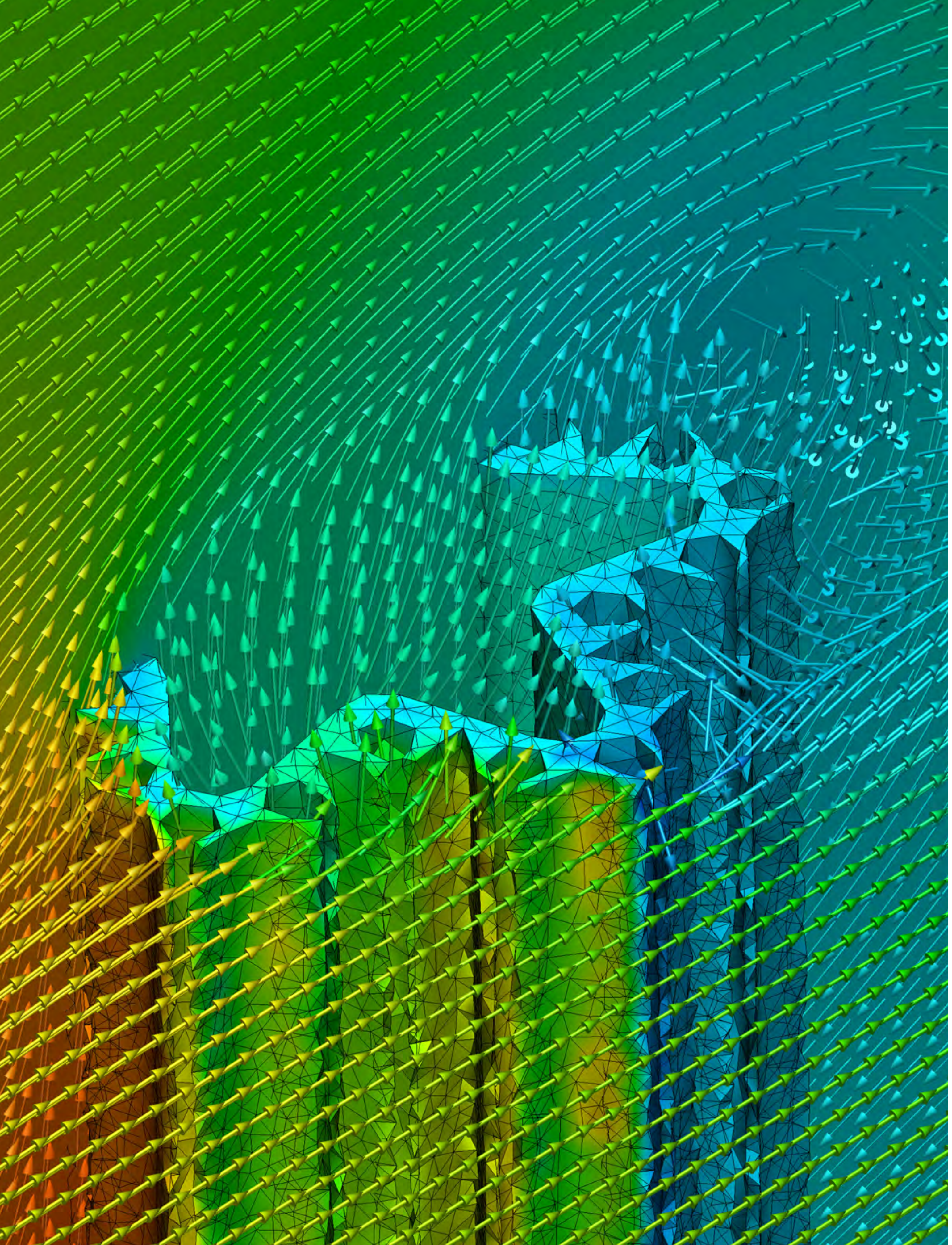

Thermal Form: Making Architecture Work

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WORK

Energy is a concept for equivalently relating many types of work to one another.[1] Alternately described as a *motion against an opposing force, or equivalent to the raising of a weight*,[2] this conceptual exchange of energy for work and vice-versa allows for a structural understanding and explanation of the various material machinations that occur between the *model* world and the physical world. Our obsession with conflating all types of work into the flattening signifier of *energy*, however, causes a variety of different systems, economies, and effects to essentially congeal into a single generic idea, simultaneously equivalent to everything, but expressive of nothing. Lacking basic material and spatial specificity, energy belies the rate at which something is done, *what* is being done, and how it is experienced, in contrast to 'work,' which is understood and monetized in radically different ways.

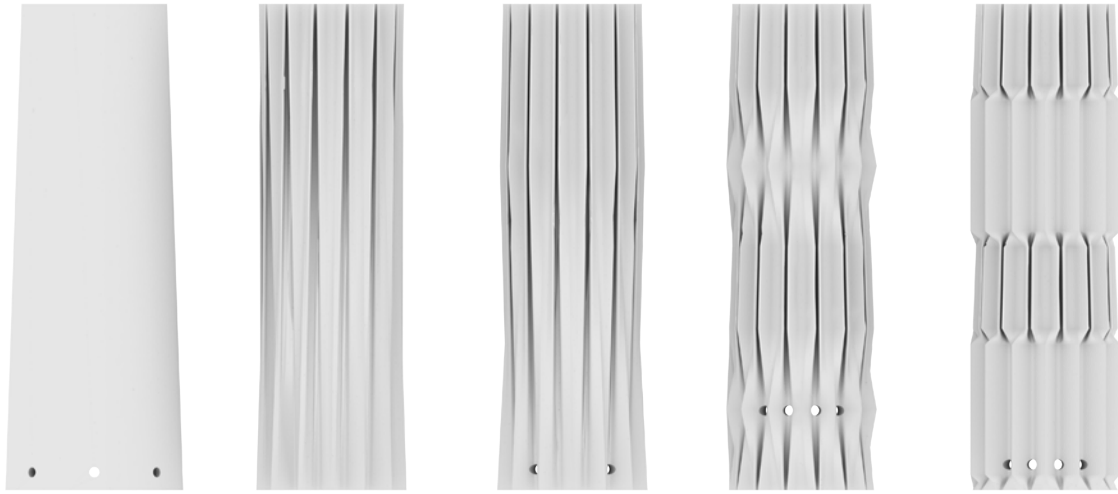
This anachronistic and pervasive mode of thinking has its roots in cybernetics and the perennial effects of post-war systems thinking[3], resulting in the translation of space and event into a persistent horizontal network of exchange, transfer, and transformation, allowing for the smooth flow of energy into multiple states, whether as a finite[4] resource, information, currency, or landscape. Systems-thinking numbs the qualitative sensory apparatus of the body, supplanting it with the metric of *comfort*, which becomes an indexical substitute for the body: a networked assemblage of stimuli and response quantitatively tracing the thermal states of air and water relative to metabolism and autonomic thermoregulation—sweating and shivering—of the human body.

Perhaps more problematic is the widespread adoption by the architectural profession of the relational concepts of energy and comfort as the primary guiding constraints that define building performance, effectively negating the difference between the varieties of thermal effect created by doing different types of work. Space is conditioned in a generic sense: heat is delivered; air is moved; and buildings are configured to accommodate infrastructure and optimized in the service of the demands posed by mechanical systems.

Though there are different types of work, the relative ambiguity of energy is only exacerbated by the established criteria for thermal comfort, emphasizing the absence of perceived thermal effect. Comfort is exclusive of pleasure, as it has historically been about managing

Figure 1: This composite view, generated in a CFD simulation, illustrates how the precise calibration of form can improve building performance. In this example, the exterior surface of an exhaust stack has been modified to redistribute air-pressure. The resulting change in air-velocity and direction eliminates the need for fan assistance in preventing back-flow.

