a worker] can restore in three." For Marx, this represented not just a use of a worker's labor power, but its spoliation. In a "normal length" or "healthy" workday, the worker would have time to fully recover his or her labor power and may be able to work thirty years or more, but as Marx argued, overly long working hours essentially extracted thirty years' worth of labor power in just ten years, leaving workers' health broken. From this, Marx calculated that in [the grand scheme of things], a worker recouped only a third of his or her own labor value; "capital" extracted the other two-thirds as "surplus value." Certainly, Marx did not disagree with Richardson, in fact he quoted Richardson's 1863 article directly in the first volume of *Capital* to establish a medical justification for his theory, but his emphasis was on length of time, not as much the quality or conditions of the space.[20]

The idea that a worker's health represented a wealth was not reserved to socially radical thinkers. American physician Edward Jarvis, who we met in chapter three with his review of ventilation texts, opened his 1874 report to the State Board of Health of

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[19] "Mary Anne Walkley" *The Spectator* 1826 (June 27, 1863): 2171.

[20] Marx, *Capital; A Critical Analysis of Capitalist Production*, 149, 217, quoted in Hamlin, *Public Health and Social Justice*, 47.

Massachusetts, "Political Economy of Health," with a comparable aphorism, "Health is the Capital of the Laboring Man." Although Jarvis's aim was to position this capital as a collective national resource—and thus justify a federal public health system—the fundamental principle is similar to Marx's; a worker's bodily health has critical value, and it represents relations more complicated than a simple one-to-one wages-for-hours formulation. The source for Jarvis's aphorism is suggestive of the complex web of actors working to characterize this formulation. It is not, as one might expect, a political writer or a philosopher, but rather a civil engineer. It came from the 1873 book *Sanitary Engineering: A Guide to the Construction of Works of Sewerage and House Drainage, With Tables for Facilitating the Calculations of the Engineer*.[21]

This chapter discusses how issues of worker health were imagined not only in the political context, but how this overlapped with the scientific, medical, and technological contexts. New spatial circumstances of work also represented quandaries for those aiming to theorize or regulate relationships between work, air, heat, and health. Particularly in the last decades of the nineteenth century, reformers began to pay more attention to the "sweating system," which by definition took place in dispersed domestic locations, not centralized factories. Although writers sometimes averred that the term was difficult to define, in general it represented the practice of subcontracting for piecework. A "middleman" would contract independent, usually unskilled workers to complete tasks in various trades such as tailoring, shirt-making, and boot-making, but the primary form of labor typically involved some repetitive sewing or assembling activity. The "evils" of this

[21] Baldwin Latham, CE, *Sanitary Engineering: A Guide to the Construction of Works of Sewerage and House Drainage, With Tables for Facilitating the Calculations of the Engineer* (London: Spon, 1873), 11

system were relatively familiar, however, namely very low wages, excessive hours of labor, and "the insanitary state of the houses in which the work is carried on."[22]

### Exposure, Occupation, and Hygiene

The environments of work were also getting more complicated. Awareness of new chemical dangers in the industrial workplace as well as in the sweatshop urged physicians and other observers to construct new classification systems for the relationships between work and health. One critical nosology, "Hygiene and Occupation" came in 1879 from the hand of physician Roger S. Tracy, a sanitary inspector of the New York Board of Health and later a close associate of Jacob Riis.[23] First published in a major compendium on hygiene and public health, Tracy's text was given official sanction by publication in the second annual report of the New York Bureau of Labor Statistics.[24]

Tracy, like Thackrah and McCready earlier in the century, recalled Ramazzini as the first author to formally investigate the relationship between occupations and health, but in Tracy's view, Ramazzini was far too pessimistic about the longevity prospects of most artisans. Not to worry, Tracy argued, Ramazzini's take was likely so "melancholy" because he hadn't yet figured out how to "sufficiently distinguish between the direct effect of the occupation and the influence of the home surroundings and food." If Ramzzini had done so, he would have realized how it was "evidently unscientific and unproductive of any

[22] David F. Schloss, "The 'Sweating System' in the United Kingdom," in "The Sweating System in Europe and America, Papers in the Social Economy Department of the American Social Science Association," *Journal of Social Science* 30 (1892): 66.
[23] Roger S. Tracy "Hygiene and Occupation" in *A Treatise on Hygiene and Public Health*, edited by Albert H. Buck (New York, W. Wood and Company, 1879); The 1866 Metropolitan Health Act of New York had endowed the new Board of Health with the responsibility for the inspection of tenement houses and factories as well as the "regulation of occupations detrimental to health." A team of sanitary inspectors, most of them physicians including Tracy, carried out this task, George Rosen, "Early Studies of Occupational Health In New York City in the 1870s," *American Journal of Public Health* 67, no. 11 (Nov 1977): 1100.
[24] *Second Annual Report of the Bureau of Statistics of Labor of the State of New York for the Year 1884* (Albany: Weed, Parsons and Company, 1885), cited in MacLaury, *Government Regulation.*

good result whatever to describe as due to the occupation diseases whose prevalence is mainly caused by bad food, insufficient sleep, or bad ventilation or drainage."[25]

Yet where Thackrah had differentiated working situations primarily as indoor or outdoor occupations, Tracy divides them broadly in terms of interior atmospheric exposures. The factory environment had improved, Tracy argues, certainly it had compared to the "ill-ventilated shops in which private workmen once had to labor" in a pre-industrial society, but "certain new dangers" had emerged in factory work, particularly those related to new chemical products now part of many manufacturing processes. The most striking examples being the use of arsenic in decorative materials and phosphate for the manufacture of matches.[26] Tracy thus classified occupations into three categories, "according to what seems to be the chief source of injury connected with them," critically occupations involving: 1) introduction of deleterious matters into the body either by inhalation (of vapors and gases or dust) or by absorption, 2) exposure to conditions that interfere with nutrition, primarily by elevated or variable temperature or over-use of certain organs (e.g. brain of brokers, eyes of engravers, muscles of athletes), but also constrained attitude (e.g. tailors, salesmen) or sedentary life (clerks, lawyers, students), or 3) exposure to mechanical violence, either by machines or other accidents or from variations in atmospheric pressure (e.g. caisson workers).[27]

That the subcategories reflecting dangers induced by air (inhalation) or temperature comprise the largest number of occupations suggests a growing awareness of the multiple risks associated with industrial production that a decade later aligned with shifting judicial

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[25] Tracy "Hygiene and Occupation," 5.
[26] Tracy "Hygiene and Occupation," 6; Ludwig Teleky, *History of Factory and Mine Hygiene* (New York: Columbia University Press, 1948), 53; MacLaury, *Government Regulation.*
[27] Tracy "Hygiene and Occupation," 10-11. In turn, Tracy's nosology followed Benjamin Ward Richardson's address on the "Unhealthy Trades" to the Society of Arts in 1876.

stakes. In the 1889 case of Wagner versus Jayne Chemical Co., an unskilled worker, Thomas Wagner, brought suit against his employer for neglecting to inform him of the potential hazards associated with his new job. As plaintiff, Wagner sought damages for "personal injuries alleged to have been sustained by inhaling fumes of nitric acid."[28] The Wagner case, which was decided in favor of the injured worker, represented a break from legal precedent, which had almost always placed responsibility with the worker for knowing and accepting risky conditions in exchange for a particular wage.[29]

Roger Tracy's framing of occupational hazards seems to invite technological amelioration, suggesting that perhaps the problems of occupational risk could be mediated by ventilation or temperature control, but as Christopher Sellers notes, in 1901 at least ten states has workplace ventilation laws, some aimed at removing harmful dust or "impurities," but that most state factory inspectors still described the requirement for ventilation as originating in dangers caused by the "exhalations of the workers themselves" rather than the byproducts of any materials with which they worked.[30] Yet it is understandable why inspectors might be confused about the purpose of ventilation requirements, for scientific and medical theory was shifting at the turn of the century.

A critical hinge in this scientific transformation was the 1895 publication of a paper entitled "The Composition of Expired Air and Its Effects upon Animal Life." This paper was neither a best seller nor a page turner, but it was a resolved statement formally rejecting traditional ventilation practice. At the time it was published, the paper received a lot of attention and determined the course of much future research and practice, but for reasons

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[28] James Monaghan, *Pennsylvania State Reports, containing cases adjudicated in the Supreme Court of Pennsylvania January term, 1892* (New York and Albany: Banks and Brothers Law Publishers, 1893), 475
[29] Sellers, *Hazards of the Job,* 36-37; Wagner was awarded $3,000 in damages by the court, which would amount to about $83,000 in 2018.
[30] Sellers, *Hazards of the Job*, 38

that are still unclear, scientists after the turn of the century often overlooked it, and perhaps as a consequence of its nineteenth-century origins it has not been fully examined by historians, even those interested in space conditioning.[31] However, a deep dive into this paper's sources and resources reveals much about the problems it was trying to address outside the laboratory.

### THE STATE OF SCIENCE: INSTITUTIONS AND THE REDEFINED RISKS OF AIR

In 1895 John S. Billings, the physician and recognized expert on ventilation, along with his colleagues S. Weir Mitchell and D.H. Bergey published a paper summarizing two years of research that aimed to settle then current controversies of air. The dominant theory, the authors explained, was Pettenkofer's of the early 1860s, namely, as described in the previous chapter, that the relative quantities of carbonic acid and oxygen in dwellings or public places, even if crowded and ill-ventilated, did not produce toxic effects or cause specific diseases. Rather the risk to health in dwellings resulted from some undefined organic matter released by "respiration and other exhalations from the bodies of the occupants." These organic impurities lessened the capacity of those continually breathing the confined air to withstand the influence of the disease-producing agents. The rule of thumb that Pettenkofer laid out, which by 1895 had been "accepted and taught by sanitarians for thirty-five years," was that the concentration of carbonic acid of an inhabited space simply indicated of the relative amount of the occupant-produced impurities.[32]

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[31] Neither Gail Cooper nor Marsha Ackermann discuss it. Architectural historian Gavin Townsend does feature it in his discussion of domestic space, but he sees it only as the end of an ear, not the beginning of a new one. Gavin Townsend, "Airborne Toxins and the American House, 1865-1895" *Winterthur Portfolio* 24, no. 1 (Spring 1989): 29-42.

[32] J.S. Billings, S. Weir Mitchell, and D.H. Bergey, *The Composition of Expired Air and Its Effects Upon Animal Life* (Washington DC: The Smithsonian Institution, 1895), 4

The immediate debate that Billings and his colleagues wished to settle was the one caused by the research of C.-E. Brown-Séquard (1817-1894), a French physician and professor of experimental medicine (physiology) at the College de France.[33] In a series of articles published between 1887 and 1889 with his associate J.-A. D'Arsonval, Brown-Séquard claimed to have identified as specific organic poison in the exhalations of humans and animals. Unlike Pettenkofer, who hypothesized that the negative effects of impure air were slow and chronically induced, Brown-Séquard asserted that the deleterious effects of respired air could be immediate and potentially fatal. Brown-Séquard's research garnered much attention and researchers in many locations undertook to replicate his results. Some saw similar results, others did not. Billings, Weir Mitchell, and Bergey thus devised an extensive set of experiments to test Brown-Séquard's theory.

From soon after the 1895 paper was published to the present day, authors have often interpreted Billings's paper as a critical hinge in the history of air, ventilation, and health. In these interpretations, ideas about air that came before 1895 were old and outdated, and ideas that came afterwards matched contemporary practice and were thus "correct."[34] This occurs along two related but separate dimensions. In engineering histories, even those of the early twentieth century, Billings's 1895 paper represented a rejection of "chemical" theories of ventilation (i.e. based on concentrations of carbonic acid or oxygen) and the

[33] Brown-Séquard took over this position from Claude Bernard in 1878. Prior to this Brown-Séquard had practiced in London, from 1864-1867 been a professor of physiology at Harvard, and from 1873-1878 practiced medicine in New York City. In between he was a professor of medicine at the École de Médecine in Paris.

[34] Leonard, Hill, Martin Flack, James McIntosh, R.A. Rowlands, H.B. Walker, *The Influence of the Atmosphere on Our Health and Comfort in Confined and Crowded Places* (Washington, DC: The Smithsonian Institution, 1913); F.L. Pleadwell, "A New Theory of Ventilation and Its Application in Certain Situations Aboard Ships," *United States Naval Medical Bulletin* 7, no. 3 (Jul 1913): 332-339; George T. Palmer, "What Fifty Years Have Done for Ventilation." In *A Half Century of Public Health: Jubilee Historical Volume of the American Public Health Association*, edited by Mazÿck P. Ravenel, 334-360 (New York: American Public Health Association, 1921); Janssen, John E. "The History of Ventilation and Temperature Control." *ASHRAE Journal* (Oct 1999): 47-52; James H. Cassedy, *John Shaw Billings: Science and Medicine in the Gilded Age* (Bethesda: Xlibris, 2009), 118-119.

acceptance of "physical" theories of space conditioning (i.e. based on temperature, relative humidity, and quantity of suspended matter). In conventional public health histories, this shift gets interpreted as a switch from miasma theory to germ theory, and by extension from muddled experience to science. Writing in 1921, George T. Palmer, a member of the New York Commission on Ventilation, asserted "the most outstanding change in ventilation since 1870 has been the substitution of experimentation for guesswork."[35] Certainly, the 1895 paper represents a transition, but in view of the literature that it references and in the papers that subsequently referenced it in the following in the following three decades, it reveals a more complicated picture of the meaning of air, heat, health, and work, and offers some clues as to the hybridity of the technology that emerged from this period.

However, first it is critical to recognize that this was not the individual and isolated work of a small group of scientific colleagues, but rather it was sponsored and supported by national and state institutions. Funding for the study was provided by a grant from the Hodgkins Fund of the Smithsonian Institution and the results published as part of the Smithsonian's *Contributions to Knowledge* series.[36] Yet equally important was the institutional location at which the investigators carried out the experiments documented in the paper. The Laboratory of Hygiene at the University of Pennsylvania was established in 1892 by a significant monetary gift from Henry Charles Lea, a historian and member of a longstanding Philadelphia publishing family. Lea had been an active member in the

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[35] Palmer, "What Fifty Years Have Done For Ventilation," 335

[36] The Hodgkins Fund was established in 1891 with a major contribution to the Smithsonian from Thomas George Hodgkins, of Setauket, New York, for the "increase and diffusion of more exact knowledge in regard to the nature and properties of atmospheric air in connection with the welfare of man." Hodgkins had been impressed by research on air, such as Paul Bert's work on oxygen and vitality. The first round of prizes and grants were given in 1893, presumably including the grant given to Billings and Weir Mitchell. Helen Waldo Burnside, *The Hodgkins Fund of the Smithsonian Institution* (Washington DC: The Smithsonian Institution, 1904), 168-174.

Philadelphia branch of the American Social Science Association and as the founder in 1870 of the Citizens' Municipal Reform Association, a reformer against established patronage politics in Philadelphia.[37] In this he shared many of the same goals as health reformers such as John H. Griscom in New York, and indeed Lea had a long correspondence with Dorman B. Eaton, the attorney who had drafted the text of New York Metropolitan Health Act, for which Griscom had been a primary advocate.[38] By directing the debate into realms of health and science, the reformers could both critique their opponents and create pathways for assumption of political power.

Thus, it benefited the sponsors of the Laboratory of Hygiene to install as director a person with established expertise and authority. Guided by the Philadelphia-based S. Weir Mitchell, one of the conditions of Lea's gift was that the directorship of the Laboratory be granted to Billings, for Billings had a reputation not only as a ventilation expert but also as a planner of academic programs in hygiene and as an advocate for national public health policy. Billings remained with the Army Medical Department until he retired from military service in 1895, and this allowed him to participate in many national-scale public health endeavors both governmental and professional, including management of the vital statistics portion of three censuses, involvement in the short-lived National Health Board (1879-1886), and leadership in the American Public Health Association.[39] Billings also lectured on hygiene topics at Johns Hopkins University and at the Columbia School of Mines and

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[37] A 1909 biography of Lea described Lea's Citizens' Reform Association as "crusade against the evils in the municipal system of government," an effort "to bring the public business to the same degree of efficiency and economy as is obtained by a private corporation" "Henry Charles Lea" *The Publishers' Weekly* 76, no. 1970 (Oct 30, 1909): 1187.

[38] Edward Sculley Bradley, *Henry Charles Lea, A Biography* (Philadelphia: University of Pennsylvania Press, 1931), 216. Eaton also worked closely with Billings on the APHA's Advisory Council on National Sanitary Legislation, formed in 1878 to lobby U.S. congress members for the establishment of a national health bureau. James H. Cassedy, *John Shaw Billings: Science and Medicine in the Gilded Age* (Bethesda: Xlibris, 2009), 144.

[39] Fielding Garrison, "The Scientific Work of Dr. John Shaw Billings," *National Academy of Sciences of the United States of America Biographical Memoirs* 8 (1917): 385-416.

created at the request of those institutions plans for extensive educational courses in hygiene. The President at Columbia, Frederick A. P. Barnard [who had in 1873 traveled to Europe and reported back to the APHA on European developments in germ theory], even asked Billings in 1883 to develop a plan for a "laboratory of hygiene to be modelled on the Pettenkofer Institute in Munich."[40] The University of Pennsylvania actively courted Billings to become part of their medical school, and in 1889 Billings became, upon agreement from the Surgeon General (Billing's then employer), part-time Director of a new Department or Institute of Hygiene, responsible for the design of its new laboratory building, as well as a Professor of Hygiene in the medical school, and the Director of the university hospital.[41]

The establishment of the Institute of Hygiene at the University of Pennsylvania represented a distinct shift in public health reform activities, from those aimed at direct state or national control to those embedded in both private and public academic institutions. These new academic programs, the first founded at the University of Michigan in 1888, combined the work of existing state-funded biological, physiological, or bacteriological laboratories, such as those maintained by the Massachusetts Board of Health, with an educational element, either courses or degree tracks in hygiene integrated with research in the laboratory. Although the Michigan laboratory was funded directly by the state legislature, Pennsylvania laws expressly forbid the allocation of public funds for "any such purposes," and it was only through Lea's gift that the establishment of the Institute was made possible.[42]

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[40] Cassedy, *John Shaw Billings*, 126.
[41] Cassedy, *John Shaw Billings*, 88.
[42] Benjamin Lee, "The Opening of the Institute of Hygiene at the University of Pennsylvania," *Official Document (No. 16), Comprising the Department and Other Reports Made to the Governor, Senate and House of Representatives of Pennsylvania* 9 (1893), 265

Billings's vision for the Institute of Hygiene at the University of Pennsylvania was modeled on German precedent, specifically that of Max von Pettenkofer, whose research on ventilation Billings of course knew well. A result of his own advocacy, Pettenkofer had been appointed to the first academic chair in hygiene at the university in Munich in 1865, and in 1879 his leadership extended to a full Institute of Hygiene. Unlike in Britain, where a professorship in hygiene had been established at the Army Medical School in 1860, Pettenkofer's appointment was at a non-military institution, and his model for hygiene education was replicated at universities throughout the German Empire. By 1882 almost every university in Germany had some form of an institute of hygiene.[43] Historian of medicine Paul Weindling has noted that as early as 1855 Pettenkofer began to replace his lectures on "medical police" with lectures on the science of hygiene, which Weindling sees as "a transfer of authority from the state to the professional academic sphere."[44] While the United States never had a tradition of medical police, the recognized German model of direct intervention in citizens' health by the state, some nineteenth-century sources linked the formation of academic programs in hygiene in the America with a conscious de-politicization of "state medicine," a way to get around the political disputes that had "in large measure checked the splendid practical work inaugurated with the formation of the National Board of Health in 1878."[45] Indeed Billings himself had been closely involved in that short-lived federally funded body.[46]

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[43] Wolfgang Gerhard Lochner, "Max von Pettenkofer (1818–1901) as a Pioneer of Modern Hygiene and Preventive Medicine," *Environmental Health and Preventive Medicine* 12 (Nov 2007): 239.

[44] Paul Weindling, "Public Health in Germany," in *The History of Public Health and the Modern State,* edited by Dorothy Porter (Amsterdam; Atlanta, GA: Rodopi, 1994), 123.

[45] "Experimental Work in State Medicine" *Medical Science* 1, no. 3 (Jan 1, 1888): 78.

[46] The National Board of Health was established by federal legislation in 1879. As a compromise between those advocates who wanted a full-time federal department of health and those who resisted federal intervention in these matters, the law called for a part-time advisory council whose activities were primarily the gathering of health information and some research. Billings served as a member of this advisory council from 1879 to 1882, when Congress significantly reduced the Board's funding. All other funding was cut by

Billings followed Pettenkofer in an expansive definition of hygiene and an insistence that the research be scientific rather than clinical, for only experimental work in the laboratory could produce the "reliable knowledge" needed to prevent disease and promote health.[47] As Billings described at the opening ceremony of the Institute, "the object of hygiene is to preserve and to improve health, and there are few matters affecting the physical, intellectual, emotional, and moral condition of man as an individual, or of men in communities that may not come within the scope of its investigations."[48] In carrying out this project, the scattered knowledge gathered by practical physicians working with individual patients simply would not do. According to Pettenkofer, who was himself a chemist, "a physicist who has also seriously studied chemistry and physiology is better suited to teach and research in the field of hygiene than a practical doctor."[49] Rather physicians would have to do the work to "keep up with improvements in plumbing, drainage, ventilation, heating, lighting, disinfection techniques, washing, laundering, cooking and housing design" that had been devised in the laboratory.[50]

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1886, although the Board remained nominally in existence until 1893. Cassedy, *John Shaw Billings*, 144, 157.

[47] Lochner, "Max von Pettenkofer," 239.

[48] John Shaw Billings, "The Objects, Plans, and Needs of the Laboratory of Hygiene, An Address Delivered at the Opening of the Laboratory Of Hygiene Of The University Of Pennsylvania, February 22d, 1892" *The Sanitarian* 28, no. 269 (Apr 1892), 296.

[49] Lochner, "Max von Pettenkofer," 239.

[50] Weindling, "Public Health in Germany," 123

Billings was clear that the scope of work in hygiene carried out at the new laboratory extended beyond bacteriology (Figure 4.3). He did acknowledge the tendency to confuse the two, pointing out that “several so-called hygienic laboratories are simply bacteriologic laboratories, the interest in this particular branch of investigation having, for the time being, overshadowed all others.” The object of hygiene in Billings’s view, however, was not exclusively the “destruction or avoidance of causes of disease,” bacteriological or otherwise. Rather it had to be “at least equally concerned with the means of making a man better fitted to resist these causes.” In other words, it had to address the physiological as well as the pathological. Certainly a hygiene lab must include the “the peculiar arrangements and apparatus which are required” for bacteriological work, but it must also be equipped with the means for the “chemical investigations of air, water, food, sewage, secretions and excretions, and the products of bacterial growth” as well as equipment for “testing the effects of gases, alkaloids, and albuminoses of various kinds upon the animal organism,” and resources for

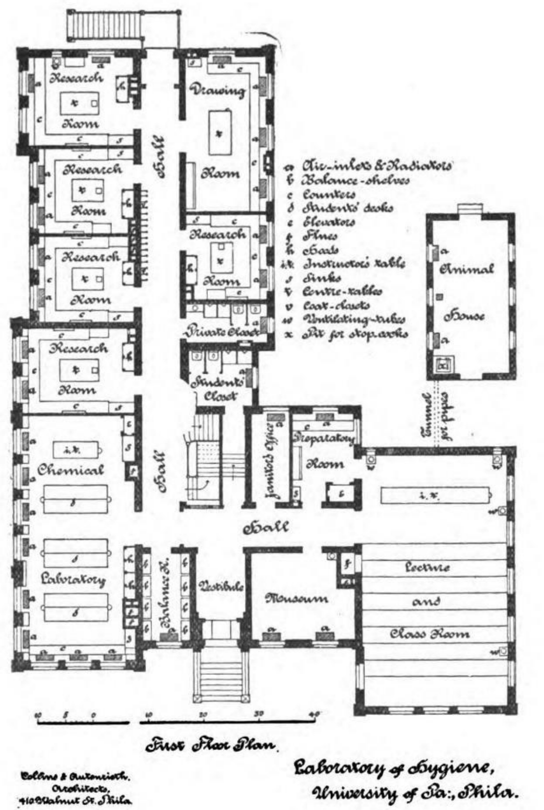

Figure 4.3 First floor plan, Laboratory of Hygiene, University of Pennsylvania, 1892. Plans published in *The Sanitarian*, as illustrations to John S. Billings “The Objects, Plans, and Needs of the Laboratory of Hygiene.”

