Interactive Adaptivity: ICT4S in Buildings

Presentation to 5th International Conference on ICT for Sustainability

John Robinson
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ICT for Sustainability

The sustainability benefits that could be provided by ICT are achievable if Canada can successfully rethink ICT, connect and empower Canadians, create new forms of social organization, and overcome challenges.
The Centre for Interactive Research on Sustainability

Vision

To be the most innovative and high performance building in North America and an internationally recognized leader in accelerating the adoption of sustainable building and urban development practices.
Regenerative in Environmental and Human Terms

Net positive on:
• Energy
• Operational carbon
• Water quality
• Structural carbon

Net positive on:
• Health
• Productivity
• Happiness
Regenerative in Environmental Terms

- All water from the sky
- All liquid waste treated on site
- All heating and cooling from the ground/neighbors/sun
- All light (when avail.) from the sun
- Green electricity (25 kW PV)
- Natural/displacement ventilation
- Wood building

A building that restores the environment around it

Continuous research:
- technical performance of building systems
- behavioural interface of building & inhabitants
Regenerative in Human Terms

Net positive on:
- Health
- Productivity
- Happiness

Passive recipients of building systems
Sense of place in, and engagement with, building
3,000 Points of Monitoring
(excluding F/A)

- Total electricity
- Electrical panels (incl. plug loads)
- Solar PV
- Solar hot water
- Domestic water supply
- Rainwater harvesting
- Reclaim water

- Storm-water redirected to aquifer
- Available day-light
- Indoor CO2 and VOC
- Weather-related (RH; CO2; air temp)
- Space controls (radiators; air temp)
- Window status and controls
- Digital video monitors
CIRS Energy Performance

Source: Chu, 2015

- Reference case:
  - 50% better than reference case

- Predicted case:
  - 40%

- Actual case:
  - 50% worse than design
CIRS Modelled & Actual Energy Flows

<table>
<thead>
<tr>
<th>Description</th>
<th>Estimated</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Recovered from EOS</td>
<td>906 MWh</td>
<td>129 MWh</td>
</tr>
<tr>
<td>Heat Sent to EOS</td>
<td>600 MWh</td>
<td>129 MWh</td>
</tr>
<tr>
<td>Heat Received by EOS</td>
<td>600 MWh</td>
<td>1 MWh</td>
</tr>
<tr>
<td>Electrical Use</td>
<td>585 MWh</td>
<td>755 MWh</td>
</tr>
</tbody>
</table>

Source: Fedoruk, 2013

Learning from failure: understanding the anticipated–achieved building energy performance gap

Laura E. Fedoruk, Raymond J. Cole, John B. Robinson and Alberto Cayuela

Centre for Interactive Research on Sustainability, University of British Columbia, 2036 West Mall, Vancouver, BC, Canada V6T 1Z4.

E-mails: laura.fedoruk@gmail.com, rjcole.ubc@gmail.com, jrobinson@ubc.ca and aberto.cayuela@ubc.ca

Now net positive on operational carbon

Will not be net positive on energy

Introduction

Many buildings have been designed and constructed over the decades. As a consequence, the design and construction of buildings have evolved to meet the needs of clients and users. However, the performance of buildings has been consistently lower than expected, resulting in a significant gap between the intended performance and the actual performance. This gap can be attributed to a number of factors, including the use of suboptimal materials, improper design, and insufficient maintenance.
CIRS Inhabitant Benefits/Opportunities

- Air quality
- Control over ventilation
- Acoustic performance
- Daylighting everywhere
- Operable windows
- Web-based lighting controls
- Real-time performance data
- Vote on control strategies
- Wood frame building & rooftop green-space
- Sustainable food services & social meeting spaces
- Information and discussion forums
CIRS vs. Previous Building

Figure 6.3: Overall rating of CIRS building compared to previous

Overall Comparative Rating of CIRS Building

<table>
<thead>
<tr>
<th>Count (n=51)</th>
<th>Inferior</th>
<th>Somewhat Inferior</th>
<th>Same</th>
<th>Somewhat Superior</th>
<th>Superior</th>
</tr>
</thead>
</table>

Median = “Superior”

Source: Coleman, 2016
Environmental and Social Sustainability in CIRS

Both positive, but social is higher

Source: Coleman, 2016
Net Positive in Terms of Self-Reported Human Wellbeing

Source: Coleman, 2016
## Human Performance Gap

### Official Story Themes
- Building represents a special kind of sustainability (net positive)
- Defining new terms of engagement, expectations
- Building as experimental change-agent; through engagement (dialogue; interactive feedback)
- Identity of CIRS Inhabitant

### Qualitative Performance Gap
- Official Story vs Lived Story
- Potential Gap: disappointment; greenwashing, but forgiveness
- Opportunity for dialogue, rectification, explanation
  - Needs interactive feedback for inhabitants
  - Communication about misfires and failings
  - Facilitation of collaboration, events

### Lived Story Themes
- Sustainable as “Green”; natural as beautiful, nourishing
- Openness, hope, tribe; pride due to Official Story (identity)
- Skepticism: “There’s a lot of talk; let’s see the walk”
- Forgiveness: CIRS = 1.1, indicating highly tolerant inhabitants

Source: adapted from Coleman, 2016
Sustainable Built Environment Performance Assessment (SBEPA) network

Address performance gap issues in sustainable buildings

Adopt a regenerative sustainability framework

  The initial focus should be on human wellbeing (e.g. health, productivity and happiness)
  Buildings should be designed to be net positive in both human and environmental terms