Figure 2 (left to right): Different surface fluting and profile configurations that investigate the ratio of surface area to cross-sectional volume and its impact on formation of vortices.



discomfort with an eye toward *maximizing the productive potential of the human body in a space*[5]. Energy savings, the *observance of limitedness in an economy of means within an industrial framework*[6], becomes the driving design motive, and comfort is reduced to serving as a referential metric which compares the cost of maintaining a space for human habitation relative to losses incurred in terms of human productivity if *comfort* is not maintained. Performance then is a comparative term, juxtaposing the cost of providing an atmosphere with the quantity and value of work performed by the occupant in that atmosphere[7]. A vague signifier that monetizes work, and a thermal criteria emphasizing absence, energy provides very few means of control and design agency for a discipline that specializes in the production of material configurations, spatial effects, habitation, and amusement. Through a perverse inversion, architecture has become the infrastructure for the infrastructure.

THE CAVE IS THE CAMPFIRE

Often cited when discussing issues related to architecture and climate, energy, sustainability and building mechanical systems, *The Architecture of the Well-Tempered Environment*, by Reyner Banham, established a historical narrative for the role of temperature in architecture, revealing the reciprocity between the organizational capacity of structure and its counterpart, the sustaining mechanical equipment. Central to this effort was classifying built and proposed precedents into categories. The Conservative, Selective, and Regenerative Modes are the terms Banham uses to approximately chart the evolution of thermal control strategies, ranging from pre-modern regional vernaculars to contemporary buildings, alternating between a linear developmental narrative—in which the conservative mode is inevitably supplanted by the manifest destiny of the regenerative mode—and a cyclical narrative, by which each of the three modes presents a potential opportunity for invention and development.

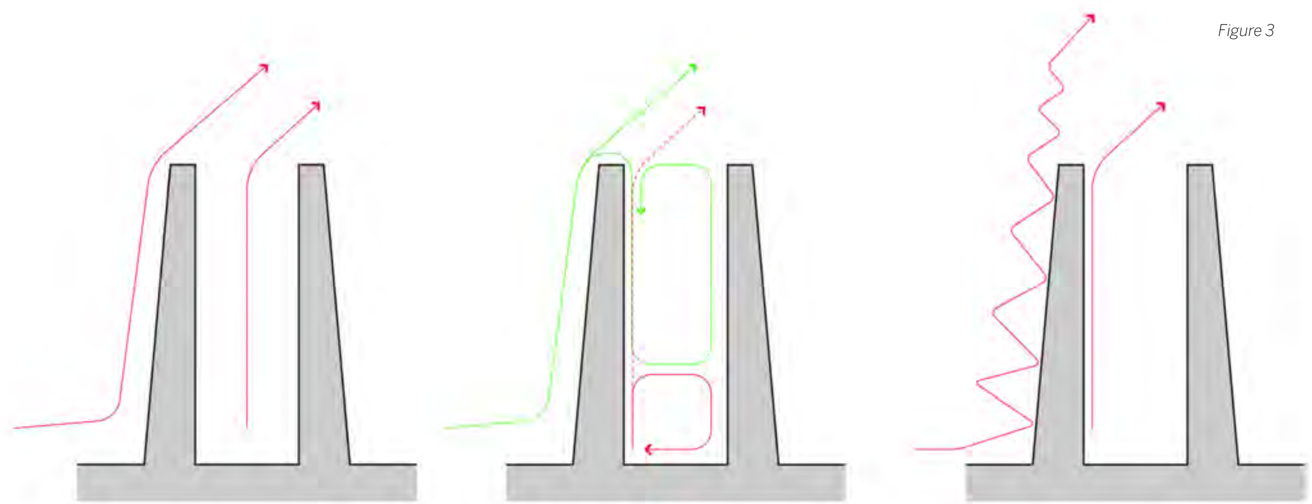
Building strategies with origins in Mediterranean vernaculars, emphasizing the configuration of structure and materials as the sole means for controlling interior thermal comfort, are classified as Conservative. The Selective mode refers to architectures that are modifications made to Conservative building types, required for situations in which the regional climate experiences large diurnal or seasonal shifts of temperature and humidity. These modifications are primarily material and structural, and would be described as passive in contemporary terms. They could also be dynamic—adjustable louvers, for example—allowing a building to adapt to changing conditions.

