BY DEFAULT

by Forrest Meggers

Behind the modern curtain wall, and beyond the central stack.

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We live in a world of standardized complexity. Our buildings propagate the mantra of high-performance operation built upon a myth of boundless thermal comfort and maximum efficiency. We expect our buildings to perform, and the complexity of this performance has grown alongside increasing expectations for amenities and building efficiencies.

The built environment has become a place in which complexity is default. This tendency for complexity has compartmentalized and obscured key aspects of building function in order to propagate the illusion that designers and engineers comprehend the building as a whole. However, a truly holistic understanding of building is untenable now, as a wide range of new building considerations, such as fantastic formal gestures, dynamic structures, model predictive control and computational fluid dynamics, just to name a few, emerge in the field. The performance of building systems, which is central to issues of energy and the environment, is a critical site in which default building practice actually reinforces a lack of appreciation of complexity. The current environment of standards and codes resists creative interpretation. It addresses complexity through simplification, rather than interpretation. Standards and codes have largely perpetuated a disinterest in complex building systems. It is much easier for architects and designers to implement cookie-cutter central air handling systems than to break codified conventions and explore a novel approach. By recognizing the existing complexity in the operation of buildings, new ideas can emerge that do not depend on comprehensive understanding, but rather on the creative interpretations of complex system interactions—new ideas, which synthesize these interactions into comprehensible design strategies.

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) [1] and its member engineers strive diligently to make creative high-performance building systems. However, ASHRAE works solely within a technical design paradigm excluded from architecture. The standards that seem to emanate from these practices reinforce an independent evaluation of performance that ignores any potential paybacks outside of the technical performance silo. Mechanical, electrical and plumbing systems (MEP) and heating, ventilation and air conditioning (HVAC), already compartmentalized in their common acronyms, are relegated and inserted by default in the plenums, basements and service spaces. Yet the role of these systems in creating a standard operation and expectation of building performance (even while silently influencing architecture) is paramount.

THE RISE OF THE DEFAULT CONDITION

The role of HVAC in buildings was minor in the first half of the twentieth century. The only buildings with any significant air conditioning were theaters, which served as the initial testing ground for the apparatus, invented by Willis Carrier in 1902. Even by the midcentury, only a tiny fraction of buildings had central air-conditioning systems. There was a significant architectural and social debate over the future role of air conditioning, discussed in the history of air conditioning from 1900-1960 researched by Gale Cooper[2] and the analysis of its role in American society by Marsha Ackerman.[3] The acceptance of air-conditioning evolved in response to the inventions and postulations of Carrier and others. Only after the middle of the century did its prevalence in the U.S. begin its rapid rise to the present situation at which 98.6 percent of office space[4] is air-conditioned. As the market for air conditioning scaled up, it reached a tipping point of affordability, and people became accustomed to the phenomenon of cooled air. The mass market of package systems separated research and development of air-conditioning systems from design research and theory for buildings. The result is a segmented system—one that provides architects with packaged systems and components that deliver fixed performance, rather than performance improvements generated through a design process.

Ironically, this obfuscation of air-conditioning systems as a central, standardized package hidden within in the building was largely initiated by the architectural movement that strove to put engineered function on display. Today, the building with the lowest "Energy Star"[5] rating in New York City (at 3 out of 100[6]) is the Seagram Building by Mies Van der Rohe.[7] The narrative of the project was to place its elegant curtain wall structure on display. However, hidden inside the building is a massive cooling system, inefficiently pumping air across all thirty-eight floors of the tower from a single location—all to avoid the inconsistency or interruptions created by intermittent mechanical floors on the modern curtain wall façade. The Seagram Building was a major architectural success, and represented a landmark in the International Style movement. Its reliance on a huge central air-conditioning system is echoed by contemporary projects, such as Skidmore, Owings & Merrill's Lever House, just across Park Avenue, and the United Nations (UN) Headquarters. Le Corbusier's involvement in the design of UN Building is an excellent demarcation of the way air conditioning enabled this new architectural style. Only ten years earlier, Le Corbusier's Salvation Army glass façade in Paris caused major overheating and had to be removed. In the UN Building, glass performed the desired aesthetic function, while the tendency of solar heat gain to cause overheating was compensated for by the power of refrigeration.

Perhaps not so coincidentally, in the year following the Seagram Building's completion in 1958, the American Society of Heating and Ventilation Engineers (ASHVE) and the American Society of Refrigeration Engineers (ASRE) merged to form what is now ASHRAE.[8] The merger was supported by Carrier himself, and created a framework for the subsequent standardization and codification of central HVAC systems into mainstream construction. The consolidation and growth of central HVAC was simultaneously reinforced by the proliferation of the International Style throughout modernist office towers, a typology made inhabitable by this technology.

