THE CAVE IS THE CAMPFIRE: THERMAL FORMS IN ARCHITECTURE

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ABSTRACT

This paper introduces the concept of Thermal Form: architectural geometries that control or transform ambient thermodynamic flows in order to reduce or simplify the environmental control systems used to temper buildings. Contemporary architectural agendas concerned with sustainability and energy typically emphasize the efficiency of mechanical systems - measured through the quantity of power used. Thermal Forms by contrast emphasize work, or, the conversion of energy via architectural geometries into dynamic flows that replicate those produced by mechanical systems. Thus sustainability, energy and building resilience are understood as intrinsic to the architectural configuration of material, envelope and structure rather than the mechanical systems. The structure of this paper looks at the historical narrative through which architecture developed in reciprocity to mechanical systems and then presents a counter-narrative based on a research and design method utilizing Computational Fluid Dynamic simulations.
INTRODUCTION

Energy is a concept for equivalently relating many types of work to one another (Atkins 2010, pp. 16-17). Alternately described as a motion against an opposing force, or equivalent to the raising of a weight, this conceptual exchange of energy for work and vice-versa, allows for a structural understanding of the reciprocity between energy and form that is contingent on material and experiential specificities (Atkins 2010, p. 17). Latent within architectures many energetic ecologies is the structural ability of form to convert ambient energies into movement. Exploring the architectural potentials of work reveals new thermodynamic typologies dubbed Thermal Form, architecture that does work. It is the application of energy as information to architectural forms that represents a new energy agenda for architecture. 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 types, environmental control system strategies, and/or perform a more radical detouring of the atmosphere of a building. Within this conceptual framework, energy attains the ability to map a range of architectural subjectivities and phenomena, thus displacing paradigms within which energy is either a reductive quantitative assessment and accounting of power-resource consumption, or, a biological systems metaphor.

Developing a capability to exercise control over ambient forces through an exploration of novel structural, material, and compositional rubrics necessarily challenges the correspondence between form and energy that is exhibited in the various “accounting” metrics used to qualify performance. Our obsession with conflating all types of work into the flattening signifier of energy 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, the legacy of which resulted in the conceptual translation of space and event into a persistent horizontal network of exchange, transfer, and transformation (Martin 2005, pp. 18-21). Though this allows for the smooth flow of energy into multiple states—whether as a finite resource, information, currency, or landscape—systems-thinking also numbs the qualitative sensory apparatus of the body, supplanting it with the metric of comfort (Illich 1971) (Note 1).

Systems then become 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. Adding to this already problematic condition is the widespread adoption by the architectural professions, of the relational concept 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, 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 discomfort with an eye toward "maximizing the productive potential of the human body in a space (Le Corbusier 1985). Energy savings, the "observance of limitedness in an economy of means within an industrial framework" (Hagen 2001) (Note 2), 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—when comfort is not maintained. Performance is then a comparative term, juxtaposing the cost of providing an atmosphere with the quantity and value of work performed by the occupant (Wang 2010). 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.

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 and sometimes celebrating the reciprocity between the organizational capacity of structure and its counterpart, the sustaining mechanical equipment. Central to Banham’s thesis was his classification of architectural precedents into three architectural “modes”—the Conservative, Selective, and Regenerative—that map the co-evolution of thermal control strategies, ranging from pre-modern regional vernaculars to the emergence of contemporary building typologies.

Building strategies based on the use of thermal mass and 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 architecture(s) 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 in contemporary terms would be best represented by architectures that make use of multiple and inter-related, passive heating and cooling strategies. 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 pochē 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 pochē—the interstitial grey space of almost-habitable spaces comprised of dropped ceilings; mechanical, electrical, and utilities chases; plumbing and more plumbing.

