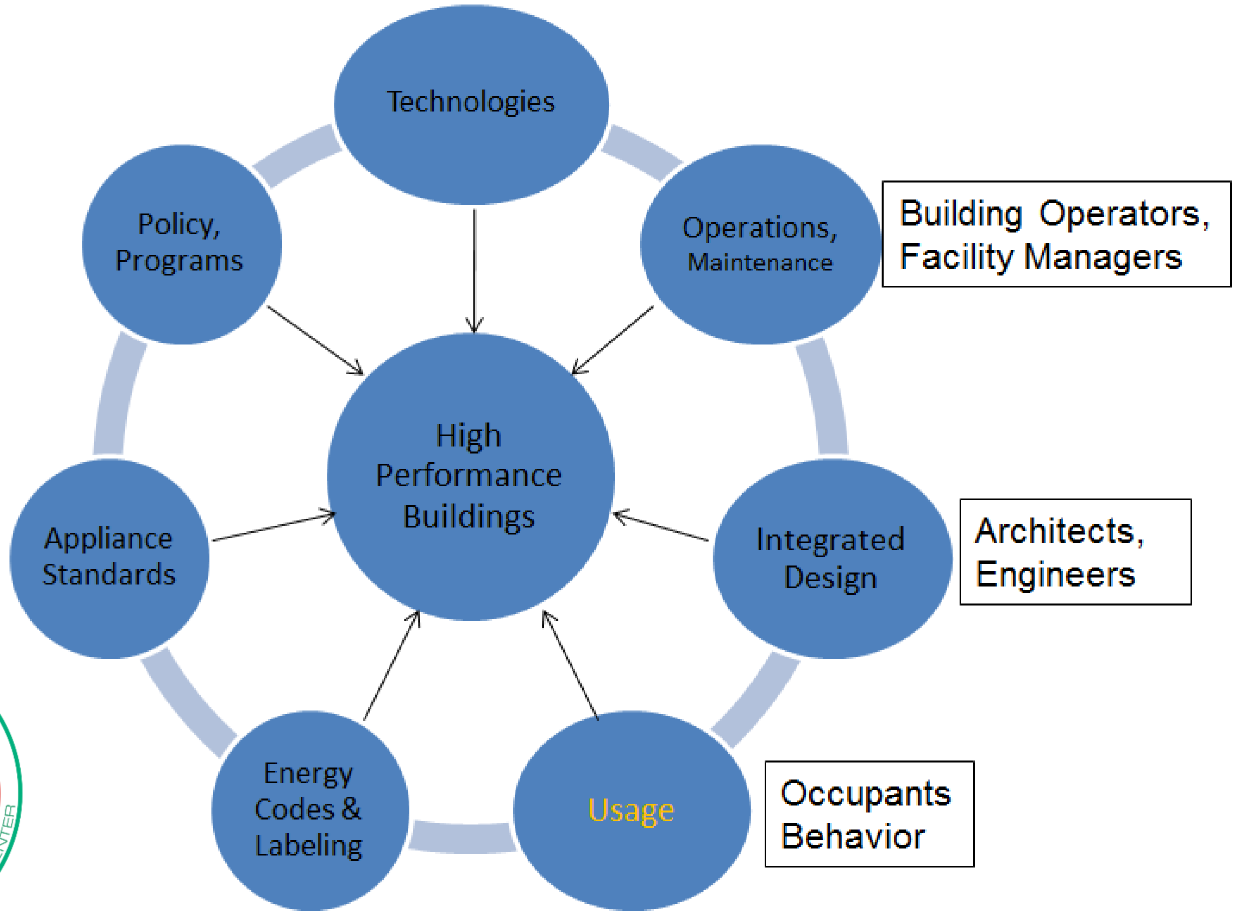
Human Behavior, Standards and Tools to Improve Design & Operation

2014 Building Technologies Office Peer Review



U.S. DEPARTMENT OF ENERGY

Energy Efficiency & Renewable Energy

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Project Summary

Timeline:

Start date: 10/1/2012 planned, 1/1/2013 actual

Planned end date: 9/30/2015

Key Milestones

1. Behavior data mining and models; 6/28/2013
2. Behavior framework; 12/20/2013
3. IEA EBC Annex 66 launched; 11/14/2013

Budget:

Total DOE $ to date: $380K (FY13 + FY14)

Total future DOE $: $220K, FY15 estimated

Target Market/Audience:

- Office and residential buildings
- New constructions and existing buildings
- Architects, engineers, operators, occupants, policy makers, energy modelers

Key Partners:

U.S. Partners	China Partners
Bentley Systems	Tsinghua University
C3 Energy	Center of Building Standards
	Center of EEB

Project Goal:

1. Deep understanding of energy-related occupant behavior in buildings
2. Development of a framework and XML schema to describe human behavior
3. Development of a software module of human behavior models
4. Integration with EnergyPlus to enable modeling of behavior impact on building performance

Purpose and Objectives

Problem Statement:

- Technologies alone not necessarily guarantee low energy use in buildings.
- Human behavior plays an essential role in building design and operation, but it is not well understood and usually over-simplified or ignored!
- Strong needs of data, methods, tools and case studies to address the behavior dimension in the building life cycle.

