Mass and Material Architecture: How to Unplug from HVAC Infrastructure

Salmaan Craig

Infrastructure Space, Ruby, 2017

Even as climates become more extreme, interior temperatures remain constant through the use of HVAC (heating, ventilation, and air conditioning) systems that exacerbate the very conditions they are meant to control. Focusing on cooling, Salmaan Craig argues for a dual approach: broadening the definition of thermal comfort and designing architectural solutions suitable for bulk use.

Blunted Sensorium

At the dawn of twentieth century, during the era of electrification, demand for artificial light far outstripped any energy savings from improved lightbulbs.[1] The same is happening today with artificial cold. Globally, energy for cooling is set to exceed energy for heating by 2060.[2] The "cold crunch" is on the horizon, and more efficient versions of the same buildings won't buck the trend.[3]

Before thinking of alternative designs, we must question our expectations for thermal comfort. Our Paleolithic tolerances have narrowed alongside the evolution of air-conditioning technology.[4] The story is documented in thermal-comfort standards written by air-conditioning engineers (who were invariably white, male, and conservatively clothed).[5]

For the major part of the twentieth century, engineers' attention was focused on reliably changing the state of the air-vapor mix.[6] This was complex enough; the subtlety of human physiology and psychology was secondary and intractable. They worked on refining a definition for a universal range of thermal conditions. The more people, activities, climates, and buildings this applied to, the better. The implicit goal was to nullify thermal sensation. The simplest way to control complexity, after all, is to avoid it entirely.

The designation of thermal "comfort" implies some recognition or anticipation of contrast. It's that mild endorphin reward released on a favorable change, or at the prospect of a favorable change. Marketeers in America's golden age of cinema knew this well; when air-conditioning was rare in homes, offices, and cars, and the thought of escaping to a cold movie theater was genuinely enticing.[7]

Today it is quite possible to move from home to car to office to mall without having to experience the outdoors. In the absence of contrast, thermal "comfort" begins to lose its meaning. Thermal "monotony," "neutrality," or "indifference" is more apt.[8] Or perhaps thermal "non-sense."

In the history of technology, the sleepwalk into luxury traps is a well-trodden path.[9] Luxuries tend to become necessities and to spawn new obligations. Once people get used to a certain luxury, they take it for granted. Then they begin to count on it. Finally, they reach a point where they can't live without it.

How does the dulling of thermal sensibility affect us? It's hardly a hot topic of research. One old military study shows that while each of us have broadly the same number of sweat glands, the total that grow to be fully operational depends on how much heat stress we experience in youth.[10] This effect is the same as a person that has strong bones today because while growing up she spent more time running and jumping than sitting and watching television.

Breathing Buildings

New thermal-comfort standards acknowledge important subtleties in thermal sensation, such as our automatic adaptation to seasonal changes.[11] This hard-fought revision has loosened the shackles significantly. A wider target comfort range, and a closer overlap with exterior temperatures, means that air-conditioning can stay switched off for longer. Design teams can now seriously consider natural ventilation.

It is hard to overstate the importance of this revision. The target comfort range is the starting point or closing door to all conversations on passive design. Not efficiency add-ons and afterthoughts, such as hi-tech glazing or new insulation materials, but bold, effective architectural designs, centered on natural ventilation. An overly conservative comfort range can give design teams the false impression that natural ventilation is possible for only a small proportion of hours in the year. Little wonder that connections to the exterior—atria, chimneys, buffer zones, and plenums—often appear frivolous.

One of the major challenges of natural ventilation is the unpredictable frequency, direction, and strength of wind. In the last decade, however, significant progress has been made in understanding a more reliable driving force. Buoyancy ventilation is natural ventilation too, but it does not rely on the wind—it is powered by the waste heat from occupants, computers, and other internal heat gains. The greater the internal gains, and the taller the room, chimney, or atrium, the greater the driving pressure difference. Out flows warm stale air from the top; in flows fresh cool air from below. Unlike wind-driven ventilation, the fresh air is pulled in, not pushed.

