

# THESIS ABSTRACT

**Title:** Human Behavior & Low Energy Architecture: Linking Environmental Adaptation, Personal Comfort, & Energy Use in the Built Environment

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Truly sustainable buildings serve to enrich the daily sensory experience of their human inhabitants while consuming the least amount of energy possible, yet building occupants remain a poorly characterized variable in even the most “green” building design and operation approaches. This deficiency hinders efforts to reduce whole building energy consumption, as discrepancies between actual and predicted energy use are increasingly attributed to inaccurate representation of occupants and their adaptive behaviors. It also counters the goal of improving Indoor Environmental Quality (IEQ) as faulty projections of how real occupants will perceive a building environment lead to frequent problems with discomfort and associated issues with productivity, health, and general well-being. Going forward, better tools are needed during the building design and operation processes for considering human occupants and their adaptive interactions with the built environment.

This thesis develops and implements the Human And Building Interaction Toolkit (HABIT), a framework for the integrated simulation of occupant thermal comfort, related adaptive behaviors, and building energy use as part of sustainable building design and operation.

The development of HABIT begins with an effort to devise more reliable methods for predicting individual occupants’ thermal comfort, which this study considers to be the driving force behind the most significant adaptive occupant behaviors from both the energy and IEQ perspectives. Here, a large database containing experimental occupant comfort data from real office buildings is used to estimate Bayesian probability distributions of individual thermal sensation, acceptability, and preference for multiple building types. The distributions allow heterogeneity across individual comfort responses to be directly modeled.

The thesis then describes the collection of comfort and behavior field data that supports the development and validation of HABIT behavior simulation routines. Semi-structured interviews are used to generate qualitative and quantitative data on behavior and its underlying causes in the field; this information then informs the development of questions for more expansive structured survey instruments as part of a longitudinal comfort and behavior data collection scheme. The longitudinal scheme is implemented over the course of a one-year case study in a median-sized office building in central Philadelphia; the study reveals the importance of personal characteristics to individual comfort and behavior outcomes; finds evidence of contextual constraints on behavior; and suggests a possible sequencing in occupants’ daily behavioral actions.

The collected field data are subsequently used to develop and validate an agent-based

model (ABM) of occupant behavior that forms the predictive core of HABIT. The full ABM is presented in detail using a protocol for describing this type of model. Validation of the ABM assigns simulated occupant “agents” the personal characteristics and environmental context of real office occupants in the field study; executes the model; and compares the model’s ability to predict observed fan, heater, and window use to the predictive abilities of several other behavior modeling options. The predictive performance of the full ABM compares favorably to that of the other modeling options on both the individual and aggregate outcome levels. The full ABM also appears capable of reproducing more familiar regression relationships between behavior and the local thermal environment.

Finally, the agent-based behavior model is linked with whole building energy simulation in EnergyPlus via the Building Controls Virtual Test Bed (BCVTB) to form the full HABIT program. Users are able to configure HABIT simulation runs using a simple Excel spreadsheet. To illustrate how HABIT may guide sustainable building design/operation, the program is used to evaluate the energy and IEQ impacts of several thermally-driven behavior scenarios in a typical office building environment, initially focusing on perimeter/core building zones across multiple climates, and subsequently expanding the simulations to the whole building scale for the Philadelphia climate. Results indicate that more efficient local heating/cooling options may be paired with wider set point ranges to yield up to 15-16% overall energy savings in the Philadelphia heating and cooling seasons, while also reducing thermal unacceptability amongst occupants. However, it is shown that the source of energy being saved must be considered, as local heating options replace cheaper, more carbon-friendly gas heating with expensive, emissions-heavy plug load electricity.

The thesis concludes with a summary of key outcomes of the research, as well as a list of suggestions for how the work may be further developed in the future.