Target Market and Audience:

- Office & residential buildings; new constructions & existing buildings; 24 Quads
- Architects, engineers, operators, occupants, policy makers, energy modelers

Planned Contribution to Energy Efficiency:

1. New methods and tools to model behavior and simulate its impact on building technologies and performance
2. Case studies and workshops to demonstrate the use of behavior tools to improve building design and operations to reduce energy use

Approach

Approach:

- Identify, understand and describe energy-related human behavior by data analytics (Data-driven)
- Develop a framework to standardize the description of behavior (Standards)
- Develop and integrate behavior models in whole building performance simulation (Robust modeling)
- Evaluate the impact of behavior on building energy use and performance of building technologies (Provide insights)

Key Issues:

- Simplified human behavior in energy modeling during building design and retrofit
- Lack common methods to analyze and model human behavior

Distinctive Characteristics:

- Use data mining methods to discover behavior patterns
- A framework and XML schema to describe human behavior
- A software module to model human behavior
- Enhancement to EnergyPlus to enable modeling

Progress and Accomplishments

Discoveries:
- Privacy concerns to share behavior data
- Lack good data
- Perceived complexity and usefulness of research

Accomplishments:
- Developed behavior models for occupancy and windows opening/closing
- Evaluated impact of occupant behavior on energy use in buildings
- Developing a software tool of behavior models
- Developing a framework and XML schema for human behavior
- Enhancing EnergyPlus to model occupant behavior

Project Contribution to Energy Efficiency:
- Potential energy savings from 5 to 50% can be achieved, based on better tools to consider and integrate human behavior in the building design and retrofit

Awards/Recognition:
- Co-founding and leading the IEA EBC Annex 66 on occupant behavior research

Project Integration and Collaboration

Project Integration:
- Actively engage industry partners in the project
- Public workshops and stakeholder meetings
- Leverage on international effort

Partners, Subcontractors, and Collaborators:
- A project under the U.S.-China CERC program
- U.S. partners: Bentley Systems, C3 Energy
- China partners: Tsinghua University, CEEB of MoHURD, CBS

Communications:
- 5 public workshops: LBNL 7/17/2013; ISHVAC, China 10/21/2013; IEA HQ, 8/23/2013; Hong Kong, 3/13-14/2014; LBNL summer 2014.
- ASHRAE seminar: energy-related occupant behavior in buildings, Seattle
- Presentations at conferences: BECC, ACEEE, ASHRAE, IBPSA
- Publications: 1 report, 5 conference papers, 5 journal articles

Next Steps and Future Plans

Next Steps:

- Refine the behavior schema
- Complete the behavior software tool
- Enhancement to EnergyPlus
- Public workshops

Future Plans:

1. Case studies to demonstrate the use of the behavior tools
2. Leverage on the international effort under the IEA EBC Annex 66
3. Feed results to BTO programs: Analysis Tools, CBI, RBI, ET
4. Synergy with related behavior research and programs: utilities, ASHRAE, ACEEE, code and standards, energy benchmarking and rating
5. Built upon the DOE/CERC research outcomes, pursuit new funding sources to develop a behavioral guide for practitioners

A Project of CERC-BEE (US-China Clean Energy Research Center Building Energy Efficiency Consortium)

Pioneering U.S. – China Innovation for Widespread Adoption of Very Low Energy Buildings Through Partnerships and Real World Impact

BERKELEY LAB · OAK RIDGE National Laboratory · MIT · ICF INTERNATIONAL · NRDC · UCDAVIS UNIVERSITY OF CALIFORNIA

U.S. Research Leads

DOW · ENERGY FOUNDATION · SAINT-GOBAIN · Bentley · CLIMATEMASTER · C3 Energy · 3M · LUTRON

U.S. Industrial Partners *(Funding +40% Annual Average Growth Rate)*

Research Strategy → Huge Impact:

- U.S./China construction market ~ 2B m2
- CO_2 savings ~ 100Mt/year by 2025

Technologies, Software → **New Patent Applications**

Demonstration Buildings, Commercial Impact, Tools and Guidebooks → **Market**

Wide Adoption Very Low Energy Buildings → **Policy**

ABOUT: CERC-BEE is a five year, $50M program created by the U.S. Department of Energy and Chinese Ministry of Science and Technology.

R&D TEAMS: U.S. national laboratories, and U.S. and Chinese universities, and research institutes team up with industry partners to accelerate innovation and deployment.

SELECTED RESEARCH OUTCOMES:

- Launched eight new products and developed two software tools (e.g. Cloud tool for microgrids, 40 new users from China)
- Won R&D Top 100 Award for GSHP by Climate Master
- Exceeded IP goals: ~ 25 patents filed, 4 approved; inventions disclosed and more in process (e.g. sprayable liquid flashing, cool roof materials)
- Developed 20 standards (e.g. LBNL involved in new Chinese commercial building code revision)
- Published 135 Chinese and 54+ US academic research papers

