Carleton University as a living lab: where research (and teaching) and operations meet

Liam O'Brien, Ph.D., P.Eng.

Associate Professor, Civil & Environmental Engineering

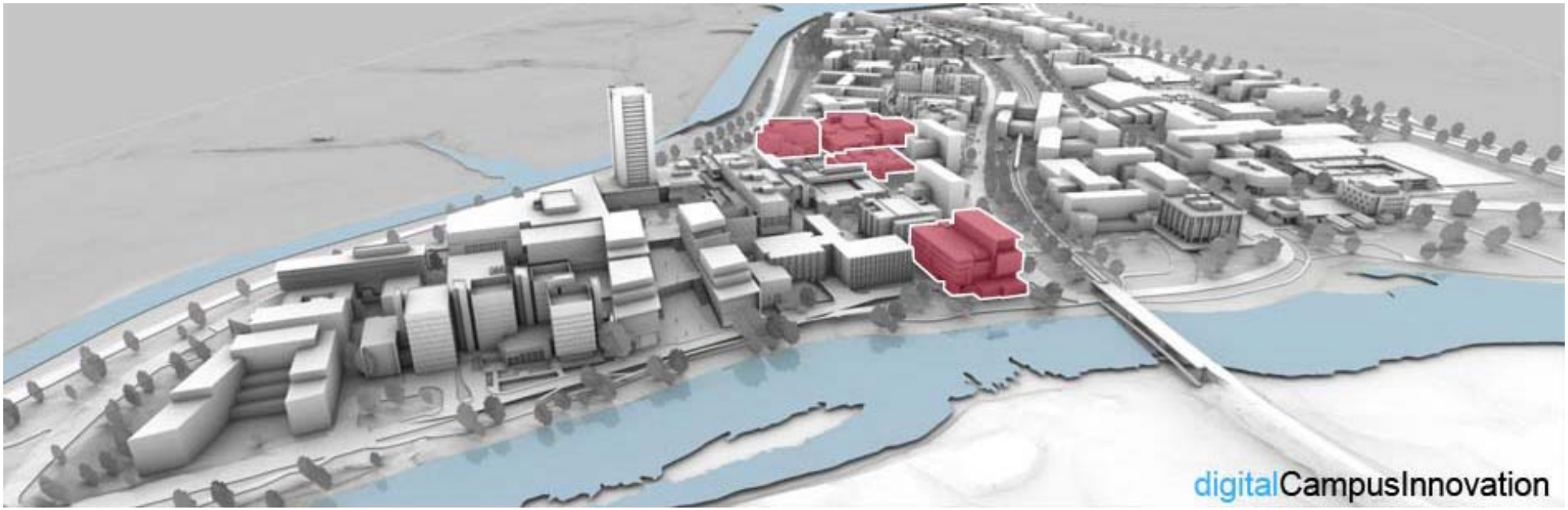
PI, Human Building Interaction Laboratory

