The fireside circle could no longer serve as social glue. The old social fabric—tied together by enforced commonalities of location and schedule—no longer coheres. What shall replace it?

William J. Mitchell, 2000

EIGHT

ENERGY

The earliest form of habitation technology was the grotto—a natural feature that humans sought out for warmth, protection, and sociability—and there they built the primordial hearth. Nomadic hunter-gatherer culture transitioned to a stable society, coalescing around the fire pit's climate control system. For both sociability and efficiency, shelter developed according to a centralized model. The hearth was a focal point of social space—as the architect Frank Lloyd Wright famously noted, it is the "psychological center of the home."

Yet as time progressed, architecture's many dimensions became decentralized, following an outward trajectory of spatial liberation. What was once a circle of firelight fractured into a proliferation of light fixtures in every room; the village well, formerly a site of gathering and gossip, flowed out through pipes to each home; even entertainment crossed the threshold of the theater and was beamed to cathode-ray tubes and screens in every living room. Elements of habitation are now individually and instantaneously delivered. Life is unmoored.

Climate control is no different—with the evolution of the hearth, heat was progressively liberated. Over time, humans exerted increasing control over temperature, until the "enforced commonalities of location and schedule" began to fray.[1] The Victorian era brought heat to homes, through pipes that circulated hot water. Each room could be temperature-controlled using iron radiators. The triumph of centralized domestic heat, half a century later, was the thermostat, a simple system that maintains a stable temperature at the desired setpoint by sensing ambient air and automatically turning central heating on or off.

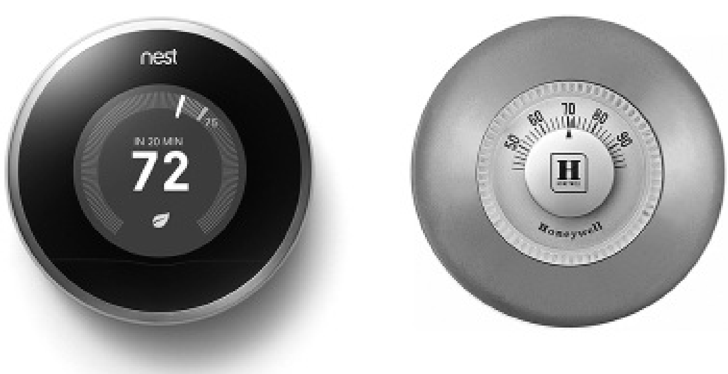
Atomization, however, comes at the cost of efficiency—particularly in the case of climate control. The hearth is no longer a shared resource that attracts people but a distributed system in which each user demands the right to comfort at all times. With central heating and a binary on-off system, there has come to be a dramatic asymmetry between human occupancy and energy use. Entire homes are heated during the day when residents are at work or school, and even when they are home, empty corners of the house are indiscriminately kept just as warm as those in active use. To ensure constant comfort, we heat every space we might possibly inhabit.

Architecture could be conceptually reduced to a functional assemblage of environmental life-support technologies. Reyner Banham's 1965 essay "A Home Is Not a House" took a critical stance toward the modern domestic situation, suggesting a dissociation between environmental support and architecture. The essay begins with an incisive question: "When your house contains such a complex of piping, flues, ducts, wires, lights, inlets, outlets, ovens, sinks, refuse disposers, hi-fi reverberators, antennae, conduits, freezers, heaters—when it contains so many services that the hardware could stand up by itself without any assistance from the house, why have a house to hold it up?"[2] The project highlights our modern dependence on climate control technologies and the obsolescence of both social and natural environments. An image titled *Un-House Transportable Standard-of-Living Package* shows Banham and Dallegret sitting naked in a transparent "Environment Bubble" on either side of an air-conditioning unit.

The thermostat was invented to keep a constant ambient temperature at the user's discretion—and Banham called out the proliferation of such technologies and our concomitant dependence on them. Recent digitization, however, allows feedback systems that dynamically manage climate and allow technology to fall into the background without radically subverting the premise of architecture. Research shows that modulating energy usage based on occupancy could reduce consumption dramatically—in the case of the United States, by almost one-third.[3] One of the earliest devices, aptly named Nest, integrates smartphones with the home heating system. The digital thermostat learns from its users' daily habits, can be controlled remotely, and encourages various environmentally beneficial patterns, including some that are based on gamification and promote playful family dynamics. The evolved thermostat works together with occupants to optimize climate systems.

Nest dynamically adjusts temperature over time, but the next step could be a similar degree of control over space—that is, synchronizing heat with residents' physical location. In a future scenario of architecture that senses and responds, a dynamic system for *local warming* could enable fine-grained control over personal climates while simultaneously improving energy efficiency.[4] Using sophisticated motion tracking paired with dynamic heat emitters, an individual thermal "cloud" would follow each human throughout a building, ensuring constant comfort while minimizing overall heat requirements. "Man no longers seek heat . . . heat seeks man."

Sensor networks integrated with fine-grained response systems are beginning to save energy across a broad spectrum of habitation systems, not only climate control systems. In addition to directing energy where and when it is needed, the trajectory toward sustainability is progressing in another way: mitigating peak loads.



Past and Future of the Thermostat: Examples from Nest and Honeywell Labs

The traditional thermostat, such as the iconic Honeywell dial depicted, maintains a constant temperature at the users' discretion, but at the expense of efficiency. Entire homes or offices are kept comfortable, even if they are entirely or partially empty. Yet digital integration is causing rapid transformations in climate control technology. Nest represents the next generation of home climate system, one that aligns heat with daily and seasonal rhythms. It self-adjusts and builds personalized schedules by integrating directly with smartphones—even warming up a home before its residents arrive if they decide to come home earlier than usual. A digital control system dynamically modulates temperature based on the patterns it learns from occupants, improving overall energy efficiency.