Website: **cercbee.lbl.gov**

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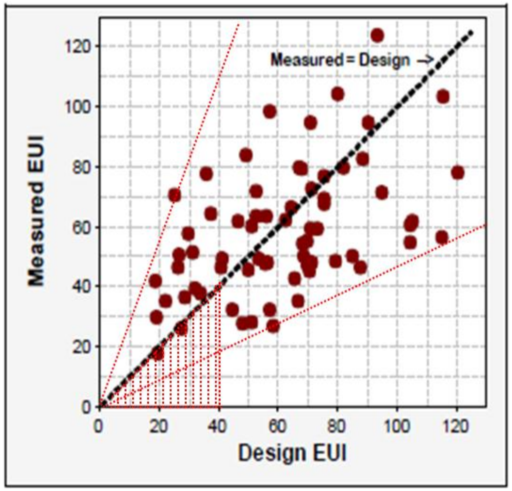
Background

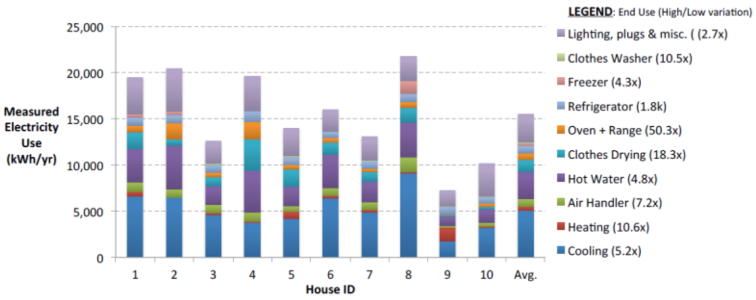
- Technologies alone not necessarily guarantee low energy use in buildings.
- Human behavior plays an essential role in building design, operation and maintenance, but it is not well understood and usually over-simplified or ignored!
- Behavior changes, usually no or low cost, has demonstrated 5 to 30% energy savings in buildings, but potential savings can be > 50% in very low energy buildings.



2008 NBI Study of LEED NC certified buildings

Homestead Cohort:
Virtually identical Homes & Efficiencies…
… but 3x Variation in Energy Use

- Even greater differences at end-use level
- End-use data extremely valuable for forensic accuracy assessment



Courtesy: Danny Parker, FSEC

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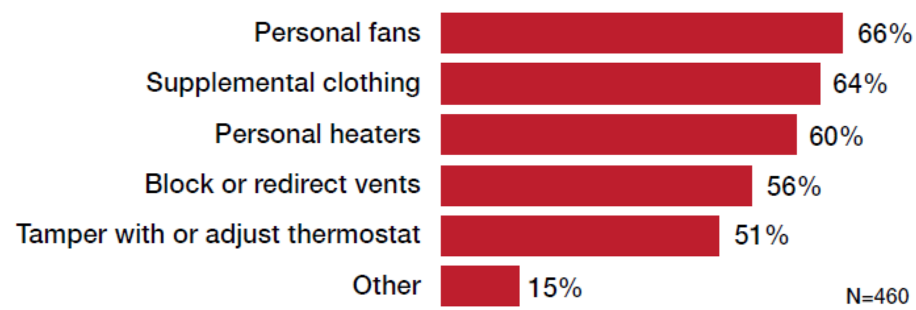
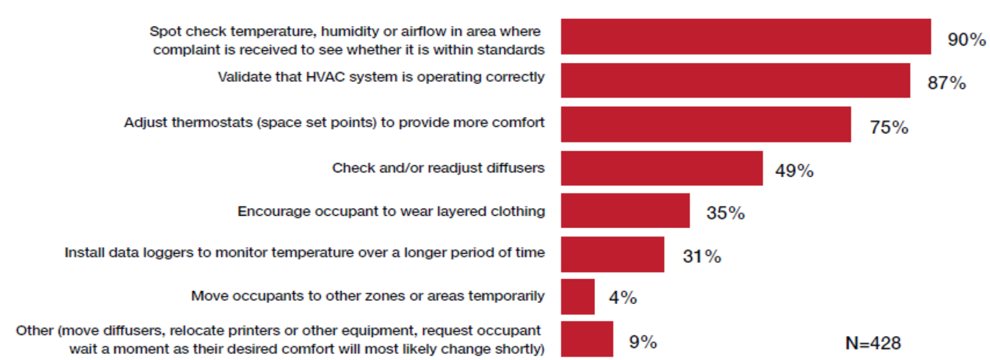
Complexity of Human Behavior

- Inherent uncertainty
- Multi-disciplinary
- Various driving factors:
  - Individual: culture, lifestyle, habit, environmental awareness
  - Temporal: time of the day, day of the year
  - Spatial: office, home,…
  - Indoor and outdoor environmental conditions
- Very limited data to help us understand

How Do Occupants Adjust to Thermal Comfort Issues?

