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"This RCEU Project Aims at Studying the Design (Modeling) Construction and Operation (Control) of Hydronically Activated Building Envelopes with both Structural and Thermally Active Functionalities with the Goal of Understanding the Mechanical and Physical Process Governing their Performances"

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2016 Research and Creative for Undergraduate Students (RCEU) Proposal

Mentoring Faculty Information

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Project Summary

This RCEU project aims at studying the design (modeling), construction, and operation (control) of hydronically activated building envelopes with both structural and thermally active functionalities, with the goal of understanding the mechanical and physical processes governing their performances. The objective is to test the hypothesis that optimal building structural and energetic performances can be simultaneously achieved by strategically circulating and pressurizing water in its envelope system. A combined experimental and analytical research will be carried out by the student to (i) demonstrate the feasibility of using fluids for maintaining building hemostat (i.e., heating and cooling); (ii) understand the fundamental mechanical-thermal phenomena governing the performance, and (iii) validate the sustainable construction and full-scale component demonstration.

The building sector accounts for 40% of the primary annual energy consumption in the United States[1], of which nearly 48% of the energy consumed in the residential sector is used for space conditioning, and another 17% for water heating. Currently, the dominant modes of building heating and cooling are centralized, air-based HVAC. However, air is, in fact, a poor medium for distributing thermal energy, i.e., the heat capacity of air is nearly 3,500 times lower than that of water for the same volume. Further complications arise as infiltration, buoyancy, and convection of airflow makes the heat flow in the building inefficient and unpredictable. Water, on the other hand, is much easier to control and has been increasingly used for heating and cooling of buildings. Lessons are taken from nature for efficient energy management and distribution using fluids; specifically, homoeothermic animals regulate deep and surface body temperature through ***hydronic exchanges*** with the circulatory and integumentary systems that use the skin as thermal source and sink, see Fig. 1. Owing to the capillary mat blood vessels and regulated blood flow, living skin develops an extraordinarily high thermal emissivity and absorptivity (i.e., higher than almost all architectural substances). As a result, warm-blood animals can maintain a fairly steady body temperature under a considerable variation of external conditions including changes in temperature, vapor pressure, air velocity, and insulation etc. Analogous to animal skin, *the two primary functions of building envelope systems are **managing the thermal load** of its enclosed spaces and **protecting** the occupants from hazardous external environments*. As the immediate shield for its residents, the building envelope often serves as the last line of defense to protect human lives from natural and anthropogenic hazards; in the meantime, as the main determinant of building thermal loads (i.e., the amount of energy needed for heating/cooling) it is also critical for reducing the life-cycle energy consumption of buildings.

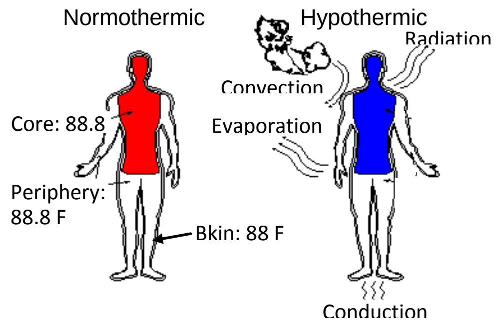

Fig. 1 Thermoregulation mechanisms

Currently, the designs of building envelope components against structural (mechanical) and thermal loads are carried out separately using independent, isolated criteria and prescriptive approaches. However, achieving seamless integration of building envelope's structural and thermal load management functionalities will lead to a substantial improvement in the system-level efficiency. This research seeks to *utilize pressure-regulated hydronic circuits, embedded in a strong and durable structural backbone, to create next generation envelope systems that are capable of performing the full range of structural functions, and in the meantime, possess variable thermal and structural properties regulated by internal pressure and flowrate*. To achieve this objective, a research plan is proposed to 1) develop hydronically-activated building envelope prototype which has both high structural strength and thermal activity, 2) study the interactions between mechanical/thermal induced damage and the mechanical and heat conduction behavior of civil structural materials, and 3) build model houses using the proposed concept in order to validate the hypothesis that building energetic and structural performance can be simultaneously improved by strategically circulation water in the building envelope system.

Student Duty

The undergraduate research assistants will work under the faculty advisor's supervision to:

[1] Federal Research and Development Agenda, "Net-Zero Energy , High-Performance Green Buildings National Science and Technology Council," 2008.

- Study the experimental (both mechanical and thermal) testing techniques for civil engineering materials, components and prototypes structures. Experiments will be performed to investigate the effects of damage on the mechanical property and thermal conductivity of materials.
- Design and perform mechanical and thermal testing to study the strength, ductility, and failure mechanism of infrastructural materials and components (e.g., concrete and polymeric composites) under combined mechanical and thermal loading. The tests will be performed at the new SHM&IM laboratory. Students will have access to a number of state-of-art testing equipment including MTS servo-hydraulic test machine etc.
- Evaluate the energetic and structural efficiencies of hydronically activated structures using prototype model structures.

It is expected that the students will work full-time (32-40 hrs/week) for 12 weeks during summer 2015. Office space located in Technology Hall (OKT) and computers will be made available to the enrolled students. The students will have access to the newly established structural hazard mitigation and intelligent materials laboratory located in the high-bay area of Tech Hall.

Mentor Supervision and Interaction

The faculty mentor will oversee the project throughout the performance period, including supervising the student and design the testing protocols associated with this project to ensure all project objectives are achieved. The mentor will examine all student's work and provide the assistance and resources needed. The student will report (in written or oral format) to the mentor periodically on a weekly base, and the mentor will ensure the student is progressing as planned. It is expected that a brief research report will be generated towards the end of the project.