Involves faculty from Architecture, Engineering, Computer Science, Environment and Public Health

Four key audiences: designers, operators, developers, policy-makers
SBEPA Conceptual Framework

- More quantitative
- More qualitative

A: Predicted Performance
B: Pre-Occupancy Evaluation
C: Post-Occupancy Evaluation

Pre-Occupancy Evaluation

Measured Performance

Post-Occupancy Evaluation
A. Prediction Gap

Predicted versus measured performance (e.g. modelled and measured energy, water consumption)
Reasons for The Performance Gap

**DESIGN**
- Lack of systematic consideration of indicators and system boundaries (e.g. energy models, contextual variables);
- Disciplinary divisions;
- Lack of IDP and IPD

**MODELLING**
- Incomplete or inaccurate (e.g. rated efficiencies) representation of varying building loads, new technologies, and climate variation;
- No as-built models

**CONSTRUCTION**
- Inaccurate installation of building systems & compromising change orders

**COMMISSIONING**
- Lack of thorough commissioning of innovative building systems

**OPERATION & OCCUPANCY**
- Changes in usage and operation from original design

Source: adapted from Chu, 2015

Prediction paradox:
- If want to predict accurately, must do it at component level
- If want to address overall performance, can’t predict

This is a function of complexity (i.e. emergence), not lack of knowledge

Possible solution: scenario analysis and backcasting
B. Expectation Gap

Expected versus actual lived experience (e.g. pre-and post-occupancy evaluations)
Interactive Adaptivity

Mutually Satisfactory Outcomes

Building Inhabitants

Building Systems

Enhanced Communication & Dialogue

Source: Cole et al, 2008

Red-light/green-light system alerting occupants to open or close windows in Jim Pattison Centre of Excellence. Source: Chu et al, 2015
Photo credit: Sylvia Coleman.
C. Correlation Gap

Measured versus perceived environmental conditions (e.g. thermal comfort measurements & survey results)
Rethinking Performance?

Should we:

– Adapt performance measurement to better reflect actual experience? OR
– Use experience to interpret performance measurement?

i.e. which is the ‘real’ performance?

Possible approach: do both, and explore the interplay between qualitative and quantitative data

– Measure more experientially meaningful outcomes, and
– use qualitative data to interpret quantitative data (instead of comparing them)
Campuses as Living Labs

All these issues lend themselves to living lab projects

Treat the campus as a kind of test-bed, involving students, faculty, operational staff and partners in the community

U of T: six living lab projects: 1 new build and 1 retrofit on each campus

We want to kick-start that process by working with you to devise ideas and approaches that might be used in these or other living lab projects at U of T
The Correlation Gap: 
Measured performance vs. Lived Experience

5th International Conference on ICT4S, Mayth, 2018

Marianne Touchie, Assistant Professor 
Jointly appointed in Civil Engineering and Mechanical Engineering
Energy and water consumption
Air and mean radiant temperature
Relative humidity
Contaminant concentrations
Light level
Noise level
Thermal comfort
Visual comfort
Acoustical comfort
Olfactory comfort
Health
How do energy retrofits impact indoor environment?

<table>
<thead>
<tr>
<th>Height</th>
<th>Low-rise</th>
<th>Mid-rise</th>
<th>High-rise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Suites</td>
<td>397</td>
<td>471</td>
<td>369</td>
</tr>
<tr>
<td>Occupancy</td>
<td>Senior</td>
<td>Bachelor</td>
<td>Family</td>
</tr>
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</table>
In-suite environmental monitoring (70)

• In-suite monitoring:
  – Long term: Temp, RH, MRT, CO₂
  – Short term: Radon, Formaldehyde, PM sampling

• Boiler efficiency monitoring

Image Source: Touchie et al., 2016
Modeling Human Thermal Comfort
Resident surveys (180)

- Demographics
- Perceived comfort
- Behaviour in suite

http://www.publicdomainpictures.net/pictures/50000/velka/open-window-frame-
Survey Results

Image Source: Chang and Touchie, 2017
Motivation for window/door opening in winter

Thermal comfort?  Smoking?  Odours?

Low-rise  Mid-rise  High-Rise
Monitored Suite Temperatures in Winter

- Low-rise: Building A, Building B
- Mid-rise: Building C, Building E
- High-rise: Building F, Building G

Temperature Distribution:
- >26.1°C: 61% of time
- >26.1°C: 59% of time
Monitoring Results

Summer Time

Image Source: Chang and Touchie, 2017
Comfort Perceptions

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<thead>
<tr>
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<th>Mid-rise (Bachelor)</th>
<th>High-rise (Family)</th>
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<tbody>
<tr>
<td>ASHRAE 55-2013</td>
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<tr>
<td>Out of Comfort Zone: Survey</td>
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<td>□</td>
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<tr>
<td>Out of Comfort Zone: ASHRAE 55-2013</td>
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Mean % of Time Outside of Comfort Zone
Addressing the Correlation Gap

Do we

- close the gap with different measurement protocols?
- use the gap to interpret what measurements mean for inhabitants?
Challenge

Come up with ideas for fruitful ways to address 3 performance gaps

Focus on ICT dimensions of the solutions

The results will feed back into the living lab projects being developed at U of T
Questions:

A. how best to address the prediction gap between projected and actual building performance?

B. How to induce interactive adaptivity: a conversation between buildings and their inhabitants?

C. How best to integrate qualitative data on human wellbeing with quantitative data on building performance?