Much of the theoretical work has come from a lineage of researchers with connections to a group at Cambridge University.[12] The findings have been summarized into simple mathematical models so that engineers can size openings and stacks relative to the internal heat loads, and thereby deliver a reliable stream of fresh air and sustain a comfortable interior temperature.[13]

With wind-driven ventilation, there is often a mismatch between occupancy and the availability of the breeze. Not so with buoyancy ventilation. As occupancy rises, so does the driving force. With sensible space planning, buoyancy ventilation is viable when the exterior is as cool as 10°C/50°F. Plenums, buffer zones, transition spaces, common areas, or winter gardens can preheat the fresh air before it enters the occupied space proper.

In hot climates, when the interior must be cooler than the exterior, downdraft buoyancy ventilation is a theoretical possibility. Chilled ceilings cool the space and the flow reverses. Energy is needed to cool the water in the pipes embedded in the soffit, but tepid water is sufficient because of the large cooling surface area. And there is no need for ductwork. While untested, this arrangement could be of importance in hot, dry, polluted cities where the air higher up is cleaner.

The influence of the Cambridge group is starting to show. Some designers are starting to realize that buoyancy ventilation makes natural ventilation a more feasible prospect. For instance, a trend can be seen in the buildings of Foster+Partners. The practice's Commerzbank Headquarters, completed in 1997 in Frankfurt, was branded as the world's first ecological office tower. A series of staggered winter gardens meant openable windows could be placed near most occupants, giving free access to side ventilation. 30 St Mary Axe in London, designed for Swiss Re and completed in 2004, had spiraling mini-atria, each stacked six stories high, enclosed by an aerodynamic form, giving occupants access to wind-driven or buoyancy ventilation, depending on conditions. It was a complex arrangement and its performance is unknown. The Apple Campus in Cupertino, currently under construction, is designed around the simpler principles of buoyancy ventilation. The Bloomberg HQ in London, also under construction, is another deep-plan office designed to run on buoyancy ventilation for the major part of the year.