This positive feedback between large-scale central HVAC systems and the scale of heat gain from thin, elegant modernist curtain walls helped build ASHRAE into a major organization—one that now boasts membership on par with the American Institute of Architects (AIA), which was formed 100 years earlier. The major industry names known in the building sector, such as Carrier, Trane and York, among others, all rode the wave of this cooling market. Central air conditioning was not just a luxury turned into a social necessity. It was also a necessity for the success of the modern design movement, which subsequently generated the massive central air-conditioning market. The result was the standardization of these complex systems into default packages. Ironically, the systems that were born out of necessity for a design movement were removed from the design process itself. Although other styles and movements have emerged, the vast majority of architecture still relies on a default central system.

The ability of a central HVAC system to switch from cooling mode in the summer to heating mode in the winter also propagated the prevalence of air-based heating systems. The beauty of the central air-conditioning system was not only its cooling effect but also its ability to provide universal conditioning of air piped through ducts. Package HVAC systems could be plugged into the ducted risers of the building, necessitating and leveraging the expansive ceiling plenums that arrived in tandem with the modern, open-plan office interior. While boilers formerly supplied heat to radiators through water-based systems, the majority of buildings in the United States are now heated and cooled with air. The shift to air-based systems further centralized the environmental control of buildings to single package systems. Yet as simple physics fundamentally reveals, air contains more than 4,000 times less energy per unit volume—it becomes instantly clear that space and power requirements for the movement of air are exorbitant.

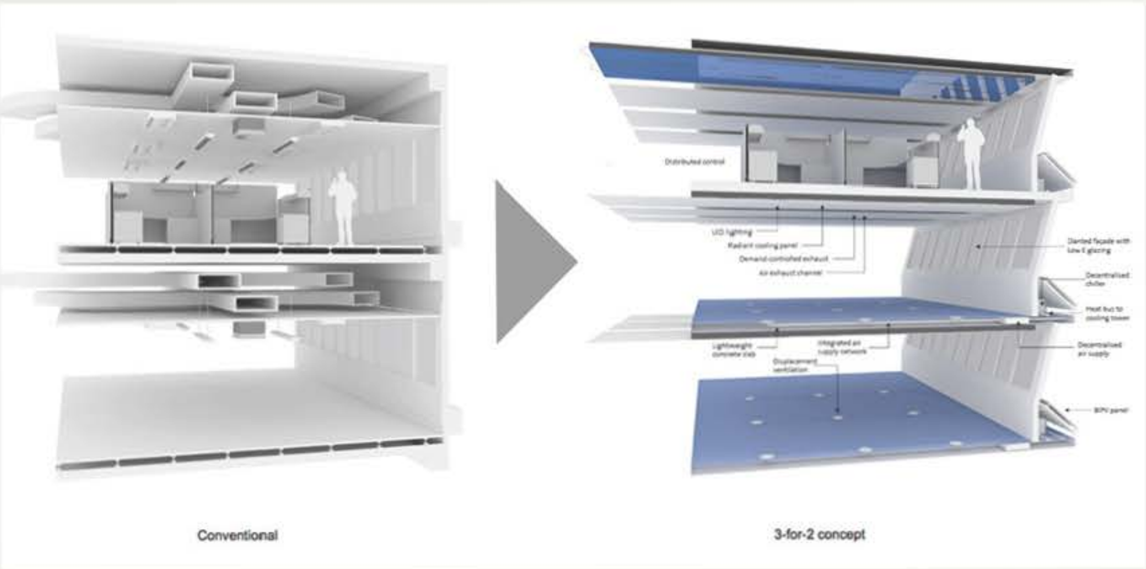
THE DEFAULT PREDICAMENT

Today, we face the challenge of climate change. Buildings contribute up to 45 percent"[9] of the U.S.'s greenhouse gas emissions, of which 15 percent is attributed to air conditioning,[10] which in turn consumes more electricity than any other building function, including electric lighting. Architects and engineers are expected to address issues of energy and material performance to mitigate the massive contribution of the building sector to global warming.

Unfortunately, though, we are still operating within the same ideological compartments invented in the 1950s to contain the complexity of our fantastic new ability to fully condition the indoor environment. This disciplinary compartmentalization is evidenced not only in the performance of the Seagram Building but also in the reliance of major contemporary architectural strategies for high performance upon natural ventilation, which is not a system-level approach.