"investigations in the domain of physics, pertaining to heating, ventilation, house drainage, clothing, soils, drainage, etc."[51]

Thus, although many interpreted the findings of Billings's 1895 one-dimensionally—either from chemical to physical, or from miasma to germ—Billings's plans for the laboratory and its research program imply a more hybrid approach. In many ways, the Laboratory of Hygiene at the University of Pennsylvania brought together the theoretical trajectories of the rivals Pettenkofer and Koch. This is expressed not only in the research results, but also in the Laboratory's people and its building. One of the younger collaborators working under the direction of Billings and Mitchell on the research program, Alexander C. Abbott, had studied under both Pettenkofer and Koch, and David Bergey, the third author of the 1895 study trained under a student of Koch's at the University of Pennsylvania.[52] In commenting on the new building constructed for the Laboratory at its opening ceremony, Benjamin Lee of the Pennsylvania State Board of Health, declared it a happy medium between existing European models, the "dark, gloomy and ill-ventilated… den in an attic" occupied by Pettenkofer's group and the ostentatious and costly facilities occupied by another bacteriological researcher, Pasteur. The Pennsylvania lab instead was to be admired for its "careful utilization of room, the floods of light, the abundance of fresh air and the absence of architectural effort and meretricious decoration." In a remark that

[51] Billings "The Objects, Plans, and Needs of the Laboratory of Hygiene," 296, 299-300.

[52] Elizabeth Fee, *The Welch-Rose Report: Blueprint for Public Health Education in America* (Baltimore, MD: Delta Omega Honorary Public Health Society, 1992), 9; Center for the History of Microbiology/ASM Archives, "Biographical Notes On The Society Of American Bacteriologists Charter Members" https://lib.guides.umbc.edu/c.php?g=836720&p=6543668

perhaps foreshadows later aesthetic discussions, Lee asserted, “Its style is severely simple. It means business” (Figure 4.4)[53]

**The Sources of Heat**

It is easy to see why readers of the report produced by Billings, Mitchell, and Bergey interpreted it rather narrowly. It is a long report, and the authors present no less than eleven rather complicated conclusions. Moreover, the eleventh point in part presents as a double negative and appears to summarize the other ten conclusions, but at close reading the report leaves some questions unresolved. Certainly the authors were attempting to provide some practical guidance, but the straightforward nature of their advice obscured some of the matters they believed needed additional research. The authors open their conclusion with a reversal, finding that “some of the theories upon which modern systems of ventilation are based are either without foundation or doubtful.” Rather than “simply diluting the air to a certain standard of proportion of carbonic acid present,” as Pettenkofer had recommended thirty-five years earlier, Billings and his colleagues suggested that in order to achieve comfort and health in inhabited rooms one must attend to “the best methods of preventing or disposing of dusts of various kinds, of properly regulating temperature and moisture, and

Figure 4.4 View of the University of Pennsylvania Laboratory of Hygiene in 1995. Historic American Building Survey, HABS No. PA-6175.

[53] Lee, “The Opening of the Institute of Hygiene,” 266.

of preventing the entrance of poisonous gases like carbonic oxide (today called carbon monoxide) derived from heating and lighting apparatus."[54]

Although many readers may assume the Billings's recommendation to "properly regulate temperature and moisture" a natural one, a direct response to objective bodily needs, but as both Crowley and Cooper have demonstrated, the translation of physical or psychological requirements into environmental definitions and standards are rarely uncomplicated.[55] Certainly, there were many traditional cultural narratives that warned against exposure to drafts and other dramatic changes in temperature, such as those experienced when leaving a hot and steamy factory on a cold night, but the authors of the 1895 report were not as concerned about fluctuations in temperature as they are about excessive temperatures in enclosed spaces. The authors divide the potential effects of these conditions into two categories, the chronic and the acute. For them, the chronic effects were primarily the facilitation of "certain specific causes of disease commonly known as contagious," and possibly "a general lowering of vitality." The acute effects have a more dramatic range, from "death in a few minutes or hours" to "simply great discomfort."[56] Perhaps because Billings and his fellow authors' interests lay more with chronic effects, they seem to collapse this range of acute effects, the same general guidance applies to

[54] The American Society of Heating and Ventilating Engineers (ASHVE) formed in September, 1894, with a goal, among others, to establish consistent ventilation standards among the various states. In a history produced by the present-day form of ASHVE, the authors do not indicate that the society was aware of the Billings report or that it influenced the initiative to form the engineering society. Rather they suggest that the society recognized that compulsory ventilation laws brought greater demand for their services. Looking back from 1904 a leader in ASHVE assumed that it was the "stress of competition, the commercial side of the business," not the results of any scientific studies that inspired "more scientific consideration" in their equipment design and application. Barry Donaldson and Bernard Nagengast, *Heat and Cold, Mastering the Great Indoors* (Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1994), 165-167.

[55] John Crowley, *The Invention of Comfort: Sensibilities and Design in Early Modern Britain and Early America* (Baltimore and London: Johns Hopkins University Press, 2001), passim; Gail Cooper, *Air-Conditioning America: Engineers and the Controlled Environment, 1900–1960* (Baltimore, MD: Johns Hopkins University Press, 1998), passim.

[56] Billings, Mitchell, and Bergey, *The Composition of Expired Air*, 2

discomfort as much as immediate death.[57] Unlike all other suppositions in the study, the authors do not cite any supporting research when explaining heat as a primary cause of discomfort in crowded rooms. Presumably, the research on the effects of extreme temperatures is supposed to operate as evidence that can be extrapolated to less extreme circumstances. The following exploration of some of the study's critical references offer evidence as to how the authors might have come to these conclusions about heat and lays the groundwork for where the research went after 1895. Cooper and Ackerman have written persuasively about the "birth" of air conditioning as a cooling technology in the years following this landmark study. The following section aims to add to the genealogy and familial influences guiding this switch and its subsequent development.

The report authors' reasoning for substituting heat for contamination did not emerge from their everyday experience nor an unexpected result in the laboratory. Rather they came to this decision in view of the extensive literature review they undertook as part of this research. Given the degree to which this idea of temperature control has come to signify within most building space conditioning practice, it serves to examine briefly the scientific sources that pointed Billings and his colleagues toward the detrimental effects of heat. The paper includes forty-four separate citations, many of them papers by Brown-Séquard and those replicating or disproving his experiments, but a few of the references supplied other avenues of reasoning, particularly in terms of attention to the effects of heat and cold and to physiological modes of measurement (recording gradations in bodily function, e.g. pulse, respirations, food intake, rather than simply observing the binary of alive or dead and studying the morbid anatomy of a deceased research animal). The lines

[57] Interest in chronic effects is implied by the follow up study by Bergey, also funded by the Smithsonian Hodgkins Fund: David H. Bergey, *An Investigation of the Influence upon the Vital Resistance of Animals to the Micro-Organisms of Disease Brought about by Prolonged Sojourn in an Impure Atmosphere* (Washington DC: Smithsonian Institution, 1898).

of research that are particularly relevant [hearken back to the 1860s to the work of Benjamin Ward Richardson, the ongoing metabolic research of Pettenkofer, as it was embedded in the work of J.Th.H. Hermans.[58]

***Richardson, Mitchell, and the Source of Animal Power***

Billings, Mitchell, and Bergey would have certainly been familiar with Richardson for his advocacy for Chadwick's sanitary idea in England, but attention to Richardson's experimental research on the effects of heat and cold on human physiology was likely drawn by Mitchell, who shared research interests and theories of overwork with Richardson. Indeed, in an 1867 lecture entitled "On the Influence of Extreme Cold on Nervous Function" Richardson referenced Mitchell's parallel research in the U.S. to build the credibility of his own observations. Richardson felt fortunate because as he was carrying out his temperature studies, "one of the most distinguished of our brethren, Dr. Weir Mitchell, of Philadelphia, has been independently working on the other side of the Atlantic." More importantly, this was done "without concert — without either of us knowing that we were investigating the same truths — we have thus been labouring in the same direction."[59] It is unclear whether the two men had communicated directly before this point, but their theoretical positions continued to overlap, especially in their philosophies of human physical capacity. Richardson's *Diseases of Modern Life* is not a far cry from Mitchell's *Wear and Tear: Hints for the Overworked*.

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[58] The references to these authors included in the 1895 paper are: Benjamin Ward Richardson "On Certain Phenomena of Life" *Transactions of the Medical Society of London* 1 (1861): 53-128; R. Angus Smith, *Air and Rain: the Beginnings of a Chemical Climatology* (London: Longmans, Green, and Co, 1872); J.T.F. Hermans "Ueber die vermeintliche Ausathmung oganischer Substanzen durch den Menschen. Ein Beitrag zur Ventilationsfrage" *Archiv für Hygiene* 1 (1883): 1-40.

[59] Benjamin Ward Richardson, "On the Influence of Extreme Cold on Nervous Function," *The Medical Times and Gazette* (May 11, 1867): 489.

As a medical investigator Richardson had a wide range of interests, but the work of Richardson's that Billings, Mitchell, and Bergey cite, his 1861 lecture series "On Certain Phenomena of Life," outlined a broad theory outlining the relationship between oxygen heat in providing "the source of animal power." The intricacies of Richardson's theory are complex, but decidedly based in a mechanical rather than a vital model of life. To follow Richardson's theory, "it was necessary to throw aside all preconceived notions regarding a specific vital force—the *'vis animae*,' *'materia vitae,' 'vis insita,'* etc," and in this Richardson revived many of the mechanical propositions laid out by Lavoisier in the previous century, although Richardson does not describe it with this pedigree.[60] One of Richardson's primary interests in these "phenomena of life" are the particular mechanisms involved in producing muscular work, as he had observed the gross effects of extreme temperatures on muscular tone, where extreme cold made muscles rigid and extreme heat relaxed them beyond use.

The specific experiments of Richardson's replicated by Billings, Mitchell, and Bergey investigated the effect of high and low temperatures on "the action of oxygen in its relations as a supporter of life."[61] Essentially both Richardson and the Institute of Hygiene team placed animals in confined spaces with varying concentrations of oxygen and carbonic acid at various temperatures and found that the animals died earlier at the more extreme temperatures. Yet where Richardson observed a relationship between the composition of the air and temperature, Billings, Mitchell, and Bergey found "the duration

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[60] Richardson, "On Certain Phenomena of Life," 172. Richardson's discussion of the relationship between oxygen, heat, and muscular activity reflects the transition in common theory between Lavoisier's idea of "caloric" and later ideas of "heat" as matter in motion. Richardson uses the old terms "caloric" and "calorification," but he essentially describes the premise of first law of thermodynamics, i.e. the conservation of energy.

[61] Richardson, "On Certain Phenomena of Life," 172-173. Richardson is clear that the effects of heat and cold are on the oxygen itself, not the body, "cold destroys the sustaining power of oxygen; but not from mere constringent action on the pulmonary capillaries."

of life, in confined spaces, is influenced to a very marked degree by temperature," but that these effects appeared to be independent of the concentration of oxygen in the air.[62] Although in their general conclusions Billings and his colleagues continue to associate the detrimental effects of temperature with the composition of the air, they make a clear shift in a long cultural discussion. The tragedy in the "Black Hole of Calcutta" was likely due more to the high temperature than to the air alone.[63]

***Hermans, Heat, and Metabolism in Germany and America***

Billings, Mitchell, and Bergey would not have been as familiar with J.Th.H. Hermans, the author of one of the few other studies cited in the 1895 review that suggested that elevated heat and moisture, not carbonic acid or oxygen, were responsible for the deleterious effects of air. Hermans was a recent doctoral graduate from the Hygiene Institute at Amsterdam in 1883, the year the paper was published, and it was a version of his doctoral dissertation, which in its conclusion proposed that the bad effects of air were due primarily to the inability of the body to cool itself in conditions of elevated temperature and moisture. Yet despite the fact that Hermans's conclusions were "not discussed by him in great detail" and "not supported by experimental evidence of his own," according to an author writing in 1914, they nonetheless "provided the much needed germinal thought" that had "developed into the most rational of all proposed explanations of the observed facts."[64]

The credibility of Hermans's ideas instead came from his educational pedigree and public support for his propositions by his mentors. In 1881 Hermans, a newly minted Dutch

[62] Billings, Mitchell, and Bergey, *The Composition of Expired Air*, 19.
[63] Billings, Mitchell, and Bergey, *The Composition of Expired Air*, 25
[64] Frederic S. Lee "Laboratory Experiments with Air" *Journal of the American Medical Association* 63, no. 19 (Nov 7, 1914): 1626

physician, began his doctoral work under Josef Forster, a professor of hygiene at the University of Amsterdam, who in turn had been a student of Pettenkofer and Carl von Voit at Munich as well as a lecturer on hygiene in that program. Pettenkofer and Forster must have thought Hermans's paper significant, for it received pride of place as the first article in the first volume of Pettenkofer's new journal *Archiv für Hygiene* that Pettenkofer launched with Forster and another of Pettenkofer's students, Franz Hoffmann, who was then a professor of hygiene at the university in Leipzig. After publication of his 1883 article, Hermans did not again contribute to Pettenkofer's journal. Rather he settled into a medical practice in Amsterdam, where he remained until his retirement in 1931.

Thus, it is most useful to see Hermans's 1883 article and its propositions as a translation of Pettenkofer's ideas and his research trajectories in Munich. The conclusions dashed off in Hermans's paper, although related in their attention to heat and moisture, actually represent two tracks in Pettenkofer's research program emerging in the 1880s, one encompassing his particular theory of disease transmission, the other exemplifying his ongoing collaboration with the physiologist Carl von Voit in the founding of the Munich School of Metabolic Research.[65] As Hermans presents it, the first danger of heat and moisture in an enclosed space came with the risk of creating beneficial environments for the growth of microorganisms. This seems to be an extension of Pettenkofer's "seed and soil" theory of disease, as later commenters described such warm and wet settings as akin to the conditions of a Petri dish. The second danger, a rise in body temperature, was internal to the human body. Although this phenomenon could be observed with a clinical thermometer, as Hermans did in his 1883 paper, in order to study its precise mechanisms,

[65] On the Munich School of Metabolic Research: Lochner, "Max von Pettenkofer," 241.

one needed a particular piece of laboratory equipment, a calibrated and mechanically equipped confined space, the respiratory calorimeter.

This "necessary apparatus" was constructed in the early 1860s by Pettenkofer and Voit to study human respiration as it pertained to human metabolism (Figure 4.5).[66] As Pettenkofer was always careful to point out, construction of the apparatus was funded by King Maximillian II of Bavaria, who was also instrumental in bringing Justus von Liebig to Munich to join Pettenkofer and Voit in the formation of the School of Metabolism.[67] Early metabolism studies with the apparatus focused on human respiratory excretions as a method to study internal processes of nutrition. This work was based on Liebig's theory of respiration and animal chemistry, which in turn was a revival and emendation of Lavoisier's theory of respiration and work.[68] Liebig's theory informed by his research on organic chemistry postulated that fats and carbohydrates

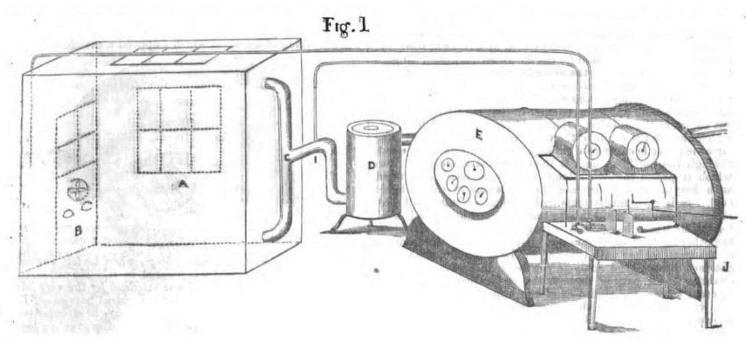


Figure 4.5 Pettenkofer's apparatus, 1862. As Pettenkofer claimed, a human subject could remain for a long period in the eight-foot-square chamber marked "A." The gasmeter, marked "E" was responsible for maintaining a constant current of air through the apparatus and accurately measuring it.

[66] Max Pettenkofer, "Researches on Respiration" *The Lancet* (Nov 1, 1862): 472; Elizabeth Neswald "Nutritional Knowledge between the Lab and the Field: The Search for Dietary Norms in the Late Nineteenth and Early Twentieth Centuries" in *Setting Nutritional Standards: Theory, Policies, Practices* edited by Elizabeth Neswald, David F. Smith, Ulrike Thoms (Rochester: University of Rochester Press, 2017), 33.

[67] Maximillian II, who came into power during the 1848 revolutions, consciously dedicated funding to develop scientific and technical resources in Munich with the intent to demonstrate that as a new-style monarch, he could improve the material conditions of Bavaria as well as maintain the traditional monarchical role in meeting the spiritual needs of his subjects, Frederick L. Holmes "The Formation of the Munich School of Metabolism," in *The Investigative Enterprise: Experimental Physiology in Nineteenth-Century Medicine*, edited by William Coleman and Frederic L. Holmes (Berkeley: University of California Press, 1988), 189.

[68] Holmes "The Formation of the Munich School of Metabolism," 183.

provided the body's heat, and protein fueled muscular labor (Figure 4.6).[69] According to Liebig's methods, one could understand the body's precise utilization of various foodstuffs by studying the body's byproducts, particularly carbon dioxide. Pursuit of this knowledge came from institutional demands for more precise calculations of dietary standards for soldiers and adequate national food economies for citizens.

Secondary observations in this line of research are what led Pettenkofer to his earlier theory of vitiated air—the one that Billings noted had been dominant for thirty-five years in 1895—but by the time of Hermans paper in the 1880s, Liebig had died, and new influences in the study of physiology had gained prominence in German-speaking universities. The new perspective on physiology was decidedly mechanistic and sometimes described as "organic physics" by it key promoters, a small group of German scientists who disagreed with the vitalist tradition of *Naturphilosophie*, then dominant in German physiology.[70] A key member of this group was Hermann von Helmholtz, who in his physiological studies of muscle metabolism conceived of the first law of thermodynamics, the conservation of energy.[71] Max Rubner, a student of Voit's


Figure 4.6 Liebig's Beef Wine, prepared by S. Stephen's, Chemist and Optician, c. 1905. In 1847 Liebig had developed a process for making beef extract, intended as a meat substitute for those who could not afford meat. Liebig made the process freely available to commercial producers. Credit: Wellcome Collection CC BY 4.0

[69] Neswald "Nutritional Knowledge between the Lab and the Field," 31.

[70] Paul L. Cranefield "The Organic Physics of 1847 and the Biophysics of Today," *Journal of the History of Medicine and Allied Sciences* 12, no. 4 (October, 1957): 407.

[71] Helmholtz was attempting to demonstrate "that no energy is lost in muscle movement, motivated by the implication that there were no vital forces necessary to move a muscle" H. Helmholtz, "On the Conservation of Force" in *Scientific Memoirs Selected from the Transactions of Foreign Academies of Science and from Foreign Journals*, edited by John Tyndall and William Francis (London: Taylor and Francis, 1853), 114-162.

working in the metabolism program at Munich, in the 1880s demonstrated in experiments on dogs that the Helmholtz's conservation law applied to both animal nutrition as well as physiological processes in general.[72] From this view, metabolism could be better understood through close attention to the production of heat by the human body, more so than the production of chemical effluvia, such as carbonic acid. Thus, by 1882, when the American agricultural chemist Wilbur O. Atwater, who had trained in Germany in the 1870s, returned to Munich for a year of research with Voit, the "apparatus" had been equipped with the capability to both experimentally measure and tightly control the temperature within the chamber.[73] Upon his return to the States, Atwater advocated for a program of study similar to that of Pettenkofer and Voit. He laid out his case in a series of articles, published in the popular magazine *The Century*. Although Atwater described the apparatus and scientific research in detail, he framed the research not only in terms of American food economies, especially for the "laboring classes," but also in terms of labor unrest and human physiological capacity:

> During the epidemic of strikes in the spring of 1886, a church was being built in this city (Middletown, Conn.). When the brick walls were partly laid, the hod-carriers struck for higher pay. The master mason, a man of resources, let them go and got a steam-engine in their place. The brick and mortar which had been carried up the ladders by Hibernian muscle were lifted by engine and windlass. The work which had been done through the consumption of meat and potatoes in the one case, was accomplished by the combustion of coal in the other, but the underlying principle was the same in both. In each case there was conversion of one form of energy into another. The food which the hod-carriers ate, and the coal which was burned under the boiler, each contained a certain amount of potential energy. That of the food reappeared in the contractile power of the muscle, that of the coal in the expansive power of steam.[74]

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[72] Neswald, "Nutritional Knowledge between the Lab and the Field," 31.
[73] Edward C. Kirkland, "'Scientific Eating': New Englanders Prepare and Promote a Reform, 1873-1907," *Proceedings of the Massachusetts Historical Society*, Third Series, 86 (1974): 39.
[74] Wilbur O. Atwater, "The Potential Energy of Food," *The Century illustrated monthly magazine* 34 (1887): 397

With funds from the Hatch Act of 1887, in which the U.S. Congress appropriated funds for the establishment of agricultural experiment stations in each state, Atwater endeavored to build a version of Pettenkofer and Voit's apparatus at his academic home, Wesleyan University. Although it took some years to construct the apparatus, Atwater quickly put it to use, and following his mentor Rubner, concluded that the law of conservation of energy applied to humans as well as animals (Figure 4.7).[75]

Billings and his colleagues may not have cited Atwater's work with the apparatus in their literature review, for it came online just after the paper's publication, but Billings would soon become quite familiar with Atwater's work and his respiratory calorimeter through Billings's membership on the physiology subcommittee of the Committee of Fifty, which engaged in a years-long battle with the Women's Christian Temperance Union over the mode and purpose of teaching physiology in public schools. Atwater's research with the apparatus on the physiology of alcohol use supported the Committee's position on moderate drinking.[76]

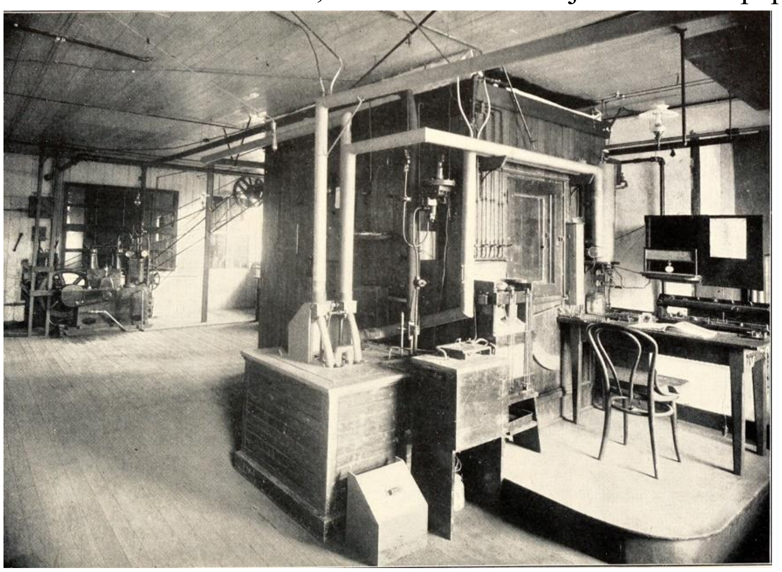

Figure 4.7 Atwater's "respiration calorimeter" in 1902.