Carleton University

Building performance visualization

Advanced controls

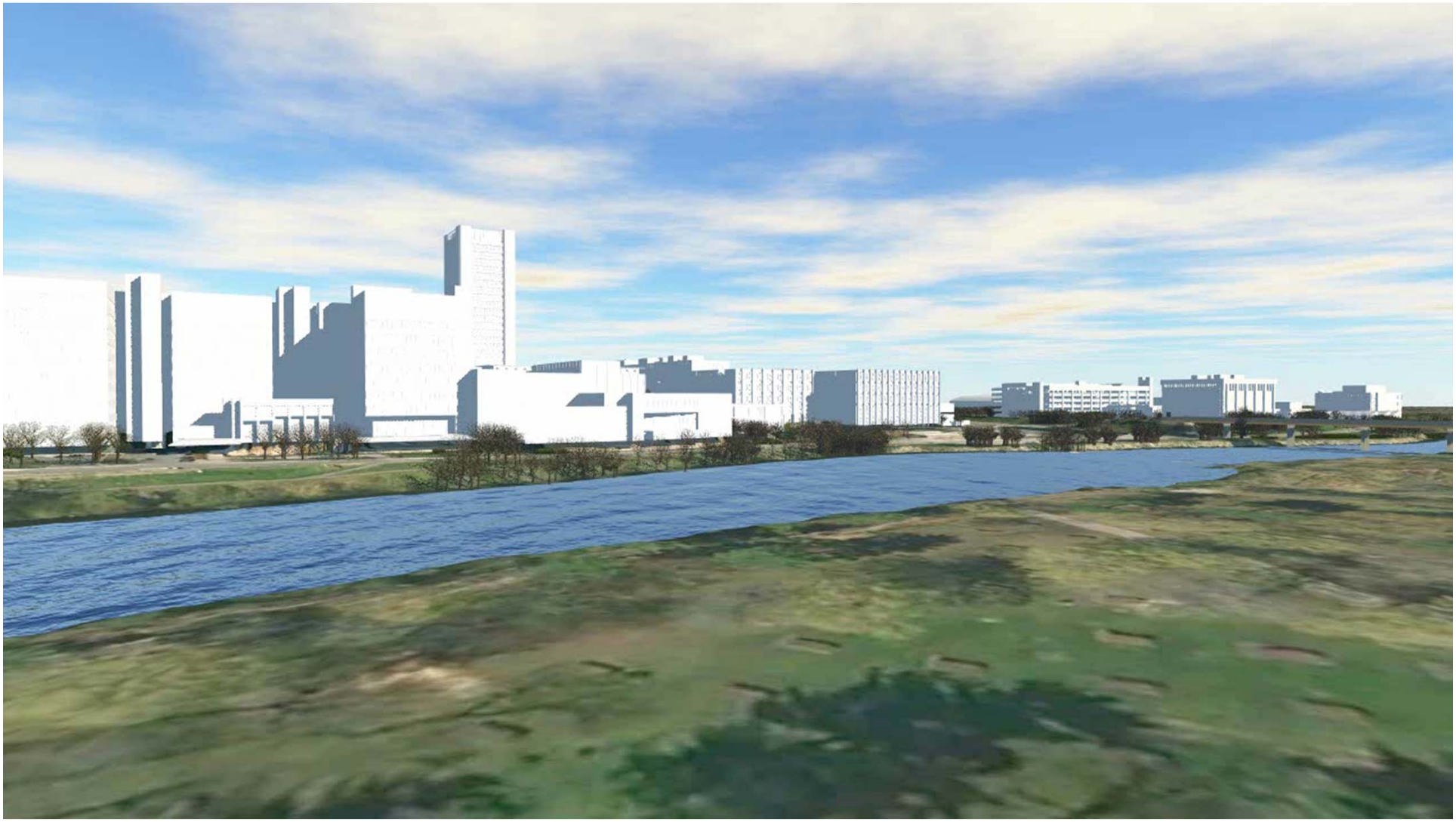
Occupant monitoring and modelling



Building information modelling

Fault detection and diagnostics

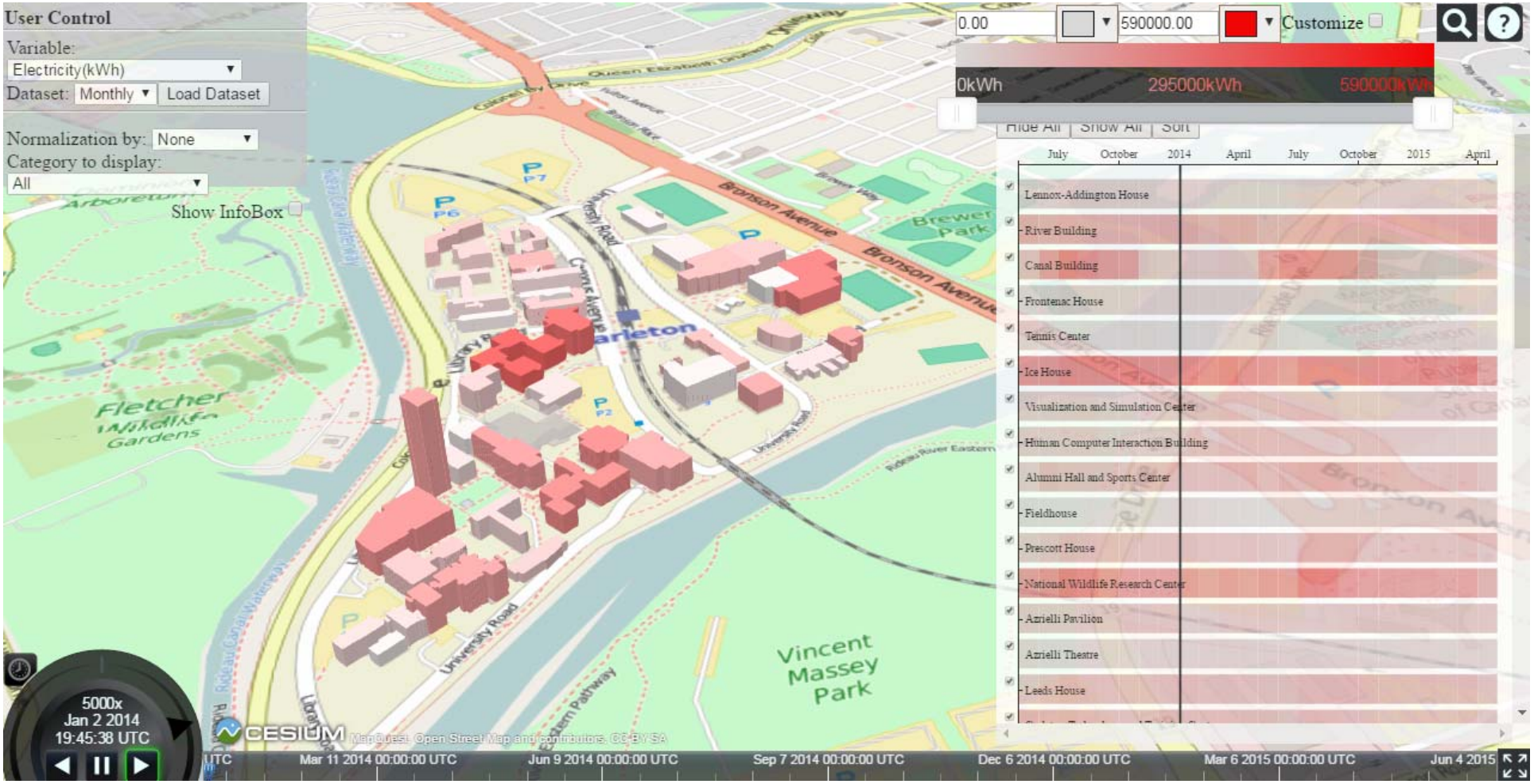
Sensor position optimization



Carleton
Immersive
Media
Studio

Carleton University
Campus
Temp 'C : 19.2
CHILL WATER RESET
PRIOR TO COOLING SEASON
Demand Reset
Demand Reset
Capacitor Banks
Pow er Factors
Building Voltage
Building Current
Building Demand
Neutral Currents
5 Loops (kW)
Campus Stm Pres
Campus Steam Dist
Campus Water Usag
MR2 MTHW Distribution
MR1 MTHW Distribution
BRONSON
Pfac
Iavg
Cond
Bronson Sub
MR1 & 2 mthw
Chil Water
CW Old
Carleton UNIVERSITY
Communications
All The Loops
Metering Documentation
Old Diagram
Gnd Water
V : 7,534.0
V : 7,536.0
V : 7,538.0
A
B
C
V : 7,443.0
V : 7,439.0
V : 7,436.0
15
02
Res-
Hartwells Locks
Rideau Canal
Experimental Farm
Colonel By Drive
Library Road
Campus Avenue
Rideau River
LOT 2
LOT 4
LOT 6
LOT 7
LOT 8
Log Server
Colonel By_Water
GymBoiler
Anniversary Park
Prescott
O-Train Station
All Athletics Meters
Field House
Keith Harris Stadium
Main Entrance
Daycare
POOL Bldg
BRONSON
MAINTENANCE
ROBERTSON
CTTC
Old GYM
AlumniHall
Ice House
Elba Nesbitt
NWRC
Vincent Massey Park
Bronson Sub
9,314
Kw_Tot
Feeder 1
A : 218
V : 13,004.2
Kw : 4,543
Feeder 2
A : 231
V : 12,888.7
Kw : 4,755
Feeder 3
A : 0
V : 0.0
Kw : 0

Building performance visualization



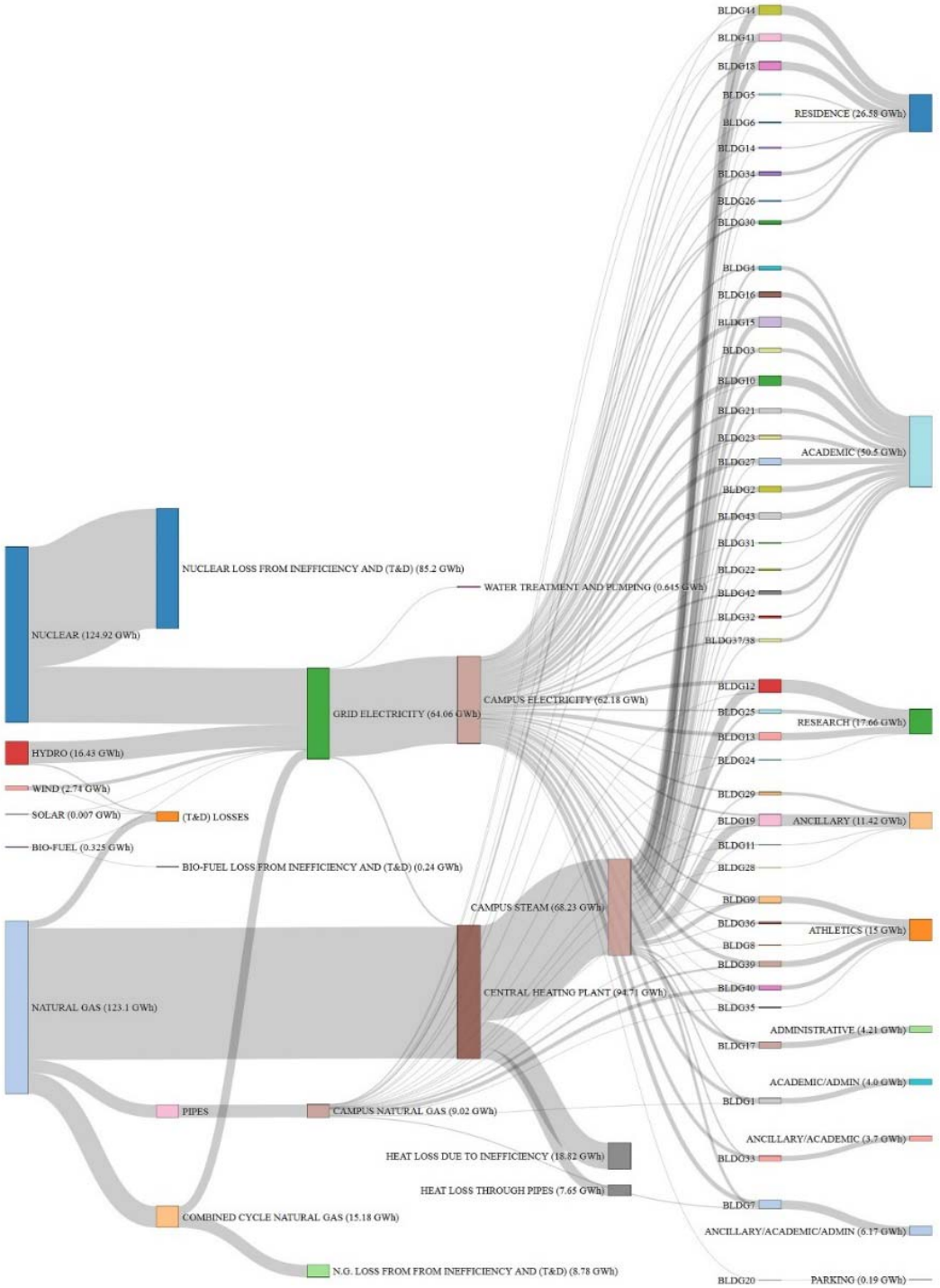
http://zixiaoshi.github.io/GeospatialVisualizer/demo.html