These architectural modes are existing thermal strategies as identified by Reyner Banham and useful for identifying historical points at which structure is “liberated” from the task of being the prime controller of the environment (Banham, Buildings 1984, pp. 71-92). They reveal 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 thermodynamic performance. This resulted in the rhetorical aestheticization of performance by architectural culture and the “celebration” of building systems that did not include the adoption of meaningful performance metrics.

Underlying the action of tempering space for each of Banham’s thermal categories is work. Though 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—a.k.a. 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—an unintentional bias is created illustrated by Banham’s cave and campfire parable against architectures that operate in the conservative and selective or traditionally passive modes (Banham, Management 1984, pp. 20-21) (Note 3).

However, architecture does not necessarily reach its technological apotheosis through the mechanization of energy. Applying information as energy to a form, and optimizing geometries in order to maximize the potential for engaging the ambient thermodynamic flows moving through it, represents a technological leap. It also reinterprets the historicized inter-relationship of Banham’s three thermal categories and their role in guiding the developments of architecture in the 20th century. For example, the aesthetics of building performance that Banham identified as one of the issues preceding, and ultimately leading to the failure of modernism in addressing climatic performance issues. In projecting “intelligence” onto form, architecture becomes invested with a physical tracery, or index of thermodynamic flows. This inevitably leads to novel formal and spatial effects, but more importantly reconsiders the contemporary potentials of conservative and selective architectural modes as defined by Banham. Thus encouraging energetic flows through 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.

This represents a conceptual rethinking of the role of structure in the thermal-mass strategies represented by the conservative mode and the mechanical systems of the Regenerative mode. Banham used the Cave and the Campfire metaphor to articulate the performative differences between traditional building systems and the mechanical centric modalities of Modernism. If the Cave represents a thermally capable structural mass and the Campfire a cooling and combustion system, Thermal Form proposes to make structure perform like a mechanical system, thus investing the architectural tectonic with a more dynamic thermodynamic potential. Ultimately, thermal forms seek to reduce 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. In this way, the structure and geometry of the cave approaches the performative intent of the campfire and dissolves the regenerative modes monopoly on the production of highly-calibrated atmospheres and spaces. Moving beyond contemporary attempts at Building Integrated Energy Systems—the literal suturing of mechanical systems onto structure and envelope—thermal form entertains the possibility of a highly figured and intelligent surface that is unmoving only in structural terms, yet highly dynamic and determined in its response to thermo-dynamic forces.

If we are to set about constructing tools and methods for the discipline that emphasize the poly-valent 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 action. 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—VGES (Figure 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 (Banham, Dark Century, pp. 36-39) (Note 4). While there are similarities in how the traditional flue and the VGES operate, the performance criteria of the latter and its proposed application differ from those of a contemporary chimney flue in several respects but primarily in that a stack exhaust deals with the removal of internal heat-gains, ventilation, and preventing the build-up of stagnant air, as opposed to smoke, soot and carbon-monoxide. Lastly, stack ventilation was chosen as the primary environmental control system to be optimized using this method owing to its role in the historic narrative outlined by Banham and because of the inherent resilience of these systems and broad scope of potential applicability (Salt and Walker 2006) (Note 5).
Determining the primary developmental forms leading to the design of the VGES began with a broad survey of existing thermodynamically performative geometries from outside of the discipline, with an emphasis on those that demonstrated some capacity to direct energy across a specified distance because of the intrinsic virtues of their form—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 or dynamic energy; turbo-fan exhaust manifolds, automotive ground-effects, and golf-balls, are some examples. Vernacular architectures that would fall into the conservative mode were also included because the radicalization of these building types is one of the possible outcomes suggested by Banham as a result of the cross-pollination of intelligent systems and "timeless ways of building" (Banham 1984, Large Buildings). Stack ventilation effects are utilized by various cultures and these "other" novel examples informed the process with a modicum of intuitive design direction.

