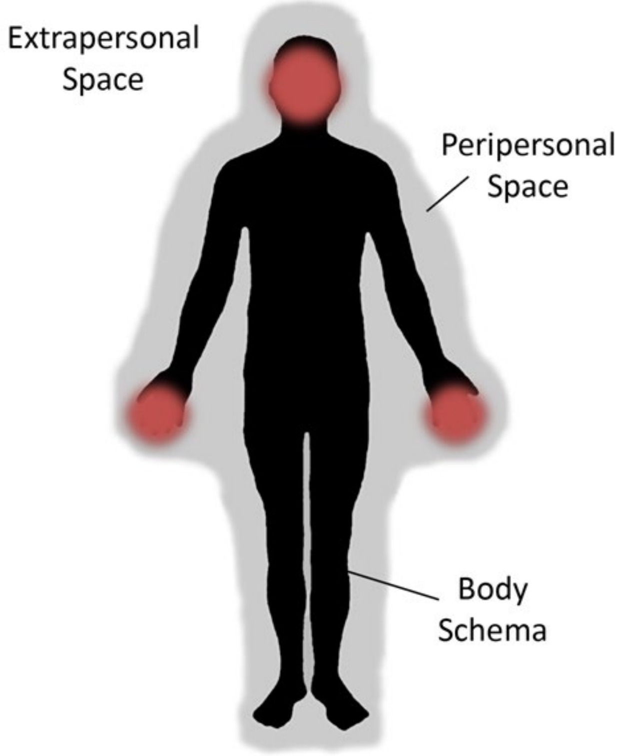
Design Motivation

Humans in the USA consume ~4 quadrillion BTUs of thermal energy per year heating spaces

Humans in the USA produce ~5 **quintillion** BTUs of thermal energy a year with their **bodies**.

BUT: mediating microclimate is not straightforward. (Focus of current NSF Cyber-Physical Systems grant.)

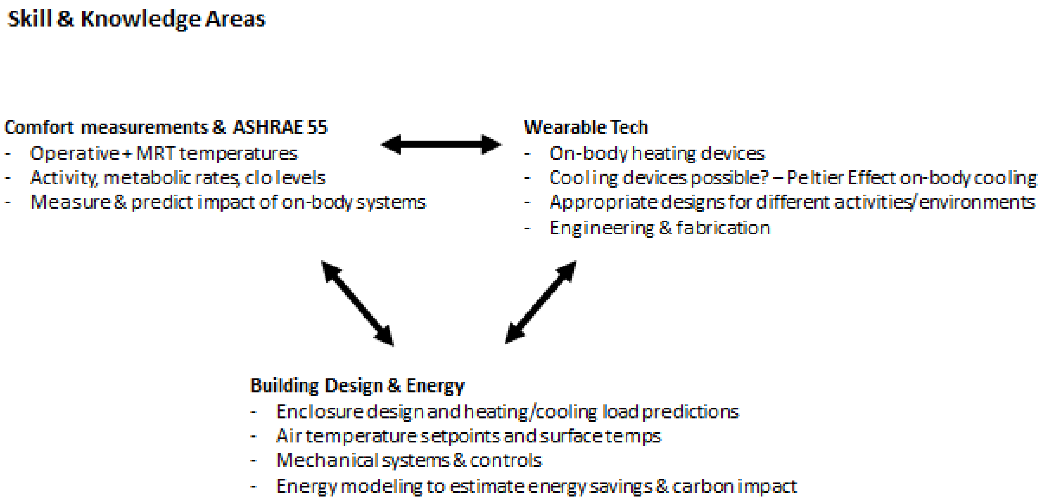


Next Steps: Closing the Loop

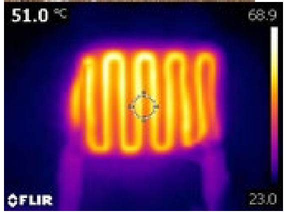
Thesis - it is possible to achieve operational carbon and energy savings through on-body heating, by replacing or reducing space conditioning energy.