Sankey diagram: Campus energy

Nuclear: 125 GWh

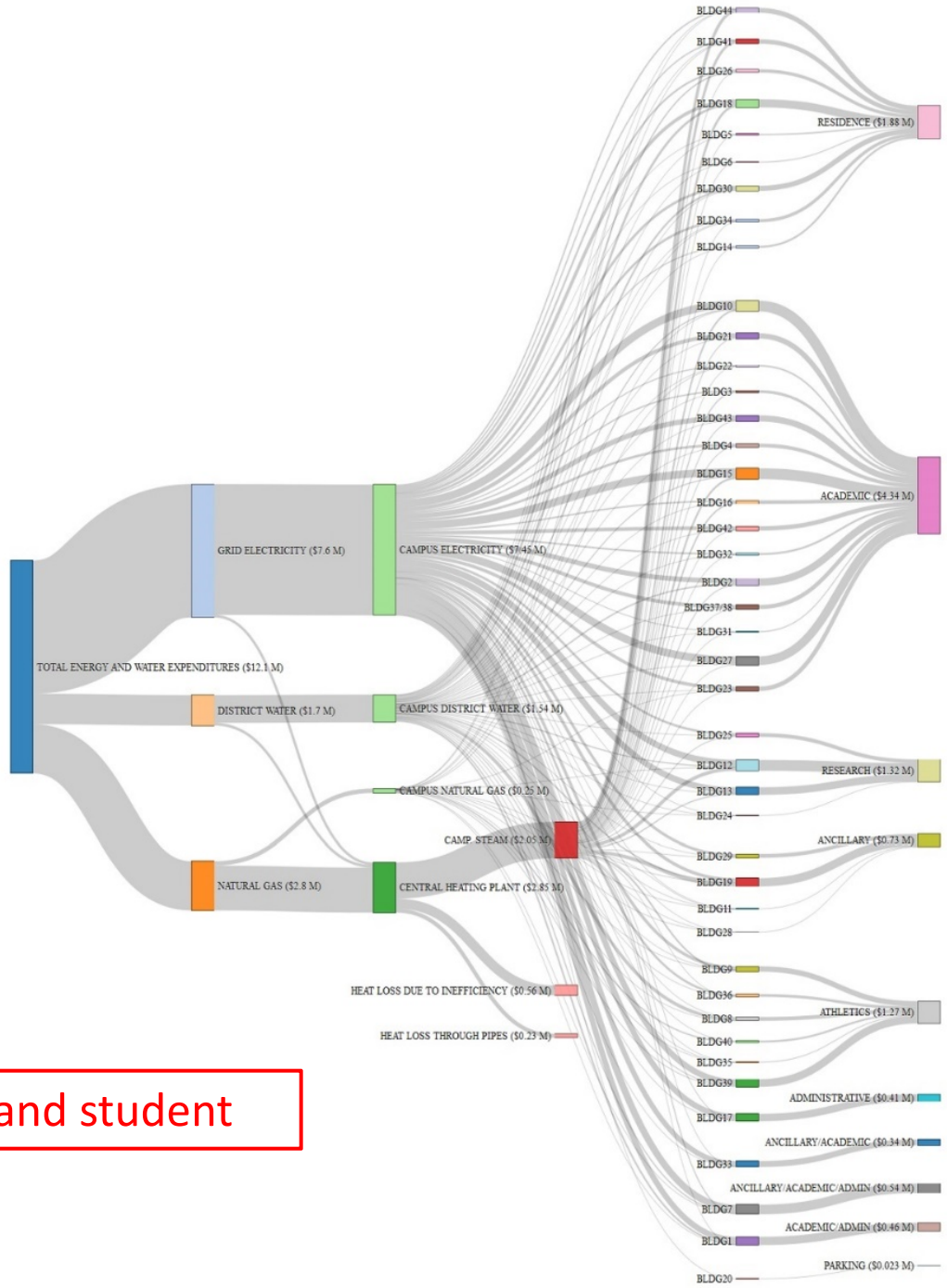
Hydro: 16 GWh
Wind: 3 GWh
Solar: 0.007 GWh
Biofuel: 0.3 GWh