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[75] Neswald, "Nutritional Knowledge between the Lab and the Field," 31

[76] Philip J. Pauly, "The Struggle for Ignorance about Alcohol: American Physiologists, Wilbur Olin Atwater, and the Woman's Christian Temperance Union," *Bulletin of the History of Medicine*, 64, no. 3 (Fall 1990): 366-392.

**The Double Meaning of Dust**

In their 1896 trade catalog, the B.F. Sturtevant Company, which manufactured large-scale ventilation fans, observed, “Although it is scarcely ten years since the first edition of this Treatise was issued, this comparatively brief period has witnessed an almost phenomenal change in public opinion regarding the absolute necessity of good ventilation.”[77] The company’s reference for this “absolute necessity” was Billings’s 1893 guide to heating and ventilation. In the book, Billings responded to questions about whether the prevailing ventilation practice was negated by Koch’s new theory of disease transmission. No, Billings argued, “on the contrary it strengthens it; in part because the probabilities of inhaling the specific disease germ are evidently greater where a number of men or animals are repeatedly breathing air contaminated by the dust of dried sputa or other excretions of their companions.”[78]

Billings’s recommendation for the removal of dust was not just a housekeeping prerogative, but rather guidance linked directly to then-emerging bacteriological theory. Although many agreed that Koch’s tubercle bacillus played a critical role in causing tuberculosis, an equal number debated how that microorganism transmitted between the sick and the healthy. An early and influential theory of transmission was Georg Cornet’s “dust theory” of disease. One of Koch’s associates at the hygiene institute in Berlin but trained under Pettenkofer in Bavaria, Cornet proposed in a widely read 1888 publication that the greatest risk of tuberculosis infection came not through the fresh expectorations of

[77] B.F. Sturtevant Company. *Ventilation and Heating: Principles And Application*: *a Treatise*. (Boston: B.F. Sturtevant Company, 1896).
[78] John S. Billings, *The Principles of Ventilation and Heating and Their Practical Application*, 2d ed. (New York, Engineering & Building Record, 1889); John S. Billings, *Ventilation and Heating* (New York: The Engineering record, 1893).

the coughing consumptive, but rather through "dust," the dried version of this sputum that disseminated in the air around the consumptive patient.[79]

The British scientific community as well as the public were primed to believe dust theory by the work and public lectures of John Tyndall, the popular albeit controversial professor of natural philosophy at the Royal Institution of Great Britain from 1853 to 1885. Tyndall, a physicist, whose work on solar radiation and atmospheric gases in the 1860s and 1870s led him to observe the abundance of "floating matter" in the air. Influenced by the work of Louis Pasteur, Tyndall assumed that this dust he observed must contain disease germs.[80] Americans physicians and advocates were introduced to dust theory directly through the medical press, but also through the work of George Sternberg, the American army physician, early bacteriologist, and close associate of John Billings.[81] Cornet's dust theory remained virtually unchallenged until 1899, when Carl Flügge, another German scientist who trained under both Pettenkofer and Koch proposed a "droplet" theory, by which tuberculosis was transmitted by very small but wet droplets released by a consumptive's cough.[82] Yet as will be explored further below, those years of dust theory dominance, however, served as an engine for a major anti-tuberculosis campaign and revealed a critical occupational health hazard that made ventilation and ventilation technology seem even more critical.

This endorsement of the dust theory by a prominent figure such as Billings in both his practical guides and his scientific publications gave credence to new public health

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[79] J.S.E. "Review of: The Dissemination of Tubercle Bacilli outside the Body by Georg Cornet" *The International Journal of the Medical Sciences* 97 (1889), 273; Nancy Tomes, *The Gospel of Germs: Men, Women, and the Microbe in American Life* (Cambridge, MA: Harvard University Press, 1998), 96-97.
[80] Tomes, *The Gospel of Germs*, 32-33.
[81] Michael E. Teller, *The Tuberculosis Movement: A Public Health Campaign in the Progressive Era* (Westport, CT: Greenwood Press, 1988), 18; Cassedy, *John Shaw Billings*, 95.
[82] Teller *The Tuberculosis Movement*, 18

initiatives focused on tuberculosis, the term many now used for the disease after Koch's naming of the tubercle bacillus. While some earlier theories, such as Henry I. Bowditch's dampness-causation theory, proposed that tuberculosis might be preventable, the general public as well as most medical professionals in the 1880s still maintained a fatalistic attitude toward the disease. In the minds of many, the disease still had hereditary sources, and there we no way to reverse the slow and painful decline of the disease once it manifested. However, the seeming success of the hygienic sanatorium treatment introduced to America from Germany in the 1870s gave people hope that tuberculosis could be cured. The dust theory not only gave people hope that tuberculosis could be prevented, but it also suggested a clear and socially acceptable set of practices to avoid it.[83]

Public health campaigns targeting tuberculosis emerged and grew rapidly. Some were municipal government programs, such as the one launched by the New York City Department of Health in 1889, and others were non-governmental, such as the Pennsylvania Society for the Prevention of Tuberculosis founded in 1892. Fairly quickly these organizations coordinated to form the National Tuberculosis Association, and by the late 1910s this organization had widespread involvement with nearly thirteen hundred affiliates and thousands of members.[84] Large life insurance companies also sponsored major tuberculosis prevention campaigns that provided educational materials for wide distribution to their subscribers and the public at large. While the advice given in these publication included many general health-supporting activities, much of it focused on air. For those who already had the disease, the literature recommended treatment of patients with copious outdoor air, at sanatoria if financially possible or in a specially constructed

[83] Teller, *The Tuberculosis Movement*, 15, 18.
[84] Teller, *The Tuberculosis Movement*, 21-22; Tomes, *The Gospel of Germs*, 114; Hoy, *Chasing Dirt*, 112.

cabin. For those who were not yet afflicted or at an advanced stage in the disease, attention to appropriate indoor air was strongly recommended.

Thus, when the “New Public Health” campaign that lay its faith in Flügge’s wet transmission theory and focused on washing hands and containing coughs, not cleaning air, set out to convince the general public of the importance of these new practices, they had an uphill battle. Yet even as this campaign began to see some success by the educational initiatives of reform groups and the advertising campaigns of soap companies, dust, air, and ventilation remained significant concerns for physiologists, engineers, and policy makers.[85] In some cases, which will be discussed in the following chapter, the “dust theory” of tuberculosis was a red herring. In the urban politics of New York City, it served as a way to critique incumbent officials’ programs and to promote regulatory reform. In the industrial world, however, there was a double meaning of dust specific to occupational health.

With common acceptance of Koch’s germ theory, most began calling the disease that had historically taken so many lives “tuberculosis,” but one group, unions representing rock-cutting workers and similar occupations, refused to call it by this new name, instead insisting on maintaining the traditional name “consumption” or “phthisis” on the grounds that they believed the disease could be caused by something else, namely the dusts present in their industrial workplaces, including hard-rock mines, potteries, foundries, and others. The chronic consumption-like disease, later termed “silicosis,” had been linked if not formally recognized as associated with stone-working trades since antiquity, but germ theory severed those ties, obscuring all other possible causes. This dissociation was

[85] Hoy, *Chasing Dirt*, 142.

particularly tragic because it came at a time when dust in the workplace was getting worse with employers introducing new mechanical tools to speed work.[86]

Physicians working directly with miners and others employed in the dusty trades had long recognized that this was an affliction caused by the work environment, but many physiologists and public health advocates, who worked primarily in laboratories, often proposed alternative etiologies that removed blame from the occupational setting. For example, John S. Billings in his 1893 guide to ventilation repeats a view common among health professionals. The dust did not cause disease directly, that should be attributed to the bacillus. Dust rather had an indirect effect. Irritation from the dust in the lungs either reduced the body's defenses or brought on less serious illnesses that eventually developed into tuberculosis.[87] Needless to say, these conflicts kept attention focused on dust, air, and tuberculosis especially within enclosed working spaces.

### ***Haldane, Mines, and Holistic Physiology in Britain***

In addition to the mechanical physiology dominant at German universities, Billings, Mitchell, and Bergey drew on a related but philosophically distinct strain of physiological research in Britain, one that emerged with various sanitary initiatives but developed within a changing British mining industry. As Hermans did in 1883, the Philadelphia group cite the 1872 publication *Air and Rain* by Robert Angus Smith as well as an 1893 paper, "The Physiological Effects of Air Vitiated by Respiration," by John Scott Haldane and James Lorrain Smith, which replicated specifically the methods and experimental settings used by both Hermans and Angus Smith. Although Billings and his colleagues included these

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[86] David Rosner and Markowitz, *Deadly Dust: Silicosis and the Politics of Occupational Disease in Twentieth-Century America*, 1991), 13-14. Both Ramazzini (1700) and Thackrah (1832) observed that workers exposed to significant quantities of dust developed serious respiratory problems.
[87] John S. Billings, *Ventilation and Heating* (New York: The Engineering Record, 1893), 107.

results in their review as evidence against the Brown-Séquard's organic poison theory, the studies seemed to suggest, ironically, that carbonic acid again might have some critical effect on human physiological function in confined spaces. What the Philadelphia colleagues did not describe is the particular type of confined space that the British researchers were representing in their laboratories, namely the shafts and drifts of hard-rock mines. Yet insight into the context of these studies reveals a complex and contentious situation of occupational health in British mines in the 1860s and provides a prelude to the role of scientists, physicians, and engineers not only in determining space conditioning standards, but also in mining labor struggles that persisted beyond the turn of the century.

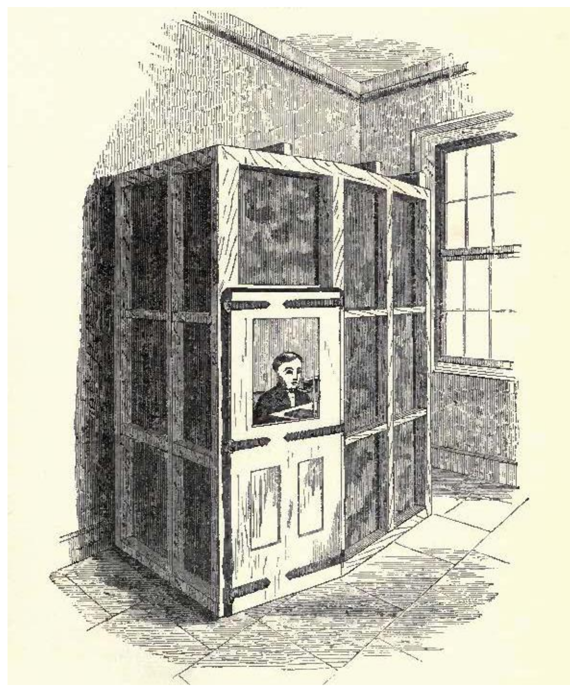

Figure 4.8 Lead-lined chamber used in experiments by R. Angus Smith, 1864. Published in Smith's 1872 book *Air and Rain.*

The majority of the experimental subjects used in the Philadelphia group's research as well as in their cited studies were animals, but Angus Smith used humans, because like the Munich group, he had the funds to construct a special lead-lined chamber large enough to accommodate a small group of human subjects (Figure 4.8). Although Smith does not describe the source of his funds in detail, they presumably came from the group sponsoring his research, a Parliamentary Commission created to inquire into the health and safety of workers in all British (non-coal) mines. Parliament had previously inquired into the mines and finding the conditions shocking, passed laws in 1842, 1850, and again in 1860 limiting the work of women and children underground, requiring certain safety measures, and allowed governmental inspection in some mines. Despite this legislation, reports of tragic mining fatalities still reached urban readers, and by 1862, the year of the Commission's formation, a disturbing new report had reached the members of Parliament, suggesting that even without accidents, miners in certain districts were dying from pulmonary diseases, particularly phthisis (consumption) in much great numbers than those living in the same districts who were not miners. It was, as the report's introducer observed, "a wasteful expenditure of human life in England."[88]

Smith was just one of several experts whom the Commission called upon to report upon the health and safety of miners working in the metalliferous mines. To the Commission, Smith provided a one-hundred plus page "Report on the Air of Mines," comprising numerous and highly detailed chemical analyses of air samples taken from the mines and surrounding above-ground areas, but in summaries given to general audiences and repeated in the Billings report, the results were given in physiological terms.[89] He found a weakening of circulation and difficulties in breathing in subjects exposed to increasing concentrations of carbonic acid in the lead chamber. At first glance this is curious because Smith was a chemist, not a physician nor a physiologist, but in the larger context of the report and its technological conclusions, a physiological measure makes more sense.[90] Responding to observations made by Thomas B. Peacock, a cardiologist, a

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88 Edward Headlam Greenhow, *Papers Relating to the Sanitary State of the People of England: the Results of an Inquiry into the Different Proportions of Death Produced by Certain Diseases in Different Districts in England, with Introductory Report by John Simon, Medical Officer of the General Board of Health* (London: George E. Eyre And William Spottiswoode, 1858), iii; Fredric Mintz, "Hard Rock Miners' Phthisis in 19th and Early 20th Century Britain: From Diagnosis to Compensation," PhD Diss., University of California Berkeley, 2009, 24.

89 Billings, Mitchell, and Bergey, *The Composition of Expired Air*, 4-5

90 Smith studied organic chemistry in the 1840s in Germany with Justus von Liebig, to whom Smith dedicates *Air and Rain*. Back in Great Britain, Smith became involved in the Chadwick's sanitary program through the Health of Towns Commission. Smith was a consulting chemist to the emerging heavy chemicals industry in Manchester, but he was known at the time to be highly critical of chemists who

founder of the London Chest Hospital in London, and the lead medical investigator for the Commission, in his clinical examinations of miners, Smith put his findings in this perspective. Peacock had found that a peculiarity of many miners, aside from the fact that many of them died early, was a particularly feeble pulse, and that the reduced pulses that Smith had observed in his lead chamber studies was "proof that the temporary results found in these experiments may be rendered permanent." Yet there was good news, "on coming into fresh air the pulse and breathing recovered in a few minutes, showing the value of ventilation."[91] Such a case had to be made for the long-term benefits of increased ventilation in mines because although ventilation in mines had long received attention, it was primarily devoted to preventing the accumulation of fire-damp, which were often the cause of underground explosions that claimed many lives. Instead, Smith argued, "the air which the miner breathes, and which, in process of time, may be as fatal to him as an explosion of fire-damp, has been but little thought of."[92]

As in Chadwick's 1842 sanitary report, more than any other element air was deemed the cause of miners' health problems, and ventilation the preventive answer. However, in the case of the Mining Commission disputes remained over what exactly about the air caused the problems. With metalliferous mining practice becoming increasingly mechanized, underground workers were exposed to progressively higher levels of siliceous

compromised their ethics and chemical evidence when testifying for hire in lawsuits against chemical companies. With this reputation, Smith was appointed the first inspector under the Alkali Act, a law passed in 1863 regulating aerial emissions of hydrochloric acid by industrial producers. Historians have found Smith more or less admirable as a scientist, but some describe him as a negotiator who made positive change by negotiating win-win technical solutions for industry. Christopher Hamlin, "Smith, (Robert) Angus," *Oxford Dictionary of National Biography* (Oxford: Oxford University Press, 2008); Roy M. MacLeod, "The Alkali Acts Administration, 1863-84: The Emergence of the Civil Scientist," *Victorian Studies* 9, no. 2 (Dec 1965): 85-112.

[91] R. Angus Smith "On some Physiological Effects of Carbonic Acid and Ventilation*," Proceedings of the Manchester Literary and Philosophical Society*, 4 (1865): 83.

[92] "Book Notices: Report on the Air of Mines and Confined Places, By Angus Smith, Ph.D., F.R.S. Part of the Appendix to the Royal Mines Commission, 1864," *The Chemical News and Journal of Industrial Science* 11 (1865): 129.

dust, and many suspected that long-term exposure to this dust was the cause of the astonishingly high death rates for male miners over thirty-five, the age at which many miners had already worked underground for several years. The physicians consulting on the Commission report as well as many local doctors who saw the miners as patients contended that it was the dust that was causing the affliction. The chemists such as Angus Smith argued that it was exposure to gases such as carbonic acid, not physical contaminants like dust that resulted in damage to health. Not only did this suggest that the miners' afflictions were caused by a less occupationally specific source, but it also meant that mining interest did not have to change any of their mechanized extraction processes. The members of Parliament sitting on the commission noted this disagreement and determined that the chemists were likely correct. The certainty of the laboratory convinced more fully than the clinical evidence gathered by the doctors and provided by the miners' own stories and bodies. There was one thing they could agree on, however, more ventilation.[93]

Perhaps it is not surprising then that soon after Scottish physiologist John Scott Haldane replicated Angus Smith's research in a similarly custom-built "confined space" he became a long-time consultant to the mining industry on issues of miners' health. In their 1895 report, Billings, Mitchell, and Bergey emphasized Haldane and Lorraine Smith's findings that when one person remained in Haldane and Lorrain Smith's air-tight chamber until the air was highly "vitiated" that subject felt no effects in terms of odors or sense of oppression. They mention only in passing that Haldane and Lorrain Smith had concluded that high proportions of carbonic acid consistently produced hyperpnoea (rapid breathing) in those confined in the chamber.[94] Yet it was their research on the physiological effects of

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93 Mintz, "Hard Rock Miners' Phthisis," 35.

94 Billings, Mitchell, and Bergey, *The Composition of Expired Air*, 9. This latter observation, however, was one that according to Haldane, Hermans had also observed in 1883, using a similar "tin cage." John Haldane, "Notes of an Enquiry into the Nature and Physiological Action of Black-damp, as met with in

carbon dioxide that caught the attention of W. N. Atkinson, then an Inspector of Mines for a northern district, who asked Haldane to perform a an investigation of suffocative gases commonly found in coal mines, particularly "black damp," which was thought at the time to be pure carbon dioxide. As Haldane's obituary writer noted, this foray established Haldane's lifetime association with the mining industry.[95]

Yet Haldane's motivation in conducting the 1893 study that Billings and his colleagues reference in the Smithsonian paper also came from his position as a junior faculty member at Oxford University, an institution that under the guidance of Haldane's mentor and uncle, John Scott Burdon Sanderson, was trying to build a laboratory and academic unit in physiology on par with those in Germany and France.[96] Towards this end, Haldane's work with Lorrain Smith occurred at the same time that Haldane was attempting to develop improvements to Pettenkofer and Voit's apparatus, as version of which had been in use "for some time" at the Physiology Laboratory at Oxford.[97] Although Haldane and Lorrain Smith in their 1893 paper reported few measurable physiological or psychological effects related to moisture or heat, Haldane nonetheless maintained that these factors could be injurious.[98] This was perhaps because he was also deeply immersed in research in the physiology of animal heat as part of an effort to develop a new type of heat-measuring

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Podmore Colliery, Staffordshire, and Lilleshall Colliery, Shropshire," *Proceedings of the Royal Society of London* 57, no 343 (1895): 255.

[95] C. G. Douglas, "John Scott Haldane. 1860-1936," *Obituary Notices of Fellows of the Royal Society* 2, no. 5 (Dec 1936): 117-118.

[96] John Haldane and J. Lorrain Smith, "The Physiological Effects of Air Vitiated by Respiration," *The Journal of Pathology and Bacteriology* 1 (1893): 168-186; Gerald L. Geison, "Social and Institutional Factors in the Stagnancy of English Physiology, 1840-1870," *Bulletin of the History of Medicine* 46, no. 1 (Jan-Feb 1972): 30-58.

[97] J. Haldane, "A New Form of Apparatus for Measuring the Respiratory Exchange of Animals," *Journal of Physiology* 13 (1892): 419; see also E.A. Schäfer, *Textbook of Physiology* vol 1 (Edinburgh and London: Young J. Pentland, 1898), 696-697.

[98] The researchers seem to present conflicting conclusions in John Haldane and J. Lorrain Smith, "The Physiological Effects of Air Vitiated by Respiration," *The Journal of Pathology and Bacteriology* 1 (1893): 173, 186.

calorimeter to rival those developed by Voit and Rubner in Munich, work that Haldane halted after a couple of years, however, because many felt that Rubner had in the meantime performed conclusive work in this area.[99] Nonetheless, Haldane's subsequent research in the areas of respiration, air, heat, and work underground built his international reputation and had significant resonance in physiological research and technological development within American institutions.

### ***Haldane and High Air Temperatures***

When faced with the double meaning of dust, Haldane took another approach, he simply redefined the problem, shifting the conversation from problems of air to problems of heat and humidity. By 1902 Haldane, now on more solid footing as a lecturer and fellow at Oxford, was serving on multiple advisory committees to the British Home Office (responsible for the internal affairs of England and Wales), investigating the ventilation of factories and workshops and separately the health of Cornish miners. In both cases Haldane recommended shifting focus from dust to heat and humidity. In both cases this was controversial.

Aboveground, Haldane suggested to the Home Office committee a relatively low standard for air circulation in factories against the objections of numerous medical authorities, including the Council of the Incorporated Society of Medical Officers of Health, which issued a formal statement rejecting Haldane's recommendation. Haldane defended his recommendations from a number of angles, but most important was that a stricter ventilation standard would be expensive for employers, a situation that was likely to cause "endless friction" with manufacturers and other employers, most of whom in

[99] J. S. Haldane, W. Hale White, and J. W. Washbourn, "An Improved Form of Animal Calorimeter," *Journal of Physiology* 16 (1894): 123-139.