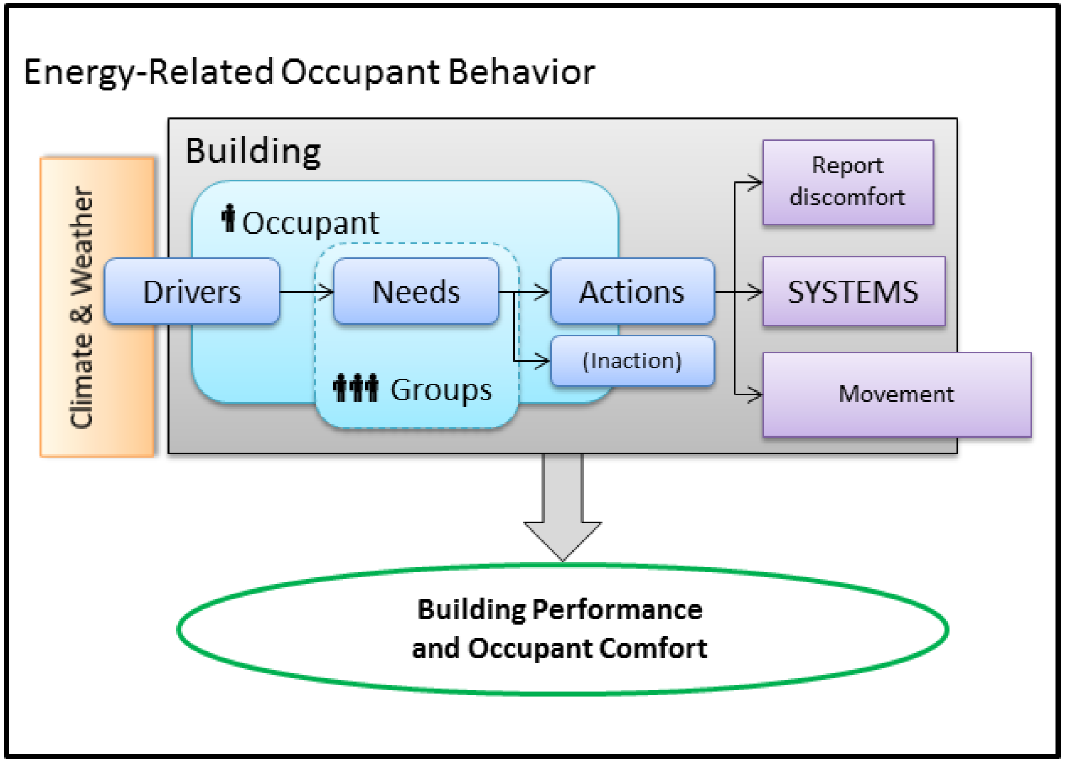


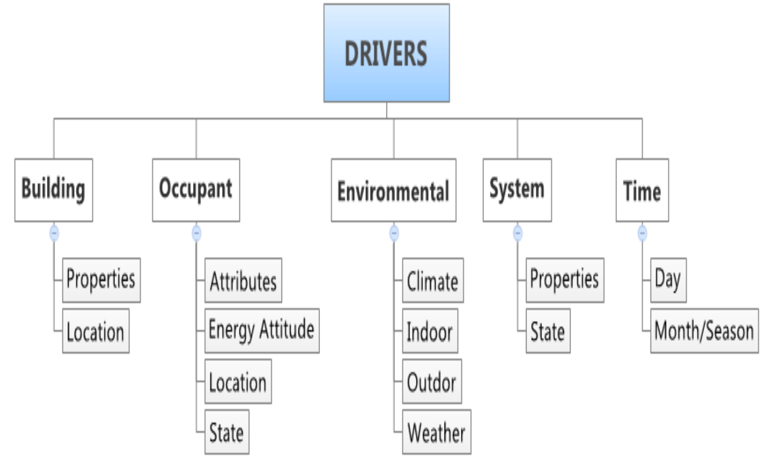
Steps Taken by Building Operators to Address Thermal Complaints

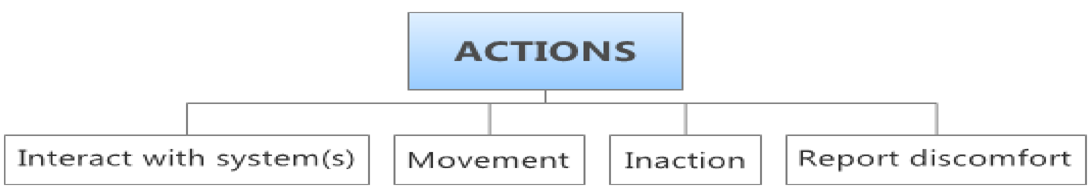


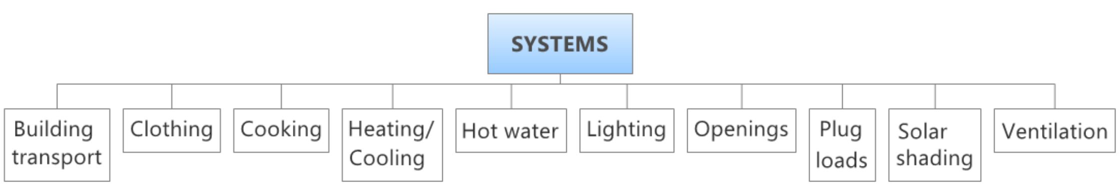
IFMA 2009 HVAC Survey of IFMA members in US and Canada with 452 responses from 3357 samples