The exhaust cowlings of jet and turbo-fan engines and automotive sheet metal techniques for reducing drag became starting points for testing and study. Both dealt—tangentially—with thermodynamic issues similar to those encountered in buildings and possessed some degree of structural capacity. Early explorations focused on identifying the particular thermodynamic specificities of each—the goal was to understand the performative reciprocity between form and flow. Testing the forms that eventually became the VGES was performed using Autodesk's Simulation CFD and progressed through iterations and permutations. Is it important to note that though the chosen forms shared—in concept—similar performative criteria to buildings, they operated at different scales of flow, force, and size. This meant that the investigations began by identifying useful scales of architectural application. 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. The test results revealed the effect of changes in geometry as variations in velocity, static pressure, velocity pressure and volume flow-rate (Figure 2).

By analyzing the underlying geometric constraints related to the exhaust cowling and then rationalizing this form by reconstructing it using a parametric scaffold consisting of circles, cones and polygons, a catalog of possible variations was developed in plan and section (Figure 3). The relationship between conical geometries and the production of a flow-field vortex or cyclone was a discovery that occurred in parallel to the CFD tests and is a well-documented phenomena with both advantageous and problematic effects that were later revealed as the course of research progressed (Elayed and Lacor 2009). Variations in the spatial and formal relationships represented by the scaffold were generated in Grasshopper, through which a cross-sectional profile of a potential stack design would then be created by drawing a continuous poly-line tangent to each circle (the stack height and width was initially set at 5m x 1m because these dimensions were a minimum required height to ventilate a single story space). At the earliest stages in the
process, testing was extremely exploratory and usually centered around a “what-if” scenario that related to intensifying an observed existing thermodynamic effect or difference by making modifications to the forms. For example, the “flut-ing” studies (Figure 4) were intended to look at the relationship between height and depth of surface figuration in relationship to the length of the resulting wake effect. These also revealed the correspondence between distribution of static-pressure on the object surface and the size of the wake area; this established the basic formal and dynamic variables guiding the design process and suggested a performative relationship corresponding directly to the dynamic effects of air-velocity and air-pressure.

A series of conical forms were originally derived with fluted planimetric 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, thus preventing back-flow (Figure 5). By examining the direction of the velocity vector relative to the surface normal, this geometry was further refined. As the first generation of thermal forms to be developed, the testing method was still being refined and did not take into account the feedback provided by tracking air-particles through the use of traces. Based on the observation of velocity vectors and air-pressure gradients the original conclusion was that the areas of high and low pressure on the interior of the stack were being shifted up or down based on both the velocity and the direction of vertical spin (Figures 6, 7). With the addition of particle-traces, it became clear that the goal was not the creation of a perfectly laminar flow vertically, but instead creating a high velocity eddy at the pressure-head that serves as a buffer for exchanging air between the interior and exterior, while eliminating turbulent back-flow.

**MANIPULATING THE PRESSURE-PLANE**

Ultimately, the variations applied to the interior and exterior surface of the VGES serve to modulate the location of the neutral pressure plane. In stack exhausts and buildings, the neutral pressure plane is the point at which the interior static air-pressure is equivalent to the exterior static air-pressure and it is generally located at the approximate vertical half-way point. This zone can move upward or downward depending on several factors such as the rate at which air infiltrates/exfiltrates the building envelope, the velocity air-pressure directed onto the envelope, pressure differences due to temperature and velocity. Varying the interior diameter or “throat” of the VGES has two primary effects that alter the vertical flow of air. As the surfaces attenuate, they perform work on the moving air and increase its velocity while simultaneously decreasing the velocity-pressure—a variation on Bernoulli’s Principle. This progressive increase in velocity prevents turbulence within the stack and produces an almost perfectly laminar flow (Figure 8).
Secondly, it also raises or lowers the interior pressure plane above or below the stack mid-point. When raised to a height near the area where air is drafted down into the stack at the pressure-head, the pressure-plane acts as a buffer and prevents exterior air from descending beyond a desired point in the interior. This is particularly true when exterior air-velocities reach a level in which they would normally prevent air from exiting the stack. Generally, this is remedied in buildings by increasing fan-power. In utilizing the dynamic effects of work performed by “intelli-gent” architectural forms, the VGES achieves a level of performance that is similar or superior to a control stack without any increase in fan power (Note 6) (Figure 9).