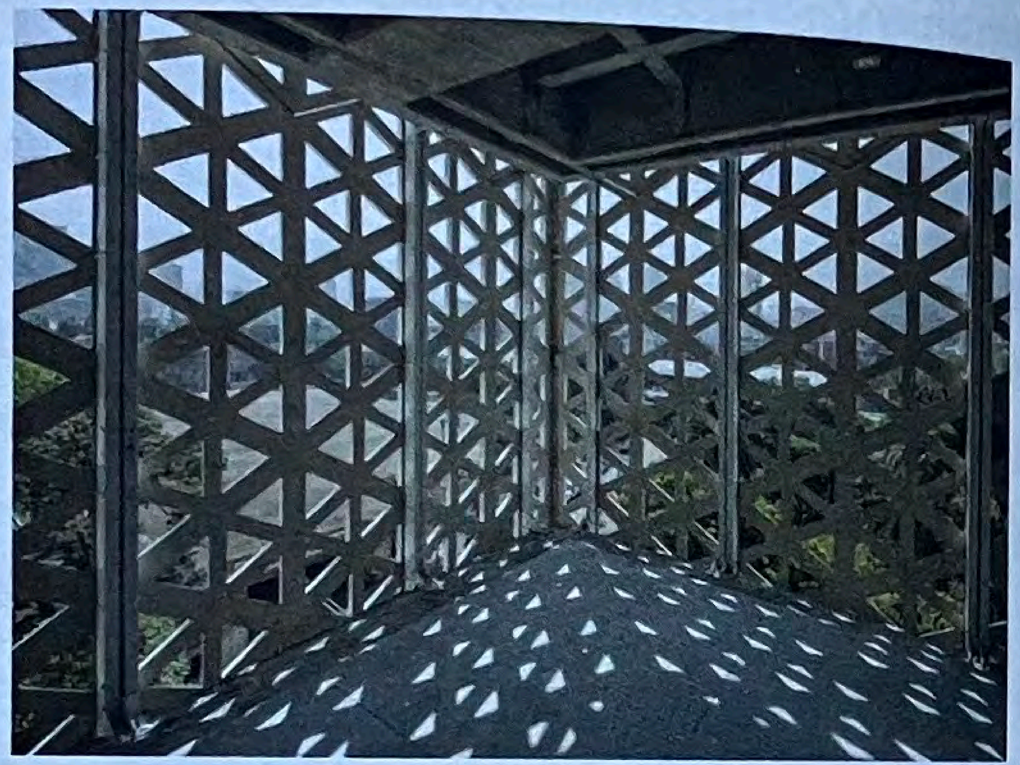


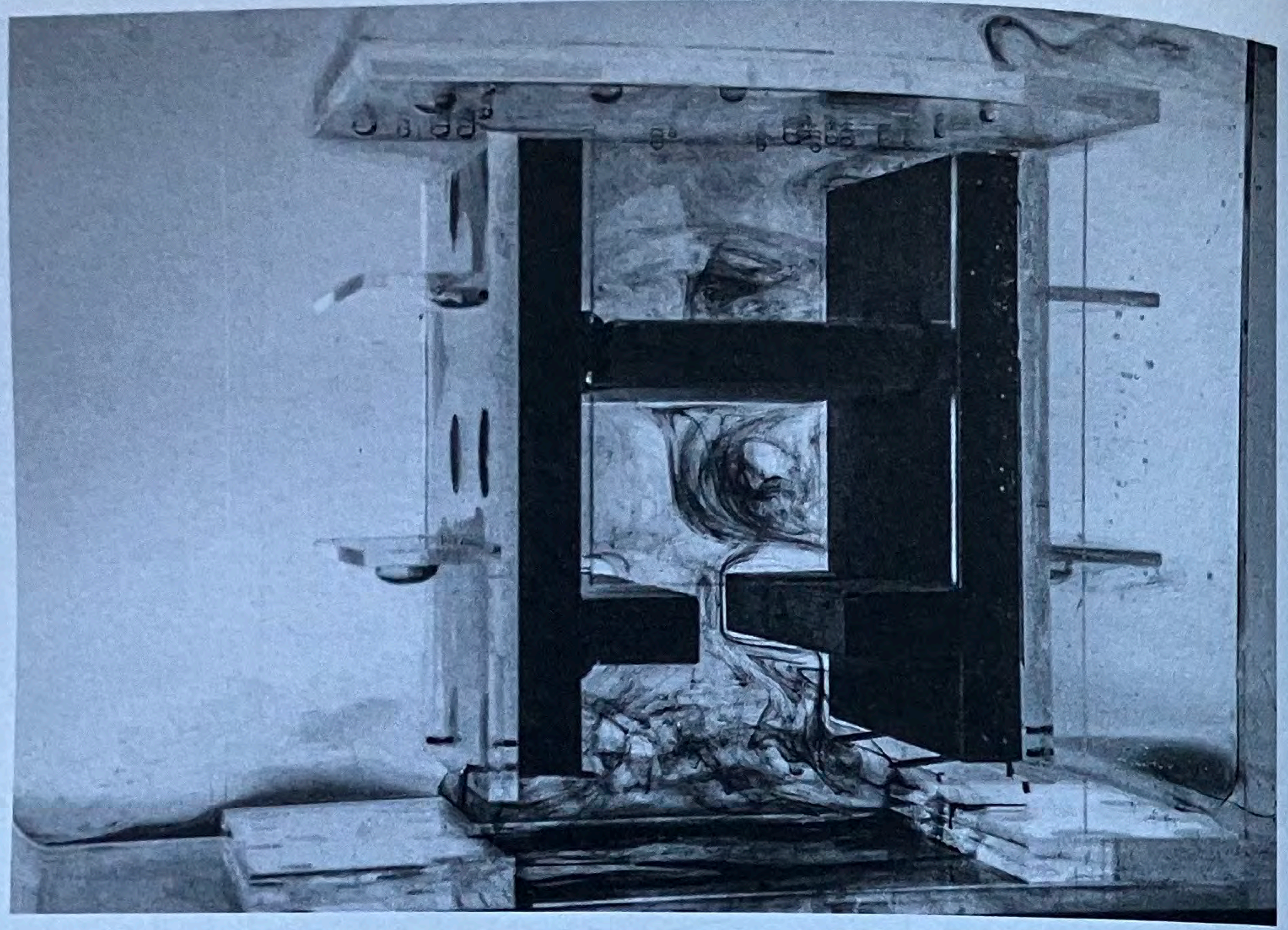
Fig. 1: New office headquarters —with no HVAC infrastructure whatsoever—designed by and for Medellín's urban planning department, *Empresa de Desarrollo Urbano* (EDU).

