VENTILATING THE EMPIRE:

ENVIRONMENTAL MACHINES IN THE BRITISH ATLANTIC WORLD, 1700-1850

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ABSTRACT OF THE DISSERTATION

Ventilating the Empire: Environmental Machines in the British Atlantic World, 1700-1850

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This dissertation provides a scientific and social history of ventilation in the British Atlantic World during the long eighteenth century. Emerging amidst the enlightened craze for improvement, the first ventilating machines, or "ventilators," aimed to extend the providential balance of particles in the atmosphere into enclosed and crowded spaces. These machines were widely adopted in the Royal Navy and in English prisons, where their use was promoted as a cornerstone of institutional reform. Early advocates of ventilation like the experimenter and clergyman Stephen Hales promised that his ventilators would thoroughly refresh these dank, putrid spaces and preserve the health of sailors, slaves and prisoners. In ships, ventilators were proposed as a means of mitigating the dangers of transition between climates, thus preserving the valuable labor resource of skilled sailors. In prisons, ventilation was proposed as a means of excluding and curing both moral and physical contagion in the new "perflated" and strictly disciplined prisons. By the end of the eighteenth century, however, the failures of ventilation to fully extinguish epidemic disease was accompanied by the emergence of tropical medicine, which essentialized hot, humid environments as unhealthy and impossible to ventilate. This led to claims by abolitionists that slave ships constituted

such an irredeemable space, and to claims by prison reformers that both the moral and physical environments of prisoners had to be completely controlled. Contemporaneously, the rationale for ventilation was changing as new chemical conceptions of air proposed by Joseph Priestley and Antoine Lavoisier emphasized the quality and temperature of air over its free circulation. These developments, and the commodification of ventilating devices by the Marquis de Chabannes and others led sanitary reformers and chemical experts like David Boswell Reid to prioritize comfortable temperatures and air purification rather than open access to the external air. These developments led to ventilation devices becoming luxury goods that aimed to provide a comfortable atmosphere insulated from the miasma and filth of the emerging industrial city.

In summation, I argue that while ventilating machines were initially designed to mitigate the negative environmental and social effects of empire through free circulation of air, the fear of hot, humid, putrid, “tropical” environments transformed ventilation into an infrastructural technology which ultimately aimed to insulate certain elements of society from others. By tracing the history of ventilating devices, *Ventilating the Empire* provides a cautionary tale of how racial and class dynamics can exert a strong influence on technological projects to avert environmental danger.

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incredibly fortunate to call him a friend and colleague. Claire Marshall's faithful friendship and consistent curiosity have been sources of frequent inspiration – I would not know anything about Taphephobia if it wasn't for her. Finally, Alexander Petrusek's empathy, intelligence, artistry, wit and passion have been a shining light throughout this journey, and his friendship is something for which I am grateful every day.

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In June of 1757, a new kind of horror story made its debut. Reported first in London newspapers, then throughout the British isles, the initial account described around 175 East India Company prisoners (the numbers varied) crammed into a small prison cell "not large enough for 50 of us to breathe in." Over the course of a seemingly endless night, the prisoners were tortured by extreme heat, thirst and suffocation. Taunted and ignored by their Bengali captors, the men scrambled and trampled over one another in a vain attempt to gain access to the meager amount of fresh air that seeped through two small, barred windows. By six in the morning, only 16 had survived being "smothered" within this "hell in miniature."[1]

This story, typically referred to in shorthand as the "Black Hole of Calcutta," is less well-known today. But for the next two hundred years, it was one of the most famous incidents in British history. Re-interpreted by Thomas Babington Macaulay as a primer on the "cruelty" and "debauchery" of Bengali Nawab Siraj-ud-Daula, the story was incorporated into patriotic children's histories like *Our Island Story*, where the horrors of the "black hole" came to serve as a prelude to Robert Clive's glorious victory over the Bengali army at Plassey. By the height of the British Empire, this story had become, in the words of journalist and author Noel Barber, as familiar to "every schoolboy…as the battle of Hastings."[2]

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[1] Isaac Kimber, ed. "Extract of another Letter from the East Indies, dated Dec. 15, 1756," *London magazine, or, Gentleman's monthly intelligencer*, vol. 26 (Jun 1757): 296-299; Other appearances of this story include: *Universal Magazine of Knowledge & Pleasure*, vol. 20 (June 1, 1757): 266-270; *The Scots Magazine*, vol. 19 (June, 1757): 252-254.
[2] It should also be noted that the version of the story is far from forgotten. In 2010, former prime minister David Cameron named *Our Island Story* as his favorite children's book: Andrew Hough, "Revealed: David Cameron's favourite childhood book is Our Island Story," *The Telegraph* (London, U.K.) Oct. 29, 2010, https://www.telegraph.co.uk/culture/books/booknews/8094333/Revealed-David-Camerons-favourite-

But for contemporaries, it was neither a myth nor an imperialist plank – it was a *ventilation* horror story. Upon his return to England the next year, black hole survivor and East India Company physician John Zephaniah Holwell published what became the authoritative account of the incident. Partially wishing to clear his name in the fort's botched defense, Holwell's tale played heavily on the theme of his own victimhood and near suffocation.[3]

"Figure to yourself," Holwell wrote, "the situation of a hundred and forty-six wretches, exhausted by continual fatigue and action, thus crammed together in a cube of about eighteen feet in a close sultry night." Crammed literally on top of each other, the prisoners immediately began to panic. In "lively and dreadful colours," Holwell recalled "every one giving way to the violence of passions" and desperately straining to force open the door. Struggling to calm his men, the doctor strove to reassure them that "the return of the day would give us air and liberty." While the men had at first cried out for water, Holwell recalled that within a few hours "AIR, AIR" had become "the general cry."

To bring more air into the room, Holwell ordered every man to strip naked and wave their hats "to produce a circulation of air." Finding that many of the men on the side opposite the window had already succumbed, Holwell found that he himself was "no longer able to bear the pains without attempting a relief, which I knew fresh air would and could only give me." Forcing his way through the scrum of men, he seized on to the

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childhood-book-is-Our-Island-Story.html (Accessed June 10, 2020); Thomas Babington Macaulay, *Critical and Historical Essays* (Leipzig: Bernhard. Tauchnitz, 1850) IV: 35-38; Henrietta Elizabeth Marshall, *Our Island* Story (London: T.C.&E.C., 1905) 434-436; Noel Barber, *The Black Hole of Calcutta: A Reconstruction* (Boston: Houghton Mifflin, 1966) 17.

[3] John Zephaniah Holwell, *A Genuine Narrative of the Deplorable Deaths of the English Gentlemen, and Others, who were Suffocated in the black Hole in Fort William, at Calcutta*," (London: A. Millar, 1758) iii-viii.

window's iron bars, and greedily gulped the little air that passed through them. In a dazed and desperate state, he barely perceived the passage of time as the men behind him began to lose strength and many "laid themselves down and expired quietly upon their fellows." Those left alive were further endangered by an "effluvia" which "arose from the living and the dead" and forced Holwell to continually raise his parched mouth to the window "to escape suffocation."

Over the course of the long night, Holwell found that the lack of aerial refreshment made his "spirits, resolution, and every sentiment of religion gave way." During an "ungovernable fit of thirst," Holwell even attempted to drink his own urine, which he found "so intensely bitter there was no enduring a second taste." Nearly losing his senses and plagued by thoughts of suicide, Holwell clung to the window until six in the morning, when the order came for their release. Suffering from a "high putrid fever" and unable to stand, Holwell flung himself "on the wet grass without the Veranda."

Of what came afterwards, and of how many had perished in the "Black Hole," neither Holwell or any of the other survivors could be certain, for "very few of them retained their senses; or at least lost them as soon as they came into the open air, by the fever they carried out with them."[4] With "no circulation of fresh air sufficient to continue life, not yet divested enough of its vivifying particles to put a speedy period to it," Holwell recalled, the lack of air in the Black Hole had turned proud soldiers and Britons into "so many miserable animals in an exhausted receiver."[5]

The terrifying idea that an insufficiently-ventilated space could lead to weakness, fever and death was *au courant* in the eighteenth century. As indicated by Holwell's

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[4] Holwell, *Genuine Narrative*, 10-31.
[5] Holwell, *Genuine Account*, 11-12, 15.

reference to an "exhausted receiver," this public awareness owed much to the fame of Robert Boyle's air-pump experiments, in which he and his followers suffocated countless birds and mice in order to test the mechanics of respiration and the composition of atmospheric air. As indicated by famous contemporary paintings like Joseph Wright of Derby's *Experiment on a Bird in the Air Pump* (1768), the social role of air pumps had shifted from producing experimental "matters of fact" to titillating viewers with the horrifying spectacle of airless spaces. As public demonstrations of natural philosophical truths grew more popular during the first half of the eighteenth century, many Britons had had witnessed firsthand how the process of respiration exchanged, in Holwell's words, the "vivifying particles" of the air for a poisonous "effluvia" which resulted in an unbearable spectacle of animal panic and gasping death.[6]

Within a few years of Holwell's account, the Black Hole of Calcutta had joined the receiver of an air pump as an image of unbearable suffocation. But with this image of an exotic prison on the far edge of the British Empire came additional connotations of the consequences of inadequate ventilation. Without air, Holwell's "spirits, resolution, and every sentiment of religion gave way." By the end of the night, he had "lost all sensibility" and was beset by a "putrid fever."[7] To deprive someone of air was to deprive them of their humanity – an unspeakable act of tyranny. In addition, this story played on the pre-existing associations of fever and disease with the hot, humid spaces of Africa, India and the West Indies, an association that was becoming more solidified with the

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[6] On the prevalence of public demonstrations in the eighteenth century, see: Simon Schaffer, "Natural Philosophy and Public Spectacle in the Eighteenth Century," *Hist. Sci.* xxi:1 (1983): 1-43: On the influence of air pump demonstration and a fascinating analysis of the cultural meaning of *An Experiment on a Bird in the Air-Pump*, see: Laura Baudot, "An Air of History: Joseph Wright's and Robert Boyle's Air-Pump Narratives," *Eighteenth Century Studies*, Vol. 46:1 (Fall 2012): 1-28.
[7] J.Z. Holwell, "A Genuine Narrative," *The Gentleman's Magazine* Volume 28 (1758): 68-75.

expansion of the empire and the contemporary emergence of tropical medicine.[8] But as the fear of suffocation reverberated throughout Britain, it became clear that any inadequately-ventilated space, including the holds of ships, prison cells, hospitals and public buildings, could become a "Black Hole of Calcutta." An over-crowded ship became "as bad a situation as the black hole"; windowless cells in Cheshire county jail "brought to mind…the *black hole* at Calcutta"; and an irked theater-goer could describe how, in seeing a "constant accession of fresh crowds at the door, my feelings realized every sensation and idea of horror described in the tragic scenes which took place in the black hole of Calcutta."[9]

But while Holwell's story and the spectacle of the air-pump had provoked horror, another air machine was promising hope. Comprised of a rectangular wooden box with a central "midriff" that could be pumped up and down to exhale air through leather valves, this machine, dubbed a "ventilator," was designed to mimic the action of human lungs. Not merely a curiosity, this and similar ventilating machines were widely adopted in mines, merchant ships, granaries and famous sites such as the Foundling Hospital and Newgate Prison.[10] In the same year as the incident in the black hole of Calcutta, the

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[8] On the eighteenth-century emergence of tropical medicine and the classical association of disease with warm climates, see: David Arnold, ed. *Warm Climates and Western Medicine: The Emergence of Tropical Medicine, 1500-1900*, Second edition (Amsterdam: Rodopi Press, 2003); Mark Harrison, *Medicine in an Age of Commerce and Empire* (Oxford: Oxford UP, 2010); and Suman Seth, *Difference and Disease: Medicine, Race, and the Eighteenth-Century British Empire* (New York: Cambridge UP, 2018).

[9] Anon. "Historical Chronicle, October 1763," *The Gentleman's Magazine* Volume 33 (1763) 514; John Howard, *The State of the Prisons* (Warrington: William Eyres, 1777) 438-9; Anon. "Letter from a Gentleman," *Diary or Woodfall's Register* (London), Issue 871 (Friday, January 6, 1792) *17th-18th Century Burney Collection Newspapers.*

[10] Thomas Yeoman letter to Taylor White esq. at Foundling Hospital re. Ventilation of Wards, Nov. 26, 1756, London Metropolitan Archive, A/FH/M/01/002/045-048; Anon. "Description of the Ventilators which are fixed in at Newgate," *Gentleman's Magazine* 22 (1752) 179-182.

Royal Navy ordered these ventilating machines to be fixed on all naval vessels.[11] As the success of these strange devices and the widely-shared horror of suffocation show, "ventilating the empire" was far from a fringe concern.

These realities prompt the central question of my dissertation: when and why did adequate ventilation become perceived as a necessity? My interest in this seemingly simple question arose from a chance archival encounter with the aforementioned machine, a "ventilator trunk" designed and avidly promoted by clergyman and experimenter Stephen Hales. Often treated by historians and biographers as a curious footnote to his influential series of experiments on circulation and respiration in plants and animals, I found to my surprise that ventilating machines were big business in the eighteenth century.[12] The lack of proper ventilation in enclosed spaces such as ships, prisons, hospitals, mines, theaters, the houses of parliament, and many other places prompted sustained discussion from administrators and natural philosophers alike. Not only Hales but also J.T. Desaguliers, John Pringle, Richard Mead, John Howard, Antoine Lavoisier and other influential natural philosophers and physicians all wrote on the topic, and many devoted substantial portions of their career to improving mechanical or architectural means of ventilation. Ventilation was proposed as a means of improving agriculture and mining, increasing trade, managing maritime labor, containing disease and insuring clear-headed government in Parliament.

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[11] "On the 17th August we gave general orders to the Officers of the several Yards for fitting ventilators on all HM ships.": John Clevland to Dockyard Officers, Sept. 4, 1756, National Maritime Museum Greenwich, ADM 354/153/235.

[12] See, for example, the treatment of ventilators in Hales' two book-length biographies: A.E. Clark-Kennedy, *Stephen Hales, D.D., F.R.S., an eighteenth century biography* (Cambridge: Cambridge UP, 1929); D.G.C. Allan and R.E. Schofield, *Stephen Hales, Scientist and Philanthropist* (London: Scolar Press, 1980).

However, despite their early success, ventilating machines were always controversial, and their use was deeply entangled with debates surrounding the slave trade, prison reform and public health. Doubts about the ability of these machines to adequately ventilate the inhumanely crammed holds of slave ships and filthy, unreformed prisons were paired with hardening conceptions of climatic difference and the connection between personal virtue and hygiene. In addition, the rationale for ventilation underwent a radical change as the chemical work of Joseph Priestley and Antoine Lavoisier revolutionized the understanding of atmospheric air and respiration. Ventilating machines had initially been intended to open enclosed spaces to the providentially-balanced atmosphere. By the mid-nineteenth century, entrepreneurial chemists like the Marquis de Chabannes and David Boswell Reid were attempting to create completely insulated and climate-controlled domestic spaces to preserve health and comfort amidst the smoky, putrid and miasmatic air of the emerging industrial city.

Ventilation clearly loomed large for enlightened natural philosophers. However, it has received relatively little attention from historians. There has been no book-length treatment of ventilation during the long eighteenth century, and articles have tended to focus on ventilating machines as precursors for modern ventilation and air-conditioning systems.[13] Historians of technology tend to class ventilation and air conditioning as "modern" technical systems that fall into the category of "infrastructures" – described by

[13] For an interesting example of such a work, see: Barry Donaldson and Bernard Nagencast, *Heat and Cold: Mastering the Great Indoors* (Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1994); The only three articles specifically discussing Hales' ventilators are: D. Fraser Harris, "Stephen Hales, The Pioneer in the Hygiene of Ventilation," *The Scientific Monthly* 3:5 (Nov. 1916): 440-454; Richard Foregger, "Two Types of Respiratory Apparatus of Stephen Hales," *Anaesthesia* 11:3 (July 1956): 235-240; and Bryan Lawton, "Tunnelling in the 1740s: The Water Mine at Coleshill House," *The International Journey for the History of Engineering and Technology* 82:2 (2012): 187-209.

historian of computing Paul Edwards as technological systems that reproduce "those properties of the natural environment that we find most useful and comfortable" and "eliminate features we find dangerous, uncomfortable, or merely inconvenient." In addition Edwards has proposed that modernity can be charted by following the construction of such infrastructures (he gives the example of roads, telecommunications networks and electrical grids) which consist of a physical manifestation of the "modern" separation of culture and the human from nature and the non-human.[14]

However, as I dug deeper into the works of Hales and other eighteenth-century advocates of ventilation, I saw little evidence of a desire to "insulate" spaces from nature. Rather, they saw their machines as a means of *extending* providential nature into enclosed, man-made spaces. Enlightened natural philosophers frequently spoke of nature as a largely benevolent and self-regulating system. Natural knowledge could enrich and enlighten humanity as ill health, ignorance and vice could all be cured. It was only after a century of controversy and the myriad failures of these machines to perform this providential redemption of enclosed spaces that ventilation began to be perceived as a means of insulation rather than extension. The irony was evident: first designed as a means of *extending* nature into man-made spaces, the Victorian era saw ventilating machines transform into a means of *excluding* the external environment in favor of an idealized, comfortable space.

[14] Bruno Latour has famously argued for the inconsistency and self-contradiction of this vision or modernity: Bruno Latour, *We Have Never Been Modern,* trans. Catherine Porter (Cambridge, MA: Harvard UP, 1993); Paul N. Edwards, "Infrastructure and Modernity: Force, Time, and Social Organization in the History of Sociotechnical Systems," in Thomas J. Misa, Philip Brey and Andrew Feenberg, eds. *Modernity and Technology* (Cambridge, MA: MIT Press, 2003): 185-225.

This realization has led me to my central claim. Ventilating machines were initially conceived in order to mitigate the negative environmental and social effects of empire and industrialization, but they paradoxically became a *means of insulating certain elements of society from others*. By tracing the history of these devices, *Ventilating the Empire* provides a cautionary tale of how racial and class dynamics can exert a strong influence on technological projects to avert environmental danger.

Historiography

As an "infrastructure" that emerged out of this early modern context, ventilation forces us to reconsider both the chronology and the character of infrastructural technologies. I argue that the desire to employ ventilating machines as a means of mitigating disease and death in compromised environments reveals that the rationality for technological mitigation of environmental dangers began well *before* the advent of modern ecological thought and "green technologies."[15]

While ventilation machines have never been the subject of a book-length treatment by a historian of science, there has been some excellent recent work on air machines and pneumatic medicine. Vladimir Jankovic has argued that by opposing the comfortable and controlled environment of the home to the random risks posed by the external climate, eighteenth century physicians "medicalized" the living space – a development that was possible "only when the modern subject could resort to technological prosthetics to create a buffer zone between controlled comfort and random

[15] The idea that "green technologies" can serve as stop-gaps between socio-economic priorities and a more proactive approach to environmental problems is brilliantly discussed in: Michael Bess, *The Light-Green Society: Ecology and Technological Modernity in France, 1960-2000* (Chicago: University of Chicago Press, 2003).

risk."[16] Taking this argument a step further, Marie-Aline Thébaud Sorger has proposed that changing English and French perceptions of air in the late eighteenth century brought about a broad "commodification of air" that fuelled the market for ventilators, lamps, "oeconomic" fire places and gas masks.[17] While historians of technology and science have viewed ventilation through the lens of changing perceptions of air as an object, architectural historians have focused on how these perceptions influenced the design of new buildings, most famously the new Palace of Westminster that was constructed during the mid-nineteenth century.[18] My project links and expands upon these studies by providing a *longue-durée* view from the inception of Stephen Hales' popular and providential vision of ventilation to the advent of climate control in the mid-nineteenth century.

Of course it would be absurd to claim that ventilation was not a concern in Western Europe before the seventeenth century. The Roman author Vitruvius emphasized that the dimensions and design of domestic buildings should relate directly to the needs and desires of the body, admitting enough light and air for comfort and health.[19] These ideas deeply influenced Italian Renaissance architects (see: Leonardo da Vinci's "Vitruvian Man") and historian of architecture Deborah Howard has argued that

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[16] Vladimir Jankovic, *Confronting the Climate* (New York, NY: Palgrave Macmillan, 2010) 4.
[17] Marie Thébaud Sorger, "Capturing the Invisible: Heat, Steam and Gases in France and Great Britain, 1750-1800." In Lissa Roberts, Simon Werrett eds. *Compound Histories: Materials, Governance and Production, 1760-1840* (Leyden: Brill, 2017): 85-105.
[18] Henrik Schoenefeldt, "The Lost (First) Chamber of the House of Commons," *AA Files* 72 (2016): 161-173; Edward J. Gillin, "Science on the Niger: Ventilation and Tropical Disease during the 1841 Niger Expedition," *Social History of Medicine* 31:3 (Sept. 2017): 605-626; Edward J. Gillin, *The Victorian Palace of Science* (Cambridge: Cambridge UP, 2017) esp. pages 121-185; Elizabeth Hallam Smith, "Ventilating the Commons, Heating the Lords," *Parliamentary History* 38:1 (March 2019): 74-102.
[19] Indra Kagis McEwan has argued that Vitruvius' ambition to provide a "corpus" of architecture was a direct reference to how he believed the body should relate to the build environment: Indra Kagis McEwan, *Vitruvius: Writing the Body of Architecture* (Cambridge, MA: MIT Press, 2003) 1-13.

environmental control was a major priority for influential early modern architects like Andreas Palladio.[20] Complementing this development in architecture, early modern medicine strongly emphasized the Hippocratic "airs, waters, places" tradition, i.e. the idea that the environment, especially air, water and food, strongly influenced both bodily composition and character.[21] In addition, eighteenth century advocates of ventilation often cited ancient and early modern machines like diving bells and bellows for mine ventilation as precursors of their own work.[22]

Classical traditions clearly informed the perceived relationship between the body and the aerial environment. However, my thesis contends that large-scale schemes of mechanical ventilation were products of the eighteenth-century craze for "improvement." Defined by historian Paul Slack as the "gradual betterment or change" of English political economy, improvement entailed the application of natural knowledge for the betterment of arts, manufacturing and agriculture.[23] For manufacturing and "arts," including the construction of machines, improvers emphasized the importance of spreading "useful knowledge" that could contribute to practical improvement.[24] Historians focusing on the social and economic role of such useful knowledge have

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[20] Deborah Howard, "Seasonal Apartments in Renaissance Italy," *Artibus et Historiae* 22:43 (2001): 127-135.

[21] Andrew Wear, "Place, Health and Disease: The *Airs, Waters, Places* Tradition in Early Modern England and North America," *Journal of Medieval and Early Modern Studies* 38:3 (Fall 2008): 443-465; See also: Charles E. Rosenberg, "Epilogue: *Airs, Waters, Places*. A Status Report," *Bulletin of the History of Medicine* 86:4 (Winter 2012): 661-670.

[22] On diving bells, see: James Delbourgo, "Underwater-works: voyages and visions of the submarine," *Endeavour:* 31:3 (September 2007): 115-120; and "Divers Things," *Hist. Sci.* xlix (2011): 149-185. For a description of ventilating machines in sixteenth-century mining, see President and mining expert Herbert Hoover and Lou Henry Hoover's translation of: Georgius Agricola, *De Re Metallica*, trans. Herbert Clark and Lou Henry Hoover (New York: Dover, 1950) 203-205.

[23] Paul Slack, *The Invention of Improvement* (Oxford: Oxford UP, 2015) 1-2.

[24] On how artisans and manufacturers attempted to apply Boylean and Newtonian natural philosophy, see: Margaret C. Jacob and Larry Stewart, *Practical Matter* (Cambridge: Harvard UP, 2004); and Lissa Roberts, Simon Schaffer and Peter Dear, eds. *The Mindful Hand* (Amsterdam: Royal Netherlands Academy of Arts and Sciences, 2007).

traditionally attempted to relate these developments to the onset of the industrial revolution.[25] However, recent studies have revealed a strong environmental character to eighteenth century improvement, as Richard Drayton has argued that the ethos of improvement spread the notion that both domestic and colonial environments could be re-made and governed.[26] Following up on this insight, Fredrik Albritton Jonsson and Anya Zilberstein have examined large-scale agricultural improvement efforts that proposed to cultivate waste-land in the Scottish highlands, and to "Europeanize" North America through planned deforestation and the transplantation of European crops.[27]

But, as the story of the Black Hole of Calcutta indicates, this growing sense of power over the natural environment was coupled with an increasing anxiety over the dangers of certain types of environments. Richard Grove has emphasized how the experience of soil exhaustion in the West Indies prompted a "desiccationist" discourse to arise that linked deforestation to soil infertility.[28] Meanwhile, Peter Brimblecombe and William Cavert have demonstrated how the seventeenth-century transition from wood to coal-burning vastly increased London's smokiness, a change that incensed contemporaries and prompted physicians to attempt some of the first measurements of the composition and healthfulness of the atmosphere. Furthermore, Cavert has argued that the obvious benefits of coal use with regard to government budgets, naval power and

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[25] The role of natural philosophy in spurring the industrial revolution has been hotly debated, as Joel Mokyr has argued for the influence of a "knowledge economy" that inspired innovation, while historians like E.A. Wrigley has emphasized the role of coal energy, and Maxine Berg has emphasized the role of consumption and consumer taste in creating markets: Joel Mokyr, *The Enlightened Economy: An Economic History of Britain 1700-1850* (New Haven, CT: Yale UP, 2012); E.A. Wrigley, *Energy and the English Industrial Revolution* (Cambridge: Cambridge UP, 2010); Maxine Berg, *Luxury and Pleasure in Eighteenth Century Britain* (New York: Oxford UP, 2005).
[26] Richard Drayton, *Nature's Government* (New Haven, CT: Yale UP, 2000).
[27] Frederik Albritton Jonsson, *Enlightenment's Frontier* (New Haven, CT: Yale UP, 2013); Anya Zilberstein, *A Temperate Empire: Making Climate Change in Early America* (Oxford: Oxford UP, 2016).
[28] Richard Grove, *Green Imperialism* (Cambridge: Cambridge UP, 1995).

manufacturing made the well-known dangers of coal smoke acceptable to eighteenth century Londoners. In Cavert's estimation, this is the same bargain that all subsequent societies have made when faced with the choice between economic growth and a clean environment.[29]

While I agree that many societies have traded environmental costs for economic benefits, I argue that they frequently did so under the assumption that aerial dangers could be circumvented through the application of new technologies and social reform. This belief has been most clearly examined in the context of the nineteenth century "sanitary revolution." Historian of Public Health Christopher Hamlin has applied a Marxist analysis to argue that Victorian sanitary reformers chose to focus on "purifying" non-commodities like air and water in order to leave profitable items like food and shelter to the free market. This economic lens has also been adopted by Dana Simmons, who argues that a desire to maximize profit inspired attempts to identify the "vital minimum" of food, water and air necessary for productive labor.[30] Both of these studies follow the convention of citing the turn of the nineteenth century, and especially the career of Lavoisier, as the crucial starting point for a renewed interest in ventilation and public health.

I argue that these studies have missed the fact that the adequate provision of fresh air was the focus of enormous amounts of natural-philosophical expertise and public investment throughout the eighteenth century. Examining the history of ventilation as an

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[29] Peter Brimblecombe, *The Big Smoke* (London: Routledge, 1987) 76-86; William M. Cavert, *The Smoke of London: Energy and Environment in the Early Modern City* (Cambridge: Cambridge UP, 2016) 35, 139-142.

[30] Christopher Hamlin, "The Necessities of Life in British Political Medicine, 1750-1850,"*Journal of Consumer Policy* 29:4 (2006): 373-397; Dana Simmons, *Vital Minimum: Need, Science and Politics in Modern France* (Chicago: University of Chicago Press, 2015).

outgrowth of the earlier passion for improvement enables me to demonstrate the longstanding entanglement between the imperial experience, projects of environmental improvement and efforts at social reform. Ventilation did not emerge as a modern "infrastructure" in the nineteenth century. Rather, it was a longstanding concern of natural philosophers and social reformers who sought to mitigate the social and environmental dangers of poverty, colonialism, overcrowding and forced labor through the application of a novel technology.

Methodology

It is my contention that ventilation and fresh air in Britain owed much to the imperial experience. But besides the peripatetic prison reformer John Howard, few of the actors in my story travelled much beyond the British Isles. I argue that despite this, their work was heavily preoccupied with the business of trade, colonization, slavery and schemes to increase the "wealth of the kingdom" through the expansion of the empire.[31] My archival sources are therefore overwhelmingly British in origin, although I have attempted to provide a full picture of imperial developments through a consultation of published primary and secondary sources.

My argument proceeds chronologically, beginning with the improvement-minded origins of mechanical ventilation in seventeenth century and concluding with the transition to a more comfort-based model of climate control in the mid nineteenth century. Since this project spans nearly two hundred years and deals with many diverse themes, I have anchored my discussion to an examination of different sites in which

[31] Increasing the "wealth of the kingdom" was a term of political economy frequently used by improvers to describe the desired outcome of their projects. See, for example: Thomas Mun, *England's Treasure by Forraign Trade* (London: Thomas Clark, 1664) 67.

ventilation was strongly emphasized. These sites include naval and slave ships, prisons and quarantine stations, and finally public buildings and private homes, all enclosed, man-made spaces where overcrowding was thought to produce an abundance of toxic "effluvia" that predisposed inmates to contagion and death.

I must beg the readers' forgiveness for not lavishing more time on hospitals, workhouses and mines. All receive brief mention, but they were not the main foci of reform for Stephen Hales, John Howard and David Boswell Reid, who are the primary actors in this study. For the purposes of this dissertation, I will note that the primary aerial concern in mines were the danger of poisonous "mine damps" rather than overcrowding and the exclusion of fresh air.[32] Thus while the ventilation of mines is a promising avenue that I intend to further explore, it lies somewhat outside of the core of my argument.

Chapter Summary

My first chapter traces the origins of mechanical ventilation and argues that attempts to re-define air and respiration in mechanical terms helped to forge a new providential ideal of environmental improvement that was closely tied to the logic of empire. The great success of Robert Boyle's air pump in measuring the effects of the "spring," or elasticity of air inspired a widespread confidence in the potential of machines to understand and manipulate the relationship between atmospheric air and the body. However, the complexity of air's chemical character frustrated mechanical explanations its role within the "animal oeconomy." The watershed moment came when Newton's

[32] The "damps of mines" was a contemporary references for gases (airs) that were either flammable or incombustible, and frequently fatal to miners. See, for example: William Rawley, *Sylva Sylvarum* (London: William Lee, 1670) 83.

matter theory and Latitudinarian doctrine allowed air to be re-interpreted as a providential chaos – a complex medium that enabled all natural processes. This changed the nature of air from a subject of debate into an article of faith. The question became not *what* air was, but rather *how* it could be manipulated for human ends, such as the maintenance of health in mines and ships and the preservation of grain. Air became a political object, and subject to the same "improvement" efforts being pursued in other aspects of English society and environment

The second chapter examines a primary site of this improvement effort: the Royal Navy. Long-distance seafaring, which necessitated extended periods in a salty environment as well as "seasoning," or transition between climates, had long been considered a perilous undertaking due to the inherent danger of being away from the terrestrial environment. However, as the wars with France and the expanding British colonies necessitated the transportation of more maritime and enslaved laborers to the far reaches of the empire, natural philosophers sought to employ mechanical ventilation as a means of turning ships into a healthier environment and preserving the scarce labor pool of skilled seamen. However, I argue that the failure of ventilating devices to adequately insure the health of sailors led to a further essentializing of certain climates as "healthy" or "unhealthy" – an argument that was employed by abolitionists to argue that slave ships were putting both maritime laborers and enslaved laborers at serious risk.

The third chapter examines the role of ventilation and contagion theory in prison reform during the late eighteenth century. Crowded, filthy and long-neglected English prisons had long been recognized as dangerous centers of moral and physical contagion. This chapter examines how the reconstruction of Newgate Prison and the work of famous prison reformer John Howard were deeply influenced by concepts of aerial contagion and practices of quarantine – a connection made explicit in Howard's sponsorship of a proposed quarantine station to be built on the River Medway. I argue that the perceived failure of ventilation and enforced hygiene to reform prisoner behavior marked a transition of the central object of state-sponsored reform from the environment to the individual.

Finally, the fourth chapter will pick up on this theme of individual versus state responsibility for the aerial environment to trace how ventilation moved out of the realm of institutional reform to became a nearly-universal feature of domestic architecture. As pneumatic chemists re-ordered the relationship between heat and the respirability of air became clearer in the late eighteenth century, a new commercial market emerged for comfortable, heated and air-purified environments. Couched in the new chemical language of Lavoisier and promoted by shrewd salesmen like the Marquis de Chabannes, machines that purported to provide controlled environments were deeply appealing to an English middle- and upper-class that was fearful of the dangers and inconvenience of the public urban environment and were eager to purchase a means of insuring domestic health and environmental comfort. David Boswell Reid's spectacular success at constructing controlled environments in Edinburgh and the temporary House of Commons and his spectacular failure at finding a means of objectively measuring aerial comfort meant that climate control moved firmly out of the hands of chemists and physicians and into the private and commercial realm of the market.

Ventilating the Empire traces how ventilation evolved from a projected means of extending the providential power of fresh air in the service of Empire into a technology of insulation that sought to isolate the diseased and dangerous elements of society from the rest of the body politic. As a means of managing the aerial boundary between human beings and the natural world, ventilation reflected how a shifting understanding of the aerial environment was influenced by both a desire to preserve health and a fear of overcrowding and the danger of foreign environments. *Ventilating the Empire* is a story of how an emerging negotiation between the priorities of political economy and understandings of nature came to revolve around machines proposed to mitigate environmental dangers. This negotiation is ongoing.

Chapter 1
Controlling Chaos: The Origins of Mechanical Ventilation

Abstract:

This chapter traces the origins of mechanical ventilation. I argue that efforts to interpret air and respiration in mechanical terms helped to forge a new providential ideal of environmental improvement that was closely tied to the logic of empire. The great success of Robert Boyle's air pump in measuring the effects of the "spring," or elasticity of air inspired a widespread confidence in the potential of machines to understand and manipulate the relationship between atmospheric air and the body. However, the complexity of air's chemical character frustrated mechanical explanations its role within the "animal oeconomy." The watershed moment came when Newton's matter theory and Latitudinarian doctrine allowed air to be re-interpreted as a providential chaos – a complex medium that enabled all natural processes. This changed the nature of air from a subject of debate into an article of faith. The question became not *what* air was, but rather *how* it could be manipulated for human ends, such as the maintenance of health in mines and ships and the preservation of grain. Air became a political object, and subject to the same "improvement" efforts being pursued in other aspects of English society and environment.

Introduction: The Fierie Spirit

In 1607, a remarkable machine was presented to James I by Dutch artisan and chymist Cornelius Drebbel. Dubbed a *Perpetuum Mobile*, or perpetual motion, this machine consisted of a brass globe, representing the earth, that was filled with "divers wheeles of brasse, carried about with moving." On the face of this globe was displayed a dazzling array of celestial information. Brass pointers showed not only the "days, months, and yeeres" but the "hours of the rising and setting of the sunne," the "signe the moon is in every 24 houres…what degree the sunne is distant from the moone," and what "signe of the Zodiacke, the sunne is in every month." Around the circumference of the globe was a "ring of Cristall Glasse, which being hollow, hath in it water, representing the sea." This water rose and fell "as doth the floud, and ebbe, twice in 24 houres, according to the course of the tides in those parts, where this instrument shall be placed." But while mechanical models of the universe were not unknown, this device had an incredible secret: it not only represented the natural and celestial forces of the universe – it was a perpetual motion machine *powered* by those mysterious forces. But how did Drebbel accomplish this mind-boggling feat? His contemporary, the Puritan author Thomas Tymme, wrote that Drebbel had somehow used his alchemy to extract "a fierie spirit," which, once being joined "with his proper air…carrieth the wheels, making a continuall rotation or revolution" which King James "could hardly believe."[33]

A few years later, Drebbel once again demonstrated the power of this mysterious "spirit." Having constructed a small, water-tight wooden compartment, Drebbel and a crew of twelve oarsmen rowed into the current of the river. Then, to the awe of King James and a crowd of assembled notables, they submerged for over three hours. When his crew found themselves "languishing…in the air shut up with them," Drebbel opened a "phiol, that dilated itself with fresh spirits into that stale, depredated and exhausted air"

[33] Thomas Tymme, *A Dialogue Philosophicall* (London: T.S. for Clement Knight, 1612) 60-62.

thus providing the crowded submariners with this much needed "food of the lungs, and the nourishment of the spirits."[34]

The ultimate illustration of the potential of Drebbel's "fierie" substance was a "Great Design" proposed to James I in 1622. Desirous of opening trade with Jahangir, the Mughal Emperor, James I had commissioned Drebbel to propose a "grand design" for curiosities and machines that would appeal to this fabulously wealthy monarch. Drebbel's proposal was breathtakingly ambitious. He would use his mysterious "spirit" to cool the Emperor's palace and build many submarines for pearl-diving and treasure-hunting. Besides reaping fabulous rewards for Jahangir and James I, this mutually-beneficial partnership between the monarchs would enable a vast expansion of English trade and deal a blow the Catholic empires of France and Spain.[35]

While his schemes failed to impress the Mughul emperor, Drebbel's "fierie spirit" that refreshed the air was a revelation to his fellow chymists and natural philosophers.[36] In his sole published treatise, *On the Nature of the Elements*, Drebbel argued in forceful language that the four elements were continually transmuting into one another – water transmuting into air, and air into fire – a process that could be controlled through the extraction of a substance that alchemists referred to as *magnesia* – a material that would enable one to control the "spirit of the world," or the vivifying agent contained in all matter that lay at the root of all motion in the universe.[37] By demonstrating this action

[34] Kenelm Digby, *Discourse Concerning the Vegetation of Plants* (London: John Dakins, 1661) 65. Gerrit Tierie speculates that the substance in the vial was saltpeter, which produces a cooling effect when mixed with water: Gerrit Tierie, *Cornelius Drebbel* (Amsterdam: H.J. Paris, 1932) 65.
[35] Vera Keller, "Air-Conditioning Jahangir: The 1622 English Great Design, Climate and the nature of Global Projects," *Configurations* 21:3 (Fall 2013): 331-367.
[36] Tierie, *Drebbel*, 64-71.
[37] Vera Keller has written extensively on this aspect of Drebbel's work. See: Vera Keller, "Drebbel's Living Instruments," *History of Science* xlviii (2010): 39-74; Vera Keller, "How to Become a Seventeenth-

within the context of useful machines, Drebbel had shown how natural forces could be managed for human ends. An inspired Francis Bacon referred to Drebbel's project as a "Polychrest" – a discovery that would have multifarious uses and lead to an expansion of human capacity.[38] Using alchemical methods, Drebbel sought to understand how air could be renewed for respiration and what part it played in the overall system of the world. Finally, he sought to employ chemical and mechanical means to use this knowledge for the ends of increasing the wealth and power of the English monarchy.

To control air is to control the world. But how does one control air? Throughout the early modern period, this "subtile" spirit resisted efforts to contain and study it, constantly escaping through receivers, and sighing from the lungs of carefully-dissected animals. One of the four classical elements described by Aristotle and developed by medieval alchemist Jabir Ibn Hayyan, air was crucially important to sustaining life – "so needful to creatures, that none liveth without it" – yet was understood primarily in terms of its qualities rather than its substance.[39] Galenic medicine, derived from the Aristotelian system, associated the four elements each with a particular bodily fluid, or humor. Air was thus associated with blood, and the heat, cold, moisture or dryness of the air were qualities it imparted to the blood via respiration.[40]

Century Natural Philosopher: The Case of Cornelius Drebbel" in Dupré et. al. eds. *Silent Messengers* (Berlin: Lit Verlag, 2011): 125-151.

[38] Vera Keller, "Air Conditioning Jahangir," 363; The influence of Bacon's reference can be seen in later references to saltpetre mixtures used in chemical cooling as "Sal Polychrestum": "Polychrest, n.". OED Online. March 2020. Oxford University Press. http://www.oed.com/viewdictionaryentry/Entry/11125 (accessed April 14, 2020).

[39] John Norris, "The Mineral Exhalation Theory of Metallogenesis in Pre-Modern Mineral Science," *Ambix* 53:1 (July 2013): 43-65; Wilhelm Adolf Scribonius, *Naturall Philosophy* (London: I.D. for Iohn Bellamie, 1621) 14.

[40] Heikki Mikkeli, *Hygiene in the Early Modern Medical Tradition* (Helsinki: Academia Scientiarum Fennica, 1999) 16.

The essential life-giving property of air was attributed to an indescribable "quintessence" which provided fuel to the "vital fire" that resided in the heart. Likewise, it appeared obvious that exhaled air, moistened, heated and deprived of its vivifying property, was a mere "carcase" that could no longer sustain life.[41] As one of the six Galenic "non-naturals," or substances that could not be produced within the body, sufficient air was absolutely necessary for human beings trying to plumb the depths of the earth in mines or descend into the watery deeps in diving bells. Fire could be kindled, and food and water could be carried, but air, that "ambient body" that abounded on the surface of the earth, appeared impossible to control.[42]

This chapter will examine the origins of mechanical ventilation by looking at how the experimental and theoretical work of seventeenth and eighteenth century natural philosophers transformed air's role as a mediator between the macrocosm of nature and the microcosm of the human body. Richard Drayton and Fredrik Albritton Jonsson have rightly noted that efforts to improve nature – through irrigation, transplantation of crops, and the introduction of new tools and techniques, were frequently tied to efforts to transform human society. My work extends this inquiry by demonstrating how machines were explicitly employed to mediate between humanity and nature by controlling the most critical medium of contact between bodies and the environment – the air.[43]

In order to make this argument, I will examine several influential attempts to understand the characteristics of air and its role in the "animal oeconomy," a term that

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[41] Robert G. Frank, *Harvey and the Oxford Physiologists* (Berkeley, CA: University of California Press, 1980) 6; Robert Boyle, *New Experiments Physico-Mechanical, Touching the Air,* 3rd. ed. (London: Miles Flesher 1682) 186.
[42] Boyle uses the term "ambient" 107 times in his *New Experiments* in order to contrast the conditions within his air pump with the ambient air outside.
[43] Richard Drayton, *Nature's Government* (New Haven, CT: Yale UP, 2000) 55; Fredrik Albritton Jonsson, *Enlightenment's Frontier* (New Haven, CT: Yale UP, 2013) 2-6.

began to be employed by eighteenth century physicians to describe the inner structure and processes of the human body.[44] While many of the experiments described in this chapter are well-covered ground by historians of science, I will be paying special attention to how this work was understood in relation to the cosmological relationship between human bodies and the natural environment.

For example, while Cornelius Drebbel's *perpetuum mobile* has frequently been described as an early example of a thermometer, Vera Keller has observed that Drebbel and his contemporaries saw it as a "cosmoscope" – a machine that demonstrated the forces of the universe as well as how those forces could be employed.[45] Machines that demonstrated natural phenomena in miniature were a crucial feature of seventeenth and eighteenth-century natural science. When replicating the universe, as in the case of orreries or mobiles, these machines catered to an elite desire for mastery over the mysterious forces of nature.[46] Ultimately, I will argue that the emergence of machines that promised to measure and mediate between the natural environment and the body helped to forge a new providential ideal of environmental improvement that was closely tied to the logic of empire.

This chapter will first examine Robert Boyle and Robert Hooke's famous efforts to understand the nature of the air and its role in respiration. By using machines like the air-pump and a human-sized air-tight chamber to re-interpret the functioning of the body

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[44] The significance of the term "animal oeconomy" varied for different schools of medicine, but it generally referred to the distribution of vital, frequently Newtonian, forces within the body. On the origin and variations of the term, see: Philippe Huneman, "'Animal Economy': Anthropology and the Rise of Psychiatry from the Encyclopédie to the Alienists," in *The Anthropology of the Enlightenment*, edited by Larry Wolff and Marco Cipolloni (Stanford: Stanford University, 2007) 262–276.

[45] Keller, "Drebbel's Living Instruments," 42-3.

[46] Historian John Tresch has pointed out that these machines and related "cosmograms" have also been used throughout history as a means of orienting oneself within the received order of nature: see John Tresch, "Technological World-Pictures: Cosmic Things and Cosmograms," *Isis* 98:1 (2007): 84-99.

in mechanical terms, these men hoped to bring many "phaenomena" within the realm of human understanding, a development that, in the words of Robert Boyle, seemed "likely to prove of moment to Mankinde."[47] The great success of Boyle's air pump in measuring the effects of the "spring," or expansive qualities, of air inspired a widespread confidence in the potential of machines to discern the relationship between atmospheric air and the body. However, the inability of the air pump to solve the puzzle of respiration and John Mayow's ambitious chemical theory of air meant temporarily frustrated mechanical interpretations. The watershed moment came when Newton's matter theory and Latitudinarian doctrine re-interpreted air as a providential chaos – a complex medium that enabled all natural processes. This changed the nature of the air from a subject of debate into an article of faith: the question became not *what* air was, but rather *how* air could be manipulated for human ends. By discerning the proper means to manage this substance the English monarch could become, in the words of diarist and Royal Society member John Evelyn, "the very Breath of our Nostrills."[48]

From Quintessence to Spring: Boyle and Hooke's Mechanics of Air

To Robert Boyle, restoring "to the troubled air…a certain Quintessence (as chymists speak)" was an achievement for which Cornelius Drebbel was "deservedly famous." However, he was careful to mention that his admiration of Drebbel did not constitute any "assent to his opinion."[49] Boyle did not condemn alchemy – indeed he was

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[47] Boyle, *New Experiments*, 2.
[48] John Evelyn, *Fumifugium* (London: W. Godbid, 1661) 5; For the politics of air in Evelyn and Boyle, see also: Mark Jenner, "The Politics of London Air: John Evelyn's *Fumifugium* and the Restoration," *The Historical Journal* 38:3 (1995): 535-551.
[49] Robert Boyle, *New Experiments*, 185-7.

an avid partaker in alchemical work.[50] Rather, he was distinguishing between Drebbel's broad claims of elemental transmutation, and his own agenda for remaking natural philosophy as the demonstration of limited claims in front of credible witnesses.[51] Machines were crucial to this effort. By describing the action of air in mechanical terms, Boyle and his collaborator Robert Hooke hoped to identify this mysterious, life-sustaining "quintessence" of air as a mechanical force, thus eliding chymical and cosmological ideas about the atmosphere and reserving a place for God's providence. By doing so, this approach enabled a mechanical reinterpretation of the relationship between the body and the atmospheric air, a crucial development for mechanical ventilation.

The central machine in these experiments was Boyle's famous air pump, constructed by Robert Hooke based on Otto Von Guericke's earlier model. In the simplest terms, the pump consisted of a spherical glass "receiver," a piston that could be worked to pump air out of it, and a four-inch-wide opening at the top through which objects could be placed inside the receiver. With the use of specialized tools and a carefully-applied sealing compound, items placed inside could be manipulated once the air had been evacuated.[52] By placing animals and plants within the receiver and removing the "external air," Boyle hoped that his pump could test the effect of the atmosphere on the "preservation of animal and other bodies" as well as on the "germination and growth of vegetables."[53]

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[50] See, for example: Lawrence Principe, *The Aspiring Adept: Robert Boyle and His Alchemical Quest* (Princeton, NJ: Princeton UP, 1998).
[51] On Boyle's plan for the formulation for the experimental production of "facts" and his now-famous dispute with Thomas Hobbes over this conception, see: Steven Shapin and Simon Shaffer, *Leviathan and the Air Pump: Hobbes, Boyle, and the Experimental Life* (Princeton, NJ: Princeton UP, 1985) 22-80.
[52] Boyle, *New Experiments*, 4-9; Shapin and Schaffer, *Leviathan and the Air Pump*, 26-30.
[53] Boyld, *New Experiments*, 10.