Natural Gas: 123 GWh



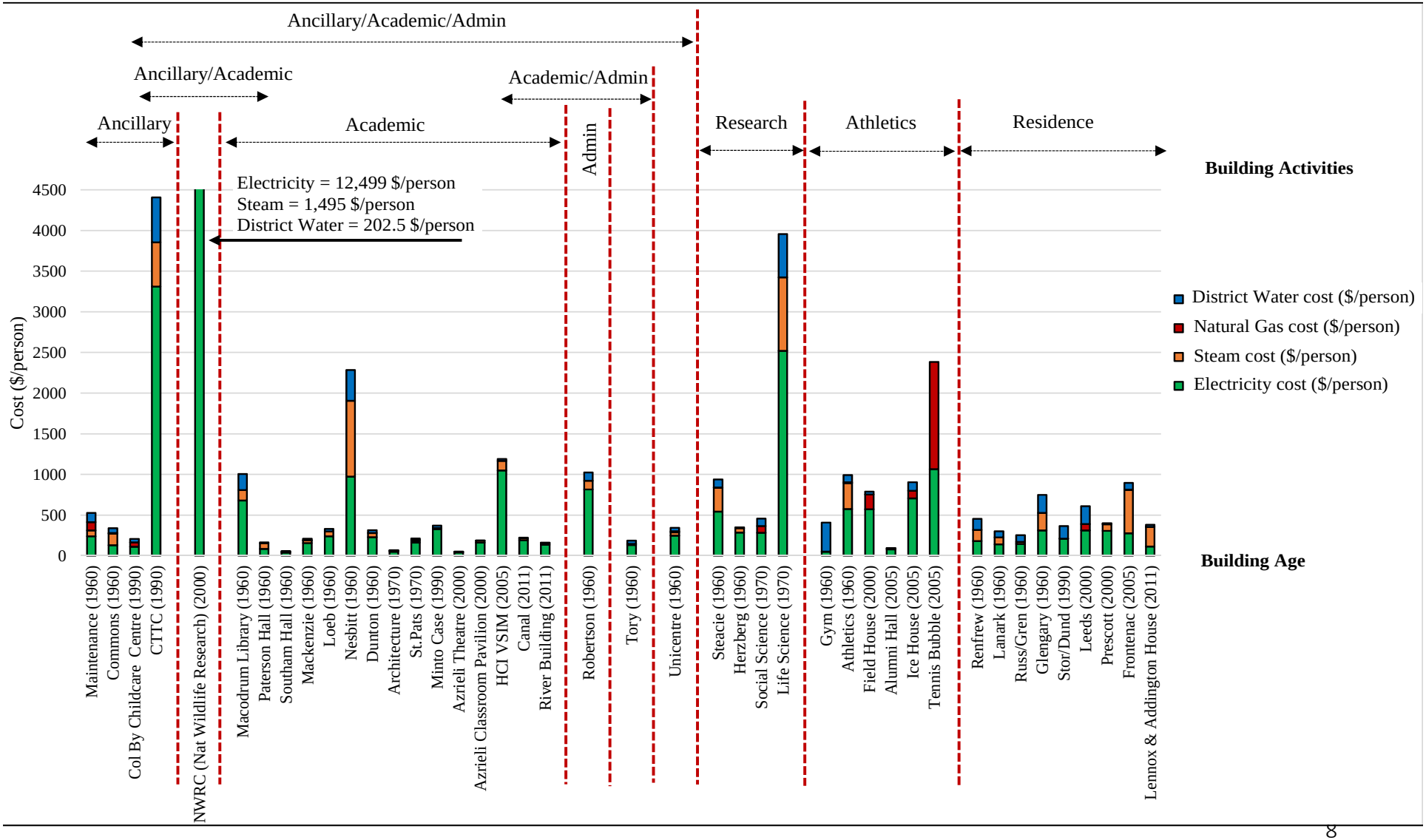
Sankey diagram: Energy costs

$12.1M utility costs/year



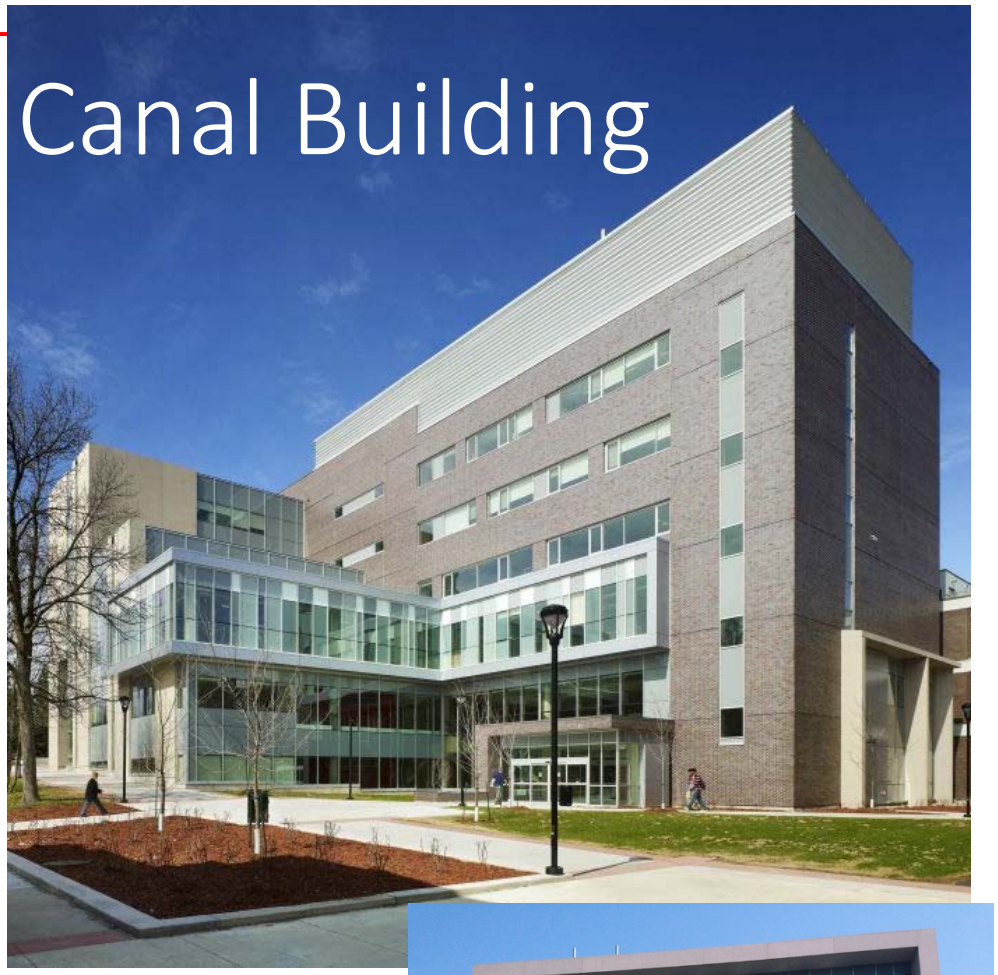
About $500/employee and student

Cost normalization by person



Building Level

- 7 storeys, 8000 m^2
- Offices, classrooms, research labs computer labs, café
- First building with Power over Ethernet controls
- CopperCube
- District steam, shared cooling plant
- Energy recovery wheel