A Framework to describe human behavior in buildings

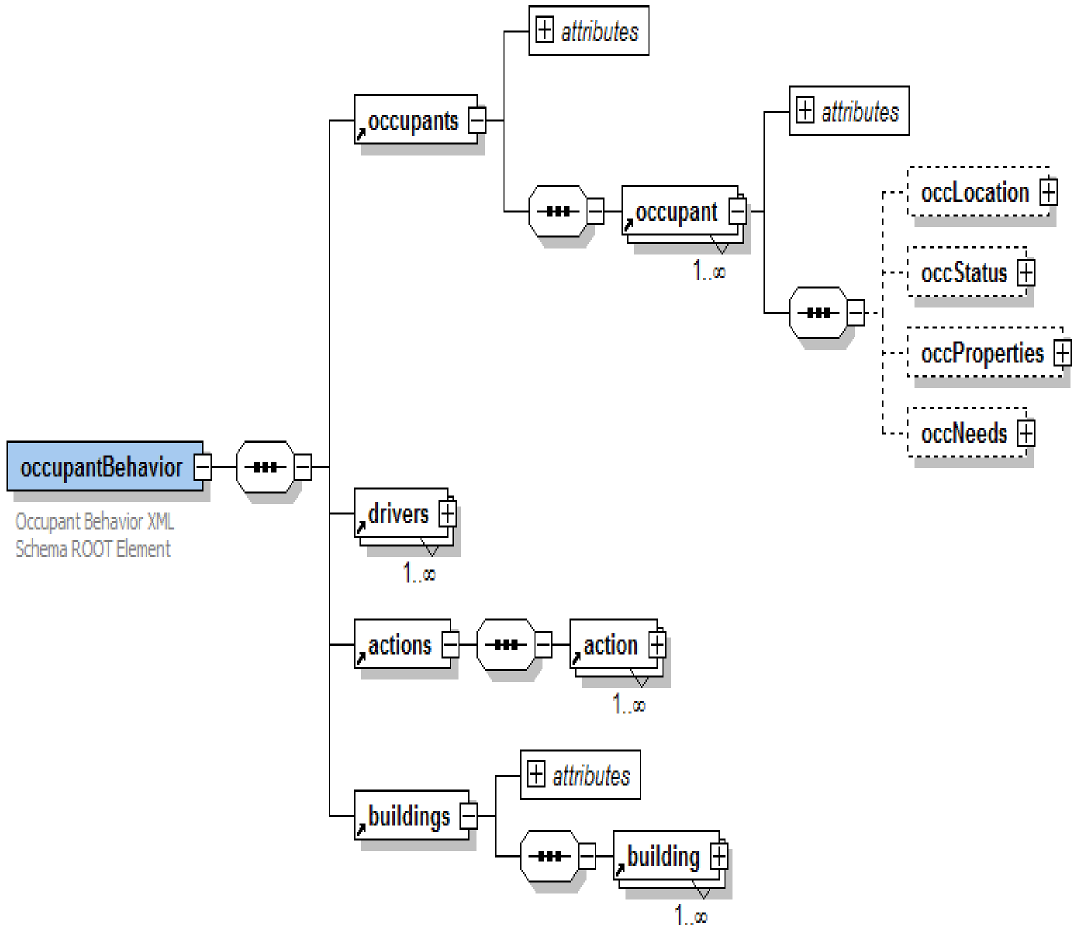








The XML Schema - *obXML*



Applications of the framework and schema:

1. Building energy modeling
   - Improve evaluation of building technologies and designs
   - Better predict actual energy use in buildings
2. Energy policy
   - Energy benchmarking and performance rating
   - Codes and standards
   - Incentive programs
3. Long term can be part of BIM

Modeling and Simulation of Occupancy in Buildings

Four types of occupancy models:

Building level – # of occupants

- How many occupants are there in a building?

Space level – occupied status

- Is a space occupied?

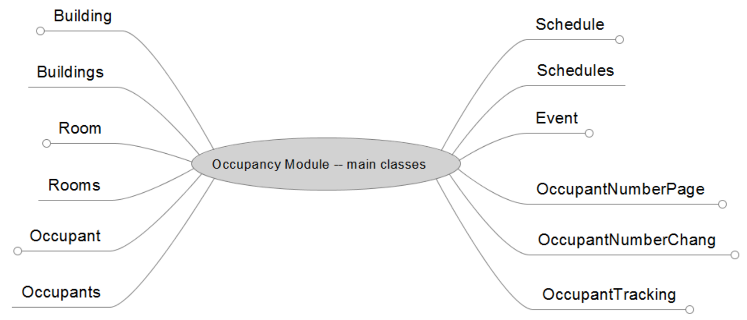
Space level – # of occupants

- How many occupants are there in a space?