Boyle's course of investigation in his *New Experiments Physico-Mechanical, Touching the Air* was deeply influenced by the classical concept of life as a fire, or "vital flame" within the heart that was nourished or regulated by some quality of the air. This classical image, which had been used by physicians from Galen to Paracelsus, had recently been elaborated by Oxford physician Ralph Bathurst, who had proposed the ubiquitous presence of a "pabulum nitrosum" or aerial niter (similar to saltpeter) which enabled flame to be kindled as well as provided nourishment for plants and animals.[54] Boyle was deeply familiar with Bathurst's lectures, and had taken parts in attempts to distill niter from atmospheric air and other substances, including a malodorous attempt at seeding saltpeter by watering it with "urine passt first through horse dung."[55] However, due to the systematic and alchemical bent of niter-related claims – which credited nitrous salt with the "foecundity of all things," Boyle was determined to re-interpret the vital quality of air in physical rather than chymical terms.[56]

While he never fully rejected the concept of "quintessence" or aerial niter, Boyle determined that the essential quality of air was it's "spring" or "elasticity." This concept – that air was composed of compressible particles that would contract under pressure and then re-expand, or "rarefy" to fill any space, became synonymous with Boyle's pneumatic philosophy.[57] Assisted by Hooke, Boyle sought to employ this concept to understand respiration. After placing mice, insects and birds within the receiver of the air pump, they found that when the receiver was evacuated, and the "spring" severely

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[54] Frank, *Harvey and the Oxford Physiologists*, 106-112.
[55] Boyle quoted in Frank, *Harvey and the Oxford Physiologists*, 122.
[56] Digby, *A Discourse Concerning the Vegetation of Plants*, 61; Frank, *Harvey and the Oxford Physiologists*, 127.
[57] Frank, *Harvey and the Oxford Physiologists*, 135-6.

rarified, the lungs ceased to distend. The lungs were not actively drawing air into the body – rather, the relaxation of the diaphragm allowed atmospheric air to rush in and fill them. In the words of Boyle, the lungs "may fitly be compar'd to a bladder" which was "dilated by being fill'd, namely, by that air which rusheth into them upon the dilation of the chest, in whose increased cavity it [the air] finds less resistance to its spring than elsewhere."[58]

Thus the spring, or "elasticity" of the air, was deemed crucial to the mechanical action of respiration. But the role that air played within the body was still mysterious. For Boyle, widely varying reactions of living creatures upon being subjected to the air pump made "respiration appear to me rather a more, than a less mysterious thing, than it did before." Crucially, however, Boyle speculated that one of the principle uses of air in respiration was for *ventilation* – "the depuration of blood" that "passeth through the lungs."[59] While there was almost certainly another vital purpose for air, Boyle's most strongly stated hypothesis was that respired air somehow carried off foul particles from the blood. In part, this could explain why animals eventually died even in sealed receivers with "no inconsiderable quantity" of air. The contained air was not sufficient to "receive the fulginous steams, from which, expiration discharges from the lungs; and, which…may be suspected, for want of room, to stifle those animals that are closely pen'd up in too narrow receptacles."[60]

But while Hooke and Boyle both suspected that the air contained some element necessary for respiration, they continued to look for the elusive link between aerial

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[58] Boyle, *New Experiments*, 167-170, 174.
[59] Boyle, *New Experiments*, 171, 196.
[60] Boyle, *New Experiments*, 168-9.

elasticity and respiration. Over the course of the next few years, Robert Hooke conducted periodic experiments before the Royal Society that attempted to zero in on the relationship between the properties of elastic air and the role of respiration in the bodily economy. One proposed idea was that the air's spring enabled the mechanical inflation and deflation of the lungs, which, in turn facilitated the processes of blood circulation, which in turn enabled the "concoction" of food in the stomach. However, a gruesome experiment by Hooke disproved this. By puncturing and then continually blowing air through the lungs of a vivisected dog, Hooke managed to provide air to the lungs without allowing them to move. The continuance and relative regularity of the dog's heartbeat proved that the motion of the lungs was not an essential life-giving property.[61]

Hoping that an experiment within his *own* body might reveal some relationship between elasticity and respiration, Hooke proposed to the Royal Society that an "air-vessel" be constructed that could fit a grown man - himself. His design consisted of two "tuns," or casks, one large enough to contain the other, with the inner cask large enough to hold a man. The inner cask would be fitted with a lid that could be "put on with cement" as well as a gauge to see "what degree the air is rarified" and a cock through which air could be let in if necessary. The outer barrel would be then filled with water so that the inner barrel was completely submerged.

This simple but clever device received the enthusiastic support of the society, and Hooke proceeded to construct and test his machine with himself as the subject. At the next meeting, Hooke reported that he had been able to stay in the vessel for "about a quarter of an hour" without "any inconvenience." For his next experiment, he decided to

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[61] "An Account of an Experiment made by M. Hook, of Preserving Animals alive by Blowing through their Lungs with Bellows," *Phil. Trans.* 2:28 (1667): 53-4; Frank, *Harvey and the Oxford Physiologists*, 200-1.

add a valved pair of bellows which would enable him to further rarify the internal air. After blowing out a tenth of the air in the vessel (measured by the gauge inside), he found "no inconvenience but that of some pain in his ears." On a subsequent experiment, Hooke managed to remain in the vessel while blowing out a quarter of the air inside, again with no effect but the uncomfortable pressure in his ears. But this experiment was accompanied with another observation – the candle that he had brought with him into the apparatus had been snuffed out *before* he had perceived any ear discomfort. Apparently, the pressure of the air did not relate to its ability to sustain combustion.[62]

In response to these confusing results, Hooke appears to have leaned towards a chymical explanation of air's properties. Writing in the wake of Boyle's air pump experiments, Hooke speculated that air behaved like a "tincture" that absorbed a great variety of particles in its passage through the "aether" of the atmosphere. Some of these particles served the purpose of respiration and others for combustion. While natural philosophers had found out how to contain and test air within a glass vessel, they had not yet found out the means of "*precipitating* air…as we can tinctures."[63] Boyle, on the other hand, had continued to focus on attempts to determine the physical effects of respiration and combustion on air by conducting a farther series of air pump experiments on ducks, frogs, vipers and kittens. Similar to Hooke's findings in his human-sized vessel, he found that flame consistently went out far more quickly than the animals suffocated. Moreover, in some experiments, the animals appeared to die in a closed receiver without the air losing any of its elasticity. The ambiguity of some of these results led Boyle to declare

[62] Thomas Birch, *A History of the Royal Society of London for Improving Natural Knowledge* (London: A. Millar, 1756) II: 462-473.
[63] Robert Hooke, *Micrographia* (London: John Martyn, 1665) 13-14.

that while the role of air in sustaining both flame and life "may be shewn to be very large and considerable," his results meant that he was now reluctant to "assert to it a larger jurisdiction than I find Nature to have assigned it."[64]

In twenty years of experiments, neither Boyle nor Hooke had managed to identify the direct role of air within the body. That honor fell to another, far less famous member of their circle, John Mayow. Done without the use of an air pump, Mayow's "experimentum crucis" was brilliant in its simplicity. Placing a "moistened bladder" over the opening of a vessel filled with atmospheric air, Mayow placed a bell jar with a mouse in it on top of the bladder. Then he placed a small weight on that jar "lest the animal inside should upset it." As the mouse was left to respire, Mayow discovered, the skin of the bladder would bulge inside the bell jar. What this proved, in Mayow's reckoning, was that "the elastic power of the air enclosed in the aforesaid jar has been diminished by the breathing of the animal, so that it is no longer able to resist the pressure of the surrounding air."[65] Without the use of an air pump, Mayow had proven something that Hooke and Boyle had been unable to verify - that respiration and combustion *did* remove some of the elasticity from the air.

Mayow wasted no time theorizing his results. Returning to the idea of the "pabulum nitrosum" posited by Bathurst, Mayow argued that both combustion and respiration drew from air "certain vital particles which are also elastic." These "nitrous particles" which were contained in air, contributed some of the air's elasticity, and, in his

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[64] Robert Boyle, *New Experiments touching the Relation betwixt Flame and Air* (London: Richard Davis, 1673) 17; Robert Boyle, "New Pneumatical Experiments about Respiration," *Phil. Trans.* 5:62 (1670): 2011-2031; See also: Robert G. Frank's interpretation of Boyle's work: Frank, *Harvey and the Oxford Physiologists*, 255-263.
[65] John Mayow, *Medico-Physical Works, Being a Translation of Tractatus Quinque Medico Physici* (Edinburgh: The Alembic Club, 1907) 72.

estimation, were also the crucial particles for fermentation within the body.[66] By deploying this broad explanatory framework, Mayow was able to solve the questions of respiration, circulation, *and* the origin of heat within the body.

For Mayow, the presence of “nitro-aerial” particles in the air held the key not only to understanding bodily processes but also to the motion and action of the atmosphere. The air, deprived of these particles either “by the burning of fire, or by the breathing of animals,” was consequently deprived of its weight and elasticity, and was driven upwards into the atmosphere, where, upon “entering the fiery element…[they] immediately glow and are impregnated anew with nitro-aerial particles.” Mayow envisioned this as a global process, whereby the inelastic aerial particles which had been deprived of their nitrous character were borne upwards by the “intense heat” of the “meridional region,” then, once being refreshed, were conveyed “obliquely towards the poles” until they reached the “lower earth for the various needs of animals.” Through this process, Mayow reasoned, “the aerial particles seem to circulated like a macrocosmic blood.” In another remarkable analogy Mayow described how, by taking on the “nitro-aerial spirit” in a “perpetual circuit” through the atmosphere, “even the air itself…in some sense breathes.”[67]

Mayow’s ambitious relation of the macrocosmic action of the atmosphere to the microcosmic processes within the body was visionary. His ideas about the air were informed not only by experimentation, but also by clever analogies to both chemical and mechanical examples. The increase in the air’s weight when “impregnated” with nitro-aerial particles was compared to a similar weight increase that happened to “antimony

[66] Mayow, *Medico-Physical Works*, 73-74, 105-8; See also: Frank, *Harvey and the Oxford Physiologists*, 263-274.
[67] Mayow, *Medico-Physical Works*, 92-3.

when calcined by solar rays." Likewise, the dry and cold north wind could be explained by the pressure placed on aerial particles as they were covered by the weight of "superincumbent air" – an action that compressed the aerial particles like a "steel spring that sets automata in motion."[68] Mayow's system brilliantly synthesized chymical ideas with the experimental results of Hooke and Boyle and the anatomical work of Malpighi to provide a holistic picture of the relationship between the macrocosm and microcosm.

Not all were impressed. After writing a painstakingly-detailed review in the *Philosophical Transactions*, secretary Henry Oldenburg wrote to Boyle that Mayow's work that "some very learn'd and knowing men speake very slightingly of ye Quinque Tractatus" which, in Oldenburg's opinion, contained "more errors than one in every page."[69] Mayow's broad vision of the air as the key solution to both macrocosmic and microcosmic mysteries ran counter to the pointed suspicion of systematizing that Boyle had attempted to instill in his circle.[70] Boyle envisioned his air pump as an experimental space in which assent to "matters of fact" could be produced by credible eyewitnessing *without* necessitating broader claims.[71] By describing niter as the "macrocosmic seed of the earth" that could explain not only respiration but also weather, the germination of plants and the production of minerals, Mayow had edged up to arguing that nature was fully knowable.[72] For the pious Boyle and his followers, who insisted that any system maintain an open-ended role for God's providence, this was a dangerous path. Machines could disclose *how* things worked – but the explanation of *why* they worked always had

[68] Mayow, *Medico-Physical Works*, 92-3.
[69] Oldenburg quoted in J.R. Partington, *A History of Chemistry* (London: Macmillan, 1961) II: 584.
[70] Frank, *Harvey and the Oxford Physiologists*, 274, 275-294.
[71] Shapin and Schaffer, *Leviathan*, 298-310.
[72] Mayow, *Medico-Physical Works*, vii, 5.

to include a strong deference to God's providence. The irony was that by eliding chymical and causal explanations in favor of mechanistic ones, pious physicians and natural philosophers were creating a crucial role for machines in God's providential plan.

Air, Blood and Chaos: Newtonian Matter Theory and the Animal Oeconomy

Boyle and Hooke's experiments on the mechanical nature of air played into a much broader controversy that had been raging over the fundamental character of matter. In his 1644 *Principiae Philosophiae,* René Descartes had posited that the universe began when God set apart the primordial mass of inchoate matter into parts with different characters that behaved according to rational laws. Once the laws that governed these parts were put in place, the whole was set in motion and God became merely the guarantor of continued motion in an infinite and rational universe.[73] In an elaboration on Descartes' theory, Gottfried Wilhelm Leibniz argued that each part, or "monad," must possess an individual and innate force that played its part in the enormous clockwork. God's design was thus expressed through a mechanism that teemed with individual "souls" – but the perfect overall structure precluded accidental or miraculous action.[74]

This explanation was fiercely rejected by Isaac Newton, who feared that God's sovereignty would be compromised in a system that relegated him to the role of a glorified clockmaker. While Newton accepted that much of the "phaenomena" of the universe could certainly be understood by mechanical principles, he declared that "the very first cause [of motion] certainly is not mechanical."[75] This belief was supported by the existence of a vacuum within the receiver of Boyle's air pump, which lent support to

[73] Peter Dear, *The Intelligibility of Nature* (Chicago: University of Chicago Press, 2006) 16-19.
[74] Jessica Riskin, *The Restless Clock* (Chicago: University of Chicago Press, 2016) 79, 98, 107-110.
[75] Isaac Newton, *Opticks* fourth ed. (New York: Dover, 1952 [London 1730]) 369.

the idea that neither the motion of the planets nor the motions of the human body could not be explained by a contiguous mechanical chain of particles acting upon one another. Instead, Newton proposed in his famous Query 31 of *Opticks*, “have not the small particles of bodies certain powers, virtues, or forces, by which they act at a distance…upon one another for producing a great part of the phaenomena of nature?”[76]

This reformulation of matter theory – that particles contained within themselves innate forces that determined their overall organization and action – utterly transformed conceptions of how both the microcosm and macrocosm functioned. Besides the heavenly bodies, Newton also proposed that his new mechanics could be applied to explain the motions within animal and human bodies, as well as processes within the atmosphere. In the air, particles were continually attracting to one another and transmuting into each other, as “dense bodies by fermentation rarify into several sorts of air, and this air by fermentation, and sometimes without it, returns into dense bodies.” Newton appeared to echo Drebbel when he wrote that nature “seems delighted with transmutations.”[77]

Ironically, by detaching the understanding of mechanics from a direct physical cause, Newton’s doctrine of particle attraction further enabled mechanistic interpretations of nature. By replacing direct physical causality with a harmonious but independent motion of parts, a “machine” could be understood as a complex system in which each particle moved according to a divine design. This idea was quickly translated into studies of anatomy, a development most clearly apparent in the writings of “iatro-mechanist” physicians Archibald Pitcairne and James Keill, who each professed the compatibility of

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[76] Newton, *Opticks*, 375-6.
[77] Newton, *Opticks*, 375.

their physiological work with Newton's principles. James Keill could therefore describe the human body as a "pure machine" whose "actions and motions are demonstrated to be the necessary consequences of its structure" while at the same time condemning the Cartesian idea that bodies could be likened to automata.[78] Similarly, Pitcairne could argue that the distribution of nourishing particles to various parts of the body was determined by the each particle's *innate* attractions – forces which Newton attributed to God's direct and ever-present influence.[79]

Pitcairne's overall project attempted to measure bodily processes by applying straightforward methods of mechanical calculation. For example, by extrapolating the pressure of the muscles surrounding the stomach from the pressure exerted by "the muscle that bends the third joint of the Man's thumb," Pitcairne estimated that digesting food was subjected to a pressure of "12951 pound, which is quadruple the natural power of the heart."[80] With respiration, Pitcairne went further, declaring that, contra Mayow's idea of the aerial niter, "no part of the air, under any denomination, enters the vessels of the lungs." Rather, the mechanical action of respiration, enabled by the elasticity and "gravity" of the air, altered the shape of the particles of blood as they passed through the lungs and enabled its distribution throughout the body.[81]

It is not clear how Pitcairne's system accounted for Hooke's famous experiment in which a dog had survived without the motion of its lungs, but his emphasis on the

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[78] James Keill, *An Account of Animal Secretion* (London: George Strahan, 1708) iii, xix, 3; René Descartes, *Discourse on Method and the Meditations*, trans. F.E. Sutcliffe (New York, NY: Penguin Books, 1968 [original 1637]) 73.
[79] Newton, *Opticks*, 370; Archibald Pitcairne, *The Works of Dr. Archibald Pitcairn* (London: E. Curll, 1715) 43-4; Anita Guerrini, "James Keill, George Cheyne, and Newtonian Physiology, 1690-1740," *Journal of the History of Biology*, 18:2 (Summer 1985): 250-1.
[80] Guerrini, "James Keill," 251.
[81] Pitcairne, *Works*, 82-3, 87-8.

closed nature of respiration was further articulated by his associate James Keill. While he agreed with Pitcairne that the mechanical motion of the lungs served to change the shape of particles within the blood, Keill also emphasized the "elastick power of the vessels" which could gradually expand or contract depending on the viscosity of the blood and the overall condition of the body.[82] But Keill's biggest innovation was the integration of Marcello Malpighi's discovery of the capillaries and alveoli in the lungs with Boyle's measurements of the "spring" and weight of the air. Estimating the surface area of the lungs to be an astounding 21,906 inches in total, Keill reasoned that with the blood spread in "the smallest capillary vessels…each globule of blood might as it were immediately receive the whole force and energy of the air, and by that be broken into smaller parts fit for secretion and circulation." This, in Keill's estimation, was the true "mechanical reason of the structure of the lungs" – they enabled the blood to "receive the virtue of the air" – virtue in this case signifying air's elastic qualities. Through this "virtuous" action of decompression, the air *physically* pressed on the blood to enable the various particles of the blood to "dissolve all the cohesions they might contract in their circulation thro' the arteries and veins" and impart their essential particles to the various parts of the body while also absorbing and secreting waste particles. Furthermore, Keill reasoned, the "intestine motion" of the blood must be enabled by the fact that "many of the particles of the blood are elastick."[83]

However, this system still relied on the elasticity of the *air* – somehow, despite not coming into direct contact, Keill reasoned that many elastic air particles were

[82] James Keill, *Account of Animal Secretion*, 97-8.
[83] James Keill, *Essays on the Several Parts of the Animal Oeconomy*, second ed. (London: George Strahan, 1717) 123-128.

imparted into the blood. The truth of this claim could be evidenced by the "great number of globules of air" in the blood, "evident from the quantity it yields in the air pump."[84] Despite the efforts of air pumps, microscopes or chemical assaying, it remained impossible to discern the precise relationship between air and the inner working of the body. Ultimately, James Keill described the blood as a kind of balanced chaos - a "simple and limpid fluid in which swim corpuscles of various figures and magnitudes, and endued with different degrees of an attractive force."[85]

This chaotic concept of blood was echoed by contemporary descriptions of the atmospheric air. Dutch chymist and physician Herman Boerhaave described the air as a "chaos, wherein all kinds of bodies float" that produced "an infinite number of effects." Just as Newton's doctrine of particle attraction had been inspired by a desire to preserve God's sovereign action in the universe, Dutch chymist and phyisican Boerhaave maintained that the mysterious character of atmospheric air was evidence of God's providential working through nature. By invoking a "chaos" to describe air's complex character, Boerhaave did not mean a meaningless and purposeless mass. Rather, he was referring to a conception voiced by English botanist and natural philosopher John Ray in his *Three Physico-Theological Discourses* – that a "*Chaos*, if soberly understood" referred to something "in the first place created by God, and preceding other beings, which were made out of it." Created by God, this chaos was subject to physical laws, "containing in its self the principles of all simple inanimate bodies" which were "variously and confusingly commixed, as though they had been carelessly shaken and

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[84] Keill, *Essays*, 209-215.
[85] Keill, *Animal Secretion*, 3; Herman Boerhaave, *A New Method of Chemistry*, trans. Peter Shaw and Ephraim Chambers (London: J. Osborn, 1727) 301.

shuffled together, yet not so, but that there was order observed by the most Wise Creator in the disposition of them."[86]

Boerhaave's strong Calvinist belief that man could not fully grasp the processes of nature could be married with Newton's version of particle attractions by explaining Newton's notion of "dense bodies" constantly rarifying and condensing into one another through the action of an aerial "chaos" containing "all kinds of menstruums."[87] Under the influence of pious natural philosophers, this conception of the atmospheric air would be placed at the center of one of the most ambitious improvement projects of the eighteenth century.

Stephen Hales' "Attempt to Analyse the Air by Chymico-Statickal Experiments"

"The necessary qualifications of an experimental philosopher" wrote renowned demonstrator and improver J.T. Desaguliers, are a "mechanical hand, and a mathematical head." Specifically, he was attributing these qualities to the Reverend Stephen Hales, whose recent series of experiments, *Vegetable Staticks*, was the subject of Desaguliers' glowing, 37-page review. By providing an "exact account of the weights, measures, powers and velocities" of the motion of the sap in plants, Hales' work had provided the evidence necessary to confirm the "truths mention'd in Sir Isaac Newton's queries."[88] For the Latitudinarian Hales, the central lesson of Newton's mathematical approach to natural

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[86] John Ray, *Three Physico-Theological Discourses*, second ed. (London: Sam Smith, 1693) 5-6; My understanding of Ray and Boerhaave's use of the term "chaos" comes from Christopher Baxfield's brilliant article: Christopher Baxfield, "Who is the Almighty that We should Serve Him?" Chaos, Providence and Natural Philosophy in Stephen Hales," *Ambix* 60:1 (2013): 31-53.
[87] Boerhaave, *New Method of Chemistry*, 298-301; on Boerhaave's Calvinist providentialism, see: Rina Knoeff, "Practicing Chemistry "After the Hippocratic Manner"" in Lawrence Principe, ed. *New Narratives in Eighteenth-Century Chemistry* (Dordrecht, Netherlands: Springer, 2007) 63-76.
[88] J.T. Desaguliers, "An Account of a Book entitul'd Vegetable Staticks," *Phil. Trans.* 34:398 (1727): 264-6.

philosophy was obvious. God had made nature according to “exact proportions, *of number, weight and measure*,” therefore the duty of the pious natural philosophy was to present a “rational account” based on these means.[89]

Following the Baconian tradition, Hales’ work cast human beings as active participants in the providential plan of nature. However, his particular version of this philosophy held a key innovation that would prove crucial for eighteenth century improvement. By rendering the reciprocal relationship human and plant bodies and the aerial environment in terms of “number, weight and measure” and then providing a mechanical means of *altering* that relationship, Hales created a schema in which machines were a crucial part of God’s providential plan. In this vision, natural philosophers would first determine the “oeconomy of nature,” and then, through the invention and construction of machines, they would enable the further extension of man’s dominion over nature.[90] The evolution of this idea can be clearly perceived in his statickal essays, his evangelical interest in intemperance and the new colony of Georgia, and most of all, in his invention and avid promotion of new machines that embodied Hales’ vision of providential improvement.

The scope and contours of Hales’ vision of the economy of nature can be best understood from an examination of his “statickal essays,” *Vegetable Staticks* published in 1727 and *Haemastaticks* published in 1733. “Statickal” referred to measurement and analysis of weight, velocity and size.[91] Hales’ direct reference for this method was James

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[89] Stephen Hales, *Vegetable Staticks* (London: W. and J. Innys, 1727) 1.
[90] This reading of Hales’ agenda is derived from Christopher Baxfield’s interpretation of Stephen Hales, *The Wisdom and Goodness of God in the formation of Man* (London: R. Manby, 1751); Christopher Baxfield, “Who is the Almighty that We should serve Him?”, 49-50.
[91] “Statical, n.1". OED Online, March 2020, Oxford University Press, http://www.oed.com/viewdictionaryentry/Entry/11125 (accessed May 13, 2020).

Keill's *Medicina Statica Britannica*, a British adaptation of Venetian physician Santorio Santorio's 1614 *De Statica Medicina*. Santorio's venerable study had compared a careful measurement of the intake of food and liquid against the weight of his urine and excrement, finding that much of the original weight of the food was lost, likely through "insensible perspiration."[92] Hales' interest in statickal inquiry was closely tied to his investment in the physico-theological idea of nature as a benevolent system in which everything was arranged by God to sustain a holistic natural balance, which had inspired him to construct a mechanical replica of Newton's universe while at Cambridge, as well as to conduct a frequently gruesome series of anatomical experiments on dogs.[93]

Much to the distaste of his animal-loving neighbor Alexander Pope, these anatomical experiments continued after Hales was granted the fashionable but rural vicarage of Teddington on the far western outskirts of London. In dissecting horses, fallow deer, and dogs, "plain Parson Hale" attempted to flesh out the studies of Pitcairne and Keill by discerning the "real force of blood in the arteries."[94] His great revelation occurred while tending a cut vine in his garden. Attempting to save the plant, Hales tied a piece of bladder over the cut. Discovering that that "force of the sap did greatly extend the bladder" Hales concluded that if "a long glass tube were fixed there in the same

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[92] Sanctorius and James Keill, *Medecina Statica*, 2nd ed., trans. John Quincy (London: W and J. Newton, 1720); D.G.C. Allan and R.E. Schofield, *Stephen Hales, Scientist and Philanthropist* (London: Scolar Press, 1980) 32.
[93] Margaret Schabas, *The Natural Origins of Economics* (Chicago: University of Chicago Press, 2006) 23.
[94] Despite complaining that Hales' hands were "imbrued with blood," Pope and Hales were friendly neighbors, and the poet referred to him favorably as "Plain Parson Hale." See:
Alexander Pope, *Epistles to Several Persons,* "Epistle II, To a Lady," (London: s.n., 1744) 34, lines 195-198.

> "From Peer or Bishop 'tis no easy thing
> To draw the man who loves his God, or King:
> Alas! I copy (or my draught would fail)
> From honest Mah'met, or plain Parson Hale."

manner, as I had before done to the arteries of several living animals, I should thereby obtain the real ascending force of the sap in that stem." Hales immediately perceived that if he could combine this measurement of the sap's velocity with "statickal" experiments to measure the inputs and outputs of the plant, he could discern the nature of plant nutrition and its relationship with the soil and atmospheric air.[95]

In a move that reveals the underlying breadth of his inquiry, Hales directly compared this process to the Dr. Keill's statickal studies on the human body. The results were surprising: when compared "bulk for bulk, the plant perspires seventeen times more than the man." Hales theorized that this explained the need for the number and extensive surface of leaves, which, when heated by the sun, drew sap and perspiration through the plant. Hales concluded this first experiment by stating that "since then a plentiful perspiration is found so necessary to the health of a plant…'tis probably that many of their distempers are owing to a stoppage of this perspiration, by inclement air."[96] But while Hales was content to borrow the mechanist concept that stagnant sap led to corruption and disease in the same manner as stagnant blood caused disease in humans, he rejected Nehemiah Grew's notion that sap circulated in plants in the same way as blood did in the body. Rather, he argued that sap was almost always drawn up through the root and stalks to the fine capillaries in the leaves of plants. Again borrowing from the Newtonian physiology of Keill, Hales argued that the "minutest parts" of plants were "ranged in such order, as it best adapted by their united force, to attract proper nourishment." In the course of his experiments, Hales also found that the cut end of stems frequently produced "innumerable air bubbles," which were "continually passed off" into

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[95] Hales, *Vegetable Staticks*, iii.
[96] Hales, *Vegetable Staticks*, 4-12.

the atmosphere. However, this amount, as far as he could measure it, was much smaller than the "considerable quantity of air…inspired by plants."[97]

This proved to be Hales' crucial insight. If living things inspired more elastick than they respired, then "great quantities" of air must be "confined in the structures of animals and vegetables." This demonstrated that elasticity must not be an "immutable property of air" since these living structures were able to contain great quantities of air "without rending their constituent parts with a vast explosion."[98] This realization led Hales back to Newton's speculation in Query 30 of his *Opticks* – that "dense bodies by fermentation rarify into several sorts of air, and this air by fermentation, and sometimes without it, returns into dense bodies."[99] Hales thus determined to devote nearly the last half of his *Vegetable Staticks* to "an attempt to analyze the air."

While Newton had provided the conceptual inspiration, the method of analysis behind Hales' "attempt" was firmly Boylean: "Since nature, in all her operations, acts conformably to those mechanick laws, which were established at her first institution," Hales reasoned, the most effective means of evaluating air would be to measure its amount and elasticity. His method of analysis was ingenious in its simplicity. By carefully arranging a bolthead in a bucket of water and cementing it to a retort, he managed to make it so that the air rising from a heated substance in the retort would press down on the water in the bolthead and bucket. By observing and marking the level of water in those vessel, Hales could determine the "quantity of air, which arose from any body by distillation." After the retort was cool and the "generated air" had settled, Hales

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[97] Hales, *Vegetable Staticks*, 96-8, 146-8.
[98] Hales, *Vegetable Staticks*, vi.
[99] Isaac Newton, *Opticks*, 3rd ed. (London: William and John Innys, 1721) 349.

could then place the bolthead upright in another pre-measured bucket of water, invert over it a glass tube in which he could further assay this air by placing a "variety of solid and fluid substances" which would either increase the amount of air or reduce it if the substances "by fermentation did absorbe or fix the active particles of air." By measuring the amount of air produced or absorbed, Hales hoped to apply the same statickal methods that he had used on plants and animals in order to determine which substances produced and which absorbed or "fix'd" the elastick air.[100]

This method revealed that especially great quantities of elastic air were contained in animal and vegetable substances. For example, "pounded apples" produced "above 48 times their bulk of air" – air whose spring must have been greatly compressed in the substance of the apples. This further confirmed his hypothesis of the enormous inspiration of air by plants, which, in warm weather, was released into the atmosphere. Likewise, a cubic inch of "hog's blood, distilled to dry scoria," produced an astonishing "thirty three cubick inches of air." Hales had determined without a doubt that blood *did* contain elastick air. Over the course of seventy-two experiments, Hales determined that "air abounds in animal, vegetable and mineral substances."

Hales immediately grasped the cosmological significance of this. Referencing Isaac Newton's observation that "those particles receding from one another with the greatest repulsive force…upon contact cohere most strongly," Hales argued that elastic air was the central principle of nature that prevented particle attraction from rendering it "one unactive cohering lump." This continual cycle of elastic particles "from an elastick to a fixt sate, by the strong attraction of the acid, sulpherous and saline particles which

[100] Hales, *Vegetable Staticks*, 155-163.

abound in the air" was part of the "beautiful frame of things" which enabled nature to be "maintained, in a continual round of the production and dissolution of animal and vegetable bodies."[101] Hales had clearly read Dutch Philosopher Bernard Nieuwentyt's statement that there was a "particular fluid matter" that prevented "all bodies in nature" from fixing into "one rigid, constituent mass."[102]

But whereas Nieuwentyt was referring to *fire*, Hales referred to *air*. By doing so, Hales had re-ordered the fundamental substances of chymistry, and made air – a "now fixt, now volatile *Proteus*" the central principle in all chemical operations.[103] More than that, Hales' *Analysis* had made air the fundamental medium of exchange between the macrocosm and microcosm. Citing the work of James Keill, Hales admitted that "whether any of these air particles enter the blood by the lungs, is not easie to determine." However, by using his apparatus to test the elasticity of air that he respired into a bladder, Hales determined that air "continually loses its elasticity in the lungs." Thus it was, in his estimation, "very probable that those particles which are now changed from an elastic repulsive, to a strongly attracting state, may easily be attracted thro' the thin partition of the vesicles, by the sulpherous particles which abound in the blood."[104]

But, unlike Mayow or the Oxonian physiologists, Hales was not particularly interested in identifying the precise *function* of respiration in the plant or animal oeconomy, nor in assaying the various parts of air. For him, like Boerhaave, it was enough to know that the atmosphere was a providentially-ordered "*Chaos*, consisting not

[101] Hales, *Vegetable Staticks*, 314-15.
[102] Nieuwentyt's statement on a "Particular fluid matter" is quoted in: Hales, *Vegetable Staticks*, 288; The rest of the quotation is from: Bernard Nieuwentyt, *The Religious Philosopher*, 2nd. ed., trans. John Chamberlayne (London: J. Senex, 1720) II: 605; my argument is derived from Christopher Baxfield, "Who is the Almighty that We should serve Him?," 40.
[103] Bernard Nieuwentyt, *The Religious Philosopher*, II: 605.
[104] Hales, *Vegetable Staticks*, 166-7, 208-211, 240-244.

only of elastick, but also of un-elastick air particles, which in great plenty float in it, as well as the sulpherous, saline, watry and earthy particles." For Hales, the fact that "the air, that wonderful fluid" maintained a balance through "infinite combinations with natural bodies," was merely proof of the God's "constant benevolence and goodness towards us." The role of the natural philosopher was not to fully understand "the wisdom and power of the divine architect," but to contribute to it by discerning God's providential plan.[105]

A year after completing the second volume of his "Statickal Essays," Hales drove this point home by publishing two passionate sermons – one a burning excoriation of gin-drinking, and the other a vision of peace and harmony that could be achieved in the new Colony of Georgia. Over the course of his final set of statickal experiments, Hales became convinced that he was being called by God to turn his growing influence towards two seemingly disparate but intimately connected causes: the abolition of spiritous liquors and the expansion of the nascent British Empire.

Intemperance and Providential Circulation

The "right healthy state of the blood," Hales wrote, "must consist in a due *equilibrium*" between the "air and sulpherous particles." Through respiration, the balance of elastic and inelastic particles in the atmospheric air was reflected by a similar balance in the blood. However, while God maintained the providential chaos of the atmosphere, the maintenance of a particle balance in the blood was a human responsibility. Blood's equilibrium, Hales wrote, was subject to the "many rude shocks it meets with, either from

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[105] Hales, *Vegetable Staticks*, A3-A4.

unkindly food, or inclement seasons, and above all from intemperance."[106] This last and most destructive force – variously referred to as "drunkenness" or "dram-drinking" - was the "most epidemical and destructive plague that ever befel mankind."[107]

This vitriolic denunciation in the midst of the second set of Hales' "Statickal Essays" reveals an emerging conception of providential improvement that was to drive Hales for the rest of his life. While God maintained nature's beneficence through constant intervention, the "skill and abilities" of mankind could either be used to participate in the divine plan and make "considerable advances." Alternatively, they could serve to counteract the will of God by "spreading evil" and making "men their own executioners."[108] The calling of a natural philosopher was to discern truths about nature, and then, in Baconian fashion, apply them for the "great benefit of mankind." But when misapplied, this knowledge could lead to destruction. To illustrate this point, Hales referred to the example of a distilling apparatus, which in the hands of a benevolent natural philosopher could make "good drink, out of unwholesome sea-water." However, the same device in the hands of a greedy or unscrupulous person "procures also…a most pernicious liquor, which yearly destroys, all over the world, innumerably more, than the three great plagues of war, pestilence or famine ever did."[109] During the course of his final "large series of experiments," Hales became increasingly convinced that his role

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[106] Stephen Hales, *Haemastaticks* 2nd. ed. (London: W. Innys, 1740) 106.
[107] Hales, *Haemastaticks*, 126.
[108] Hales' understanding of this process is derived from Newton: "does it not appear… that there is a Being incorporeal, living, intelligent, omnipresent, who in infinite space, as it were his sensory, sees the things themselves intimately?": Isaac Newton, *Opticks*, 2nd ed. (London: J. Innys, 1718) 345; Hales, *Haemastatics*, vi; Stephen Hales, *A Friendly Admonition to the Drinkers of Brandy and other Spiritous Liquors* (London: Joseph Downing, 1733) 12.
[109] This reading of Hales and this example are borrowed from Christopher Baxfield, "Who is the Almighty that We should Serve Him?" 50: Stephen Hales, *Philosophical Experiments Containing Useful and Necessary Instructions for such as undertake long Voyages at Sea* (London: W. Innys and R. Manby, 1739) 18.

was not merely to understand God's providential plan of nature, but to participate in its improvement. Even while he was in the midst of conducting his statical investigations into the "animal oeconomy," Hales was conducting experiments specifically to show "the manner of brandy's working its pernicious effects on our bodies."[110]

Having carefully measured the pressure and velocity of blood flow in horses, fallow deer and dogs, Hales determined to use this "inimitable embroidery of blood vessels" to use in order to demonstrate the evils of distilled liquors. First, he hung up and bled to death a "young Spaniel." Then, after opening the dog's abdomen, Hales inserted a four-and-a-half foot tall glass tube into the dog's aorta, in which he poured a height of water equal to that of the "force…with which the blood is there impelled by the heart." Hales then carefully cut open the dog's gut, so that the "innumerable small capillary vessels" were "cut asunder thro' the whole length of the slit gut." Hales then poured in pots of warm water, and, using a pendulum to count the seconds, measured how quickly they passed through the dog's circulatory system and out into a bucket below. Next, he tried the experiment with brandy, and then again with warm water. Finding that the water passed in fifty two seconds, a smaller amount of brandy had taken an entire sixty eight seconds to pass through the dog. For Hales, this confirmed that "brandy contracts the fine capillary arteries of the guts." Extrapolating from Boerhaave's observation that a mixture of cold water and spirits immediately gained heat, Hales argues that the "unhappy habitual drinkers of brandy" were continually subjecting their blood to superheating and coagulation and their capillaries to an unnatural contraction, which was immediately

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[110] Stephen Hales to Henry Lee Warner, August 7, 1733, Norfolk Record Office, NRA 27665/19.

followed by a “cold, relaxed and languid state” which “impetuously drives them to seek for their relief in that liquor.”[111]

Hales’ enthusiasm for temperance and practical applications of natural philosophy was closely tied with his evangelical interests. His brother Robert had become deeply involved in schemes to re-settle Protestant refugees from Germany, Spain and France in England and the Americas. Through his influence, Stephen Hales had been admitted to the Society for Promoting Christian Knowledge (S.P.C.K.) in 1722, and his personal agenda began to strongly reflect the priorities of the society, namely reforming prisons, spreading knowledge of the Gospel and enabling the growth of Protestantism through schemes to convert Native Americans and resettle Protestant refugees in the Americas, specifically the new colony of Georgia.[112]

Hales was deeply influenced by this scheme. Being named a trustee of the colony, Hales published a sermon in which he urged the use Georgia as a springboard for converting American Indians and African slaves to Christianity, declaring that that “the Law of Nature obliges us thus to benefit, to assist and support, to ease and comfort one another; and every man who does it not is inhuman.” Thus the “dispirited state” of habitual drinkers in England was not only destructive to them: it placed the entire nation and her colonies at risk. While the pagan Native Americans were “sensible of the great destruction distill’d spiritous liquors have made among them” and had “frequently and earnestly desired that no such liquors might be sold to their people,” English Christian

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[111] Hales, *Haemastaticks*, 48, 123-5.
[112] For the agenda of the early S.P.C.K., see: W.O.B. Allan and Edmund McClure, *Two Hundred Years: The History of the Society for Promoting Christian Knowledge, 1698-1898* (London: S.P.C.K., 1898) vi; See also: Cowie, Leonard W. "Bray, Thomas (bap. 1658, d. 1730), Church of England clergyman." Oxford Dictionary of National Biography. 23 Sep. 2004; Accessed 19 May. 2020. https://www-oxforddnb-com.proxy.libraries.rutgers.edu/view/10.1093/ref:odnb/9780198614128.001.0001/odnb-9780198614128-e-3296.

settlers were “continually furnishing them with materials to continue” in that “beastly and destructive vice.”[113] By doing so, they had severely undermined “the real interests of religion” in “the most distant parts of the world.”

While his role as a cleric was to dissuade people from partaking in their “self-destruction,” Hales saw his role as a natural philosopher as providing the practical means to insure that “neither mountains nor valleys nor the vast expanse of the sea stop the course of your humanity.”[114] As the colony of Georgia floundered during the 1730s, Hales became increasingly involved in schemes to improve long-distance shipping and seafaring. With J.T. Desaguliers, he had co-invented a “machine for measuring any depth of the sea” in 1727, but by the mid-1730s he was conducting experiments on how sea water could made “fresh and wholesome,” on how biscuits could be preserved, and how meat could be “preserv’d in hot climates, by salting animals whole.”[115]

These experiments made up Hales’ first book-length publication since his Statical Essays. Dubbed *Philosophical Experiments containing useful and necessary instruction for such as undertake long voyages at sea*, this work marks Hales’ transition from natural philosopher to practical inventor. The unambiguous failure of nearly all the experiments in the book has obscured its importance as a turning point for Hales’ conception of the role of machines in natural improvement. One failed experiment in particular illustrates Hales’ belief that natural means could be turned to the ends of man. Appearing before several Lords of the Admiralty on the morning of April 17, 1736, Hales cut the jugular of

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[113] Hales, *Friendly Admonition*, 11.
[114] Hales, *A Sermon for establishing the Colony of Georgia in America* (London: T. Woodward, 1734) 7-12.
[115] Stephen Hales and J.T. Desaguliers, “An Account of a Machine for Measuring any Depth of the Sea,” *Phil. Trans.* 34 (1727-8): 559-562; Hales, *Philosophical Experiments,* title page.

an ox, then waited patiently for it to bleed to death. Laying the beast on its side, he sewed up the severed vein with pack-thread and a crooked needle. Next he carefully sliced into the belly, removing the innards to locate the renal artery. Using a pair of scissors, he inserted a double-ended brass cock into the artery with the larger nozzle pointed towards the beast's head. Making tight the incision with more packthread, Hales had his assistant attach the open end of the cock to a ten-foot tall piece of cane which was then elevated into a vertical position. Filling the cane with highly concentrated salt water, he opened the stopper on the cock and, for the next half hour, pumped forty gallons of the brine into the circulatory system of the unlucky animal until the "body of the ox was greatly swelled all over" and the water bubbled "frothy through the windpipe" and "ouzed into the stomach and bowels." [116]

Throughout this gruesome process, Hales took care that the brine's temperature remained as close as possible to the warmth of the blood that had just been evacuated, and that the height of brine in the cane matched "the height to which the blood is raised…by the force of the heart."[117] By replicating the exact conditions that enabled the free circulation of blood within the body of the animal, Hales hoped to create a new method of "salting animals whole" which would enable the easier and better preservation of meat for long sea voyages, thus sparing sailors the "very bad stinking flesh they were sometimes obliged to eat at sea."[118] Hales was so confident in the efficacy of this method that he dispatched two of these brass salting cocks to the colony of Georgia, and gave one to his friend Edward Boscawen who claimed later to have used it successfully on a

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[116] Hales, *Philosophical Experiments*, 91-2.
[117] Hales, *Philosophical Experiments*, 86..
[118] Hales, *Philosophical Experiments*, 86-7.

stopover in Madagascar.[119] The admiralty, however, were not impressed. The demonstration had been a complete failure. The meat "soon stank to a very great degree" and "would not keep many days." Even when cured with additional dry salt, "it was judged not fit for men to eat, as its juices were entirely eaten up by the salt, and it fell to pieces like rotten wood."[120]

Despite the failure of this method, Hales remained convinced that similar such devices and techniques would contribute to "the greatly inriching, but also…inlarging the minds of mankind, and…the civilizing and improving of them, by the communication of mutual benefits."[121] His passionate involvement in the S.P.C.K. was reflected in his efforts to combat distilled liquors, which he referred to tellingly as "those great decolonizers, those mighty destroyers and debasers of the human species."[122] But the abject failure of his *Philosophical Experiments* began to lead him away from attempts to reform the microcosm of the human and animal body and back towards an assessment of the condition of the air – an urgent need that his friend J.T. Desaguliers was already striving to address.

Air Machines and the Panacea of Providence

In 1735, a curious machine, dubbed a "blowing wheel" appeared in the journal of the Royal Society. Invented by J.T. Desaguliers, it consisted of a paddle-wheel, seven feet in diameter and a foot wide. Mostly enclosed in a wooden case, the rotating wheel

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[119] Allen D. Candler, ed. *The Colonial Records of the State of Georgia* (Atlanta, GA: Franklin Printing and Publishing, 1905) III, 178; Stephen Hales, *Treatise on Ventilators* (London: R. Manby, 1758) 284.
[120] Hales, *Philosophical Experiments,* 92-3.
[121] Hales, *Philosophical Experiments*, vi.
[122] Stephen Hales letter to William Heberden, Aug. 31, 1758: quoted in Ernest Heberden, ed. "Correspondence of William Heberden, F.R.S. with the Reverend Stephen Hales and Sir Charles Blagden," *Notes and Records of the Royal Society,* 39:2 (Apr. 1985): 180.

drew in air through an open passage on the side, and then expelled it via a pipe at the top. The working of the machine required "very little labour" and could be used for either "drawing out foul air, or forcing in fresh air."[123] Despite attracting the attention of the Royal Society and being fixed above the houses of Parliament, Desaguliers' ventilating devices were not widely adopted. In this brief section I will argue that this is due not to any deficiency in the mechanisms, but rather because Hales' providential vision of improvement, embodied in his "Ventilator Trunks," was better suited to emerging imperial ambitions.

While Desaguliers later traced his interest in ventilation and air purification to his 1715 translation of a work on the improvement of stoves and chimneys, it is highly probable that the idea for mechanical motivation was directly inspired by *Vegetable Staticks*.[124] Desaguliers had been present with Hales for several experiments, including one in which Hales had constructed a gas mask made with a bladder and four flannel filters. Finding that he could breathe continuously with the use of a filter treated with a "very highly calcined sal tartar," Hales suggested that a similar device could be useful for those who "may have urgent occasion to go for a short time into an infectious air." However, he noted that the same solution would be useless in the "damps of mines" since they could not sufficiently screen "so very noxious vapours."[125] The next year, Desaguliers demonstrated a machine before the Royal Society that employed pumps and

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[123] J.T. Desaguliers, "An Account of an Instrument or Machine for Changing the Air of the Room of Sick People…" *Phil. Trans.* 39 (1735): 41-43.
[124] J.T. Desaguliers, *A Course of Experimental Philosophy 2nd ed.* (London: W. Innys, 1744) II: 557-9: Desaguliers' translation of Gauger's *La Mecanique du Feu* is entitled: Nicolas Gauger, *Fires Improv'd: Being a New Method of Building Chimneys so as to prevent their Smoaking*, trans. J.T. Desaguliers (London: J. Senex, 1715).
[125] J.T. Desaguliers, "The Conclusion of Dr. Desaguliers' Account of Mr. Hales' Vegetable Staticks," *Phil. Trans.* 35(1727-8) 323-331; Hales, *Vegetable Staticks*, 262-270.

"square wooden trunks" to "shew how damps, or foul air, may be drawn out of any sort of mines."[126] This machine was intended for use on the Earl of Westmoreland's estate, but his death the same year may have blunted the scheme.[127]

Desaguliers' hopes for his blowing wheel were more ambitious: it could be used for "sick rooms, for prisons, for warming, cooling, or perfuming any chambers at a distance." Desaguliers, fully expected it to be soon applied in the Royal Navy and in mines to "suck away all the heavy poisonous damp" and thus "fill all the subterraneous caverns with fresh and wholesome air." He had already managed to have it "fix'd in a room above the House of Commons," where it was currently employed to "draw away the hot steam arising from the candles, and the breath of the company in the house, when it is very full, in warm weather."[128]

However, the apparent success of Desaguliers' device in Parliament was deceiving. The true reason his device had been fixed was because his initial solution, which involved using a fire to draw the foul air up through "heated cavities" above the house, was so disturbing to "Mrs. Smith, the housekeeper, who had possession of the rooms over the House of Commons," that she "did what she could to defeat the operation of theses machines."[129] The blowing wheel was apparently less disruptive to Mrs. Smith

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[126] J.T. Desaguliers, "An Attempt made before the Royal Society to shew how Damps, or foul Air, may be drawn out of any Sort of Mines, &c." *Phil. Trans.* 35(1727-8): 353-356.
[127] Desaguliers, *Course*, II: 561; Jonathan Spain, "Fane, John, seventh earl of Westmorland (bap. 1686, d. 1762), army officer and politician," *Oxford Dictionary of National Biography*, 23 Sep. 2004; Accessed 21 May, 2020: https://www-oxforddnb-com.proxy.libraries.rutgers.edu/view/10.1093/ref:odnb/9780198614128.001.0001/odnb-9780198614128-e-9134.
[128] J.T. Desaguliers, "The Uses of the Foregoing Machine, communicated in a letter to Cromwell Mortimer," *Phil. Trans.* 39 (1735): 47-49.
[129] Desaguliers, *Course*, II: 560-561.

and was retained as the primary means of ventilation in the commons.[130] Desaguliers' other ambition – to get his device fixed on Navy ships – was disappointed several years later, when Sir Jacob Acworth, commissioner of works for the Royal Navy, refused to even see Desaguliers' machine in action despite several successful tests.[131] Frustrated by this unjust treatment and beset by increasingly sharp demands of his patron the Duke of Chandos, Desaguliers was forced to admit defeat: "Thus ended my scheme, which I hoped would have been of great benefit to the publick."[132]

However, by the time Desaguliers relinquished his ambitions for the blowing wheel in late 1740, he was facing sustained competition from three other ventilating machines. Likely inspired by Desaguliers' invention, the "Director of Mechanicks" in the Kingdom of Sweden, Marten Triewald, had devised a "ventilating machine" for use in naval vessels.[133] That same year, Stephen Hales proposed to the Royal Society his plan for "large ventilators" that would be "very serviceable, in making the air in ships more wholesome." When Cromwell Mortimer, secretary of the society, received a letter from Triewald proposing his plan, Hales remarked at the "very extraordinary circumstance, that two persons at so great a distance from each other…should happen to hit on inventing a like very useful engine."[134]

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[130] This device remained in periodic use for most of the next century. See: Elizabeth Hallam Smith, "Ventilating the Commons, Heating the Lords, 1701-1834," *Parliamentary History* 38:1 (Feb. 2019): 76-79.

[131] Desaguliers, *Course*, II: 568.

[132] Desaguliers, *Course*, II: 568; On the demands of the Duke of Chandos during this time, see: Audrey Carpenter, *John Theophilus Desaguliers* (London: Continuum, 2011) 168-171.

[133] On Marten Triewald and Desaguliers, see: Marten Triewald, "Queries, Concerning the Cause of Cohesion of the Parts of Matter," *Phil. Trans.* 36:408 (1730) 39-43 and Svante Lindqvist, *Technology on Trial: The Introduction of Steam Power Technology into Sweden, 1715-1736* (Uppsala: Almqvist & Wiksell International, 1984) 194-99.

[134] Hales, *Description of Ventilators*, x-xii.

