Enhancing Façade-Interior Thermal Vascularity to Improve Utilization of Climatic Thermal Resources in Internal Load-Dominated Buildings

by

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Abstract

During the era of industrialization, methods of thermal climate control in large commercial buildings emerged according to certain prevailing paradigms: mechanization, concentration of populations, and the capitalization of abundant, inexpensive sources of energy. In concert with parallel economic, philosophical, and design trends, these methods resulted in the massive, high-occupancy, deep-floor plate architecture of the Modern era, and the International Style in particular. These built environments are impressive systems, but they fail to meet requirements for human comfort and well-being due (in part) to the inherent difficulties in heating and cooling such large volumes, such as lack of proximity to façade area. These failures have serious consequences for energy consumption as well, because climate control systems must not only compensate for the building's internal thermal loads, but for inputs from energetic, climatic processes as well: airflow, ambient temperatures, and insolation. Building stock in the US consumes over 40% of the national energy budget, and nearly half of that is due to losses in the generation and distribution of electricity. Heating, ventilation, and air conditioning of office spaces are largely electrically-driven, and consume roughly 10% of the building sector's energy total. As concerns mount over the wise use of world energy supplies and the penalties of over-consumption, it becomes necessary to address major causes such as this ineffective operation of built commercial space.

Some reductions in large commercial building energy use can be gained through high-efficiency HVAC systems such as those that utilize hydronic distribution, and technologies now becoming available such as passively phase-changing thermal massing. But as evolutions of the original paradigm of centralized, electrically-driven air conditioning, these advances do little to address the fundamental problem: deep-floor plate buildings trap heat

because effective pathways for its escape don't exist in the same distributed manner that the heat is generated.

Climatic energies, however, do impact buildings in a distributed manner. Using these resources to power the thermal transfer processes in building interiors has the potential to relieve much of the burden on HVAC systems, and to reduce associated energy costs. The benefit is three-fold: the harnessing of climatic resources reduces the need to consume externally-sourced energy, and reduces the energy that impacts the building and its systems. In addition, because diffuse climatic flows typically impact HVAC systems as thermal loads, the ability to concentrate them at the building façade (such as is possible with the transformation of sunlight into electricity and high-grade thermal energy using current solar collection systems) is akin to passively concentrating a diffuse resource; a rare and valuable opportunity. To accomplish this, however, thermal distribution in the building must be reconsidered. Currently, heating and cooling resources (typically air or water flows) originate at a centralized plant, located within the volume that it serves in a building, and are pumped out through that volume as required. The resulting trunk-and-branch structure of these systems isn't effective at transmitting resources that originate at the building façade, and so this topography needs to be revised. In addition, although outdoor ambient thermal conditions promise to be a useful sink to the excess energy interior to load-dominated buildings, the temperature differences available are typically too small for traditional building-scale heat transfer technologies to utilize, at least during the times when augmenting those differences is not an option.

If a network of better-conducting thermal energy conduits was available in this building typology to connect heat and cold generated at the façade to interior spaces in need of conditioning, there would exist an appropriate bridge between demands and available resources. This network can be envisioned as thermally *vascular*, selectively transporting heat through volumes and across their surfaces, along pathways determined to be efficient. This specific vascularity would bear much in common with existing vascular networks, such as the circulatory system in animals, or the consolidation, channeling and braiding, and eventual deposition and branching that occurs with hydrological flow across a landscape; the specific characteristics, however, would arise from the interaction of the thermal flow and its substrate, the built environment.

In the specific case examined in this study, this network couples the thermal concentration and control abilities of CASE's Integrated Concentrating Solar Façade (ICSF) system to façade-exterior heat exchangers, small-scale absorption cooling, temporary heat and cold storage, and radiant ceiling panels in the discrete thermal zones of a floor of a typical internal load-dominated office building. In developing the requirements for this vascular thermal redistribution, this study explores the heat transfer relationships amongst these system elements and their setting: outdoor conditions and the programmatic requirements for thermal control. These relationships are tested through the simulation of a prototypical large office building, which is run over the course of one year, and located in three distinct climates. The effects of ICSF (as well as equivalent evacuated tube solar collection, for comparison) is introduced to the simulation, as is the hypothetical heat extraction via the proposed vascular thermal network. A physical system design proposal is introduced, the goal of which is to satisfy (to the extent possible) building thermal requirements with climatic resources, and the results are analyzed. The parametric framework that develops through this exercise has utility beyond this specific study, in the evaluation of other thermally-active elements within a building context.

This study is limited to representations of the system elements and circumstance examined. In particular, humidity management, which is integral to the quality of a built environment, is considered solely through the consideration already given in the design of constituent elements. The principles of vascular thermal transfer and storage techniques, however, also apply to other climate-interactive systems and thermally characteristic elements of building design, and generally in expanding the application of local thermal energy resources to demands of the built environment.