The Regenerative mode is defined by buildings that are tempered almost exclusively through the use of some form of combustion, challenging the historical dominance of structure and form as the primary strategy in managing internal climate. The Regenerative mode segregates structure from any relationship to temperature, other than as a passive scaffold, leading to a transformation of poche from a device that describes structural cross-section, surface profile, and thermal mass, to one that is characterized by its mimicking structural organization and use as a concealment strategy, dubbed: the new poche—the interstitial grey space of almost-habitable spaces comprised of: dropped ceilings; mechanical, electrical and utilities chases; plumbing; and more plumbing.

Active behind each of these categories is work. Though, while some form of work is done in the conservative and selective modes, it is the addition of heat to a system through combustion in the regenerative mode that *perceived* architectural agency—*modernity*—is achieved. Through the purposeful maintenance of an internal climate by the user, based on systems that separate form from power and structure from temperature—illustrated by the cave and campfire parable[8]—an unintentional bias is created against architectures that operate in the conservative/selective or traditionally passive modes. This is because stewardship of an internal climate and thermal effects provides a physical and conceptual connection between the occupant and the structure—it is a cultural sign of inhabitation and demonstration of the practice of ownership. Under these terms, *passive* structures—those building forms categorized as belonging to the conservative mode—are positioned as lesser in both their ability to provide comfort and their ability to satisfy the desire to inhabit. Additionally, the capacity of the *conservative* mode to do work in comparison to the regenerative mode is significantly diminished because conservative/selective structures maintain thermal comfort levels through the manipulation and mediation of external thermodynamic flows—their perceived level of performance is diminutive in comparison, less responsive, and less robust. This is an unnecessary bias stemming from the building and development boom in extreme climatic regions enabled by air-conditioning and rural electrification.

It is the inherent agency of the individual exhibited in the control over internal climate by the application of combustion, of work (as defined by Banham in the *regenerative* mode), that unwittingly forwards an image of architecture that is incapable of performing work without the support of mechanical systems, echoing the tyranny of aestheticized performance that Banham identified as one of the issues preceding, and ultimately leading to the failure of modernism in addressing climatic performance issues with any degree of expertise, relegating it instead to the domain of the heating and mechanical engineer. Architecture does not necessarily reach its technological apotheosis through the mechanization of energy. Instead, the application of information and energy to a form, transforming geometry in order to maximize its potential for engaging thermal flows, continuously surrounding and passing through it, representing a technological leap, and inverting Banham's three thermal categories. This means that the application of combustion and the production of heat is not necessarily a mechanical process but one that can be generated through the manipulation of form—the *application of radical intelligence and organized knowledge to the ancient craft of building*—though in a slightly different way than Banham may have envisioned. In this way, the structure and geometry of the cave *becomes* the campfire, moving beyond contemporary attempts at Building Integrated Energy Systems—the literal conflation of mechanical and structural systems—and instead entertains the possibility of a highly figured and intelligent surface that is unmoving only in structural terms, but highly dynamic and determined in its response to thermodynamic forces.

Figure 3



Exterior Air Velocity (X Vector and Z Vector at head) and Exhaust Velocity (Z Vector) are proportional to each other.

Exterior Air Velocity (sum of X-vector and Z-Vector) is greater than the Exhaust Air Velocity (Z Vector). Air pressure at the head drops due to cavitation, drawing air into the exhaust stack— i.e. Back Flow.

Air Vortex is generated by exterior surface, drawing air vertically past the line of the pressure head, preventing cavitation and back-flow.

