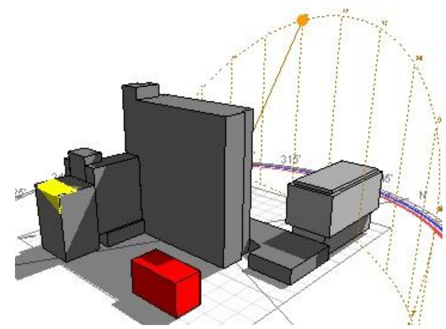
Firefly Sensor Demonstration

Building Envelope Energy Sensing: Sensitive Façades for Smart Controls

In every control system, from manufacturing to automobiles, sensing is a critical component to accurate and reliable control. Building control systems are quickly advancing to the level of complexity found in manufacturing systems, however this has mostly been limited to advanced modeling and control. While modeling can create a control methodology for a system with known variables, modeling will not serve completely to predict changing external microclimates, building degradation, irregular weather patterns, and other disturbances. With advanced sensing and communications, control algorithms can not only become more robust but also respond and stabilize significantly more quickly than open loop control systems. As Lord Kelvin said, "If you cannot measure it, you cannot improve it."

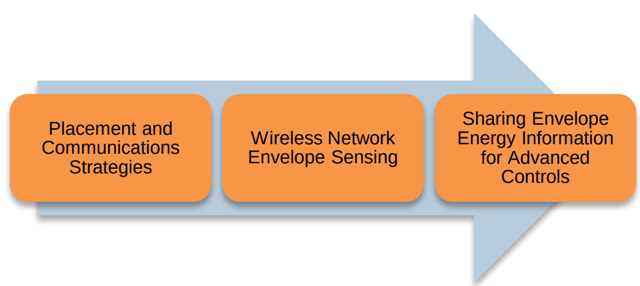
In June of 2012, Penn State, the University of Pennsylvania, PPG, and Princeton joined efforts as the Building Envelope Energy Sensing team to achieve a new strategy in energy sensor and controls use on the façade of the built environment. Recent advancements in sensing technology and microcontroller systems, wireless, self-powered, network capable sensors are available off the shelf at extremely low (<$10) component cost, enabling sensing fidelity that has been previously unavailable to the building industry. While these types of sensors and their more expensive predecessors have been used extensively in component characterization, a systematic large-scale study of whole building envelope energy flux has not yet been performed. Researchers discussed energy reductions via advanced envelope sensing with the Zavala group at Argonne National Laboratory (ANL), and were able to confirm a realizable goal of 6-18 percent reduction in total building energy use in the mid-Atlantic region via real time envelope sensors communicating to empirical control systems. ANL has reported that added real time sensing can achieve from 10-30 percent in HVAC energy savings (up to 20 percent of the total building energy consumption).[1]



Ecotect model of solar irradiance and shadowing

Sensitive Façades: Path to BEMS

The Building Envelope Energy Sensing team is addressing the following issues: *What to sense, how to sense, where to sense, and how to share that data?* The research includes developing methodologies for real time analysis/measurement of energy flux across building envelopes (sensitive façades), identification of low-cost, robust/accurate wireless networks for building envelope sensor systems, installation and validation of envelope sensor systems to measure irradiation and microclimate, and sharing the envelope sensor data for analysis and empirical control methods in the next generation of Building Energy Management Systems (BEMS).



The exterior of the built environment is strongly affected by irradiance (solar power absorbed by the façade and

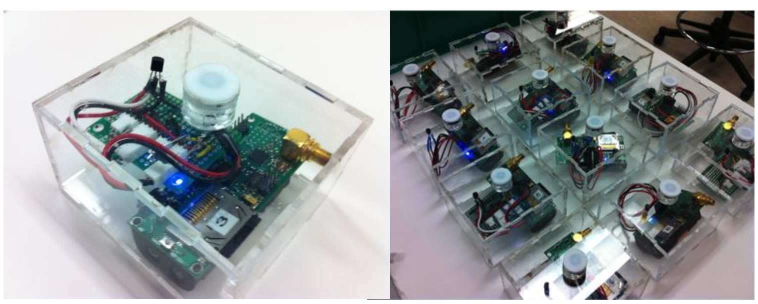
[1] V. M. Zavala. *Proactive Energy Management for High-Performance Buildings: Exploiting and Motivating Sensor Technologies.* Future of Instrumentation International Workshop, 2011

interior spaces) and local temperature regimes (microclimates) associated with variable weather conditions and surrounding structures. In the urban environment, shading or reflective surfaces from surrounding buildings can affect the solar energy balance, and information from rapid changes in meteorological conditions might permit rapid control response within the built environment. The team is taking advantage of low cost sensor collection and communications capabilities, emerging in microelectronics and spreading to the open source maker communities (e.g. Arduino). To specify the smallest economical set of sensors for any given structure that can use a coordinate-free wireless communications strategy, the team is developing an application of algebraic topology combined with Geographic Information Systems (GIS) analysis of Navy Yard buildings.

Solar Skin Envelope Sensor Network:

Penn State researchers are developing GIS sensor placement and data aggregation strategies (Urban Solar Analyst, algebraic topology of sensor placement and communication), while University of Pennsylvania researchers are creating new sensor networks for testing, along with HVAC control strategies that make use of the empirical data stream. PPG contributes extensive envelope expertise for window and walls along with process control system expertise to expand the capabilities of the team, while Princeton researchers are expanding the palette for miniaturized sensing technologies and allowing for broader form factor possibilities in the future.

In June of 2012, the University of Pennsylvania and Penn State researchers deployed a fleet of FireFly sensor nodes on Building 101 in The Navy Yard, the Solar Skin Envelope Sensor Network. The FireFly Sensor Networking Platform, co-developed by the University of Pennsylvania PI, Prof. Rahul Mangharam, offers inexpensive low-power hardware for wireless sensor networking. Each Firefly node has a thermal sensor and silicon photodiode (a pyranometer), capable of temperature and irradiance measurements in the plane of the façade, and stored on SD card format. Wireless capabilities will be deployed later this year, streamed on the Building 101 data network.



FireFly wireless sensor network system with multiple on-board sensors. A network has been deployed on the façade of Building 101 in the Navy Yard.

The stream of data on the exterior of the building was confirmed to be significantly different from day to day, and for each receiving surface of data collection. The irradiance and temperature signals were both leading building temperature signifcantly, suggesting ample time to signal an BEMS response in future systems integration.

Real-time sensing of envelope energy flux will fill a documented gap in building control systems and allow quick identification, response, and prediction of energy “disturbances” such as occupancy change, micro-climates, local weather, environment change, building degradation, etc. Additionally this information will provide algorithm, building, and component designers with empirical data to guide new concepts. Broader community developments will include cataloguing available off-the shelf technologies in a database, discussing desired building external boundary metrics with EEB Hub participants and modeling teams, and interfacing with the "do-it-yourself" community for open source technologies to engage creative entrepreneurial interest in sensitive façade strategies.