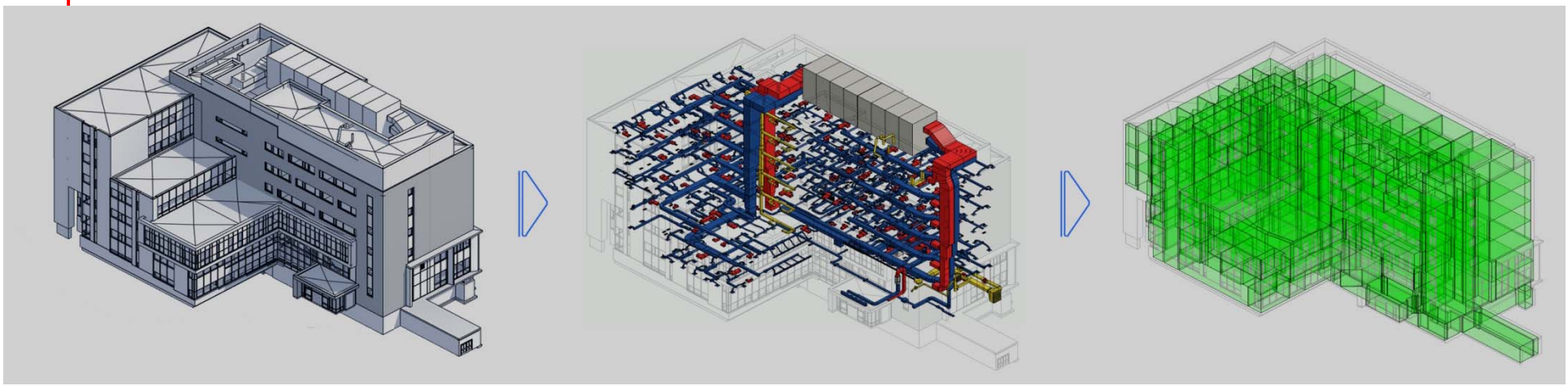
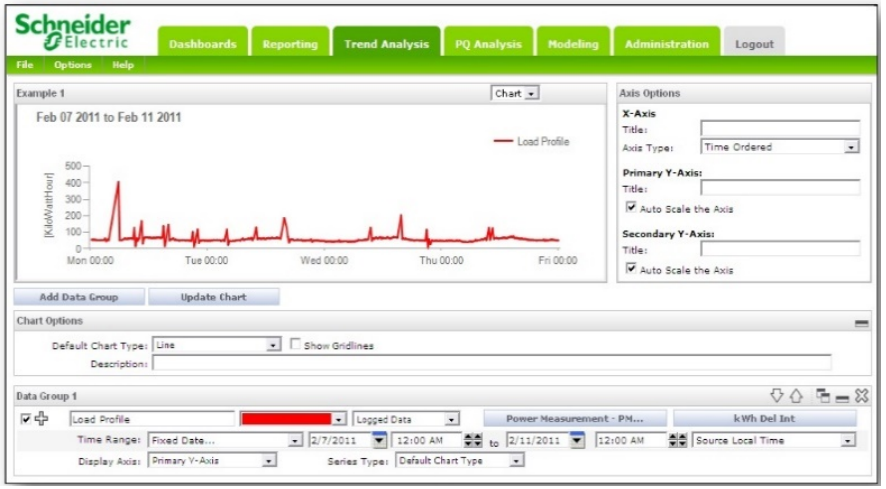
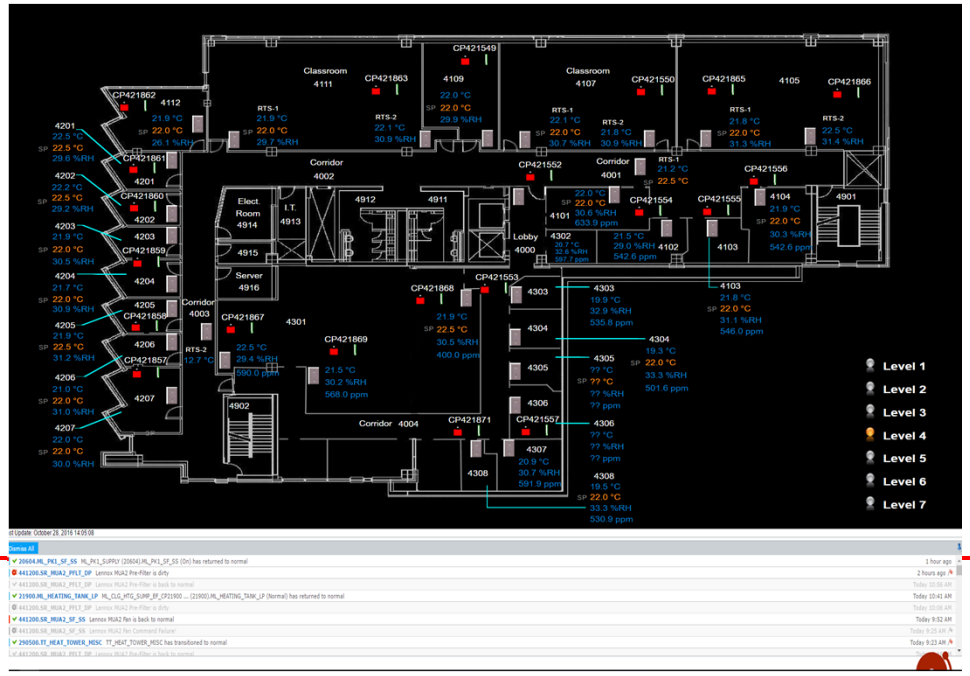