The “extraordinary circumstance” could be explained very easily. Both Hales and Triewald were well aware of Desaguliers’ machine. Hales possessed a blowing wheel at Teddington, and Triewald was a longstanding acquaintance of Desaguliers, who frequently published their correspondence in the *Philosophical Transactions*.[135] However, while Hales mentioned that Triewald’s devices had been fixed on “every man of war and hospital ship” in Sweden, and had been ordered fixed in French ships by King Louis XV, he scrupulously avoided mention of Desaguliers’ blowing wheel as a precedent for his ventilator trunks.[136] This omission clearly bothered Desaguliers, who included a post-script in the second edition of his *Course of Experimental Philosophy* reminding reader that “I have made experiments these 28 years upon the purifying of air, conveying it from one place to another, and changing it for the advantage of those that breathe it in close places.” With an excess of generosity that belied his respect for Hales, Desaguliers reasoned that the reason for his exclusion in the text was “pure forgetfulness.”[137]

The real reason why Hales did not mention Desaguliers’ ventilating scheme was philosophical: he saw a clear difference between that project and his own. While he did not mention Desaguliers by name, he did mention “a wheel with fans, in a drum,” noting that it had been described in the *Philosophical Transactions* as well as in Georgius Agricola’s 1556 text on mining *De Re Metallica*. The “great difference” between this device and his, Hales wrote, was in “the velocities, and consequently the quantities of air

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[135] Desaguliers, *Course*, II: 556; Martin Triewald, “Queries, concerning the Cause of Cohesion of the Parts of Matter, proposed in a letter to Dr. Desaguliers,” *Phil. Trans.* 36 (1730) 39-43; Lindqvist, *Technology on Trial*, 194-99.
[136] Hales, *Description of Ventilators*, xv.
[137] Desaguliers, *Course*, II: 556-568.

that are conveyed." While Desaguliers' device had been designed to provide "fresh air to sick people insensibly," Hales' devices were designed to "put great quantities of air in motion with ease…in imitation of nature."[138]

This last point was the crucial one. Hales' ventilators were not merely ventilators: they were providential machines that conformed to "Nature's own method of working." Through the course of his Statickal Essays, Hales had come to the conclusion that by manipulating the air, human beings would be enabled to make nature herself "beneficial to us in many respects." Hales envisioned Ventilating trunks becoming a "very valuable furniture" which could supply any space with "fresh air, in such proportions as shall be most commodious." In this way, not only would the health of human beings be preserved in mines, jails, hospitals, work-houses and ships, but by carrying off damp and foul air all "the necessary products of the earth" could be preserved, enabling the preservation of meat, the purification of water, and the drying and winnowing of grain, thus "increasing the quantity of corn in the world." By the same means, rust could be prevented in "large armories, such as are in the Tower of London" and trades such as brewing and manufacturing could be served by the powerful and precise application of air in kilns and brewhouses. "Air is one of the great instruments of nature," Hales wrote, and by using his ventilators, human beings could render it "serviceable to all the products of the earth."[139]

Conclusion

The role of the natural philosopher was not to seek out the means of nature as a "meer trifling amusement," Hales wrote. Rather it was to discern how to make the "gift

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[138] Hales, *Description of Ventilators*, 14: The blowing wheel is described in: Georgius Agricola, *De Re Metallica*, trans. Herbert Clark and Lou Henry Hoover (New York: Dover, 1950) 203-205
[139] Hales, *Description of Ventilators*, 49, 112-113, 127-8, 158.

of kind providence, this natural world, the more beneficial to us."[140] Beginning with Cornelius Drebbel's grand vision that the control of air would enable the extension of empire, natural philosophers avidly sought to assay the atmospheric air and determine its relationship to another fundamental fluid, the blood. The great success of Robert Boyle's air pump inspired a widespread confidence in the potential of machines to manipulate this powerful substance. However, while the limitations of mechanical measurement frustrated attempts to fully understand the role of air in human and animal bodies, Newton's matter theory opened the door for the conception of air as a providential chaos – a complex medium that enabled all natural processes. The nature of the air was no longer a subject of intense debate – it was an article of faith. Air became a political object. the question became not *what* air was, or its precise role in the animal oeconomy, bur rather *how* air could be manipulated for human ends.

Ventilators were thus designed for, as Hales constantly stated, "the Great Benefit of Mankind." While Desaguliers had secured influential patrons and accomplished impressive projects, the scope of Hales' ambition and the broad influence of his Statickal Essays placed him in a position to apply his ventilating vision on a national and even international scale. Using his contacts as a Georgia trustee, Hales was able to secure numerous trials for his ventilators aboard merchant ships.[141] By 1750, he was appointed personal chaplain to Caroline, Princess Dowager of Wales, which provided him with further influence with the Board of Trade and the Navy Board.[142] *Vegetable Staticks* was quickly translated into French by a young Comte de Buffon, who along with agronomist

[140] Hales, *Description of Ventilators*, viii.
[141] Hales to Henry Lee Warner, April 9, 1741, Norfolk Record Office, NRA 27665/27; Hales to Henry Lee Warner, April 4, 1745, Norfolk Record Office, NRA 27665/30.
[142] Allan and Schofield, *Stephen Hales*, 108.

and naval expert Henri-Louis Duhamel du Monceau read Hales' work as part of a project by the Academie des Sciences to import English agricultural knowledge. By 1744, Du Monceau had translated Hales' *Description of Ventilators* and wrote to Hales that he had "kept a large heap of corn sweet and free from weevils, for two years without turning it, but only blowing air upwards thro it with ventilators." While Hales complained that English grain-merchants refused to try his machines despite it being "most easie to be done with little expence," ventilators became so widely used in continental granaries that Hales lamented that "we shall have the disgrace of learning it of the Dutch or the French."[143]

As Hales would soon learn, the political character of air was just as complicated as its physical character. In his 1733 *Essay Concerning the Effects of Air on Human Bodies*, physician and polymath John Arbuthnot wrote that "it seems probable that the genius of nations depends upon that of their air." Temperament, moral character, political institutions, even differences in language could be traced back to the character of the local air. Not merely a "thin fluid which surrounds the earth in which we move and breathe," air was "the principal instrument in the generation, accretion, resolution, and corruption of all terrestrial bodies." However, while he was keen to attribute the temper of the French to their Gallic atmosphere, and the curtness of northern peoples to a reluctance to open mouths to gusts of cold air, Arbuthnot did not believe that humanity was doomed to aerial determinism. While animals chose the "countries and climates most adapted to their constitutions," humans, on the other hand, were "in society, and under government, and subject to passion, to which he sacrificeth the greatest blessings of

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[143] Hales to Henry Lee Warner, March 15, 1748, Norfolk Record Office, NRA 27665/33; Hales to Henry Lee Warner, May 25, 1751, Norfolk Record Office, NRA 27665/35.

health and life." If a means of managing the air could be achieved, then humans would be able to "bear extremities" with the help of the "many contrivances of art."[144]

The project to enable the global preservation of goods and the safety of sailors, "those numerous, useful and valuable persons, *who occupy their business in great waters*," would bring Hales and fellow advocates of ventilation into contact with other complicated political realities of the eighteenth century British Empire: the urgent need to manage maritime labor and the emerging medical concepts of tropical disease and climatic determinism.[145]

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[144] John Arbuthnot, *An Essay Concerning the Effects of Air on Human Bodies* (London: J. Tonson, 1733) 1-2, 93, 140-153.
[145] Hales, *Description of Ventilators*, 159.

Images:

Figures 1 and 2: Two images of Cornelius Drebbel's *Perpetuum Mobile*. Left: detail from Hieronymus Francken II and Jan Brueghel, "The Archdukes Albert and Isabella Visiting the Collection of Pierre Roose," 1621-3. [Courtesy of: The Walters Art Museum, Baltimore, MD: Access. No. 37.2010] Right: Thomas Tymme, *A Dialogue Philosophicall* (London: T.S. for Clement Knight, 1612) 61.

Figures 3 and 4: Stephen Hales' "Staticka‌l" Experiments. The left image is Hales' apparatus for assaying the amount of air produced or consumed by various substances. (Stephen Hales, *Vegetable Staticks* [London: W. and J. Innys, 1727] 160.) The right image is a much later illustration of Hales' method of using a hollow cane attached to an artery in order to measure the "force of the blood raised by the heart." Originally from *Medical Times*, 72:11 (1944).

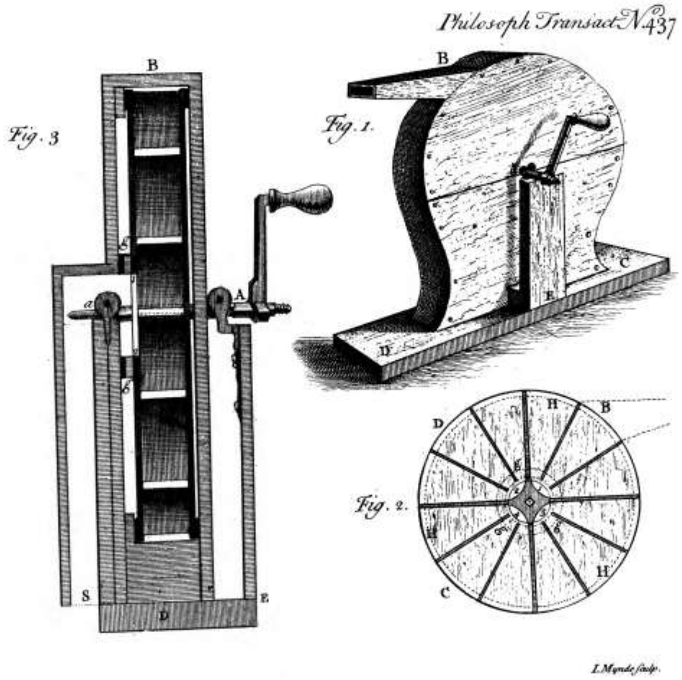

Figure 5: John Theophilus Desaguliers' "Blowing Wheel." (J.T. Desaguliers, "An Account of an Instrument or Machine for Changing the Air of the Room of Sick People…" *Phil. Trans.* 39 (1735): 41-43.)

Figure 6: One of Stephen Hales' "ventilators" as described in his 1743 *Description of Ventilators*. Image credit: Wellcome Collection. Attribution 4.0 International (CC BY 4.0)

Chapter 2
"The Lungs of a Ship": Labor, Climate and the Shipboard Environment

Abstract:

This chapter examines the history of shipboard ventilation in the British Empire during the eighteenth century. Long-distance seafaring, which necessitated extended periods in a salty environment as well as "seasoning," or transition between climates, had long been considered a dangerous undertaking. However, as the wars with France and the expanding British colonies necessitated the transportation of more maritime and enslaved laborers to the far reaches of the empire, natural philosophers sought to employ mechanical ventilation as a means of turning ships into a healthier environment and mitigating the effects of climatic transition. I will argue that natural philosophers understood the ship itself *as* an environment – a "mid-cosm" between the macrocosm of the unforgiving ocean and the fragile microcosm of the human body. By restoring this understanding, we can navigate the panoply of ideas that were proposed to preserve the health of sailors and examine changing ideas about hygiene, individual responsibility and the inherent healthfulness/danger of maritime and tropical climates. I will further argue that the failure of ventilating devices to adequately insure the health of sailors led to a further essentializing of certain climates as "healthy" or "unhealthy" – an argument that was employed by abolitionists to argue that the holds of slave ships were inherently dangerous.

Introduction

Nathaniel Henshaw never left Europe, and rarely boarded a ship. But in 1664, he proposed a machine that could take him to any climate in the world. From the humid, sun-drenched West Indies to the heights of Mount Tenerife in the Canary Islands, Henshaw's device could replicate any aerial environment – indeed, it could "rarifie the air to a far higher degree, and make it such, as is not again to be found upon the face of the whole habitable world." Henshaw's device, or "domicil," consisted of a compartment, "some twelve or fourteen foot square…exactly well ceiled…that the air might not have any vent." The inhabitant of this sealed room was to be provided with "a very large pair of organ bellows" which were to be joined to a valved copper pipe that passed through the wall. By working these bellows to change the pressure of the internal atmosphere, Henshaw believed that the "natural functions" within the body could be regulated, and "enabled the better to endure the conflict with…diseases."[146] To this end, Henshaw proposed that his device "be made use of aboard ships," allowing sailors to "reduce the tone of the air to his own soil or climate" and thus "become very serviceable to such, whose implyments ingage them to undertake voyages into very remote parts, and there to reside, far from their own countries."[147]

Henshaw's device was never built. But the theory behind it reflected a common assumption of seventeenth-century medicine: that certain climates – especially hot, humid, "torrid" zones – posed a threat to European constitutions used to a cooler, drier climate. This idea in turn emerged from the Hippocratic conception that the body was a porous "microcosm" that was deeply influenced by the "macrocosm" of surrounding environment. Most seventeenth and early eighteenth-century physicians believed that the porous nature of human bodies meant that they could adapt to different climates – a

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[146] Nathaniel Henshaw, *Aero-Chalinos: or, a Register for the Air* (Dublin: Samuel Dancer, 1664) 82-3, 88, 91.
[147] Henshaw, *Aero-Chalinos*, 91.

process referred to as “seasoning.” However, since the composition and functioning of the body was strongly influenced by the soil, food and air of ones’ birthplace, transitioning between climates was understood to be fraught with risk – a belief apparently borne out by the shockingly high mortality rates experienced by sailors, soldiers, slaves and colonists in the West Indies.[148]

However, as the nation “fam’d for carrying on the most extended commerce in the world,” eighteenth-century Britons considered the ability to transition between climates as a matter of paramount importance.[149] Over the course of the eighteenth century, physicians, natural philosophers, and naval administrators strove to re-make the holds of sailing ships from "noisome caves,” ever-damp spaces that gave way to rot and unhealthy vapors, to a “sweet and dry” space that could insulate the sailors’ bodies from the dangerous maritime and tropical environments they encountered. At the center of these efforts was the Royal Navy, that employed a “floating city” of over 40,000 men during wartime – a population larger than any contemporary British city besides London. Many of these men were pressed into service, making the navy, in the estimation of one historian, the second-largest pool of unfree labor in the British Empire.[150] The largest pool of unfree labor – the roughly 3.1 million African slaves transported across the ocean

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[148] See: Andrew Wear, “Place, Health, and Disease: The *Airs, Waters, Places* Tradition in Early Modern England and North America,” *Journal of Medieval and Early Modern Studies* 38:3 (Fall 2008); for death rates in the West Indies, see: Kenneth F. Kiple and Kriemhild Coneè Ornelas, “Race, War and Tropical Medicine in the Caribbean” in David Arnold, ed. *Warm Climates and Western Medicine: The Emergence of Tropical Medicine, 1500-1900,* Second edition (Amsterdam: Rodopi Press, 2003): 68-70.
[149] Daniel Defoe, *A Plan of the English Commerce* (London: Charles Rivington 1728) 1.
[150] I am borrowing Denver Brunsman’s re-application of the term “floating city” to refer to the Royal Navy. It was originally applied by Benjamin Sulte to describe a French ship in 1734: Benjamin Sulte, “Un voyage à la Nouvelle-France En 1734,” *Revue canadienne* 6, no. 22 (1886) 22: quoted in Denver Brunsman, *The Evil Necessity: British Naval Impressment in the Eighteenth-Century Atlantic World* (Charlottesville, VA: University of Virginia Press, 2013) 7.

in British ships – also feature prominently in this story, as the appalling conditions on slave ships came to illustrate the ultimate limits of shipboard ventilation.[151]

For most of the eighteenth century, the question of whether any climate was *inherently* unhealthy was the subject of open debate – a fact witnessed by the emergence of a substantial contemporary medical literature on the diseases of warm climates.[152] In the midst of the myriad disagreements over the nature of tropical and maritime diseases, there was one universally acknowledged factor: the quality of the air. To maintain a healthy constitution, Galenic medicine emphasized the importance of fresh, pure air. The qualities that made an air good or bad and the relationship between the composition of the external air and of the blood was an ongoing debate. But for ventilation, the crucial opinion was issued by experimenter and clergyman Stephen Hales. In his analysis of the air, he concluded that atmospheric air was a "*Chaos*, consisting not only of elastick, but also unelastick air particles."[153] If the air was full of too many "inelastick" particles, it disrupted the balance in the blood – a condition frequently found in enclosed spaces, especially the holds of ships. As discussed in the previous chapter, Hales' "ventilators" were designed to counteract these effects by extending the providential balance of atmospheric air to enclosed spaces. They were intended to mimic the action of human lungs, with a "midriff" or Diaphragm that would rise and fall gently, pushing foul air out and drawing in fresh air through valves. Hales' devices were "intended to promote a free

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[151] David Eltis, "The Volume and Structure of the Transatlantic Slave Trade: A Reassessment," *William and Mary Quarterly*, 3:58 (2001) 9-17.
[152] Suman Seth, *Difference and Disease: Medicine, Race, and the Eighteenth-Century British Empire* (New York: Cambridge UP, 2018) 277-8.
[153] Stephen Hales, *Vegetable Staticks* (London: W. Innys, 1727) 315.

perspiration and breathing, by conveying large quantities of fresh air into ships in exchange for a very bad air."[154]

From their inception, these machines were primarily intended for use in ships. "Were an animal to be formed of the size of a large ship," Hales reasoned, "there would be ample provision made to furnish that animal with a constant supply of fresh air, by means of large lungs, which are formed to inspire and breathe out air in the same manner as these ventilators do."[155] In effect, the addition of these "lungs of a ship" would transform the interior of a ship from a dangerous environment to a healthful one. They would provide a counter-action to the overcrowded decks and damp, humid environment on board by providing the necessary "elastic" air that would invigorate sailors' bodies.

Beginning with the labor crisis faced by the Royal Navy at the outbreak of the War of Jenkins' Ear in 1739, Hales and other advocates of ventilation focused their efforts on eliminating the bad air that they saw pervading naval ships. At the center of these efforts was the question of labor – how could the lives of seamen, the "industrious instruments, by which the…distant nations of the earth carry on an extensive commerce and intercourse with eachother" be preserved in the midst of the hot, humid, "poisonous" man-made environment of a sailing ship?[156]

By restoring the contemporary view of the ship as a dangerously contained space full of poisonous effluvia, we can see how changing ideas about the healthfulness of both interior and exterior climates shaped debates over the best way to transport and utilize labor in the growing British Empire. The idea of the ship as an environment – a mid-

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[154] Stephen Hales, *A Description of Ventilators* (London: W. Innys, 1743) xix.
[155] Hales, *Description of Ventilators,* 38.
[156] Stephen Hales, *Philosophical Experiments* (London: W. Innys, 1739) vi.

cosm between the macrocosm of the unforgiving ocean and the fragile microcosm of the human body – also enables us to navigate the panoply of ideas that were proposed to preserve the health of sailors and slaves on long sea voyages. At the center of this story is the idealized British sailor: courageous and manly, and willing to brave any danger – yet vulnerable to vice, poor treatment and above all, to the "noxious effluvia" that pervaded in the holds of ships and the fears of naval administrators and natural philosophers. Efforts at hygienic reform aboard naval ships treated sailors with an attitude that was frequently patronizing or critical or both: sailors were either passive victims of bad maritime environments, or foolish and misled men who failed to properly care for their health and cleanliness.[157]

Enslaved Africans, on the other hand, were far less likely to be granted any agency. Slave merchants and captains frequently cast them as essentially different than Europeans in preferring the hot, humid, and rough conditions of the slave deck.[158] Meanwhile, abolitionists painted both African slaves and white sailors as passive victims whose inhumane treatment in appallingly ill-kept slave ships was a waste of skilled labor and a blight on the national honor. Parliament's proposition that the ships be regulated and fitted with Hales' ventilators was countered by the emerging language of tropical medicine, which argued that some spaces were unredeemably unhealthy. By employing this language, abolitionists like Thomas Clarkson, Thomas Trotter and Alexander

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[157] See, for example, naval surgeon and eventual commissioner of the Sick and Wounded Board Gilbert Blane's heavy emphasis on cleanliness of sailors rather than the environment: "as the air is so pure at sea, and as the causes of disease peculiar to a sea-faring life are chargeable rather to the mismanagement of men, than to the unavoidable course of nature, we are encouraged to exert our attention to endeavouring to eradicate them": Gilbert Blane, *A Short Account of the Most Effectual Means of Preserving the Health of Seamen* (London: N.P. 1780): 1-2.

[158] See, for example, slave merchant Robert Norris' testimony quoted in Marcus Rediker, *The Slave Ship: A Human History* (New York: John Murray, 2007) 327-328.

Falconbridge argued that the holds of slave ships were unredeemably unhealthy spaces which no ventilator could freshen and no British sailor could survive.

The Great Bridge of the Ocean

While Hales compared a ship to an animal, a more famous comparison was made by satirist Edward Ward: a man-of-war was a "wooden world, fabricated by the frail hand of man." Indeed, this creation was superior to God's – for while the cosmos would "drop to pieces, if but one atom only was wanting" the ship "holds firm together, when batter'd worse than a bawdy-house." But unlike the clear gradations of the Great Chain of Being, the inhabitants of the wooden world were difficult to categorize: "They can't be all flesh…because many of them live under water…yet they have no more gills than an oyster." Because the ocean was not their natural environment, sailors were obliged to "feed and sleep in their shell, like worms in a nut." However, despite the protection it afforded against the fatal ocean, ships were themselves a deadly environment, both for sailors and for society. For Ward, they represented "the great bridge of the ocean, conveying over to all habitable places death, pox and drunkenness."[159] This section will examine the perceived dangers of long-distance seafaring and of the shipboard environment and the origins of attempts by sailors and physicians to mitigate those perils.

While long distance seafaring had assumed a central role in British trade and conceptions of national greatness by the early eighteenth century, British ships continued to be remarkably deadly and dangerous spaces.[160] Contemporary medical theories for

[159] Edward Ward, *The Wooden World Dissected* (London: H. Meere, 1707)1-6.
[160] Roger Morriss calculates that from 5.9 percent of the total naval complement died between 1755-7. Marcus Rediker conservatively estimates that the death rate during the middle passage was around 15 percent. See: Roger Morriss, *The Foundations of British Maritime Ascendancy* (London: Cambridge

why sailors suffered such disproportionate disease and death frequently cited the danger of seasoning between climates. Northern Europeans, possessing tight bodily fibers and an excess of blood to endure cold climes, became overheated in the south as their blood "rarified" and rushed through their bodies, increasing all secretions except urine and stool.[161] But climatic transition did not explain diseases like scurvy, a condition observed on land but experienced most acutely at sea, which seemed to strike with frustrating unpredictability and doom sailors in icy and tropical seas alike.

For their part, sailors downplayed the differences of climates and rather emphasized the difference between the land and maritime environment. According to sailing tradition, too much time at sea was unnatural and unhealthy for land-dwelling human beings. Famously proud of their seagoing expertise and unwilling to accept diagnoses from landmen, this belief formed part of a compendium of practical sailing know-how that dated back hundreds of years.[162] Jacobean explorer Richard Hawkins wrote that "The sea is natural for fishes, and the land for men" and recommended that captains have their men take "the air of the land" as frequently as possible.[163] Sailors also privileged "freshness" – food and water fresh from the land, regardless of the climate. Over a century after Hawkins, Admiral George Anson, fresh from his disastrously fatal circumnavigation, recounted how his scorbutic men would fill their away boats with

University Press, 2011) 251-5; for mortality in the slave trade see: Marcus Rediker, *The Slave Ship: A Human History* (London: John Murray, 2007) 5.

[161] John Williams and Parker Bennet, *Essays on the Bilious Fever* (London: T. Waller, 1752) 30.

[162] Joyce Chaplin argues that this set of longstanding beliefs represented a form of "global consciousness" – Sailors believed that all humans were equally land-dwelling creatures. Joyce E. Chaplin, "Earthsickness: Circumnavigation and the Terrestrial Human Body, 1520-1800," *Bulletin of the History of Medicine*, 86:4 (Winter 2012): 515-542.

[163] Hawkins quoted in Joyce Chaplin, "Earthsickness," 524.

grass which they hoped would “prove a dainty” addition to their diet.[164] One of the men even threw himself upon the shore of a South Sea island and began grazing on grasses like a “beast of the field.” This story was complemented by one in which some of Anson’s sailors put the mouth of their weakened companion to a recently-dug hole in the ground, so that he could breath the air directly emanating from the earth. According to Anson, the man almost immediately recovered.[165] In some respects, the intuition of sailors correlated with the Hippocratic beliefs of physicians – both agreed that scurvy was due to the lack of some essential nourishment from the land.

The sailors’ emphasis on “freshness” reflected a longstanding and widely-held medical distinction between “fresh” and “putrid.” While “fresh” air and food were nourishing and healthy, “putrid” substances corrupted the humors and led to disease.[166] Putridity arose chiefly from rotten substances, and produced a tell-tale smell that everyone could identify. In the words of seventeenth century Anglican cleric John Ward, “Frogs and serpents canne lesse live in Ireland, foxes in Crete, stagges in Africa, horses in Ithaca, and fishes in warme water, than the heart of man abide with impure smells, or live long in infected air.”[167] For sailors and physicians alike, the symptoms of scurvy, which included rotting gums and loss of teeth, black ulcers on arms and legs, and sensitive, ashen skin marked it as a “putrid” disease brought about by the “corruption of the blood, and the whole mass of the bodily humours.”[168] Fevers that occurred at sea

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[164] George Anson, *A Voyage Round the World, in the year MDCCXL, I, II, III, IV*, 5th ed. (London: John and Paul Knapton, 1749) 111.
[165] Anson quoted in Richard Mead, *The Medical Works of Richard Mead* (London: C. Hitch, 1762) 445-7.
[166] Andrew Wear, *Knowledge and Practice in English Medicine, 1550-1680* (Cambridge: Cambridge UP, 2000) 136-7.
[167] Charles Severn, ed. *Diary of the Rev. John Ward, Vicar of Stratford-Upon-Avon, extending from 1648-1679* (London: Henry Colburn, 1839) 255.
[168] Mead, *Medical Works*, 437.

were also frequently "putrid" fevers, as the increase of body heat upset the processes of fermentation within the body and accelerated internal decay.[169]

However, while sailors tended to focus on soil and vegetation, medical men were united in agreement that the essential health-destroying element was the air. In his *Discourse on the Scurvy*, Richard Mead noted that "nothing is clearer…than this, that the air is, even more than any other agent, concerned in bringing on [scurvy]." At sea, the air lost its elasticity and ceased to bring about the "intestine motion" necessary for the secretion of the body's natural juices. This resulted in not only "weakness of the body," but "dejections of mind" as the animal spirits ceased to excite the courage and vigor natural to sailors' temperaments.[170]

But what made the air at sea so bad? Seventeenth century Hippocratic theory denigrated the emanations that emerged from the ocean as unhealthy, theorizing that they originated from the putrefying fish, excreta and seaweed which must cover the deep ocean floor. However, such views had begun to moderate by the mid-eighteenth century, and some physicians had even begun to recommend cold sea-bathing as a means of invigorating the body. [171] The true culprit for diseases was not in the macrocosm of the natural world, but within the wooden world itself. Bad air, Mead and others concluded, was the combined effect of crowded sailors breathing enclosed air, and the incredibly poisonous effluvia that arose from the most dangerous part of the ship: the well.

Unlike the natural world, in which air circulated freely and was kept in global "æquilibrium" by the wind, air in the wooden world quickly became "vitiated".

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[169] Andrew Wear, *Knowledge and Practice*, 146.
[170] Richard Mead, *Medical Works*, 439-440.
[171] Alain Corbin, *The Lure of the Sea*, trans. Jocelyn Phelps (Berkeley, CA: University of California Press, 1994) 16, 65-70.

Following the reasoning of Robert Boyle, Mead reasoned that once air was truly enclosed, it "expands itself, and in proportion to the closeness of the place, loses its spring."[172] This problem was compounded in new ships, where green timbers exuded moisture and a dangerous "sappy wreak." Ships that carried large supplies of grain were likewise vulnerable, as the "vapours" that arose from the grain necessitated the thorough airing of the hold before sailors could safely venture down.[173] But while new timber and grain storage were circumstantial dangers, crowding was unavoidable. When air was respired by "many men crouded in close-quarters" the hot, moist effect of breathing further rarified the air and destroyed its elasticity. Physician William Watson noted that the three worst kinds of ships in this regard were "Ships of War, Hospital ships, and these used in the Guinea trade for negroes."[174]

But below these enclosed and crowded men lurked another, more potent source of effluvia: the water of the well. The water that collected at the bottom of the ship carried with it the crudescence of the entire vessel. While sailors could get used to the tang of fresh tar, the reek of sweat and the mild, troubling hint of excrement that characterized their abode "'tween decks," no one doubted that steady stream of putrescence arising from the well was unhealthy. One of the most unpleasant tasks of sailors was going down into the well to remove blockage from the bilge-pumps. As sailors descended the ladders into the bilge, squeezing past barrels, carefully-folded canvas and coiled hemp cables to climb down into the drained water at the ship's bottom, they were confronted with a

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[172] 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 (1741): 42-43.
[173] Hales, *Description of Ventilators*, 33-34.
[174] Richard Mead, "An Account of Mr. Sutton's Invention," 42-43; William Watson, "Some Observations upon Mr. Sutton's Invention to Extract the foul…air from…ships," *Philosophical Transactions* 42 (1741): 63.

mildewed and moldy cave of timbers, scummy water, and the putrid, rotting corpses of the pests that constantly threatened the salted provisions and biscuits. This water was sometimes "so extremely poisonous" that it threatened to suffocate seamen who encountered it. Indeed, in the estimation of William Watson, it could even "affect persons at a distance with violent head-achs, cold sweats, and frequent vomitings."[175] The dangers of the well, or bilge in later terms, were a distillation of the perils facing eighteenth century seamen: overcrowding and putrefaction were combined with the danger of changing climates from the relative health of the upper decks to the filth of the bilge.

Sailors and physicians agreed that the most dangerous and intolerable features of these dangers was the damp and putrid air aboard ships. This soon led to calls for greater ventilation. In his memoirs of his voyage around the world, Anson blamed the inability to sufficiently ventilate his ships as a central cause of his fleet's appalling mortality. In a vain attempt to increase airflow, his men had cut air ports in the sides of the ships, but there seemed to be no way to bring air down into the depth of the well. If a means could be invented, Anson pleaded, to render the well "sweet and clean, by a constant supply of fresh air," should not "policy, and a regard to the success of our arms, and the interest and honour of each particular commander…lead us to a careful…examination of every probable method?"[176] In the years following his voyage, the Royal Navy would undertake an extraordinary effort to correct these disgusting aerial conditions.

[175] William Watson, "Some Observations," 63.
[176] George Anson, *A Voyage Round the World*, 30.

The "Grand Patron of All Mechanick Traders"

Anson's call did not go unheeded. Finding a way to keep ships "fresh," dry and free from putrefaction became a key priority for the Royal Navy in the 1740s. With a fleet of over two hundred ships that represented a capital investment of over two million pounds, the dockyards of the Royal Navy were uniquely well-funded centers of manufacture in early eighteenth century Britain. [177] The public and political prioritization of the navy and the possibility of lucrative contracts drew ambitious natural philosophers and engine-makers to propose a wave of new machines and techniques. From pumps, stoves and fire-engines to pulleys and blocks, the eighteenth-century Royal Navy purchased huge numbers of machines, and was thus at the center of a unique network of mechanical innovation and mass manufacturing that has been compared to that of the early industrial revolution.[178] In the words of Edward Ward, the navy was the "grand patron of all mechanick traders, by sinking and destroying one half of their manufactures, to bring the other half to a good market."[179]

The immediate impetus for the Navy's interest in ventilation came in 1739, when a massive typhus epidemic broke out in the Portsmouth fleet at the beginning of the war against Spain. The navy had been so desperate for men that they had stocked their ships with, in the words of Admiral Philip Cavendish, "thieves, house breakers, Newgate birds, and the very filth of London."[180] As the poorest and sickest members of British society were taken out of dilapidated prisons and crowded into the holds of ships, the results

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[177] Brewer, John. *The Sinews of Power: War, Money and the English State, 1688-1715* (New York: Alfred A. Knopf, 1989) 34.
[178] Carolyn Cooper, "The Portsmouth System of Manufacture," *Technology and Culture* 25:2 (April 1984): 182-225.
[179] Ward, *Wooden World*, 2.
[180] Daniel Baugh, *British Naval Administration in the Age of Walpole* (Princeton: Princeton UP, 1965) 165, 179.

were predictable. A tour of inspection in April of 1740 revealed “six or seven hundred of the poor creatures sick and dying dayly” at Portsmouth alone.[181] This tragedy was compounded by an outbreak of yellow fever in the West Indies. During 1741, the two squadrons stationed at Jamaica lost over 2,500 men, seventeen percent of their total complement.[182] Public criticism mounted as lack of healthy seamen left much of the Portsmouth fleet cached in the harbor and Spanish ships appeared to match Britain’s finest in combat.[183]

Both of the most prominent proposals for the ventilation of ships cited this epidemic as the central inspiration. The scheme to gain early prominence was proposed by brewer and coffeeshop owner Samuel Sutton, who conceived the idea for his “ventilating pipes” after being informed by some of his customers that the ships in port at Spithead “stunk to such a degree, that they infected one another.” Sutton’s proposed solution was simple but elegant. At home, he had observed that by sealing a room with three fireplaces and lighting a fire in two of them, he could “bring the air to draw down the third Chimney, with such force as to put out a candle.” Building on this principle, Sutton concluded that if a pipe could be lowered into the well of a ship, and heated by fire at the other end, “a change of air would follow, and that by this means rendered sweet and pure, and fit for respiration.”[184] Stephen Hales wrote that he first conceived of the idea for ventilators after being invited to submit his ideas for keeping air clean on Lord Cathcart’s ill-fated 1740 expedition to Cartagena. After suggesting that cloths

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[181] Baugh, *British Naval Administration*, 181.
[182] Nicholas Rogers, *The Press Gang: Naval Impressment and its Opponents in Georgian Britain* (New York: Hambledon Continuum, 2008) 83.
[183] Sarah Kinkel, “Disorder, Discipline, and Naval Reform in Mid-Eighteenth-Century Britain,” *English Historical Review*, vol. CXXVIII no. 535 (Dec. 2013): 1465.
[184] Samuel Sutton, *Historical Account of a New Method for Extracting the Foul Air out of Ships* (London: J. Noon, 1745) 1-3.

dipped in vinegar could act as filters for air passing through the ship, Hales spent some months imagining a machine that could introduce more fresh air into the enclosed parts of the ship.[185]

Almost immediately, these competing inventions came into conflict. After a failed audience with Jacob Ackworth, the notoriously anti-innovation surveyor of naval works, Sutton had secured the support of Dr. Richard Mead, who, along with president of the Royal Society Martin Folkes, agreed to write to the Admiralty on Sutton's behalf.[186] For Mead, Sutton's device perfectly answered the needs of naval ships. Since every ship was already fitted with a copper or iron stove for preparing meals, the pipes could be installed with minimal interference in the operations of the ship.[187] William Watson concurred: Sutton's machine worked in a way "exactly conformable to the doctrine of pneumatics." The air at the heated end of the tube would "rarify," creating a suction that would draw out the foul air, which would quickly be replaced by "a supply of fresh air from the other parts of the ship."[188]

Meanwhile, Hales worked behind the scenes, using his status and connections to curry support for his devices within the Admiralty.[189] At a meeting of the Royal Society in 1741, both devices were demonstrated. While Sutton's devices had already gained the support of prominent members, J.T. Desaguliers, who observed the trials, decisively preferred Hales' machines. The airs from the well were so full of "sulpherous steams," that they were "in danger of taking fire, and by their explosion putting the ship in

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185 Hales, *Description*, ix-x.
186 Sutton, *Historical Account*, 12.
187 Mead, "An Account of Mr. Sutton's Invention," 44.
188 Watson, *Observations*, 67.
189 D.G.C. Allan and Roger Schofield, *Stephen Hales* (London: Scolar Press, 1980) 86.

danger."[190] Desaguliers' preference for Hales' devices was partially based on the fact that they worked by a similar principle as his own "blowing wheel," which he himself had proposed to the Admiralty as a potential solution. In a bitter post-script to the second edition of his *Course of Experimental Philosophy*, Desaguliers noted that "not one of the lords of the admiralty…so much as saw the experiment made." While he reluctantly recommended Hales' ventilators, he resented the fact that the competition between the ambitious brewer and the enthusiastic clergyman had "jockey'd" him out of his project.[191]

However, while Hales' machines seemed on the ascendant, the central test of which machines would be adopted would have to rely on their ability to accomplish two tasks: removing and freshening the foul air in the well and keeping the ships' timbers dry. The gauge of their success would be both their practicability – how much space and labor they required – and the healthiness of the crews in the ships that sailed with them. While Sutton complained bitterly about Hales' use of his status and influence, it was actually Sutton's pipes that saw the first sea trial in the navy.[192] Sutton had sufficiently impressed First Lord Sir Charles Wager that he authorized a sea-trial to proceed and wrote to Portsmouth to insure that Sutton encountered "no obstruction or discouragement from anybody." However, delays in installation meant that this trial was not able to take place until 1743.[193]

This test took place on a voyage to West Africa by the *H.M.S. Norwich,* and revealed some of deep ambiguity that active sailors felt about these new ventilating

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[190] J.T. Desaguliers, *A Course in Experimental Philosophy*, 2nd. Ed. (London: W. Innys, 1744) II:568.
[191] Desaguliers, *Course of Experimental Philosophy*, II:556, 558.
[192] Sutton, *Historical Account*, 30.
[193] Sutton, *Historical Account,* 16-17.

machines. Captain Gregory wrote that he had been obliged to "stop up" two of the air pipes "by reason the fire came down between decks." While the third pipe had operated throughout the voyage, Gregory found it impossible to judge its efficacy since the ship had leaked enough that the bilge had been constantly pumped, which had kept the well water sweet and the ship "so healthy as to bury only two men the whole time I was on the coast."[194] Naval officers, shipbuilders and sailors frequently complained about the potential inconveniences and hazards of the machines they were ordered to test. In the tight space of an eighteenth-century ship, even pipes could be a hazardous intrusion. A cadre of shipbuilders wrote a humble but insistent warning to the navy board that the installation of Sutton's pipes on some ships would require them to disrupt the run of cables and cut holes in the decking between the galley stove and the powder room – an enormous hazard.[195]

However, the perceived need to ventilate ships in order to preserve the health of sailors frequently overruled the objections of the sailors themselves. When the ardent reformer Lord Sandwich became first lord of the Admiralty in 1748, he blithely over-ruled the objections of officers and ordered Sutton's pipes to be fixed aboard all new ships.[196] While the primary purpose of Sutton's device was to keep ships healthy, in 1749 the Navy decided to conduct a new sea trial to determine whether his devices were effective at keeping ships dry – an essential quality to enable the preservation of food and powder. This test resulted in a minor scandal when the *HMS Humber*, which had recently

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[194] Sutton, *Historical Account*, 15-19.
[195] Woolwich Shipbuilders to Navy Board, August 1, 1741, National Maritime Museum, Greenwich, ADM 354/115/63.
[196] Sheerness dockyard officers to Navy Board, Oct. 12, 1748, The National Archives Kew, ADM 106/1064/323.

been fitted with Sutton’s pipes, found its powder so damp that they were unable to make a proper salute when returning from a voyage to Guinea and the West Indies.

Had Sutton’s devices kept the ship dry and “sweet”? Or had they been the cause of this serious lapse in Naval readiness? In order to determine what, or who was to blame, the.Navy Board ordered that testimonies be collected from the captain, carpenter, gunner and the yeoman in charge of the powder room. William Walker, the carpenter, spoke in favor of Sutton’s pipes, noting that the ship had been “dry, sweet, and wholesome during the whole voyage.” The bad powder, which was so damp that they had to break it apart with mallets before loading the guns, was the fault of blamed duplicitous suppliers in Jamaica, a fact proven by the the dryness of the timbers in the powder room.[197] A completely contradictory report was submitted by the captain, who said that Sutton’s pipes had not been able to make up for the greenness of the timbers and the dampness of the air in Guinea, an extreme condition witnessed by the “very keys rusting in our pockets.”[198] Given such contradictory evidence, and perhaps not wanting to implicate those responsible for bringing aboard low quality naval stores, the dockyard officers found it impossible to determine the cause of the damp powder. [199]

While they were installed widely, Sutton’s pipes failed to convince many in the navy that they could effectively guarantee the health of seamen. As Captain Pye’s testimony illustrates, the ventilating pipes were not believed to be powerful enough to compensate for a damp, hostile climate. One of the most influential detractors of Sutton’s

[197] William Walker to Navy Board, February 13, 1759, National Maritime Museum Greenwich, ADM 354/144/73.
[198] Captain Pye to Navy Board, January 30, 1750, National Maritime Museum Greenwich, ADM 354/144/73.
[199] Portsmouth Dockyard Officers to Thomas Corbett, Navy Office, March 4, 1750 National Maritime Museum Greenwich, ADM 354/144/73.

devices was the renowned naval physician and expert on maritime diseases Dr. James Lind. In his *Essay on the Most Effectual Means of Preserving the Health of Seamen,* Lind recounted a story in which the *HMS Sheerness*, recently fitted with Sutton's pipes, arrived in the Cape of Good Hope without a single sick man aboard. Eager to ascribe this extraordinary healthfulness to the effects of Sutton's pipes, the captain discovered that, due to the "neglect of the carpenter, cock of the pipes had been all this while kept shut." Making sure that the pipes were open on the return journey, twenty men quickly came down with "scorbutic and other disorders." For Lind, this incident illustrated a crucial point: the healthfulness of the ship had not been due to the action of the ventilating pipes, but to the fact that the sailors had been consuming fresh rather than salted provisions, a crucial measure when travelling in those "southern climates."[200]

Lind's new focus on shifting the regimen of sailors to mediate between the processes in their bodies and the specific conditions of their geographic location reflected a growing consciousness of the dangers of hot, humid, tropical climates.[201] As the navy ventured more and more frequently into these climates, it was not sufficient to suck out the foul air of the well. The focus was gradually shifting from the danger of the internal, shipboard environment to the external environment, and physicians would have to focus on mediating the relationship between sailors' bodies and the various climates they encountered. For Lind, this task could only be accomplished by a continual process of adaptation - taking aboard fresh provisions when possible, and employing a variety of

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[200] James Lind, *Essay on the most effectual means of preserving the Health of Seamen*, 2nd ed. (London: J. Murray, 1778) 29-30.

[201] On this topic, see: David Arnold, ed. *Warm Climates and Western Medicine: The Emergence of Tropical Medicine, 1500-1900*, Second edition (Amsterdam: Rodopi Press, 2003); Mark Harrison, *Medicine in an Age of Commerce and Empire* (Oxford: Oxford UP, 2010); and Suman Seth, *Difference and Disease: Medicine, Race, and the Eighteenth-Century British Empire* (New York: Cambridge UP, 2018).

techniques to maintain the constitutions of the sailors, for example, instructing sailors to take cold baths in hot climates, or the chewing of garlic when too wet and cold. In addition, ships would have to be "incessantly" ventilated and kept spotlessly clean – a new regimen of labor that would provide a crucial opening for Sutton's main competitor, the Reverend Stephen Hales.[202]

The Lungs of a Ship

By 1749 Sutton had died and his pipes were well on the way to falling out of favor with the Admiralty. Besides the ambiguity about their ability to keep ships dry and free from putrefaction, Sutton had constant submitted sharply-worded petitions and remonstrances for lack of payment. An inheritance dispute following his death finally pushed the navy to cease the installation of his pipes in 1753.[203] In the meantime, Stephen Hales had mounted a persistent publicity campaign for his ventilators, publishing a new *Description of Ventilators* in 1758 that re-described the natural-philosophical principles underlying his devices and providing additional examples of their potential uses, from the drying of grain to the freshening of brackish water through bubbly ventilation.[204]

[202] Lind, *Essay*, 11-14, 45-49. For an informative recent book on the political and social background of the new regime of discipline that was instituted in the Royal Navy ships during the mid-eighteenth century, see: Sarah Kinkel, *Disciplining the Empire: Politics, Governance and the Rise of the British Navy* (Cambridge, MA: Harvard University Press, 2018).
[203] Samuel Sutton to Navy Board, January 16, 1748, The National Archives Kew, ADM 106/1075/108; Samuel Sutton to Navy Board, July 4, 1748, The National Archives Kew, ADM 106/1064/48; Samuel Sutton Petition to Navy Board, Sept. 15, 1748, The National Archives Kew, ADM 106/1064/50; Samuel Sutton Petition to Navy Board, September 5, 1748, The National Archives Kew, ADM 106/1064/50; George Bellos to Navy Board, February 3, 1753, The National Archives Kew, ADM 106/1108/67.
[204] Stephen Hales, *A Treatise on Ventilators*, (London: Richard Manby 1758) 222-224; Stephen Hales, *An Account of a Useful Discovery to Distill Double the Usual Quantity of Sea-Water* (London: Richard Manby) 1756.

While Sutton's pipes had represented a pragmatic solution to the problem of foul air that required little space or labor, Hales' ventilators represented a more ambitious plan to completely re-make the shipboard environment by converting the ship into a reflection of a healthy body. His ventilators were thus designed to resemble lungs in every practical respect. The design consisted of two long, wide and shallow wooden boxes with thin wooden "midriffs" fixed inside. By using an iron handle to alternately move these midriffs up and down, air was sucked into the trunks through one set of valved doors and then blown out of the other set.[205] In order to direct ventilation, these doors could be connected to various parts of the ship via leather pipes or wooden ducts.[206] Unlike Sutton's pipes, which continually sucked air, or wind-sails, which could be rigged in fair weather to blast air into the lower decks, Hales' ventilators blew air at a steady, gentle speed of 25 miles per hour. This made them ideal for ventilating sick or sleeping men, as the "easy rising and falling of the midriff" mimicked "the way which nature makes use of, to convey fresh air into the lungs of men."[207]

Hales' devices also promised to serve the Navy's practical goal of preserving the fabric of the ship. "Putrified air will dissolve not only the blood and humours of human bodies" Hales warned, "but even heart of oak also," a costly disaster that "nothing but a succession of fresh air can prevent."[208] By providing this steady stream of fresh air, his ventilators would preserve "the timbers and planks of the hold itself." Hales promised

[205] Hales, *Description of Ventilators*, 25-6, 39.
[206] Ann Fowke to Navy Board, 1738-9, The National Archives Kew, ADM 106/908/84.
[207] Hales, *Description of Ventilators*, 2-3, 31.
[208] Stephen Hales to Navy Board, Jan. 3, 1750, The National Archives Kew, ADM 106/1091/3.

that his ventilators would also hasten the drying of green timbers, thus insuring that ships would be tighter and less prone to leaking.[209]

Despite these elaborate promises, Hales devices were decidedly impractical. In order to meet their purpose, Hales envisioned that the ventilators would have to work *constantly*. That meant that two men, one on each side of a heavy iron handle, would have to pump the machine sixty times a minute continuously for twenty-four hours a day.[210] Besides that, his machines were unwieldy, and officers commented that their size – ten feet by four feet by thirteen inches deep – took up much-needed space below decks.[211] Responding to these critiques, Hales argued that he size and labor required for his ventilators were a proof of their providential utility. If God had allotted "nearly one half of the trunk of our body for the office of respiration…can any one…grudge the little space these will take up in a ship?" Responding to the objection of labor, Hales claimed that working his devices would reinforce the disciplinary aims of the Navy: "shall it be said of the brave and undaunted British sailor; that rather than pull his hand out of his bosom and work…he will chuse to lie down and suffer that brave manly spirit to be suffocated in a frowzy stench?"[212]

In order to prove these assertions, Hales used his connections at the admiralty to secure an elaborate test for his ventilators. For six months, Hales was given direction over the inactive 20-gun ship *Sheerness*. Directing his trusted assistant Thomas Yeoman, the 73-year old Hales turned the *Sheerness* into a laboratory to demonstrate the effectiveness of his machines. First, he ordered his ventilators to be fixed on the lowest deck, just

[209] Hales, *Description*, 33-4.
[210] Hales, *Description*, 12.
[211] Hales, *Description*, 25-6.
[212] Hales, *Description*, 36.

beneath the orlop, which he had determined to be the most practical place.[213] Yeoman and the dockyard workers then connected the iron handles that operated the ventilator to a windmill, specially constructed on the ships' deck.[214]

For the next six months, whenever the wind would permit, the ventilator was set to work. Careful notes were kept marking how long the ventilator worked each day, and of the state of the ship's hold. The amount of dampness and mildew in the lowest parts of the ship were the primary gauges that would be used to judge the ventilator's effectiveness. Reports submitted by the officers noted that the windmill was frequently working between nine and twenty-four hours a day. However, by the end of the first month, there was very little change in the state of mildew in the hold. At this point, to gauge whether the machine was working, Hales directed pieces of wet canvas to be hung and damp wood to be placed at various points of the ship. After several days of ventilation, the pieces hung near the ventilator were marginally drier, but there was no discernable difference in those in the hold or in any of the pieces of wood.[215]

At this point, Hales requested that the ship be moved to a less sheltered position so that his machines could work even more frequently. In addition, he requested that the arms of the windmill be extended and made ten feet long each.[216] At the end of the six months, the dockyard officers reported that the ship's hold was "now in a worse condition with regard to mildew than wen the ventilator was fix'd on board." In their

[213] Hales, *Description*, 25.
[214] Stephen Hales to Navy Board, Jan. 3, 1750, The National Archives Kew, ADM 106/1091/3.
[215] Journal of Dr. Hales' Windmill and Ventilator fixed on the *Sheerness* submitted to Navy Board, Mar. 20, 1751, National Maritime Museum Greenwich, ADM 354/144/118.
[216] Stephen Hales to Navy Board, Jan. 3 1750, The National Archives Kew, ADM 106/1091/3.

official report on the ventilator to the Lords of the Admiralty, they concluded simply that "we are of the opinion that it will not answer the service intended."[217]

The apparent failure of his device did not deter Hales. After a series of letters proposing further trials, the admiralty agreed to a different test of his ventilators aboard the *H.M.S. Prince*, then docked at Chatham. This test would determine the ability of ventilators to dry green timber. With so many new ships being built, Hales noted that this was a crucial test, as the "very putifying nature" of the sap of new timber was the reason why ships "built of green, unseasoned timber are observed to be very unhealthy."[218] In this test, six pieces of wet green oak were cut and weighed to the exact same specifications. Three pieces were placed on the ventilated *Prince*, and the other three were placed on the unventilated *H.M.S. Russel*. After twelve days of continual ventilation, the timber on the *Prince* had lost two pounds, fourteen ounces, while that on the ventilated *Prince* had lost a paltry one pound eight ounces.[219] A similar test, conducted a few weeks later with larger timbers on three separate ships found similarly ambiguous results. While the timber on the ventilated *Prince* weighed less than that on the unventilated *Barfleur*, that on the *Russel* again weighed in at over a pound less. In response, Hales proposed *four* additional sets of ventilators to be placed on the *Prince.* However, the officers at Chatham dockyard demurred, noting that "those fixt already doth not disperse the ventilated air against the timber…as was intended."[220]

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[217] Journal of Dr. Hales' Windmill and Ventilator fixed on the *Sheerness* submitted to Navy Board, Mar. 20, 1751, National Maritime Museum Greenwich, ADM 354/144/118; Deptford Dockyard Officers to Navy Board, Mar. 27, 1751, National Maritime Museum Greenwich, ADM 354/144/119.
[218] Stephen Hales to Navy Board, Aug. 13, 1753, The National Archive Kew, ADM 106/1111/318.
[219] Chatham Dockyard Officers to Navy Board, Sept. 10, 1754, National Maritime Museum Greenwich, ADM 354/149/40.
[220] Chatham Dockyard Officers to Navy Board, Dec. 24, 1754, National Maritime Museum Greenwich, ADM 354/149/169.

