Continuous and Real-time Sensing of Occupant Satisfaction with Indoor Ambient Factors

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Building Energy Consumption

Energy Consumption in the U.S.

Roughly 87% of today’s buildings will still be used in 2050, composing an estimated 70% of the building stock.

Source: Energy Data Book (2007); EERE, U.S. Department of Energy
Energy Operations

- Currently energy systems are operated for the *peak opposed to optimal*
- Facility manager is forced to “play it safe”, resulting in sub-optimal operations
- Occupant comfort is based on *predefined standards*
- Standards are based on *one time surveys or limited experiments* and individual occupant complaints
Comfort Estimation

- Occupant comfort ranges are found to be larger and more forgiving than predicted ranges
- Weak and context dependant correlations between code-defined comfort ranges and occupant reported comfort ranges
- Research proves that there is great potential in improving comfort level
- Energy consumption could be reduced, while improving/maintaining occupant comfort
Energy Efficiency

Understand impact of occupant satisfaction with performance, productivity, mood

Understand discrepancies between actual measured vs. perceived subjective values

Develop a database of occupant perceptions for trending and improvements to energy operations (heating/cooling, ventilation, building design)

Develop optimization algorithms for “learning” and “adaptive” energy control

BUILDING DESIGN

BUILDING SYSTEM DESIGN

BUILDING OPERATIONS

BUILDING PERFORMANCE
Participatory Data Sensing

Mobile triangulation brings up a list of three nearest buildings
Participatory Sensing

Occupant Profile

Occupant Preferences

Supplementary Data for Energy Analysis
Mobile Apps

a) Android version (optional module for permanent occupants)

b) iPhone version (optional module for temporary occupants)
AmbientFactors
By USC

Description
The AmbientFactors application has been designed to collect buildings occupants’ preferences about ambient factors including temperature, lighting and air flow. In addition, it asks for some optional information regarding the clothing level and appliances in use. The application covers University of Southern California (USC) campus buildings. The occupants feedback is used in implementing adaptive control strategies for temperature, lighting and airflow. Accordingly, using the application, buildings’ occupants provide valuable information which leads to occupant comfort increase and building energy consumption decrease.

iPhone Screenshots

App Screenshots

Visit Developer’s Website

Open iTunes to buy and download apps.

Customer Ratings
We have not received enough ratings to display an average for the current version of this application.
Comfort Estimation

- Ten days - eight rooms
- ~ 65% of occupant perceptions of temperature differed from the neutral condition
- Could be due to the malfunctioning sensors or mismatch between comfort ranges / set points

Building Level Energy Management System

- 50 permanent residents (staff/faculty/grad students) and more than 2000 temporary residents
- 64-wired sensors
- 500+ WiFi-based wireless sensors (temperature, humidity, light, CO2, sound, magnetic, and motion sensors) deployed in 60 moveable sensor boxes and 100+ actuators
- 10 sub-meters (sub-floor, floor and building level for measuring energy consumption of lighting, receptacles, HVAC, elevator, and emergency power)
Energy Literacy

Tangible energy awareness through social influence

Visualization

Input

Energy Awareness

Public Awareness About Energy

Broad Cultural Shift – Social Influence

Personal energy choices vs. global well-being?

Real-time sharing and visualization of ambient features for immediate use
Data Visualization

Energy consumption plotted in 3D for influencing occupant behavior
Data Visualization

Occupants input mapped on 3D building models and floor plans
Energy Networking User Forum
Energy Networking User Forum
Energy Networking User Forum
Occupant Feedback

• Focus on the contribution of building occupants in energy reduction

• Occupants are asked to reduce lighting level during the day without compromising visual comfort

• Assess the influence information on occupants’ behavior towards energy conservation:
  
  – Reminding to reduce lighting w/o any supporting information
  
  – Energy consumption w/Environmental information are provided to encourage lighting level adjustment
  
  – Peers/colleagues’ tendency to reduce lighting level is revealed to all occupants to use social influence for energy consumption reduction

Changes in occupants behavior towards energy conservation is monitored by wireless light sensors which are used to measure the electricity consumption indirectly
Occupant Feedback

- Areal-world test scenario; a pilot sample of participants (staff on campus)
- To investigate the impact of different types of information for changing occupant behavior

Test Group I: no additional information, simply ask to reduce the level of lighting

Test Group II: information including participant’s own energy use, rate, and environmental motives

“By reducing (dimming) the lighting level in your office, you can reduce the total building energy consumption. If you agree, the annual energy savings at the building level are 26000 kWh on average, which is equivalent to the reduction of CO2 emissions of 2.2 homes for one year and greenhouse gas emissions avoided by recycling 6.2 tons of waste.”

## Occupant Feedback

Table 3: Lighting Negotiation Results (*: p < 0.1)

<table>
<thead>
<tr>
<th></th>
<th>Avg. Accep. Rate (%)</th>
<th>User Rating (Max: 5.0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group I</td>
<td>28.79 (11.03)</td>
<td>3.82 (0.26)</td>
</tr>
<tr>
<td>Group II</td>
<td>68.18 (9.65)</td>
<td>4.18 (0.18)</td>
</tr>
<tr>
<td>Mean Diff.</td>
<td>39.19*</td>
<td>0.36</td>
</tr>
</tbody>
</table>
Energy Conservation

- By increasing energy awareness and literacy, occupants could contribute to sustainable environments.
- Energy consumption could be adjusted by using adaptive control mechanisms and occupant preferences.
- System improvement highly depends on collective endeavor of occupants.
- iCampus infrastructure is a platform that can dramatically improve public awareness.
- Green behavior through social reputation could be facilitated by social capabilities of iCampus platform.
Thank you!