For the first time we can contemplate high-density offices free of HVAC (heating, ventilation, and air-conditioning) infrastructure. At the time of writing, I am consulting on the design of a mid-rise office tower in Medellín, Colombia, a climate so perfect for natural ventilation that they call it *la eterna primavera*. There is little wind, however, so we are applying a new model to design the building so that it is controlled by buoyancy

Fig. 2: The exterior shading screen is made from prefabricated Glass-fibre Reinforced Concrete (GRC). A single-glazed facade will be fitted behind the screen, on the interior side. The lack of HVAC infrastructure means double or triple glazing is unnecessary.

ventilation, powered by internal gains, with a boost in the afternoon from a west-facing solar chimney.[15] There is also exposed thermal mass to reduce the radiant temperature, and the effect of mass on stack pressure has been accounted for. The idea is that every person will receive the same twenty liters of fresh air per second, and experience the same range of operative temperatures.

On each floor, 28 people will share a space of 100 square meters, but no HVAC infrastructure will be installed. The new headquarters is for the Urban Planning Department (EDU) of Medellín, which is willing to see it as an experiment in robust, buoyancy-centered design, not only for its architects but for the wider research community too. We plan to monitor the behavior of the building and the response of occupants live on the Internet. The performance of simple measures will be under the spotlight. For instance, the windows will be manually operable, with graphics on the glazing indicating by how much that window should be opened depending on the occupancy on that