Hales tests were a complete failure. His ventilators had not been able to dry green timber, freshen the water in the well, or reduce the amount of observable rot and mildew in the ships' hold. While he had been able to test them with a windmill on board the docked Sheerness, at sea they would require an enormous amount of additional labor to operate. What possible reason could there be for the navy to adopt them?

The Labor of Breathing

The answer was that his machines promised something that had not been measured in the Admiralty's tests: Hales' machines promised to invigorate the spirits of unwilling laborers. During the early 1750s, Hales launched a one-man propaganda campaign that relied on the testimony of captains who had employed his ventilators to deliver large groups of people safely to distant environs.

With the use of a published testimony in the *Philosophical Transactions*, Hales answered complaints that ventilators required too much labor by demonstrating that men were actually *eager* to work the ventilators. Captain Thomson of the Frigate *Success*, wrote that his men "all agreed" that the ventilators were of "great service." Rebuffing the idea that ventilators would require too much labor to work, Thomson swore that his men were "so sensible of the benefit of them, that they required *no driving* to work that which they received so much benefit by." After a long journey, the *Success* arrived in Georgia with all men healthy, a fact all the more remarkable since they were "pressed men, and delivered me out of gaols, with distempers among them."[221]

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[221] Thomson quoted in Stephen Hales, "An Account of the Great Benefits of Ventilators…in preserving the health and lives of people in slave and other transport ships," *Phil. Trans.* 49 (1755): 334-5.

This testimony from a naval officer was complemented by further examples from slave and transport ships. Less than three months after the failure of his tests on the *Sheerness*, Hales appeared before the Royal Society to read a letter from Henry Ellis, a young slave-ship captain who Hales had persuaded to install his ventilators. Of the 130 slaves that he had transported from Cape Monte to the West Indies, Ellis reported that not one had taken sick. Contrary to naval fears about the labor required to work the ventilators, Ellis reported that "far…from being inconvenient" the machines were "good exercise for our slaves" who were "very sensible of the benefits of constant ventilation."[222]

Besides publishing these accounts in the *Gentleman's Magazine* and *Philosophical Transactions*, Hales made a direct appeal to the expansionist interests in the Admiralty. By the late 1740s, the naval board was controlled by the ambitious "Bedford Circle", an ambitious group that included the Earl of Sandwich and Lord Halifax, who as First Lord of the Admiralty and President of the Board of Trade would work assiduously to increase the deployment of ships and troops around the world.[223] Hales convinced Halifax to fix ventilators on transport ships meant to carry German protestants to Nova Scotia. Writing in the *Gentleman's Magazine*, Hales wrote that his ventilators were "being daily more and more experienced to be of great advantage" and, contrary to the negative reports of the dockyard officers, it was "not questioned but this invention will be brought into general use in the Navy."[224]

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[222] Henry Ellis, "A Letter to the Rev. Dr. Hales from Captain Henry Ellis," *Phil. Trans.* 47: (1752): 212-213.
[223] Kinkel, "Disorder, Discipline, and Naval Reform," 1461, 1472-3.
[224] Stephen Hales, "Ventilators in Use," *Gentleman's Magazine* 20 (1750): 282.

The coup de grace came when Hales managed to persuade Admiral Edward Boscawen to fix ventilators aboard his flagship, the *Royal George* before a patrol in the North Atlantic in early 1756. Boscawen's good report and another looming manpower crisis in the face of the impending war with France convinced the admiralty to order that Hales' ventilators be fixed on all Royal Navy ships in September of 1756.[225] The next edition of the admiralty regulations included the following instructions:

> "Whereas His Majesty's Ships are ordered to be furnished with Ventilators, at a very great Expence, in order to keep the ships free from foul air, and the captains in the Navy, in general, not understanding the proper use of them; they are hereby strictly required and directed, to cause them to be made use of, at least one half Hour in every watch; and the Mate of the Watch to note in the Log-Book the time of tis being so made use of."[226]

Hales had won over the Admiralty. But his ventilators never convinced the men they were intended to benefit. A brief survey of Royal Navy log-books from the decades following the official adoption of ventilators reveals that the idea of men "cheerfully" working the ventilators was not borne out.[227] While it is clear that ventilators *were* widely installed, they had a deeply mixed reputation. Captains rarely marked use of ventilators, and those that did ceased to do so within a year or two after the adoption of the devices.[228]

When ventilators did appear in Navy Board records, it was usually because they were useless. Shortly after installation of his ventilator, Captain LeGrass of the H.M.S. *Winchester* wrote to the navy board to complain of the machines' "inutility," claiming

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[225] "On the 17th August we gave general orders to the Officers of the several Yards for fitting ventilators on all HM ships.": John Clevland to Dockyard Officers, Sept. 4, 1756, National Maritime Museum Greenwich, ADM 354/153/235.
[226] Anon. *Regulations and Instructions relating to His Majesty's Service at Sea*, 9th ed. (London, 1757) 215.
[227] Hales, *Description*, 37.
[228] I looked through Captains' logs for ships that were listed as having had ventilators installed between 1756-1809. Ships included the HMS Royal George, HMS Magnanime, HMS Union, HMS Vestal, HMS Vesuvius, HMS Censor, HMS Stork, HMS Vigilant, HMS Rolla, HMS Temeraire, The National Archives Kew, ADM 51/3958, ADM 51/3895; ADM 51/1019; ADM 51/1034; ADM 51/1980; ADM 51/805.

"that his men were much healthier when he left off working them than they were before." Stephen Hales himself patiently examined LeGrass's complaint and concluded that he had not been properly instructed in the use of ventilators, and that the vents and tubes of the ventilator had not been correctly tightened and directed to send the foul air out of the ship. The Dockyard officers deferred to Hales, but given his evident frustration, it is hard to imagine that Captain LeGrass would have directed his men to work the heavy iron cranks in future voyages.[229] A similar complaint was lodged in 1770 by Captain Gower of the H.M.S. *Pearl*, who described the ventilator as "useless to the ship, and a great incumbrance in her, and the occasion of much water leaking into the Boatswain's store room." Fearing that his ships' stores might be damaged as a result, Gower requested that the officers of the dockyard remove it immediately. The navy board meekly complied.[230]

But while Hales' ventilators had not proven their utility to captains, they continued to be favored by naval physicians and natural philosophers. John Pringle, who wrote admiringly of Captain Cook's efforts at keeping air fresh and clean through the frequent washing of the decks and airing of hammocks, noted with regret that the explorer had not deigned to bring a ventilator on his second voyage. "The credit of the ventilator," Pringle noted, "is yet far from being firmly established in the navy."[231]

The Limits of Ventilation

In his 1768 *Essay Concerning Diseases Incidental to Europeans in Hot Climates,* Lind added a medical coda to the age-old sailor logic that land was inherently healthier

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[229] Captain Le Crass to John Clevland and Navy Board, Aug. 8 1757, National Maritime Museum Greenwich, ADM 354/156/178.
[230] Captain Gower to Navy Board, April 1, 1770, The National Archives Kew, ADM 106/1187/242.
[231] John Pringle, *Discourse upon some late improvements of the Means for Preserving the Health of Mariners* (London: Royal Society, 1776) 31.

than the ocean. While most places around the world contained havens of fresh, pure air and wholesome soil, there were locations into which "unseasoned Europeans" could not possibly survive. Uncultivated lands and the mouths of rivers, where men could encounter "pestiferous nocturnal air" were particularly dangerous, and Lind remarked that "it does not seem consistent with British Humanity to assign such employments to a regiment of gallant soldiers or to a company of brave seamen." If slavery could possibly be justified, Lind mused, "it must be from the absolute necessity of employing them in such services as this."[232]

Lind's influential text was responding to the enormous expansion of the British Empire in the wake of the Seven Years' War, which had spurred a renewed medical interest in the relationship between climate and health, especially in relation to the preservation of sailors and soldiers.[233] This discourse also marked a growing pessimism about the ability of ventilation to maintain "freshness" in the face of damp, hot, tropical climates. As the emphasis on maintaining the health of sailors began to emphasize their susceptibility to such climates, abolitionists began to argue that there were certain *shipboard* climates that were similarly unbearable. James Lind's pessimistic assessment of ventilators noted that while they were useful, there were some spaces that "the purest air cannot cleanse."[234] In medical texts and statistical surveys, slave-trade abolitionists argued that the holds of slave ships constituted just such a place.

In his 1786 *Observations on the Scurvy*, former slave-ship surgeon Thomas Trotter recounted the conditions on his ship. Low decks of five to six feet were split in

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[232] Lind quoted in Suman Seth, *Difference and* Disease, 109.
[233] Suman Seth, *Difference and Disease*, 101-105.
[234] James Lind, *Essay on the Health of Seamen*, 2nd ed. (London: D. Wilson, 1762) 5, 314.

two in order to maximize the number of people the ship could carry. The slaves were stowed “spoonways” – forced into a sideways embrace that further maximized the space and meant that they were so close together that it was “not possible to tread among them.” [235] The result of these conditions was a continual temperature of over 100 degrees Fahrenheit and an “effluvia so intolerable, that in a few minutes you may have the condensed vapour from your face in great quantity.” By the time Trotter’s ship had reached Antigua five weeks later, forty of the slaves had died, and more than half the ship was suffering from scurvy as well as guinea worm brought about by putrid water that had been brought aboard for slaves. While Trotter mainly blamed the poor provisioning of the slaves, he emphasized again the role of the “atmosphere…where the slaves are kept” with “so high a temperature, tainted with the offensive effluvia from so many scorbutic lungs” “Can we wonder” he went on, “that this foul air, when breathed again, or applied to the bodies of others…should be highly noxious?”[236]

Despite the obviously repugnant treatment inflicted on the slaves, Trotter’s fellow abolitionists continually emphasized the danger slave holds represented to white British sailors. Another surgeon-turned-abolitionist, Alexander Falconbridge, emphasized that sailors were deeply vulnerable to the “noxious…foul air that arises from the negroes when they are much crowded.” Combined with a poor diet of cheap provisions and the worm-infested water frequently encountered in West Africa, sailors were rendered “extremely susceptible of putrid fevers and dysentaries.”[237]

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[235] Thomas Trotter, *Observations on the Scurvy* (Edinburgh: Charles Elliot, 1786) 32.
[236] Trotter, *Observations*, 32-41.
[237] Alexander Falconbridge, *An Account of the Slave Trade on the Coast of Africa* (London: J. Phillips, 1788) 24-5, 38-9.

Falconbridge's claim that the slave trade damaged white sailors, that "body of people so valuable in a commercial state," played directly into the longstanding anxiety that Britain was deficient in able-bodied seamen.[238] This angle of argument was methodically exploited by Thomas Clarkson, who argued that the slave trade represented a "grave" for British sailors. In his 1788 *Essay on the Impolicy of the Slave Trade,* Clarkson relied on evidence gathered from in-person surveys of Liverpool slave ships to calculate that "not less than *five hundred*" British seamen every year became "martyrs to this inhuman trade."[239] Besides the cruelty of captains, Clarkson argued that the very nature of the slave trade subjected seamen to debilitating conditions. The climate of Africa was "excessively hot," with "excessively cold and heavy" dews. The ship, which was the only insulation sailors had from the climate, was filled with slaves, and sailors were thus forced to sleep on the open decks, often without even a tarpaulin to cover them. This led to rheumatism and fevers and left sailors either dead or "unserviceable to the state."[240]

Sailors participating in the slave trade were thus caught between two unhealthy environments – the hot, wet climate of West Africa and the foul, noxious hold of the slave ship. As war with France began to seem likely and another manning crisis loomed on the horizon, Clarkson's conservation-of-labor argument found a sympathetic ear in Parliament – and once again Hales' ventilators took center stage.

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[238] Falconbridge, *Account,* 48; Denver Brunsman argues that Britain's "manning crisis" was not necessarily because of a deficiency of seamen available to the navy, but of the fiscal-military state's desire to fully man both the merchant marine and the navy during wartime: Brunsman, *The Evil Necessity*, 33.
[239] Marcus Rediker, *The Slave Ship: A Human History* (New York: John Murray, 2007) 325-6.
[240] Thomas Clarkson, *Essay on the Impolicy of the Slave Trade* (London: J. Philips, 1788) 58, 68, 71.

The Demise of Ventilators

In 1788, pressed by petitions from abolitionist groups and by anti-slave-trade MPs, Parliament passed the first bill to regulate the slave trade. A primary architect of this bill was the elderly Oxford MP William Dolben, whose determination to regulate the slave trade had been forged during his tour of a slave ship docked in London. Finding that it was common practice to cram slaves together "like herrings in a barrel," he was horrified by the prevalence of "putrid and fatal disorders," which also affected the ships crew. While he hoped for the total abolition of the trade, Dolben felt that the deepest horrors could be reduced by regulating the numbers of slaves a ship could legally carry and by "obliging them to let in fresh air."[241] The resulting legislation, referred to as the "Dolben Act," limited the number of slaves a ship could carry depending on the tonnage, and required ships to keep a surgeon who was responsible for filling out a report on the health of the "cargo" at the beginning and the end of the voyage. But the primary means of maintaining health were to be the "two several ventilators, which are hereby directed and required to be affixed in every such ship…and to be daily worked."[242]

The inclusion of ventilators in Dolben's bill illustrates the ongoing faith in the machines that existed among reformers of all stripes – a testament to Hales' ongoing influence and the continued belief that ventilation could reform even the most pestilential environments. But debates in Parliament over the effectiveness of the bill and its potential renewal reveal that optimism about the potential of Hales' ventilators was beginning to fade. For their part, Pro-slave-trade advocates argued that ventilators were unnecessary.

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[241] Thomas Clarkson, *The History of the Rise, Progress, and Accomplishment of the Abolition of the African Slave-Trade* Volume 1 (London: Longman, 1808) 519-520; Hugh Thomas, *The Slave Trade: The History of the Atlantic Slave Trade, 1440-1870* (New York: Simon and Schuster, 1997) 507-9.
[242] Slave Trade Act 1788, 28 Geo. III, c. 54.

Their ships were already healthy, clean, and well-ventilated and any potential danger emerged from the African climate, not the practices of the slave trade. Robert Norris, a Liverpool-based slave merchant who had served as a captain in the trade, testified that his ships had been perfectly well-ventilated before Parliament's regulations. His ships had "air ports in each side…and gradings the length of the deck, over which were suspended wind sails, for throwing down fresh air into the room." Furthermore, Norris claimed that slaves *chose* to remain close, warm and unventilated: "warmth is so acceptable to negroes, that when a ship had only half its complement…on board, those negroes then there lay as close to eachother by choice as afterwards in case of necessity." The heat was so desirable, that slaves "frequently desire to have a part of the gratings covered."[243]

However, when asked about ventilators, Norris' answers became less confident.

> Did you use ventilators in your own vessels?
> - I said I had windsails.
>
> Have you not heard that other ships have ventilators?
> - I never saw one, nor when I was at sea do I believe there was one.
>
> Do you know there is any objection to ventilators in hot latitudes?
> - The objection, if any, is to the space they would occupy.
>
> Have you never heard that Doctor S. Hales wrote a book , to recommend such ventilators in African Voyages?
> - I have, and seen in Dr. Mead's Works such a ventilator.
>
> Do not you know that after that publication they were tried in ships in the African trade?
> - No – nor ever heard of one being employed.

Other witnesses confirmed Norris' statements – slave traders knew about ventilators, but the machines were perceived as unnecessary, ineffective, and a waste of space. Royal Navy officer John Mathews, who had previously served in the slave trade, testified that "the first ship I went to in Africa had ventilators; but they soon got out of

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[243] "Minutes of the Evidence taken in the Last Session of Parliament before the Committee of the Whole House, to Whom the Bill for Providing certain Temporary Regulations respecting the transportation of the Natives of Africa, in British Ships, to the West Indies, and elsewhere was committed." House of Commons Sessions Papers (HCSP) 68: 4-6, 19

repair and consequently became useless." Upon being asked whether he believed that ventilators would be useful, he responded in the negative, and gave his opinion that wind sails "would answer the purpose much better."[244] George Young, a Royal Navy captain who had inspected slave ships confirmed that the primary objection to ventilators was the space they would occupy. He noted that they would be useful on board ships, but stated his opinion that the mortality suffered by sailors was inexorable from the nature of the African slave trade itself. The "unhealthiness of the climate, from the necessity of remaining long in rivers, and in the rains, and from bad accomodations on board the ships, and from frequent want of provisions." This resulted in a typical mortality rate of half the ships complement and an annual loss of seamen that amounted to "the manning of two ships of the line."[245]

The resulting renewal of the Dolben Bill in 1789 again focused on preserving the health of sailors health – but this time the zone of danger was extended beyond the hold of the ship to encompass elements of the African environment. The bill forbid sailors from venturing into uncultivated lands deemed so unhealthy by James Lind. Rather, "the master of the said ship…will hire and employ the natives in their craft to wood and water the said ship." In order to insure that they would be protected from the "dews" and

[244] "Minutes of the Evidence taken in the Last Session of Parliament before the Committee of the Whole House, to Whom the Bill for Providing certain Temporary Regulations respecting the transportation of the Natives of Africa, in British Ships, to the West Indies, and elsewhere was committed." HCSP 68: 19-23.
[245] United Kingdom. Board of Trade. *Report of the Lords of the Committee of Council appointed for the Consideration of all Matters relating to Trade and Foreign Plantations: submitting to His Majesty's consideration the evidence and information they have collected in consequence of his Majesty's order in Council, dated the 11th of February 1788, concerning the present state of the trade to Africa, and particularly the trade in slaves; and concerning the effects and consequences of this trade, as well in Africa and the West Indies, as to the general commerce of this kingdom.* (London 1789): 115-6.

"excessive heat" of the climate, the new bill required that sufficient space be set aside belowdecks for sailors to shelter themselves from the inclement weather.[246]

Abolitionists argued that no regulation could possibly be adequate to protect sailors from these dangers. In a gripping 1790 testimony, Thomas Trotter vigorously denied Norris' assertions that slave ships were well ventilated, recalling that slaves aboard his ship had exhibited the same behaviors as "expiring animals in the exhausted receiver of air pumps." Rather than asking for the air-gratings to be covered, slaves reached through the gratings trying to pull them up, crying "kickeraboo, kickeraboo," which Trotter translated as "we are dying."[247]

This dismal picture of the slave ships as airless, fatal environments was emphasized again and again in abolitionist literature. Writing of his own passage on a slave ship, Olaudah Equiano wrote that the slaves were often "near suffocation, from the want of fresh air…for whole days together." In the crowded hold, each person "produced copious perspirations, so that the air soon became unfit for respiration, leading to sickness and death.[248] Slave ships were so poisonous that they were more like otherworldly infernos. Abolitionist poet James Field Stanfield referred to the holds of slavers as a "noisome cave," and a "gorged cell of dim disease." Out of that "rank maw"

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[246] "A Bill with the amendments to continue and amend an act, made in the last session of Parliament, intituled "an act to regulate for a limited time the shipping and carrying slaves in British Vessels from the Coast of Africa." Slave Trade Act 1788, 29 Geo. III, c. 66.

[247] "Minutes of the evidence taken before a committee of the House of Commons, being a select committee, appointed on the 23rd day of April 1790, to take the examination of the several witnesses ordered by the house to attend the committee of the whole house, to whom it is referred to consider further the circumstances of the slave trade." HCSP 73: 84-5.

[248] Olaudah Equiano, *The Interesting Narrative of the Life of Olaudah Equiano*, Second ed. (London: 1794) 51-54.

arose a "morbid steam" that, by killing so many sailors, "bares our fleets and widows half the isle.[249]

Conclusion

In the spring of 1841, an expedition set out from London for the coast of West Africa, intending to sail up the River Niger. Led by three modern steamships, the *Albert*, the *Soudan*, and the *Wilberforce*, the mission of this expedition was not to procure slaves but to extinguish the institution. Sponsored by the Society for the Extinction of the Slave Trade and for the Civilization of Africa, this expedition was to sail up the Niger River, distribute Arabic Bibles and evangelical pamphlets, and establish a "model farm" that would demonstrate to the local inhabitants the potential of modern agriculture.[250]

However, this work of evangelization was not to be done by English people – the extreme danger of tropical diseases meant that white crewmen would be at enormous risk. The proposed solution was that while passing up the mouth of the river, black converts would conduct the diplomacy and evangelization on land while white crewmen remained sealed in the ship, protected by an ambitious ventilation system designed by the chemist and ventilation expert David Boswell Reid. To insure that no dangerous contagions entered the ship, air would be taken from far above the deck through an air shaft and then passed through a filtration system. Constant circulation and purification would be enabled by a steam-powered fan, supplying the interior of the ship with "medicated air" that contained none of the poisonous vapors outside the hull.[251]

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[249] James Field Stanfield, *The Guinea Voyage* (London: James Phillips 1793).
[250] Edward Gillin, "Science on the Niger: Ventilation and Tropical Disease during the 1841 Niger Expedition," *Social History of Medicine* 31:3 (Fall 2017): 608, 620.
[251] D.B. Reid, "Dr. Reid on the Ventilation of the Niger Steam Vessels," *Friend of Africa*, (1841) 41, 43-47; Gillin, "Science on the Niger," 614-6.

The system was a complete failure. While expedition organizers had hoped that the ships would represent a brilliant example of the "British nation and character," the ships had instead become floating hospitals. Nearly a quarter of the total complement had taken ill by September and by the time the ships returned to Britain, fifty on board had died. The expedition's apparent failure to impress the Aboh and Eggarah people compounded the sense of disappointment among the expedition's evangelical sponsors. However, Reid's ventilation system was spun as a success. Compared to earlier expeditions, the death toll on the *Albert, Soudan* and *Wilberforce* had been minimal.[252] The official documents presented before Parliament stated that Reid's device had "undoubtedly contributed to the comfort of the crews" and was deemed "very valuable" by the mission's chief medic.[253]

While Hales' ventilators had disappeared from Admiralty regulations after 1808, the Niger expedition illustrates how ventilation continued to be viewed as a vital means of protection from dangerous, non-European climates. The long transition from Sutton's pipes, to Hales' Ventilators to Reid's elaborate purification systems illustrates how the perceived locus of aerial danger had shifted from the inside of the ship to the exterior – the hot, insalubrious climates that formed a larger and larger part of Britain's empire and the imperial consciousness.

While Britons in the early eighteenth century had prided themselves in "carrying on the most extended commerce in the world," the often deadly circulation of free and unfree labor that this commerce necessitated had inspired enormous efforts to maintain

[252] Gillin, "Science on the Niger," 617.
[253] David Boswell Reid, *Official Documents, Reports and Papers Referring to the Progress of Dr. Reid's Plans for Ventilation* (London: N.P. 1846) 14.

health aboard British ships.[254] By the late eighteenth century, as the empire expanded to encompass more and more of the torrid, tropical regions famed for deadly diseases, the blame for mortality aboard ships shifted from the ships themselves to the inherent perils of the "hot climates." British ships were healthy – the torrid zone was not. Rather than a "free circulation of fresh air," the goal of ventilating machines had become to insulate British bodies from the inhospitable environment of the tropics as well as from the appalling conditions and harsh toil that dominated the experience of enslaved Africans. While Hales' "Lungs of a Ship" had triumphed, the vision of Nathaniel Henshaw's enclosed, disease-free "domicil" remained.

[254] Defoe, *A Plan of the English Commerce*, 1.

Images:

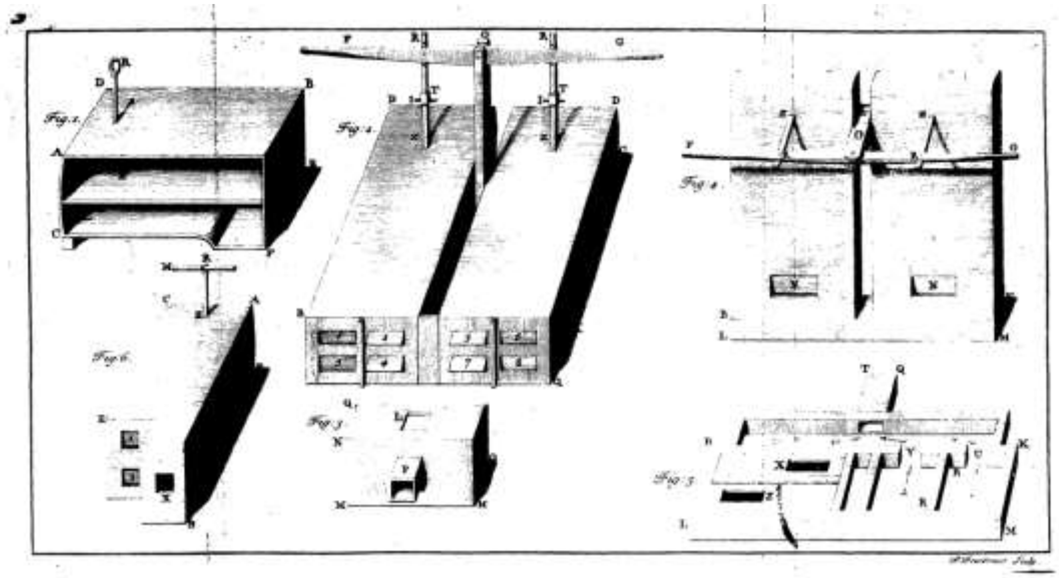

Figure 1: Various configurations of Hales' ventilators for aboard ships. Clockwise from left: Fig. 1. A cross section showing the midriff and handle. Fig. 2. A ventilator in the typical horizontal position with a levered handle at the top. Fig. 4. Ventilator in a vertical position for better accommodation on some ships. Fig. 5. Valves for adapting the ventilator for vertical use. Fig. 3. Valved "receptacle" used by Hales to measure the exhaling force of the ventilator. Fig. 6. Small ventilator intended for the bread room aboard ship. [Stephen Hales, *A Description of Ventilators* (London: W. Innys, 1743) Plate 1].

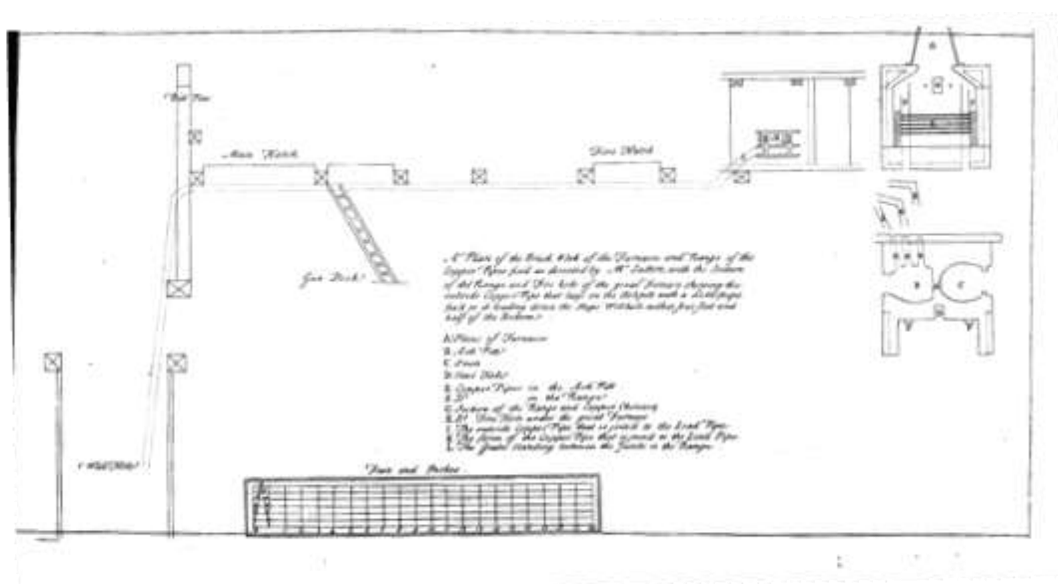

Figure 2: Samuel Sutton's "Ventilating Pipes." This simple apparatus ran a copper pipe from the well of the ship (left) to the galley stove, where heat created a convection that ventilated the ship. [Samuel Sutton, *An Historical Account of a New Method for extracting the foul Air out of Ships* 3rd ed. (London: J. Brindley, 1757) Plate 1]

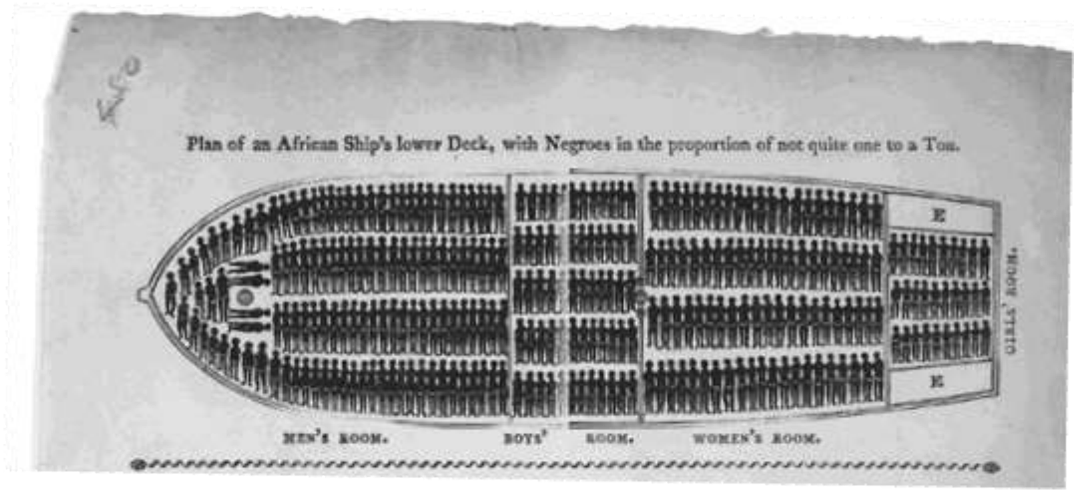

Figure 3: Original anti-slavery broadside depicting the stowage of the slave ship *Brookes* conforming to the Dolben Bill of 1788. This image was re-printed and elaborated upon countless times as an illustration of the inhuman conditions aboard even regulated slave ships. [William Elford, *Remarks on the Slave Trade* (Plymouth: Samuel Wood, Plymouth Society for Effecting the Abolition of the Slave Trade, 1788)].

Fig. 299.

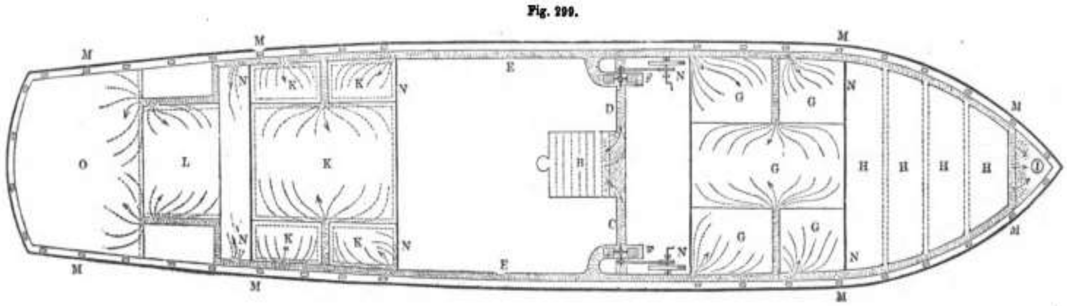

Figure 4: Illustration of one of David Boswell Reid's ventilated Niger vessels. The arrows show projected airflow. [David Boswell Reid, *Illustrations of the Theory and Practice of Ventilation* (London: Longman, Brown, Green, & Longmans, 1844) 405].

Chapter 3:
Disciplining the Environment: Contagion Theory and Prison Reform

Abstract:

This chapter examines the prison reform movement that emerged in the mid-eighteenth century through the lens of contagion theory and projects that sought to ventilate and sanitize prisons. I argue that the new architecture of prisons and the disciplinary regime emerged as a direct result the reformers' intense concern with containing physical contagion by managing the aerial environment. Following the logic of contemporary medical and natural-philosophical beliefs, John Pringle, Stephen Hales, and John Howard believed that moral and physical health were linked and closely tied to the qualities of the environment. Since air was viewed as the primary vector of disease, reformers hoped first and foremost to prevent outbreaks of disease by containing prisoners within a clean, fresh, and salubrious environment that would purify the soul by first curing the body. This chapter examines how the reconstruction of Newgate Prison and the work of famous prison reformer John Howard were deeply influenced by concepts of aerial contagion and the longstanding Mediterranean practice of quarantine – a connection made explicit in Howard's sponsorship of a proposed quarantine station to be built on the River Medway. I argue that the perceived failure of ventilation and hygiene to reform prisoner behavior prompted state-sponsored reform to concern itself less with the environment and more on enforcing individual discipline.

Introduction: Finding Fever

At Kherson, in the depths of a bitter Russian winter, prison reformer John Howard drew his last breath. He was far from the only one to die in the Ukraine that winter. The city lay at the mouth of the Dnieper river on the shores of the Black Sea and had developed a reputation for unhealthiness. Captured from the Crimean Khanate by the army of Empress Catherine the Great, construction of the fortified city had been spearheaded by Prince Potemkin, engineering enthusiast and the Tsarina's former lover, who had been named viceroy for the southern provinces.[255] In the months prior to Howard's arrival, the city had become crowded with officers recently returned from the Turkish front. Flushed with news of victory over the Ottomans, the city's inhabitants had "testified their joy" by fêting the new arrivals with balls and masquerades. However, these festivities were punctuated with grief, as many who attended the balls were "almost immediately afterwards attacked with fevers."[256]

Curiously, an outbreak of fever was precisely what Howard had been seeking. Ever un-impressed by grandeur and frivolity, the dour middle-aged dissenter had spent nearly two decades inspecting prisons, bridewells, hospitals, and insane asylums in order to gain a better understanding of how the health of inmates could be improved. What fixed Howard's attention most was not the immorality of the prisoners or the neglect of their caretakers, but the "*goal-fever*" (also spelled "goal" or "jayl") which he saw "prevailing to the destruction of multitudes."[257] In his efforts to find the origins of the disease and discover how it could be prevented, he had spent much of the 1780s touring "Lazarettos" (also known as "Lazarets" or "quarantine stations") in France, Italy, Malta, Greece, and the Ottoman Empire.

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[255] Viceroy Potemkin's willingness to host Howard reflected his keen interest in institutional reform. He had recently employed Samuel Bentham to help reorganize the factories on his estates, with fairly disastrous results. See: Peter Linebaugh, *The London Hanged: Crime and Civil Society in London in the Eighteenth Century* (Cambridge: Cambridge UP, 1992) 372-3.
[256] John Aikin, *A View of the Character and Public Services of the Late John Howard, esq.* (London: J. Johnson, 1792) 190.
[257] John Howard, *The State of the Prisons in England and Wales* (Warrington: T. Cadell, 1777): 1-2.

Shortly after completing his new *Account of the Principal Lazarettos in Europe*, Howard decided to undertake another journey "for the purpose of revisiting Russia, Turkey, and some other countries, and extending his tour in the East."[258] Now in his early sixties, Howard's determination to travel Eastward dismayed many of his friends and admirers, who worried that he was in the grips of a death wish. After more than two decades of much-celebrated philanthropy, he wrote in his diary about the feelings of guilt which still pricked him. "Ease, Affluence and Honours are temptations that the world holds out… Fatigue, Poverty, Suffering and Dangers, with an approving conscience… strangling and death, sooner than deliberately forsake my God. My God, oh!"[259]

However, other passages from Howard's diary provide a more tangible rationale for his journey: he was seeking the geographic source of disease. Following the longstanding contagionist theory which identified the East as the source of all "plagues," Howard wrote in 1789 that disease "must originally have taken its rise in some particular place, as perhaps in Egypt and the Coasts of Barbary." While he believed it impossible to fully trace how disease moved from country to country, he hoped that a journey eastward could provide more information about how its spread may be contained and the symptoms cured. ""Though I have never said that I knew the cause of the plague, yet I do see, that when the infection has by any means entered, and the dreadful consequences are thought not to be avoided, that infection may be mitigated, and those consequences not so dreadful."[260]

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[258] Howard quoted in Aikin, *Character and Public Services*, 183.

[259] Emphasis in original: John Howard Notebooks, 1788-89, Bodleian Library, Oxford University, MS Eng. Misc. 401.

[260] Richard Mead was the most prominent and influential English exponent of this belief, and his thinking on the subject heavily influenced the work of James Lind, John Pringle, and others who sought to combat epidemic diseases in the Army, Navy, and the City of London: "Plagues seem to be of the growth of the *Eastern* and *Southern* parts of the world, and to be transmitted from them into colder climates by the way

Since his death, Howard has been endlessly lauded as a prison reformer. Latter-day historians of the prison have interpreted his legacy as a "pre-Benthamite" – a devout disciplinarian who understood prisons as part of a "technology of salvation" that could bring about moral reform through discipline, laying the foundations for the heavily-surveilled penitentiaries of the Victorian era.[261] But Howard's fatal obsession with fever and his extraordinary death 1500 miles from the prisons he labored to reform begs the question: how did efforts to contain and eliminate airborne contagion shape prison reform in the eighteenth century?

Histories of the prison have hitherto focused on how the evangelical philanthropy of eighteenth-century thinkers like Howard, Jonas Hanway, and George Onesiphorus Paul contributed to an emerging regime of "discipline" that came to full fruition in the silent, solitary, hyper-surveilled penitentiaries of nineteenth-century Britain. These studies have tended to cast the eighteenth century as an abortive first attempt at reform that was hampered by the dominance of local gaol committees and the lack of coherent organization on the part of the reformers.[262] This feeling on the part of historians seems to be supported by despairing comments made by reformers like Howard and G.O. Paul about the supposedly "reformed" prisons of Newgate and Cold-Bath Fields, and by the

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of *commerce*." Richard Mead, *Discourse Concerning Pestilential Contagion* (London: Sam Buckley, 1720) 4-5.

[261] Michael Ignatieff, *A Just Measure of Pain* (New York: Columbia University Press, 1978) 56-7.

[262] This is the reading given by Michael Ignatieff, and echoed by Robin Evans in his study of prison architecture and Michael Meranze in his study of crime and punishment in revolutionary and early-Republic Philadelphia: Michael Ignatieff, *A Just Measure of Pain* (London: Penguin, 1978); Robin Evans, *The Fabrication of Virtue: English Prison Architecture 1750-1840* (London: Cambridge UP, 1982); Michael Meranze, *Laboratories of Virtue: Punishment, Revolution, and Authority in Philadelphia, 1760-1835* (Chapel Hill, NC: University of North Carolina Press, 1996).

pearl-clutching horror of later reformers like Elizabeth Fry when visiting these same sites.[263]

However, this version of events only makes sense if one views Foucauldian discipline as the inevitable end towards which all prison reform must ascend. A thorough examination of the minutes of the Newgate Gaol Committee, the private papers and correspondence of John Howard, and the published writings of Hanway, Paul and others reveals that while Christian philanthropy and a desire to reform prisoners certainly played a central role in their work, the fundamental logic of their designs was drawn from a contagionist understanding that both moral and physical disorders could be eradicated by a thorough reformation of the *aerial environment*. The primary medium upon which the new prisons were designed to work was not the minds of the prisoners, but the air that they breathed.

Curiously, there has been no study of how John Howard's work on Lazarettos or his long and much-celebrated travels through Europe and the Levant influenced his continuing work on prison reform. Despite the substantial literature on prison reform which grew up in the wake of Michel Foucault's classic *Discipline and Punish*, there has been no scholarly assessment of the relationship between practices of quarantine and the logic of prison reform.[264] This historical lacuna obscures the centrality of contagionist

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[263] Howard noted that the newly-built Newgate prison "has some manifest errors. It is now too late to point out particulars"; John Howard, *State of the Prisons,* 4th ed. (London: J. Johnson, C. Dilly, and T. Cadell: 1792) 213; G.O. Paul, in an 1808 letter to Richard Philips, Sherriff of London, Richard Phillips, declined an invitation to inspect the city's prisons by saying "if what I had said had been useless, what I should further say would be equally so": Richard Phillips, *A Letter to the Livery of London* (London: T. Gillet, 1808) 253; on visiting the womens' side of Newgate in 1816, Elizabeth Fry described "begging, swearing, gaming, fighting, singing, dancing, dressing up in men's clothes; scenes too bad to be described, so that we did not think it suitable to admit young persons with us": Elizabeth Gurney Fry, *Memoirs of the Life of Elizabeth Fry with Extracts from her Journal and Letters,* 2nd ed. (London: John Hatchard and Son, 1848) 257.
[264] Michel Foucault, *Discipline and Punish*, trans. Alan Sheridan (New York: Penguin Books, 1977).

theory to the reform project. Restoring the central place of quarantine procedures to the thinking of the reformers and prison architects reveals that houses of correction were constructed in order to both contain and ventilate diseased prisoners who had come to be viewed as physical and moral danger to the wider community.

Furthermore, a history of contagionist theory and ventilation in prisons helps us to better untangle the seeming contradiction of reformed prisons which were designed to perfectly contain prisoners and their "effluvia" while also providing an ample circulation of purifying air. The notion of quarantine also helps to illuminate the origins of separate confinement of various classes of prisoners (men, women, apprentices, felons, debtors, etc.) which reformers envisioned as a kind of internal quarantine that would prevent the uncontrolled spread of moral as well as physical contagion. This connection between practices of quarantine and incarceration becomes explicit in John Howard's involvement in debates over the establishment of a new Lazaretto in England – a project justified on the grounds that it would improve both public health and private finances by excluding plague and promoting direct trade with the Ottoman Empire.

Under the influence of Foucault, historians have cast eighteenth-century reformers' concerns over disease as an "analogy" that justified their true agenda of evangelical moral reform.[265] I argue that physical contagion was very much not an analogy. Following the logic of contemporary medical and natural philosophical beliefs, John Howard and his followers understood both the moral and physical character of prisoners to be products of their environment. Since air was viewed as the primary vector

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[265] See, for example, Randall McGowan's discussion of the "disease analogy": Randall McGowan, "The Well-Ordered Prison: England 1780-1865," in Norval Morris and David J. Rothman, eds. *The Oxford History of the Prison*, (Oxford: Oxford UP 1995): 82-83.

of disease, reformers hoped first and foremost to create a clean, fresh, and salubrious environment that would purify the soul by first curing the body. This period marks the transition of the central object of state-sponsored reform from the environment to the individual – a transition that is reflected clearly in the shifting logic of individual vs. state responsibility that doomed both reformed prisons and a proposed English lazaretto. Eighteenth-century prison reform did not represent the failure of an early attempt at moral discipline, but rather a transition in the way that moral and physical disease were understood to relate to one another.

The Deadly Danger of Effluvia: Contagion Theory and The Fatal Assize of 1750

It has always been rare for London's Lord Mayors to die in office. Representing the city's livery companies and performing ancient ceremonial duties can certainly be taxing - however, most holders of the office have survived their one-year term of office. Sir Samuel Pennant was not so lucky.

On April 25, 1750, as he settled into his seat at the Old Bailey to oversee the quarter sessions, Pennant was struck by a "noisome stench" emanating from the ragged, coughing, lice-ridden prisoners brought before the bench. The courtroom was packed, as judges and aldermen were joined by sympathetic crowds who had come to see the trial of Captain Edward Clark, a Royal Navy officer who had been arraigned for killing a fellow officer in a duel. While the packed house generated a fetid, uncomfortable heat, those who stepped out for a breath were buffeted by an uncommonly frigid wind from the East, which persisted through the evening hours.[266] Grateful to escape and shed his heavy

[266] Anon. "Proceedings of the Old Bailey" *Gentleman's Magazine*, April 25, 1750, p. 235-6, DOI 17311907.

scarlet robes, Pennant braved the cold which quickly dried the sweat that had been torturing him with a mild itching sensation all day.

Within a month, Pennant and fifty-six others lay dead.[267] The outbreak of "gaol fever" that had struck the attendees of the Old Bailey that day had been the worst in twenty years, and reminded many of the famous "Black Assize" of 1577, which had taken the lives of nearly three hundred unfortunate Elizabethans.[268]

There was little doubt as to what had caused the illness. The humid heat of the courtroom and the diseased and filthy condition of the prisoners had provided a perfect aerial environment for the spread of the fever. In discussing the incident, the *Gentleman's Magazine* printed a quotation from Dr. Richard Mead, Royal Physician and renowned expert on plagues and fevers. "Goal Fever" the prominent doctor wrote, "is always attended with a degree of malignity, in proportion to the closeness and stench of the place." It would "well become the wisdom of the government, as well with regard to the health of the town" Mead continued, to keep all prisons "as airy and clean" as possible.[269]

Immediately, ideas for the reform of prisons focused on space, cleanliness, and air. Physicians like Mead and his followers James Lind, John Pringle, and others, had come to think of disease as being caused by the presence of *physical* contagions.[270] Contagions began to be conceived of as tiny, perhaps microscopic, particles that caused disease by powerfully disrupting the body's natural balance. Mead compared diseased

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[267] Correspondence, John Pringle to Stephen Theodore Janssen, Alderman of the City of London, Letter concerning the "reality of infection from Jayls, and the best means for obtaining a purity of air in Newgate," 15 Oct. 1750, Gaol Committee Notes on Ventilating Newgate, London Metropolitan Archives, CLA/035/02/049.
[268] Candace Ward, *Desire and Disorder* (Lewisburg, PA: Bucknell UP, 2007) 101, 103-105.
[269] Mead quoted in: Anon. "Historical Chronicle," *Gentleman's Magazine*, April 25, 1750, p. 235-6.
[270] See, for example, the discussion of mechanical medicine in Melvin Santer, *Confronting Contagion* (Oxford: Oxford UP, 2015) 145-8.

bodies to a "fermenting liquor" that throws off active particles that "particularly upon …the mouth and skin…will generally infect those who are very near to the sick person."[271] Essential to this conception was the understanding that air was the primary vector by which these "active particles" travelled. A fresh, clean air quickly dispersed the particles and invigorated bodies against their influence. A contained, moist, heavily-respired air was potentially rife with contagion, and the presence of impurities within the air weakened the constitution and predisposed it to infection.[272]

This understanding of contagion as an aerial infection fundamentally changed the social nature of disease. Whereas Hippocrates had understood illness as a complex interaction between the environment and the individual "patient's habits, regimen, and pursuits," contagionists believed that disease did *not* discriminate between lowly prisoners and healthy, well-mannered, and respectable members of society. The fault was not in the body, but in the environment. In the words of historian Vladimir Jankovic, the focus of disease prevention moved from the individual's bodily predisposition to the "space between bodies."[273]

This new focus on space can be clearly seen in the aftermath of the "Deadly Assizes." The death of the Lord Mayor and other prominent citizens at the Old Bailey was a shock to the London establishment, and the Gaol Committee – the municipal body in charge of administering the city's prisons – was convened to discuss how such another such disaster could be prevented. The central influence on the committee's thinking was

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[271] Richard Mead, *A Short Discourse Concerning Pestilential Contagion* (London: Sam Buckley, 1720) 12.
[272] See, for example, the analysis of air in Stephen Hales, *Vegetable Staticks* (London: J. Innys, 1727) 308-317.
[273] Hippocrates, *Of the Epidemics*, trans. Francis Adams (London: Sydenham Society, 1849; Internet Classics Archive, n.d.) Book 1, http://classics.mit.edu/Hippocrates/epidemics.1.i.html; Vladimir Jankovic, *Confronting the Climate: British Airs and the Making of Environmental Medicine* (London: Palgrave Macmillan, 2010) 2-4.

the work of Scottish army physician John Pringle, author of the *Observations on the Nature and Cure of Hospital and Jayl Fevers* and ardent admirer of Stephen Hales.[274] The committee's report on the outbreak demonstrates the clear relationship between space, cleanliness and the condition of the air within the Old Bailey courtroom, and is worth quoting at length:

> The court at the Old Bailey is a room only about thirty feet square. Whether the air was at first tainted from the bar, by some of the prisoners, then ill of the jail distemper, or by the general uncleanliness of such persons, is uncertain since, from the latter cause it will be easy to account for its corruption: especially as it was then farther vitiated by the foul steams of the bail-dock, and of the two rooms opening into the court, in which they were the whole day crouded together, till they were brought out to be tried. And as it appeared afterwards, these places had not been cleaned for some years. The poisonous quality of the air was still aggravated by the heat and closeness of the court, and by the perspirable matter of a great number of all sorts of people, penned up for most of the day without breathing the free air or receiving any refreshment.[275]

Notably, the report refused to unconditionally blame the diseased prisoners for the outbreak. The fault was laid upon the "poisonous quality of the air" which was a combined result of the crowded courtroom, exhalations from the ante-chambers, and the "foul steams of the bail-dock" which "had not been cleaned for some years." The report went on to note that the lethality of the infection appeared to have been mitigated by the direction of airflow within the courtroom. "It was remarkable, that the Lord Chief Justice and the Recorder, who sat on the Lord Mayor's right hand, escaped, whist he himself, with the rest of the bench on his left, were seized with the infection; and that the Middlesex jury on the same side of the court lost so many, whilst the London jury, opposite to them, received no harm."