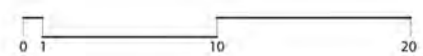
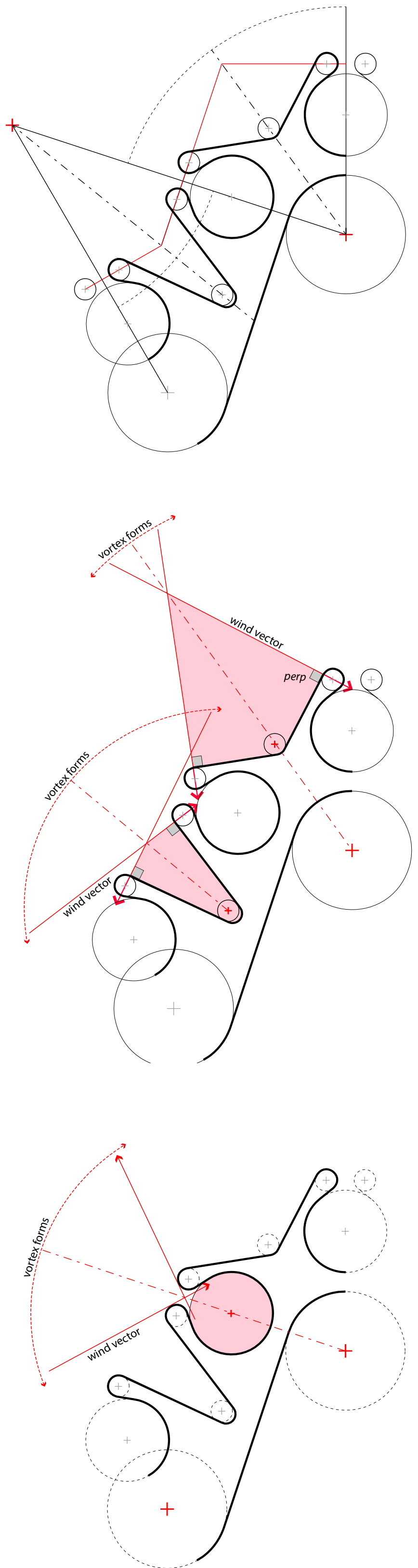


Figure 4



Interior surface curvature corresponds to external vertical surface channels. As radius varies the "length" across which air passes is reduced. This minimizes cavitation.

Angle between external air channels corresponds to vertical channels and interior curvature radius. The depth of these v-shaped grooves is based on negotiating between channel radii cross-section of the stack. A smaller cross-section increases the likelihood of cavitation; a larger cross-section results in turbulence at the pressure head, which negates the positive effects generated by the generated vortices.

THERMAL FORM

The thermal categories established by Reyner Banham are useful for identifying historical points at which structure is "liberated" from the task of being the *prime controller of the environment*[9] , as well as identifying the impact on design culture, which given the freedom to invest structure with a high degree of sculptural plasticity, exaggerated the disconnect between form and thermal performance, resulting in a situation in which form is inherently viewed as incapable of performing work equivalent to mechanical systems. This is a particular frame of logic that resonates with other disciplines as well. Until recently, it was believed that a sailboat could not move at a speed exceeding the velocity of the driving wind[10].

Thermal Form is architecture that does *work*. Or, it is the application of energy as information to architectural geometry, with the express purpose of using the resistance of structure against an opposing thermodynamic force, in order to manipulate and direct flows that exist in both the interior and along the exterior of a building. By examining the relationship between surface configuration, surface area, and type of energy transfer occurring, with a focus on the mechanism of transfer, thermal form strategies can be used to further optimize existing building typologies and environmental control system strategies, or to perform a more radical detouring of the atmosphere of a building.

It also represents a departure from the passive strategies typical of the *conservative mode* because the express goal is to replace high-performance mechanical systems with high-performance form, making architectural form and not the mechanical infrastructure do the *work*, enabling the conversion of the thermal flows attributable to any interior space to be harvested, transformed, and directed in ways that replicate or make unnecessary the various thermally regulating mechanisms used in contemporary building. This is a strategy that reduces the amount of power necessary to temper a building by reducing the amount and complexity of mechanical equipment needed to achieve the same level of interior comfort.