Occupant level - individual tracking

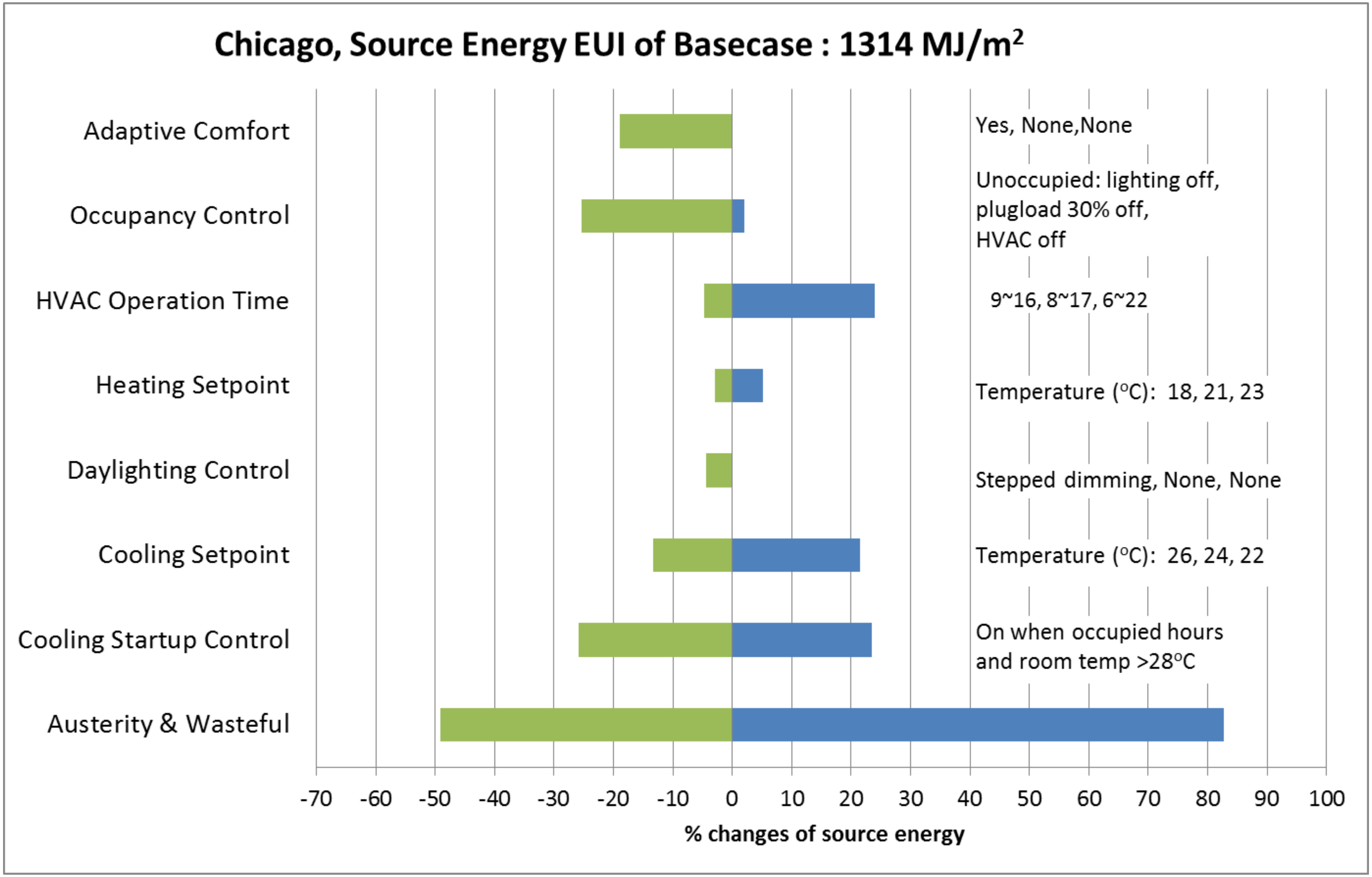
- Where, in which space, is an occupant?

A Software Module of Behavior Models



- Run stand-alone as an executable file
- Called by other tools as a DLL
- Used as co-simulation with energy modeling tools, e.g. EnergyPlus

Impact of Occupant Behavior on Energy Use in Private Offices



Data Mining and Statistical Methods –

Occupant Behavior of Window Opening/Closing

Phase 1
Statistical Analysis
Logistic regression function

Factors influencing window opening and closing
Variables
Coefficient

Phase 2
Cluster Analysis
k-means algorithm

Behavioral patterns
- How long?

window state
h/day windows stay open/close
- How often?

window change
n changes/day
- How much?

window position
schedules of tilting angle
- Why?

window opening/closing drivers
variables and coefficients

Phase 3
Association Rule Mining
FP-growth algorithm

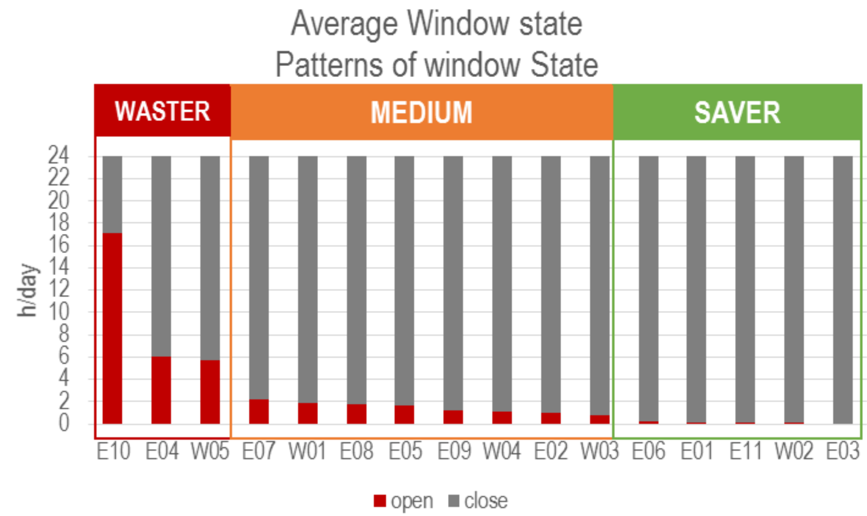
From behavioral patterns to
User profiles

