Human Building Interactions Laboratory (HBIL)

A Facility for Studying Next-Generation High-Performance Building Technologies and their Interactions with Occupants

Overview of HBIL design features: The HBIL is a reconfigurable building-within-a-building that is part of the Center for High Performance Buildings and located within the Herrick Laboratories. The HBIL enables the study of human interactions and satisfaction with different comfort delivery, control, and interface technologies for residential and commercial buildings such as smart thermostats, smart speakers, smart displays, modular radiant heating/cooling devices, smart lighting, controllable daylighting, model-predictive controls, etc. The facility has the capability to provide thermal comfort with different methods such as wall radiative systems, air systems, etc. The design is modular with thermally active wall panels which are supported by a truss structure as shown in Figure 1.

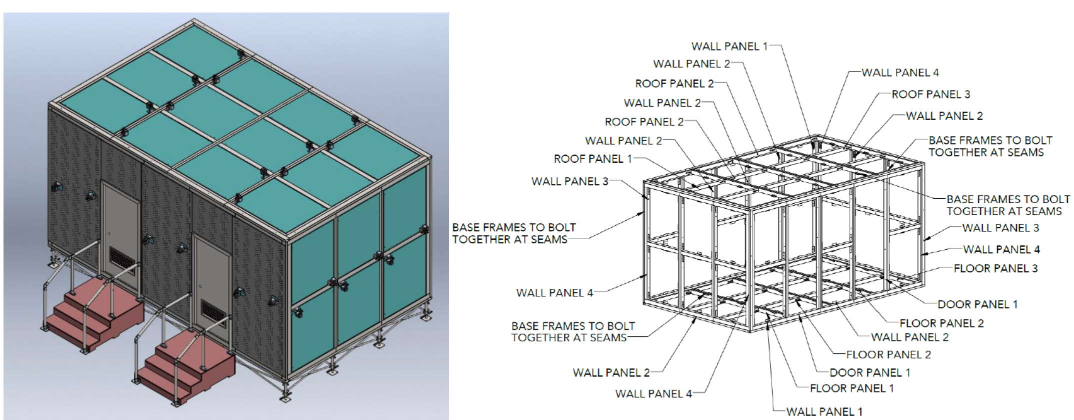

Fig. 1. HBIL facility isometric view (left); steel support structure with panel configuration (right)

The layout can be configured to be office or residential spaces (single large room or two individual smaller rooms) based on study requirements. The thermally active panels enable emulation of local comfort delivery and/or exterior walls exposed to different outdoor conditions representative of summer (cooling) or winter (heating). Smart occupant interfaces will be developed and deployed for the HBIL to evaluate localized human-in-the-loop control concepts in a realistic environment. Advanced building occupancy sensing (e.g., IR sensors) will be deployed to facilitate development and evaluation of automated control of localized comfort delivery systems. Figure 2 depicts the concepts of individual and automated control of local environments that could be investigated within the HBIL.

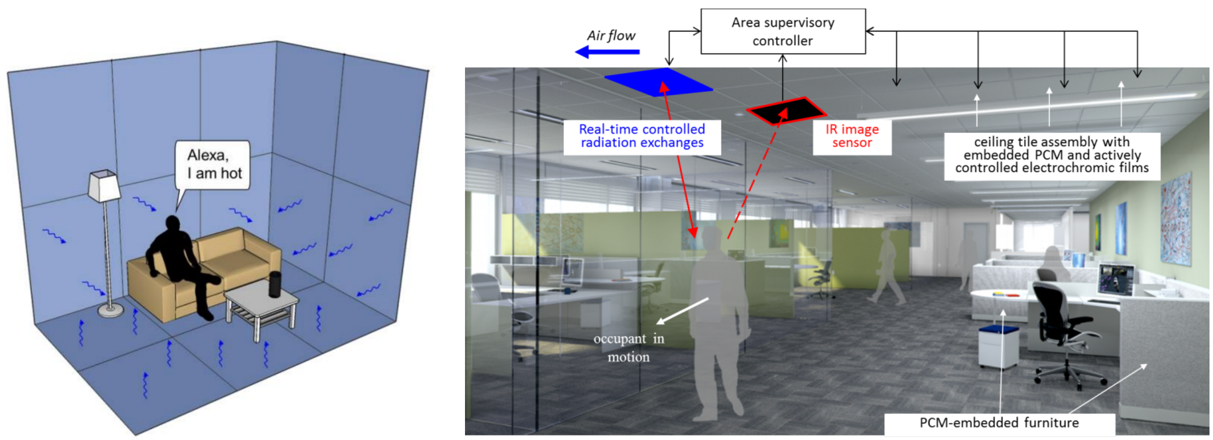

Fig. 2. Localized comfort delivery with voice control (left); automated localized comfort delivery (right)