METHOD

If we are to set about constructing tools and methods for the discipline, emphasizing the polyvalent experiential qualities of work, in lieu of contemporary design protocols obsessed with energy and performance, a systematic investigation is required into the relationship between geometry and the various species of thermodynamic figure.[11] Thermal Form is a conjoining of disciplinary issues—representation and composition—juxtaposed with quantitative data analysis. A majority of previous analytical precedents exploring the relationship between geometry and environmental response have dealt with climate data analysis/visualization and the reciprocity between bioclimatic factors and the modification of building envelope—with the exception of projects that examine the adaptation of structure to environmental stresses.

Projects like the Vortex Generating Exhaust Stack[12] (fig. 1) follow a modified research trajectory, which has its roots in the late 19th-century efforts at developing performative systems for the maintenance of indoor air-quality. These systems employed a minimal external combustion source—the waste heat of the kitchen—in conjunction with the spatial and tectonic reorganization of the traditional building exhaust system: the flue[13].

The process for determining the primary developmental form began with a broad survey of existing thermodynamically performative geometries, with an emphasis on those that demonstrated a dynamic ability to direct energy across a specified distance—to perform the classical definition of work. There were several examples in which the surface geometry affected the behavior of thermodynamic flows through the transfer of heat energy. These processes were both fluid and based on the introduction of the specified geometry into an existing flow field at moments of greatest spatial or thermal difference. Two in particular were further investigated through morphological iteration, in which the geometric constraints were identified and manipulated to generate an index of a range of performative types. While the morphological index has come and gone as an aesthetic signifier of numerous contemporary projects, its utility in this case was in generating a constrained sample of forms, or panel, that would be used for Computational Fluid Dynamic simulations. In fixing certain variables, the effect of changes in geometry could be read in the progressive results.

Air Cavitation was chosen for development primarily because of the computing limitations associated with testing convection in relationship to humidity—processes associated with mass transfer. In both cases, classical compositional concepts, such as figure/ground and symmetry, often emerged as quantitative factors. Variations in stereotomic qualities—figuration and surface profile (fig. 2)—quickly became an ad hoc notational tool with which to visually inspect and speculate on the vortex generating potential of the numerous systems studied.

Through iterative parametric modeling and CFD testing, we arrived at a series of conical forms with fluted planometric profiles that generated high-pressure and low-velocity pockets of air in close proximity to the surface. As the velocity of the surrounding air is increased to a level at which back-flow would typically occur in a normative stack (of equivalent height, exhaust cross-sectional area and exhaust velocity) without surface figuration, the pockets of high-pressure air become entrained, forming vertical columns of rotating air—vortices—that prevent a negative velocity pressure to occur at the pressure head (fig. 3), and thus preventing back-flow. This geometry was further refined by examining the direction of the velocity vector relative to the surface normal (fig. 4).

The result is a passive exhaust stack of conservative height that operates under all conditions, from mild to extreme, without any significant change in the rate of building air exhaust. It eliminates the need for fans to mechanically assist in countering pressure changes at the head and in this way suggests an effective means of reducing the power use of buildings—by reducing the complexity or eliminating components of the environmental control system (fig.5).

CONCLUSION

The significance of this approach is that unlike existing contemporary precedents that use CFD visualization to reconfigure the relationship of interior spaces and programs under the rubric of "thermal cascades", Thermal Form directly targets the stuff behind the dropped ceiling—the architecturally latent grey area of mechanical poche space remains an untapped and unexplored zone of architectural invention. By changing our disciplinary definition of passive architecture, or, Banham's Conservative Mode, through the formal and experiential criteria of Work instead of Energy, we open the simultaneous possibility of continuing Banham's historical project and reinvesting the profession with a more comprehensive design agency.