Haldane's opinion showed "great public spirit in matters relating to the health of their employees." Haldane argued that, based on his team's measurement, on average if "the cases of very bad ventilation and gross neglect were eliminated," ventilation in factories was actually quite good, and that impurities such as dust and gases could probably be controlled at their source rather than diluted through increased air exchange. Aside from these actual impurities, Haldane posited that there were "two factors which are probably of great importance in relation to ventilation. One of these is temperature of air, and the other its motion." Although Haldane was a skilled laboratory physiologist, he did not present any experimental evidence to support this claim. Rather it was the "experience gained in the 'open-air' treatment" of tuberculosis and other diseases that seemed "to indicate that cool and moving air produces a marked favourable influence on health." Haldane's reasoning here was hardly rigorous, it was simply that he could not think of another way to explain the success of the open-air treatment.[100]

Belowground, the situation was more complicated. In 1904, Haldane had been called in by a separate Home Office committee to advise on the health of Cornish miners, the same group that had the attention of R. Angus Smith and the Royal Commission in the 1860s. The conditions of these tin mines in Cornwall were particular (Figure 4.9). Unlike the coal mines in the north of England, the Cornish metals mines did not historically have ventilation systems in place because they did not have the same risk of coal-dust explosion. The metalliferous mines were also particularly hot—temperatures often exceeded 100° F—as mining companies pursued mineral veins deeper into the earth. Relief from these conditions was not easy to come by in the course of a day's shift. Because descent into the mine workings by ladder took close to an hour, miners did not leave the close spaces during

[100] John S. Haldane, "Standards of Ventilation," *Public Health* 17 (Oct 1904–Sep 1905): 32-39.

the work period. Particular contract conditions—workers were paid individually by the ton of material mined—also encouraged miners to work continuously with few if any breaks.[101]

These conditions had only gotten worse with the introduction of mechanical drilling. Miners might now be able to extract more tonnage, but statistical evidence gathered just a few years earlier showed that miners' mortality was increasing in direct correlation with the introduction of mechanized drilling and the increased dust those machines produced. After exploring various methods for dust reduction, Haldane recommended installing water jets alongside the mechanical drills to limit the quantity of airborne dust. Mine owners supported this recommendation because the wet-drilling system was much cheaper and easier to install than the ventilation systems capable of removing the greater quantities of finer dust produced during mechanized drilling. However, the miners themselves did not like the water-jet method. It drenched them and increased the humidity in their working areas to unbearable levels. Already irritated that they had not been consulted on alternatives, the miners frequently unhooked the water jets and worked without them. In turn, Haldane and the mine managers blamed the miners themselves for

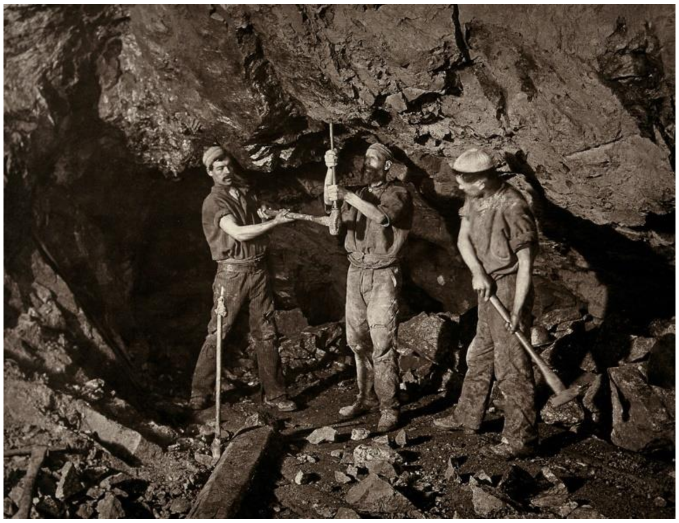

Figure 4.9 Cornish tin miners drilling an "upper" hole using hand tools, c. 1900. Credit: Wellcome Collection CC BY 4.0

[101] E.S. Proctor, "The Health of the Cornish Tin Miner 1840-1914," *Journal of the Royal Society of Medicine* 92 (Nov 1999): 596.

their own poor health, framing their refusal to use the wet-drilling technique as working-class ignorance.[102]

Although Haldane does not explain it exactly as such, this conflict over wet-drilling seems to have informed the direction of his critical 1905 paper, "The Influence of High Air Temperatures," which many scientific and engineering organizations cited as turning the discourse on confined air distinctly towards the physical (heat and humidity) and away from the chemical (vitiation). Haldane noted that his topic was of wide interest including those concerned with the "effects of very warm weather and tropical climates," but his research was decidedly about working conditions in his home country, the "many industrial occupations in which men or women have to work daily in very warm air." His aim in the investigation was "to ascertain the limits within which men can continue to exist normally, and to work, when the air temperature is abnormally high," and to study what might happen to the human body if these limits were exceeded.[103]

Haldane was inspired to initiate the study, he says, by a trip down into a particular mine, where the conditions were somewhat unique and the workers "exceptionally healthy for Cornish miners." This remarkable health Haldane attributed to the unusual dampness of the mine, which meant that these miners "suffered less from inhalation of stone dust than many other Cornish miners." Yet despite this better overall health, Haldane found fault with the heat of the mine, in that it limited the workers' output. This "leisureliness" of all work in the mine Haldane found in "very striking contrast" to a typical English coal mine, which were similarly deep, but much cooler.[104]

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[102] Proctor, "The Health of the Cornish Tin Miner," 598.
[103] John S. Haldane "The Influence of High Air Temperatures," *Journal of Physiology* 5, no. 4 (1905): 494-495.
[104] Haldane "The Influence of High Air Temperatures," 498-499.

Haldane conducted numerous experiments in many settings, taking measurements of increases in body temperature, pulse rate, respiration rate, and reported headaches or general feelings of exhaustion and discomfort. From these studies, he concluded that in warm, still air what was most important to "the persons present" (that is, workers) was not the air temperature, relative humidity, or absolute humidity, but rather the "wet-bulb" temperature, essentially the air's capacity to promote evaporation. If this wet-bulb temperature rose too high, Haldane argued, "continuous hard work" became "impracticable." The good news was that if the air was moving, the wet-bulb limit could be much higher, and working conditions could still be considered humane. Take for example, the miners working the mechanical drills in a hot part of a mine. One would think these would be the worst conditions, but indeed, Haldane maintained, these workers "have the great advantage" because the exhaust from the drill kept the air in constant motion, and because this exhaust air was very dry it reduced the wet-bulb temperature considerably, "*even if the rock be wet or damped by a jet or spray of water to prevent dust* (italics added)."[105]

In coming to this conclusion, Haldane not only endorsed scientifically his own technical solution, but managed to claim that it could achieve healthy working conditions. Haldane's shift in focus from ventilation to heat and humidity was sanctioned by the Departmental Committee on Ventilation of Factories and Workshops of Great Britain, who in their 1907 report recognized that "the removal of excessive heat and moisture was one of the primary objectives of ventilation." By 1909, the recommendations of the English

105 Haldane "The Influence of High Air Temperatures," 498-499.

Departmental Committee on Humidity and Ventilation in Cotton Weaving Sheds had "marked the complete acceptance of the thermal view of ventilation."[106]

Yet just influential in certain scientific circles, specifically in early twentieth century America, was Haldane's particular vitalist philosophy. Developed in the context of an emerging school of Scottish idealism, Haldane's outlook actively rejected the mechanistic reductionism premised by Ludwig and the other promoters of German "organic physics." Instead Haldane, who was born and educated in Edinburgh, advocated a holistic view that imagined organisms not as functional collections of individual parts, but rather as purposeful and self-perpetuating individual beings actively responding to particular environments. Haldane's philosophy, which he developed throughout his life and in dialogue with his elder brother, lawyer and politician Richard Haldane, had social and political implications. It emphasized social responsibility and social reform over material gain, and in the political realm it rejected the interventionist policies of the Utilitarians like Chadwick and imagined individual moral and civic responsibility as the glue for society.

As Steve Sturdy argues, this philosophy shaped not only Haldane's physiological theories, but also his activities as a medical and scientific consultant to industry.[107] It assumed that morally responsible employers, who had somehow transcended a unilateral profit motive, were better equipped to make decisions about industrial safety measures than the state. Workers too, in Haldane's philosophy, were to be viewed not as a one-dimensional mass but rather as individuals, who importantly could take more responsibility for their own safety. Haldane's philosophy also suggested, by extension through admiring physiologists in America, a particular model of the human body's relationship to its

[106] New York Commission on Ventilation, *Ventilation: Report of the New York State Commission on Ventilation* (New York: Dutton and Co., 1923), 9, 11.
[107] Steve Sturdy, "Biology as Social Theory: John Scott Haldane and Physiological Regulation," *The British Journal for the History of Science*, 21, no. 3 (Sep 1988): 316-317, 321.

environment, and in turn a novel justification for the application of air-conditioning technology. This had complicated implications for workers' health as well as their ability to argue for improved working conditions, workers compensation, or higher wages for more dangerous work. The following section describes the transit of Haldane's ideas, both technical and philosophical, through American channels, specifically through the work of three laboratories, those of the New York Commission on Ventilation (1913), the Pittsburgh Experiment Station at the U.S. Bureau of Mines (1919), and at Harvard University, the Ventilation and Illumination Laboratory (1925) and its adjunct the Fatigue Laboratory (1927), which will be discussed in the following chapter.

**The Resources of Science: Billings's Legacy in Carnegie's "Gospel of Wealth"**

Billings died in 1913, the year of the first meeting of the New York Commission on Ventilation, but in the years between 1895 and 1913, Billings made critical recommendations for the direction of philanthropic funds towards scientific and engineering institutions that would provide technical and theoretical foundation to the Commission's work. Despite the effort that the University of Pennsylvania had made in luring John S. Billings to Philadelphia, following the publication of "The Composition of Expired Air and Its Effects upon Animal Life" by the Smithsonian in 1895, Billings did not stay long. He left the University for the opportunity to become the first director of the recently consolidated New York Public Library. Billings's long experience as the manager of the Army Surgeon General's library collection made him an appealing candidate for the sponsors of the library, and in this capacity, Billings met Andrew Carnegie, in the philanthropy of whom Billings played an influential role in certain initiatives. Billings's guidance motivated not only Carnegie's funding of New York's system of branch libraries, but also his philanthropy in science, engineering, and industrial safety.

Carnegie had announced his philosophy on philanthropic giving, "The Gospel of Wealth," in 1889, and Billings guided this new stream of funds in the direction of science, motivating Carnegie to establish the scientific research organization, the Carnegie Institution of Washington (CIW), in 1902. As an original trustee of the Institution, Billings authored the plan for the organization imagined as an administrative body, primarily funding work by researchers at existing organizations, rather than as an independent and self-contained institution.[108] In its early years, the Institution funded research in wide range of disciplines, including economics and sociology under the guidance of Caroll D. Wright, and most infamously, "experimental biology," which grew to become an insidious promoter of eugenics.

Although the Carnegie Institution typically maintained Billings's vision of the organization as a funder not a builder, it did establish a few independent bricks-and-mortar research facilities. One of those facilities was the Nutrition Laboratory, built in Cambridge, Massachusetts in 1907 just adjacent to the Harvard Medical School.[109] The CIW-selected director of the Nutrition Laboratory was Francis Gano Benedict, who since 1895 had been Wilbur Olin Atwater's research assistant and protégé at Atwater's nutrition research station in Connecticut. In establishing nutrition research for the Carnegie Institution, however, Benedict shifted away from Atwater's focus on diet as an element of individual and social welfare and towards "a highly technical, apparatus-based, and specialized field of metabolism research and its clinical applications."[110] This was not an unusual shift in this period, when many activities were coming under the aegis of philanthropic organizations.

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[108] David Madsen, "Daniel Coit Gilman at the Carnegie Institution of Washington," *History of Education Quarterly* 9, no. 2 (Summer 1969): 156.

[109] "The Research Work of the Carnegie Institution," *Popular Science Monthly* 74 (Jan-Jun 1909): 516.

[110] Elizabeth Neswald, "Strategies of International Community-Building in Early Twentieth-Century Metabolism Research: The Foreign Laboratory Visits of Francis Gano Benedict," *Historical Studies in the Natural Sciences*, 43, no. 1 (Feb 1, 2013): 7-9.

Indeed, Rockefeller's monetary gifts often required its recipient organizations to shift from a reform to a technical perspective.[111]

Billings's connections with the engineering world through the *Sanitary Engineer* and his popular textbooks likely informed or aligned with Carnegie's promotion of engineering expertise and technical remediation. This was most material in Carnegie's endowment for the United Engineering Society buildings in 1904. This project, for which Carnegie provided $1,500,000, consisted of a new twelve-story building to house an extensive engineering library, lecture halls and meeting rooms, and headquarter offices for the American Society of Mechanical Engineers, American Institute of Electrical Engineers, American Institute of Mining Engineers, and an adjacent building to house an Engineers' Club.[112] Carnegie's announced his intent for the buildings in brief remarks at the buildings' dedication in 1906, saying "Here engineers can consult with one another and cultivate friendship. They can from a brotherhood, which will be a great benefit to all."[113] Although the engineers themselves were a little wary of such efforts to bind together the independent societies, most popular coverage of the project saw it as "an important means of advancing the interests of numerous engineering and quasi-engineering societies and indirectly of

[111] Hindy Lauer Schachter, "The New York School of Philanthropy, the Bureau of Municipal Research, and the Trail of the Missing Women: A Public Administration History Detective Story," *Administration & Society* 43, no. 1 (2011): 5.
[112] "Palatial Home and Workshops for New York Engineers" *New York Times*, Sep 4, 1904. The Billings connection on this project is reinforced by the arrangement made for the library at the new Engineers Building to receive "all the books on engineering now owned by the city, and originally intended for the Astor Library, in Bryant Park." This would not likely have been possible with library director Billings's encouragement and blessing.
[113] "Americans Good Mixers, Says Andrew Carnegie, Lays a Cornerstone and Lauds United Effort in Science, Mrs. Carnegie Helps, Too," *New York Times*, May 9, 1906.

promoting the solidarity and efficiency of the scientific profession of engineering" (Figure 4.10).[114]

The Engineers Building in turn became home in 1910 to another Carnegie-supported organization, the American Museum of Safety. The museum, founded as the American Museum of Safety Devices and Industrial Hygiene in 1907 by "social gospel" movement preacher Josiah Strong and reformer and social scientist William Tolman, was originally aimed at reforming the "social economy," its supporters hoping the museum's exhibits would not only address the growing number of industrial accidents (and lawsuits) and but also begin to heal what they saw as the damage done to the social contract by the disruptive forces of industrialization and immigration. Through exhibits promoting "safety" they sought to quell potential dissent and social disintegration. With the support of industrialists and social reformers, the fledgling museum mounted popular demonstrations of various machine safeguarding devices and sanitary equipment in rented quarters in central Manhattan. With its move to the Engineers Building, the museum was able to expand its program with public lectures and special meetings, and with an annual gift of $5,000 from Carnegie between 1911 and 1919, it enlarged its publicity efforts with new pamphlets and books on various safety topics. The institution, now renamed simply

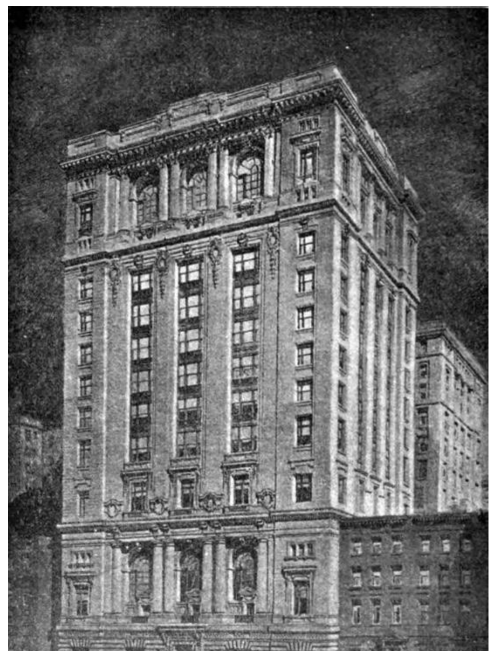

Figure 4.10 Drawing of the Engineers Building, New York City, 1906. Published in *Popular Science Monthly*, June 1906.

114 "A Division of the Carnegie Gift Suggested," *Engineering News* 51, no. 6 (1904): 132; "The Engineering Building of New York City," *Popular Science Monthly* 68 (1906): 567.

the American Museum of Safety, embodied much of Carnegie's philosophy, stressing individual responsibility and social stability. Its objective was "social engineering" more than "social economy."[115]

In this chapter we saw how changes in ventilation theory were tied to problems in the workplace and research programs ultimately aimed at worker productivity. These concerns embedded in scientific research that reframed the problem from one of air to one of heat, essentially invalidating the embodied knowledge of the workers who experienced these conditions. With new funding from philanthropic sources, this science expanded and drew in engineering practice to embed these propositions into material technologies. This is biopower at work.

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[115] Ross Wilson, "The Museum of Safety: Responsibility, Awareness and Modernity in New York, 1908-1923," *Journal of American Studies* 51 (2017): 915, 918, 923-924.

# Chapter 5. The Philanthropy of Engineering: Laboratories and the Heat of Work

When ventilating engineer Dwight D. Kimball addressed the American Academy of Political and Social Science on the topic of "Ventilation and Public Health," he was sure to include an economic analysis. One insurance company, he asserted, paid nearly $800,000 a year just for death claims on account of tuberculosis alone. This was wasteful, Kimball implied, because tuberculosis was "known to be preventable, principally by the use of plenty of fresh air." Putting the issue into even broader context, Kimball summoned Yale economist Irving Fisher, repeating Fisher's claim that "It has been conservatively calculated that eight years could be added to the normal period of human life by merely securing reasonably pure air, water and milk."[1]

This was good news for ventilating engineers, for Fisher's endorsement not only provided a readymade cost-savings argument to promote to potential clients, it also imbued their work with national significance as part of the emerging resources conservation movement. Fisher's chapter on "national vitality" for Gifford Pinchot's 1909 National Conservation Commission Report had outlined much of the thinking on "human conservation" within the movement, and later provided a basis for Roosevelt's later Public Health Act of 1912. Fisher's model of public health echoed not only Roosevelt's personal program for the self-fortifying "strenuous life," but also the conservation movement's preoccupation with efficiency and prevention of waste. For Fisher, economic waste did come from the unnecessary mortality of disease and industrial accidents, but more significantly it came from "undue fatigue." In Fisher's calculation, even "relatively slight

[1] D.D. Kimball, "Ventilation and Public Health," *The Annals of the American Academy of Political and Social Science*, 37, no. 2 (Mar, 1911): 214. Note that Fisher in turn was addressing the Association of Life Insurance Presidents.

impairment of efficiency due to overfatigue" set off an insidious pattern of effects. First came fatigue, "then 'colds,' then tuberculosis, then death."[2] A key prerogative of Fisher's concept of human conservation then was prevention of industrial fatigue. Certainly, Fisher himself also supported workers' compensation and more strenuous industrial safety laws, but in his economy, prevention and public health improvements were a less fractious way to address the worst effects of industrial life in a country that constitutionally limited governmental intervention in such matters.[3]

Similar beliefs in the redeeming power of efficiency and prevention informed the agendas of local charitable organizations, which often funded programs in social, medical, and scientific research. This was the case especially in New York City, where the Association for Improving the Condition of the Poor (AICP) had long promoted "scientific philanthropy" as a method for rationalizing charitable giving and social reform. In the early years of the twentieth-century, the AICP's gospel of efficiency led some of its members to form in 1906 the Bureau of Municipal Research, an organization with the mission to research methods for making municipal government more "rational" and efficient, the exact opposite of how the Bureau's first director, William H. Allen, and the AICP imagined the persisting patronage system to be.[4]

As it had since the days of John H. Griscom, the AICP and now the Bureau of Municipal Research promoted "preventive health work" and campaigned for intervention

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[2] Irving Fisher, *Bulletin 30 of the Committee of One Hundred on National Health, Being a Report on National Vitality: Its Wastes and Conservation* (Washington DC: Government Printing Office, 1909), 68 quoted in Ian Tyrell, *Crisis of a Wasteful Nation: Empire and Conservation in Theodore Roosevelt's America* (Chicago; London: University of Chicago Press, 2015), 178.

[3] Tyrell, *Crisis of a Wasteful Nation,* 173-188. It must be noted that the human conservation movement at times overlapped in terms of supporters and ideas with the burgeoning eugenics movement. Tyrell makes the case that while there were some shared ideas, the "progressive" human conservationists believed that concerted efforts towards self-improvement could ameliorate some of one's inherited weaknesses, where the "conservative" eugenicists saw one's hereditary destiny as immutable.

[4] Bruce D. McDonald, "The Bureau of Municipal Research and the Development of a Professional Public Service," *Administration & Society* 42, no. 7 (2010): 817.

by the Department of Health in the Board of Education-controlled public schools. These efforts intensified as the AICP and the Bureau saw opportunity in the tremendous amounts of funding becoming available through the new philanthropic sources. Yet the philanthropists were not yet on the same page. Thus when William H. Allen addressed the same meeting of the American Academy of Political and Social Science as Kimball, he complained that "among the world-famous gifts of Mr. Rockefeller and Mr. Carnegie, which together total nearly $350,000,000, not one dollar has been given specifically for furthering the administrative use of health knowledge already possessed, whether by experts or by the public."[5] Allen did acknowledge these philanthropists had given nearly $10,000,000 "for hospitals and medical research," but he did not recognize that Carnegie had indeed been addressing a version of health improvement, it was just that he was doing this through programs aimed at advancing engineering and science. Yet in funding the Carnegie Institution of Washington, the Engineering Society of New York, and the American Museum of Safety, Carnegie, like the AICP, advanced technical expertise and scientific knowledge as the remedy for social problems. In the New York Commission on Ventilation, these two approaches—the AICP's focus on efficiency and vitality and Carnegie's support of engineering and science—came together.

This chapter describes the work of three centers critical in the construction of scientific knowledge about airs and working bodies. Although the establishment of these three laboratories, the "experimental plant" of the New York Commission on Ventilation; the "psychrometric chamber" of the U.S. Bureau of Mines in collaboration with the U.S. Public Health Service and the American Society of Heating and Ventilating Engineers; and the Ventilation and Illumination Laboratory at the Harvard School of Public Health in

[5] William H. Allen (Director Bureau of Municipal Research), "Health Needs and Civic Action" *The Annals of the American Academy of Political and Social Science*, 37, no. 2 (Mar, 1911): 247.

collaboration with the Fatigue Laboratory at the Harvard Business School occurred within a relatively short period, from 1913 to 1927, their research activity occurred sequentially. In following the subjects of air and heat through this series of laboratory spaces, struggles between workers, reformers, and employers come into relief. The removal of research from that had before occurred in mine shafts and factory floors and its installation in laboratory spaces allowed social conflicts to be worked out in the purportedly more "neutral" spaces of the lab, but as sociology of science scholars remind us, the lab is never neutral territory. It is a confined space in which certain ideas are admitted and others are excluded. Certain variables are considered and others are not, and the work of these three labs reveals growing awareness and concern about workplace contaminant exposure, which was sometimes addressed and sometimes not. Nonetheless, the new knowledge that emerged from these laboratories also served as new endorsement for particular forms and configurations of technology.

Gail Cooper argues that the present-day idea of "comfort" as quantified psychological satisfaction emerged from conflict between physiologists and engineers over ventilation in New York schools. She contends that the heating and ventilating engineers' professional society (the American Society of Heating and Ventilating Engineers, or ASHVE), in the face of evidence reported by the New York Commission on Ventilation that appeared to significantly undermine their professional claims, scrambled to reframe their professional purview. To do this, the engineers recruited their own experimental science to change the narrative from health to comfort, from air to heat. In 1919, they opened their own laboratory housed at the U.S. Bureau of Mines to study and define the physical properties of air (temp, humidity, air movement) that made it *comfortable*, not the chemical properties that made it healthy. This was followed by the society's establishment between 1916 and 1923 of the "Comfort Chart" that is still used today.[6]

While the chronological sequence of these events is accurate, there is more to the story than the engineers—the actors at the center of Cooper's study—reconstruct in their telling of events. It is the case that at the 1911 meeting of ASHVE members, a paper by Dr. W.A. Evans (read in his absence) did question the credibility of the then current volumetric standards of air for ventilation and instead called for a revised standard that considered dust levels, temperature, humidity, and odors, not just carbonic acid levels. However, the engineers were not surprised, indeed many of them questioned the standard themselves. What the next speaker, Dr. Luther Gulick, formerly the director of physical training for the New York City public schools, offered was reassurance that a physiological standard was within sight. In fact, much research had already been done, and new theories were available.

Gulick, who by this time was the director of the Russell Sage Foundation's child hygiene program, presented a model for space conditioning based on the work of British physiologist Leonard Hill, who in 1911 was a lecturer in physiology at London Hospital but soon after became the Director of Applied Physiology of Britain's newly formed Medical Research Committee.[7] Much of Hill's interests, research, and theories overlapped with those of John S. Haldane. This is not surprising, as Hill and Haldane worked as assistants together in the physiology lab at Oxford, and although they did not appear to collaborate directly, they frequently cited each other's work.[8] They also served alongside

[6] Cooper, *Air-conditioning America*, 51-79.
[7] The Medical Research Committee was founded in 1913 with the mandate to distribute research funds allotted by the National Insurance Act of 1911.
[8] Austin Bradford Hill and Brian Hill, "The Life of Sir Leonard Erskine Hill FRS (1866-1952)," *Proceedings of the Royal Society of Medicine* 61 (Mar 1968): 312.

each other as expert advisers to many governmental inquires, most recently the Departmental Committee on Humidity and Ventilation in Cotton Weaving Sheds that had endorsed Haldane's ideas about ventilation, heat and humidity.