City dwellers tend to demand energy at the same time (for example, at 7 p.m.), so to ensure that lights illuminate when any person (or every person) flips a switch, power plants must constantly produce enough energy to satisfy the maximum possible demand. Pattern analysis and predictive models can help align supply to demand, but even so, it is difficult for plants to tailor production effectively.

Local Warming by the MIT Senseable City Laboratory

A staggering amount of energy is wasted on heating offices, homes, and partially occupied buildings. Energy is used to change the temperature of empty air, rather than the temperature of people themselves. Local Warming addresses this asymmetry by synchronizing climate control with humans. Responsive infrared heating elements, guided by sophisticated motion-tracking sensors, are mounted around a room. These emitters can transmit collimated heat to create a precise personal (and personalized) climate for each occupant. Individual thermal clouds follow people through space, ensuring constant comfort while dramatically reducing overall energy use. Pictured is an early prototype of Local Warming.

In 1981, Buckminster Fuller put forward the radical concept of a Global Energy Grid, a worldwide system of electroducts for international energy transfer. This would enable different countries to balance each other's supply and demand: when Europe is demanding energy during the day, China is asleep, and vice versa.[5] Furthermore, at any given moment, one side of the globe is facing the sun and could potentially be harvesting solar energy. In theory, the Global Energy Grid would send power from the sunny regions with surplus energy to dark regions with a deficit. The crux of Fuller's plan was reducing variations in the global system: mitigating the peaks and valleys. Fuller summarized the concept in characteristically sweeping terms:

> I have summarized my discovery of the option of humanity to become omni-economically and sustainably successful on our planet while phasing out forever all use of fossil fuels and atomic energy generation other than the Sun. I have presented my plan for using our

increasing technical ability to construct high-voltage, superconductive transmission lines and implement an around-the-world electrical energy grid integrating the daytime and nighttime hemispheres, thus swiftly increasing the operating capacity of the world's electrical energy system and, concomitantly, living standard in an unprecedented feat of international cooperation.

Global demand would dictate energy transfer, sparking what Fuller believed would be a shift of the economic standard from gold to kilowatt hours. "Such intercontinental network integration would overnight double the already-installed and in-use electric power generating capacity of our Planet," Fuller concluded.[6] The idea carried remarkable implications for sustainability, economy, and society.

Although the idea of a global superconductor network is alluring, it remains technologically and financially challenging. However, optimizing existing systems from the individual to the urban scale might achieve similar ends. Today, built environments are beginning to dynamically respond to humans in real time using sensing and actuating feedback loops. These responsive digital systems may control energy generation, demand, and distribution. The behavior of these dynamic systems "changes over time, often in response to external stimulation or forcing." The term "feedback" refers to "a situation in which two (or more) dynamical systems are connected together such that each system influences the other and their dynamics are thus strongly coupled."[7] As these systems blanket our cities, every dimension of habitation can be transformed, from the simplest example, occupancy-sensing lights in a single room, to complex systems for sensing, modulating, and optimizing energy patterns across an entire city.

According to the United States Department of Energy, "We are stretching the patchwork nature [of the existing electric grid] to its capacity. To move forward, we need a new kind of electric grid, one that is built from the bottom up to handle the ground-swell of digital and computerized equipment and technology dependent on it—and one that can automate and manage the increasing complexity and needs of electricity in the 21st Century."[8] This is the promise of the *smart grid*.

In a very basic sense, the smart grid is simply an introduction of dynamic control systems for energy production, distribution, and consumption. The concept is rooted in an infrastructural framework of distributed (preferably renewable) energy production. With an integrated digital control system at the neighborhood or regional level, each house could generate energy and share surplus with others nearby or store it in local batteries. Today's archaic energy-switching technology will transition to a digitally controlled system, allowing faster response to real-time conditions.

Smart devices for end users can dynamically configure their consumption patterns based on information from the grid—a refrigerator, for example, can cool when energy is inexpensive and cycle off during peak demand. But the system is not exclusively automated top-down control. It also enables bottom-up incentivized response. Networked smart meters stream real-time information, monitor local and regional demand, and offer incentives directly to users. Surge pricing—that is, pricing that changes in response to demand—provides a financial incentive for users to conserve resources. Individuals are free to make decisions and can do so with the knowledge of overall energy demand. In more domestic terms: your refrigerator might automatically adjust its on-off cycles for efficiency, but running the dishwasher or charging a computer are still individual choices. Smart meters can inform real-time dynamic pricing so that people are free to use power however they want, but when demand is high, the cost will rise. By whatever means, the goal of the smart grid is to mitigate and level out peaks in demand and to reduce the amount of power generation required.

A truly functional smart grid is still quite far in the future, yet it is already possible to implement more efficient energy systems. The likely interim step will be a hybrid system situated between local and regional production, one that incorporates a wide array of urban infrastructures, from architectural batteries to systems for using cars as accumulators. Efficiency will be achieved by centralized distribution systems, optimized by responsive feedback loops, and incrementally supplemented with organically growing local production and consumption networks. If the two can balance dynamically, the marriage of complementary systems would allow for large centralized energy harvesting to fill in the gaps of local production grids.

This points to a future in which the overall energy infrastructure is dynamically managed, as each kilowatt-hour package is tagged and carries a variable price based on real-time supply and demand. Energy will be directed and delivered with intention, precisely where it is needed. In a near future, every device—and every vehicle and every building—will transfer energy in and out, constantly communicating with the broader network to balance overall system flows. Energy supply will respond to demand: the network itself will mitigate peaks and dips as it interacts with human dynamics.