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[274] John Pringle, *Observations on the Nature and Cure of Hospital and Jayl-Fevers* (London: A. Millar, 1750).

[275] "Account of the Fatal Assize," Gaol Committee, Notes on Ventilating Newgate 1750-1755, London Metropolitan Archives, CLA/035/02/049.

The perceived immunity of the members of the London Jury and of the Lord Chief Justice and the Recorder was attributed by some to the "cold taken by opening a window," a cause also mentioned in the report of the *Gentleman's Magazine* on the incident.[276] However, the Gaol Committee, thoroughly convinced of the validity of contagionist theory, dismissed this as the suppositions of those "unacquainted with the dangerous nature of putrid effluvia." The fresh air had merely "directed the putrid steams to that part of the court above mentioned." It was beyond a doubt that "all septic particles that pass into the blood become…active and fatal."[277] As the committee moved the focus of its investigation to conditions at Newgate Prison, it soon became clear that the "smell of the jail" was putting not only the Old Bailey, but the entire city of London at risk.

By this point, Pringle himself became directly involved. In a letter to the committee, Pringle stated his opinion that "the jayls of this city may be reckoned among the greatest and most constant sources of foul and unwholesome air." Pringle blamed prisons for the frequency of fever outbreaks in the city of London, and noted that the prisons were both over-crowded, "ill situated" and had "no areas, ventilators, or other means of renewing the air."[278] The focus of Pringle's harshest criticism was Newgate prison, the source of the infectious prisoners who were the primary suspects in the recent

[276] Mead quoted in the *Gentleman's Magazine*, "Historical Chronicle," *Gentleman's Magazine*, April 25, 1750, p. 235.
[277] "Account of the Fatal Assize," Gaol Committee, Notes on Ventilating Newgate 1750-1755, London Metropolitan Archives, CLA/035/02/049.
[278] Correspondence, John Pringle to Stephen Theodore Janssen, Alderman of the City of London, Letter concerning the "reality of infection from Jayls, and the best means for obtaining a purity of air in Newgate," 15 Oct. 1750, Gaol Committee, Notes on Ventilating Newgate 1750-1755, London Metropolitan Archives, CLA/035/02/049.

"havock" at the Old Bailey.[279] Newgate was constantly overcrowded, with "insufficient and filthy privies" and no yards for prisoners to "take the air."[280]

Paradoxically, Newgate was both open and closed, porous and unhealthily contained – the prisoners appear able to go where they please, yet, in the words of a 1703 pamphlet, "the only air they enjoy…is in a yard, whose length is scarce so much as one may swing a cat in it."[281] In Pringle's estimation, the prison was unsalvageable: "As for the remedies against these evils, I can scarce conceive any to be efficacious, without building a new Jayl from the foundation." However, since it would take years for a new prison to be designed and constructed, he proposed a stop-gap solution: the installation of Dr. Hales' Ventilators.

Labor, Individual Responsibility and the Limits of Mechanical Ventilation

Ventilators were in fact already being used in Newgate. In a private letter, Hales had boasted that they were proving "very salutary" and "little more than one third of the usual number have dyed, since they were daily ventilated thereby."[282] However, the reality was far more complex. Hales machines relied on the willing labor of an ill-supervised and often resentful incarcerated population. His attempts to ventilate Newgate reveal one of the central controversies of eighteenth century prison reform: how much responsibility could be placed on prisoners for their own reformation?

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[279] Stephen Theodore Janssen, *A Letter to the…Committee Appointed for Rebuilding the Jail of Newgate* (London: 1767) 1.
[280] Correspondence, John Pringle to Stephen Theodore Janssen, Alderman of the City of London, Letter concerning the "reality of infection from Jayls, and the best means for obtaining a purity of air in Newgate," 15 Oct. 1750, Gaol Committee, Notes on Ventilating Newgate 1750-1755, London Metropolitan Archives, CLA/035/02/049.
[281] Anon. *Hell Upon Earth: Or the…History of Whittington's Colledge otherwise (vulgarly) called Newgate*, (London: 1703) 1.
[282] Correspondence, Letter from Stephen Hales to Henry Lee Warner, Jan. 28, 1747, Norfolk Record Office, NRA 27665/32.

Hales first believed that by demonstrating the benefit of his ventilators, prisoners would be voluntarily convinced to work them. Installed at Winchester County jail and in Newgate during the mid-1740s, Hales' "Hand Ventilators" required considerable labor to operate, as prisoners had to continually work an iron crank in order to drive putrid air out and pull in fresh air. In a private letter to Thomas Yeoman, the millwright who built most of his ventilators, Hales described the special care he had taken to demonstrate the value of his machines at Winchester County jail. To "encourage" the prisoners, Hales placed a "small turning windmill" at the entrance of the air-trunk, which spun as air entered the room, proving that the machine was working.[283]

While Hales proudly stated that "the keepers, the prisoners, and all who have seen the effects…agree that they are very beneficial," the final specifications and installation of the ventilators reveals a different attitude. Unlike in hospitals, where Hales' ventilators were placed on the floor at the center of the room for maximum circulation, the prison machines were bolted to the ceiling "so that being out of reach, they cannot be damaged by the prisoners."[284] Likewise, Hales recommended that Yeoman build strong grooves into the machines to govern the motion of the levers, "to prevent the wrenching of the lever sideways, by idle people, which may spoil the work."[285]

Whether or not the prisoners had been convinced of the benefits of mechanical ventilation, by 1750 it was clear that Hales' machines were doing little to prevent outbreaks of fever. Likewise, the committee was having little luck in convincing the

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[283] Correspondence, Letter from Stephen Hales to Thomas Yeoman, April 11, 1745, Royal College of Physicians Archives, RCP MS111/6.
[284] Correspondence, Thomas Yeoman letter to Taylor White, Nov. 26, 1756, London Metropolitan Archives, A/FH/M/01/002/045-048; Correspondence, Stephen Hales to Thomas Yeoman, July 4, 1745, Royal College of Physicians, RCP MS111/8.
[285] Correspondence, Stephen Hales to Thomas Yeoman, Dec. 21, 1744, Royal College of Physicians, London, RCP MS111/3.

prisoners to go along with their schemes to improve healthfulness at all. While prisoners were happy to have the toilets unclogged and the wards cleared, they stridently resisted attempts to wash the floors. Prisoners claimed that the wet floors would "give them cold" and actually *increase* the prevalence of disease. Another recommended measure for disease prevention – the further separation of prisoners into different wards – aroused misgivings from the keepers, who stated that it was actually "safer for the Goal to have a number of prisoners confined in one place, than in separate apartments."[286] In response to these issues, Hales proposed a radical solution. He designed an ambitious new system of ventilation that would completely avoid the need for convict labor and which would place complete control over ventilation into the hands of the wardens.

The central innovation of Hales' new design was to remove labor from the equation. Rather than requiring prisoners to continuously pump air in and out of the wards, the new ventilator would be operated by a windmill affixed to Newgate's roof. This machine would power four large "air trunks," each containing a nine-by-four foot wooden fan, or "midriff." Each trunk contained two valves – an internal valve that opened to suck in "foul air" on the downstroke of the midriff, and an external valve that belched it into a chimney running to the roof of Newgate.[287] By removing the need for "mens hands", Hales supposed that he had enabled the continual and salutary ventilation of the wards in a manner that would improve the aerial environment without having to win the approval of skeptical prisoners and reluctant wardens.[288]

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[286] Minutes, Committee to Inquire into the State of Newgate Gaol and how the same may be enlarged, June 19, 1755, London Metropolitan Archives, COL/CC/NGC/01/01/001.
[287] Stephen Hales, "A Description of the Ventilators which are fixed in Newgate," *Gentleman's Magazine* 22 (1752): 179-180.
[288] Stephen Hales, *Treatise on Ventilators* (London: Richard Manby, 1758) II, 31.

In addition, Hales' ventilators promised to tilt the balance of power into the hands of the prison's administrators. The ventilators were not powerful enough to ventilate the entire prison at once. Thus, the elaborate ducting was also fitted with a series of sliding shutters that allowed the operators of the ventilator to choose which of the 24 wards would receive air. The sliders were painted with numbers to indicate the wards with "handles…locked fast, that it may not be in the power of the prisoners to shut or open them."[289] If the keepers lacked the manpower and the authority to effectively control the prisoners, they could at least control the atmosphere in which the prisoners lived.

To demonstrate the effectiveness of his scheme, Hales employed the relatively new method of referring to statistics.[290] In a letter to the Gaol Committee, he wrote that in the four months since the Ventilator was installed at Newgate, there had been a marked improvement in the mortality rate within the prison. By comparing those months to the "same months of the six preceding years," Hales concluded that his ventilators were saving "more than *nine* lives every four months." Furthermore, Hales demonstrated the efficacy of his machines by measuring the rate at which they pumped air, writing to the Lord Mayor that the new ventilator sucked effluvia out of Newgate "at the rate of about 7000 tuns of four air in an hour."[291] How Hales arrived at this number is not described in the letter, but his usual method was to simply calculate the internal area of the air trunk times the number of strokes of the midriff per hour – with a "tun" of air being represented by forty cubic feet.[292] For Hales, who had made his reputation as an "experimenter" by

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[289] Stephen Hales, *A Description of the Ventilators* (London: W. Innys) 80.
[290] See, for example: Ted McCormick, *William Petty and the Ambitions of Political Arithmetic* (New York: Oxford UP, 2010); Theodore Porter, *The Rise of Statistical Thinking* (Princeton, NJ: Princeton UP, 1986).
[291] Letter from Stephen Hales to Stephen Theodore Janssen, quoted in Stephen Theodore Janssen, *Letter to the…Lord Mayor…and the..committee…for the Rebuilding of the Jail of Newgate* (London: 1767) 36.
[292] Hales, *A Treatise on Ventilators, Part I* (London: Richard Manby, 1758): 2-10.

measuring the rates of respiration and circulation in plants and animals, these numbers spoke for themselves. Writing in the *Gentleman's Magazine* in 1753, he declared his windmill ventilator a "humane example" that he hoped "many may be induced to follow."[293]

The Social Danger of Putrid Effluvia

Despite Hales' hopeful statistics, Newgate continued to be a dangerously infectious space – and worse yet, the danger appeared poised to spread into the wider community. Both Hales and Pringle had recommended the building of a new prison, with the ventilators serving as a crucial stopgap. But in the immediate wake of their installation, the new ventilators appeared not to solve the problem, but to exacerbate it. In a separate report to the Gaol Committee that was later published in both the *Gentleman's Magazine* and *Philosophical Transactions*, Pringle recounted a visit made alongside Dr. Hales to inspect the newly installed ventilator. While the wards seemed generally more airy than on his last visit, Pringle also noted that the "tubes from the several wards, uniting in one great trunk, convey all the putrid steams by that channel into the atmosphere," creating a "considerable stream of air, of a most offensive smell."[294] This danger was highlighted when seven of the eleven workmen who had been tasked with installing the new ventilation system came down with the fever.[295]

Furthermore, the public was becoming more and more annoyed with the state of the prison. Upon invitation from the London Gaol Committee, several respected

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[293] Stephen Hales, "Account of the Good Effect of Ventilators" *Gentleman's Magazine* 23 (1753): 70-71.
[294] John Pringle, "An Account of Several Persons seized with the Goal-Fever, working in Newgate" *Philosophical Transactions*, 48 (1753-4) 42-55.
[295] Pringle, "An Account of Several Persons seized with the Goal-Fever," 42-55.

inhabitants of Newgate street gave accounts of the “inconveniancies” they had experienced from the prison. Prisoners were constantly calling to persons” along the street and frequently threw out “dirty water and other filth upon them.” This greatly damaged the business along the street as one resident, a hosier by the name of “Mr. Holmes,” testified that many customers were “afraid of coming to his shop, and that they came round by Saint Paul’s church yard, rather than come thro’ Newgate.” All of those interviewed agreed that the present jail posed a great danger of infection to the entire neighborhood. In a remarkable piece of testimony, Mr. Holmes, a hosier, stated that he had “frequently observed the smoke or effluvia come out of the west windows in several of the rooms when the ventilators were working.” The opinion of the townsmen was unanimous: the best solution would be to remove the prison to a place with “more room and a convenience for airing the prisoners.”

An inspection of the prison and the Old Bailey confirmed this testimony. The Gaol Committee found the buildings “in a very bad condition.” Inspectors found the privies in the jail “frequently stopt and overflows which may contribute to the distemper.” The internal design of the jail was “very badly contrived” and the rooms “built in such a manner that the air cannot have a free passage.” [296] The ventilator, which was “often standing still” had apparently not been maintained, as no person had been appointed to clean the trunks and regulate the sliding valves.[297]

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[296] Minutes, Committee to Inquire into the State of Newgate Gaol and how the same may be enlarged, June 19, 1755, London Metropolitan Archives, COL/CC/NGC/01/01/001.

[297] John Pringle, “Letter to the Right Honourable Stephen Theodore Janssen, 15 Feb. 1755” in Stephen Theodore Janssen, *Letter to the…Lord Mayor…and the..committee…for the Rebuilding of the Jail of Newgate* (London: 1767) 45.

However, reluctant to commit to the expense of building a new prison, the committee opted instead to allocate 13 pounds a year for a dedicated operator of the ventilator.[298]

After nearly another decade of delay, Londoners "residing near the gaol of Newgate" submitted a petition directly to the House of Commons complaining of over-crowding at the prison, but especially of the danger of jail fever from the "noxious effluvia from the said gaol" which had become a "most dangerous nuisance." Finally the London Council gave in. City architect George Dance was tasked with designing a new prison by which "the publick" could be "rendered more safe from any dangerous infection."[299]

Containment or Ventilation?

From the beginning, Dance's plans confronted a clear contradiction: how to effectively contain prisoners while also providing a sufficiently free flow of air to prevent outbreaks of fever? With large, open courtyards for "airing" prisoners, ample privies and cells for "refractory" inmates, the new design aimed to address the deficiencies of the old prison by making it easier to clean and patrol than the old prison had been. However, the defining feature of the new prison faced outward. "New" Newgate was to be surrounded by a high and windowless wall, with only three entrances – one for felons, one for debtors, and one for the Keeper's house. Gone were the begging grate and the outward facing windows, replaced with bricked-up arches that served to break up the monotony of the façade while retaining its imposing aspect. The only ornament was a bouquet of

[298] Minutes, Committee to Inquire into the State of Newgate Gaol and how the same may be enlarged, June 19, 1755, London Metropolitan Archives, COL/CC/NGC/01/01/001.
[299] Minutes, Committee to Inquire into the State of Newgate Gaol and how the same may be enlarged, June 19, 1755, London Metropolitan Archives, COL/CC/NGC/01/01/001.

chains and shackles that hung above the debtors' and felons' doors to remind prisoners of their culpability and the impossibility of escape.[300]

Before construction was even complete, it was clear that the new prison would be inadequate to prevent outbreaks of fever. Budgetary concerns and the expected increase in the number of inmates due to the outbreak of the American Revolution forced Dance to reduce the number of cells and privies and the size of the courtyards.[301] However, the greatest damage was done by the anti-Catholic Gordon rioters, who burned down the new prison less than a year after its completion. However, despite causing over £26000 of damage to Newgate alone, the Gordon Rioters failed to bring about any change in the design of the new prison. The London Committee for Rebuilding Newgate Gaol refused to make any internal design alterations, instead focusing on securing the prisoners who would be left to languish inside.

Ventilation was not forgotten: expense reports reveal a periodic commitment to keeping at least the Debtor's quadrangle ventilated. Between six and ten pounds a month were set aside for coal braziers that were lit to "air" rooms and passageways, and in 1783, the entire jail was white-washed and painted at the cost of 105 pounds. That same year, the committee mandated iron grates be installed on the chimneys of the prison, to insure that prisoners could not shimmy out with the foul air.[302] When it came to Newgate ventilation was desirable – but containment was imperative.

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[300] George Dance, Plan, Section, and Elevation of Designs for a New Prison; George Dance, undated, London Metropolitan Archive COL/PL/02/U/005/d; Harold Kalman, "Newgate Prison," *Architectural History*, vol. 12 (1969): 50-61, 108-112.
[301] Robin Evans, *The Fabrication of Virtue*, 109.
[302] Letter from College of Physicians to The Committee for Rebuilding the Gaol of Newgate, July 1, 1780, London Metropolitan Archives, COL/CC/NGC/03/02/002; Misc MSS., The Committee for Rebuilding the Gaol of Newgate, 1784-5, undated (1784-5), London Metropolitan Archives, COL/CC/NGC/03/02.

Fresh air was a much more evident concern at the Old Bailey, the only remaining contact-zone between London's elite and the denizens of Newgate. Dr. Hales' hand ventilators were continually worked, costing thirty-seven pounds per year. The committee also guaranteed that the court had enough coal to fumigate the Sessions house thoroughly before each session. In 1784, nearly five hundred pounds were spent to to improve ventilation by installing a new window and white-washing the interior. The next year, an entirely new ventilator system similar to the one that Hales' had designed for Newgate was installed in the ceiling.[303]

In order to insure the purity of the Old Bailey's atmosphere, successive walls were constructed around the exterior in order to keep crowds away from the proceedings, as well as a walled passageway from Newgate to the courthouse in order to prevent prisoners (and their noxious effluvia) from interacting with the public.[304] Newgate had been obnoxious to the respectable classes for a long time. Now its inmates would be effectively quarantined from the public behind an impenetrable wall, whose only evidence of their existence would be their effluvia rising with the coal smoke through the bars of the grated chimneys.

Controlling Contagion: John Howard and the Medical Logic of Prison Reform

For his part, John Howard was unimpressed with the city's efforts. After examining Dance's plans and touring the yet-to-be-completed prison in the 1770s, Howard wrote that the jail had some "manifest errors." With an air of resignation atypical

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303 Misc. MSS. The Committee for Rebuilding the Gaol of Newgate, March 4, 1785, Miscellaneous MSS. COL/CC/NGC/03/02, London Metropolitan Archives.

304 Plans for Newgate Prison, undated, London Metropolitan Archives, COL/PL/02/U5/A-H, J-Z, AA-KK.

for a tireless reformer, he demurred from specific comment about the plans, concluding his comments with: "all I will say, is, that without more than ordinary care, the prisoners will be in great danger of the Gaol-Fever."[305] The decade that followed witnessed a tectonic shift in British prison reform. Following ideas expressed in Cesare Beccaria's *Of Crimes and Punishments*, reformers called for proportional punishments in place of an over-reliance on the death penalty.[306] But for many of these men, the most dangerous lack of proportionality was not in the punishments doled out at court, but in the atmosphere of the prison.

Deeply concerned with the apparently random nature of disease, Jonas Hanway's landmark proposal for solitary confinement emphasized first and foremost the need to protect prisoners from mutually communicating contagion – both moral and physical. His plan showed an intense regard for the preservation of "life and health," noting that the prison should be constructed on the "declivity of a hill" in order "to give abundant air, as necessary for health." While the prisoners would be kept separate, each cell was to have access to "abundant air" and plumbing in order to "carry off foul water."[307]

G.O. Paul, high sheriff of Gloucestershire and devout disciple of John Howard, stated unequivocally that his interest in prison reform was motivated by the "shocking" state of health he found in his county's jail. While the law "has decreed imprisonment," it did not intend that "loss of liberty" be accompanied by "loss of health, (perhaps of life) by disease and famine."[308] Paul noted that maintaining the health of prisoners was not

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[305] John Howard, *State of the Prisons*, 1st ed. (1777) 152.
[306] Cesare Beccaria, *An Essay on Crimes and Punishments*, Anonymous translation (Dublin: John Exshaw, 1767) 20-21; See also, Clive Emsley, *Crime and Society in England*, 3rd Ed. (Harlow: Pearson Longman, 2005) 253-267.
[307] Jonas Hanway, *Solitude in Imprisonment* (London, J. Brew, 1776) 3-4, 111-113.
[308] G.O. Paul, *Considerations on the Defects of Prisons* (London: T. Cadell, 1784) 1.

only a duty to the prisoner, but to the nation, which would be deprived of the military and labor capacity of prisoners who died needlessly from the lack of cleanliness and "wholesome air, which is life itself."[309]

Of these reformers, none was more influential nor more obsessed with preventing disease than John Howard. From his first foray into a prison after his appointment as Sheriff of Bedfordshire in 1773, he had been convinced that God was calling him to improve the lot of the "emaciated dejected objects" he found there. While Howard's zeal was new, his diagnoses of the ills of prison air were not. In his *State of the Prisons*, Howard frequently quoted Stephen Hales, John Pringle and James Lind, noting that the keeping of prisoners on the floor, in confined cells, and in prisons with no courtyards had the effect of depriving them of fresh air, the "genuine cordial of life" and leaving them imprisoned in their own "effluvia." The air in prisons was so foul, Howard recalled, that after a few hours, clothes, papers, and even the vial of vinegar that he periodically sniffed as a guard against infection became "intolerably disagreeable."[310]

Howard's initial solution to deaths in prison was exactly the same as Hales' – the introduction of hand ventilators. In order to insure that prisoners had an adequate supply of air, Howard even reached out to Thomas Yeoman, who was now chairman of the Society for the Encouragement of Arts, in hopes of spurring the technical improvement of Hales' ventilators. While this effort proved fruitless, Yeoman renewed the premium

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[309] Sir William Blackstone quoted in G.O. Paul, *Considerations*, 19-22.
[310] Howard, *State of the Prisons* 1st ed., 12-14.

annually for over fifteen years in hopes of finding a satisfactory machine for airing prisons.[311]

While ventilators proved ineffective, Howard had recourse to a more eminent wind machine – the House of Commons. The restlessness of the American colonies had begun to severely limit the transportation of debtors and felons to America – a punishment that had accounted for seventy percent of all criminal convictions doled out by the Old Bailey during the 1760s.[312] As prison populations swelled, incarceration *as* a punishment began to be thought of as a practical, if problematic alternative.[313] At the insistence of reformers like Hanway and Howard, Parliament passed the 1774 "Act for Preserving the Health of Prisoners in Gaol" which stated that jail fever was caused by the "want of cleanliness and fresh air" and mandated that all interior walls and ceilings be scraped and white-washed annually and "constantly supplied with fresh air, by means of hand ventilators or otherwise."[314]

However, Howard noted ruefully, this act provided no provision for the construction of new jails and was hamstrung by the fact that it placed all responsibility for the cost and carrying out of these reforms on local councils. As had been the case with Newgate, many prisons were close and damp and would inevitably see recurrence of Gaol Fever. In order for prisoners to be reformed, they would have to be placed within a truly airy, clean, and healthful atmosphere. Thus, Howard determined to pursue a more

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[311] The society offered a premium for the improvement of prison ventilators until 1792, but repeated trials failed to yield any notable improvements to Hales' original design: Committee Minutes 1775-1792, Royal Society of Arts Archive, RSA/AD/MA/100/12.
[312] Ignatieff, *Just Measure of Pain*, 20.
[313] Clive Emsley, *Crime and Society in England*, 3rd Ed. (Harlow: Pearson Longman, 2005) 268-272.
[314] Act for Preserving the Health of Prisoners in Gaol and Preventing the Gaol Distemper, 1774, 14 Geo. III, c. 59.

radical proposal for prison reform based on a uniquely contagionist institution – the Lazaretto.

The Prison and the Lazaretto

As a young man, Howard had travelled extensively in France and Italy, and was familiar with the practice of quarantine.[315] Originating in the Republic of Venice during the fourteenth century, quarantine aimed to isolate and air goods and passengers suspected of carrying plague. Usually constructed on an isolated spit or outcropping away from the main harbor, Lazarettos (also known as Lazarets) were kept under guard by officers who would use wooden staffs and metal tongs in order to scrupulously avoid physical contact with passengers or goods. At the end of the quarantine, personnel would be examined by a physician, who would then provide the final clean bill of health for their re-entry into society.[316]

From his description of an ideal prison, it is likely that Howard derived many of his ideas from quarantine institutions. The central concern was to promote as much airflow as possible, while isolating the inmates from contact with the outside world. His proposed prison was to be completely isolated in a "spot that is *airy*," and ideally near a stream, so that no stagnant water or sewage could build up and produce effluvia. If no such spot could be found, Howard suggested building the institution on an "eminence" to allow air to enter the prison yard. In any case as much of the jail as possible was to be

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[315] Aikin, *A View of the Character and Public Services of the Late John Howard*, 15-16; Ignatieff, *A Just Measure of Pain*, 50-51.

[316] John Booker, *Maritime Quarantine, the British Experience, 1650-1900* (Aldershot, England: Ashgate, 2007), xiii; Anonymous, *The Nature of Quarantine as it is Performed in Italy* (London: J. Williams, 1767): 25-29.

"raised on arcades" in order to improve the freshness of air and keep the interior as dry as possible.[317]

Practices inside the jail would also be made to conform to quarantine regulations. Arriving prisoners would be made to strip and their clothes would be hung in an oven for "purifying." After a cold and warm bath, prisoners would be given "coarse washing clothes" to wear while their own were in the oven. Each prisoner would be given a clean shirt every week, and each ward supplied with "pails, mops, brooms, soap, vinegar, and fuel for the oven." In addition, the entire jail would be cleaned regularly and whitewashed twice a year.[318]

Hoping to put these ideas into nationwide practice, Howard collaborated with William Eden and William Blackstone to write a new Parliamentary bill that would provide clear guidelines for the management of jails in order to transform them into effective instruments of punishment and reform. According to this bill, arriving prisoners would be stripped, bathed, and their old clothes burned. After four days in quarantine to determine if they were a liability for introducing disease, they would be sorted into one of three classes according to the seriousness of their crimes and housed separately. Work would be required, in order to avoid idleness, which Howard believed contributed to a buildup of noxious effluvia, especially in the "robust" young men who were frequently subject to incarceration.[319] The aim of these guidelines was to create an institution where the health of prisoners would be maintained, but the life therein would be unpleasant enough to spur penitence and a desire to return to productive life outside. In addition, the

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[317] Howard, *State of the Prisons*, 1st ed., 41-45.
[318] Howard, *State of the Prisons*, 1st ed., 58-60.
[319] Howard, *Account of the Principal Lazarettos in Europe* 1st ed. (Warrington: T. Cadell, J. Johnson, C. Dilly and J. Taylor: 1789) 231-2.

bill provided for the construction of two new, model institutions – one for men and one for women – to be built in London.[320]

But the project was short-lived. William Blackstone died in 1780, the same year that Eden was made Chief Secretary for Ireland. Finding himself without allies, and with little support from the Lord Mayor of London, Howard wrote to Lord Bathurst to resign from his advisory position. This frustration marked Howard's last sustained involvement in the "obstinate contention" of local and national politics. The next few years also marked the painful realization that even the well-ventilated model prisons built according to his guidelines "infectious diseases continued occasionally to arise and spread."[321]

In the execution of the 1779 plan, Howard had sincerely hoped that his "observations upon similar institutions in foreign countries would, in some degree, qualify me to assist," and had resumed his travels in order to report on the conditions of European prisons.[322] Now, judging that the "further sacrifice of my time" was unlikely to yield positive results in London, Howard decided to embark on an ambitious new plan: to personally search the entire western world for the best methods of preventing disease and foul effluvia.

Expanding the Quarantine – The Levant Merchants and the English Lazaretto

While quarantine had not engaged public interest to the same degree as prison reform, the improvement of disease prevention had been a recurring public concern for

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[320] An act to authorize, for a limited time, the punishment by hard labour of offenders who, for certain crimes, are or shall become liable to be transported to any of his Majesty's colonies and plantations 1779 (Penitentiary Act) 19 Geo. III, c. 43.
[321] John Howard, *Account of the Principal Lazarettos in Europe* (Warrington: William Eyres, 1789) 1.
[322] Letter reprinted in Thomas Taylor, *Memoirs of John Howard* (London: John Hatchard and Son, 1836) 157-8.

much of the last century. Dr. Richard Mead's famous *Practical Treatise of the Plague*, the contagionist tract that had strongly influenced the work of Hales and Pringle, had been commissioned by Parliament in response to a 1720 outbreak of Bubonic plague in Marseilles that had killed half of the city's population. A subsequent outbreak at Messina in 1753 led the House of Commons to pass an act requiring every English ship that received a foul bill of health in the Mediterranean to perform quarantine in one of the French or Italian lazarettos before returning to England.[323] For his part, John Howard's previous experience of lazarettos had convinced him that "establishments, effectual for the prevention of the most infectious of all diseases (the plague), must afford many useful hints for guarding against the propagation of contagious distempers in general."[324]

In order to take up those hints, Howard embarked on an ambitious plan: he would travel from England to the Levant and put himself through quarantine at every notable lazaretto in between. Besides his usual practice of noting down the size, cleanliness, and practices within each institution, Howard also brought along a questionnaire for the physicians at each Lazaretto, asking their opinion on how the plague arose and spread, and how a space could be "purified."[325]

From the beginning, the Ottoman Empire was the goal. While Howard echoed the patronizing European views that the Turks were "little enlightened by the modern improvements in arts and sciences," he was sure that "their intimate acquaintance with the disease in question" would have given them insights into how to prevent and cure the plague. Howard was hopeful that he could penetrate "the great difference between their

[323] Booker, *Maritime Quarantine*, 220-1.
[324] Howard, *Account of the Principal Lazarettos*, 1.
[325] Howard, *Account of the Principal Lazarettos*, 33-41.

customs and manners, and ours" and find "some practices…not unworthy the notice of more polished nations."[326]

Contemporary to Howard's Mediterranean travels, the English merchants of the Levant Company were lodging a series of complaints that Greek officials at Smyrna were giving English ships exaggerated foul bills of health in order to force them to perform long quarantines at Malta, Leghorn, or Venice. "By obliging our vessels to go to perform a long and expensive quarantine," the merchants' cargo of cotton was frequently held up for "no less than seven months," while Greek ships, which carried on "three fourths of the Dutch as well as Italian trade," underwent a brief quarantine in Holland and beat the English goods to market.[327] The goal of the Smyrna merchants was not to abolish quarantine, but rather to establish an "English Lazaretto" where they could air their goods without interference from their chiefly Dutch competitors. The merchants argued that a reliable, domestically-operated quarantine would enable a direct trade between England and the Ottoman Empire, thus increasing profits and providing a more effective barrier against disease than the "slovenly" quarantine performed by the Dutch.[328]

In Smyrna, Howard's and the English Merchants' concerns found common ground. While Howard was shocked by the frequent use of physical punishment he witnessed in Turkish prisons, he found Turkish lazarettos well-constructed and much in line with his conception of proper quarantine practice, even affording "some good ideas for the construction of a house of correction."[329] Overall, Howard found the Ottoman

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[326] Howard, *Account of the Principal Lazarettos*, 1-2.
[327] Correspondence, Extract of a letter from the consul and factory at Smyrna, 1790-1792, Levant Company Memorials to William Pitt, British Library, Add MS 38351, fol. 252-254.
[328]Correspondence, Mr. Wilkinson's Affadavit, 1790-1792, Levant Company Memorials to William Pitt, British Library, Add MS 38351, fol. 250-251.
[329] Howard, *Account of the Principal Lazarettos*, 9-10.

institutions to be credibly efficient and the precautions against plague to be effective – far better than the "filthy" conditions he experienced in Venice, where he found the very walls "saturated with infection" not having been cleaned "probably for half a century."[330]

As a guest of the merchants, Howard was regaled with stories of how Greek inspectors were falsely giving foul bills of health to English ships and using the subsequent delay to send their own goods through a quick Dutch quarantine and beat English cotton to market. This story touched a nerve for Howard. The irregular conduct of Dutch quarantine meant that all English people were being placed at risk of foreign infection. It was beyond doubt, Howard concluded, that the great London plague of 1666 had "entered this island by means of contagion, and was brought from Holland" in merchandise imported from the Levant.[331]

Howard had found his answer. While he could not be sure that fever never arose spontaneously in prisons, it was clear that disease was entering England from abroad, mainly as the result of her reliance on the inadequate quarantines and corrupt institutions of her national and religious rivals the French, Italians and the Dutch. Howard's personal diary recorded his extreme distaste for the French, whose "national character I detest." In a fascinating note entitled "The Turks are not Cruel," he blamed the "Greeks, French, and Italians" for "acts of violence, murder and the perpetration of the greatest cruelties" which had "drawn upon themselves the severity of the Turks, who are a kind and hospitable people."[332] By cutting Britain's continental rivals out of the equation, Britain could enjoy not only a profitable trade with the Ottoman Empire, but a far lower risk of

[330] Howard, *Account of the Principal Lazarettos*, 11.
[331] Howard, *Account of the Principal Lazarettos*, 30-32.
[332] John Howard Notebooks, 1786, Bodleian Library, Oxford University, MS Eng. Misc. 400.

foreign infection with disease. Assuring the merchants of his support, Howard published a copy of a letter from the Merchants alongside his proposed regulations for an English lazaretto, which he hoped might "prove an advantage to our commerce."[333]

Commerce and Philanthropy

For Howard and his contemporaries, commerce and philanthropy were intimately connected. One of Howard's friends and most enthusiastic correspondents was John Haygarth, superintendent of the smallpox hospital at Chester, near the port of Liverpool. Writing in 1789, Haygarth noted to Howard that an increased trade with Turkey would be highly beneficial to Liverpool since the slave trade seemed "likely to be abolished." Besides reducing the danger of plague, the trade would provide "an extensive vent…for British manufactures."[334]

Besides the commercial advantages, Howard's contemporaries believed that a better understanding of how plague arose and spread could eventually lead to a complete elimination of the disease. "No measure appears more practicable," Haygarth wrote, "than to extermine the contagion from the whole world." The central cause of disease, in the minds of the reformers, was not accidental, but a result of human neglect and inaction: "We have less reason to blame and wonder at the folly of the Turks, for nursing this pestilence in their bosoms, while the enlightened nations of Europe preserve and propagate another dreadful pestilence, the small pox, with nearly an equal degree of absurdity." If only the leaders of these nations could be persuaded to adopt the

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[333] Howard, *Account of the Principal Lazarettos*, 30-32.

[334] Correspondence, John Haygarth to John Howard, May 30, 1789, Papers of John Howard, Bodleian Library, Oxford University, MS Eng. Misc. c. 332, 22-34.

prophylactic measures proposed by Howard in his works on prisons and lazarettos, disease could be practically eliminated. In the words of Haygarth, "All the necessary regulations are founded on two words, namely cleanliness and separation."[335]

To spread the gospel of sanitation and to trace contagion as closely to the source as possible, Howard determined to take another trans-European tour. This journey would take him through Germany and the Russian Empire to visit Turkey from the North. After that, Howard planned to visit Ottoman Egypt and see for himself the historical source of plague. His thoughts on the subject were recorded in his diary just prior to his departure for Russia: "It is very probable that the plague flies about from one country to another as accident or negligence give it opportunity so that disease arises spontaneously, that is without being able to trace an imported infection. Tho' it must originally have taken its rise in some particular place, as perhaps in Egypt and the Coasts of Barbary. Important is the inquiry whether it is ever found thus to arise spontaneously."[336]

Howard was determined to discover the origins of disease even if it cost him his life. In a letter to his friend Dr. Richard Price, Howard wrote that "my medical acquaintance give me but little hope of escaping the plague in Turkey. I do not look back, but would readily…encounter any dangers, to be an honour to my Christian profession."[337] However, The journey through the Mediterranean and his many conversations with doctors at quarantines and prisons had convinced Howard that disease was communicated chiefly through the air. While some physicians warned him against

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[335] Correspondence, John Haygarth to John Howard, June 19, 1789, Papers of John Howard, Bodleian Library, Oxford University, MS Eng. Misc. c. 332, 35-41.
[336] John Howard Notebooks, 1788-9, Papers of John Howard, Bodleian Library, Oxford University, MS Eng. Misc. 401.
[337] Howard letter to Richard Price, Sept. 22, 1789, quoted in Aikin, *Sketch of the Character of John Howard*, 188.

touching patients, he was "so assured" that air was the primary vector that "I have not scrupled going, in the open air, to windward of a person ill of the plague and feeling his pulse."[338]

Ironically, that was precisely how John Howard caught his fatal illness. Hoping to spend a mild winter at Kherson, he had been called to the bedside of young girl suffering from a fever. While examining the patient, he was conscious of "the effluvia from her body" which was "very offensive to him." According to his travelling companion, Thomas Thomason, "it was always his own opinion that he then caught the fever."[339] After two weeks of attempting to purge the infection by drinking James' Powder (a widely popular fever medicine) and Sal Volatile (smelling salts) mixed with tea, Howard succumbed on January 20th, 1790.[340] Whether he was stricken by the "effluvia from her body" or by contagion that passed via their touch, Howard's death in Kherson marked a premature end of his attempt to discover the origins and means of best preventing the spread of contagion.[341]

Conclusion: Prisoner, Ventilate Thyself

While the late John Howard had been frustrated with the apparent lack of action on the part of Parliament to forward the construction of his ideal prisons and Lazaretto, both were in the planning stages at the time of his death.[342] The Smyrna merchants had gained the ear of William Pitt and were continuing to press for an English lazaretto, and

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338 Howard, *Lazarettos*, 25.
339 Thomas Thomason quoted in Aikin, *A View of the Character and Public Services of the Late John Howard*, 191.
340 Aikin, *A View of the Character and Public Services of the Late John Howard*, 192-4.
341 Aikin, *A View of the Character and Public Services of the Late John Howard*, 191.
342 This attempt, which lasted over twenty years and eventually came to nothing, has been chronicled in an excellent article: Peter Froggatt, "The Lazaret on Chetney Hill", *Medical History* 8:1 (Jan. 1964): 44-62.

at Cold Bath Fields in London, the Middlesex House of Correction was being completely re-built to conform to Howard's 1779 Gaol Act.[343]

Both of these enterprises engaged considerable resources – yet both would be declared failures by the second decade of the nineteenth century. As well-resourced attempts to exclude contagion failed to bring about a holistic transformation of the prisoners' character, the locus of reformers and philanthropically-minded physicians began to shift from the environment back towards the individual. While ventilation was still seen as an effective barrier to disease, delinquents ceased to be understood as products of an unhealthy aerial environment. Prisoners were transforming from the "emaciated, dejected objects" of John Howard to the subjects of the "moral discipline" ardently championed by Elizabeth Fry.[344]

At Cold Bath Fields prison, the ventilated, solitary cells, advocated by Hanway, Howard, and Haygarth became a target for radicals and romantics who saw them as a refinement of barbarous cruelty. In their 1799 satirical poem "The Devil's Thoughts," Robert Southey and Samuel Coleridge envisioned Satan taking pleasure in the prison: "As he went through Cold-Bath Fields he saw/ A solitary cell/ And the Devil was pleased, for it gave him a hint/ For improving his prisons in Hell."[345] These sentiments were echoed in Parliament, where radical M.P. Francis Burdett, decried Cold Bath Fields

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[343] Levant Company Memorials to William Pitt, Extract of a letter from the consul and factory at Smyrna, 1790-1792, British Library, Add MS 38351, fol. 252-254.
[344] Katharine Fry and Rachel Elizabeth Cresswell, eds. *Memoirs of the Life of Elizabeth Fry*, 2nd. Ed. (London: John Hatchard and Son, 1848) 292.
[345] Robert Southey and Samuel Taylor Coleridge, "The Devil's Thoughts," *Morning Post and Gazetteer,* 6 Sept. 1799, *17th-18th Century Burney Collection Newspapers*.

as "The English Bastille!" and successfully called for a parliamentary inquiry into its operation.[346]

The resulting inspection found that the prisoners seemed utterly unmoved by the improvements that had been made for their ventilation. Annoyed by the constant cold air that entered through the ventilating grates, many prisoners attempted to block up as many of them as possible. Brought in to supervise the inspection, Howard's staunch ally G.O. Paul found that the adjustable wooden ventilation shutters had been destroyed in over 70 of the cells.[347] While keeper Thomas Aris assured the House of Commons that the health of prisoners "in general grew much better" during their stay in Cold Bath Fields, the testimony and evidence gathered by Burdett proved otherwise.[348]

However, while Aris was reprimanded, he was not removed from his position. The philanthropic zeal that had characterized prison reform was quickly fading in the wake of Howard's death and the resumption of transportation in 1787, and despite the outcry of a few concerned authorities like Burdett, reformed prisons had begun to bear a striking resemblance to the dungeons of the 17th century.[349] A report from the keeper of Newgate from 1816 reveals that the prison continued to host exactly the drunkenness, idleness and destruction that Howard and his followers had sought to expunge:

> June 17: Michael Collett put in a cell for being drunk and abusing the gatesman.
> June 21: Some cupboards and other woodwork destroyed by the women transports.
> June 23: William Foreman put into a cell for assaulting burrows the Wardsman.

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[346] Francis Burdett, *Cold Bath Fields Prison, by some called The English Bastile! The Speech of Sir Francis Burdett in the House of Commons* (London: 1799).
[347] "Report of the commissioners of enquiry into the state of and management of H.M. Prison in Cold Bath Fields," quoted in Robin Evans, *Fabrication of Virtue*, 163.
[348] Francis Burdett, *An Impartial Statement of the Inhuman Cruelties Discovered!* (London: J.S. Jordan, 1800) 14; "Minutes taken before the committee, 12 March 1799," *The Journals of the House of Commons*, Volume 54 (1803) 442.
[349] Ignatieff, *A Just Measure of Pain*, 128-9.

> 4 July 1816 George Sutton the Wardsman was fired for having half a gallon of gin in a tin case along with a funnel and two glasses.[350]

By the first decades of the nineteenth century, the energy had clearly gone out of the reformers. In a lengthy letter to Richard Philips, Sherriff of London, G.O. Paul refused an invitation to inspect London's prisons and wrote that he no longer held out hopes for nation-wide reform. When men in Parliament "who know no more of the interior of prisons, than I do of a Turkish harem" could declare that "'the plans of Howard…have failed," then it was time to pass responsibility on to the next generation.[351]

For their part, the advocates of the English Lazaretto were having an equally difficult time. As the wars with France cut off access to many Mediterranean quarantine stations, the British government had been improvising quarantine with disused men-of-war, which were converted into "floating lazarettos" by replacing the decks with open gratings and placing ventilation shutters on the gun-ports. However, these temporary accommodations were quickly overwhelmed, and in 1799, a medical advisory committee of Gilbert Blane, famed Naval Surgeon, and Patrick Russell, former Levant Company physician and author of the *Natural History of Aleppo*, recommended to Parliament that a land lazaretto be built according to Howard's specifications.[352]

The result was a costly disaster. While the plans were modelled on Howard's, the site that the government had chosen as the "proper place for a lazaretto" proved to be a

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[350] "Newgate Journal": Reports on 'The State of His Majesty's Gaol of Newgate'; Apr. 29, 1816-Feb. 27, 1819, British Library, Egerton MS 3802, p. 6.
[351] Richard Phillips, *Letter to the Livery of London* (London: T. Gillet, 1808) 246-254.
[352] G.S. Boulger and Mark Harrison, "Patrick Russell (1727-1805)" in David Cannadine, ed. *Oxford Dictionary of National Biography* (Oxford: Oxford UP, 2004) https://www.oxforddnb.com/view/10.1093/ref:odnb/9780198614128.001.0001/odnb-9780198614128-e-24334

marshy island that was impossible to build on.[353] After fifteen years and £95,000 pounds wasted, the government concluded that floating lazarettos would have to serve the necessary purpose and auctioned off the remaining building materials for a grand total of £15,000.[354]

However, the demise of the perflated prisons and the English lazaretto were not merely the result of fiscal realities. The intransigence of prison inmates and the inability of a reformed aerial environment to cure their poor behavior had forced reformers to see that their ultimate object of reform was moral, not physical. Rather than emphasizing the danger of gaol fever and the conditions of the prison, nineteenth century reformers emphasized the need for moral instruction. William Wilberforce argued in 1810 that criminal justice should focus on "religious instruction and moral precept" in order to bring criminals to a "sense of shame and repentance for his past conduct."[355] Emphasizing the role of voluntary repentance, Elizabeth Fry even assured female convicts that they would be able to vote on the rules for their own moral conduct.[356] For his part, Gilbert Blane noted that while "ventilation and cleanliness" were essential for the "welfare of the human species," the government should not focus on imposing them, but rather on "cultivating them as moral and religious duties."[357]

In the end, ventilation ceased to be the central concern of prison reformers and philanthropists. As doubts grew about the validity of contagion theory and global trade

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[353] Correspondence, An account of the measures which have been taken by government respecting the building of a Lazaretto, June 5, 1792, Levant Company Memorials to William Pitt, British Library, Add. MS. 38351, fol. 255-6.
[354] Froggatt, "The Lazaret on Chetney Hill," 53-54.
[355] Wilberforce quoted in Randall McGowen, "A Powerful Sympathy: Terror, the Prison, and Humanitarian Reform in Early Nineteenth-Century Britain," *Journal of British Studies* 25:3 (July 1986): 312-334.
[356] Ignatieff, *A Just Measure of Pain*, 143-4.
[357] Gilbert Blane, "Letter to John Hippisley," in *Observations on the Diseases of Seamen* (London: 1799): 614-615.

increased, quarantine receded as a cost-effective or necessary practice.[358] For the next forty years, until Edwin Chadwick's famous *Report on the Sanitary Condition of the Labouring Population,* the cause of large-scale public health measures seemed contradictory to the order of nature, as embodied in the self-regulating free market. Disease prevention and ventilation had become the responsibility of the individual rather than the state.

Illustrating this transition, the 1820s witnessed a growing preference for the "treadmill" machine as a mode of discipline. First proposed by engineer and millwright William Cubitt in 1822, this machine was composed of a long cylinder of wooden steps that prisoners would be forced to ascend "an endless flight of steps." Most versions of this machine did not produce any tangible commodity - they were for no other purpose than to provide "suitable employment for prisoners sentenced to hard labour."[359] In an ironic echo of Hales' ventilating windmill, visitors to Cold Bath Fields in the 1860s found the treadmill hooked up to an enormous fan that accomplished no practical purpose but, in the words of the prisoners, "grinding the wind."[360] Rather than forcing prisoners to work a ventilator to improve the aerial environment, nineteenth century prisoners were made to work useless machines on order to improve themselves. Ventilation had now entered the realm of bourgeoisie respectability.

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[358] The combination of costs and doubts as to quarantine's effectiveness led Parliament to repeal many quarantine restrictions in 1825: Booker, *Maritime Quarantine*, 401-403.
[359] William Cubitt, *Description of the Tread Mill* (London: T. Bentley, 1822) 4-5.
[360] Henry Mayhew and John Binny, *The Criminal Prisons of London and Scenes of Prison Life* (London: Griffin, Bohn and Co. 1862) 307.

Images:

Figure 1: George Romney's study for a never-completed painting of John Howard visiting a Lazaretto. In this highly romanticized schema, Howard is the figure on the left, being appraised by a cleric of the situation of the unfortunate inmates of the lazaretto. George Romney, *John Howard Visiting a Lazaretto* (1790-95) Museum of Fine Arts, Boston, MA.