EFFECTS OF VORTICES ON STACK VENTILATION
In addition to varying the interior stack diameter, the exterior surface area is increased through the addition of an array of conics. The resulting observable effects on air-flow around the VGES caused by this figuration are: greater distribution of velocity-pressure on the exterior surface, increase in the area of wake-effect and an increase in the upward draft on the leeward side of the stack. As mentioned, the conics also generate air-vortices—rotating columns of air—that once established are able maintain a direction of flow that is somewhat resistant to turbulence. As air-velocities were increased in tests, it became apparent that the air-vortices were interacting with the area above the pressure-plane in such a way that they increased the rate at which air was being exchanged, increased the rate at which the eddies in the pressure-head spun and thus prevented the formation of turbulence at the pressure head. They did however produce a significant and turbulent wake effect. When deployed without the corresponding controls applied to the pressure-plane via the variations in the interior diameters, the conics also produced eddies that extended the entire depth of the stack (Figure 10).

CONCLUSION
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 scope. Thermal Form directly targets the stuff behind the dropped ceiling; the architecturally latent grey area of mechanical space remains an untapped and unexplored zone of architectural invention. Proposals like the VGES demonstrate an approach to energy that is intent on realizing the energetic potential of architectural structure to perform levels of work similar to some of its mechanical counterparts. As a result, the thermal pochê indicative of the—now radicalized—conservative mode takes on the same performative capabilities of the mechanical systems intrinsic to the regenerative mode.

Though the capacity for smart geometry to perform a mode of work may appear somewhat 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 in-formation. As consumer grade CFD software becomes available, and increasingly powerful, the impact on modes of architectural representation will necessarily require a disciplinary adjust-ment of how architectural space is conceived. In privileging a shift from a focus on energy and quantitative analysis of performance, to one emphasizing the thermodynamic figure, the capaci-ty of architecture to do work through the manipulation of forms inherently suggests a design agenda that reconsiders how high-performance passive Architecture is considered and evalu-ated (Moe 2010, p. 120-124).

To speculate on the further application of Thermal Forms, consider the impact on quality of life that the augmentation of form can achieve in areas where either economic or geo-graphic condi-tions make the use of robust mechanical systems limited or impossible. In these regions, pre-fabricated and lightweight components could be easily deployed, or thermal forms could be re-produced 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.

NOTES

1 For Illich, it is the monetization of the idea of energy that substantiates the rhetoric of an en-ergy 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 (Illich 1974).

2 Hagen looks at the industrial transformation of labor and its correlation to the development of architectural systems that enabled energy intensive forms of construction (Hagen 2001).

3 The focus of Banham’s parable is a savage western European tribe that given a pile of tim-ber would either build a shelter - the structural solution - or, build a fire - the combustion op-tion. Either structure or combus-tion will provide some measure of defense against the ele-ments, but comfort will only be achieved by a rational application of both. According to Ban-ham, the choice is predominately based on cultural tradition and in the case of Western Eu-ropean societies, often favors massive structural solutions (Banham 1984, pp. 20-21).

4 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 decreas-ing the density of the air and increasing the pressure difference between inlet and pressure head” (Banham, “A Dark Satanic Century”, pg 36-39).

5 Resilience is used within Ecology to describe a systems capability to recover from disruption by external or internal forces. It also refers to the degree of disruption that an ecosystem can absorb before failing (Salt and Walker 2006).

6 The criteria used to compare the VGES to a neutral stack are the volume flow-rate m³/s at the pressure head and the observance of particle traces generated in Simulation CFD.
REFERENCES


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