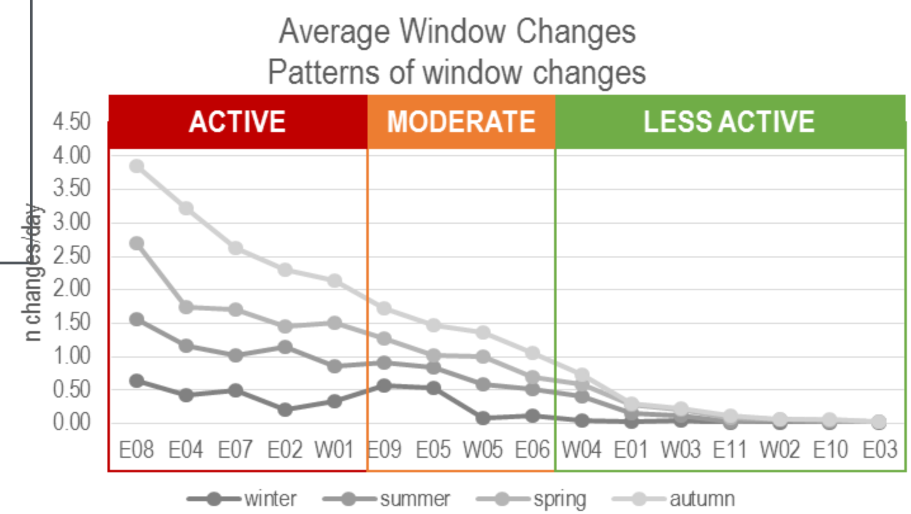
Statistical Analysis	**Data mining Framework**	**Building energy simulation**
Driving factors	*Cluster centroids*	*Stochastic inputs*
Human energy behavior	Behavioral patterns	Typical user profiles

Dataset and Results

- **16 offices of a natural ventilated building**
- **5-minute interval data over two complete years**
- **measured indoor and outdoor physical parameters**
- **measured behavior and energy use**

Outdoor	Indoor	Behavior and Energy Use
Solar radiation [W/m²]	Room air temperature [°C]	Occupancy [0/1]*
Rain – amount [l/m²]	Surface temperature [°C]	Window contact [0/1 ; Reed contacts]*
Rain – event [yes/no]	Ceiling slab temperature [°C]	Top light control [0/1 ; Reed contacts]*
Light intensity– horizontal [lx]	CO_2 concentration [ppm]	Sun protection [% of closure: 0% = open to 100% = closed]
Light intensity - South [lx]		Electricity consumption [kWh]
Light intensity - East [lx]		
Light intensity - North [lx]		
Light intensity - West [lx]		
Outdoor temperature [°C]		
Wind – velocity [m/s]		
Wind – direction [°]		
CO_2 content in air [ppm]		
Outdoor humidity [%rH]		





Project Budget

Project Budget:

2013: $160K

2014: $220K

2015: $220K estimated

Variances: None

Cost to Date: 2013: 100%; 2014: 10%

Additional Funding: None so far

Budget History					
1/1/2013 – FY2013 (past)		FY2014 (current)		FY2015 – 12/31/2015 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$160K	$250K	$220K	$300K	$220K	$300K

Project Plan and Schedule

Project plan:

- Start date: planned 10/1/2012, actual 1/1/2013
- Completion date: projected 9/30/2015

Project Schedule		
Project Start: 1/1/2013		Completed Work
Projected End: 9/30/2015		Active Task (in progress work)
		Milestone/Deliverable (Originally Planned)
		Milestone/Deliverable (Actual)

	FY2013				FY2014				FY2015			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Q1: Evaluation of energy impact of behavior in private offices												
Q2: Occupancy models and simulation												
Q3: Behavior software module												
Q4: Public workshops												
Q1: Behavior framework, XML schema												
Current/Future Work												
Q3: Data mining of windows opening/closing												
Q4: New features in EnergyPlus												

Appendix Slides

Occupant Behaviors in Private Offices

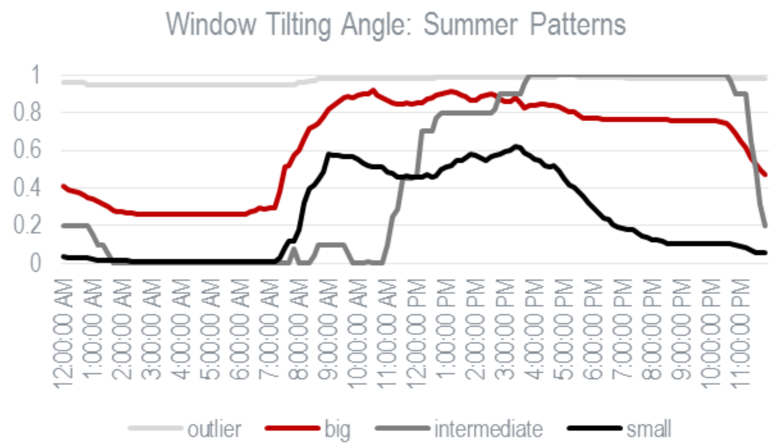
Behavior	Austerity Lifestyle	Standard Lifestyle	Wasteful Lifestyle
Cooling Setpoint (°C)	26	24	22
Heating Setpoint (°C)	18	21	23
HVAC Operation Time (Cooling and Heating)	9:00am - 4:00pm	8:00am - 5:00pm	6:00am - 10:00pm
Occupancy Control	If unoccupied • Lighting: off • Plug-load: 30% off • HVAC: off	Scheduled	If unoccupied • Lighting: on • Plug-load: on • HVAC: on
Cooling Startup Control	Cooling starts when $T_{zone, air} \geq 28°C$ during occupied hours, once started maintains the cooling setpoint; Cooling off during unoccupied hours.	Follow fan schedule & cooling thermostat during 8:00am - 5:00pm	Cooling always on during 6:00am - 10:00pm
Daylighting Control	Stepped Dimming	None	None
Adaptive Comfort	Yes	None	None