Hill shared Haldane's and others' contention that bad indoor conditions were caused by the physical properties of the air not its chemical composition, but because of Hill's particular areas of expertise in physiology, he focused particularly on the temperature, variability, and motion of the air. Hill's early work examined the circulatory system and thus he explained his theories of good air by reference to blood and skin. Overheated air drew blood to the skin and away from the brain and muscles and thus caused mental and bodily fatigue.[9] Conversely, cool air accelerated the heart and respiration, sent more blood to the muscles, and increased a body's output of energy.[10] Critical to Hill's formulation was that the air temperature and motion be variable, for as Hill saw it, the "inflow of sensations keeps us active and alive and all the organs working in their appointed functions." Air acted "on the skin and through it braces the whole body. The changing play of wind, of light, cold and warmth stimulate the activity and health of mind and body."[11]

From Hill's theory Gulick constructed an idea of good air and an appropriate ventilating system based on a distinction between "fresh" and "pure" air. In Gulick's definition, "fresh air" was "air that is cool, in motion, free from odor." In contrast "pure air" was "normal air, outdoor air, having the normal percentage of oxygen and carbon dioxide, nitrogen and so on." Existing ventilating systems were clearly capable of keeping

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[9] Luther Gulick, Discussion following "Standards of Ventilation" by W.A. Evans, *Transactions of the American Society of Heating and Ventilating Engineers*, 17 (1911): 145.
[10] Leonard Hill, "Stuffy Rooms" *Popular Science Monthly* 81 (1912): 377.
[11] Hill, "Stuffy Rooms," 375.

the air pure, Gulick allowed, but “they do not and cannot automatically keep it also fresh.”[12] Both the standards and the systems needed adjustment.

While there may have been, as Cooper suggests, a more direct conflict in Chicago between ventilating engineers and the “open-air crusaders” for open-air schools, in New York the spirit was collaborative. The members of ASHVE voted to form a committee with the American School Hygiene Association, of which Gulick was a founding member and Theodore Roosevelt the honorary president, to investigate the ideas further as well as to consider Evans’s propositions. Reginald Bolton, then president-elect of ASHVE, considered out loud where they might get funding to forward such an investigation. He suggested that they might draw on “the great resources of the Government or of the Carnegie Institute or similar institutions,” and the matter concerned “the health of all classes of people and in every part of this country.”[13]

### LABORATORY 1: THE NEW YORK COMMISSION ON VENTILATION’S “EXPERIMENTAL PLANT”

Thus, the New York Commission on Ventilation, which appears to be a direct outcome of this discussion, did not represent a split between physiologists and engineers, but rather exemplified a close collaboration between engineers and research physiologists. This was not accidental, but instead embodied a concerted effort on the part of certain philanthropists, such as Andrew Carnegie, to recruit engineering to solve the health problems of industrial work, and political economists, such as Irving Fisher through his protégé Charles-Edward Amory (C.-E.A.) Winslow, to reconcile industrial enterprise and national vitality. Thus, in name this was a commission about air, but in practice it was a

[12] Gulick, Discussion following “Standards of Ventilation,” 145-146

[13] Reginald P. Bolton, Discussion following “Standards of Ventilation” by W.A. Evans, *Transactions of the American Society of Heating and Ventilating Engineers*, 17 (1911): 139.

commission about human efficiency and fatigue, and counter Cooper's telling, the associated technological investigation was not driven primarily by improvements to industrial processes, but by ideas about improvements to workers' bodies.

Although the instigator of the discussion at ASHVE, Luther Gulick, worked for the Russell Sage Foundation, the funding for the Commission on Ventilation ultimately came as a small portion of a $750,000 gift from Memorial Fund Association to the AICP, which implemented the project.[14] Having apportioned $50,000 for the "investigation of the problems of ventilation" and secured an official appointment of the Commission by the Governor, the AICP and the Memorial Fund managers requested the assistance of Livingston Farrand, then director of the National Association for the Study and Prevention of Tuberculosis and editor of the Journal of the American Public Health Association, in selecting the Commission's members.[15] As planned, the designated members represented a range of disciplines, a ventilating engineer, a physiologist, a physician, a chemist, a psychologist, and a sanitarian, so that "it might be said that this Commission represents all classes of workers interested in the subject."[16]

The Commission members convened their first informal meeting in May, 1913, before its official recognition by the Governor, but the shape of the committee may have

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[14] Daniel M. Fox, "The Significance of the Milbank Memorial Fund for Policy: An Assessment at Its Centennial," *The Milbank Quarterly*, 84, no. 1 (2006), 7. The Memorial Fund Association was founded by Elizabeth Anderson Milbank and later called the Milbank Memorial Fund. Albert G. Milbank, cousin of Elizabeth Milbank Anderson and fellow manager of the philanthropy, had been on the board of managers of the AICP since 1904. Along with another AICP member, Albert Milbank arranged for the appointment by Governor Sulzer of a commission "to assess the science bearing on ventilation policy in new school buildings."

[15] D. D. Kimball and George T. Palmer, "Experimental Laboratory of the New York State Commission on Ventilation and A Description of the First Year's Work," *Transactions of the American Society of Heating and Ventilating Engineers* 21 (1915): 135; New York Commission on Ventilation, *Ventilation: Report Of The New York State Commission On Ventilation* (New York: Dutton and Co., 1923), vii.

[16] "Final Contribution of the New York Commission on Ventilation" *The Milbank Memorial Fund Quarterly Bulletin*, 10, no. 1 (Jan 1932): 38; quote is by C.-E.A. Winslow in discussion following Kimball and Palmer, "Experimental Laboratory," 209.

begun forming soon after Gulick's presentation at the 1911 ASHVE meeting. The journal *Engineering News* published a feature in late 1912 called "A Symposium on Ventilation," collecting and reprinting four papers presented in various sessions at the International Congress on Hygiene and Demography, held in Washington DC earlier that year.[17] Three of the papers were given by future members of the Commission on Ventilation, D.D. Kimball, C.-E.A. Winslow, and Frederic S. Lee, and as Engineering News saw it, together the authors saw the purpose of ventilation as "largely a matter of controlling temperature and humidity" and its effects as primarily physiological.[18] A brief description of these three members' positions and prerogatives demonstrates the marriage of technology and physiology that defined space conditioning in the early twentieth century.

**The Cash Value of Ventilation: C.-E. A. Winslow's Revitalization of Public Health**

From early in his career the Chair of the New York Commission, Charles-Edward Amory Winslow, had proposed technological solutions to worker health problems. At the Sixth International Congress on Tuberculosis in 1908, Winslow made a case for "The Cash Value of Factory Ventilation" citing employers' cost savings in terms of reduced worker illness and absence, to the section considering the "Hygienic, Social, Industrial, and Economic Aspects of Tuberculosis."[19] Although Winslow himself was trained as a bacteriologist, it is not surprising that he would pose a technological solution. Winslow in 1908 was a recent graduate and young instructor in the sanitary engineering program at the Massachusetts Institute of Technology, and institution with an expansive view of

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[17] "A Symposium on Ventilation," *Engineering News* 68, no. 22 (Nov 28, 1912): 996-1004.
[18] The fourth paper was given by Yandell Henderson, a professor of physiology at Yale who did not become a member of the Commission, but by his close intellectual association of John S. Haldane shared many of the perspectives as those members who formed its core.
[19] C.E.A. Winslow, "The Cash Value of Factory Ventilation," *Transactions of the Sixth International Congress on Tuberculosis, Washington DC* (1908): 184-190.

engineering and its role in medicine, as Winslow described early on in a 1903 article "The Engineer in Preventive Medicine."[20] As Winslow saw it, there were two professions primarily responsible for both the control of disease and the promotion of health, "the engineer who deals with the environment and the physician who cares for the individual."[21]

Winslow thus proselytized a definition of public health shaped by his mentor at MIT, William Sedgewick, who encouraged his students to examine both "man and the environment," a shift from the environment-only public health of the nineteenth century.[22] Winslow applied these ideas to the emerging field known as "industrial hygiene," and shared these them widely in both the educational and public realms. In 1905, he was teaching the first course offered in industrial hygiene at MIT, and he offered similar courses at the College of the City of New York, where in 1910 he became an associate professor of biology. In 1909 become the director of publicity and education for the New York Department of Health and the curator of a new Department of Health at the American Museum of Natural History in New York.[23] It was likely this background and experience that made Winslow appealing as a leader for the Commission just as it made him appealing to Yale University, which in 1915 invited Winslow to lead its new graduate program in public health, a program that was the brainchild of Irving Fisher.[24]

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[20] C.-E.A. Winslow, "The Engineer in Preventive Medicine," *Public Works* 2 (1903-1904): 10. Winslow taught on of the first courses in industrial hygiene at MIT in 1905.

[21] Arthur J. Viseltear, "C.-E.A. Winslow and the Early Years of Public Health at Yale, 1915-1925," *The Yale Journal of Biology and Medicine* 55 (1982): 141.

[22] Viseltear, "C.-E.A. Winslow," 140.

[23] "Editorial: The Winslow Tradition," *Journal of Public Health Policy*, 5, no. 3 (Sep 1984), 321; Milton Terris, "C.-E. A. Winslow: Scientist, Activist, and Theoretician of the American Public Health Movement Throughout the First Half of the Twentieth Century," *Journal of Public Health Policy* 19, no. 2 (1998): 134-146; Julie K. Brown, "Connecting Health and Natural History: A Failed Initiative at the American Museum of Natural History, 1909-1922," *American Journal of Public Health* 104 (2014): 1877–1888

[24] Viseltear, "C.-E.A. Winslow," 141.

**Engineering Society: Dwight D. Kimball's Exhibition of Safety**

Soon after the Governor's announcement of the Commission in June, 1913, D.D. Kimball, the Commission's ventilating engineer member, began plans for the construction of "special rooms for physiological and psychological investigation" of various air conditions in the biology department of the College of the City of New York, where Winslow held a faculty position.[25] This was Kimball's primary responsibility on the Commission, and he brought familiarity with the latest literature relating health to ventilation as well as detailed knowledge of the latest equipment and configurations available in the field. Although it is unclear why he chose to pursue it, Kimball's awareness of the scientific and medical literature of the topic was on display in an extensive series of articles on hospital heating and ventilation in the architectural journal *The Brickbuilder* from May to October of 1909.[26] His expertise with equipment came from his work as a consulting engineer in his father's heating and ventilating engineering firm, Richard D. Kimball Co., but also his position as the chairman of the Ventilation and Heating Department of the American Museum of Safety.

Little biographical information is available for Kimball, but he appears to have joined the museum staff around 1911, and he had a formal museum affiliation by the time he presented his paper, "The Present Status of Ventilation," at the Congress on Hygiene and Demography in 1912. At the museum, Kimball was responsible not only for collecting testimony and examples of ventilation systems in place at industrial and administrative workplaces, but also for mounting a permanent working model exhibit of "a complete

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[25] Kimball and Palmer, "Experimental Laboratory,"135.

[26] D. D. Kimball, "Warming and Ventilation with Special Reference to Hospital Buildings, I-VI," *The Brickbuilder* 18 (1909): 95-98, 111-113, 141-143, 169-172, 190-191, 202-203. Kimball's literature review may have been sponsored by *The Brickbuilder*, as the journal was holding a competition for hospital design in the same year, or it may have been that Kimball was attempting to build a specialty for his firm.

ventilating plant."[27] This was not small undertaking, the exhibited system featured a seven-foot-long air washing system that promised to free the air of dust and provide "such humidification as is desired" (Figure 5.1).[28]

That an exhibit of an air-washing system was necessary suggests that it was unfamiliar to its intended audience, but its design and display addressed an ongoing campaign against industrial dust exposure by Frederick L. Hoffman, a trustee and statistician, both for the museum and for his employer, the Prudential Life Insurance Company. According to Hoffman, "foremost among the health-injurious factors in industry" was "the menace of industrial dust." This problem was worst in mines, but as Hoffman observed in his study of "the dusty trades" for the U.S. Bureau of Labor in 1908, it affected a number of industries.[29] Attention to the issue of dust and its address by ventilation was one of the chief stimuli motivating the

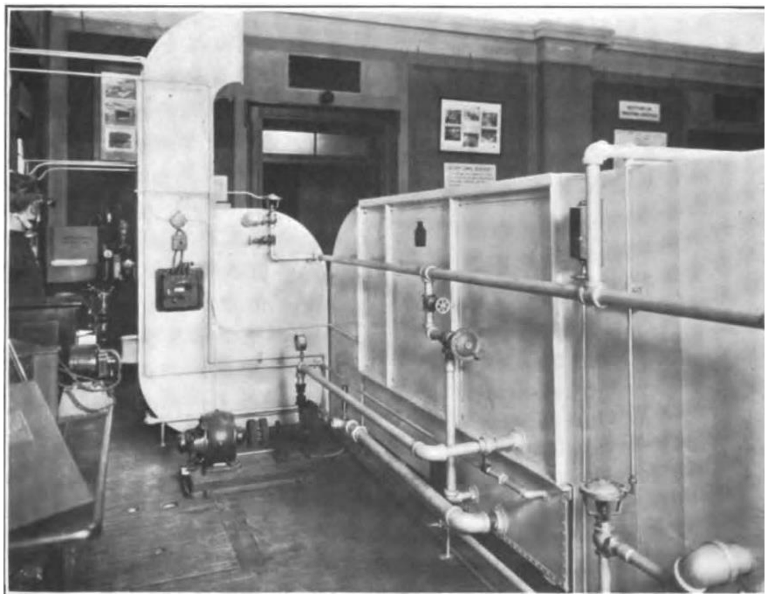

Figure 5.1 View of the ventilating plant exhibit at the American Museum of Safety, 1915.

[27] D.D. Kimball, "Practical Results with Ventilation Systems," *Safety: Monthly Bulletin of the American Museum of Safety* (June 1914): 142-143; "The Practical Value of Ventilation Systems," *Safety* (Dec 1914): 259-261.
[28] D.D. Kimball, "Ventilation Exhibit at the American Museum of Safety," *Safety: Monthly Bulletin of the American Museum of Safety* (Mar 1915): 74-76
[29] Frederick L. Hoffman, "The Mortality from Consumption in Dusty Trades," *Bulletin of the Bureau of Labor* 79 (Nov 1908); Frederick L. Hoffman, "The Dust Problem in Industry" *Safety: The Bulleting of the American Museum of Safety* (Mar 1914): 59.

establishment of Kimball's department of ventilation.[30] This issue extended to Kimball's work on the Commission on Ventilation. Sometime before 1916, the Museum of Safety formally partnered with the New York Commission on Ventilation "to find a practical and efficient method for the determination of atmospheric dust content in factories and workrooms," and in the course of study, the Commission, probably through the work of Kimball and Winslow, developed a new apparatus for collecting and sampling dust in factories.[31] This work did not make Kimball unpopular among heating and ventilating engineers, rather ASHVE elected him as president of the national organization in 1915.

### Fatigue and Efficiency: Frederic S. Lee's Metabolism of Work

Where Kimball fulfilled the engineering half of Winslow's vision for a new public health, Frederic S. Lee fulfilled the physician half and then some. As a research physiologist, Lee did not assess bodies in clinical settings, but rather in experimental settings, such as the one constructed for research on ventilation by the New York Commission. By the time Lee joined the Commission's research team, he was already prominent in the field of physiology and an established specialist in the theory of human fatigue. Lee had received his PhD in physiology from Johns Hopkins University in 1885 and had spent a postdoctoral year in Leipzig studying with Carl Ludwig. He accepted a position at Columbia University in 1891, arriving in the optimistic time of Seth Low's presidency, during which Low was actively promoting the university as a source of scientific expertise on issues of social reform.[32] Lee began his research into physiological

[30] D.D. Kimball, "The Museum's Section on Ventilation," *Safety: Bulletin of the American Museum of Safety* (Mar 1914): 65.
[31] H.C. Ward, "Determination of Standards for the Atmospheric Dust Content in Factories and Work Shops An Investigation Conducted by The American Museum of Safety" *Safety: Bulletin of the American Museum of Safety* 4, no. 7 (July-Aug 1916): 166.
[32] Richard Gillespie, "Industrial Fatigue and the Discipline of Physiology" in *Physiology in the American Context 1850–1940* edited by G.L. Geison (Springer, New York, 1987), 243.

fatigue likely around the time he achieved professorship in 1904, presenting a detailed review of the field in a 1906 lecture to the Harvey Society, which was founded just a year earlier with the mission of "the diffusion of the medical sciences by means of public lectures."[33]

Thus, Lee was happy to participate in a public-service Commission and to further his research on fatigue, which by 1913 was developing against a backdrop of conflict over the length of the industrial workday. Several labor campaigns for a limited eight-hour work day had risen up to assert some control over work patterns in the face of Taylorist "efficiency" incentives—usually seen by workers as methods to intensify and speed up—as well as to gain more time for union organizing, education, and leisure, and a means of uniting various labor groups—skilled, unskilled, native, immigrant—that were typically at odds.[34] The federal government had long avoided such labor issues, but in 1907 Congress had passed the Hours of Service Act, which in the interest of avoiding railway accidents, required eight hours of rest between sixteen-hour shifts of railroad workers, and the courts ruled in *Muller v. Oregon* in favor of the government's right to limit working hours, despite its customary non-intervention in contracts between private parties.[35]

Physiological concepts resembling fatigue had been around since Benjamin Ward Richardson's experiments with heat and muscle contraction, but Italian physiologist Angelo Mosso's book *La Fatica* (1891, English translation 1904) made the term fatigue common. The mechanisms of human fatigue were very much up for debate, and in his 1906 lecture Lee laid out his theory of fatigue. The phenomenon, Lee asserted, was a

[33] "Preface" *The Harvey Lectures Delivered under the Auspices of the Harvey Society of New York 1905-1906* (Philadelphia and London: J.B. Lippincott, 1906), np.
[34] David R. Roediger and Philip S. Foner *Our Own Time: A History of American Labor and the Working Day* (Westport, CT: Greenwood Press, 1989), 177-182.
[35] Roediger and Foner *Our Own Time*, 174

characteristic of all biological life, and it could be defined as a "depression of the total capacity for work, whatever the intensity of the stimulus." For example, in the laboratory, an isolated frog muscle, when stimulated with a small electrical charge, contracted powerfully, but after several stimulations the muscle responded with less and less intensity. Many thought there might be an analogous explanation for mental fatigue, exhibited as a reduced faculties of memory and attention, but as Lee explains, the physiological evidence was not yet sufficient. Some physiologists studying fatigue focused on the nervous system, but Lee believed the phenomenon must have a metabolic component. Previous research supported the theory that the chief source of muscular energy was carbohydrate, and Lee posited that some derangement of metabolic activity, perhaps caused by muscular overuse, produced a chemical "fatigue substance"—lactic acid and carbon dioxide were both under suspicion—that inhibited further muscle activity. Within this, Lee was optimistic that physiologists might one day find a chemical "antidote" to fatigue, but for now only rest and sleep were known to provide the "assimilation and detoxication" necessary to restore working power. Only further studies of fatigue and metabolism could overcome this limited state of human performance.[36]

By 1912, Lee's study had extended to consider "the multitude of external conditions," particularly temperature and humidity, that influenced the production of fatigue.[37] Physiologists too often overlooked the role these external factors played, Lee

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36 Frederic S. Lee, "Fatigue," *The Harvey Lectures Delivered under the Auspices of the Harvey Society of New York 1905-1906* (Philadelphia and London: J.B. Lippincott, 1906), 169-194.

37 Although Lee had delivered this paper on the effects of temperature and humidity on fatigue at the International Conference on Hygiene and Demography, it is probably not a coincidence that Lee's paper was published in the issue of the *Journal of the American Public Health Association* (APHA) dedicated to "Cold Storage and Public Health." A symposium on that topic had been held in September 1912 at the annual meeting of the APHA in Washington DC. The Hygiene and Demography conference was held in the same month in the same location, so it is likely that people attended sessions at both conferences. The cold storage discussion, introduced by William T. Sedgewick (Winslow's mentor), centered around food spoilage and the national food supply, and Lee's paper is not addressed directly in any of the editorial introductions. It is of note, however, that the editor of the journal at that time was Livingston Farrand, the

maintained, because of their over-fondness for internal mechanisms, but Lee found Max Rubner's calorimeter studies of body heat and vasodilation, J.S. Haldane's observations on high heat and humidity in mines, and Leonard Hill's arguments for cutaneous involvement to provide useful structure on which to build a theory of external conditions and fatigue.[38] To this structure Lee added his metabolic theory, informed as it was by new evidence that the phenomena of heat stroke seemed to be caused by some kind of self-produced "acute poison." That Lee's theory of metabolically created "fatigue substances" were of a chemical nature had particular significance, for it was a long-established theory that heat augmented the action of certain chemical substances, especially poisons, on "various forms of living substance," such as the heart or the motor nerves. Thus, elevated temperatures made the effects of Lee's fatigue substances more pronounced and under continuous exposure possibly toxic. As environmental temperatures went up, working power accordingly lessened, but if there was prolonged exposure to these environmental conditions, the result could be pathological.[39]

In his 1912 paper, Lee purposefully limited his discussion to extreme conditions of high temperature and high humidity, although he acknowledged that there was "a certain medium range of variation [of temperature and humidity] within which the human body is capable of performing its best work."[40] To Lee, this was a matter of common sense; "one need not be a man of science to realize this truth," he says. Yet by 1914, after the first few

figure who assisted the AICP and the Milbank memorial fund select members of the New York Commission on Ventilation.

[38] Lee cites Rubner and Haldane directly, but Hill only indirectly. Nonetheless Lee notes his concurrence with Hill by reference to fellow physiologist Theodore Hough: "when in a hot and humid atmosphere the blood vessels of the skin are dilated and overcharged with blood, the brain and spinal cord among other organs are rendered correspondingly anemic. This is sufficient of itself to account largely for the feeling of weariness, the indifference and apathy toward laboring that are then present."

[39] Frederic S. Lee, "The Effects of Temperature and Humidity on Fatigue," *American Journal of Public Health* 2 (Nov 1912): 863-870.

[40] Lee, "The Effects of Temperature and Humidity on Fatigue," 863.

months of research as part of the New York Commission on Ventilation, Lee saw purpose to the laboratory study of "the conditions of ordinary life." Although the results of the Commission's study were not yet in publishable form, Lee could say that the aim of the Commission's work was "to learn in what respects, if any, the physiologic functions and *the mental and physical efficiency* of the individual are altered by alterations in air conditions."[41]

Fatigue research embodied a number of aims and methods across a spectrum of actors. In 1908, social reformer Jane Addams and physician Alice Hamilton, both then based at Hull House in Chicago, had used fatigue theory and a purportedly fatigue-measuring instrument (the ergograph) in their attempts to make a direct link between "sweat-shop" work and illness and thus to garner scientific substantiation for reform of the piece-work system of employment (Figure 5.2).[42] Josephine Goldmark's review of fatigue research, published in 1912 as *Fatigue and Efficiency: a Study in Industry,* provided an important rhetorical grouding for the winning side in the *Muller v Oregon* case.[43] While Lee supported those

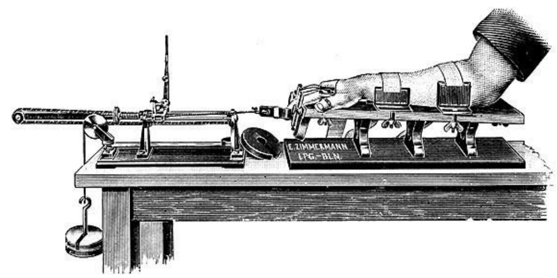


Figure 5.2 An ergograph, 1898. Angelo Mosso developed this instrument to measure muscular contraction in repetitive motions. Credit: Max Planck Institute for the History of Science Virtual Laboratory.

41 Frederic S. Lee "Laboratory Experiments with Air," *Heating and Ventilating Magazine* 11, no. 11 (Nov 1914): 23, italics added.

42 Jane Addams and Alice Hamilton, "The 'Piece-Work' System as a Factor in the Tuberculosis of Wage-Workers," *Transactions of the Sixth International Congress on Tuberculosis, Washington DC* (1908): 139.

43 Gillespie, "Industrial Fatigue," 241; Roediger and Foner *Our Own Time*, 174. Roediger and Foner argue that although some have regarded Muller v Oregon as radical or leftist, it was instead a measure of conservative reform. The arguments "rested on a need to institute moderate reforms to forestall demands for more extreme measures, on perception of women as biologically inferior beings whose morals a capacity for motherhood needed protection, and on the view that greater efficiency in fewer hours would benefit employers. Goldmark's book, they argue, was also not the antidote to Taylorism as some have contended. By the time of the publication of Goldmark's book by Russell Sage Foundation in 1912, it included "an homage to Taylorism."

projects, he believed that only physiological science in the laboratory could provide the ultimate solution. If one could accurately determine the exact physiological basis for fatigue, one could simply live and work by those biological limits or develop a chemical or physical remedy for it. It was the technocratic dream that science would find the right answer, no struggle between workers and managers was necessary. Through Lee, space conditioning became part of that dream.