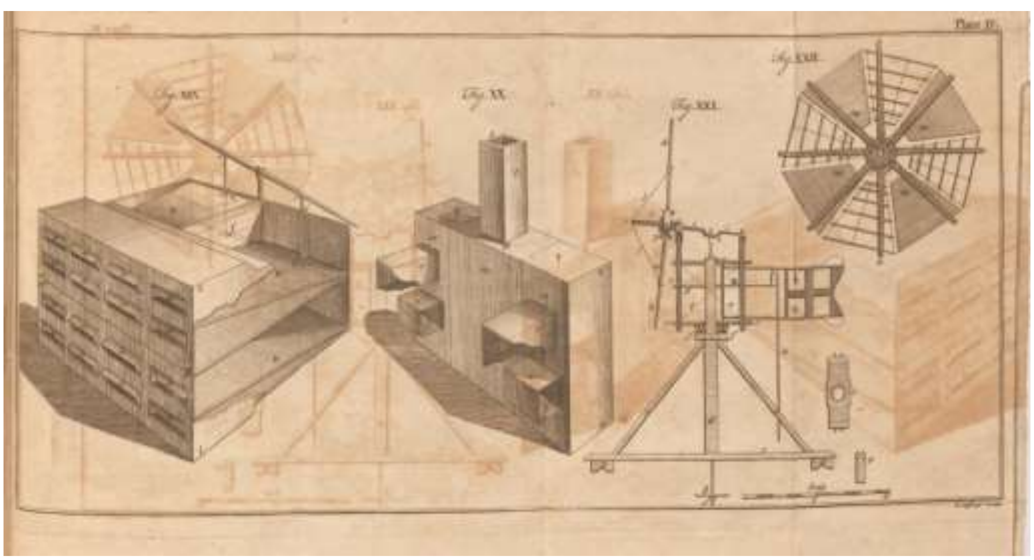


Figure 2: The Newgate Prison Ventilator designed by Stephen Hales. The windmill (right) raised and lowered the "midriffs" within the ventilator (left) which drew in foul air and exchanged it for fresh air via the valves on the ventilator's front face. These valves connected to a system of ducts that ran from a central trunk (center) that could be managed via crude registers to supply air to the various wards of the prison. (Hales, *A Treatise on Ventilators* (1758): 31-40, Plate IV [Cornell University Library, Digital Collections])

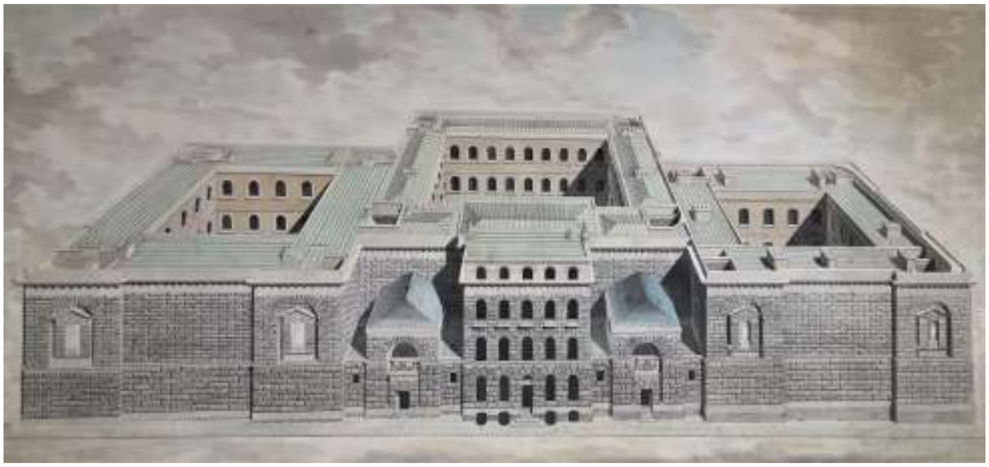
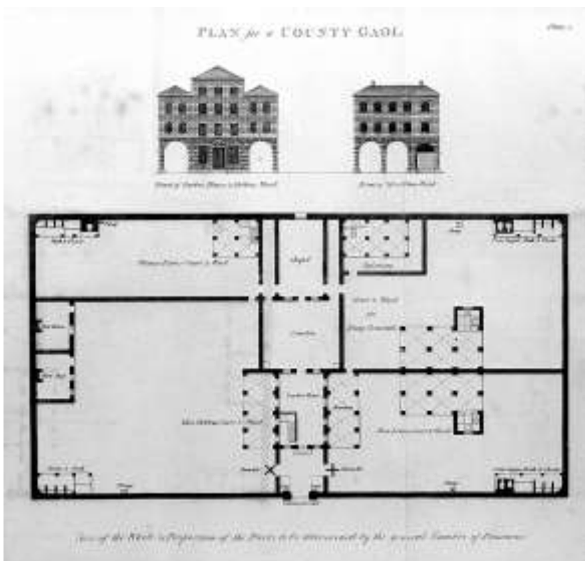
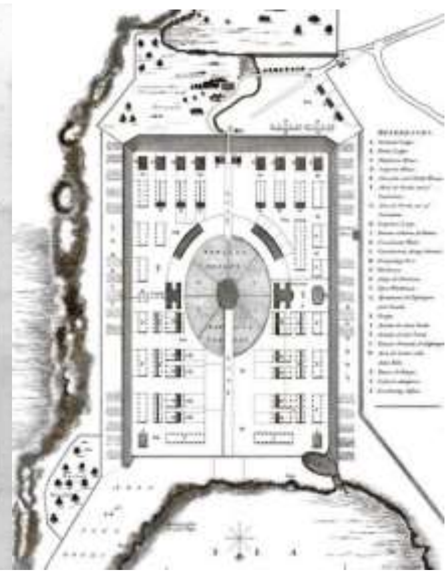


Figure 3: The final design of the "New" Newgate Prison by George Dance the Younger (Sir John Soane's Museum, London: D4/4/16 Newgate Gaol Contract drawings & designs, 1769- c.1813: Photo by author)





Figures 4 and 5: John Howard's plans for an ideal county gaol (left) and an ideal lazaretto (right). Note how the prison is raised on arcades to promote the circulation of air and prevent the escape of contagion. The lazaretto has been constructed on a spit of land open to the wind on three sides and accessible by only one road for the same purpose. Left: John Howard, *State of the Prisons* (Warrington, T. Cadell, 1777) Plate 1. Right: John Howard, *An Account of the Principal Lazarettos in Europe*, (1789): Plate 14.

Figure 6: The treadmill at Brixton Prison. Note the weighted air-resistance fan above the prison building. Society for the Improvement of Prison Discipline and for the Reformation of Juvenile Offenders, *Description of the tread mill for the employment of prisoners* (London : Longman, Hurst Rees, Orme and Brown, 1823) [Courtesy of Harvard University Library]

Chapter 4: The Costs of Comfort

Abstract

As pneumatic chemists re-ordered the relationship between heat and the respirability of air became clearer in the late eighteenth century, a new commercial market emerged for comfortable, heated and air-purified environments. Couched in the new chemical language of Lavoisier and promoted by shrewd salesmen like the Marquis de Chabannes, machines that purported to provide controlled environments were deeply appealing to an English middle- and upper-class that was fearful of the dangers and inconvenience of the public urban environment and were eager to purchase a means of insuring domestic health and environmental comfort. David Boswell Reid's spectacular success at constructing controlled environments in Edinburgh and the temporary House of Commons and his spectacular failure at finding a means of measuring aerial comfort meant that climate control moved firmly out of the hands of chemists and physicians and into the private and commercial realm of the market.

Introduction

"A chief object of this day's experiments" wrote a twenty-six year old Charles Blagden, "was to ascertain the real effect of our cloaths in enabling us to bear…high degrees of heat." At the invitation of physician and chemist George Fordyce, Blagden and several other natural-philosophically-minded gentlemen had gathered in a suite of rooms that Fordyce had specially engineered for heat-related experiments. Stripping off his coat, waistcoat and shirt and tying wooden sandals to his feet, Blagden stepped into a room which had been sealed to prevent the escape of air. Meanwhile, Fordyce stoked furnaces and blew heated air into the room via flues in the floor. With only the protection of a piece of cloth that he held in front of the flues to preserve his bare skin from the blasts of heat rising through the floor, Blagden noted that "my first impression of the heated air was much more disagreeable than I had ever felt it with my cloaths." As the temperature rose to 220 degrees Fahrenheit, "a profuse sweat broke out, which gave me instant relief." However, throughout this ordeal, Blagden was surprised to report that he "felt nothing of the oppression on my breath." [361] After finally leaving the hellish chamber, he concluded that "heating the air does not make it unfit for respiration, communicating to it no noxious quality except a power of irritating." The only difference was "a want of that refreshing sensation which accompanies a full inspiration of cool air."[362]

By spending a few minutes in their scientific sauna, Blagden and Fordyce had contributed to a fundamental re-ordering of the relationship between heat, air and the body. Contrary to prevailing medical and chemical beliefs, which held that heated air was capable of producing the "most acute disease in an instant," their experience had proven that the human body was able to adapt to the most extreme temperatures imaginable with no ill effects on respiration whatsoever. While heat certainly affected the processes of putrefaction and fermentation that could potentially foul the air, the experience of unhindered breathing and the remarkable capacity of the body to adapt its temperature to extreme circumstances had demonstrated "the mistake of Dr. Boerhaave and most other authors." Such a remarkable capacity could not be explained by anything the "mechanical

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[361] Charles Blagden, "Further Experiments and Observations in an Heated Room," *Philosophical Transactions* 65 (1775): 488-9.
[362] Charles Blagden, "Experiments and Observations in an heated Room" *Philosophical Transactions* 65 (1775): 117-122.

and chemical physicians have devised," and could only be referred to as a "principle of life itself."[363]

This "principle of life" – the self-regulation of temperature – was strongly tied to an emerging conception of personal and physical *comfort*. The new emphasis on "comfort" that appeared in the late eighteenth century is frequently found in studies of Victorian furniture, architecture and material culture, which frequently emphasize the deeply conservative aspects of a style that strove to project wealth and respectability while simultaneously reducing the visibility of household labor and dividing spaces according to gender.[364] After Blagden's experiments and the related developments in pneumatic chemistry spearheaded by Joseph Priestley, Antoine Lavoisier, chemically-minded ventilation experts like Jean Baptiste de Chabannes and David Boswell Reid shifted the emphasis of ventilation from the provision of merely *fresh* air to the creation of an aerial environment that was not only ventilated but also warm: in a word, *comfortable*. In the words of physician, sanitarian and ventilation expert Neil Arnott, heating and ventilation became so "intimately connected" that became difficult to speak of one without the other.[365]

Informing the work of many of these men was Jeremy Bentham's distinction between necessary "subsistence" – food, shelter, the necessities of life - and comfortable "abundance" – any excess wealth that could be used for comfort and enjoyment. Bentham's fundamental tenet of "the greatest happiness to the greatest number" demanded that all human beings be provided firstly with subsistence, but did not deny the

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[363] Blagden, "Experiments and Observations," 111, 122-123.
[364] See, for example: John Gloag, *Victorian Comfort* (London: A. & C. Black, 1961); Asa Briggs, *Victorian Things* (London: B.T. Batsford, 1988).
[365] Neil Arnott, *On Warming and Ventilating* (London: Longman, 1838) 15.

benefit of abundance to the more fortunate.[366] While eighteenth-century chemists and physicians tended to focus on ventilation as a means of provisioning necessary air, their nineteenth century heirs, influenced by Bentham, invested considerable resources and effort into making machines that provided warm and “abundant” air. While Stephen Hales had expected his machines to use labor and instill self-discipline, Victorian consumers of ventilation assumed cost (of complex machines and fuel) and demanded comfort.[367]

This development was lengthy and highly contested. Clashes over experimental methods and chemical language in late eighteenth-century chemistry reflected strong differences of opinion in how scientific knowledge could serve the public good, and enabled the rise of a concept of ventilation that was less focused on institutions like prisons and hospitals and more focused on the society as a whole. Meanwhile, the London elite’s growing desire for comfort created a market for machines that could do insulate them from excessive cold, heat, bad smells and “filth”. This desire for insulation was validated by the findings of reform-minded sanitarians whose work contributed to a growing conceptual divide between public responsibility and private comfort. Finally, the high-profile attempts of the David Boswell Reid to create a completely controlled environment decisively transformed ventilation from a matter of public health into a means of subjective comfort. No longer the purview of social reformers, ventilation was to become a largely commercial commodity.

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[366] Janet Semple, “Bentham’s Utilitarianism and the Provision of Medical Care,” in Dorothy Porter and Roy Porter eds. *Doctors, Politics and Society: Historical Essays* (Amsterdam: Rodopi, 1993): 33.
[367] This is Simon Schaffer’s idea, which he was kind enough to share with me over a round of Greene King IPAs.

The Chemistry of Comfort

The discovery of “eminently respirable air” was partially a discovery of chemical comfort. Using an easily-assembled apparatus of glass jars, gun barrels and kitchen utensils, Priestley had found that by heating calx of mercury, he was able to produce an “eminently respirable” air in which mice could live longer than in ordinary air. However, the ability to respire and survive was not merely a function of adequate air. Priestley noted that when a “fresh mouse” was put inside a vessel that contained heavily respired air, it was “instantly thrown into convulsions, and died.” However, a mouse that had been living inside the chamber frequently *continued to live*. Priestley concluded that the “first shock” of an unfamiliar atmosphere was dangerous – however, if a mouse was “habituated to it by degrees,” it could live much longer. “If the experiment of the Black Hole (of Calcutta) were to be repeated,” Priestley concluded, “a man would stand the better chance of surviving it, who should enter at the first, than at the last hour.”[368]

After his discovery of “eminently respirable” or “vital” air, Priestley found that by mixing nitrous air with atmospheric air over water, and observing the change in volume, he could determine the air’s potential respirability without having to subject mice to suffocation.[369] While he was delighted to have a chemical test that enabled him to test respirability without killing mice, Priestley maintained the belief that the healthfulness or lethality of certain environments depended on the condition of the living subject. The cumulative effect of prior circumstances heavily influenced how one’s body would react to a given atmosphere. While temperature and chemical composition could be measured,

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[368] Joseph Priestley, *Observations on Different Kinds of Air* (London: W. Bowyer, 1772) 38-9.
[369] Trevor Levere, *Transforming Matter* (Baltimore, MD: Johns Hopkins UP, 2001) 58-60.

the "shock" of entering an extreme or heavily-respired aerial environment would differ from individual to individual.

For Priestley, a radical democrat who believed in the rationality and perfectibility of both nature and politics, the relativity of the air's quality was not measured merely on a chemical scale but on a moral one. Thus air that supported life was "virtuous," while that which failed to do so "lacked virtue." Priestley's notion of nature's rational balance was most clearly seen in his claim that while animal respiration removed virtue from the air, plant respiration restored it.[370] The desire to combine the two emphases was most clearly seen in Priestley's attempts to discern the relationship between society and the conditions of the local aerial environment in his short-lived science of "eudiometry," which attempted to use Priestley's nitrous air-test – embodied in a class of devices that were collectively referred to as "eudiometers" - to determine a topography of air quality in the Florentine state, Paris and London.[371]

While he shared Priestley's democratic sympathies, the aristocratic Antoine Laurent de Lavoisier did not subscribe to the English clergyman's agnosticism about the subjective functioning of living beings. Rather, Lavoisier believed that the "animal economy," or the working of the body, could be fully described through a careful measurement of inputs and outputs. For Lavoisier, life was a process of combustion, in which air was consumed and carbonic acid, the key component in irrespirable air, was

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[370] See Jan Ingenhousz, *Experiments Upon Vegetables* (London: P. Elmsly 1779) xvi-xvii.
[371] See Simon Schaffer, "Measuring Virtue: eudiometry, enlightenment and pneumatic medicine," in Andrew Cunningham and Roger French, eds. The Medical Enlightenment of the Eighteenth Century (London: Cambridge UP, 1990): 292-314.

expelled. A body could be compared to a candle – the bodily substance was maintained by the consumption of food, and then "burned" with exercise and respiration.[372]

Thus, Lavoisier sought to fully integrate the bodily economy within his chemical system that did away with aerial "virtue" and the entire conceptual language of Priestley in favor of a system that heavily prioritized the role of heat, which he referred to as "caloric."[373] Dubbed an "imponderable" because it had no weight or discernable substance, Lavoisier conceived of heat as an invisible fluid that was essential to chemical processes.[374] But Lavoisier's emphasis on instrumentation and quantification, on measuring "caloric" rather than "virtue," had another aim: he hoped to do away with the role of the human body in producing chemical facts.[375] In order to make this case persuasive, Lavoisier invested a substantial proportion of his aristocratic fortune into the construction of specially-made precision balances that would weigh the gases. Heat, which could not be weighed, was measured by another expensive instrument – the "ice calorimeter" which measured the amount of caloric, or heat, produced in the experiment by registering the amount of ice melted by chemical combustions that were performed inside its central chamber.[376]

While Lavoisier's chemistry was adopted fairly quickly in France and Germany, he faced stiff opposition from chemists working in the English and Scottish tradition of Hales, Cullen and Black, most notably Joseph Priestley. For Priestley, Lavoisier's use of

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[372] This is Dana Simmons' description of Lavoisier's 1790 "Memoir on Animal Respiration": Simmons, *Vital Minimum* (Chicago, IL: University of Chicago Press, 2015) 2-3.
[373] Jan Golinski, *Science as Public Culture* (Cambridge: Cambridge UP, 1992) 130, 147.
[374] Levere, *Transforming Matter,* 64-5.
[375] This line of argument follows Lissa Roberts' thesis in: Lissa Roberts, "The Death of the Sensuous Chemist: The 'New' Chemistry and the Transformation of Sensuous Technology," *Studies in the History and Philosophy of Science* 26:4 (1995): 503-529.
[376] Levere, *Transforming Matter,* 70-77, Golinski, *Science as Public Culture*, 133.

expensive apparatus and his neutering of the language of "virtue" completely undermined the ideals of using aerial chemistry to expand the public understanding of nature and improve society. Writing in 1800, Priestley proclaimed that he would not accept the French terminology and mode of chemical operations until "the French chemists can make their experiments in a manner less operose and expensive."[377]

While Lavoisier himself had strongly sympathized with revolutionary viewpoints, his execution during the terror seemed to arch-conservatives as a proof of the folly of radical politics and radical chemistry alike. Priestley's unabashedly democratic politics, which had been tenable in the 1770s when he had written that the English Hierarchy had "reason to tremble even at an air pump," became far less so after the outbreak of the French Revolution.[378] Conservatives like Edmund Burke pounced on such statements and wrote of Priestley and his followers that "these philosophers consider men in their experiments, no more than they do mice in an air pump, or in a recipient of mephitic gas."[379] Burke's attacks and the destruction of his Birmingham laboratory by a pro-establishment mob in 1791 forced Priestley to decamp to the nascent United States.[380]

While Priestley's departure removed the most outspoken opponent of Lavoisier's chemistry from the English scene, the accommodation of the French system by English chemists was gradual and English chemistry retained a heavy focus on bodily experience. The chemist whose career most signifies this transition is the radical physician Thomas Beddoes, whose ambitious vision for using various gases to cure diseases at his short-

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[377] Joseph Priestley, *The Doctrine of Phlogiston Established and that of the Composition of Water Refuted* (Northumberland: A. Kennedy, 1800) 50.

[378] Joseph Priestley, *Observations on Different Kinds of Air*, 2nd ed. (LondonL J. Johnson, 1775) xiv.

[379] Edmund Burke, *A Letter from the Right Honourable Edmund Burke to a Noble Lord* (London: J. Owen 1796) 62.

[380] Levere, *Transforming Matter,* 59.

lived Pneumatic Institute became a starting point for some of the most crucial developments in the link between Lavoisier's theory of respiration and the radically different conception of ventilation that emerged in the nineteenth century.

In a published letter to Erasmus Darwin, Beddoes revealed a remarkable vision of Lavoisier's chemistry of respiration being adapted to an everyday machine. While convalescing from a respiratory illness that had left him short of breath, Thomas Beddoes imagined that his health and would be much improved by a pneumatic devices that could add "oxygene" to atmospheric air. Going a step further, Beddoes noted how Lavoisier's chemical understanding of respiration as the consumption of oxygen and the production of heat could be turned to the creation of a new aerial economy that managed the relationship between respiration and the maintenance of a comfortably warm temperature: "is there not room to conjecture…from the remarkable tendency of oxygene to generate heat…that many invalids may be advantageously fortified against the cold of winter by breathing atmospheric improved by the addition of oxygene air?" The creation of such a device was not, Beddoes hoped, far in the future, as oxygen machines would surely soon be "ranked among the ordinary articles of household furniture." [381]

While Beddoes' envisioned device was never built, and his Pneumatic Institute was permanently shuttered in 1802, his vision of an everyday machine that would improve comfort by managing the aerial economy proved to be one of the few failures in the career of his most ambitious assistant, Humphry Davy. In moving from the "stormy" climate surrounding the Pneumatic Institute to the "mild and unvarying temperature" of Count Rumford's newly-founded Royal Institution in London, Davy found himself in a

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[381] Thomas Beddoes, *A Letter to Erasmus Darwin on a New Method of Treating Pulmonary Consumption* (Bristol: Bulgin and Rosser, 1773) 55.

milieu in which a growing market for machines that attempted to provide fresh, clean air in the midst of London's increasingly smoky and overcrowded streets.[382] Davy's ventilation projects were unsuccessful, but his career helped to transform the radical character of pneumatic chemistry into something that could appeal to an elite desire for comfort and control.

Necessity or Luxury?

In late 1776, an advertisement appeared for a ventilator designed to be placed directly on a woman's head. Specially designed for the "convenience of the ladies," this ventilator was incased in a wig made by one of a hundred Parisian hair-dressers that had been engaged by the proprietor. This ventilator consisted of a pasteboard dome, hidden in the shape of the wig, that maintained a "hollow cavity" above the woman's head. At the back of this dome was a hole fixed with a "tin ventilator, to admit the fresh air, and likewise to discharge the sweaty effluvia which arises from the head." The ventilator was operated by a string which ran down the woman's back and into a pocket, where "the lady can pull the string at pleasure, with great ease and facility, and by that means, let in the air…by either closing or opening the plate."[383]

Signed "A Mechanical Genius," this advertisement marked an entertaining starting point for the explosion of ventilators that appeared on the British market in the early nineteenth century. While patents for ventilators were rare in the eighteenth century, with only seven being filed between Samuel Sutton's ventilating pipes and the turn of the

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[382] Trevor Levere, "Dr. Beddoes: Chemistry, Medicine, and Books," in Lawrence M. Principe, ed. *New Narratives in Eighteenth Century Chemistry* (Dordrecht, Netherlands: Springer, 2007) 166; Letter from Gregory Watt to Davy, 7 February 1801, quoted in Golinski, *Science as Public Culture,* 188.

[383] "Ladies' hat ventilator," *Morning Chronicle and London Advertiser* (London, England), Thursday, October 31, 1776; Issue 2324, 17th-18th Century Burney Collection Newspapers.

nineteenth century, the next fifty years saw an explosion of ventilators on the commercial market, as over 75 new patents were approved for devices ventilating everything from tents to carriages to ship cabins to greenhouses.[384] While chemists were increasingly following Lavoisier in understanding ventilation and heating in terms of providing subsistence and a minimum level of heat and air, the London public had begun to view ventilation as a desirable luxury. This difference in understanding contributed to two of Humphry Davy's most spectacular public failures and opened the door for one of the most remarkable ventilation advocates of the nineteenth century: Jean-Frédérique, the Marquis de Chabannes.

It is remarkable that two of Humphry Davy's most public failures were in the field of ventilation. The first occurred in 1807 when he was invited to consult on a means of ventilating and sanitizing Newgate Prison. After two reconstructions and the best efforts of reformers, the prison had obstinately retained its "foul" character. No record remains of Humphry's recommendations, but his visit to the prison resulted in a months-long fever that nearly killed him. The one positive outcome was a revival of Davy's poetic ambitions, as he penned a romantic meditation on life and the powers of dubbed "Lines Written While Recovering from a Dangerous Illness."[385]

The second failure was much more public and embarrassing. The House of Lords had been forced to a new building in 1801, and the peers expressed consistent frustration with the chronic lack of fresh air and spotty and inefficient heating. After several attempts to improve the ventilation, a new committee was formed to address the problem

[384] Commissioners of Patents, *Abridgements of Specifications relating to Ventilation, 1632-1866* (London: George E. Eyre and William Spottiswoode, 1872) 4-20.
[385] J.Z. Fullmer, "The Poetry of Humphry Davy," *Chymia* 6 (1960): 108.

and Davy was called in as an expert consultant.[386] Davy's plan was fairly simple and was based on what Royal Institution colleague Count Rumford had referred to as one of the "principles of pneumatics," was the idea that "warm air in a room rushes out at an opening …when colder air from without is permitted to enter."[387]. However, he did not deign to explain this principle to the Lords Commissioners, writing that "it will not be necessary for me again to speak of the general principle proposed."[388] To facilitate a constant rising action to draw foul air upwards out of the Lords chamber, Davy recommended that copper or plate-iron pipes be routed from the "free atmosphere" outside of the building, alongside a brick flue which would heat the air. By regulating the fire that heated the adjoining flue, the fresh air would be matched to the temperature required and would rise through "numerous apertures in the floor of the House." To draw out the respired air, Davy proposed that two copper tubes be placed in the ceiling of the house which would be connected to "wrought-iron tubes, which can be heated by a small fire, if a great draught is necessary, as in cases when the house is full."[389]

Hoping to improve his prestige with the Lords and demonstrate the applicability of his work on a large scale, Davy had a scale model of the House of Lords constructed for one of his lectures at the Royal Institution and demonstrated how air "deteriorated by respiration" was conveyed out of the model room by the heated pipes in the roof.[390] However, since Davy neglected to fully describe the principles at play in Rumford's

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[386] Elizabeth Hallam Smith, "Ventilating the Commons, Heating the Lords, 1701-1834," *Parliamentary History* 38:1 (February 2019) 95-6.
[387] Benjamin Rumford, *Count Rumford's Experimental Essays, Political, Economical, and Philosophical: Essay IV: Of Chimney Fire-Places* (London: 1796) 302.
[388] Humphry Davy letter to Lords Commissioners, 7th Sept. 1811, quoted in Charles James Richardson, *A Popular Treatise of Warming and Ventilation* (London: J. Weale, 1839) 102-104.
[389] Humphry Davy letter to Lords Commissioners, 7th Sept. 1811, quoted in Charles James Richardson, *A Popular Treatise of Warming and Ventilation* (London: J. Weale, 1839) 102-104.
[390] J.A. Paris, *The Life of Sir Humphry Davy* (London: Henry Colburn, 1831) 219.

pneumatics, the commissioners and builders of the system did not appreciate the importance of a narrowed passage in the ceiling pipes to facilitate the proper drawing of air upwards out of the chamber. When the system was put into action, smoke from the ceiling ventilator drifted into the chamber and the thermometer quickly rose to eighty degrees. In his report, the labourer in charge of the system, Adam Lee, wrote to the commission that the windows were "constantly obliged to be opened, otherwise it would have risen still higher."[391] Lee recommended that the narrow, pneumatically-precise ceiling ventilator that Davy had designed be replaced with a large open ventilator and an air-pump to further assist in drawing the air upward. However, even this was "not sufficient" to save Davy's plan. Besides earning the ire of the peers for this costly failure, Davy was subjected to ridicule in what one of his biographers termed "numerous epigrams, not exactly of a character to meet the public eye."[392]

Davy's failure illustrated a gap between the theoretical principles of pneumatics, as laid out by Count Rumford, and the growing demands among the London elite for machines that would facilitate a comfortable, pleasant-smelling and temperate atmosphere. This desire was certainly justified with language about the perceived dangers of "mephitic," or pestilential vapors that arose from excrement, rotting organic matter, polluted rivers and open drains.[393] Smoke was a secondary concern – unpleasant and obnoxious when it blackened clothing, but, remarkably, it was not considered a danger to

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[391] Letter from Adam Lee, Labourer in trust to the Committee on the House of Lords, June 1813 – printed in C.J. Richardson, *A Popular Treatise of Warming and Ventilation*, 105-106.
[392] Elizabeth Hallam Smith, 96; Paris, *The Life of Sir Humphry Davy*, 219.
[393] See, for example, Alain Corbin's discussion of how class distinction was partially related to sensitivity to foul smells; Alain Corbin, *The Foul and the Fragrant: Odor and the French Social Imagination*, trans. Aubier Montaigne (New York: Berg, 1986) 147.

health until at least the mid-nineteenth century.[394] Far more frequently mentioned in patents and advertisements for ventilators after 1800 was the ability to "renew" and "warm or cool" the air.[395] Smell was dangerous – but guides for ventilation appealed far more to a desire for *comfort* than for safety. During the first half of the nineteenth century, as the number of patents for ventilators and ventilating stoves soared, a growing number of middling and elite Britons sought new machines that would "renew" and condition whatever air they happened to inhabit.[396] While pneumatics and miasma theory provided a rationale, the fundamental demand was for comfort. It is perhaps not surprising then that one of the first men to grasp this distinction was a child of privilege – Jean-Frédérique, the Marquis de Chabannes. By prioritizing the pleasurable experience of his controlled environment, Chabannes managed to tap into the nascent middle class desire for insulation from the unfriendly and unpredictable exterior environment of a rapidly growing London.[397]

Luxurious Ventilations

This transition from "fresh" air to "renewed" air owes largely to the work of the most spectacular ventilation promoter of the 1810s – Jean-Frédérique, Marquis de Chabannes. Achieving remarkable success and celebrity in the brief period from 1815-1820, Chabannes promoted and sold ventilation systems which promised aerial comfort

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[394] Frederick Cornewall quoted in William Cavert, *The Smoke of London* (Cambridge: Cambridge UP, 2016) 227; On the perceived healthfulness of smoke, see: Peter Thorsheim, *The Invention of Pollution* (Athens, OH: Ohio UP, 2006) 16-18.
[395] Commissioners of Patents, *Abridgements*, 4-20.
[396] On the increase of patents in early nineteenth century Britain and Ireland, see: Sean Bottomley, "Patenting in England, Scotland and Ireland during the Industrial Revolution, 1700-1852," *Explorations in Economic History*, 54 (2014): 48-63.
[397] F.M.L. Thompson, *The Rise of Respectable Society: A Social History of Victorian Britain, 1830-1900* (Cambridge, MA: Harvard UP, 1988).

based on Lavoisier's chemistry.[398] Much of Chabannes success can be credited to his creation of a new *economy of comfort*. Rather than emphasizing "salubrity" and "savings of fuel" as Rumford had done, Chabannes emphasized the vast improvement in comfort that could be attained through the purchase of his ventilating machine. By offering his customers "a variety of enjoyments within [their] grasp, yet which escape his penetration because unthought of," Chabannes aimed to create a new market for machines that simultaneously regulated the temperature and purity of air with an eye towards rendering homes "pleasant and agreeable" while making no reference to the providentially-maintained aerial economy.[399] With his "Calorifere Fumivore" stoves, Chabannes adapted the language of chemistry and public health in order to market products that appealed to the nascent middle class desire for insulation from the unpredictable exterior environment of a rapidly growing London.

Chabannes' insight into middle- and upper-class desires owed much to his own experience as a French émigré. The scion of a noble family and the first cousin of Tallyrand, Chabannes was an avid traveller who had served as an attaché to the Baron de Vioménil during the closing stages of the War of American Independence and who later married the daughter of a wealthy Dutch merchant while a guest at the Dutch factory in Smyrna in the Ottoman Empire. Inheriting the title of Marquis in the inauspicious year of 1789, Chabannes' showed little sympathy for the revolution and soon decamped from his familial estate to stay with his wife's family in Smyrna. After taking part in the failed

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[398] Jean Frederic Marquis de Chabannes, "Apparatus for Consuming Smoke and Warming Apartments," U.K. Patent #3875, 1815.
[399] Jean Frederic Marquis de Chabannes, *On Conducting Air by Forced Ventilation* (London: N.P. 1818) 16.

Royalist invasion of Britanny in 1795, Chabannes evaded execution by passing himself off as a Swiss officer, and managed to re-settle with his wife in England.[400]

Upon arriving in England, Chabannes had thrown himself into ambitious projects that aimed to both take advantage of the commercial atmosphere of his adopted country. Having settled in the Barnes region on the outskirts of London, Chabannes engaged in a large-scale scheme to use steam-heated hot-houses in order to provide "tender and unseasonable fruits and vegetables, in greater perfection, and at a lower rate than they had heretofore been supplied by English gardeners."[401] He was likely inspired in this by his prior familiarity with the steam-heating of hot-houses in France by Jean Simon Bonnemain.[402] However, despite building "very extensive hot-houses and conservatories," Chabannes' scheme failed due to unforeseen difficulties in adapting plants to the English climate, and he was forced to sell off his materials.[403] After repeatedly failing in several other schemes including an attempt to re-constitute usable fuel from coal dust and a failed transportation company that aimed to use his specially-designed carriages, dubbed "vélociferes," to convey mail and passengers along France's recently improved roads, Chabannes' returned to domestic matters with a remarkable technological proposals to completely revolutionize the home economy.[404]

His pamphlet, entitled "Project for the Construction of New Houses" which envisioned an entirely new domestic architecture that expanded Rumford's ideas for

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[400] Martin Meade and Andrew Saint, "The Marquis de Chabannes, Pioneer of Central Heating and Inventor," Transactions of the Newcomen Society 66:1 (1994): 193-195.
[401] Richard Phillips, *A Morning's Walk from London to Kew* (London: J. Adlard, 1817) 223.
[402] Emmanuelle Gallo, "Jean Simon Bonnemain (1743-1830) and the Origins of Hot Water Central Heating," in Construction History Society eds. *2nd International Congress on Construction History* (April, 2006) 1048-9.
[403] Phillips, 223.
[404] Meade and Saint, 196-8.

steam heating to a community-wide scale.[405] The proposal called for a square of uniform houses to be constructed with a garden in the center. Constructed using a "new manner of joining cast iron without screws or nuts" (a cement composed of sulphure, ammonium chloride and iron filings) this would enable the improvement of "all the features which go into the construction…of a house, and at less than half the price." Most importantly, each household was to be equipped with a steam engine which could provide steam and hot water on demand and could move "all sorts of mechanisms."[406] The decorative iron columns that fronted each house would double as chimneys for the steam engines, would be arranged in a square around a common garden.[407] Chabannes predicted that these houses would provide "great economy and an abundance of enjoyment" for its residents.[408]

There is no evidence that anyone ever took Chabannes up on this proposal. But it reflected a clear turning point in his quixotic career. Seeking to correct the lack of control he had felt during his experience of the Revolution, Chabannes found that the idea of creating devices to manage the domestic environment was a proposition that resonated strongly with his British clientele. Declaring how he had been driven from France by an intense "sorrow and affliction" over "destiny of the House of Bourbon, and the future miseries of my too unhappy country," the Marquis declared that his "sole design" in

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405 Jean-Frédéric de Chabannes, *Prospectus d'un projet pour la construction de Nouvelles maisons, dont tous les calculs de details procureront une trés-grande économie, et beaucoup de jouissances* (Paris, Lenormand, 1803); Rumford's influence can be seen on page xi where Chabannes notes "l'ignorance ou la negligence dans les constructions (des cheminées)" – a point echoing Rumford's complaint of the "plague of a smoking chimney" in: Benjamin Rumford, *Count Rumford's Experimental Essays, Political, Economical, and Philosophical: Essay IV: Of Chimney Fire-Places* (London: 1796)
406 Chabannes, *Prospectus*, xi-xii; Meade and Saint, 199-200.
407 Meade and Saint, 199-200; Chabannes, *Prospectus*, 43-5.
408 Chabannes, *Prospectus*, frontispiece.

returning to England had been in “guarding myself from the cold.”[409] To do so, he adapted his earlier stove design into a variety of new stoves which he dubbed “Calorifere-Fumivores” or just “Caloriferes.”

Available in a variety of shapes and frequently decorated in the ornate empire style, the principle of the “Patent Calorifere” was exceedingly simple – iron tubes connected with an outside supply of air were placed in a chamber between the firebox and the chimney. As the heat from the firebox warmed the tubes, the air was rarified by the heat and dispersed throughout the room, while the smoke carried up the chimney. The resulting heat then forced the “decomposed or impure” air to rise up to a “patent chimney-ventilator” which used the force of wind to draw foul air through openings in the ceiling and out of the house.[410] In larger homes and public buildings like churches or theaters, this process would be aided by multiple well-placed Caloriferes and gas-powered lamps or chandeliers which could also be fitted with iron tubes to encourage the rarefaction of air towards the vents in the ceiling.[411]

The theory behind Chabannes’ stoves was based far more on comfort than on a clear understanding of pneumatics. Referring to himself as the “author of forced ventilation,” Chabannes described the aerial environment as too fragile and changeable to be managed by the principle of heat convection alone. Air, “being elastic, is apt to be compressed” by even “the least draught” from the external atmosphere – a change that could seriously disrupt the comfort of the internal atmosphere.[412] To emphasize this

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[409] Chabannes, *On Conducting Air,* v.
[410] Chabannes, *On Conducting Air*, 52-3; Jean Frederic Marquis de Chabannes, *Explanation of a New Method for Warming and Ventilating Homes* (London: Schulze and Dean, 1815) 5-6.
[411] Chabannes, *On Conducting Air*, 22, 61.
[412] Chabannes, *On Conducting Air*, 17.

point, Chabannes used the example of a dinner party: "How unpleasant" he remarked, "at a dinner party," to be subjected to "a cutting wind on the continual and hurried opening of the door." In order to prevent this, Chabannes recommended keeping doors and windows shut, and allowing exterior air to enter the Calorifere through only a box of "several sieves, each finer than the other," which was designed to filter the "vast quantity of particles of smoke, or dust of coal" found in London air.[413] In addition, he recommended placing a Calorifere stove or steam-radiator near doorways and staircases in order to avoid unpleasant "rushes of air" from the outside or unheated portions of the house. "The equality of the temperature in dwellings," Chabannes declared, "is undoubtedly one of the first requisites to comfort."[414]

To promote his devices, Chabannes addressed a circular letter "to the physicians and medical gentlemen in London" inviting them to examine his home at No. 1 Russel Place to experience the comfortable temperature and evaluate the ability of his apparatus to expel "miasmata" and "damp air."[415] This strategy was remarkably successful. By 1817, Chabannes had received orders to install his devices at the Metropolitan Bazaar, the Covent Garden Theatre, and the Subscription Rooms at Lloyd's.[416] Of these contracts, the most extensive system was the one put in place at Covent Garden. To heat the building to a suitable temperature, Chabannes commissioned a huge boiler for the basement of the theater which provided heat via forty-four "patent steam cylinders" placed around the floor underneath the stage and near the entrances to the audience pit

[413] Chabannes, *On Conducting Air*, 23.
[414] Chabannes, *On Conducting Air*, 53-4.
[415] Chabannes, *On Conducting Air*, viii.
[416] Chabannes, *On Conducting Air,* 30-35; Jean Frederic Marquis de Chabannes, *An Account of a Forced Ventilation Produced in the Metropolitan Bazaar* (London: Schulze and Dean, 1817).

where they could prevent "the cold from annoying persons seated in the front benches of the pit, but rushing to their legs and feet."[417] Fresh air was pulled via heat convection from above the ceiling of the theater via two "air trunks" – wooden ducts that ran from the ceiling to the first and second circles of the audience. This air was then heated and admitted to the theater from corridors near the pit. In the ceiling above, two massive ventilating cowls drew the air upwards with the assistance of a large gas-lit chandelier which heated more iron pipes to draw up the foul air. For the well-to-do audience in the box seats, a specially-constructed Calorifere Fumivore was placed in the gallery at the rear of the theater with pipes running to each of the boxes to even more swiftly whisk away the "vitiated air."[418] Additional Calorifere stoves were placed in the staircases and near the entrance – wherever cold air was likely to issue.[419] Chabannes impressed visitors from the Royal Institution with the efficacy of his system by placing thermometers throughout the building, which were kept at a steady temperature of sixty degrees Fahrenheit.[420]

However, while the Royal Institution pronounced his system to be "ingenious," Chabannes' greatest success was destined to be his downfall. After several high-profile commissions, which he relentlessly advertised in pamphlets and letters to the *Morning Post*, Chabannes was called in to ventilate the most famous but obstinately vitiated building in Britain – the House of Commons.[421] While several convection-based

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[417] Anon., "On the Ventilation of Covent Garden Theatre," *The Journal of Science and the Arts* (London: John Murray, ,1818) 302
[418] Chabannes, *On Conducting Air*, Plates I, III and XIV.
[419] Charles Tomlinson, *A Rudimentary Treatise on Heating and Ventilation* (London: John Weale, 1850) 220.
[420] "Ventilation of Covent Garden Theatre," 301.
[421] For Chabannes' self-promoting, see, for example: Jean Frederic Marquis de Chabannes, "On the Forced Ventilation of Covent Garden Theatre" *Morning Post* (London) 14719, March 24, 1818.

ventilation systems had been tried since that of Davy, none had been found satisfactory. When Chabannes was called into consult the House was still relying on one of Theophilus Desagulier's hand-turned blowing wheels that had been first installed ninety-five years earlier.[422]

During his consultation, Chabannes immediately noted that the "small size of the house for its members" and the construction of the galleries would be obstacles to the free ascent of air.[423] The mechanism the Marquis proposed was a beefed-up version of what he had installed at Covent Garden. Fearing that a simple vent to the outside would be inadequate to force air into the chamber, Chabannes attached Desagulier's blowing wheel to the air intake, which would run through a filter and past twelve steam cylinders to pump fresh, heated air through vents beneath the members' seats. The heat would be provided by a boiler system in the basement of the Lords. To solve the problem of foul air being stuck underneath the overhanging galleries, Chabannes decided to place *sixteen* steam cylinders in two additional ventilating tubes, which he hoped would create a powerful convection to draw foul air up to three of his patented chimney ventilators which would feed into in a large, 4-foot-wide cowl filled with ventilating tubes which would be heated by steam rising from another small boilers in the basement. With this system in place, Chabannes promised that the quality of the air "will never be impaired." The respirability of the air would be proven by the 'brightness of the (gas) lights" which would be "an undeviating proof of its purity." While the heat conduction and the crowded nature of the building made some increase of heat "unavoidable," he assured the office of

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[422] Hallam Smith, 86-7; J.T. Desaguliers, *A Course of Experimental Philosophy* 2nd. Ed. (London: W. Innys, 1744) ii, 560.
[423] Chabannes, *Appendix to the Marquis de Chabannes' Publication on Conducting Air by Forced Ventilation* (London: Spragg, 1818) 3.

works that the temperature within the House of Commons would never be higher than six to twelve degrees above the external temperature.[424]

This was a promise that Chabannes proved unable to keep – and his devices soon sparked fear of both fire and suffocation. When the boilers were put into operation, the chamber quickly became intolerably hot. The heat was so extreme that the office of works was immediately called in to press Desaguliers' blowing wheel back into service.[425] In addition, there was considerable concern in the office of works – as well as from the laborers in charge of the boilers - over the risk of fire from Chabannes' machines.[426] The final straw came when Chabannes, who had taken his commission on the condition that he not be paid until the atmosphere in the commons was satisfactory, began submitting bills to the office of works that were nearly double his initial estimates.[427] By July of 1819, only a few months after the installation of Chabannes' system, the Office of Works were ordered to find a more "effectual means of ventilating."[428]

The Marquis' ventilation system in Covent Garden was also being found unsatisfactory. In a self-published apologia in the *Morning Post*, Chabannes admitted that "various causes…have hitherto partly counteracted its beneficial effects."[429] Adding to the Marquis' troubles, his long-jilted English creditors had followed the bread-crumb trail

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[424] Chabannes, *Appendix*, 3-6, Plate 2.
[425] Elizabeth Hallam Smith, 89.
[426] A Mr. Wilkinson of the Office of Works enclosed a letter detailing Chabannes' ideas to architect John Soane, asking whether the building was "likely to be endangered" from the Marquis' proposal: Office of Works to John Soane, August 29, 1818, Letters to/from the Marquis de Chabannes, John Soane Museum, John Soane Priv. Corr. XI, D no. 38); for laborers, see Elizabeth Hallam Smith, 89.
[427] Meade and Saint, 209.
[428] Elizabeth Hallam Smith, 89.
[429] Chabannes, "On the Forced Ventilation of Covent Garden Theatre" *Morning Post* 14719, March 24, 1818. *Gale Primary Sources – British Library Newspapers.*

of self-promotion and had begun to hound him – this was likely the cause of his early demand for payment from Parliament and the subsequent closure of his "Patent Calorifere Fumivore Manufactory and Foundry" in Drury Lane.[430] Years after Chabannes' death, engineer Walter Bernan wrote that the Calorifere stove was "one of the worst of its class." Even with a "very moderate fire," Bernan wrote, the Calorifere's ventilating pipes became "so hot as to burn not only the light substances floating in the air, but to decompose the air itself."[431]

By attaching an aristocratic vision of comfort and control to a mechanical product that *also* promoted health and economy, Chabannes had created a new luxury that was acceptable to English sensibilities. However, the dysfunction and potential danger of heating systems meant that, in the words of physician Neil Arnott, the best means of ventilation were "yet very imperfectly diffused among the people."[432] While it had been determined that heat convection was the best means of simultaneously meeting the needs of ventilation and comfort, the perceived danger of fire or excessive heat damaging the respirability of air presented a significant engineering and public perception obstacle.

This Dangerous Comfort

In a gambit to address both the technical and sensible aspects of heating and ventilation, physician and public health advocate Neil Arnott proposed a design for an inexpensive and self-regulating "Thermometer-stove," which would safely and efficiently heat homes to a healthy and uniform temperature. In addition, the stove would produce a

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[430] Meade and Saint, 209. Chabannes, *Appendix*, Frontispiece.
[431] Walter Bernan, *On the History and Art of Warming and Ventilating Rooms and Buildings* (London: George Bell, 1845) II, 92.
[432] Neil Arnott, *On Warming and Ventilating* (London: Longman, 1838) 11-12.

minimum of smoke by re-circulating combusted air back into the fire. To prevent the air of the room from being burned on the hot surface of the stove, the entire firebox would be insulated by water, which would keep the metallic exterior below a maximum temperature of 200 degrees Fahrenheit. Finally, a thermometer attached to a regulating arm would open or close the stove's air passage to regulate combustion. Thus the operator could keep the room at a comfortable and uniform temperature simply by keeping the stove fed with coal or whatever other suitable fuel was available. Arnott claimed that the stove was so efficient that "a sheet of paper set fire to, and put into a cold stove, will warm the whole almost as if boiling water had been poured into it."[433]

In order to promote the widespread use of this invention, Arnott presented it before the Royal Institution and "decided not to reserve for myself any patent right" to the device.[434] However, the public reception of his machine was not as successful as he hoped. While a bevy of manufacturers raced to cash in on this well-publicized but unpatented product, the low quality of many of these "Arnott Stoves" made them the opposite of safe – they frequently exploded. In a series of extraordinary letters to the editor of the *London Times*, Dr. Arnott debated the safety and utility of his stoves with a series of pseudonymed interlocuters. The first letter, by "A Country Gentleman" who had purchased an Arnott Stove, declared that after being fed with good "Welsh stone coal," a burst of gas "blew out of the regulating valve underneath the chair I was sitting on, carrying with it sparks of fire." The second burst rushed "far into the room" and "blew back the breakfast cloth." Finally, a "violent explosion took place, lifting the stove off the

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433 Arnott, *On Warming and Ventilating*, 47.
434 Arnott, *On Warming and Ventilating*, iv.

ground, breaking a carved marble mantlepiece into three pieces" and creating a huge cloud of "smoke, or gas rising up before the looking glass."[435]

Stating his initial desire to rid himself of this "very dangerous comfort," the "Country Gentleman" noted that he was not opposed to another trial if helpful advice could be offered on how to avoid another explosion. In a deeply defensive response, Arnott himself wrote that the fault was not with the stove design, but with the "extraordinary errors and failures on the parts of both the manufacturers and purchasers." In addition, Arnott noted that "were a chronicle to appear of the accidents from open fires occurring in London during a single day, as of rugs and carpets damaged by live coals shot upon them, ladies dresses set on fire, often with serious consequences to the person, children burnt to death by being left near fires unguarded" then the public would realize the vast superiority of even a flawed copy of his stove.[436] Despite their apparent danger, the quantity of advertisements for Arnott's stoves give a strong impression of their popularity. However, as the character of the "country gentleman" suggests, much of Arnott's appeal was directed not towards the poor, but towards the upper and middle classes. Writing in 1838, Arnott noted that while "most educated members of civilized communities" were "well acquainted with the four necessaries of life, and with the means by which these are to be secured."[437]

Public vs. Private – the Hierarchy of Heat

This distinction between the ventilation knowledge and responsibility of the "educated" and uneducated members of society and the commercial character of Arnott's

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[435] A Country Gentleman, "Dr. Arnott's Stoves" *London Times*, Issue 17234, Dec. 25, 1839.
[436] Neil Arnott, "Dr. Arnott's Stoves," *London Times*, Issue 17239, Dec. 31, 1839.
[437] Arnott, *On Warming and Ventilating*, 11-12.

stoves gets at a central issue in public health – the distinction between public and private responsibility. The tetrarchy of Arnott, Thomas Southwood-Smith, James Philips Kay and Edwin Chadwick are usually credited with spurring the movement for public health reform in the 1840s. Chadwick's *Report on the Sanitary Condition of the Labouring Poor of Great Britain*, based on research carried out with Smith, Kay and Arnott, demonstrated the need for government action in response to alarming mortality rates in poor urban areas. On the one hand, sanitary reformers agreed that sources of miasma – in the form of rotting garbage, excrement and stagnant water – was a public responsibility and must be addressed by public action. In the words of Chadwick, the most important "defects" in public sanitation were "are those chiefly *external* to the dwellings of the population, and principally arise from the neglect of drainage."[438] However, the provision of fresh air and heat to private homes was tied up with valuable commodities like fuel and expensive machinery like ventilating stoves that reformers were inclined to relegate to the free market.[439]

The difficulty of parsing public health from private responsibility can be most clearly seen in the early writings of Thomas Southwood Smith. A strong anti-contagionist, Smith rejected the belief that epidemic diseases could be traced to a foreign source, and instead identified tropical sources of disease all around him as "nature with her burning sun, her stilled and pent-up wind, her stagnant and teeming marsh, maunfactures plague on a large and fearful scale." While the stagnant water and filth of the urban streets became potent sources of this poison, the private apartments of the poor

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[438] Edwin Chadwick, *Report on the Sanitary Conditions of the Labouring Population of Great Britain*, (London: 1842) 25.