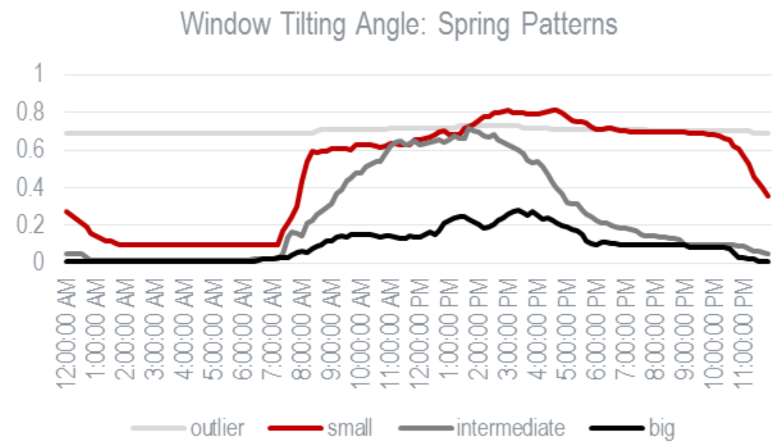
Data Mining Approaches, Cluster Analysis
Disaggregate occupant behavior into clusters

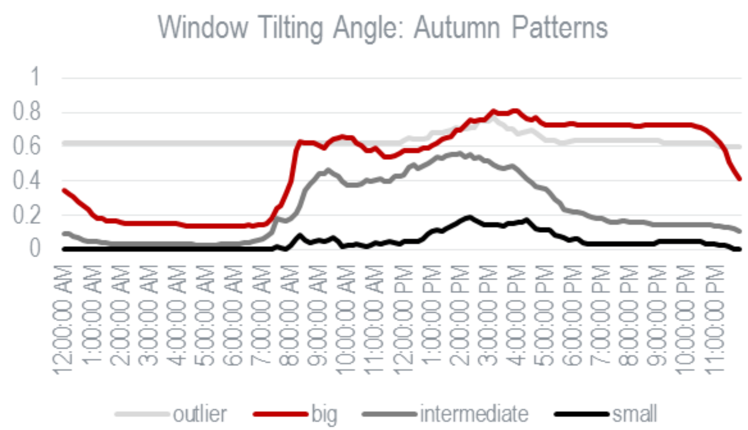
WINDOW POSITION

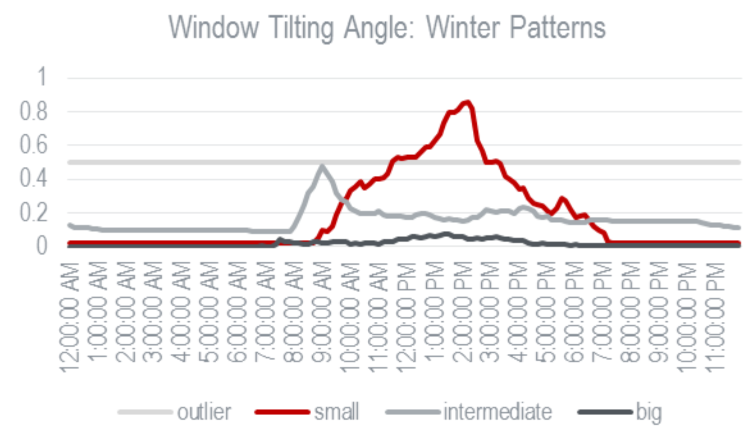
Schedule

Tilted angle









Data Mining Approaches, Cluster Analysis
Disaggregate occupant behavior into clusters

WINDOW POSITION

Schedule

Tilted angle

	autumn	spring	winter	summer	pattern
E01	small	small	small	small	small opening
E02	small	small	small	small	small opening
E03	small	small	small	intermediate	small opening
E04	big	big	intermediate	big	big opening
E05	intermediate	intermediate	big	small	Intermediate opening
E06	small	small	small	small	small opening
E07	small	intermediate	small	small	small opening
E08	intermediate	intermediate	small	frequent	Intermediate opening
E09	intermediate	small	intermediate	small	small opening
E10	outlier	outlier	outlier	outlier	big opening
E11	small	intermediate	small	small	small opening
W01	intermediate	small	small	big	small opening
W02	small	small	small	intermediate	small opening
W03	small	small	small	big	small opening
W04	big	intermediate	small	small	Intermediate opening
W05	big	big	small	big	big opening

Season Cluster

Then

Classification Cluster