### *Results of the First Years*

The construction of the Commission's experimental plant occupied the first four months of D.D. Kimball's time as part of the research group (Figure 5.3). The result of his work was a 1,150 cubic foot "ventilation chamber" in which one to six people could be "confined for any desired number of hours." The room was equipped with a custom air washer, fan blowers, heating elements, a drying pan, and a bevy of thermostatic and hygrostatic controls.[44] In the "observation room" research subjects would perform either mental or physical tasks under a "definite combination of air conditions." Lee's research plan imagined that the investigators would collect various quantitative measures, such as bodily temperature, skin sensitivity, pulse and blood pressure, respiratory exchange, as well as "the size of the dead space of the air passages, carbohydrate and protein metabolism, the production of heat, the duration of digestion, and various phenomena of the urine" in order

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[44] Kimball and Palmer, "Experimental Laboratory," 141-147. In the drying pan, moisture was removed from the air by calcium chloride.

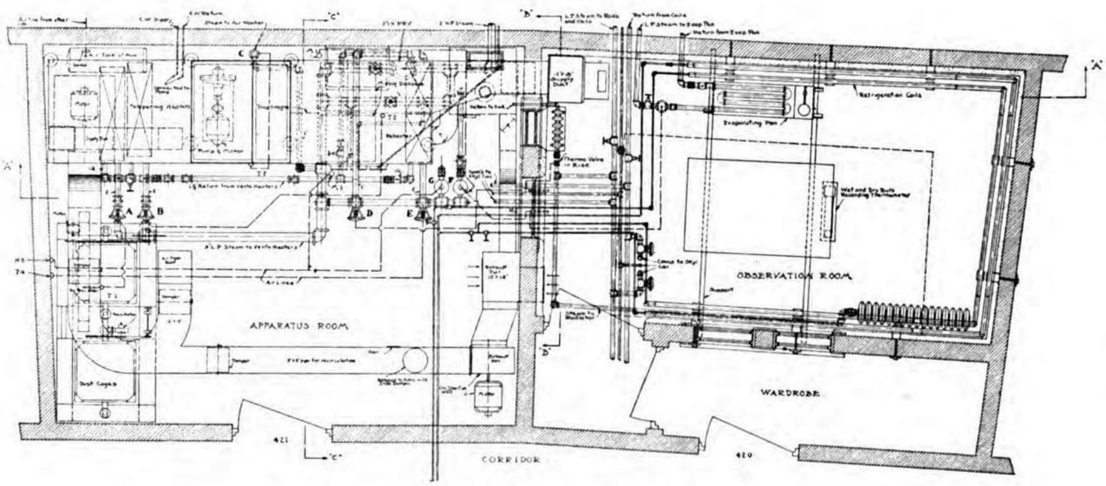


**Fig. 1. Plan of Experiment Rooms.**

Figure 5.3 Plan of experiment rooms, New York Commission on Ventilation, 1915.

"to learn in what respects, if any, the physiologic functions and the mental and physical efficiency of the individual are altered by alterations in air conditions."[45]

After two weeks the team decided that the original design of the experimental plant was "handicapped." They felt they did not have enough control over the conditions in the experimental chamber, so they made a number of alterations, insulating the observation room with two inches of cork and a half inch coating of cement plaster, adding 4 ½ ton refrigerating plant and a humidifying pan, and completely insulating all of the duct work and critical equipment.[46] This need for these changes was not so surprising to Kimball because the researchers wanted very refined control of the room conditions, and in a room so small, every little thing, including the research subjects themselves, had a serious effect on the room's temperature and humidity.[47]

[45] Frederic S. Lee "Laboratory Experiments with Air," *Heating and Ventilating Magazine* 11, no. 11 (Nov 1914): 23.
[46] Kimball and Palmer, "Experimental Laboratory," 157.
[47] Kimball and Palmer, "Experimental Laboratory," 140-141.

The request for these alterations probably came Lee, for based on his list of physiological variables that he expected they would collect data on, he seemed to be thinking of research typically done in a respiratory calorimeter like Benedict's at the Carnegie Nutrition Lab. Indeed, in the Commission's final report, they cite Benedict as having conducted "one of the most important pieces of experimental work ever carried out in this field."[48] Benedict, in turn had credited "the unusual control of thermometric and hygrometric conditions" in his respiration calorimeter, which had allowed him to "preclude the conditions of temperature and humidity ordinarily present in poorly ventilated rooms."[49] The team must have reached a compromise in the end, for as Winslow reasoned, they needed refined control because the effects they wanted to observe "would naturally be slight," but on the other hand, these were not in fact supposed to be calorimeter experiments, but rather with research on the effects of ordinary atmospheric conditions upon the human body. Thus it was not absolutely essential that the conditions in the observation room "be regulated within closer limits than those attainable under the best practical conditions."[50] Nonetheless, because they could control the variables of temperature and humidity, these became the controlling variables.

Once the facility was up and running, the team ran a number of experiments with over a hundred different human subjects, both men and women. The participants spent "periods approximating a day or a half day of factory work" in the observation room. Under controlled variations of the room's temperature and humidity the subjects were asked to complete a variety of mental tasks (multiplication, color naming) and physical activities

[48] New York Commission on Ventilation, *Ventilation,* 9.
[49] F.G. Benedict and R.D. Milner *Experiments on the Metabolism of Matter and Energy in the Human Body,* U. S. Department of Agriculture, Office of Experiment Stations, Bulletin 175 (1907), 261.
[50] C.-E.A. Winslow, "The experimental plant of the New York State Commission on Ventilation," *Proceedings of the Society for Experimental Biology and Medicine* 12 (1914-1915): 111-112.

both heavy (riding a stationary bicycle) and light (typewriting) (Figure 5.4).[51] Throughout the tests, the researchers measured the accuracy of the subjects' performance, took physiological measurements, and asked the subjects to record their opinion "as to the state of comfort."[52]

At the end the first year of research, the Commission team had reached few conclusions, but by early 1916 Winslow and Lee had begun sharing their results. The two men had differing opinions as to the action that should follow from their Commission's findings, but their interpretation of the research data reveals a subtle but profound meaning in this and future definitions of the concept of "comfort." As Winslow put it, the experiments provided very clear evidence that higher temperatures (74° - 86° F) produced a "marked disinclination to any form of physical work, even such light work as typewriting." (Figure

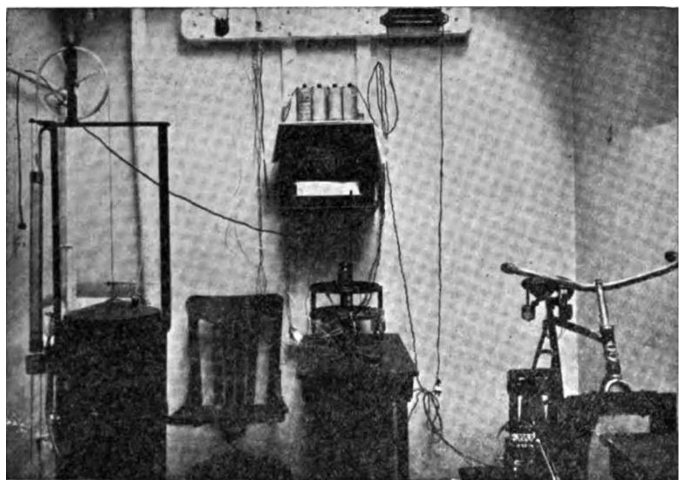

Figure 5.4 Observation Room, New York Commission on Ventilation, 1915. At upper center is a body temperature recorder, at right is a bicycle ergometer, at left is a spirometer used to collect and measure exhaled air.

[51] C.-E.A. Winslow, "Effect of Atmospheric Conditions upon Fatigue and Efficiency," *Monthly Review of the U.S. Bureau of Labor Statistics* 4, no. 2 (Feb 1917): 285-286.

[52] Kimball and Palmer, "Experimental Laboratory," 184. The rating scale for comfort was presented as (in this order):

5. I feel as comfortable as I ever do.
3. I feel about as I usually do at the close of an afternoon of hard mental work.
1. I feel as uncomfortable as I would with a severe headache or an attack of the grippe.
4. My condition is half-way between 3 and 5
2. My condition is half-way between 1 and 3.

5.5)[53] By extension then, comfort described conditions that evoked an *inclination to do work*. Thus, this form of space conditioning technology, at least in its origins, was not intended for sensory pleasure, it was meant for business.

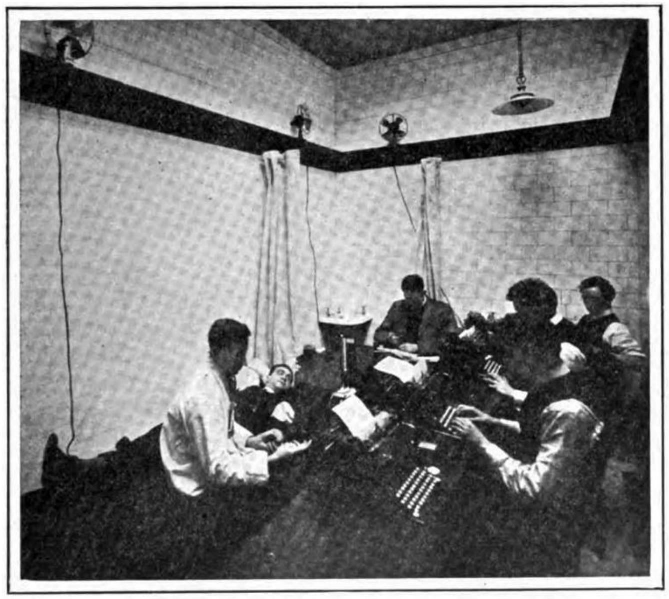

Figure 5.5 Research subjects performing mental tasks in the Observation Room, 1915. At left, a physiologist takes the pulse of the reclining subject.

Winslow and Lee disagreed about whether the environmental conditions ultimately affected the psychological will or the physical ability to do work. Winslow saw the results through a Taylorist lens, focused on will and incentive as drivers of work. The critical result, then, was that at higher temperatures the subjects chose idleness over a work, even when they were offered a monetary incentive. This was less often the case at lower temperatures. From this, he could conclude, "the effect of heat upon efficiency, unless the influence is a prolonged one, is exercised rather upon the will than on the power to work."[54] Lee disagreed. He was sure that there was a physiological basis for this effect, and that the observed disinclination must be linked to some physical inability to do work, not a mental inability to motivate oneself.[55] Lee thus believed that additional research, especially with

53 Winslow, "Effect of Atmospheric Conditions," 290.

54 Winslow, "Effect of Atmospheric Conditions," 286. Winslow describes in detail the work of Ellsworth Huntington, the Yale geographer who claimed in a feat of climatic determinism that cooler climates made humans more productive, but he notes that the work of the Commission is different, because Huntington's conclusions related "to general outdoor conditions, not to those which exist in the factory itself." Huntington's philosophy and work are discussed in detail in Ackermann, *Cool Comfort*, 17-26.

55 "The Real Meaning of Fresh Air" *Journal of the American Medical Association* 67, no. 14 (Sep 30, 1916): 1023.

animal subjects was needed before any final conclusions about temperature and fatigue could be made. Winslow went ahead and made a direct link between factory ventilation and productive capacity. Securing a means to prevent overheating was "one of vital importance to all who are interested in minimizing fatigue and increasing production in American industry."[56]

### War, Munitions, and the Double Meaning of Fatigue

Entry into World War I may have interrupted the work of the New York Commission on Ventilation, but it ramped up concern about industrial fatigue, as it was now a concern not just for individual companies, but also for national governments tasked with coordinating the industrial productivity deemed critical to military success. A subsequent upsurge in fatigue research of course came first in Britain, where soon after entry into the war in 1914, the government suspended many union workshop practices and lifted limitations on the length of the working day.[57] The following year, the British government turned to scientists to address the potential problems of worker fatigue, establishing the Health of Munitions Workers Committee (HMWC) and staffing it with multiple research physiologists, including Leonard E. Hill. The U.S. followed a similar path in 1917, forming the Committee on Industrial Fatigue as part of the coordinating Council of National Defense.[58] The committee was chaired by a representative of industry, Thomas Darlington, physician to the American Iron and Steel Institute, but it also included Frederic S. Lee, Josephine Goldmark, David L. Edsall, then a professor of clinical medicine

[56] Winslow, "Effect of Atmospheric Conditions," 290.
[57] Gillespie, "Industrial Fatigue," 244-245.
[58] After the war, the Health of Munitions Workers Committee became the Industrial Fatigue Research Board.

at Harvard, and J.W. Schereschewsky, who oversaw industrial hygiene studies for the U.S. Public Health Service.

Wartime productivity was an essential impetus to ventilation and fatigue research in these years, but there was a secondary, often undisclosed, but perhaps more fundamental reason that governments were concerned with fatigue, unknowns about the health effects of working with tri-nitro-toluene (TNT). This explosive was relatively new in the munitions industry and had been introduced because many considered it less toxic than other explosives then currently in use. Despite an extensive initiative in Britain beginning in 1916 to censor information about the poisonous effects of TNT in the press, workers nonetheless heard rumors and were sometimes refusing to work in factories that produced TNT-packed shells (Figure 5.6). The authorities made some basic recommendations for increased factory ventilation and dust removal, but under the program to suppress knowledge about dangers of TNT work, the HMWC established guidelines to identify and remove workers before the worst effects could be witnessed in the factory. These guidelines hinged on the identification of so-called ‘susceptibles,’ those workers who could be deemed in a state more sensitive to the effects of TNT. The characteristics of a


Figure 5.6 Munitions workers, National Filling Factory, Chilwell, Nottinghamshire, 1917. Credit: Imperial War Museum © IWM (Q 30014)

‘susceptible’ were various and poorly defined, but critical factors were malnourishment and over-fatigue.[59]

Given these motivations to reduce potential for fatigue, the HMWC pursued new fatigue research, and the results of this endeavor shifted emphasis to factory environments. This shift is perhaps most pronounced in the environmental theory of Leonard Hill. Prior to the war, Hill had promoted exposure to cool outdoor breezes for what he saw as their healthy bracing variability; they acted as a preventive measure for tuberculosis and in turn a scientific justification for housing reform and the building of garden cities.[60] However, with the advent of the war and his subsequent membership in the Health of Munitions Workers Committee, Hill applied his theory of heat stagnation to industrial work. In Hill’s model, the relative warmth of a factory increased the flow of blood to the skin, making the body work too much. If one cooled the environment, fatigue would be resolved. Indeed as Hill put it “cool surroundings are of the utmost importance to stimulate men to work.”[61] Hill even fashioned in 1916 an instrument, the “kata” thermometer, to test the capacity of the air to cool the human body by radiation, convection, and evaporation.[62]

Translated into the post-war setting, this physiological model of fatigue allowed factory owners a scientifically endorsed solution to labor problems that re-emerged after the cessation of wartime hostilities. If heat was a primary cause of fatigue, not overwork itself, the problem was fixable with a technological solution. Lee’s Committee on Industrial

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59 Antonia Ineson and Deborah Thom, “T.N.T. Poisoning and the Employment of Women Workers in the First World War,” in *The Social History of Occupational Health,* edited by Paul Weindling (London: Croom Helm, 1985), 89-93.

60 Leonard Hill, “Report on Ventilation and the effect of Open Air and Wind on the Respiratory Metabolism,” *Reports to the Local Government Board on Public Health and Medical Subjects* no. 100 (London: H.M. Stationery Office, 1914), 7.

61 Leonard Hill, *Atmospheric Conditions and Efficiency. A Lecture given in the Dept. of Industrial Administration, College of Technology, Manchester, 1 April 1919*. (Manchester: University Press, 1919).

62 C.-E.A. Winslow, “The Kata Thermometer as a Measure of the Effect of Atmospheric Conditions upon Bodily Comfort,” *Science*, New Series, 43, no. 1116 (May 19, 1916): 716-719.

Fatigue in their report published only near the end of the war in 1918 likewise emphasized environmental adjustments over limitations to working hours or overtime.[63]

Thus, although the experimental work of the New York Commission on Ventilation paused in 1917 as its members participated in national war efforts, its primary propositions gained traction during the war. Moreover, its concepts and experimental approaches informed ventilation research at the next laboratory under consideration, the ASHVE Laboratory at U.S. Bureau of Mines, where after the metaphorical dust of war had settled, the literal dust of mines remained a problem.

### LABORATORY 2: THE BUREAU OF MINES / ASHVE "PSYCHROMETRIC CHAMBER"

In her book *Air-Conditioning America,* Gail Cooper made much of the purported autonomy of the ASHVE laboratory, located at the U.S. Bureau of Mines Research Station in Pittsburgh. The engineers, she posits, frustrated by the confounding research of the New York Commission on Ventilation, took science into their own hands and established their own laboratory for the purpose of establishing their own standards. Certainly the members of ASHVE had their own prerogatives, but the engineers also served as useful research partners to the physiologists at the Bureau of Mines, in that the engineers had the skills to assemble and operate controlled laboratory environments. A second look at the research carried out at the Bureau of Mines suggests that the collaboration between the Bureau of Mines and ASHVE was much closer than Cooper implies.

The New York Commission on Ventilation's work clearly informed the collaborative work of the ASHVE lab. In describing the physiological work of the ASHVE lab to members of the society in 1923, the research team noted the rationale of their current

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[63] Committee on Industrial Fatigue, "How Industrial Fatigue May Be Reduced," *Public Health Reports* 33, no. 33 (Aug 10, 1918): 1347-1355.

inquiry, namely to find the "best method available for measuring the endurance, consistent with health, of those exposed to abnormal environmental conditions" and to determine "whether it is possible to differentiate between a disinclination to do work under unusual temperature conditions and actual inability."[64] This echo of Winslow's conclusion as well as Haldane's 1905 observations implies that the program at the Bureau of Mines was in part fatigue research, even if they did not call it fatigue.

So perhaps there is reason to ask what the Bureau of Mines wanted from ASHVE instead of considering the engineering association's research agenda in isolation. In describing the lab's research tasks in a 1922 brochure, the ASHVE committee on research notes the Bureau's material and intellectual support.[65] By cooperative agreement with the Bureau, it "provided the [ASHVE] Laboratory with a building which cost over one-half million dollars, which is equipped with the best apparatus obtainable." Also available to the ASHVE research team was "the best talent in this country, among the scientists who are employed in the Bureau of Mines."[66] If the Bureau was willing to give so much to

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[64] W.J. McConnell, F.C. Houghten, and F.M. Phillips, "Further Study of Physiological Reactions, Practical Application of Data Developed in Laboratory Tests on Effect of Various High Temperatures and Humidities in Still Air*" Journal of the American Society of Heating and Ventilating Engineers* 29 no. 6 (Sep 1923): 507-513.

[65] Although it is unclear as of yet through what channels ASHVE and the Bureau of Mines partnered, in 1917 the ASHVE committee on research had recommended that they partner with the U.S. Bureau of Standards for "testing and rating heating apparatus" and they seek "cooperation" of the Carnegie Institute or the Russell Sage Foundation in establishing the lab. Their model was the $15,000 of funding that the American Society of Refrigerating Engineers had successfully convinced Congress to appropriate to the Bureau of Standards for "conducting certain tests of refrigeration." When ASHVE approached the Bureau of Standards, however, that agency had told them they did not have any funds available. The organization was thus casting about for an institutional partner. The members thought it was important to have the imprimatur of an unbiased-appearing institutional partner and worried about the optics of the engineers and manufacturers funding their own research. This last point was the organization's hesitation to use Pierce Foundation funding for the research facility because it came from the estate of John B. Pierce, the founder of American Radiator Company. "Report of Committee on Research Bureau," *Transactions of the American Society of Heating and Ventilating Engineers* 23 (1917): 322-332.

[66] American Society of Heating and Ventilating Engineers*, Research laboratory of the American Society of Heating and Ventilating Engineers, operated at Pittsburgh, Pa., in cooperation with the U.S. Bureau of Mines* (New York: Committee on Research of the American Society of Heating and Ventilating Engineers, 1922), 7. In 1923, the director of the ASHVE lab noted that the collaboration with the Bureau of Mines was

ASHVE, it makes sense to ask what the Bureau gained through a partnership with the engineers.

A series of tragic mine explosions encouraged the creation of the U.S. Bureau of Mines in 1910 as a section of the Department of Interior, with the mission to "conduct inquiries and investigations calculated to increase health, safety, economy, and efficiency" in the mining and minerals industries in the U.S.[67] At the prompting of Frederick L. Hoffman, who, as he was at the American Safety Museum, was concerned about the prevalence of lung disease among the "dusty trades," the Bureau of Mines in 1911 formed a partnership with the U.S. Public Health Service to investigate the "sanitary conditions surrounding metal mining under ground."[68] In 1914, at the prompting of a local branch of the Anti-Tuberculosis Association in the lead-zinc mining district around Joplin, Missouri, the Bureau deployed a research team—one mining engineer, Edwin Higgins, from the Bureau and one medical specialist, Anthony Lanza, from the Public Health Service—to the area to investigate the high rates of tuberculosis and lung disease among the miners. As Haldane had found in the tin mines of Cornwall, the recent introduction of machine drills at Joplin had significantly increased dust exposure in the mines. However, there was another problem in addition to dust exposure. Although the new technologies extracted ore more quickly from the earth, there was not a parallel technology to load and move that ore

a "cooperation that leaves nothing to be desired. Everything is given to us that we want; mathematicians, photographers, computers, investigators of all sorts, instrument makers, skilled mechanics— in fact, anything that we ask for, appears as if produced by the magic of Aladdin's lamp" F. Paul Anderson, "Address of Director Anderson on the Research Laboratory" *Transactions of the American Society of Heating and Ventilating Engineers* 29, no. 2 (March 1923): 112.

[67] Fred Wilbur Powell *The Bureau of Mines: Its History, Activities, and Organization* (New York; London: D. Appleton and Company, 1922), 1.