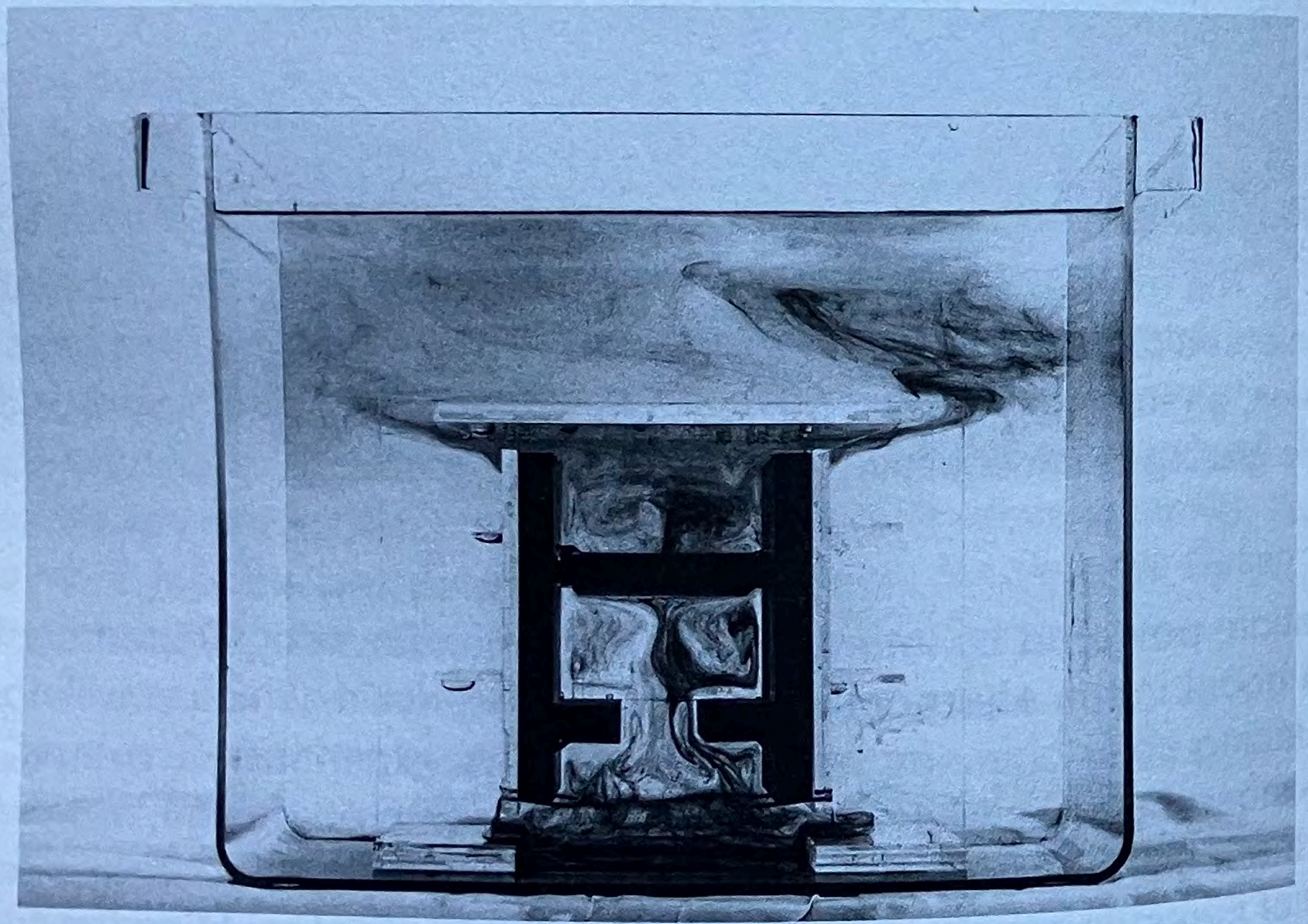


Fig. 3: Buildings can be ventilated naturally and reliably in the absence of wind by exploiting an interior-exterior pressure difference, powered by the waste heat from people and equipment. These water bath models—a form of "analogue" computing, well established in the field of fluid dynamics—explore how a warm, massive envelope (dark gray) could generate the necessary updraft. A comparably cool mass generates a downdraft of equal strength.

floor. The occupants are architects who are keen to learn about buoyancy ventilation by experience so they can apply the knowledge in future designs to help stop Medellín from sleepwalking into the "HVAC trap." The client is unique in that they understand the value of Post-Occupancy Evaluation and are willing to be transparent with the results.

Thermal Texture

We adapt to seasonal changes and diurnal shifts in temperature. But there are many more subtleties of thermal sensation to explore. Some are bound to suggest energy dividends.

There is an experiment I recreate with my students that has been attributed to John Locke, the seventeenth-century philosopher.[16] I ask a volunteer to come to the front of the class, where he finds a table with three buckets of water. One is hot, one is cold, and one is at room temperature. He puts one hand in the hot bucket, and the other hand in the cold bucket. After acclimatizing to the temperatures, he takes both hands out, and plunges them both into the middle bucket—the one full with water at room temperature. When I ask him to guess the temperature, he struggles to respond: "I can't tell, because my hot hand feels cold, but my cold hand feels hot!"