The current facility employs a hydronic system to provide heating or cooling to individual wall, ceiling, and floor panels within the HBIL. Each panel has an embedded surface temperature measurement and can be individually control by adjusting a mixture of hot and cold supply water. In addition, each panel is reconfigurable to allow different interior surface treatments to achieve different visual and acoustic conditions. Also, the temperatures of window panes are controllable to emulate the effect of different ambient conditions on window surface temperature and its radiative effect on human comfort. It is also possible to change entire wall panels to investigate alternative approaches for local comfort delivery, including walls that embed micro-heat pumps and phase change material (PCM). Figure 3 shows a photo of the current facility that exposes hydronic panel heat exchangers, a photo of removal interior surface treatments, and a conceptual drawing of a ceiling panel with an embedded heat pump, PCM, and controllable surface treatments.

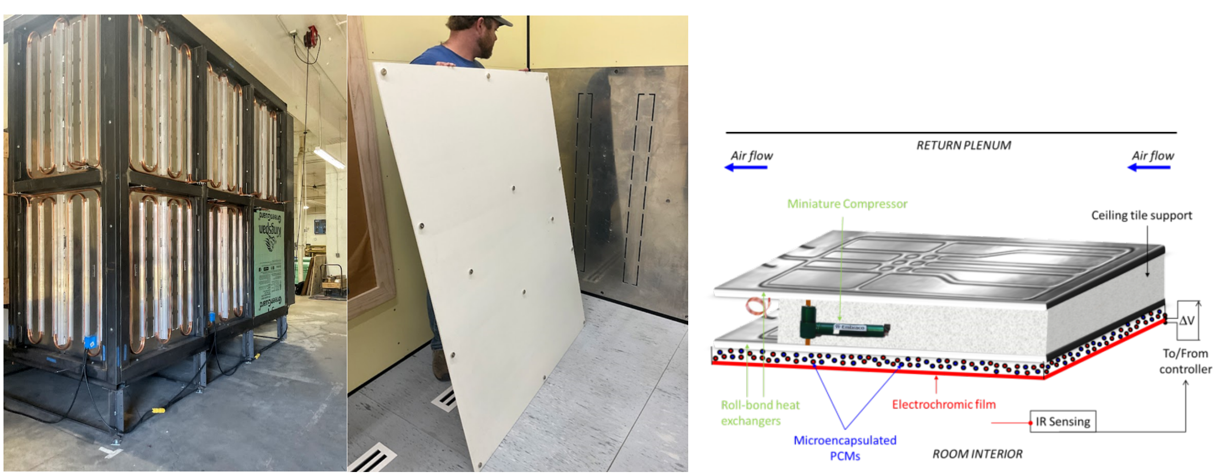

Fig. 3. Photo of HBIL exterior showing hydronic panel heat exchangers (left); photo of removal interior surface treatment with metal back panel (center); conceptual drawing of a ceiling panel with an embedded heat pump, PCM, and controllable surface treatments.

Research Opportunities: The development of the HBIL was motivated by a desire to investigate advanced building concepts that address sustainability, modularity, and embedded intelligence. Residential and commercial buildings account for about 41% of primary energy, 72% of electricity, 55% of natural gas, and 38% of CO2 emissions within the U.S. High performance building solutions are the exception rather than the rule because of the costs associated with engineering and constructing customized buildings. Most buildings are constructed entirely on site with local labor and the implementation of new technologies requires a degree of risk taking that is much greater than for mass produced products, such as automobiles that incorporate an iterative design process supported by extensive modeling and laboratory testing. As a result, it has been challenging to deliver affordable high-performance buildings at scale and tailored to specific design and performance requirements.