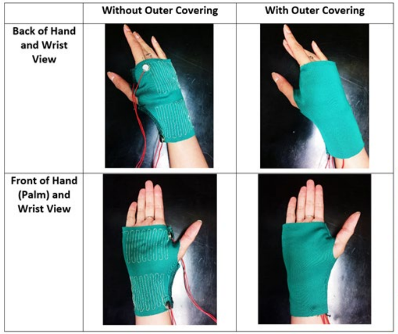
Communication between on-body and building heating systems

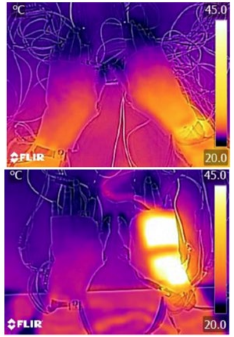
Controlling smart buildings: inputs and efficiency models

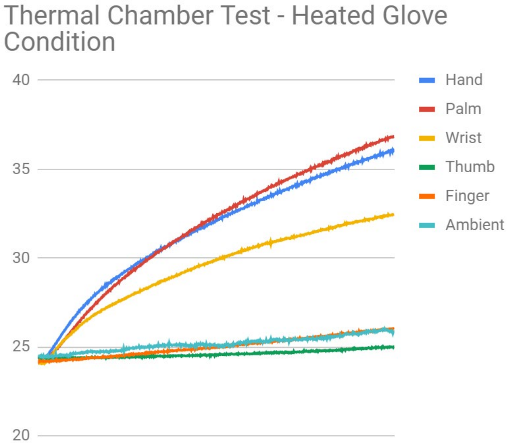


Wearable System Development









Modeling Deployment Scenarios

Use energy modeling to determine potential for energy/carbon savings

Garment/Social Factors

1) Thermal capability (capacity for temperature differential)
2) Heat output (IGs to space)
3) Energy consumption
4) Controls/coordination with mechanical system
5) User acceptance (where it can/will be worn)

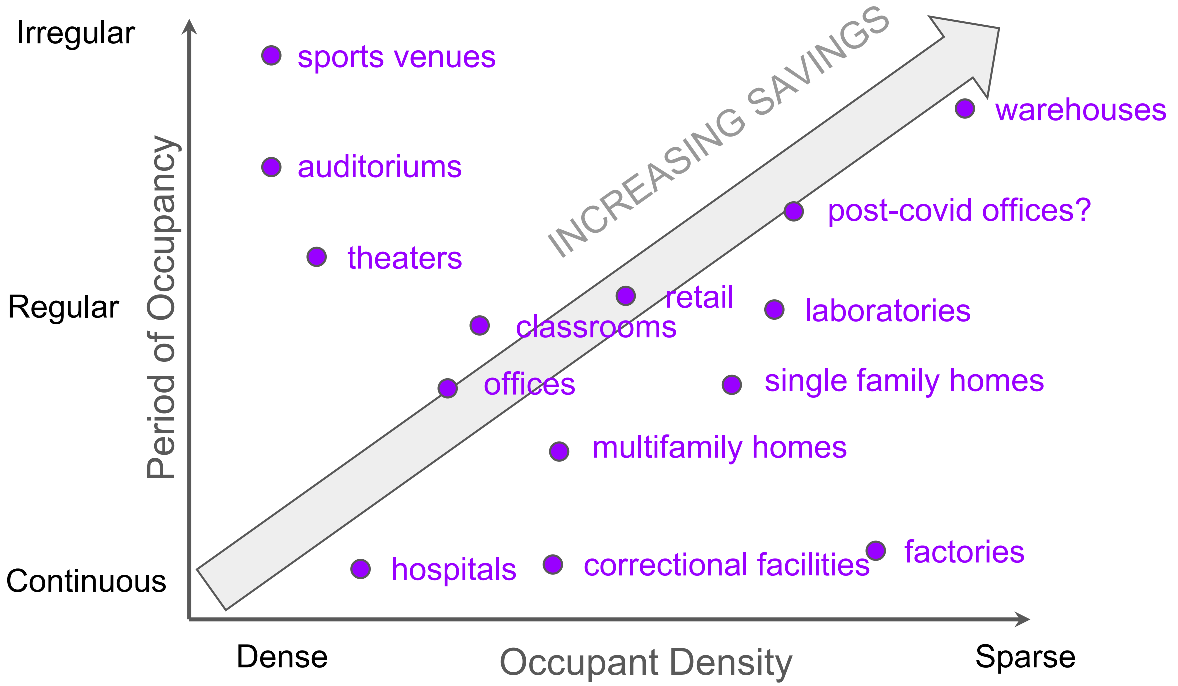
Building Factors

1) Climate zone (cold, mixed, etc)
2) Building geometry, enclosure, and type
3) Heat load of space/building - internal dominated (more cooling) vs. enclosure dominated (more heating)
4) Capacity, and efficiency of mechanical system
5) Occupant density, schedule, and internal gains