These crossed wires highlight that our bodies are not objective measures of temperature. Our thermal senses are change seeking. They are tuned to cultivate an internal homeostasis, but the calibration is subjective. We sense comfort, discomfort, pleasure, or pain, depending on the thermal stimulus, and whether it has the potential to threaten or ameliorate our internal state of homeostasis.[17] The hardware is Paleolithic, but the software is being blunted, and the range is narrowing. Are we like tops in a spin, which can tolerate a nudge, but no longer a push?

Le Corbusier said that architecture is the "play of masses brought together in light."[18] If only he'd had the foresight to add heat. There is more to heat than temperature, just as there is more to light than lux. And more so, since heat comes in many forms. Daylight has been sculpted by architects to create scenes of drama, tension, and difference; to program social interaction; to cultivate individual calm; and to heighten group alertness. Where is the appetite for exploring heat and the subtleties of its perception? The "cold crunch" demands that we *atomize* the idea of thermal comfort. Without this curiosity, we will never find an antidote to HVAC infrastructure.

Smart Geometry, Dumb Materials

A camel is a horse designed by committee. This old saying springs to mind on seeing Rem Koolhaas's installation of a contemporary office ceiling, suspended claustrophobically below a soaring dome frescoed with scenes of the evolution of art, for his exhibition "Elements of Architecture,"[19] at the 14th Venice Architecture Biennale, in 2014. According to Koolhaas:

"The ceiling used to be decorative, a symbolic plane, a place invested with intense iconography. Now, it has become an entire factory of equipment that enables us to exist, a space so deep that it begins to compete with the architecture. It is a domain over which architects have lost all control, a zone surrendered to other professions."[20] I propose another name for this "surrendered space": the "clusterduct." Because while it has been handed over to a splintered pack of specialists, a rabble who do not care for Architecture with a capital A, *they are not in control of it either.*

For some years now, commentators have looked on with despair at the fragmented, chaotic state of our industry's knowledge, labor, and materials supply chain.[21] This decentralized, fickle network of self-interested, risk-adverse actors tends to reinforce the status quo, making anything more than incremental innovation unlikely. Those who lament this state of affairs used to advocate moving construction sites into factories. Now they are more likely to sing the praises of BIM (Building Information Modelling).

One futurist tale of radical, disruptive innovation is that we will ride on the coattails of busy, genius materials scientists, who have invented more new materials in the last fifty years than in the prior history of human civilization.[22] But a pair of little-discussed graphs makes for sober reading. When comparing the cost of materials we use, and the value we add to them, we fall in line at the bottom of the ladder, next to the packing industry.[23]

While shoe designers and aerospace engineers can afford to use materials that cost $10 per kilogram and up, architects, civil engineers, and packaging designers must work in the order of $1 per kilogram. This is because construction demands an especially high throughput of materials. Buildings and civil structures are big, and there are a lot of them. This is obvious but the upshot is perverse. Per unit mass, the building you are in costs the same to make as the disposable cup in your hand or the foil around your sandwiches.

This explains why insulation materials and packing materials are so interchangeable. It also explains why the usual suspects for structural materials dominate—wood, concrete, steel, glass, fired clays. As bulk structural materials, they are the cheapest and best performers per unit mass or volume.[24] The same list of candidates comes up when examining the structural performance per unit of embodied energy or carbon dioxide.[25] By orders of magnitude, they are the best bulk performers within budget.

Are we condemned to use concrete? Can we build towers with timber? Should clothing designers share responsibility for steering clear of the cold crunch? The stark reality is that we are tasked at doing better—much better—with the palette of materials we already have.

Materials scientists will not fire a silver bullet anytime soon—but we can learn from them. The majority of them are not searching for fundamentally new materials; they realize that this is unlikely. Most are working on new hybrids of existing materials. The idea is to superimpose properties and get more than the sum of the parts.[26] There are lots of basic materials to play with, lots of possible combinations, and plenty of successful precedents. Think of fiber-reinforced plastics, cellular materials, and other composites—or reinforced concrete and multilayered structural glass.