PHOTO by GRCArchitects

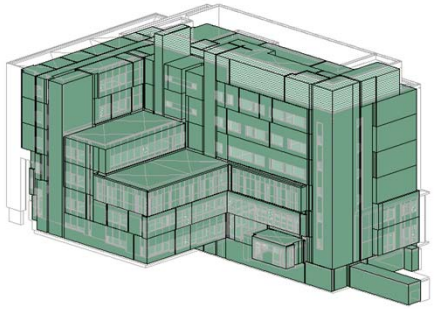
BIM by CIMS

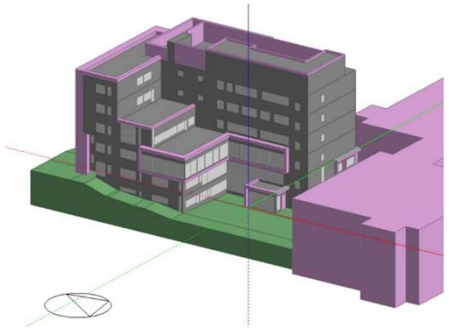
Building performance visualization

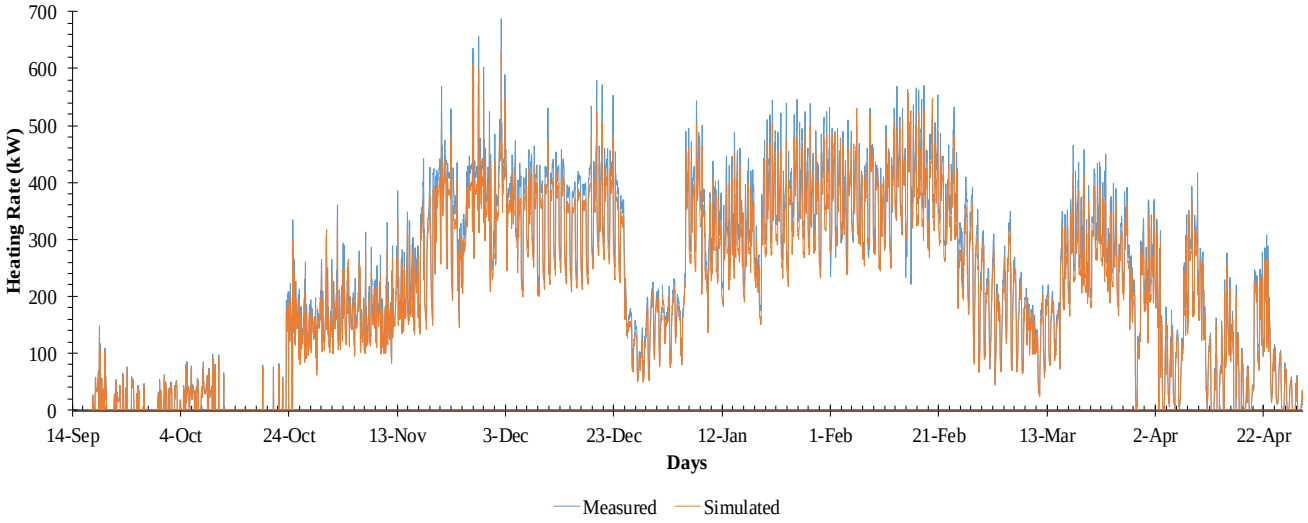


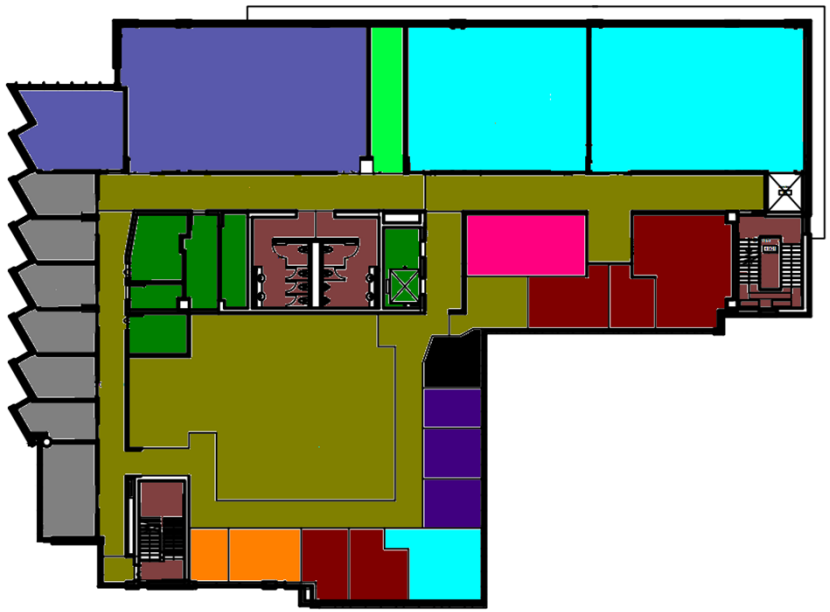


BIM->BPS and model calibration