Modeling Deployment Scenarios

Different space/ occupancy types offer different energy/carbon savings potentials.

Sparse and irregularly occupied spaces may use a lot of space- heating energy for little benefit. They could offer the best opportunity for energy/ carbon savings.



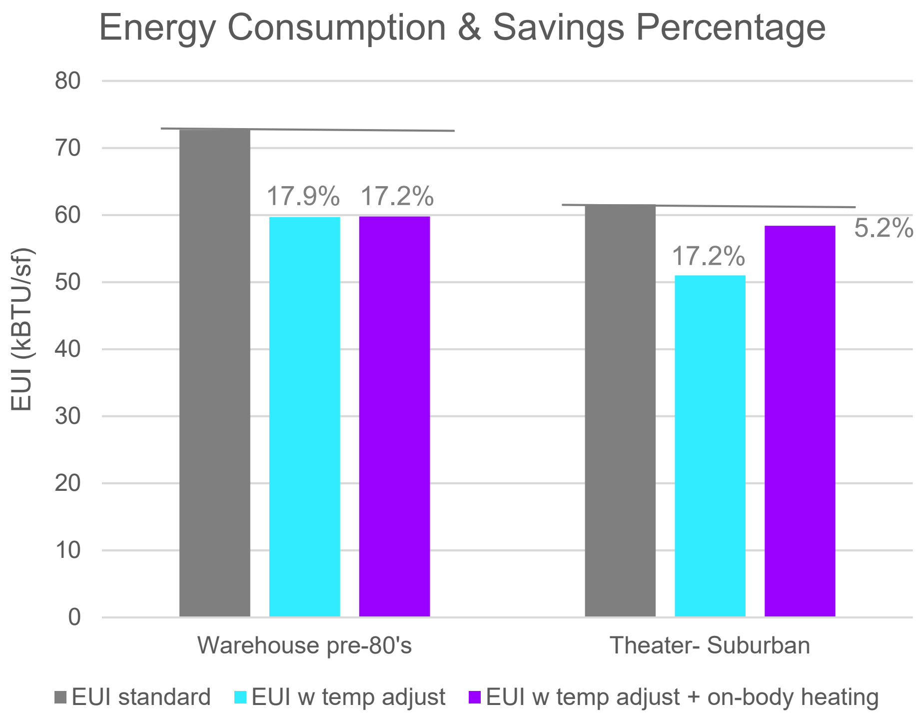
Modeling Deployment Scenarios

Warehouse, pre-80's

- Poor thermal envelope
- Large volume of interior space to condition
- Sparse occupancy

Large, suburban theater

- Average thermal envelope
- Large volume of interior space to condition
- Higher occupancy



Assume on-body heating consumes 100W/person

Research Questions

1) **Thermal garment design** - which textiles, heating elements, element placement, garment type, and user interfaces are best?
2) **Effectiveness** - What is the reduction in air temperature that can be achieved with on-body heating in different occupancies while maintaining comfort for all users?
3) **Energy and carbon impacts** - What energy and carbon savings are possible for different occupancy/building types?
4) **Control systems** - What are the impacts of control systems (the interaction between the building mechanical system and on-body heating systems)?
5) **Building Implications** - What are the thermal envelope and mechanical system changes that can optimize the function and energy savings of these garments?

Target Outcomes: Collaborative Research Grant

High priority grants:

1) NSF Cyber-Physical Systems
2) NSF Smart and Connected Cities

Lower priority grants:

1) NSF Convergence Grant
2) AIA Upjohn Research Initiative
3) Department of Energy grants (?)