Though the capacity for smart geometry to perform a mode of work is limited, this is due largely in part to the limitations of computation, or the constraints of making all potential thermodynamic criteria actionable in formal responses because of the absence of information. As consumer-grade CFD software becomes available—and increasingly powerful—the impact on modes of architectural representation will necessarily require a disciplinary adjustment of how architectural space is conceived, privileging a shift from a focus on energy and quantitative analysis of performance, to one emphasizing the thermodynamic figure, the capacity of architecture to due work through the manipulation of forms and realized as a new high-performance passive Architecture.

To speculate on the further application of Thermal Form, consider the impact on quality of life that the augmentation of form can achieve in areas in which either social, economic, or geographic conditions make the use of robust mechanical systems limited or impossible. In these regions, prefabricated and lightweight components could be easily deployed, or the formal configurations could be reproduced from locally available materials, delivering a level of performance in proportion to the amount of material and labor necessary exceeding that of traditional passive vernaculars.

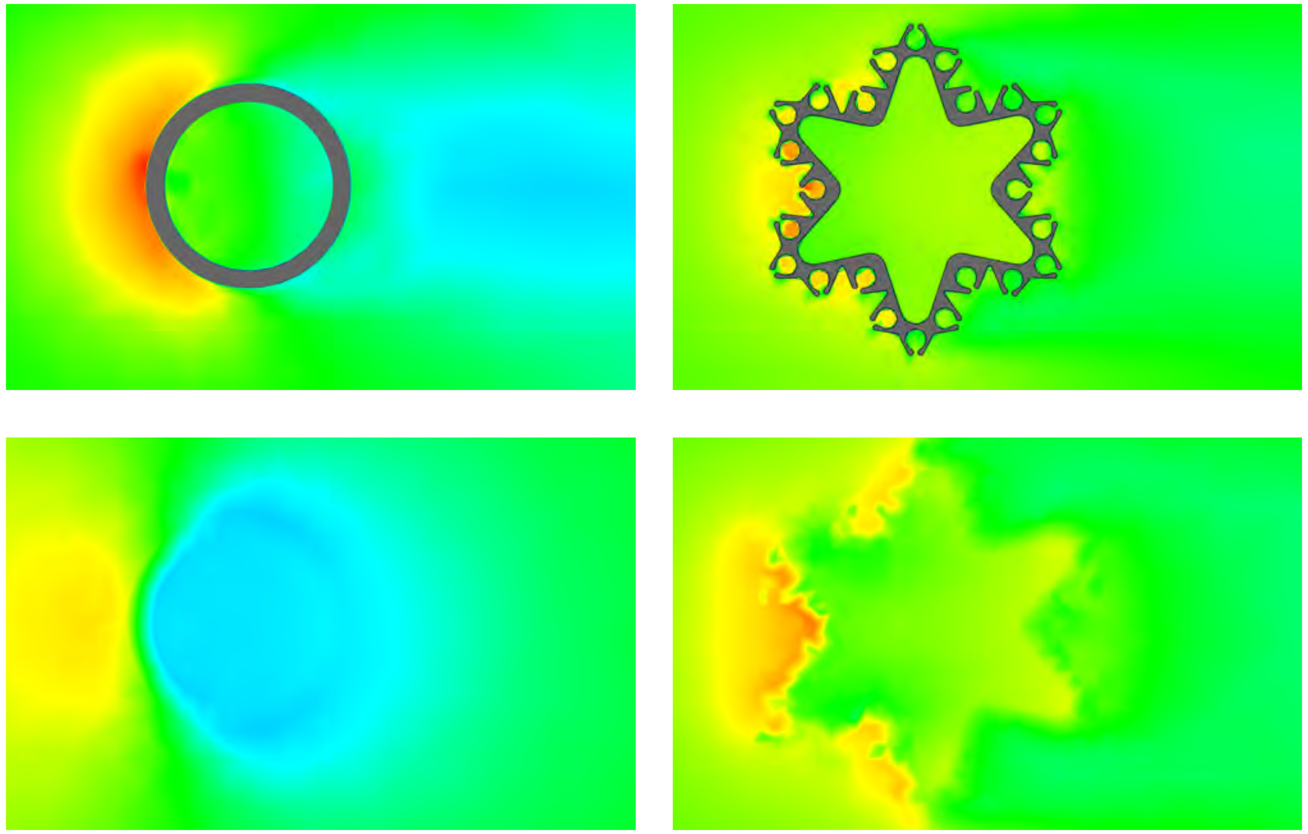


Figure 5: (Top left) As air comes into contact with the exhaust stack surface a high-pressure zone forms. In the images above we see that this high-pressure zone is relatively compact and localized. The distribution of air-pressure around the stack is as expected; air-pressure is highest on the windward side and an area of negative pressure forms on the leeward side (Bottom left) At a distance of 1 meter above the pressure-head/exhaust opening, the localized zone of high-pressure below, produces a negative-pressure as it passes over the stack, creating a back-flow condition. The use of fans and dampers is typically used to counter this effect. (Top right) In the proposed stack geometry, air-pressure is distributed across a larger cross-sectional area on the windward side and the negative-pressure zone on the leeward side is greatly reduced. (Bottom right) At a distance of 1 meter above the pressure head, we see that the high-pressure zone of distributed air across the cross-sectional area below has formed a high-pressure column of air above. This high-pressure zone forms a virtual barrier or wall of air around the pressure-head/exhaust opening and draws air out of the stack, thus preventing back-flow and reducing or eliminating the need for fan assistance.

ENDNOTES