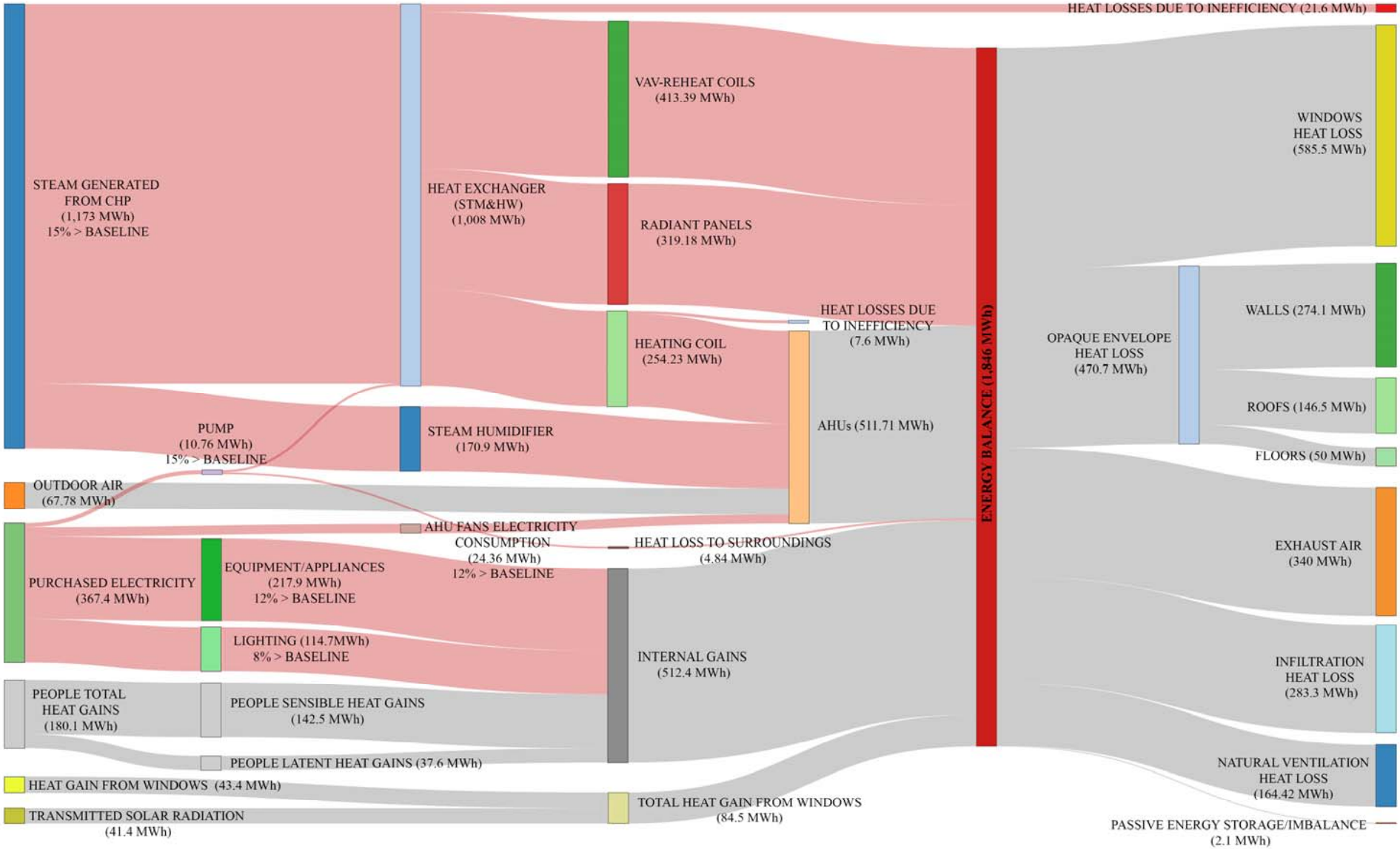




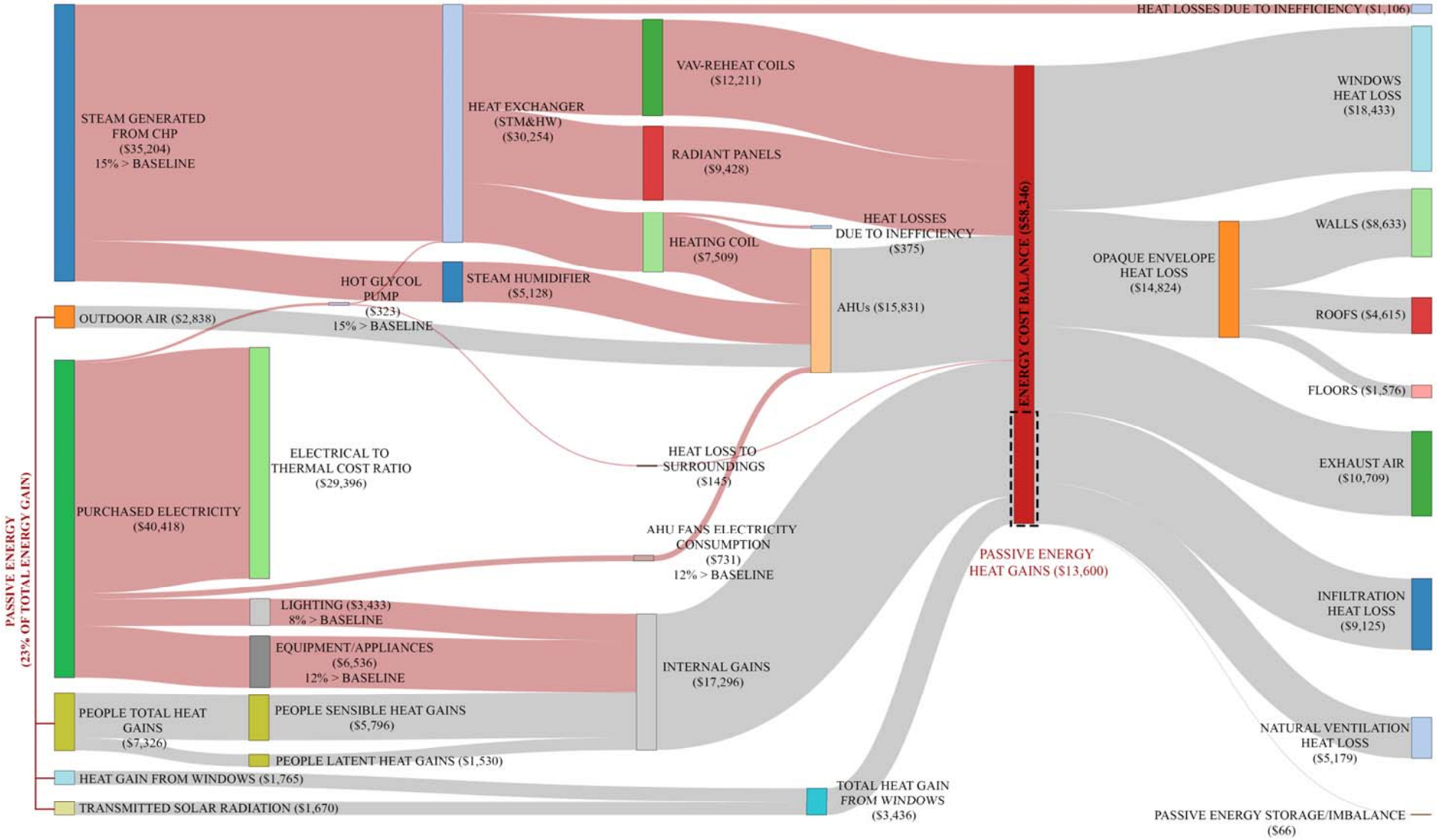




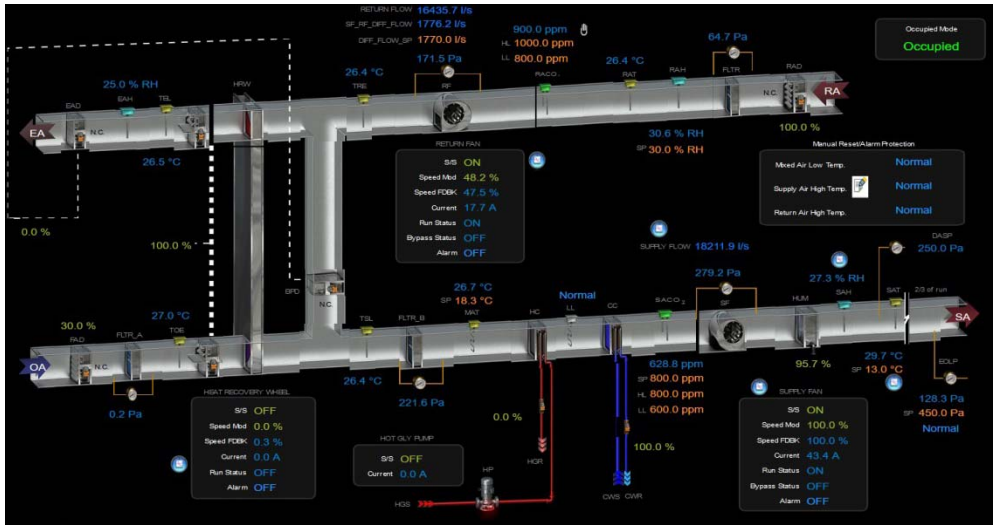
Canal Building – Heating Season Energy

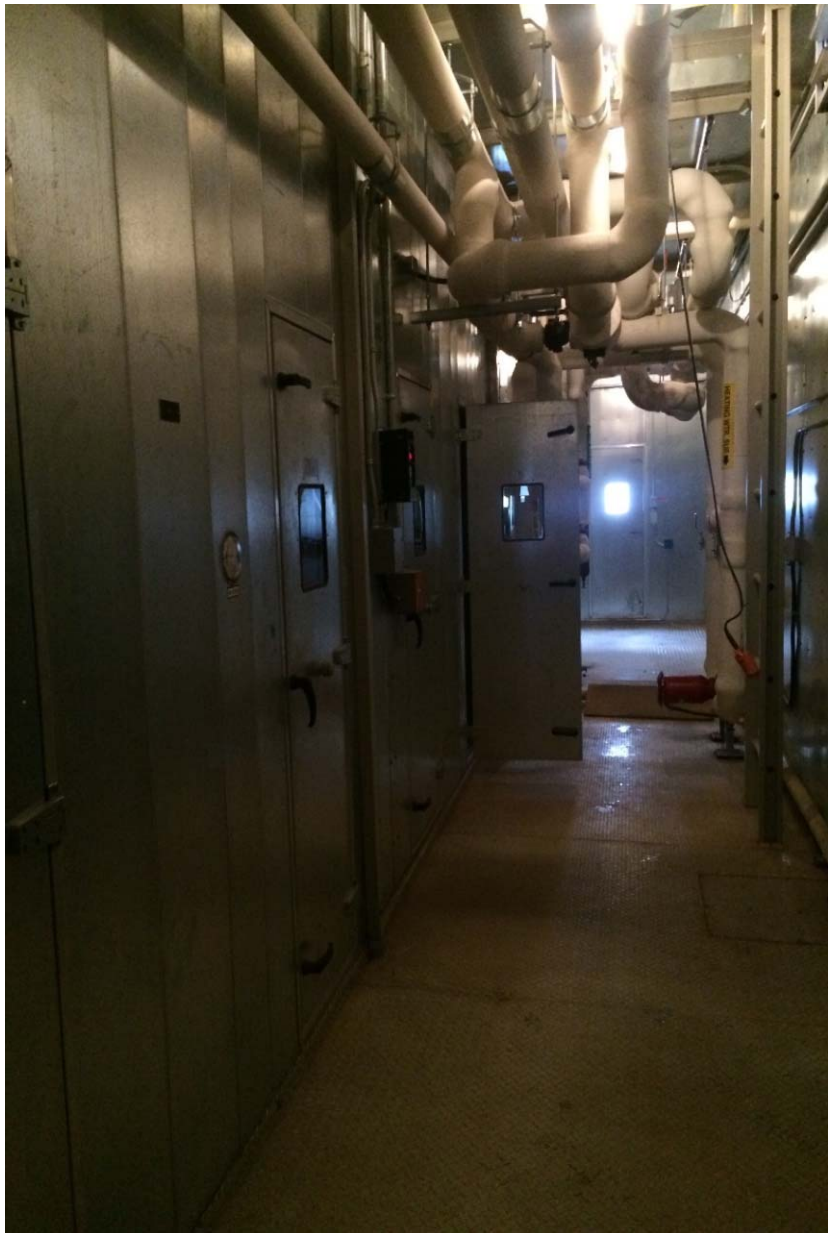


Canal Building – Heating Season Cost

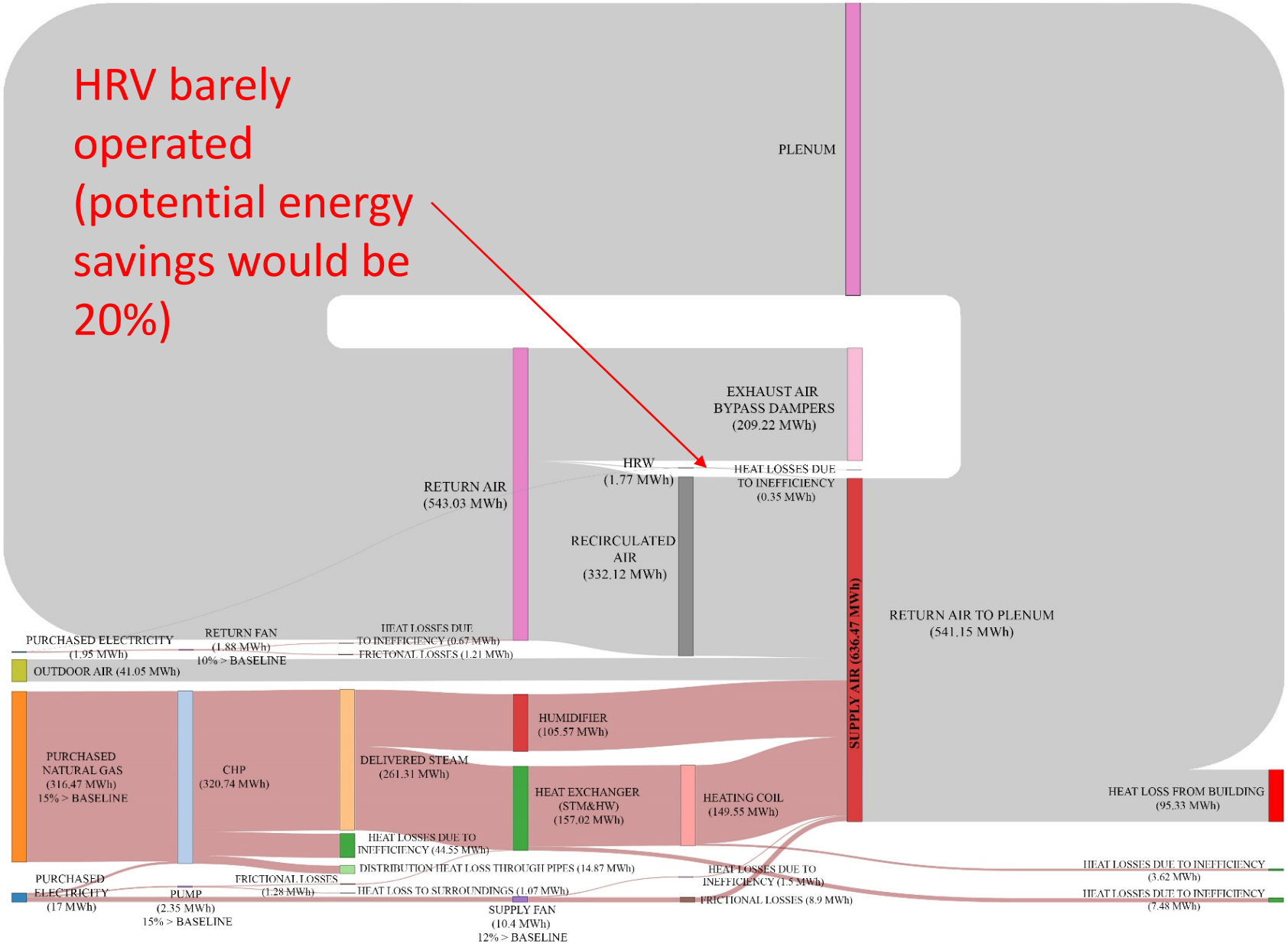