[68] Board of Directors, National Association for the Study and Prevention of Tuberculosis, Minutes, 15 April 1911 quoted in Alan Derickson, "Federal Intervention in the Joplin Silicosis Epidemic, 1911-1916" *Bulletin of the History of Medicine*, 62, no. 2 (Summer 1988): 237. It can be noted that Livingston Farrand, who was essential in selecting the members of the New York State Commission on Ventilation, assisted Hoffman in urging the partnership between the Bureau of Mines and the Public Health Service.

to the surface. Thus, mine operators introduced work "incentives," essentially a piecework system, to encourage workers to keep up with the pace of the new technology. With wages kept low, mine laborers had to work intensely with few pauses if they wanted to make ends meet.[69]

As Higgins and Lanza saw it, "overwork and consequent exhaustion are the great contributing causes of tuberculosis among working people," and this is why a section on "overwork" appears in the section on "sanitary conditions underground" in Higgins and Lanza's report summarizing their investigation in Joplin. However, there seemed little that could be done about overwork, because as Higgins and Lanza concluded, there was "seemingly no prospect of any change in the piecework system, as it suits all concerned." The only "undesirable factor" that could be eliminated in this case was the short, 20-minute lunch period that the miners usually took. The mining law of Missouri provided for an hour-long break at lunch, and Higgins and Lanza recommended that the rest period be enforced. In their eyes, there was "no good reason why the miners should not have an adequate rest in the middle of their shift," not recognizing that it was not likely that workers were being prevented from taking a longer break, but rather that the system of wages was encouraging the worker to cut the break short.[70]

Plans for improvements to the Bureau of Mines Research Station at Pittsburgh began while the Joplin survey was underway. An appropriation of $500,000 for the new buildings at the Pittsburgh Experiment Station of the Bureau of Mines was made by Congress in 1913, and with a contribution of $25,000 from the state of Pennsylvania, planning for the new edifice began. The setting of the new buildings was critical to its

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[69] Derickson, "Federal Intervention," 241.
[70] Edwin Higgins, A.J. Lanza, F.B. Laney, and George S. Rice, *Department of Interior, Bureau of Mines Bulletin 132: Siliceous Dust in Relation to Pulmonary Disease Among Miners in the Joplin District* Missouri (Washington DC: Government Printing Office, 1917): 74.

mission of research, education, and technological improvement. One side of the building would face the Carnegie School of Technology, another side addressed the Carnegie Institute, and nearby was the University of Pittsburgh campus. Plans drawn up by the Supervising Architects for the Treasury included a main building that would incorporate administrative offices, a lecture hall, a library, and rooms for demonstration and training in mine rescue and first-aid. A mechanical building would provide space for experiments and tests of mining machinery and appliances, and a chemical building providing space for investigation and analyses of fuels, explosives and various mineral substances. The Bureau hoped to have the buildings completed by fall of 1915 and to honor its opening with a second National Mine Safety Demonstration similar to that held at Pittsburgh a few years earlier.[71] Although the buildings were complete by late 1917, the war delayed the dedication of the new buildings until September, 1919. The occasion of the dedication brought a warm greeting from President Wilson, demonstrating the national interest in the work of the research station. Wilson, who sent his salutation via telegram, expressed his "deep interest in the work being done by such instrumentalities for the increase of production, the safeguarding of life and the raising of the standard of labor and scientific endeavor."[72]

The first collaboration of the Bureau of Mines and ASHVE at the Pittsburgh Research Station hewed along lines more traditional to the coal mining area of Pennsylvania. In 1918, the Bureau of Mines asked ASHVE to act as a consultant on a study to suggest a basis for a possible limitation of the coal supply to domestic users. Such a limitation was already in place in England and many countries in Europe, and the Bureau

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[71] "The Pittsburgh Experiment Station of the Bureau of Mines," *Science* 39, no. 1006 (Apr 10, 1914): 528-529.
[72] "Dedication of the Pittsburgh Experiment Station of the Bureau of Mines," *Scientific Monthly* 9 (Nov 1919): 474.

hoped to establish recommendations for such rationing specific to the American situation and climate. That same year, the engineers decided to establish the Research Bureau of the American Society of Heating and Ventilating Engineers to operate "in conjunction with the U. S. Bureau of Mines and with such educational institution laboratories and experiment stations as the directing Committee may select." The outline of work of this new research bureau was certainly aimed at placing heating and ventilating work on a "more scientific basis," as well as to address some "unusual heating and ventilating conditions" such as those in "modern tall office buildings" and "modern large factory buildings," but it does not clearly indicate an intent to carry out any kind of physiological research or to construct a specialized chamber for such research.[73]

Although the engineers were likely aware of the physiological research completed by the New York Commission on Ventilation, the primary impetus for physiological research at the Bureau of Mines in Pittsburgh instead came from mines in the west. In 1920, the Bureau of Mines appointed Royd R. Sayers as its chief surgeon and the chief of its Health and Safety Branch. Sayers, a chemist and physician, had joined the U.S. Public Health Service (PHS) soon after his graduation from medical school in 1914 and maintained a dual appointment with PHS while working for the Bureau of Mines. Prior to his promotion to chief surgeon at the Bureau of Mines, Sayers had participated as an assistant surgeon for the PHS in the health survey of the Joplin mining district along with Lanza.[74] Following the Joplin survey, Sayers worked again on the same team as Lanza, this time in an investigation of the health conditions of miners at copper mines around Butte,

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[73] "Progress Report Of The Committee On Research Bureau," *Transactions of the American Society of Heating and Ventilating Engineers* 24 (1918): 269-272.

[74] "Men You Should Know About," *Engineering and Mining Journal* 110, no. 5 (1920): 226.

Montana, "with special reference to silicosis and the effects on miners of the high temperatures of the deep workings."[75]

In the Butte studies, Lanza recognized a ventilation paradox. The hot, humid, and stagnant air in the Butte mines, in addition to damaging the miners' vitality, greatly decreased the working ability of the miners.[76] In an eight-hour shift, miners were actually engaged in work for only about four or five hours, and maybe even less. However, from observations in Butte and elsewhere, Lanza noted that "an adequate movement of air, even if it did not lower the temperature, would greatly increase the efficiency of the men." If the ventilation in these working places were improved, the miners would work longer and harder during their shifts, but here was the rub, if the ventilation system did not simultaneously improve dust conditions, which many of them did not, "the men, working harder would breathe more deeply and more frequently and consequently fall victims to the dust much more readily." This is what Lanza believed he had witnessed in Joplin, where the mines were shallower and thus much cooler than the mines in Butte.[77] Thus, in their final recommendations, Lanza and his research partner, Daniel Harrington, a mining engineer and specialist in ventilation, recommended not only increasing the circulation of air to reduce the effects of heat and humidity, but also elimination of all dry drilling along with piping of all mines to facilitate wet drilling and water spray to settle fine dust.[78]

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[75] Daniel Harrington and A.J. Lanza, *Bureau of Mines Technical Paper 260: Miners' Consumption In The Mines Of Butte, Montana, Preliminary Report of an Investigation Made in the Years 1916-1919* (Washington DC: Goverment Printing Office, 1921), 5.

[76] Temperature and humidity affected vitality "by causing an increased tendency to colds, bronchitis, and to pneumonia, especially in those men who have dust-injured lungs."

[77] Harrington and Lanza, *Bureau of Mines Technical Paper 260*, 13-14. According to Lanza, the miners at Joplin fell victim to consumption in such high numbers because "the unusual amount of work they were able to perform (averaging 10 tons per shift per underground man, and 22 tons per shift for shovelers) in very dusty atmospheres, because of the low temperature of the mines."

[78] Harrington and Lanza, *Bureau of Mines Technical Paper 260*, 17-18.

One senses that these recommendations were not likely to be carried out. In the introduction to the report, H. Foster Bain, the Acting Director of the Bureau notes that many of the mining companies in Butte were attempting to make improvements, but that water drilling was still generally experimental and that one company which had made concerted efforts to improve ventilation had spent several hundred thousand dollars on its system. Bain does not say as much, but it is unlikely that other mining companies would spend anywhere near that amount on a ventilation system.[79]

In February, 1920, the Bureau of Mines created the new position of chief surgeon, and Sayers, newly ensconced in this appointment, shifted the conversation from dust to heat and humidity, as Haldane had in Britain.[80] Indeed Haldane's 1905 paper, "The Influence of High Air Temperatures" provided both the reasoning and method for Sayers investigations at Butte, the results of which were published first in the trade publication *Engineering and Mining Journal* with the all-in-the-headline title, "Physiological Effect of High Temperatures and High Humidities in Metal Mines: A Preliminary Study of the Results of Atmospheric Conditions Underground—The Observations Show the Importance of Low Humidity and Rapid Circulation of Air in Hot Working Places."[81]

For this research Sayers and his colleagues spent almost two months' time "making daily observations of the miners and of the investigators." Underground they took readings of temperature and humidity of air in working places, the temperature at compressed-air blowers, and air velocity, collected physiological data such as body temperature, blood

[79] Harrington and Lanza, *Bureau of Mines Technical Paper 260*, 6.

[80] Fred Wilbur Powell *The Bureau of Mines: Its History, Activities, and Organization* (New York; London: D. Appleton and Company, 1922), 46.

[81] R.R. Sayers and D. Harrington, "Physiological Effect of High Temperatures and High Humidities in Metal Mines: A Preliminary Study of the Results of Atmospheric Conditions Underground—The Observations Show the Importance of Low Humidity and Rapid Circulation of Air in Hot Working Places" *Engineering and Mining Journal* 110, no. 9 (Aug 28, 1920): 401-404. The same results were published as R.R. Sayers and D. Harrington, "A Preliminary Study of the Physiological Effects of High Temperatures and High Humidities in Metal Mines," *Public Health Reports* 36, no. 4 (Jan 28, 1921): 116-129.

pressure, and pulse rate, and noted the type of work being done in the area.[82] Another team under the supervision of Sayers and Harrington collected similar data in the metal mines of the Lake Superior mining district. This second team also noted subjective symptoms and compared these with observations made with a version of Leonard Hill's kata-thermometer which they used to determine the "cooling power of the atmosphere."[83]

In the underground studies Sayers and Harrington were able to show the effects of various temperatures and humidities, but it was not possible to carry out "studies on many controlled temperatures and humidities." Thus, they thought it would be best to undertake further experiments in a laboratory with a plan to "apply the results to the industry insofar as practicable." In the laboratory they could also measure the effects of less extreme conditions of temperature and humidity, which they thought might be "predisposing causes of fatigue, discomfort and disease." This laboratory work was carried out—as Sayers and his collaborator W. J. McConnell, an assistant surgeon of the Public Health Service described it—as a cooperative effort to study "the physiological effects of heat and humidity," cooperating with the American Society of Heating and Ventilating Engineers.[84] Even if they were performing some of their own experiments, the engineers were hardly as autonomous as Cooper suggested.

To execute the research that Sayers and McConnell envisioned, the group constructed a psychrometric chamber at the Bureau of Mines Research Station at Pittsburgh in which air conditions of temperature, humidity, and air velocity could be controlled independently of each other. For Sayers and McConnell the chamber represented an

[82] Sayers and Harrington, "Physiological Effect of High Temperatures," 401.
[83] H. Foster Bain, *Eleventh Annual Report by the Director of the Bureau of Mines to the Secretary of the Interior* (Washington DC: Government Printing Office, 1921), 28.
[84] Yes, they use "cooperate" twice. W.J. McConnell and R.R. Sayers, "Some Effects on Man of High Temperatures," *Report of Investigations, Department of the Interior, Bureau of Mines,* Serial No. 2584 (Mar 1924), 1.

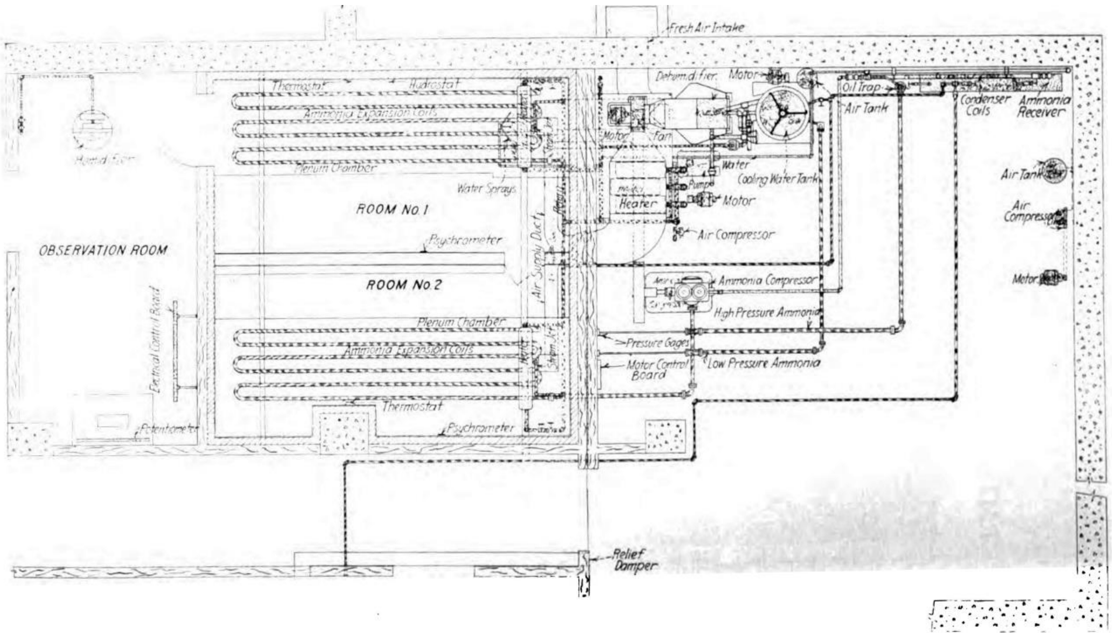


Figure 5.7 Plan of the psychrometric chamber, U.S. Bureau of Mines / ASHVE lab, 1923.

"instrument of precision for determining relative comfort in varying atmospheric conditions" that could replace the clumsy approximations provided by a wet-bulb thermometer or a kata-thermometer. Instead "With the elaborate equipment of the chamber human subjects can be used instead of the Kata."[85] The design of the plant at the Bureau of Mines closely resembled the experimental chamber of the New York Commission on Ventilation down to the finishing of the observation room in cork and cement plaster (Figure 5.7). The observation room was similarly controlled by refrigeration equipment, humidifiers, heaters and fans. The only difference between the two experimental plants was that the Bureau of Mines chamber had two adjoining rooms, completely insulated from each other. By having subjects pass quickly between the two rooms, the research team could observe the "sensitiveness" of the body to changes of temperature and humidity. Sayers and McConnell's broad research trajectory was planned in four phases, in which

[85] R.R. Sayers and W.J. McConnell, "A Psychrometric Chamber and Its Uses," *The Nation's Health* 5, no. 4 (Apr 1923): 237-238.

they would take physiological measurements of subjects in varying conditions of heat and humidity while they were: 1) at rest in still air, 2) at work in still air, 3) at rest in moving air, and 4) at work in moving air.[86]

To operate the complex experimental plant at the Bureau of Mines, the research team retained Constantin Yagloglou (later changed to Yaglou). As F. Paul Anderson, the ASHVE director of the research bureau described him, Yagloglou was "a young scientist, educated in Turkey," who skillfully maintained "temperature and humidity in those rooms constant to within a very small percentage, day in and day out with the possible exception of two experiments out of hundreds" (Figure 5.8)[87] Although Yagloglou was not a member of ASHVE at the time, he is often remembered in engineering histories as the author of the "comfort zone" study.[88] Yet despite the importance given the comfort zone in Cooper's book, in view of the Bureau of Mines research agenda, the determination of the comfort zone was a secondary pursuit. In their eyes, it was a reasonably simple exercise to establish the "relative importance between the dry and wet bulb temperatures," which would allow air conditioning engineers to know

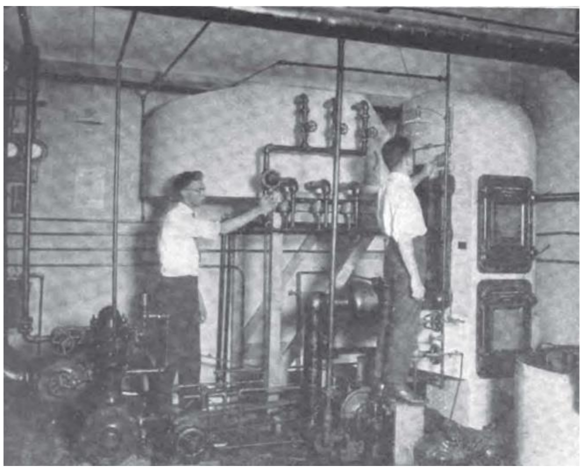

Figure 5.8 The apparatus for temperature control, U.S. Bureau of Mines / ASHVE lab, 1923.

[86] Sayers and McConnell, "A Psychrometric Chamber and Its Uses," 238.
[87] F. Paul Anderson, "Address Of Director Anderson On The Research Laboratory," *Journal of the American Society of Heating and Ventilating Engineers* 29, no. 2 (Mar 1923): 113.
[88] F.C. Houghton and C.P. Yagloglou, "Determining Equal Comfort Lines: Laboratory Tests Conducted Give Results for Still Air Conditions," *Journal of the American Society of Heating and Ventilating Engineers* 29, no. 2 (Mar 1923):165-176; F.C. Houghton and C.P. Yagloglou, "Determination of the Comfort Zone with Further Verification of Effective Temperature within this Zone," *Journal of the American Society of Heating and Ventilating Engineers* 29, no. 6 (Sep 1923): 515-528.

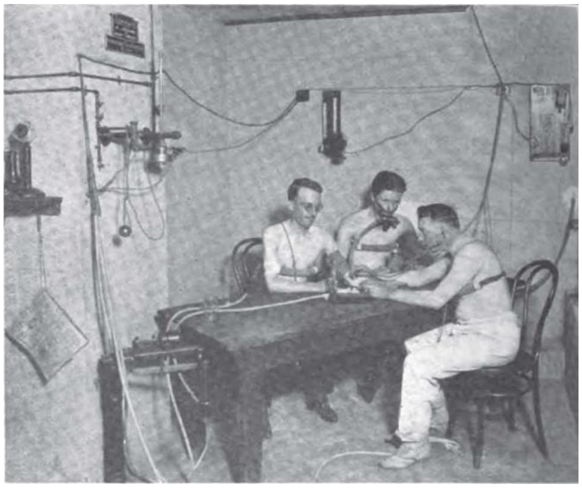

Figure 5.9 Subjects in the test chamber at the U.S. Bureau of Mines / ASHVE lab, 1923.

what ratios of humidity and temperature were acceptable, to what extent they could substitute one for the other, and to what extent air movement could substitute for excessive temperature or humidity.[89]

It is the case that Yagloglou and Houghton, in their execution of the comfort zone research, relied in part on subjective responses from a relatively varied group of people, but their research was still very much embedded in the physiological research of Sayers and McConnell's team. That latter team just happened to be interested not only in comfort conditions (in which workers could work at maximum efficiency), but also in the extremes (in which workers could physically no longer work). The engineers and the physiologists were actually working together to establish the "scale of effective temperatures," which they defined as "a true index of all heat effects on the human body, *both primary sense and physiological*" (Figure 5.9). The engineers nonetheless found the concept of effective temperature was difficult to describe precisely because it embodied a complex set of variable relationships. In the most concise terms, it was the "temperature and humidity condition, or the heat and moisture condition, of the air which determines the transfer of heat between it and the human body, normally clothed."[90] Physiologists had different ideas about how that transfer of heat between body

[89] W. J. McConnell and F.C. Houghten, "Some Physiological Reactions to High Temperatures and Humidities," *Journal of the American Society of Heating and Ventilating Engineers* 29, no. 2 (Mar 1923): 136; W. J. McConnell, F.C. Houghten, and F.M. Phillips, "Further Study of Physiological Reactions" *Journal of the American Society of Heating and Ventilating Engineers* 29, no. 6 (Sep 1923): 508.
[90] Houghton and Yagloglou, "Determination of the Comfort Zone," 517. Italics added.

and environment translated to a conscious experience, but many saw subjective reports as just another variable in the complex calculation of effective temperature.

**Comfort Lines and Compressors**

It is the case that after the publication of the “comfort zone” research many manufacturers, particularly the Carrier Corporation, removed it from its original context of work, labor, and health, in order to market it for commercial and recreational use, but it was not as divorced from a medical or physiological basis as Cooper implies. Indeed, it was directly integrated with it at the Bureau of Mines. The establishment of the comfort zone (first described as “comfort lines”) was instead intended to resolve a dispute more technical than metaphysical. As early as 1912, there was a conflict between one physiologist and one engineer, namely John S. Haldane and Willis Carrier, and that conflict was over humidity.[91] As described in the previous chapter, Haldane’s recommendation for appropriate humidity levels for “continuous hard work” called for a low wet-bulb temperature and lowered humidity. At that time, Carrier’s “air conditioning” system was essentially a humidifier or “air washer” system that marginally lowered temperatures, but did not lower humidity. In those early days, it was only for a few industries in which low humidity was absolutely critical that Carrier designed the expensive and complex refrigeration equipment that could that could chill the air washer’s spray water and lower the humidity.[92]

This dispute may have been one reason why J.I. Lyle, as Carrier’s partner in founding the Carrier Air Conditioning Corporation, was so eager to establish an

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[91] J. I. Lyle, "Relative Humidity--Continued, Its Effect on Comfort and Health," *Engineering Review* (Sep 1912): 28-32.
[92] Cooper, *Air-Conditioning America*, 55.

"independent" ASHVE lab.[93] An outcome of that Bureau of Mines research, the "comfort zone," embodied Haldane's low humidity recommendation but reconciled it with dry-bulb temperatures. This was fine for Lyle and Carrier, because in 1923, the year that the comfort chart research was published, Carrier had patented his centrifugal refrigeration compressor, a relatively inexpensive chiller that allowed their engineers to closely control humidity at all temperatures (Figure 5.10).[94] The original engineering concept of air conditioning was not always tied to refrigeration, but it became so after 1923.

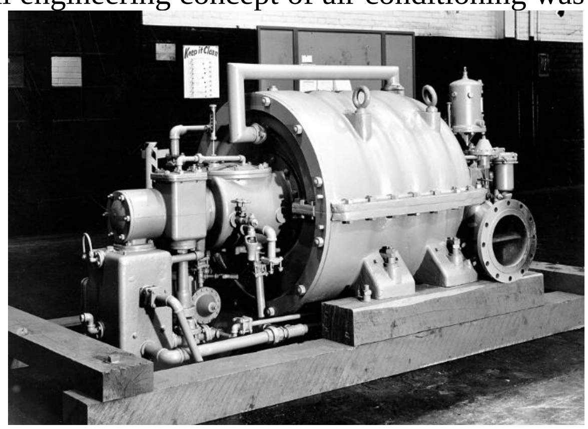

Figure 5.10 Carrier centrifugal refrigeration compressor, 1922. Credit: National Museum of American History

Certainly, there were additional disagreements, especially with the publication of the final New York Ventilation Commission report in 1923, and again when the Commission revived in 1926. The disagreement at that time—which sounds similar to, but is actually different from the one in 1912—was about the effectiveness of open-window versus mechanical ventilation, and according to Marsha Ackerman, fairly easily resolved after a *tête-à-tête* between C.-E.A. Winslow and Willis Carrier. Cooling, not ventilation, would be the future of air conditioning.[95]

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93 Cooper, *Air-Conditioning America*, 68-69; F. Paul Anderson, the director of the ASHVE lab describes Carrier as the impetus for the comfort zone research and observes that it seems to be the only or at least the primary result from the lab that Carrier cares about. F. Paul Anderson, "Address Of Director Anderson On The Research Laboratory," *Journal of the American Society of Heating and Ventilating Engineers* 29, no. 2 (Mar 1923).

94 Smithsonian National Museum of American History, "Carrier Centrifugal Refrigeration Compressor" https://americanhistory.si.edu/collections/search/object/nmah_846092. The museum holds Carrier's original compressor in its collection.

95 Ackerman, *Cool Comfort*, 32-36. The American Society of Refrigeration Engineers (ASRE) formed in 1904. ASRE and ASHVE merged in 1959 to create the American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE), the organization that persists today. As described by the Milbank

## Industrial Resistance to Fatigue

Yet there were other reasons why ASHVE might chose to distance itself from the Bureau of Mines and its overlapping association with the Public Health Service. In 1920, the National Industrial Conference Board and industry-sponsored journals began to push back against government-funded research related at all to the concept of fatigue or overwork. The group aimed its most contemptuous critique at Committee on Industrial Fatigue, and its report, published by the PHS as Public Health Bulletin 106, advocating an eight-hour work day.[96] The document, an account written by Josephine Goldmark and Mary Hopkins, describing investigations undertaken by Frederic S. Lee and Philip Sargant Florence, compared productivity, accident, and employee turnover rates at two identifiable factories, one with an eight-hour system (Ford Motor Company), the other with a ten-hour system (Scovill Manufacturing Company). The report came out on the side of shorter hours, maintaining that a limited workday both sustained economical production as well as conserved and improved workers' health, and it was embraced by the American Federation of Labor.[97] Lee's ideas about industrial fatigue were far from radical. In his own publications, he did not call for significant change in what he saw as the "unavoidable" conditions of work such as long hours until more scientific evidence could be assembled. Rather he argued it was best to aim resources at improving the secondary and ultimately

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Fund: "The war postponed the publication of the final report of the Commission's activities until 1923, after which the original Commission passed out of existence. Three years later, however, in 1926, evidence had grown overwhelmingly strong, says the present report, that the one important essential in school ventilation was the maintenance of an atmosphere which would remove the heat produced in metabolism so as to avoid overheating, without unpleasant drafts. "Final Contribution of the New York Commission on Ventilation" *The Milbank Memorial Fund Quarterly Bulletin*, 10, no. 1 (Jan 1932): 37.