We envision a future where buildings are assembled on site from factory manufactured modular elements that integrate the smart technology needed to enable scalable cost-effective solutions with autonomous, occupant-centered, healthy, and sustainable features. The use of modular elements would mean that buildings are assembled rather than constructed on site with better quality control, less material waste, and more predictable schedules. A transformed modular building industry could deliver a range of high performance and intelligent buildings as products targeted to different customer requirements, including health, sustainability, autonomy, resiliency, minimum cost of ownership, etc. This would enable cost-effective integration of climate-responsive building envelopes, novel heating/cooling devices, sensors, embedded intelligence, and networking that make resiliency and de-carbonization technologies more affordable. The integration of Artificial Intelligence (AI) and smart technologies would open up new horizons for two-way interactions with humans to improve their comfort, health, and well-being.

The HBIL is truly a one-of-a-kind research facility that exists nowhere else in the world and will allow us to investigate both modular building concepts of the future and many other fundamental and applied research topics connected to occupant comfort, satisfaction and building interaction. Some of the future research topics to be addressed with the facility include:

- *Modular building construction from manufactured and 3-D printed elements.*
- *Decentralized heating and cooling systems such as micro heat pumps embedded in the wall panels with integrated thermal storage.*
- *Thermally active wall panel elements that incorporate thermoelectric devices.*
- *Active building materials such as phase change materials and electrochromic surface treatments.*
- *Smart technology with humans in sensing, control, and decision-making frameworks (e.g., wall-mounted tablets, voice-control assistants such as Amazon Alexa) and integrated digital applications ("apps").*
- *Configurable acoustic environment through the use of modular noise sources and surface treatments.*
- *Novel sensing systems including wireless low-cost sensor networks with automatic configuration and maintenance features, biometric sensors, smart meters.*
- *Learning-based control solutions, embedded intelligence into components/devices.*
- *AI-Enabled building energy and comfort delivery systems.*
- *Building ventilation and human exposure assessment.*
- *Building digital twins and cyber-physical systems*

The uniqueness of the HBIL facility will be leveraged to pursue these research topics through various federal funding opportunities. For example, the **U.S. DOE's Building Technologies Office (BTO)** is emphasizing the need for smarter buildings that reduce energy consumption, carbon emissions and provide services to the grid. The **Grid-interactive Efficient Buildings (GEB)** initiative supports the development of technologies that combine energy efficiency and demand flexibility through smart technologies to deliver space conditioning. The "*Connected Communities*" program is an example of a recent funding opportunity and future calls will focus on smart buildings and their equipment. In fact, the **E3 (Energy, Emissions and Equity) initiative**[1] will focus on next generation space heating and cooling technologies, water heating systems, low-GWP working fluids and smarter diagnostic tools for residential and commercial buildings. The HBIL facility encompasses all these crucial aspects and will lead to technology innovation and will accelerate the deployment of smart technologies in buildings. Smart buildings require fundamental research on autonomous buildings and occupant-centered comfort delivery solutions. Several programs within the **National Science Foundation** such as **Smart and Connected Communities (S&CC)**[2] aim at investigating the effect of rapidly changing intelligent technologies within residences. In particular, these programs will support integrated research approaches that address fundamental technological and human-centered aspects of smart and connected communities and the HBIL will allow demonstration of the research outcomes and enable scalability and transferability of the proposed solutions.

Opportunities for Cross-Disciplinary Collaborations. The development of the HBIL has been a collaboration between the following faculty from Mechanical and Civil Engineering: Panagiota Karava (*pkarava@purdue.edu*), Jim Braun (*jbraun@purdue.edu*), Davide Ziviani (*dziviani@purdue.edu*), and Travis Horton (*wthorton@purdue.edu*). We believe that this new facility available within the Center for High Performance Buildings will provide a unique platform to foster new cross-disciplinary collaborations of additional faculty from Civil and Mechanical Engineering that will result in new industry and government-funded research as well as technology transfer and entrepreneurship initiatives.

Herrick Laboratories: https://purdue.edu/herrick

Center for High Performance Buildings: https://engineering.purdue.edu/CHPB

[1] U.S. DOE EERE "E3 Initiative". Link: https://www.energy.gov/eere/buildings/energy-emissions-and-equity-e3-initiative

[2] NSF S&CC Program. Link: https://www.nsf.gov/pubs/2022/nsf22529/nsf22529.htm