[439] Christopher Hamlin, "The Necessities of Life in British Political Medicine, 1750-1850,"*Journal of Consumer Policy* 29:4 (2006): 386.

were even more dangerous. If a fever was already present, a “small and heated apartment in London, with no perflation of fresh air” could be “perfectly analogous to a stagnant pool in Ethiopia, full of the bodies of dead locusts.” This inability to distinguish a healthy atmosphere from an unhealthy one was the ultimate danger of “penury and ignorance” which could, “at any time, and in any place, create a mortal plague.”[440] For the Unitarian Southwood Smith, the suffering and disease caused by improper heating and ventilation were signs that human beings were failing to conform to the divinely-ordained principles of nature. Epidemic diseases would be cured directly “in proportion to our conformity in our public and private life to the spirit of these divine principles.”[441]

As a matter of private responsibility, the adequate provision of heat and ventilation in one’s home was analogous to one’s personal virtue and social development. “One of the most valuable arts which divine goodness has placed within our reach” wrote engineer and passionate self-improver Thomas Tredgold, “is that of producing and distributing heat.” This power enabled the creation of a healthy and comfortable dwellings, without which, “the condition of man would not be much superior to that of the lower animals.”[442] Physician and public health advocate Neil Arnott took this a step farther. The progress of society could be traced through the development of heating and ventilation. While humanity had first been in a state of “natural ventilation,” in which atmospheric air passed each “person, as the water of a mountain stream is passing its finny inhabitants,” the necessary construction of dwellings had made ventilation “very

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[440] Thomas Southwood Smith, *A Treatise on Fever* (London: Longman, 1830) 364.
[441] Thomas Southwood Smith, *On the Common Nature of Epidemics and their Relation to Climate and Quarantine* (Philadelphia, PA: J.B. Lippincott & Co., 1866) 59.
[442] Thomas Tredgold, *The Principles of Warming and Ventilating Public Buildings* 2nd ed. (London: Josiah Taylor, 1824) 1-2.

irregular and imperfect." While the "savages of north America" were content to "sit around in the smoke," Europeans had adopted chimneys, then stoves, then ventilating stoves, and finally steam heat – a progression which reflected an increasing perfection but which required "not a little art."[443]

However, in Arnott's opinion, this progress was in grave danger from a lack of understanding on the part of the urban poor of what constituted a healthy environment. This was not just an ignorance of the technical aspects of ventilation, but of the *sensory* ability to detect foul, unhealthy air. To prove his point, Arnott gave the example of some poor lace-making girls in Buckinghamshire. Being unable to afford fuel for a fire, these women would find the smallest available room where "twenty or thirty of them" would huddle together "and keep themselves warm by their breathing." After a short time,

> "the odour of their breaths, although unperceived by themselves, soon became, to a stranger entering, exceedingly offensive. The pale faces, broken health, and early deaths, of many of these ignorant self-destroyers, told, to a better-informed observer, what they had been doing; but it was very difficult to convince themselves of their folly."

To Arnott and his fellow sanitarians, this story proved "how much is yet to be done, to inform the public sufficiently on this subject."[444]

As Arnott wrote of this "folly" in 1838, he frequently mentioned a glowing counter-example – a place where a system of warming and ventilation had managed to convey "air of perfect purity" – the House of Commons. The man who had accomplished this incredible feat which had evaded Davy and the Marquis de Chabannes was a Scottish chemist named David Boswell Reid, whose ventilation of the temporary House of Commons was "perhaps…the only instance of effectual ventilation for such a place."[445]

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[443] Arnott, *On Warming and Ventilating*, 2, 19-30.
[444] Arnott, *On Warming and Ventilating*, 57-8.
[445] Arnott, *On Warming and Ventilating*, 65, 87.

A chemist trained in Edinburgh, Reid's success had come from a new mode of managing airs that promised to vastly increase control over interior space. In short, he promised to completely privatize the aerial environment.

The Chemistry of Control

For his part, Reid shared the sanitarians' anxiety about the willingness of private individuals to ventilate their own homes. A lifelong advocate of public and practical scientific education, Reid said of ventilation that "unless the public be sufficiently informed to second the efforts that are made…a long and lingering period may elapse before ventilation can be generally introduced."[446] However, his career demonstrates the ultimate conclusion of the conception of mechanical ventilators as "environmental machines." As Reid attempted to discern "the precise amount of air required for health and comfort" in his ill-fated attempt to heat and ventilate the new Palace of Westminster, it became clear that an idealized, comfortable, and artificial environment had become more desirable than a free and healthy circulation of air.[447] Comfort had overcome health and mechanical ventilation was moving from the purview of the physician and the chemist and into the realm of the architect and engineer.

As a practical chemist and educator, Reid's interest in ventilation came from his need to control the space of his classroom in order to efficiently accomplish his goal of practical, public education. As an assistant to Thomas Charles Hope at the University of Edinburgh, Reid proved to be an engaging speaker and demonstrator, and his lectures

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[446] David Boswell Reid, *Illustrations of the Theory and Practice of Ventilation* (London: Longman, Brown, Green, & Longmans 1844) x.
[447] Elisha Harris, "Preface" in David Boswell Reid, *Ventilation in American Dwellings* (New York: Wiley & Halsted, 1858) xix.

attracted large crowds from all walks of life. By keeping prices for his lectures low, Reid attracted not just medical students but "miners, manufacturers, engineers, agriculturists, amateurs."[448] Part of the flavor of these lectures can be gleaned from his 1836 published textbook, *Rudiments of Chemistry*, which emphasized the "chemical phenomena of daily life" and featured well-illustrated examples of ventilation and the relative advantages and disadvantages of furnaces and fireplaces. Reid's methods strongly emphasized "practice" over "theory" – he was convinced that "a man who is already acquainted with the mechanical and practical part of an art, receives instruction with much more advantage."[449] Reid's popularity and his desire for job security prompted him to appeal to the town council to set up a new chair of Practical Chemistry at the University of Edinburgh. Despite the support of many of the town's manufacturers and the endorsement of Neil Arnott, the determined opposition of Thomas Charles Hope sank Reid's case. Leaving his university post in frustration, Reid designed a large new lecture-room behind the hall of the College of Surgeons in Edinburgh.[450]

The design of this classroom demonstrates how closely Reid tied chemical instruction with the aerial control of a space – the environment of the classroom itself was central to his educational aims. Comprising a lecture hall and a "practical classroom," the space was designed to accommodate 300 students.[451] First of all, the space had to be adapted for a wide variety of chemical experiments. In front of the lecture

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[448] Hugo Reid, *Memoir of the Late David Boswell Reid* (Edinburgh: R. Grant, 1863) 8.
[449] David Boswell Reid, *Rudiments of Chemistry* (Edinburgh: William Chambers, 1836) v, 45-53.
[450] Edward J. Gillin, *The Victorian Palace of Science* (Cambridge: Cambridge UP, 2017) 130-132, 140; Edward J. Gillin, "Reid, David Boswell (1805–1863), chemistry teacher and ventilation engineer," *Oxford Dictionary of National Biography*, 23 Sep. 2004; Accessed 27 Jun. 2020. https://www-oxforddnb-com.proxy.libraries.rutgers.edu/view/10.1093/ref:odnb/9780198614128.001.0001/odnb-9780198614128-e-23327.
[451] Reid, *Illustrations*, 312.

benches, Reid installed a variety of different furnaces for refining and tempering various metals - a blacksmith's forge for metal-work, a reverberatory furnace for melting alloys, a muffle furnace for gold and silver and a blast furnace for refining iron complete with a steam-powered air supply (in the form of a blowing wheel).[452] A system of descending flues linked each of these furnaces to a central furnace, which created an "artificial current determined by a column of heated air." In addition, ventilating apertures in this central chimney pulled fumes out of the room. In the practical side of the classroom, reid had an enormous amount of chemical equipment laid out on benches as well as six additional chemical furnaces, each arranged around a pillar which served as an additional chimney for the dispersal of fumes.[453] With this apparatus, Reid calculated that he and his students sometimes performed 2000 experiments per hour with no ill effect from smoke or "disengaged fumes."[454]

As that mind-boggling number of experiments suggests, Reid's classroom was designed to provide an efficient, clear and didactic space. For this reason, acoustics were crucial: to mitigate the "severe and varied action of the voice" necessitated by teaching "for seven and eight hours daily, in successive classes, where the interruption occasioned by the endless variety of experiments performed," Reid designed his classroom with a low roof and a "rough and inelastic floor, made of an earthy composition" which both would absorb detritus from the furnaces and excess sound from his diverse array of students. "In every part" of both the lecture portion and the practical area, "the slightest

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[452] Reid, *Rudiments*, 49-50.
[453] David Boswell Reid, *Text-Book for Students of Chemistry* 3rd ed. (Edinburgh: Maclachlan, Stewart and Co. 1839): frontispiece.
[454] W.S. Inman, *Report of the Committee of the House of Commons on Ventilating, Warming and Transmission of Sound* (London: John Weale, 1836) 56.

whisper or the loudest noise was heard distinctly without offensive reverberation."[455] To maximize its use as an instructive space, Reid had chemical formulae inscribed on the pillars of the room.[456]

Reid's success as an educator brought him national fame, and inspired some in Parliament to envision how his exemplary system could be brought to the houses of parliament. The strongest advocate of this development was Lord Chancellor Henry Brougham, himself a keen advocate of practical, public education who had assisted in the founding of the London Mechanics' Institute (now Birkbeck college). Brougham toured Reid's classroom along with the parliamentary delegation that had come to visit Edinburgh for the 1834 meeting of the British Association for the Advancement of Sciences.[457] Brougham noted the acoustic measures and "paid particular attention to the system of ventilation."[458] By the next year, he had successfully lobbied for the creation of a committee to examine "ventilation, warming and transmission of sound" in the House of Commons. The 1835 report of this committee reflected how broad-ranging Brougham's ambitions were for re-making the aerial space of the House. To insure that they would receive the best possible advice on the ventilation of the house, this committee called for expert testimony from Reid, fellow chemists and educators Michael Faraday, William Thomas Brande and George Birkbeck, as well as architect Robert Smirke (the designer of the temporary House of Commons) and civil engineer John Sylvester.[459]

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[455] Reid, *Illustrations*, 312.
[456] Edward Gillin, *The Victorian Palace of Science*, 140; Sophie Forgan, "Context, Image and Function: a Preliminary Enquiry into the Architecture of Scientific Societies," *BJHS* 19:1 (1986): 113.
[457] Gillin, *Victorian Palace of Science*, 140-141.
[458] Anon, "The Lord Chancellor," *Preston Chronicle* (Preston, England), 20 September, 1834; Issue 1151.
[459] Inman, *Report*, xiv.

Not merely consulting these luminaries on practical advice, the committee sought to derive a universally acceptable means of heating and ventilating the House by placing the building's atmosphere in relation to a *global* history of heating and ventilation. In order to gain a perspective on how humans had adapted to extreme climatic situations, the report cited both the hot-room experiments of Blagden and Fordyce and the freezing conditions encountered during the recent polar expedition of Sir John Ross, and discussed known means of cooling and ventilating from the ancient Egyptians to the recently-completed arrangements of the American House of Representatives and the French Hall of Deputies.[460]

Throughout this series of interviews, Reid's testimony deeply impressed the committee. His testimony was full of "prompt and ample" evidence, and his "general attainments in science" proved that he was far more than a mere "systematizer."[461] To prove that his system would be effective in the current building, Reid constructed a model of the Commons with a miniature version of his system in place. Reid's proposed system functioned much like that in his classroom, except on a much grander scale. Air would be purified then heated or cooled and supplied to the commons through a series of apertures beneath the benches. Drawn upwards to ventis in the roof with the aid of gas-lit chandeliers, the air would be swiftly pulled from the chamber to be expelled through a large adjacent chimney in which a powerful furnace would be constantly lit. Within the chamber, the temperature and condition of the air would be monitored by a thermometer

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[460] Inman, *Report*, 8-9, 23-24.
[461] Inman, *Report*, 22.

and a carbonometer. After a period of experimentation, Reid was permitted to install his system in the actual House of Commons.[462]

The reason why Reid was so impressive was that he was able to promise complete control over an interior atmosphere. In the present temporary houses of parliament, despite decades of attempts to improve ventilation, "unpleasant effluvia" were "always perceptible." Reid promised that his system would provide a current of fresh air so gentle that it would be "imperceptible to members; and the inlets and outlets be perfectly under control."[463] This promise was deeply appealing to Britain's ruling classes. Besides being contracted to handle the ventilation for the new Palace of Westminster, over the course of the next decade Reid was called in to ventilate or improve ventilation in high-profile public buildings throughout Britain, including the Old Bailey and St. George's Hall in Liverpool. In addition to the much-lauded three-ship expedition bound for the Niger, Reid's ventilation system was also installed on new naval ships and, most famously, on Queen Victoria's royal Yacht, the *Victoria and Albert*.[464] In securing these commissions, Reid displayed a complete confidence in the efficacy of his systems and promised that once in place, purchasers would be in complete command of their atmosphere.

The appeal of Reid's promises can be seen in his failed attempt to secure a commission to ventilate the Royal Exchange in 1839. Like the House of Commons, the exchange was housed in temporary accommodations and frequently beset with "offensive" and cold currents of exterior air. Complaining that the Exchange trustees had determined that theirs was the "the only publick room in the city…to whose benefits the

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[462] Gillin, *The Victorian Palace of Science*, 150-152.
[463] Inman, *Report*, 8.
[464] See: David Boswell Reid, *Extracts from Official Documents, Reports and Papers Referring to the Progress of Dr. Reid's Plans for Ventilation* (London: 1846).

improvements of the age shall be not applied," over three hundred members of the exchange (along with 46 of the proprietors) signed a petition in December of 1838 demanding an improved system of heating and ventilation.[465] Eager to address the concerns of so may chilly and annoyed shareholders, the managers and trustees invited proposals from architects and engineers to address the issue. Of the five submissions deemed worthy of consideration, Reid's was by far the most expensive and ambitious. In exchange for a hefty price of "not less than £1500-1800," Reid promised:

1. The supply of an adequate amount of air.
2. The absolute control over the quantity supplied.
3. The prevention by double windows of offensive currents or the precipitation of foul air.
4. The purification of the external air.
5. The equal diffusion and supply of air.
6. The certain extraction of the vitiated air without its being allowed to contaminate the fresh air as it enters.

Hesitant about the high cost and Reid's demand for a twenty-guinea assessment fee despite having pledged a free appraisal, the exchange committee decided against adopting the doctor's plan in favor of exploring cheaper alternatives.[466]

While not adopted, Reid's rapid success and the episode with the Royal Exchange illustrates a crucial aspect of Victorian ventilation and heating: the demand for atmospheric comfort. Respectable Britons were proving themselves willing to accept *some* cost in exchange for a warm, fresh-smelling, and breathable atmosphere. However, these conditions of comfort varied from individual to individual. Reid knew this. In his experiments and preparations for the new Palace of Westminster, Reid attempted to account for wide variance of preferences of the many M.P.s by attempting to quantify a

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[465] Letter from W.G. Williamson to Managers and Trustees, Jan. 3, 1839, London Stock Exchange Managers & Trustees Minutes 1833-1842, Guildhall Library MS 19297/2.

[466] Minutes, Jan. 6, 1842, London Stock Exchange Managers & Trustees Minutes 1833-1842, Guildhall Library MS 19297/2; Dr. Reid's Report on Ventilating the Exchange, March 16, 1842, London Stock Exchange Managers & Trustees Minutes 1833-1842, Guildhall Library MS 19297/2.

precise temperature, moisture and chemical condition of the air that would provide the optimum amount of health and comfort for the majority of members. His failure would signify a definitive shift in the history of ventilation.

Quantifying Comfort

Reid's understanding of the relationship between respiration, ventilation and heat was thoroughly chemical. "Before the work of Priestley, Scheele, Lavoisier and Black," Reid declared, "the term Ventilation could have had no distinct and definite meaning."[467] While Thomas Tredgold and Neil Arnott had provided "ingenious suggestions" to place ventilation on a more "consistent" position, it remained to Reid to "determine by practical experiments made on living men, by means of apparatus and in rooms constructed specifically for this purpose, the precise amount of air required for health and comfort."[468]

The premise for Reid's experiment was to determine the temperature, moisture and pressure that would make the most healthful and comfortable atmosphere for most people. Reid's ambition was breathtaking: he hoped to remake the entire fields of architecture and urban planning to be focused on the efficient and healthful provision of heat and ventilation.[469] While "architectural art" provided a more "obvious attraction" than ventilation, such structures were only the "shell or body of that interior atmosphere"

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[467] Reid, *Illustrations*, viii-x.
[468] Elisha Harris, "Preface" in David Boswell Reid, *Ventilation in American Dwellings* (New York, NY: Wiley & Halsted, 1858) xix.
[469] Robert Bruegmann, "Central Heating and Forced Ventilation: Origins and Effects on Architectural Design," *Journal of the Society of Architectural Historians*, 37:3 (October 1978): 160.

through which "heat light and electricity convey their influence upon the human frame."[470]

The role of human beings within the "apparatus" could be calculated by adjusting the system to account for the combined needs of the bodies inside. While "natural ventilation" – the provision of fresh air provided by the movement of wind in a pure atmosphere, was adequate for "ordinary purposes," the growth of cities and the number of crowded public buildings necessitated by government and industry meant that this means was no longer adequate.[471] Following Lavoisier's measurement of respiration in terms of oxygen inhaled and heat and carbonic acid expelled, Reid recommended that air be considered "in the same light as food." Ventilation, Reid declared, should be the central concern when constructing new buildings. Adding ventilation to existing buildings was both expensive and frequently ineffective. Constructing a building without consideration for the precise supply of air required was frequently "an irreparable evil."[472]

In order to come up with these precise measurements, Reid relied both on previous studies of the amount of air required for respiration and a series of innovative experiments. Following the measurements of oxygen consumption by Lavoisier and Robert Menzies and contemporary chemists Charles Coathupe and Julius Liebig's measurement of the amount of carbonic acid discharged, Reid calculated that the mean amount of air inhaled was 320 cubic inches per minute, including 32 cubic inches of oxygen and resulting in the exhalation of 25 cubic inches of carbonic acid gas.[473] By

[470] Reid, *Illustrations*, 71.
[471] Reid, *Illustrations*, 92.
[472] Reid, *Illustrations*, 8.
[473] Reid, *Illustrations*, 17.

multiplying this basic measurement by the number of people contained within a space, Reid calculated the amount of air that would need to be provided. For a sizable building like the House of Commons, “natural ventilation” would never provide enough air flow, so Reid determined to install steam-powered fans with blades between ten and twenty feet in diameter that would slowly rotate to provide adequate airflow without creating uncomfortable drafts.[474] In order to facilitate the removal of this air, Reid again followed Lavoisier. A human body was like a candle – it both consumed oxygen, and produced heat. Therefore, the air that came in contact with the body “is usually elevated about five degrees in its temperature as it escapes above the head.” This is why Reid’s systems for public buildings insisted on air entering at the floor of a room – the heat and subsequent rising action created by the crowd of bodies pushed air upwards, where it could be whisked away by vents in the ceiling.[475]

To determine the precise amount of airflow necessary, Reid conducted several “extreme experiments.” Placing himself in an “oblong metallic box, not larger than was necessary to contain me in the horizontal position,” Reid had the door “carefully cemented and soldered, so that no air could either enter or escape.” The doctor found that he had “no difficulty in remaining from one to two hours” in this sealed coffin. Reid combined the results from these experiments with the data he had gathered from “numerous assemblies and meetings, where there were means for estimating the quantity of air with which they were provided.” These considerations revealed to Reid that supply of air was only a tiny part of the calculus of comfort. While 320 cubic inches of air was

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[474] Reid, *Illustrations*, 108.
[475] Reid, *Illustrations*, 95.

adequate for respiration, when it came to comfort "100 cubic feet of air on some occasions does not give so much relief as that of a few cubic feet in others."[476]

However, adequate airflow only solved part of the problem. While general *health* could be maintained through a mean calculation of oxygen/carbonic acid, the amount of air needed for *comfortable* respiration varied from individual to individual. The number of factors at play were enormous – "age, temperament, habit, health and strength, diet, previous exposure, mental anxiety, artificial illumination, the nature of the occupation, exercise, fatigue, clothing, draughts and currents" could all affect one's preferred temperature and oxygen requirements.[477] In order to determine a measure of air that would be more generally comfortable, Reid constructed a wooden booth not dissimilar to the Pneumatic booths that Humphry Davy had used for his famous nitrous oxide experiments. Selecting men of various ages, weights, and "constitutions," Reid had them sit within an air-tight chamber. Giving them a long glass tube, with which they could take full advantage of the air within the box, Reid would place various chemical substances on shelves in the box "either for the purpose of absorbing various ingredients from the air…or of communicating different materials to it." In order to find the precise nature of this phenomenon, Reid determined to continue his experiments until he had found a way to tune his system, like a "musical instrument," to meet the needs of the inhabitants.[478]

Reid's experiments were, as Edward Gillin has observed, a means of both testing his machinery and gaining credibility with the members of the house. A fascinating report in the *London Times* reveals how Reid attempted to convince skeptical elements in

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[476] Reid, *Illustrations*, 176, 179, xiii.
[477] Reid, *Illustrations*, 196-7.
[478] Reid, *Illustrations*, 176, 179, xiii.

parliament of the efficacy of his system. First, Reid asked that the house be filled. In order to accomplish this, off-duty army officers were called to fill the seats until the number amounted to four hundred and twelve. Reid then placed a glass model of the House of Commons on the central table and described the functioning of his system – how the ventilation shaft would draw foul air through the false ceiling which had recently been completed. To prove the efficacy of this, he then proceeded to pump smoke into the chamber until it was "so dense that it was impossible to see five yards forward." Then, instructing that the ventilator flues be opened, "in about one minute and a half…it was entirely expelled." This experiment was repeated with ether, "which was strongly perceptible to every person present," and then with the scent of oranges. The MPs and "several other gentlemen connected with literature and science" were deeply impressed by this display.

However, the *Times* correspondent struck a more skeptical tone. In order to evenly distribute the potentially annoying draughts of fresh air that would enter through the floor, Reid had drilled "the almost incredible number of 350,000" holed in the floor. These cone-shaped apertures were only a sixth of an inch wide at the top but opened downwards to prevent blockage. In addition, to provide the strong convection needed to clear the air of the house, "an exceedingly large coal fire" had to be maintained in the ventilator shaft, "a portion of which below the fire has a communication with the square shaft…in immediate contact with the house." While the attending MPs had been largely supportive, the reporter noted that the "discipline of the military audience" bore little resemblance to how an actual assembled parliament would behave – "a more orderly house we never saw."[479]

This nameless correspondent's observation of the potential downsides of Reid's system – too many ventilating apertures, a danger of fire, and the changeable demands of a privileged parliament – proved prophetic. Over the course of the next decade, as Reid labored to "tune" his system and to design an even more ambitious plan for the new Palace of Westminster, he was beset with a growing chorus of criticism and condemnation. But while fire danger proved a powerful argumentative tool for Reid's rival, Westminster architect Charles Barry – the most frequent basis of complaint was that Reid's system made MPs uncomfortable.

Reid's Failure and the Limits of Environmental Control

Having placed himself at the center of an apparatus that had promised a quantitatively-determined mean level of comfort to each MP, Reid soon became a lightning rod for every problem the House experienced. Almost immediately after Reid's system was put in place, MPs began complaining about the amount of dust raised by the constant flow of air from the floor. While Reid had covered the perforations with mats to dampen the draughts, the mats soon became dirty and would send up a cloud of dust to the "great annoyance" of the MPs.[480] Reid vigorously responded to this problem by entirely reversing the airflow of his system – instead of convection drawing the air upward, it would now be sucked *down* through the carpets to prevent dust from rising. Again, Reid demonstrated his system by filling the room with various pleasant odors and

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[479] A Correspondent, "Alterations in the House of Commons," *London Times*, Nov. 5 1836, issue 16253.
[480] Arnott, *On Warming and Ventilating*, 87.

having them whisked away in front of an audience of MPs, men of science and the press.[481]

Reid expressed frustration at the great difficulty in meeting the finicky demands of the members, whose feelings "fluctuate with every change of circumstance in the state of the internal or external atmosphere that is not immediately controlled." In recalling how his system had been received by the House when first put into action, Reid wrote that the first sideways remark addressed to him was "the temperature is rising, we shall be suffocated immediately." Soon after, another member complained "I am shivering with cold, I can bear this house no longer." Reid soon discovered that while some members asked for a temperature around 70 degrees Fahrenheit, others demanded it be kept closer to 50.[482] In addition, as work began on the new palace, demolition near the temporary commons opened drains and sewers which completely changed the condition of the outside air. Members immediately complained of the horrible smell entering through the ventilation system and blamed Reid for failing to improve the air at all. In 1846, as criticism of Reid was beginning to mount, radical M.P. Edward Protheroe stood before the house and declared that Reid had made the air "peculiarly agreeable to him" for, like those who will not "touch cheese that is not decayed," he did not relish air unless it had "a smack of the burial-grount on one side, and a strong, sewer-like flavor...on the other."[483]

Reid defended himself by publishing several lengthy publications explaining his systems and addressing specific criticisms – but also by adjusting his system to attempt to

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[481] Gillin, *Victorian Palace of Science*, 157.
[482] Reid, *Illustrations*, 294.
[483] Anon. "Dr. Reid," *London Times*, May 27 1846, Issue 19247.

meet his customers' demands. In order to prevent noxious odors from entering the house, Reid designed a filtration system that would force entering air first through a gauze filter, then through a series of water jets. By passing the air through water "charged with lime or other absorbents of offensive impurities" the air would be cleaned, cooled and moistened.[484] In an increasingly exasperated tone, Reid argued that most of the complaints of the house had to do with the "evils arising from the totally yaltered relations of the external atmosphere within the past two years" as the new Palace of Westminster was under construction. Despite "chemical preparations to the air to a very great extent," no system could make "every one equally comfortable under all conditions."[485]

By 1846, the ever-rising expense of Reid's system, the ongoing dissatisfaction of MPs and the behind-the-scenes antagonism of Charles Barry, who deeply resented Reid's insistence that the aesthetics of architecture be subjected to the requirements of ventilation, had spurred a firestorm of satire against Reid in the *Times* and *Punch*. Criticizing the "extraordinary freaks of Dr. Reid," a letter printed in the *Times* cited the cost of Reid's system and personal salary: "What can this sum of £34,722…have been expended for? Surely not for ventilating a room 38 feet wide by 76 long?"[486] A particular bone of contention was the ventilation system Reid had installed in the temporary House of Lords. In a strikingly impolitic letter to Viscount Charles Canning, Reid attempted to explain that the particular difficulties of ventilation for the chamber was largely due to

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[484] Reid, *Illustrations*, 287.
[485] David Boswell Reid, *Ventilation: A Reply to Misstatements made by "The Times" and "The Athenaeum" in reference to Ships and Buildings Ventilated by the Author* (London: :Madden and Malcolm, 1845) 12-13.
[486] Anti-Aeolus, "Reid Ventilation," *London Times*, April 25, 1846, issue 19220.

the demands of the peers themselves: "in no house are opposite demands so frequently made at the same moment as in the [current] House of Peers. This arises essentially from difference of dress, of time of life, of period of refreshment, and above all from the manner in which the house is subject to irruptions of air from the lobbies." In such conditions, Reid claimed, it was "impossible to work the ventilation in the same manner as at the House of Commons."[487]

In an attempt to address their growing rift and gain clarity on the issue, Barry was called to testify before Parliament in June. In his testimony, Barry complained that Reid had claimed enormous spaces for his ventilation system and that he had received none of the necessary drawings or instructions for the new House of Lords from Reid. Furthermore, he assured the Lords that he could have their chamber ready for use by the next year if given authority to do away with Reid and adapt his existing works to "my own system, if I may so call it."[488] For his part, Reid argued in a published pamphlet that the failures of his system were not his fault, but due to either improper installation, operator error, or a false understanding of the state of the exterior air and how it had to be adjusted for the interior.[489] As criticism of Reid mounted in the press, Lord Brougham and his allies continued to support Reid while remaining skeptical that Barry could accomplish his promises. To create a compromise between the doctor and the architect, Parliament elected to literally separate the two – a wall was constructed and Barry was given a chance to install his chosen system in the Lords while Reid was given complete command over his separate system in the Commons.[490]

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[487] Reid, "The Great Ventilator," *London Times*, June 13, 1846, Issue 19262.
[488] Anon. "Ventilation of the New Houses of Parliament," *London Times*, July 3 1846, issue 19279.
[489] Reid, *Ventilation*, 13.
[490] Gillin, 172, 180.

While the contest between Reid and Barry was ongoing, Reid pressed on. However, as complaints continued, Reid's tone began to grow more frustrated, "How many complaints arise from temporary or external causes which interfere with the proper working of the ventilation, and over which I have not control?" A "sudden fall of the barometer…causing a universal exhalation from the banks of the river, and those drains in the vicinity that are not ventilated – a particular inclination of the wind, driving the air from a manufactory conducting offensive operations during the night – have at times so largely affected the external atmosphere that even with the most extended arrangements, it is impracticable entirely to subdue their influence."[491]

While Reid's position in Westminster became more and more tenuous, he invested more time in the construction of the new St. George's Hall in Liverpool. This enormous neo-Grecian hall, designed to accommodate over 4,000 people, would be was part of a sizable project for a new city center that had been placed under the supervision of architect Harvey Lonsdale Elmes. Given a much freer hand than he had been at Westminster, Reid envisioned that this would be the site where his grand vision for ventilation might truly come to fruition. Publishing a projected view of the Hall and assizes complete with statues on plinths and an ornamented central ventilation tower as the frontispiece for his *Illustrations of the Theory and Practice of Ventilation,* Reid declared that "it will be obvious that few places would present a more fit opportunity for the ventilation of a whole district under the operation of some central power."[492]

In his *Illustrations of the Theory and Practice of Ventilation,* Reid envisioned how his system could be extended in order to deal with the chaos of the urban

[491] Reid, *Ventilation*, 13.
[492] Reid, *Illustrations*, 76.

atmosphere. First of all, a central ventilation shaft, much like that at the temporary House of Commons, could be constructed. Homes and public buildings could then be connected to it via a system that provided each with “an ingress and an egress for air, controlling valves, and such diffusion (of air) as the numbers likely to occupy each apartment might render necessary.” By thus placing the ventilation of entire “streets, squares, or districts” on a “systematic footing,” Reid envisioned that heating and ventilation would be more cost-efficient, the population more healthy and comfortable, and public lighting more brilliant in the absence of constant smoke. Finally, in regards to aesthetics, “thousants of towers, spires, pillars, and minarets &c. &c. would gradually replace the tens and hundreds of thousands of common chimneys that are at present seen on almost every dwelling” thus rendering these neighborhoods “highly ornamental.”[493]

As St. George’s Hall neared completion, Reid attempted one last gambit to improve comfort in the new Palace of Westminster. Responding to complaints that the temperature in the House was too high, Reid installed a new steam fan and installed a new system of lighting to both boost the air supply and reduce the temperature. However, it proved impossible to coordinate the power of the fan, the convection of these new lights, and the extraction power of the ventilation system. Reid had been unable to create a perfect feedback system with human comfort as one of the variables. In 1852, he was finally let go from his position.[494] Reid’s apparent failure in Parliament inspired him to follow Joseph Priestley’s path to the United States in 1855, where he held several

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[493] Reid, *Illustrations*, 76-77.
[494] Henrik Schoenefeldt, “The Lost (First) Chamber of the House of Commons,” *AA Files*, 72 (2016), 72.

academic and sanitation posts, and was appointed inspector of military hospitals, a position he held until his death in 1863.[495]

Reid's success in promoting himself as an expert in aerial chemistry backfired when he proved unable to find a mean calculation of comfort that was acceptable to all. His success in raising the public profile of mechanical heating and ventilation is undeniable – however his high-profile failure at Westminster put a final end to attempts to create an ideally-healthy and comfortable aerial environment. Heating and ventilation became a private matter where the ideal environment would be limited only by an individual's preference and the amount of money they were willing to spend to secure it.

Conclusion

Far from the eighteenth-century ventilating vision that centered around enabling the flow of "pure" atmospheric air, the first half of the nineteenth century saw a significant change in the conception of what constituted a desirable atmosphere. Besides being fresh, air had to be odor-free, temperate and humidity-controlled. While eighteenth century Londoners had pined for clean, "country air," freshness alone was not adequate for Victorian Britons. By 1872, the Register of Patents defined ventilation not only as the exchange of air, but as "the operation whereby the air, when unduly heated or cooled, is *renewed* with air of more suitable temperature." This operation "also necessarily comprises, in a subsidiary sense, treating or preparing the air – such as drying,

[495] Edward J. Gillin, "Reid, David Boswell (1805–1863), chemistry teacher and ventilation engineer," *Oxford Dictionary of National Biography.* 23 Sep. 2004; Accessed 27 Jun. 2020, https://www-oxforddnb-com.proxy.libraries.rutgers.edu/view/10.1093/ref:odnb/9780198614128.001.0001/odnb-9780198614128-e-23327.

moistening, heating, or purifying it."[496] Doing so required a substantial investment in complex machines and the fuel to operate them. The providentially fresh "atmospheric" air that had first been investigated by Stephen Hales had permanently receded to the countryside, and was not attainable to the poor until they managed to gain sufficient means to purchase ventilating stoves, chimney flues, gas lighting, and filtered ventilators.

This development was lamented by the elderly Charles James Richardson. Having trained under John Soane, an early advocate of mechanical ventilation, Richardson declared that for every class, the "chief point of attraction in the English dwellings, during winter's wet, cold, and fog, is centered in the fireplace." But the necessity of efficiently and safely warming spaces meant that this traditional comfort was passing away, as "not one of these stoves, nor those that are called "smoke-consuming stoves," make a good companionable fire." In addition, the huge amount of smoke produced by coal fires and the chronic problems with urban sewage meant that more and more ingenious means were needed to prevent fumes and smoke from entering apartments, resulting in "numerous unsightly appendages in the forms of cowls, turncaps, and windguards which appear alike on our houses, churches and palaces."[497]

However, while the constant smoke and the clunky machines obscured the "picturesque" architecture, the sixty-five year old Richardson was confident that a new generation of engineers would find a brilliant technological solution. Perhaps some system would be invented that could use the neutralizing property of the smoke to cleanse and sanitize the gas of the sewers? Or, perhaps a system of flues could be constructed

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[496] Commissioners of Patents, *Abridgements of Specifications relating to Ventilation, 1632-1866* (London: George E. Eyre and William Spottiswoode, 1872) iv.
[497] C.J. Richardson, *The Englishman's Home from a Cottage to a Mansion* (London: John Camden Hotten, 1871) 404-406.

throughout all towns to "carry off all the smoke and other atmospheric impurities" to "tall shafts or chimneys" where, with the assistance of furnaces, it would "burn spontaneously in a similar manner to the combustion of foul air from old shafts connected with coal mines." But while Richardson was optimistic that such schemes would soon "permit the full and cheering light of the sun to shine alike in country and town," he recognized that "The public have so long been accustomed to be choked with smoke, and their health affected by deleterious gases, that they look upon the proposal of any scheme to secure pure air as the hallucinations of dreamy philosophers or inexperienced utopians."[498]

As the chemical relationship between heat and the respirability of air became clearer in the late eighteenth century, and pneumatic chemists found that certain chemically-treated airs were *eminently* respirable, a new commercial market emerged for comfortable, heated and air-purified environments. Couched in the new chemical language of Lavoisier and promoted by shrewd salesmen like the Marquis de Chabannes, machines that purported to provide such an environment were deeply appealing to an English middle- and upper-class that was fearful of the dangers and inconvenience of the public urban environment and was eager to purchase a means of insuring domestic health and warmth – environmental comfort. David Boswell Reid's spectacular success at constructing a controlled environment and his spectacular failure at meeting the multifarious demands of Westminster MPs meant that climate control moved firmly from the hands of chemists and public health advocates and into the private and commercial realm of the market.

[498] Richardson, *The Englishman's Home*, 429-431, 444.

Images:

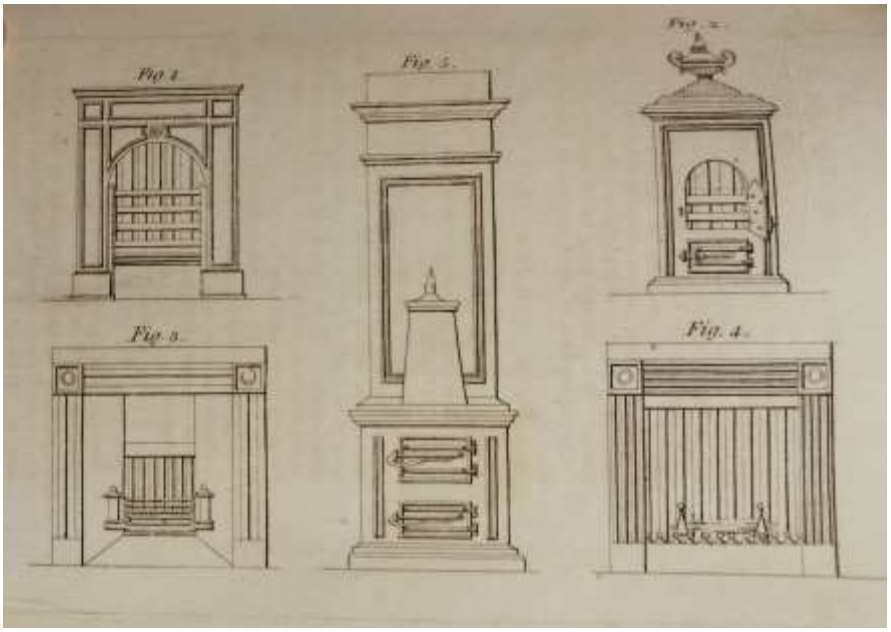
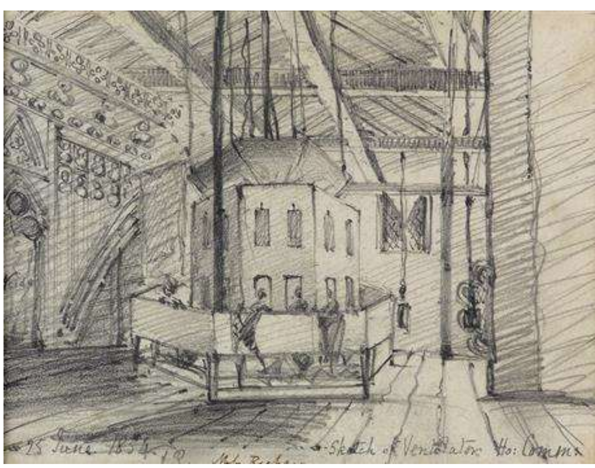
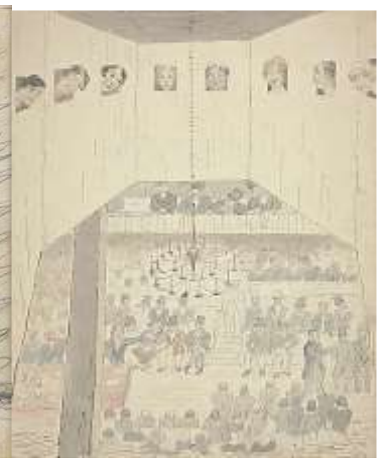
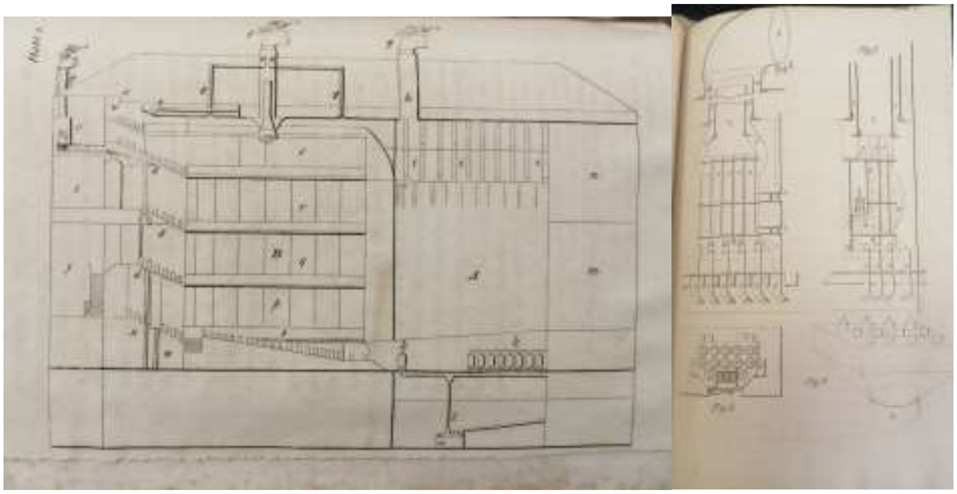


Figure 1: Calorifere Fumivores. Chabannes' stove design was sold in various models for various sizes of rooms and aesthetic preferences. Note the vertical ventilating pipes surrounding the fire. (Marquis de Chabannes, *On Conducting Air by Forced Ventilation* (1818): Plate VII.

Figures 2 and 3: House of Commons Ventilator and Ladies' Gallery, circa 1834. The chandelier in figure 3 was intended to draw air upwards into the ventilation slots, which also served as the viewing ports of the Ladies' Gallery, the only place from which women were allowed to hear debates. (Figure 2: Frances Rickman, "Sketch of a ventilator in the Ladies Gallery Attic in St. Stephens, 1834 [Parliamentary Art Collection, WOA 26]; Figure 3: Pencil and watercolour drawing by Lady Georgiana Chatterton, c. 1821 [Shakespeare Birthplace Collection, DR 7594/4]



Figures 4 and 5: The Marquis de Chabannes' plan for ventilating Covent Garden [left] and the large Calorifere Fumivore designed for the theater [right]. Note the furnace (l) and the ventilating chandelier and cowl, complete with trumpeting angels (above s) (Marquis de Chabannes, *On Conducting Air by Forced Ventilation* (1818): Plates I and III.

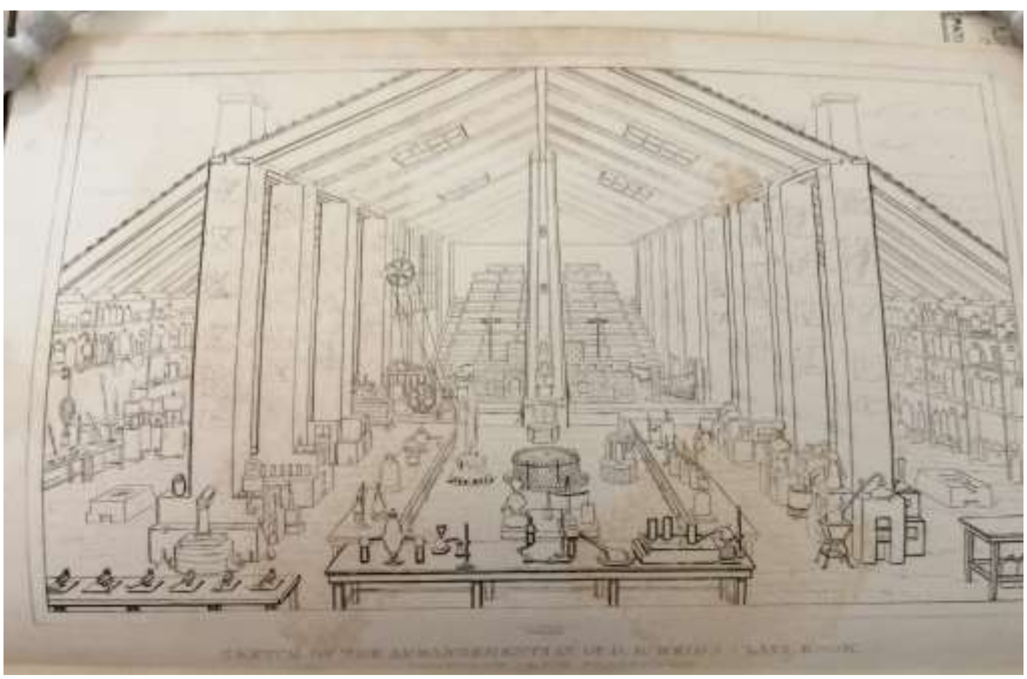


Figure 6: David Boswell Reid's Edinburgh classroom. Note the six chimneys, each with a furnace for experiments and the set of furnaces at the back in front of the lecture hall. (D.B. Reid, *Text-Book for Students of Chemistry* 3rd ed. (Edinburgh: Maclachlan, Stewart and Co. 1839): frontispiece.

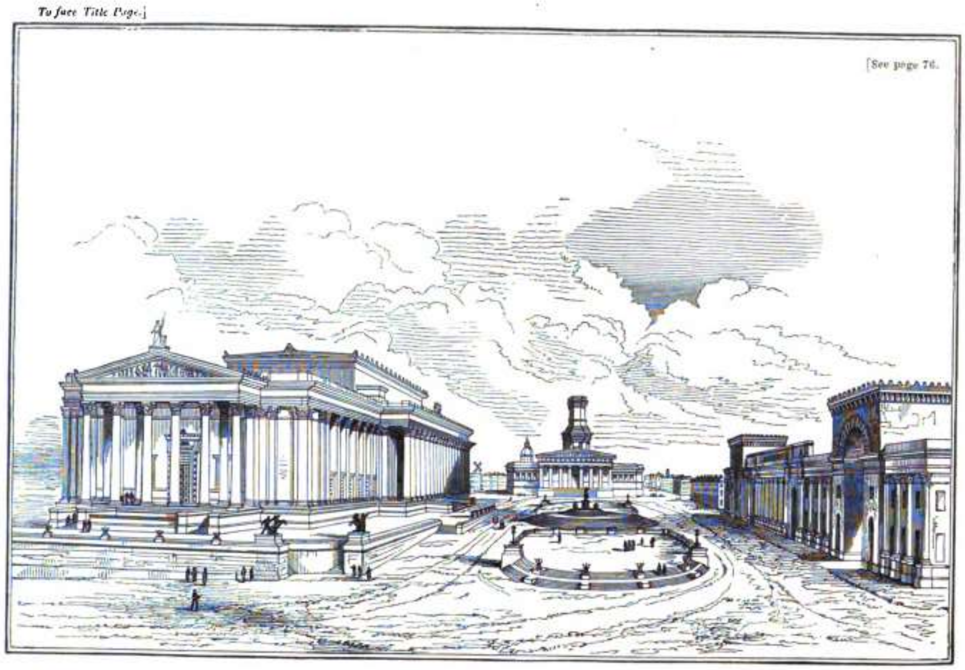


Figure 6: David Boswell Reid's ideal plan of the new Liverpool city center. *Left:* St. George's Hall *Center*: Reid's proposed central ventilating chimney. (David Boswell Reid, *Illustrations of the Theory and Practice of Ventilation* (London: Longman, Brown, Green, & Longmans, 1844): frontispiece.

Figure 7: At the height of Reid and Barry's public controversy over the ventilation of the new Palace of Westminster, *Punch* published several cartoons lampooning Reid's system. The above lampoons Reid's claim that he could furnish the MPs with their preferred "draughts of different kinds of atmosphere." (Anonymous, "Reid's Air Brewery," *Punch* vol. 10 (1846): 168.