Some materials scientists even see themselves as architects. That is, they "architect" materials.[27] They design on a smaller scale, between the micrometer and the centimeter. But the variables they tinker with are undeniably architectural: the choice of materials, their relative volumes, the shapes and their connectivity, and the length scale of the features. They are in the business of organizing matter in space. The purpose is to better orchestrate phenomena.

With the new capabilities afforded by digital fabrication, in particular 3-D printing, the mesoscale tinkering of materials has fallen within remit of some architects in academia and practice. This "bottom-up" trend is nascent and bears a distinct hacker-collective spirit. Contributors seem more interested in communicating and sharing than laying claim to intellectual property.

Historically, only two types of patents gain traction in the construction industry: those for mass-production material processes, such as float-glass or rock-wool insulation, or those for higher-tech plug-in modules, such as AC units. This makes sense when looking at the special conditions of the construction industry. That is, the highly fragmented knowledge and materials supply chain, the severe constraints on material cost, and the fact that "solutions" must be flexible so they can be adapted to local circumstances, since there is not much opportunity for wholesale repetition. Either you score on bulk materials that everyone in the network can use according to the demands of their project, or you score with something that can be easily added in fit-out.

In between, there is a space where another type of innovation takes place. Here intellectual property is part of a shared commons. This commons is stored in the minds of architects and engineers who learn details, make adjustments, and pass them on. It is embodied in built examples all around.

The "solutions" are tectonic in nature: they relate to the configuration of materials and parts in space. Historically, they are configurations that can be seen clearly with the naked eye. They occur on the centimeter to the meter scale. (We are talking orders of magnitude; so the meter scale involves features that are tens or hundreds of meters in length scale too.) Now, with the growth in "architectured" materials, we can add another length scale to the commons of solutions.

To make an impact on construction, to change how buildings are built, your ideas must proliferate in the commons. To proliferate in the commons, *the ideas must be adaptable configurations of standard materials.*

Conclusion

Global energy for cooling is set to exceed energy for heating by 2060. More efficient versions of the same buildings won't buck the trend. We need to figure out how to unplug buildings from HVAC infrastructure. This is now feasible for high-density offices in certain climates, thanks to revisions in thermal-comfort standards and advances in the theory and practice of buoyancy ventilation. To make these "breathing buildings" feasible in a wider range of climates, building envelopes must be put to work as heat exchangers. The designs must be open-source, adaptable to local circumstance, and made—or "architectured"—from standard materials. Otherwise there is little chance of them being taken up industry-wide.