At present, the two most dominant areas of research in building performance are thermal comfort and energy efficiency. Building performance is expected to maintain a minimum amount of energy demand and environmental impact without compromising unprecedented demands for reliable, steady temperatures and humidity control for thermal comfort. While great research opportunities lie in this challenge, architects and engineers are not addressing them with coherent perspectives. As Avigail Sachs points out in the first issue of this journal,[11] research in architecture has shifted away from fundamental sciences—the very science that HVAC researchers rely on to develop these complex high-performance systems. Even in the 1950s, the U.S. National Science Foundation awarded large scientific grants to faculty at Princeton University's School of Architecture such as the Olgyay brothers with their Thermoheliodon project, also described by Daniel Barber in the first issue of this journal, [12] to develop new technical and social concepts for buildings in response to climate.[13] But subsequently, the research into performance retreated into engineering schools as large-scale HVAC became the status quo, and the industry and institutions like ASHRAE standardized these default methods.

Presently at Princeton, our research at the Cooling and Heating for Architecturally Optimized Systems[14] (CHAOS) Lab attempts to approach the challenge of cooling and heating buildings outside of standard paradigms. We have developed a design concept that integrates building systems such as ducting and hydronic heating and cooling into the slab of the building. This approach, aptly titled 3-for-2[15] , can fit three floors in the height of two for an office building in Singapore[16] and researches system integration practices to save space as demonstrated in the pilot project[17] in Singapore.



3-for-2 typical sections demonstrating the ability of mechanical system integration to free up significant space in a building- in this case making 3 floors in the space of 2. Image courtesy of Low Exergy Module at the Future Cities Laboratory.

We have also worked to leverage the phenomenon of heat transfer by radiation to push for a paradigm shift away from a focus on air temperature as the sole measure of thermal comfort. Your body does not sense air temperature; it only senses the rate of heat exchange, which is why even a room-temperature pool feels much colder when you jump in. In terms of buildings, if you sit with a friend in a room conditioned to a uniform air temperature, the one closest to the cold window will feel colder due to radiation exchange with the cold window surface. Likewise, in summer, the sun makes an outdoor patio comfortable at temperatures well below comfort standards. This expanded definition of comfort, along with a holistic view of thermodynamics (one that includes important components related to system entropy flows), enables a better appreciation for complexity and opportunity in building systems.[18]

There are complexities inherent to the thermodynamics of energy systems that are ignored by default central HVAC design standards. We leverage the concept of exergy, which merges energy and entropy flows, to generate a more holistic system design paradigm, and to question the rationale of default central HVAC systems. Low exergy (LowEx) systems,[19] the focus of the International Energy Agency[20] (IEA) research annex[21] (Annex 64) for a third time, have created a framework to rethink the way we condition buildings, consider temperature and evaluate comfort. Conditioning systems must move beyond air as the default medium. Consideration of temperature is expanded to include air, surfaces and all heat exchange mediums. Evaluation of comfort should incorporate a more informed view of environmental interactions.

These ideas were embodied in collaboration between researchers from the Princeton School of Architecture and the Andlinger Center for Energy and the Environment over the course of summer 2014. We designed a pavilion with the capacity to condition an outdoor space with zero air-conditioning. The combination of architectural expertise in geometry and fabrication with engineering tools for evaporative cooling and heat exchange (along with a little robotic assistance) led to the creation of the Thermoheliodome. Named in homage to the Olgyay brothers' former project, the Thermoheliodome is a cut dome in the shape of the sun path for optimal shading. It uses indirect evaporative cooling through a series of pipes to generate a large cool surface under the pavilion, shifting the perceived temperature of anyone standing below. The surface itself is not, in fact, cooled. The geometry reflects infrared radiation from the pipes centered in the cones to generate six times the surface area in radiation, while actually minimizing the area of cool pipe surface in places where the cool energy (and exergy) is lost to the fleeting outdoor air. The Thermoheliodome is neither an architectural statement nor an engineering invention. It aims to bridge the divide that exists between the two, and demonstrate that interesting possibilities exist at the intersection of these two disciplines.

Thermoheliodome experimental reflective radiant cooling structure powered by indirect evaporation as part of the Beyond Shading project funded by the Andlinger

Center for Energy and the Environment and the Princeton Environmental Institute.
Image courtesy of C.H.A.O.S. Lab.

We strive to envision and achieve new opportunities for performance, and build a new dialogue between the architect and the engineer in their perception, interpretation and implementation of research. The critical question is not how engineers can make the most energy-efficient building or how architects can design the best natural ventilation, but where architectural research practice and engineering design mentality meet. Currently, the default central systems in buildings and the focus on exterior form in architecture leaves little room for dialogue. If we appreciate, and acknowledge, that the history of both rely on one another, as well as accept new ways of thinking, we can simultaneously achieve new levels of design and system performance.

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