Conclusion
Insulating the Empire

In July of 1844, another ventilation horror story appeared. Emerging from the pen of Edgar Allan Poe, the central character in this story was neither a sailor, nor a prisoner nor a doctor stationed at the far reaches of the British Empire, but an unnamed, well-to-do American. This man was confidently unafraid of the horrors of the Black Hole of Calcutta, and even felt a sort of "pleasurable pain" while reading about the "stifling of the hundred and twenty-three prisoners." Death from overcrowding was far from his thoughts, for he knew that the most "ghastly extremes of agony are endured by man the unit, and never by man the mass." However, what did fill this man with an "appalling and intolerable horror" was the fear of suffocating *alone*. Like many of his Victorian contemporaries, he was utterly terrified of being buried alive.

Premature burial meant suffocating in a "narrow house," tormented by an "unendurable oppression of the lungs" and "the stifling fumes from the damp earth." Beset by a "perpetual horror" at this, Poe's narrator found himself unable to "ride, or to walk, or to indulge in any exercise that would carry me from home." Fearing that they would not check his medical condition thoroughly enough to be sure that he was truly dead, the man began to doubt "the care, the fidelity of my dearest friends."

Like many of his eighteenth-century predecessors, Poe's narrator turned to machines as a means of quelling these fears. Remodeling his family tomb for the "free admission of air and light," the man made sure that his coffin was "warmly and softly padded" and fitted the vault door with a system of springs so that it could be opened by the "feeblest movement of the body." Already insulated from overcrowding and contagion by his privileged position in society, the narrator hoped that this comfortable and ventilated tomb could free him from the anxieties of suffocation and early death.[499]

While it does not deal with the topic directly, this story reveals much about the changing emotional and social rationale for ventilation machines. The fear of live burial, dubbed "taphephobia" or "fear of the grave," was a widespread phenomenon in nineteenth century Britain, Germany and the United States.[500] While eighteenth century Britons had feared becoming "so many miserable animals in an exhausted receiver," Victorian terror fixated on the idea of being entrapped in an unventilated "narrow house," isolated and overcome with an all-consuming sensation of suffocation and abandonment.[501] But rather than opening and "freshening" enclosed spaces through the copious admission of providentially-balanced air, Victorian Britons strove to insure that their private spaces were warm, comfortable, and well-supplied with "renewed" air.[502] By the mid nineteenth century, the consensus opinion was that the maintenance of health and comfort in an urban setting required complex and expensive machines for ventilation and heating.[503]

But this desire was undermined by a sense of something missing. In imagining his premature burial, the unnamed narrator was tormented most by darkness, isolation and

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[499] Edgar Allan Poe, "The Premature Burial" *Dollar Newspaper* (Philadelphia, PA), vol. II, no. 28, July 31, 1844.

[500] Andrew Mangham, "Buried Alive: The Gothic Awakening of Taphephobia," *Journal of Literature and Science* 3:1 (2010): 10-22.

[501] On safety coffins and other devices to prevent premature burial, see: Jan Bondeson, *Buried Alive: the Terrifying History of our most Primal Fear* (New York: Norton, 2001): 110-136: and H. Dittrich, "Devices to Prevent Premature Burial," *Journal of the History of Medicine and Allied Sciences*, 3:1 (December, 1948): 161-171

[502] John Zephaniah Holwell, *A Genuine Narrative of the Deplorable Deaths of the English Gentlemen, and Others, who were Suffocated in the black Hole in Fort William, at Calcutta*," (London: A. Millar, 1758) 11-12, 15; Commissioners of Patents, *Abridgements of Specifications relating to Ventilation, 1632-1866* (London: George E. Eyre and William Spottiswoode, 1872) iv.

[503] Robert Bruegmann, "Ventral Heating and Forced Ventilation: Origins and Effects on Architectural Designs," *Journal of the Society of Architectural Historians*, 37:3 (Oct. 1978) 153.

"thoughts of the air and grass above."[504] The idea that airy, open, bucolic spaces were the most healthful was still very current. As late as 1859, Florence Nightingale would write that the "the very first canon of nursing" was to "KEEP THE AIR HE BREATHES AS PURE AS THE EXTERNAL AIR," and primly argued that "if a Hospital must be ventilated artificially, it betrays a defect of original construction which no artificial ventilation can compensate." While Nightingale's belief that "Heated air" produced "disease of the lungs" was shared by few of her contemporaries, her sentiment that "our grandfathers' lofty fire-places are the greatest loss in modern house architecture" had wider purchase.[505] The fantasy of an idealized, airy countryside with a roaring fireplace continued to inform the design construction of heating and ventilation systems, which sought to replicate as closely as possible these "chief point(s) of attraction in English dwellings."[506]

This sense of nostalgia highlights the fact that the adoption of mechanical ventilation was not a development that happened quickly, or that coincided neatly with the turn towards political, social or technological "modernity." Rather, it was a gradual development motivated by shifting political priorities and social anxieties, conducted via trial and error in some of the most high-profile institutions of the nascent British Empire. From the beginnings of the Royal Society, the circle of natural philosophers around Robert Boyle had identified air as a potent fundamental substance that might hold the key to, as polymath and proto-improver Samuel Hartlib memorably put it, opening the

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504 Edgar Allan Poe, "The Premature Burial" *Dollar Newspaper* (Philadelphia, PA), vol. II, no. 28, July 31, 1844.
505 Florence Nightingale, *Notes on Nursing* (London: Harrison, 1859) 8. Emphasis in original; Florence Nightingale, *Notes on matters affecting the health, efficiency, and hospital administration of the British Army* (London: Harrison and Sons, 1858) 489-90
506 C.J. Richardson, *The Englishman's Home from a Cottage to a Mansion* (London: John Camden Hotten, 1871) 404

"conduit pipes of natural knowledge."[507] Through the use of Boyle and Hooke's air pump, they re-interpreted the air and respiration in mechanical terms, and created the conditions in which an air machine could be viewed as an effective prophylactic for the dangers of crowded, foul-smelling and disease-prone spaces. But the evident failure of these machines to preserve health and sanitize the holds of ships was coupled with an emerging sense that some spaces – notably slave ships and tropical environments – were fundamentally unhealthy and irredeemable.

This growing fear of hot, humid, overcrowded environments was transposed onto ill-kept and fever-ridden British prisons, spurring a large-scale effort at reform that also turned to mechanical ventilation as a means of excluding contagion and promoting cleanliness and virtue. But the inability of John Howard to trace the geographic source of contagion and the unwillingness of prisoners to submit to this disciplinary regime led powered the public perception that there was a clear link between hygiene and personal virtue. By the early nineteenth century, Joseph Priestley and Antoine Lavoisier's new pneumatic chemistry had transformed the conception of air from a providentially-regulated chaos into a mixture of health-giving "celestial" substances that could be purified and made eminently breathable through the introduction of heat. But as philanthropic efforts to "sanitize" the slums relegated the cost of fuel and air-stoves to the forces of the market, ventilation became a matter of private rather than public responsibility. Advocates for public health and private entrepreneurs alike realized that a sweet-smelling, comfortable and well-heated space was the central priority of their largely upper-middle-class audience.

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[507] Samuel Hartlib, "To His Excellency Oliver Cromwell [dedication]" in Gerard Boate, *Ireland's Naturall History* (London: John Wright, 1652) A4.

Thus, while initially conceived as a means of extending a providential and naturally benevolent natural air into artificially-enclosed spaces, ventilation became an infrastructure – a system devised, in the words of Paul Edwards, to reproduce "those properties of the natural environment that we find most useful and comfortable" and "eliminate features we find dangerous, uncomfortable, or merely inconvenient."[508] The irony of this development is that many of the dangerous fumes that ventilators were originally designed to exclude were *not* natural, but rather the "effluvia" generated by an imperial political economy that depended on ships, prisons and the labor of a concentrated, impoverished urban workforce. This is the fundamental paradox of ventilation machines: they were devices designed and employed to correct the aerial conditions arising from concurrent and frequently-related efforts of improvement and social reform.

In this view, ventilators are just one example of an early modern technology that could be interpreted as "environmental machines." Richard Drayton, Fredrik Albritton Jonsson and Anya Zilberstein have persuasively argued that early modern "improvers" had a strong consciousness of the link between the political economy of empire and the natural environment.[509] I argue that the knowledge of the coextension of nature and culture was not simply jettisoned at inception of the modern era. Rather, following theorist Bruno Latour, I propose that a contingent set of developments in the sciences and society created the circumstances in which nature became understood as inert and

[508] Paul N. Edwards, "Infrastructure and Modernity: Force, Time, and Social Organization in the History of Sociotechnical Systems," in Thomas J. Misa, Philip Brey and Andrew Feenberg, eds. *Modernity and Technology* (Cambridge, MA: MIT Press, 2003): 185-225.

[509] Richard Drayton, *Nature's Government* (New Haven, CT: Yale UP, 2000); Frederik Albritton Jonsson, *Enlightenment's Frontier* (New Haven, CT: Yale UP, 2013); Anya Zilberstein, *A Temperate Empire: Making Climate Change in Early America* (Oxford: Oxford UP, 2016); Margaret Schabas, *The Natural Origins of Economics* (Chicago: University of Chicago Press, 2006).

manipulable and technology was part of a "transcendent" culture no longer dependent on its whims. This dynamic has been brilliantly illustrated in Sara Pritchard's recent study of the Fukushima disaster, which has highlighted how the failure of nuclear engineers to account for natural forces led to an "envirotechnical" disaster.[510] As the development of ventilators shows, eighteenth and nineteenth century improvers and engineers were well aware of the environmental costs associated with the slave system, the penal system, and the military, but believed they would be outweighed or evaded through the strategic employment of "environmental machines."[511] Further studies of such technologies, for example "smokeless" stoves and furnaces, sewer systems, gas lighting and many others, could flesh out our understanding of how political economy vied with evolving conceptions of the environment to inform technological development.

As a final note, I will suggest that many of today's "green technologies" are subject to the same political forces. Controversies over the development and use of wind and solar power frequently revolve around how these machines will affect employment, where devices will be manufactured and who will cover the associated increases in energy costs.[512] Western governments frequently tout their "green" credentials by incentivizing energy efficiency, windmill farms and eco-friendly farming practices while maintaining ties to fossil fuel conglomerates and conducting large-scale traffic in

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[510] Bruno Latour, *We Have Never Been Modern*, trans. Catherine Porter (Cambridge, MA: Harvard UP, 1993) 28-34; Sara B. Pritchard, "An Envirotechnical Disaster: Nature, Technology, and Politics at Fukushima," *Environmental History* 17 (April 2012): 219-243.

[511] The claim that machines were understood as prophylactics elaborates on William Cavert's argument that eighteenth-century people accepted the cost of smoke and effluvia as a feature of economic growth; William M. Cavert, *The Smoke of London: Energy and Environment in the Early Modern City* (Cambridge: Cambridge UP, 2016) 139-142.

[512] See, for example: Rasi Kunapatarawong and Ester Martínez-Ros, "Towards Green Growth: How does green innovation affect employment?" *Research Policy* 45:6 (July 2016): 1218-1232; Finn Arne Jørgenson, *Making a Green Machine* (New Brunswick, NJ: Rutgers UP, 2011) 4.

weapons and petrochemicals.[513] In the private sector, electric cars and home solar panels frequently serve as signs of socio-economic status as well as ecological consciousness.[514] This has resulted in the construction of what environmental historian Michael Bess dubs a "light-green society." The "accelerating interpenetration" between nature and culture has forced certain concessions from governments, businesses and individuals, but efforts to contend with climate change and ecological imbalance have mostly run "shallow and wide."[515]

But there is much hope to be gleaned from this story as well. The deep and ongoing intersection of social and environmental concerns means that both can and must be addressed together. The blinkered approach of Stephen Hales, who sought to ventilate the holds of slave ships with little thought to the millions suffering from enslavement can be countered with the inspirational examples of Thomas Clarkson, who argued tirelessly that the slave system was both morally unacceptable and ecologically senseless, or John Howard who placed his life at risk in an effort to stop contagion in prisons. Flawed as their conceptions of social and environmental justice were, the energy and activism of these men is worthy of emulation.

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[513] While American policy has recently shed even a pretense of attention to environmental concerns, the European Union provides a good example of this policy dissonance. See the EU's statement on environmental policy: Anon. "Towards a Greener and More Sustainable Europe," Europa.eu, European Union, accessed June 23, 2020, https://europa.eu/european-union/topics/environment_en; See also economic data provided by the European Chemical Industry Council: Anon. "Petrochemicals Industry: Largest Investor in EU Chemical Sector in 2018," petrochemistry.eu, Petrochemicals Europe [European Chemical Industry Council], accessed June 23, 2020, https://www.petrochemistry.eu/mediaroom/petrochemicals-industry-largest-investor-in-eu-chemical-sector-in-2018/; on the lack of effective regulation in foreign arms sales, see: Susanne Therese Hansen and Nicholas Marsh, "Normative Power and Organized Hypocrisy: European Union Member States' Arms Export to Libya," *European Security* 24:2 (2015) 264-286.

[514] Paul A. Eisenstein, "Tesla electric car becoming a must-buy for the wealthy," nbcnews.com, NBC, Nov. 4, 2013, https://www.nbcnews.com/businessmain/tesla-electric-car-becoming-must-buy-wealthy-8C11522443 (accessed June 23, 2020).

[515] Michael Bess, *The Light-Green Society* (Chicago: University of Chicago Press, 2003) 4, 162.

On that note, we return to Edgar Allan Poe's wealthy American taphephobe. Awakening from a deep sleep one night, he discovered that his fear had coalesced into reality. Finding himself enclosed in complete darkness, he desperately attempted to cry out but found that "no voice issued from the cavernous lungs," which felt as if "oppressed…by the weight of some incumbent mountain." Feeling around desperately, he realized with increasing panic that none of his mechanical safeguards were accessible. Instead, he perceived only an immovable wooden board six inches from his face. In desperation, he let loose a "long, wild and continuous shriek."

Immediately a "gruff voice" replied: "Get out o' that! What do you mean by yowling in that ere kind of style like a cattymount?"[516] Gradually, the narrator realized that he had been asleep in the berth of a vessel he hired for a pleasure cruise. In contemplating this incident, he realized that his fear of the grave was deeply disproportionate, and had kept him from living a full and happy life. Finally freed of these imaginary horrors, his "soul acquired tone — acquired temper. I went abroad. I took vigorous exercise. I breathed the free air of Heaven."[517]

Breathing free air is a necessity for all human beings. By understanding and appreciating the political choices and environmental costs that have been designed into our technologies, I believe that we can contribute to building a just and humane society where all can breathe freely.

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[516] "Cattymount" is a dialectic spelling of "catamount," or "cat of the mountain," i.e. a mountain lion or panther: "catamount, n.". OED Online. June 2020. Oxford University Press. https://www-oed-com.proxy.libraries.rutgers.edu/view/Entry/28732?redirectedFrom=catamount (accessed June 23, 2020).

[517] Edgar Allan Poe, "The Premature Burial" *Dollar Newspaper* (Philadelphia, PA), vol. II, no. 28, July 31, 1844.

Bibliography

References

House of Commons Sessional Papers (HCSP)

Oxford English Dictionary (OED)

Oxford Dictionary of National Biography (DNB)

Periodicals

All accessed via HathiTrust or the Burney Collection 17th and 18th Century Newspapers.

Diary or Woodfall's Register

The Gentleman’s Magazine

London Times

London magazine, or, Gentleman's monthly intelligencer

Morning Post

Morning Post and Gazetteer

The Scots Magazine

Universal Magazine of Knowledge & Pleasure

Manuscript Sources

For the sake of brevity I list only sources cited rather than all sources consulted.

Greenwich, U.K. National Maritime Museum

ADM 354: Boards of Admiralty, In-Letters from the Navy Board

Kew, U.K. The National Archives

ADM 106: Navy Board Misc. Correspondence

ADM 51: Admiralty: Captain’s Logs

London, U.K. British Library

Add. MS 38351: Levant Company Memorials to William Pitt

Egerton MS 3802: Reports on the State of His Majesty’s Gaol of Newgate

London, U.K. Guildhall Library

MS 19297: London Stock Exchange Managers & Trustees Minutes 1833-1842.

London, U.K. John Soane Museum

Priv. Corr. XI, D no. 38: Letters to/from the Marquis de Chabannes

London, U.K. London Metropolitan Archive

A/FH: Records of the Foundling Hospital

CLA: Records of the Newgate Gaol Committee

COL/CC/NGC: Committee to Inquire into the State of Newgate Gaol

COL/PL: Plans, maps and diagrams of streets and properties in the City of London

London, U.K. Royal College of Physicians Archives

RCP MS111/6: Letters from Stephen Hales to Thomas Yeoman

London, U.K. Royal Society of Arts Archives

RSA/AD/MA: Committee Minutes 1775-1792.

London, U.K. Science Museum

PATENTS: Letters patent and specifications of letters patent (U.K.)

Norwich, U.K. Norfolk Record Office

NRA 27665: Letters from Stephen Hales to Henry Lee Warner

Oxford, U.K. University of Oxford, Bodleian Library

MS. Eng. Misc. 401: John Howard Notebooks

MS. Eng. Misc. 332: John Howard Papers

Published Primary Sources

Agricola, Georgius. *De Re Metallica*. Translated by Herbert Clark and Lou Henry Hoover. New York: Dover, 1950.

Aikin, John. *A View of the Character and Public Services of the Late John Howard, esq.* London: J. Johnson, 1792.

Anon. *Hell upon Earth: Or the…History of Whittington's Colledge otherwise (vulgarly) called Newgate*. London: N.P. 1703.

Anon. *The Nature of Quarantine as it is Performed in Italy*. London: J. Williams, 1767.

Anon. "On the Ventilation of Covent Garden Theatre," *The Journal of Science and the Arts* .London: John Murray, 1818.

Anon. *Regulations and Instructions relating to His Majesty's Service at Sea*, 9th edition. London, 1757.

Anson, George. *A Voyage Round the World, in the year MDCCXL, I, II, III, IV*. Fifth edition. London: John and Paul Knapton, 1749.

Arbuthnot, John. *An Essay Concerning the Effects of Air on Human Bodies*. London: J. Tonson, 1733.

Arnott, Neil. *On Warming and Ventilating*. London: Longman, 1838.

Beccaria, Cesare. *An Essay on Crimes and Punishments*, Anonymous translation. Dublin: John Exshaw, 1767.

Beddoes, Thomas. *A Letter to Erasmus Darwin on a New Method of Treating Pulmonary Consumption*. Bristol: Bulgin and Rosser, 1773.

Bernan, Walter. *On the History and Art of Warming and Ventilating Rooms and Buildings.* London: George Bell, 1845.

Birch, Thomas. *A History of the Royal Society of London for Improving Natural Knowledge*. London: A. Millar, 1756.

Blagden, Charles. "Experiments and Observations in an heated Room" *Philosophical Transactions* 65 (1775): 111-123.

—— "Further Experiments and Observations in an Heated Room," *Philosophical Transactions* 65 (1775): 484-494.

Blane, Gilbert. *A Short Account of the Most Effectual Means of Preserving the Health of Seamen* .London: N.P. 1780.

—— *Observations on the Diseases of Seamen*. London, 1799.

Boate, Gerard. *Ireland's Naturall History*. London: John Wright, 1652.

Boerhaave, Herman. *A New Method of Chemistry*. Translated by Peter Shaw and Ephraim Chambers. London: J. Osborn, 1727.

Boyle, Robert. "New Pneumatical Experiments about Respiration." *Philosophical Transactions* 5:62 (1670): 2011-2031.

—— *New Experiments touching the Relation betwixt Flame and Air*. London: Richard Davis, 1673.

—— *New Experiments Physico-Mechanical, Touching the Air.* Third edition. London: Miles Flesher 1682.

Burdett, Francis. *Cold Bath Fields Prison, by some called The English Bastile! The Speech of Sir Francis Burdett in the House of Commons*. London: N.P. 1799.

—— *An Impartial Statement of the Inhuman Cruelties Discovered!* London: J.S. Jordan, 1800.

Burke, Edmund. *A Letter from the Right Honourable Edmund Burke to a Noble Lord*. London: J. Owen 1796.

Candler, Allen D. Editor. *The Colonial Records of the State of Georgia*. Atlanta, GA: Franklin Printing and Publishing, 1905.

Chabannes, Jean-Frédéric. *Prospectus d'un projet pour la construction de Nouvelles maisons, dont tous les calculs de details procureront une trés-grande économie.* Paris, Lenormand, 1803.

—— *Explanation of a New Method for Warming and Ventilating Homes*. London: Schulze and Dean, 1815.

—— *An Account of a Forced Ventilation Produced in the Metropolitan Bazaar*. London: Schulze and Dean, 1817.

—— *On Conducting Air by Forced Ventilation* .London: N.P. 1818.

—— *Appendix to the Marquis de Chabannes' Publication on Conducting Air by Forced Ventilation*. London: Spragg, 1818.

Chadwick, Edwin. *Report on the Sanitary Conditions of the Labouring Population of Great Britain*. London: 1842.

Clarkson, Thomas. *Essay on the Impolicy of the Slave Trade*. London: J. Philips, 1788.

—— *The History of the Rise, Progress, and Accomplishment of the Abolition of the African Slave-Trade* Volume 1. London: Longman, 1808.

Commissioners of Patents. *Abridgements of Specifications relating to Ventilation, 1632-1866* .London: George E. Eyre and William Spottiswoode, 1872.

Cubitt, William. *Description of the Tread Mill*. London: T. Bentley, 1822.

Defoe, Daniel. *A Plan of the English Commerce*. London: Charles Rivington 1728.

Desaguliers, John Theophilus. "An Account of a Book entitul'd Vegetable Staticks." *Philosophical Transactions* 34 (1727): 264-291.

—— "The Conclusion of Dr. Desaguliers' Account of Mr. Hales' Vegetable Staticks," *Philosophical Transactions* 35 (1727-8): 323-331.

—— "An Attempt made before the Royal Society to shew how Damps, or foul Air, may be drawn out of any Sort of Mines, &c." *Philosophical Transactions* 35 (1727-8): 353-356.

—— "An Account of an Instrument or Machine for Changing the Air of the Room of Sick People…" *Philosophical Transactions* 39 (1735): 41-43.

—— "The Uses of the Foregoing Machine, communicated in a letter to Cromwell Mortimer." *Philosophical Transactions* 39 (1735): 47-49.

—— *A Course of Experimental Philosophy 2nd edition.* London: W. Innys, 1744.

Descartes, René. *Discourse on Method and the Meditations*. Translated by F.E. Sutcliffe .New York, NY: Penguin Books, 1968 [1637].

Digby, Kenelm. *Discourse Concerning the Vegetation of Plants*. London: John Dakins, 1661.

Ellis, Henry. "A Letter to the Rev. Dr. Hales from Captain Henry Ellis." *Philosophical transactions* 47: (1752): 211-216.

Equiano, Olaudah. *The Interesting Narrative of the Life of Olaudah Equiano*. Second edition. .London: 1794.

Evelyn, John. *Fumifugium*. London: W. Godbid, 1661.

Falconbridge, Alexander. *An Account of the Slave Trade on the Coast of Africa*. London: J. Phillips, 1788.

Fry, Elizabeth Gurney. *Memoirs of the Life of Elizabeth Fry with Extracts from her Journal and Letters*, 2nd edition. London: John Hatchard and Son, 1848.

Fry, Katharine and Rachel Elizabeth Cresswell, editors. *Memoirs of the Life of Elizabeth Fry*, 2nd. Edition. .London: John Hatchard and Son, 1848.

Gauger, Nicolas. *Fires Improv'd: Being a New Method of Building Chimneys so as to prevent their Smoaking*. Translated by J.T. Desaguliers. London: J. Senex, 1715.

Hales, Stephen. *Vegetable Staticks*. London: W. and J. Innys, 1727.

—— *A Friendly Admonition to the Drinkers of Brandy and other Spiritous Liquors*. London: Joseph Downing, 1733.

—— *A Sermon for establishing the Colony of Georgia in America* .London: T. Woodward, 1734.

—— *Philosophical Experiments Containing Useful and Necessary Instructions for such as undertake long Voyages at Sea* .London: W. Innys and R. Manby, 1739.

—— *Haemastaticks*. Second edition. London: W. Innys, 1740.

—— *The Wisdom and Goodness of God in the formation of Man* .London: R. Manby, 1751.

—— "An Account of the Great Benefits of Ventilators…in preserving the health and lives of people in slave and other transport ships." *Philosophical Transactions* 49 (1755): 332-339.

—— *An Account of a Useful Discovery to Distill Double the Usual Quantity of Sea-Water*. London: Richard Manby. 1756.

—— *Treatise on Ventilators*. London: R. Manby, 1758.

Hales, Stephen and J.T. Desaguliers. "An Account of a Machine for Measuring any Depth of the Sea," *Philosophical Transactions* 34 (1727-8): 559-562.

Hanway, Jonas. *Solitude in Imprisonment*. London, J. Brew, 1776.

Heberden, Ernest. Editor. "Correspondence of William Heberden, F.R.S. with the Reverend Stephen Hales and Sir Charles Blagden." *Notes and Records of the Royal Society* 39:2 (Apr. 1985): 179-189.

Henshaw, Nathaniel. *Aero-Chalinos: or, a Register for the Air*. Dublin: Samuel Dancer, 1664.

Hippocrates. *Of the Epidemics*. trans. Francis Adams. London: Sydenham Society, 1849; Internet Classics Archive, n.d. Book 1, http://classics.mit.edu/Hippocrates/epidemics.1.i.html.

Holwell, John Zephaniah. *A Genuine Narrative of the Deplorable Deaths of the English Gentlemen, and Others, who were Suffocated in the black Hole in Fort William, at Calcutta*. London: A. Millar, 1758.

Hooke, Robert. *Micrographia*. London: John Martyn, 1665.

—— "An Account of an Experiment made by M. Hook, of Preserving Animals alive by Blowing through their Lungs with Bellows." *Philosophical Transactions* 2:28 (1667): 53-55.

Howard, John. *The State of the Prisons in England and Wales*. Warrington: T. Cadell, 1777.

—— *Account of the Principal Lazarettos in Europe* 1st edition. Warrington: T. Cadell, J. Johnson, C. Dilly and J. Taylor: 1789.

—— *State of the Prisons*, 4th edition. London: J. Johnson, C. Dilly, and T. Cadell: 1792.

Inman, W.S. *Report of the Committee of the House of Commons on Ventilating, Warming and Transmission of Sound*. London: John Weale, 1836.

Ingenhousz, Jan. *Experiments upon Vegetables*. London: P. Elmsly, 1779.

Janssen, Stephen Theodore. *Letter to the…Lord Mayor…and the..committee…for the Rebuilding of the Jail of Newgate*. London: 1767.

Keill, James. *An Account of Animal Secretion* .London: George Strahan, 1708.

—— *Essays on the Several Parts of the Animal Oeconomy*. Second edition. London: George Strahan, 1717.

Keill, James and Sanctorius. *Medecina Statica.* Secoond edition. Translated by John Quincy. London: W and J. Newton, 1720.

Lind, James. *Essay on the Health of Seamen*, 2nd edition. London: D. Wilson, 1762.

—— *Essay on the most effectual means of preserving the Health of Seamen*. Second edition. London: J. Murray, 1778.

Mayhew, Henry and John Binny. *The Criminal Prisons of London and Scenes of Prison Life*. London: Griffin, Bohn and Co. 1862.

Mayow, John. *Medico-Physical Works, Being a Translation of Tractatus Quinque Medico Physici*. Edinburgh: The Alembic Club, 1907.

Mead, Richard. *Discourse Concerning Pestilential Contagion*. London: Sam Buckley, 1720.

—— "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 (1741): 42-45.

—— *The Medical Works of Richard Mead*. London: C. Hitch, 1762.

Mun, Thomas. *England's Treasure by Forraign Trade*. London: Thomas Clark, 1664.

Newton, Isaac. *Opticks*. Third edition. London: William and John Innys, 1721.

—— *Opticks*. Fourth edition. New York: Dover, 1952 [1730].

Nieuwentyt, Bernard. *The Religious Philosopher*. Second edition. Translated by John Chamberlayne. London: J. Senex, 1720.

Nightingale, Florence. *Notes on matters affecting the health, efficiency, and hospital administration of the British Army*. London: Harrison and Sons, 1858.

—— *Notes on Nursing*. London: Harrison, 1859.

Paris, J.A. *The Life of Sir Humphry Davy*. London: Henry Colburn, 1831.

Paul, G.O. *Considerations on the Defects of Prisons*. London: T. Cadell, 1784.

Phillips, Richard. *A Letter to the Livery of London.* London: T. Gillet, 1808.

—— *A Morning's Walk from London to Kew*. London: J. Adlard, 1817.

Pitcairne, Archibald. *The Works of Dr. Archibald Pitcairn*. London: E. Curll, 1715.

Poe, Edgar Allan. "The Premature Burial" *Dollar Newspaper* .Philadelphia, PA., vol. II, no. 28, -July 31, 1844.

Pope, Alexander. *Epistles to Several Persons.* London: S.N., 1744.

Priestley, Joseph. *Observations on Different Kinds of Air* .London: W. Bowyer, 1772.

—— *Observations on Different Kinds of Air.* 2nd edition. London: J. Johnson, 1775.

—— *The Doctrine of Phlogiston Established and that of the Composition of Water Refuted.* Northumberland: A. Kennedy, 1800.

Pringle, John. "An Account of Several Persons seized with the Goal-Fever, working in Newgate" *Philosophical Transactions*, 48 (1753-4): 42-55.

—— *Observations on the Nature and Cure of Hospital and Jayl-Fevers*. London: A. Millar, 1750.

—— *Discourse upon some late improvements of the Means for Preserving the Health of Mariners*. London: Royal Society, 1776.

Rawley, William. *Sylva Sylvarum*. London: William Lee, 1670.

Ray, John. *Three Physico-Theological Discourses*. Second edition. London: Sam Smith, 1693.

Reid, Hugo. *Memoir of the Late David Boswell Reid*. Edinburgh: R. Grant, 1863.

Reid, David Boswell. *Rudiments of Chemistry*. Edinburgh: William Chambers, 1836.

—— *Text-Book for Students of Chemistry.* 3rd edition. Edinburgh: Maclachlan, Stewart and Co. 1839.

—— "Dr. Reid on the Ventilation of the Niger Steam Vessels." *Friend of Africa* 3:28 (1841) 43-47, 65-73.

—— *Illustrations of the Theory and Practice of Ventilation*. London: Longman, Brown, Green, & Longmans 1844.

—— *Ventilation: A Reply to Misstatements made by "The Times" and "The Athenaeum" in reference to Ships and Buildings Ventilated by the Author*. London: Madden and Malcolm, 1845.

—— *Extracts from Official Documents, Reports and Papers Referring to the Progress of Dr. Reid's Plans for Ventilation*. London: N.P. 1846.

—— *Ventilation in American Dwellings*. New York: Wiley & Halsted, 1858.

Richardson, Charles James. *The Englishman's Home from a Cottage to a Mansion*. London: John Camden Hotten, 1871.

—— *A Popular Treatise of Warming and Ventilation* .London: J. Weale, 1839.

Severn, Charles. Editor. *Diary of the Rev. John Ward, Vicar of Stratford-upon-Avon, extending from 1648-1679*. London: Henry Colburn, 1839.

Scribonius, Wilhelm Adolf. *Naturall Philosophy*. London: I.D. for Iohn Bellamie, 1621.

Southwood Smith, Thomas. *A Treatise on Fever*. London: Longman, 1830.

—— *On the Common Nature of Epidemics and their Relation to Climate and Quarantine*. Philadelphia, PA: J.B. Lippincott & Co., 1866.

Stanfield, James Field. *The Guinea Voyage*. London: James Phillips, 1793.

Sulte, Benjamin. "Un voyage à la Nouvelle-France En 1734." *Revue canadienne* 6, no. 22 (1886): 15-25.

Sutton, Samuel. *Historical Account of a New Method for Extracting the Foul Air out of Ships.* London: J. Noon, 1745.

Taylor, Thomas. *Memoirs of John Howard*. London: John Hatchard and Son, 1836.

Tomlinson, Charles. *A Rudimentary Treatise on Heating and Ventilation*. London: John Weale, 1850.

Tredgold, Thomas. *The Principles of Warming and Ventilating Public Buildings*. 2nd edition. .London: Josiah Taylor, 1824.

Triewald, Marten. "Queries, Concerning the Cause of Cohesion of the Parts of Matter." *Philosophical Transactions* 36 (1730) 39-43.

Trotter, Thomas. *Observations on the Scurvy*. Edinburgh: Charles Elliot, 1786.

Tymme, Thomas. *A Dialogue Philosophicall*. London: T.S. for Clement Knight, 1612.

Rumford, Benjamin. *Count Rumford's Experimental Essays, Political, Economical, and Philosophical: Essay IV: Of Chimney Fire-Places*. London: 1796.

United Kingdom Board of Trade. *Report of the Lords of the Committee of Council appointed for the Consideration of all Matters relating to Trade and Foreign Plantations: submitting to His Majesty's consideration the evidence and information they have collected in consequence of his Majesty's order in Council, dated the 11th of February 1788, concerning the present state of the trade to Africa, and particularly the trade in slaves; and concerning the effects and consequences of this trade, as well in Africa and the West Indies, as to the general commerce of this kingdom.* London, 1789.

Ward, Edward. *The Wooden World Dissected*. London: H. Meere, 1707.

Watson, William. "Some Observations upon Mr. Sutton's Invention to Extract the foul…air from…ships." *Philosophical Transactions* 42 (1741): 62-70.

Williams, John and Parker Bennet. *Essays on the Bilious Fever*. London: T. Waller, 1752.

Secondary Sources

Allan, D.G.C. and R.E. Schofield. *Stephen Hales, Scientist and Philanthropist*. London: Scolar Press, 1980.

Allan, W.O.B. and Edmund McClure. *Two Hundred Years: The History of the Society for Promoting Christian Knowledge, 1698-1898*. London: S.P.C.K., 1898.

Arnold, David. Editor. *Warm Climates and Western Medicine: The Emergence of Tropical Medicine, 1500-1900*. Second edition. Amsterdam: Rodopi Press, 2003.

Barber, Noel. *The Black Hole of Calcutta: A Reconstruction*. Boston: Houghton Mifflin, 1966.

Baudot, Laura. "An Air of History: Joseph Wright's and Robert Boyle's Air-Pump Narratives." *Eighteenth Century Studies*. Vol. 46:1 .Fall 2012: 1-28.

Baugh, Daniel. *British Naval Administration in the Age of Walpole*. Princeton: Princeton University Press, 1965.

Baxfield, Christopher. "Who is the Almighty that We should Serve Him?" Chaos, Providence and Natural Philosophy in Stephen Hales." *Ambix* 60:1 (2013): 31-53.

Berg, Maxine. *Luxury and Pleasure in Eighteenth Century Britain*. New York: Oxford University Press, 2005.

Bess, Michael. *The Light-Green Society: Ecology and Technological Modernity in France, 1960-2000*. Chicago: University of Chicago Press, 2003.

Bondeson, Jan. *Buried Alive: the Terrifying History of our most Primal Fear*. New York: Norton, 2001.

Booker, John. *Maritime Quarantine, the British Experience, 1650-1900*. Aldershot, England: Ashgate, 2007.

Bottomley, Sean. "Patenting in England, Scotland and Ireland during the Industrial Revolution, 1700-1852." *Explorations in Economic History*, 54 (2014): 48-63.

Brewer, John. *The Sinews of Power: War, Money and the English State, 1688-1715*. New York: Alfred A. Knopf, 1989.

Briggs, Asa. *Victorian Things*. London: B.T. Batsford, 1988.

Brimblecombe, Peter. *The Big Smoke*. London: Routledge, 1987.

Brunsman, Denver. *The Evil Necessity: British Naval Impressment in the Eighteenth-Century Atlantic World*. Charlottesville, VA: University of Virginia Press, 2013.

Carpenter, Audrey. *John Theophilus Desaguliers.* London: Continuum, 2011.

Cavert, William M. *The Smoke of London: Energy and Environment in the Early Modern City*. Cambridge: Cambridge University Press, 2016.

Chaplin, Joyce E. "Earthsickness: Circumnavigation and the Terrestrial Human Body, 1520-1800," *Bulletin of the History of Medicine*, 86:4 .Winter 2012.: 515-542.

Clark-Kennedy, A.E. *Stephen Hales, D.D., F.R.S., an Eighteenth Century Biography*. Cambridge: Cambridge University Press, 1929.

Cooper, Carolyn. "The Portsmouth System of Manufacture." *Technology and Culture* 25:2 (April 1984): 182-225.

Corbin, Alain. *The Lure of the Sea*. Translated by Jocelyn Phelps. Berkeley, CA: University of California Press, 1994.

—— *The Foul and the Fragrant: Odor and the French Social Imagination*. Translated by Aubier Montaigne. New York: Berg, 1986.

Cunningham, Andrew and Roger French, eds. *The Medical Enlightenment of the Eighteenth Century* .London: Cambridge University Press, 1990.

Dear, Peter. *The Intelligibility of Nature*. Chicago: University of Chicago Press, 2006.

Delbourgo, James. "Underwater-works: voyages and visions of the submarine." *Endeavour:* 31:3 (September, 2007): 115-120.

—— "Divers Things," *History of Science* xlix (2011): 149-185.

Dittrich, H. "Devices to Prevent Premature Burial." *Journal of the History of Medicine and Allied Sciences*, 3:1 (December, 1948): 161-171.

Donaldson, Barry and Bernard Nagencast. *Heat and Cold: Mastering the Great Indoors*. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1994.

Drayton, Richard. *Nature's Government*. New Haven, CT: Yale University Press, 2000.

Dupré, Sven and Christoph Herbert Lüthy. *Silent Messengers*. Berlin: Lit Verlag, 2011.

Eltis, David. "The Volume and Structure of the Transatlantic Slave Trade: A Reassessment." *William and Mary Quarterly*, 3:58 (2001) 9-17.

Edwards, Paul N. "Infrastructure and Modernity: Force, Time, and Social Organization in the History of Sociotechnical Systems," in Thomas J. Misa, Philip Brey and Andrew Feenberg, editors. *Modernity and* Technology. Cambridge, MA: MIT Press, 2003: 185-225.

Emsley, Clive. *Crime and Society in England*. 3rd edition. Harlow, U.K.: Pearson Longman, 2005.

Evans, Robin. *The Fabrication of Virtue: English Prison Architecture 1750-1840*. London: Cambridge University Press, 1982.

Foregger, Richard. "Two Types of Respiratory Apparatus of Stephen Hales." *Anaesthesia* 11:3 (July 1956): 235-240

Forgan, Sophie. "Context, Image and Function: a Preliminary Enquiry into the Architecture of Scientific Societies." *British Journal of the History of Science* 19:1 (1986): 89-113.

Foucault, Michel. *Discipline and Punish*. Translated by Alan Sheridan. New York: Penguin Books, 1977.

Frank, Robert G. *Harvey and the Oxford Physiologists*. Berkeley, CA: University of California Press, 1980.

Fraser Harris, D. "Stephen Hales, The Pioneer in the Hygiene of Ventilation." *The Scientific Monthly* 3:5 (Nov. 1916): 440-454.

Froggatt, Peter. "The Lazaret on Chetney Hill." *Medical History* 8:1 (Jan. 1964): 44-62.

Fullmer, J.Z. "The Poetry of Humphry Davy." *Chymia* 6 (1960): 102-126.

Gallo, Emmanuelle. "Jean Simon Bonnemain (1743-1830) and the Origins of Hot Water Central Heating." In Construction History Society, *2nd International Congress on Construction History* (April, 2006) 1043-1060

Gillin, Edward. "Science on the Niger: Ventilation and Tropical Disease during the 1841 Niger Expedition," *Social History of Medicine* 31:3 (Fall 2017): 605-626.

—— Edward J. *The Victorian Palace of Science*. Cambridge: Cambridge University Press, 2017.

Gloag, John. *Victorian Comfort*. London: A. & C. Black, 1961.

Golinski, Jan. *Science as Public Culture*. Cambridge: Cambridge University Press, 1992.

Grove, Richard. *Green Imperialism*. Cambridge: Cambridge University Press, 1995.

Guerrini, Anita. "James Keill, George Cheyne, and Newtonian Physiology, 1690-1740." *Journal of the History of Biology*, 18:2 (Summer 1985): 250-1.

Hamlin, Christopher. "The Necessities of Life in British Political Medicine, 1750-1850." *Journal of Consumer Policy* 29:4 (2006): 373-397.

Hansen, Susanne Therese and Nicholas Marsh. "Normative Power and Organized Hypocrisy: European Union Member States' Arms Export to Libya." *European Security* 24:2 (2015): 264-286.

Harrison, Mark. *Medicine in an Age of Commerce and Empire* .Oxford: Oxford University Press, 2010.

Howard, Deborah. "Seasonal Apartments in Renaissance Italy." *Artibus et Historiae* 22:43 (2001): 127-135.

Huneman, Philippe. "'Animal Economy': Anthropology and the Rise of Psychiatry from the Encyclopédie to the Alienists." In *The Anthropology of the Enlightenment*, edited by Larry Wolff and Marco Cipolloni .Stanford: Stanford University, 2007.

Ignatieff, Michael. *A Just Measure of Pain*. New York: Columbia University Press, 1978.

Jacob, Margaret C. and Larry Stewart. *Practical Matter*. Cambridge: Harvard University Press, 2004.

Jankovic, Vladimir. *Confronting the Climate*. New York, NY: Palgrave Macmillan, 2010.

Jenner, Mark. "The Politics of London Air: John Evelyn's *Fumifugium* and the Restoration." *The Historical Journal* 38:3 (1995): 535-551.

Jonsson, Fredrik Albritton, *Enlightenment's Frontier*. New Haven, CT: Yale University Press, 2013.

Jørgenson, Finn Arne. *Making a Green Machine*. New Brunswick, NJ: Rutgers University Press, 2011.

Kalman, Harold. "Newgate Prison." *Architectural History*. 12 (1969): 50-61, 108-112.

Keller, Vera. "Drebbel's Living Instruments," *History of Science* xlviii (2010): 39-74.

—— "Air-Conditioning Jahangir: The 1622 English Great Design, Climate and the nature of Global Projects." *Configurations* 21:3 (Fall 2013): 331-367.

Kinkel, Sarah. "Disorder, Discipline, and Naval Reform in Mid-Eighteenth-Century Britain." *English Historical Review*, vol. CXXVIII no. 535 (Dec. 2013): 1451-1482.

—— *Disciplining the Empire: Politics, Governance and the Rise of the British Navy.* Cambridge, MA: Harvard University Press, 2018.

Kunapatarawong, Rasi and Ester Martínez-Ros. "Towards Green Growth: How does green innovation affect employment?" *Research Policy* 45:6 (July 2016): 1218-1232.

Lawton, Bryan. "Tunnelling in the 1740s: The Water Mine at Coleshill House." *The International Journey for the History of Engineering and Technology* 82:2 (2012): 187-209.

Latour, Bruno. *We Have Never Been Modern.* Translated by Catherine Porter. Cambridge, MA: Harvard University Press, 1993.

Levere, Trevor. *Transforming Matter.* Baltimore, MD: Johns Hopkins University Press, 2001.

Linebaugh, Peter. *The London Hanged: Crime and Civil Society in London in the Eighteenth Century*. Cambridge: Cambridge University Press, 1992.

Macaulay, Thomas Babington. *Critical and Historical Essays*. Leipzig: Bernhard. Tauchnitz, 1850.

Mangham, Andrew. "Buried Alive: The Gothic Awakening of Taphephobia." *Journal of Literature and Science* 3:1 (2010): 10-22.

Marshall, Henrietta Elizabeth. *Our Island* Story. London: T.C.&E.C., 1905.

McCormick, Ted. *William Petty and the Ambitions of Political Arithmetic*. New York: Oxford University Press, 2010.

McGowen, Randall. "A Powerful Sympathy: Terror, the Prison, and Humanitarian Reform in Early Nineteenth-Century Britain." *Journal of British Studies* 25:3 (July 1986): 312-334.

McEwan, Indra Kagis. *Vitruvius: Writing the Body of Architecture*. Cambridge, MA: MIT Press, 2003.

Meade, Martin and Andrew Saint. "The Marquis de Chabannes, Pioneer of Central Heating and Inventor." *Transactions of the Newcomen Society*. 66:1 (1994): 193-213.

Meranze, Michael. *Laboratories of Virtue: Punishment, Revolution, and Authority in Philadelphia, 1760-1835*. Chapel Hill, NC: University of North Carolina Press, 1996.

Mikkeli, Heikki. *Hygiene in the Early Modern Medical Tradition*. Helsinki: Academia Scientiarum Fennica, 1999.

Mokyr, Joel. *The Enlightened Economy: An Economic History of Britain 1700-1850*. New Haven, CT: Yale University Press, 2012.

Morris, Norval and David J. Rothman, eds. *The Oxford History of the Prison*. Oxford: Oxford University Press, 1995.

Morriss, Roger. *The Foundations of British Maritime Ascendancy*. London: Cambridge University Press, 2011.

Norris, John. "The Mineral Exhalation Theory of Metallogenesis in Pre-Modern Mineral Science." *Ambix* 53:1 (July 2013): 43-65.

Partington, J.R. *A History of Chemistry*. London: Macmillan, 1961.

Porter, Dorothy and Roy Porter, editors. *Doctors, Politics and Society: Historical Essays* .Amsterdam: Rodopi, 1993.

Porter, Theodore. *The Rise of Statistical Thinking*. Princeton, NJ: Princeton University Press, 1986.

Principe, Lawrence. *The Aspiring Adept: Robert Boyle and His Alchemical Quest*. Princeton, NJ: Princeton University Press, 1998.

——— Editor. *New Narratives in Eighteenth-Century Chemistry*. Dordrecht, Netherlands: Springer, 2007.

Rediker, Marcus. *The Slave Ship: A Human History*. New York: John Murray, 2007.

Riskin, Jessica. *The Restless Clock*. Chicago: University of Chicago Press, 2016.

Roberts, Lissa. "The Death of the Sensuous Chemist: The 'New' Chemistry and the Transformation of Sensuous Technology." *Studies in the History and Philosophy of Science* 26:4 (1995): 503-529.

Roberts, Lissa, Simon Schaffer and Peter Dear, editors. *The Mindful Hand*. Amsterdam: Royal Netherlands Academy of Arts and Sciences, 2007.

Rogers, Nicholas. *The Press Gang: Naval Impressment and its Opponents in Georgian Britain*. New York: Hambledon Continuum, 2008.

Rosenberg, Charles E. "Epilogue: *Airs, Waters, Places*. A Status Report," *Bulletin of the History of Medicine* 86:4 (Winter 2012): 661-670.

Santer, Melvin. *Confronting Contagion*. Oxford: Oxford University Press, 2015.

Schabas, Margaret. *The Natural Origins of Economics*. Chicago: University of Chicago Press, 2006.

Schaffer, Simon. "Natural Philosophy and Public Spectacle in the Eighteenth Century." *History of Science*. XXI:1 (1983): 1-43:

Schoenefeldt, Henrik. "The Lost (First) Chamber of the House of Commons." *AA Files* 72 (2016): 161-173.

Seth, Suman. *Difference and Disease: Medicine, Race, and the Eighteenth-Century British Empire*. New York: Cambridge University Press, 2018.

Shapin, Steven and Simon Shaffer. *Leviathan and the Air Pump: Hobbes, Boyle, and the Experimental Life*. Princeton, NJ: Princeton University Press, 1985.

Simmons, Dana. *Vital Minimum: Need, Science and Politics in Modern France*. Chicago: University of Chicago Press, 2015.

Slack, Paul. *The Invention of Improvement*. Oxford: Oxford University Press, 2015.

Smith, Elizabeth Hallam. "Ventilating the Commons, Heating the Lords." *Parliamentary History* 38:1 (March 2019): 74-102.

Thébaud-Sorger, Marie. "Capturing the Invisible: Heat, Steam and Gases in France and Great Britain, 1750-1800." In Lissa Roberts, Simon Werrett eds. *Compound Histories: Materials, Governance and Production, 1760-1840*. Leyden: Brill, 2017: 85-105.

Tierie, Gerrit. *Cornelius Drebbel*. Amsterdam: H.J. Paris, 1932.

Thomas, Hugh. *The Slave Trade: The History of the Atlantic Slave Trade, 1440-1870*. New York: Simon and Schuster, 1997.

Thompson, F.M.L. *The Rise of Respectable Society: A Social History of Victorian Britain, 1830-1900*. Cambridge, MA: Harvard University Press, 1988.

Thorsheim, Peter. *The Invention of Pollution*. Athens, OH: Ohio University Press, 2006.

Tresch, John. "Technological World-Pictures: Cosmic Things and Cosmograms." *Isis* 98:1 (2007): 84-99.

Ward, Candace. *Desire and Disorder*. Lewisburg, PA: Bucknell University Press, 2007.

Wear, Andrew. *Knowledge and Practice in English Medicine, 1550-1680*. Cambridge: Cambridge University Press, 2000.

—— "Place, Health, and Disease: The *Airs, Waters, Places* Tradition in Early Modern England and North America." *Journal of Medieval and Early Modern Studies* 38:3 (Fall 2008): 443-465.

Wrigley, E.A. *Energy and the English Industrial Revolution*. Cambridge: Cambridge University Press, 2010.

Zilberstein, Anya. *A Temperate Empire: Making Climate Change in Early America*. Oxford: Oxford University Press, 2016.