1. Roger Fouquet and Peter J. G. Pearson, "Seven Centuries of Energy Services: The Price and Use of Light in the United Kingdom (1300–2000)," *Energy Journal* (2006): 139–77.
2. "Birmingham Energy Institute Policy Commission: Doing Cold Smarter – University of Birmingham," accessed January 19, 2016, http://www.birmingham.ac.uk/research/activity/energy/policy/cold/doing-cold-smarter.aspx.
3. Jon Henley, "World Set to Use More Energy for Cooling than Heating," *The Guardian*, October 26, 2015, sec. Environment, http://www.theguardian.com/environment/2015/oct/26/cold-economy-cop21-global-warming-carbon-emissions.
4. Daniel Lieberman, *The Story of the Human Body: Evolution, Health, and Disease*, 1st ed. (New York: Pantheon Books, 2013).
5. Pam Belluck, "Chilly at Work? Office Formula Was Devised for Men" *New York Times*, August 3, 2015, http://www.nytimes.com/2015/08/04/science/chilly-at-work-a-decades-old-formula-may-be-to-blame.html?_r=0.
6. Gail Cooper, *Air-Conditioning America: Engineers and the Controlled Environment, 1900–1960*, Johns Hopkins Studies in the History of Technology (Baltimore, MD: Johns Hopkins University Press, 1998).
7. Ray Bert, "Losing Our Cool: Uncomfortable Truths about Our Air-Conditioned World (and Finding New Ways to Get Through the Summer)," *Civil Engineering* 80, no. 9 (2010): 82.
8. Stephen Healy, "Air-Conditioning and the 'Homogenization' of People and Built Environments," *Building Research & Information* 36, no. 4 (2008): 312–22, doi:10.1080/09613210802076351; Thomas Parkinson, Richard de Dear, and Christhina Candido, "Thermal Pleasure in Built Environments: Alliesthesia in Different Thermoregulatory Zones," *Building Research & Information* 44, no. 1 (2016): 20–33.
9. Yuval Noah Harari, *Sapiens: A Brief History of Humankind* (Random House, 2014), 84–88.
10. Daniel Lieberman, *The Story of the Human Body*, 295–98.
11. Richard J. de Dear and Gail S. Brager, "Thermal Comfort in Naturally Ventilated Buildings: Revisions to ASHRAE Standard 55," *Energy and Buildings* 34, no. 6 (2002): 549–61.
12. Torwong Chenvidyakarn, *Buoyancy Effects on Natural Ventilation* (Cambridge: Cambridge University Press, 2013).
13. Andrew Acred and Gary R. Hunt, "A Simplified Mathematical Approach for Modelling Stack Ventilation in Multi-compartment Buildings," *Building and Environment* 71 (January 2014): 121–30, doi:10.1016/j.buildenv.2013.09.004.
14. T. Chenvidyakarn and A. Woods, "Top-Down Precooled Natural Ventilation," *Building Services Engineering Research & Technology* 26, no. 3 (2005): 181–93, doi:10.1191/0143624405bt129oa.
15. Andrew Acred and Gary R. Hunt, "Stack Ventilation in Multi-Storey Atrium Buildings: A Dimensionless Design Approach," *Building and Environment* 72 (February 2014): 44–52, doi:10.1016/j.buildenv.2013.10.007.
16. Edward A. Arens, H. Zhang, and C. Huizenga, "Partial- and Whole-Body Thermal Sensation and Comfort, Part II: Non-uniform Environmental Conditions," Center for the Built Environment, University of California, Berkeley (2005).
17. Richard de Dear, "Revisiting an Old Hypothesis of Human Thermal Perception: Alliesthesia," *Building Research & Information* 39, no. 2 (2011): 108–17, doi:10.1080/09613218.2011.552269.
18. Le Corbusier, *Toward an Architecture*, Texts & Documents (Los Angeles: Getty Research Institute, 2007).
19. Rem Koolhaas et al., *Elements of Architecture* (Venice: Marsilio Editori Spa, 2014).
21. Cited in Oliver Wainwright, "Rem Koolhaas Blows the Ceiling Off the Venice Architecture Biennale," *Guardian*, June 5, 2014, http://www.theguardian.com/artanddesign/architecture-design-blog/2014/jun/05/rem-koolhaas-architecture-biennale-venice-fundamentals.
21. *Rethinking Construction: The Egan Report* (Oxford: Blackwell Science Ltd, 2008 [1998]).
22. M. F. Ashby, *Materials Selection in Mechanical Design*, 4th ed. (Amsterdam: Elsevier, 2011), 4–8; Mike Ashby, "Materials: A Brief History," *Philosophical Magazine Letters* 88, no. 9–10 (2008): 749–55, doi:10.1080/09500830802047056.
23. Ashby, *Materials Selection in Mechanical Design*, 482–83.
24. Ibid., 138–42.
25. M. F. Ashby, *Materials and the Environment : Eco-Informed Material Choice*, 2nd ed. (Amsterdam: Elsevier, 2013), 250–55.
26. M. F. Ashby and Y. J. M. Brechet, "Designing Hybrid Materials," *Acta Materialia* 51, no. 19 (2003): 5801–21, doi:10.1016/S1359-6454(03)00441-5.
27. Mike Ashby, "Designing Architectured Materials," *Scripta Materialia* 68, no. 1 (2013): 4–7, doi:10.1016/j.scriptamat.2012.04.033.