1. Peter Atkins, "The First Law: The Conservation of Energy," in *The Laws of Thermodynamics* (Oxford: Oxford University Press, 2010) 16-17.

2. Atkins, *The Laws of Thermodynamics,* 17.

3. Reinhold Martin, "The Organizational Complex," in *The Organizational Complex: Architecture, Media, and Corporate Space* (Cambridge: MIT Press, 2005) 18-24.

4. Ivan Illich, *Energy and Equity (Ideas in Progress)* (London: Marion Boyers Publishers, 1974).For Illich, it is the monetization of the idea of energy that substantiates the rhetoric of an energy crisis. In the very real terms of thermodynamics, the availability of energy approaches infinity. Political and economic structures make energy scarce through transformation and control.

5. Le Corbusier, *Vers Une Architecture (Towards a New Architecture)* (London: Dover Publications, 1985).

6. Susannah Hagen, *Taking Shape: A New Contract Between Architecture and Nature* (Oxford: Architectural Press/Butterworth-Heineman, 2001). Hagen looks at the industrial transformation of labor and its correlation to the development of architectural systems that enabled energy-intensive forms of construction.

7. Michael Wang, "Into Thin Air: The Merging of Architecture and Environment," in *ART FORUM International* 49, no. 9 (2010).

8. Reyner Banham, "Environmental Management," in *The Architecture of the Well-Tempered Environment 2nd Edition,* (Chicago: University of Chicago Press, 1984) 20-21. The focus of Banham's parable is a savage western European tribe that given a pile of timber would either build a shelter—the structural solution—or, build a fire—the combustion option. Either structure or combustion will provide some measure of defense against the elements, but comfort will only be achieved by a rational application of both. According to Banham, the choice is predominately based on cultural tradition and in the case of Western European societies, often favors massive structural solutions.

9. Banham, "The Environments of Large Buildings."

10. The Yacht: l'Hydroptère; Name: Alain Thébault FRA and 10 crew; Dates: 4 September 2009

11. Kiel Moe, "Thermodynamic Figures in Architecture," in *Thermally Active Surfaces in Architecture* (New York: Princeton Architectural Press, 2010) 120-24.

12. Patent Pending/January 31, 2014

13. Banham, "A Dark Satanic Century,"36-39. The "Doctor's" Houses, in particular the *Octagon* House by Dr. John Hayward, reconfigures the chimney flue to act as a passive stack ventilation system by running a vertical masonry partition through the flue and routing the return air adjacent to the kitchen, thereby decreasing the density of the air and increasing the pressure difference between inlet and pressure head.