[96] Sellers, *Hazards of the Job*, 151. The Conference Board had just published a summary of its own research on the "hours of work problem" in five major industries.

[97] Alan Derickson, "Physiological Science and Scientific Management in the Progressive Era: Frederic S. Lee and the Committee on Industrial Fatigue," *Business History Review* 68 (Winter 1994): 508.

"avoidable" causes of fatigue, poor ventilation or other sanitary conditions.[98] Yet in the eyes of many industrial employers, Lee's position was unacceptable in that it acknowledged the physical and physiological reality of fatigue, which could provide workers leverage in negotiations and even worse it could summon government intervention. Even more disturbing to industry must have been Florence's 1924 *Economics of Fatigue and Unrest*, in which Lee's protégé rejected his technocratic vision and with a revolutionary critique of the capitalist organization of work.[99]

Not all members of the Committee on Industrial Fatigue were as combative. David Edsall, now dean of the medical school at Harvard University recognized that "there has been a common feeling among employers that anyone who is interested in this matter [fatigue] is really interested in shortening hours and is a partisan of labor."[100] Edsall was critical even of Lee's technocratic conciliation, maintaining that Lee had a regrettable tendency to link science to social action. For Edsall it was inappropriate "to hitch up the medical work and welfare work together," for the medical work was "vastly more important and this connection is damaging to it."[101] Edsall's colleague at Harvard, physiologist Cecil Drinker, criticized what he saw as the PHS Bulletin 106's premature enthusiasm for the eight-hour day. The only legitimate way to answer the length-of-day question was with more carefully controlled research. He urged more laboratory, less factory.[102]

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98 Frederic S. Lee, *The Human Machine and Industrial Efficiency* (London: Longmans, Green, and Co., 1918), 19-20, 36.
99 Gillespie, "Industrial Fatigue," 248
100 David Edsall, "Medical-Industrial Relations of the War," *Johns Hopkins Hospital Bulletin* 29 (1918), 198, quoted in Sellers, *Hazards of the Job*, 151.
101 David Edsall quoted in Gillespie, "Industrial Fatigue" 254.
102 Derickson, "Physiological Science," 508-510.

## LABORATORY 3: HARVARD'S VENTILATION AND ILLUMINATION LAB / FATIGUE LAB

Edsall offered an alternative to industry. He reframed academic medicine, especially at Harvard, as disinterested and autonomous, making it possible for research to become independent arbiters in disputes between capital and labor. Aiming to appeal to industrial corporations, Edsall in establishing an industrial hygiene program at Harvard removed fatigue as well as exposure research not only from government purview but also from the factory floor, where reforming social scientists like Josephine Goldmark had gathered their evidence. Fatigue research would now happen in a university-based laboratory, and the subjects more likely to be experimental animals than workers.[103]

Harvard's public health program began in 1913 with the founding of its School for Public Health Officers as a cooperative effort with MIT. Students in this program took classes in anatomy, physiology, sanitary engineering, hygiene, demography, and other areas and were expected to fill what the school's advisers saw as a lack of professional administrators for the growing number of state and municipal public health programs. With the help of a subscription fund raised by a group of New England industrialists, the program in 1918 added a Division of Industrial Hygiene to train future factory physicians. Research in industrial hygiene began during the intensified industrial production of World War I, when physiologist Cecil K. Drinker established a research program in response to a dramatic increase in plant managers seeking advice on potential health problems in hazardous industries. In 1922, by request from the Rockefeller Foundation, which had just given the school a generous endowment, Harvard ended the joint program with MIT and

[103] Sellers, *Hazards of the Job*, 144, 149.

established the Harvard School of Public Health, with David Edsall as dean (joint with the medical school) and Cecil Drinker heading its Division of Industrial Hygiene.[104]

Cecil Drinker, who maintained a joint appointment in the medical school's physiology department, specialized in the study of industrial dust hazards, and in 1921 brought his brother, chemical engineer Philip Drinker, onto the faculty of the Division as an instructor in air analysis, ventilation, and illumination. In 1924, Philip Drinker announced the opening of the Laboratories of Ventilation and Illumination in the School of Public Health (Figure 5.11), to be dedicated to studies of air and gas flow, "atmospheric conditions and their physiological significance," and standards for ventilation and illumination. The goal of Philip Drinker's lab and course of instruction was to teach ventilation and illumination from both engineering and medical points of view such that "the students may have a common ground on which to meet the physicians or the engineers with whom they may come in contact."[105] Students could gain experience with measurement of air flow, psychometry, and the use of the Kata-thermometer and skills needed to consult on the design of air conditioning systems for factories.

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[104] H.S. Brightman and J.D. Spengler, "Indoor Environmental Quality Research and Education at Harvard University," in *Education and Training in Indoor Air Sciences*, edited by Nadia Boschi (Dordrecht; Boston; London: Kluwer Academic Publishers, 1999), 109-110.

[105] Philip Drinker, "Laboratories of Ventilation and Illumination, Harvard School of Public Health, Boston," *Journal of Industrial Hygiene* 6, no. 1 (1924): 57.

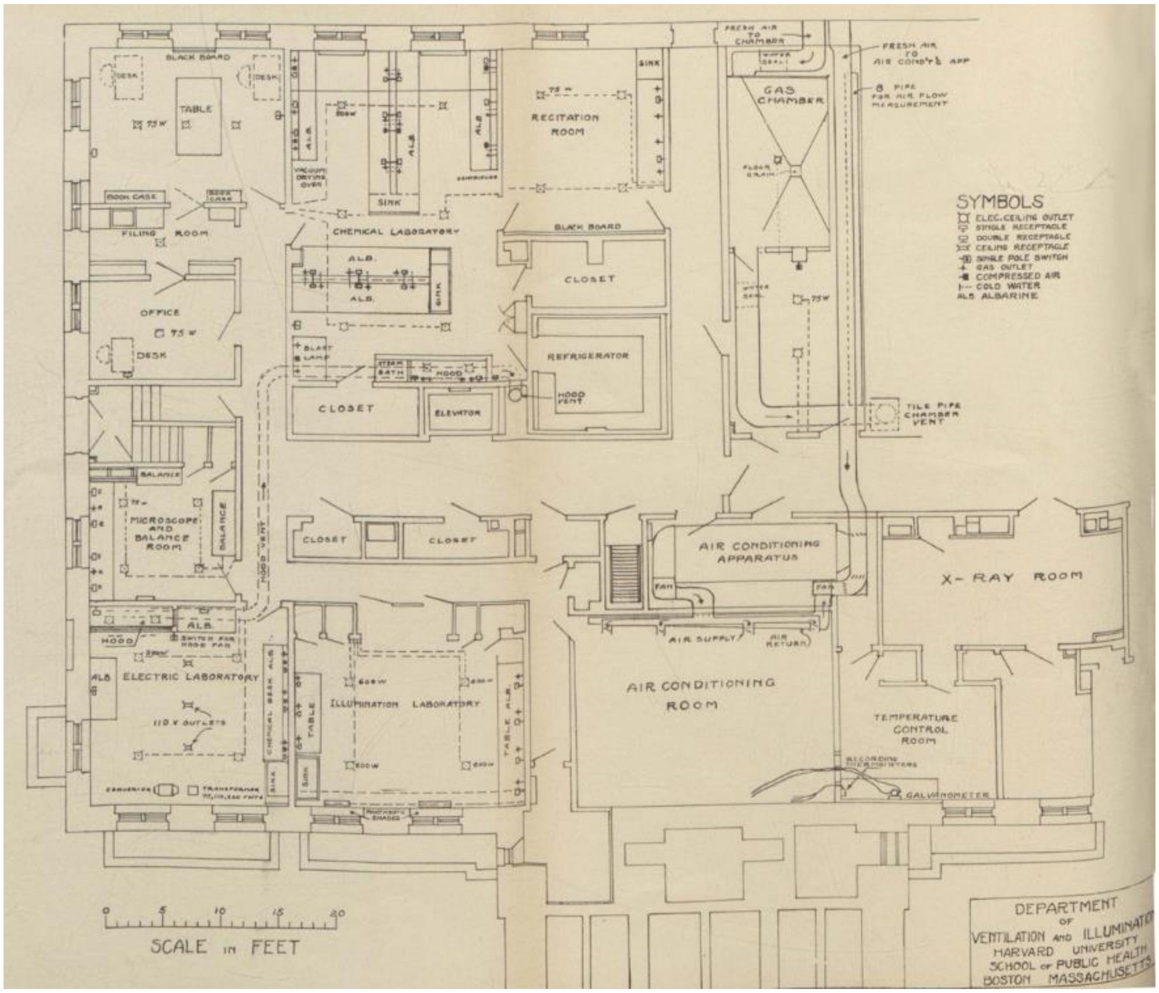


Figure 5.11 Plan of the Ventilation and Illumination Lab, Harvard University, 1924.

The Laboratory of Ventilation and Illumination at Harvard closely resembled the facilities at the Bureau of Mines. R.R. Sayers, the Public Health Service/Bureau of Mines Chief Surgeon who established the lab at Pittsburgh, consulted with Drinker on the outfitting of the lab, and in 1925, the school brought on Constantin Yagloglou, straight from the Bureau of Mines/ASHVE laboratory, as an Instructor to facilitate a research program on the effects of temperature and humidity.[106] Yet the lab facility at Harvard

[106] Drinker, "Laboratories of Ventilation and Illumination," 66; The Harvard Education and Research Center for Occupational Safety and Health, "Some History: Occupational Safety and Health at Harvard University," 1.

differed from the Bureau of Mines lab in one key respect. It brought together in one research unit facilities to study hazardous exposure as well as the effects of temperature, humidity, and air movement. Research on gases and other air contaminants had been carried out at the Bureau of Mines, sometimes under the direction of Harvard physiologist Yandell Henderson, but the two research teams were not directly linked. At Harvard, the Ventilation and Illumination Laboratory contained both an "air conditioning" room (Figure 5.12) for studying heat, humidity, and air movement and a "gas chamber" for studying the physical behavior and physiology of dusts, fumes, smokes, and gases. With the opening of the Fatigue Laboratory at Harvard in 1927, Edsall had successfully replicated or replaced all of the research facilities studying workers and work environments that had once been under the aegis of the Public Health Service.[107]

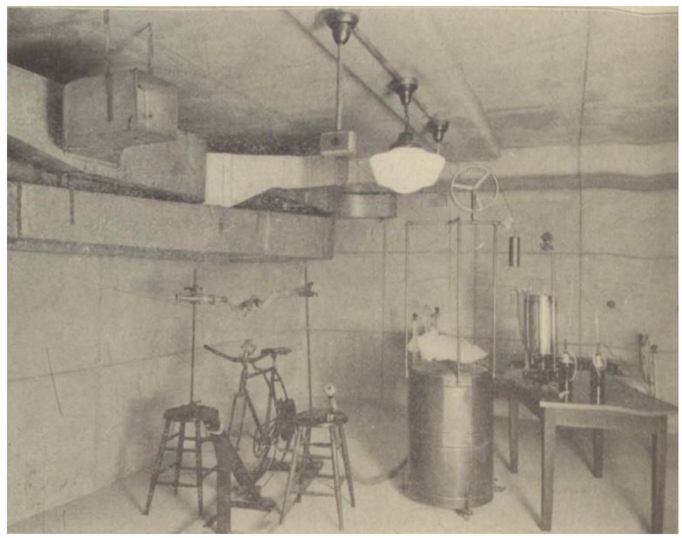

Figure 5.12 Air-conditioning room, Ventilation and Illumination Lab, Harvard Univ, 1924.

Under the direction of David Edsall, this collection of research programs recast the concept of fatigue and study of the working body as a rarified problems of internal physical chemistry and regulatory physiology. Investigations of fatigue at Harvard would now center on how research subjects established internal equilibrium under physical conditions of stress, and this study of equilibrium aligned with concurrent study of the immediate

[107] The Fatigue Laboratory was a separate facility housed in the Harvard Business School, but served as a facility for collaborations with faculty members from the Medical School and School of Public Health. David Edsall acted as its coordinator. Curran, *The Founders of the Harvard School of Public Health*, 278

external surroundings of the human organism. The results of this research became the foundation of Walter B. Cannon's critical concept of homeostasis, but its inspiration came from a philosophy shared with J.S. Haldane.[108]

**The Steady State: Haldane's New Physiology and Homeostasis at Harvard**

Gail Cooper rightly observed that the tight control afforded by air conditioning—the elimination of all fluctuation in temperature or humidity—served an important industrial purpose, and she argues that these process-control needs were the primary drivers behind the design and purchase of early air-conditioning systems; the health or comfort of workers was secondary. Certainly, this was the case from the perspective of the engineer and manufacturer—the main characters of Cooper's book—but arguments for a uniform and unchanging environment emerged in parallel in scientific and medical discourses. Walter B. Cannon's concept of homeostasis provided a rationale that made air conditioning seem appropriate and perhaps even necessary in industrial as well as non-industrial settings. Its philosophical foundation, however, also provided a justification for physiologists and other medical experts to eschew any critique of increasingly hazardous work environments.

On the surface, the premise of homeostasis is elegantly simple, but its basis is highly complex and embodies a career of research on the part of Cannon. When Cannon began articulating the concept of homeostasis in scientific circles around 1925, he had already been the chair of the Harvard physiology department for twenty years, having joined that faculty as a professor immediately after his graduation from the Harvard's medical program in 1900. Broadly, Cannon defined homeostasis as ''a fairly constant or

108 Sellers, *Hazards of the Job*, 165; Scheffler, "The Power of Exercise and the Exercise of Power," 392-393.

steady state, maintained in many aspects of the bodily economy even when they are beset by conditions tending to disturb them."[109] Specifically, it represented the unconscious and composite maintenance by the body of vital functions such as body temperature, fluid balance, and blood sugar within a particular range. Although Cannon's theory, which imagines a human body in balanced equilibrium with its surroundings, may at first glance seem to be an effortless reality—the word homeostasis combines the Greek words *homoios* (similar) and *stasis* (stillness)—Cannon in fact emphasized the dynamic work that a human body had to perform constantly in order to remain in equilibrium.[110]

In response to Cannon's proposition, physicians and engineers such as Yagloglou (now Yaglou) argued that if environmental conditions could be made steady, human bodies would not have to work as hard to maintain internal constancy. A steady environment would benefit both trifling illnesses (colds, coughs, headaches) as well as chronic diseases.[111] The idea filtered out into the architectural community as well. Architectural historian James Marston Fitch, who despite his involvement in the promotion of residential air conditioning with *House Beautiful* magazine's "Climate Control" project, remained ambivalent about its proliferation, reasoned this way in the 1948 edition of his book *American Building: The Forces That Shape It*:

> It is apparent that the body is well equipped to maintain the thermal equilibrium so necessary to its survival under varying circumstances. Indeed Cannon regarded this 'as one of the most valuable advances in biological evolution.' The external thermal environment is by no means always friendly to such constancy however; and though the body is designed to accommodate itself to fairly wide fluctuations, its limits of accommodation are fixed. It is to take up the discrepancy between

[109] Cannon, 1925 presentation at the Congress of American Surgeons, quoted in Steven J. Cooper, "From Claude Bernard to Walter Cannon. Emergence of the Concept of Homeostasis," *Appetite* 51 (2008): 424.
[110] Cooper, "From Claude Bernard to Walter Cannon," 424.
[111] C.P. Yaglou, "Physical and Physiologic Principles of Air Conditioning," *Journal of the American Medical Association* 108, no. 20 (May 15, 1937): 1710; Murray B. Ferderber and F.C. Houghton, "Effective Temperature Scale: A Measure of Human Comfort in Environmental Temperature," *Journal of the American Medical Association* 116, no. 6 (Feb 8, 1941): 474.

> what we need and what we get, that we heat and cool our buildings. We thus create a synthetic thermal environment which takes the load off our own shoulders, in much the same way as the shell protects the unhatched chick.[112]

That Cannon's 1932 book *The Wisdom of* the *Body*, which described the concept of homeostasis to a general audience, was popular beyond the medical field is hardly surprising, especially as it came out in the great social turmoil of the Depression, but reflection on the philosophical genealogy of Cannon's theory reveals a more immediate medical interpretation. As a cultural idea, the concept of a self-regulated and self-righting system appealed to economists (self-correcting markets), botanists (nature as a balanced ecosystem), and mathematicians (cybernetics, or machines "governed by autonomous control systems stabilized by "feedback" loops").[113]As a way of imagining a human body in its environment, the self-regulating system can be refashioned as a self-healing mechanism that is naturally resilient in the face of considerable environmental imposition.

Cannon's immediate mentor at Harvard was Henry P. Bowditch, an early crusader for the establishment of a department of physiology at Harvard. Bowditch in turn had studied with French physiologist Claude Bernard, whose 1865 book, *An Introduction to the Study of Experimental Medicine,* is often credited as an essential text critical to the expansion of scientific physiology in the second half of the nineteenth century.[114] In the 1860s, Bernard had proposed the concept of the *milieu intérieur,* essentially the stable and self-contained internal environment maintained by some living beings independent of their surroundings. Bernard reasoned that this ability to maintain a stable body temperature was essential to more "evolved" organisms. It was, in Bernard's oft repeated phrase, "the

[112] James Marston Fitch, *American Building: The Forces That Shape It* (Boston: Houghton Mifflin 1948), 199.
[113] Siddhartha Mukherjee, "My Father's Body, at Rest and in Motion," *New Yorker,* Jan 8, 2018.
[114] Charles G. Gross, "Three before their time: neuroscientists whose ideas were ignored by their contemporaries," *Experimental Brain Research* 192, no. 3 (Jan 2009): 321-334.

condition for a free and independent life," by which he meant the freedom to move between varying environments and to consume a wide variety of foods and liquids.[115]

More immediately, Cannon was part of a broader movement among physicians and other intellectuals in the 1920s encouraging a holistic view of biological life. In part positioned in response germ theory, which this group saw as taking a too narrow view of living organisms, the movement emphasized a constitutional approach in medicine and a perspective that saw a living organism and its environment as an integrated system always working to maintain equilibrium.[116] In this model, if there was something detrimental in the environment, the organism would naturally adjust and compensate to resist it.

Particularly influential on Cannon and some of his colleagues at Harvard was John S. Haldane. In 1916, Haldane delivered several lectures in the United States, the prestigious Silliman lecture at Yale and an address to the Harvey Society in New York City, entitled "The New Physiology." In this latter lecture, Haldane argued that previous vitalist and mechanist models of physiology were inadequate. The vitalists of the early nineteenth century simply put their faith in a so-called vital force, the undiscoverable controller of physiological action in a living being. The mechanists of Carl Ludwig and Benjamin W. Richardson's era were equally misguided. Their search for the actual mechanisms underlying physiological phenomena led only to a "tangled maze of causal conditions," and any physiologists who looked for definite "causal chains" would find themselves caught in a "network of apparently infinite complexity." Instead, Haldane argued, biological phenomena could be distinguished by "one universal characteristic" that "the structure, activity and life history of an organism tend unmistakably to maintain a

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[115] Melanie P. Hoenig and Mark L. Zeidel, "Homeostasis, the *Milieu Intérieur*, and the Wisdom of the Nephron," *Clinical Journal of the American Society of Nephrology* 9, no. 7 (Jul 7, 2014): 1272-1281.
[116] Sarah W, Tracy, "George Draper and American Constitutional Medicine, 1916-1946: Reinventing the Sick Man," *Bulletin of the History of Medicine,* 66, no. 1 (Spring 1992): 67 (53-89). It should be noted that the group represented a broad range of actors, some of whom were leading promoters of eugenics theory.

normal."[117] The evidence that Haldane draws on to support his proposition for a "new physiology," all came out of physiological laboratories in the U.S. and Europe, but some link Haldane's physiological philosophy to his life-long resistance to seeing industrial dust, whether in mines or factories, as a direct cause of silicosis or other occupational disease.[118] If one studies the "normal," one can neglect the cause.

In this sense, one can interpret space conditioning technology, as it was envisioned in 1930, as not about improving the environment, but improving the body. A system that "takes the load off" the working body, frees that biological system to improve its well-being and resilience. Technologies that promoted such non-specific effects must also have been appealing in the contentious early years of workmens' compensation laws, which were introduced in piecemeal form in various states beginning in the 1910s. By the 1920s a more significant shift had happened in the world of work. Industrial physiology was being replaced by industrial psychology, the practices of which focused on selecting workers with the "right" attitude and appropriate level of resilience for a job, not improving conditions for existing workers.[119] Yet at the beginning of the twenty-first century, these issues are intersecting again within programs of worker wellness, well-being, and well buildings. This is the subject of the following brief epilogue.

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117 J.S. Haldane, "The New Physiology," *Science* 44, no. 1140 (Nov 3, 1916): 619-620.

118 Andrew Perchard and Keith Gildart, "'Buying Brains and Experts': British Coal Owners, Regulatory Capture and Miners' Health, 1918-1946," *Labor History* 56, no. 4 (2015): 471 (459-480).

119 Gillespie, "Industrial Fatigue," 255.

## Epilogue: Hi, How Are You? Are you WELL?

Or maybe you are tired, worn out, and perhaps feeling a little blue. Don't worry, your building will make you well. In 2014 the recently formed International Well-Building Institute launched a new building rating system, the WELL Building Standard™. Premised around seven concepts (air, water, nourishment, light, fitness, comfort, mind), the system promises to generate well-being, to fashion more sustainable humans. Although this sounds great—who doesn't want to be well without trying?—it calls into question what exactly these humans must sustain and what might be elided in the process.

Certainly the WELL system represents a positive move away from assemblies associated with "sick building syndrome" in the 1990s, but the tactics endorsed by WELL reinforce concerns expressed by sociologist William Davies, who in his 2015 book *The Happiness Industry* critiques the corporate promotion of "well-being" as an indirect strategy devised to combat increasing psychological disaffection in post-industrial workplaces that expect and indeed demand round-the-clock digital commitment.[1] But rather than supporting structural and cultural changes such as work-hour limits or off-hours digital demand relief that could undercut revenue and profit, many organizations have chosen to focus instead on making "resilient" or "sustainable" humans that can better withstand the rigors of the extended and pressure-filled working periods. An emerging element of this strategy is to assign the well-making task to buildings and work environments, hence WELL buildings.

Viewed in the frame of biopower, we should think critically about the implications of these systems. Although the WELL standard offers some overtures to the social and

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[1] William Davies, *The Happiness Industry, How the Government and Big Business Sold Us Well-Being* (London: Verso, 2016), passim.

subjective, the approach is primarily physiological and technological. Perhaps the most telling, however, is the case made to potential investors. The marketing literature claims that WELL can improve employee health without pesky issues of conscious worker participation. For me, it demonstrates the importance of framing technologies not in problem-solution binaries, but rather as choices that leave outside the frame other etiologies or courses of action. The mode by which employers hope to have effects (through physiological or psychological means; or more bluntly through body or mind) says something about how engaged they want their employees in the conditions of their work broadly speaking. With media attention to fears about the health consequences of overwork increasing and the possibility of labor organizing among white-collar tech workers around these issues stirring, perhaps it makes sense not to simply ask “are you well?” but to engage with questions like “what time is it?”[2]

[2] James Surowiecki, “The Cult of Overwork.” *New Yorker*, January 27, 2014; Zaria Gorvett, “Can You Work Yourself to Death?” *BBC-Capital*, September 13, 2016. http://www.bbc.com/capital/story/20160912-is-there-such-thing-as-death-from-overwork; Melissa Chan, “How Working Too Much Can Actually Kill You.” *Time.com*, October 6, 2017. http://time.com/4972787/death-overwork-japan-heart-stress

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