Canal Building AHU

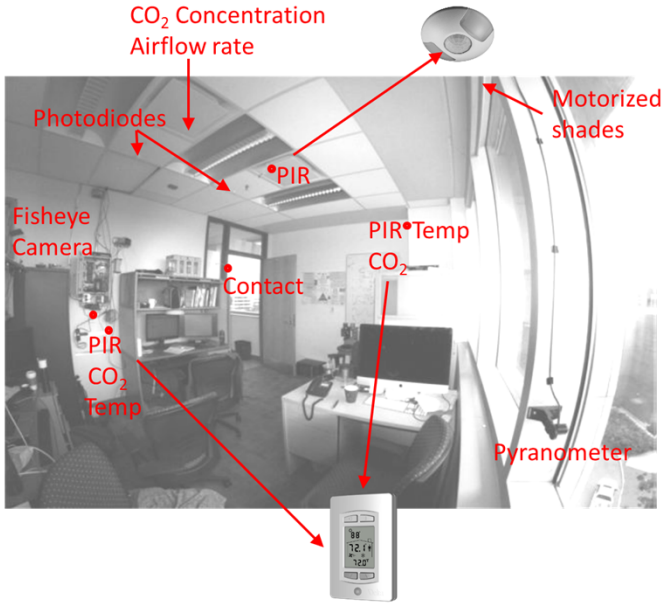


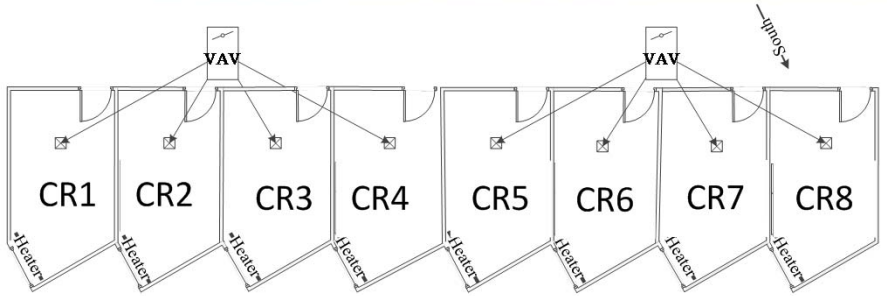


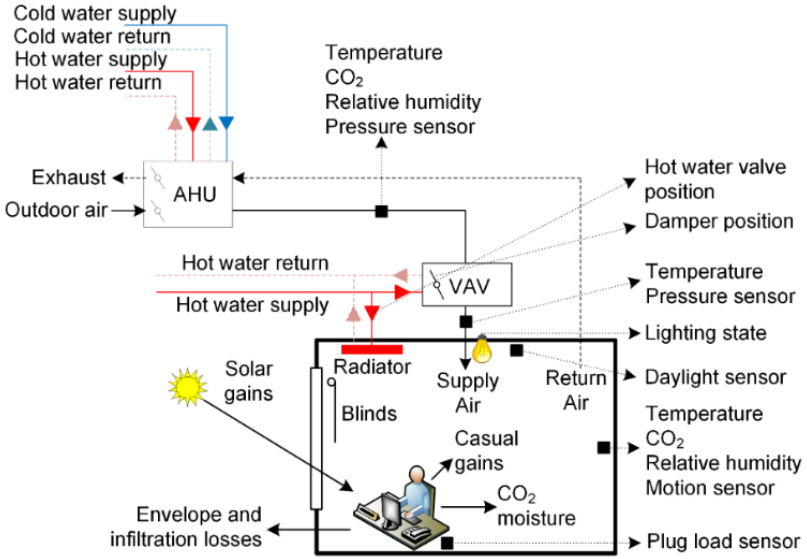
Air Handling Unit – Heating Season Energy

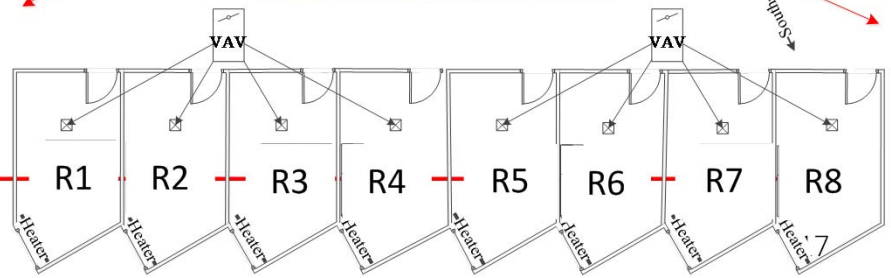


Canal Building Offices

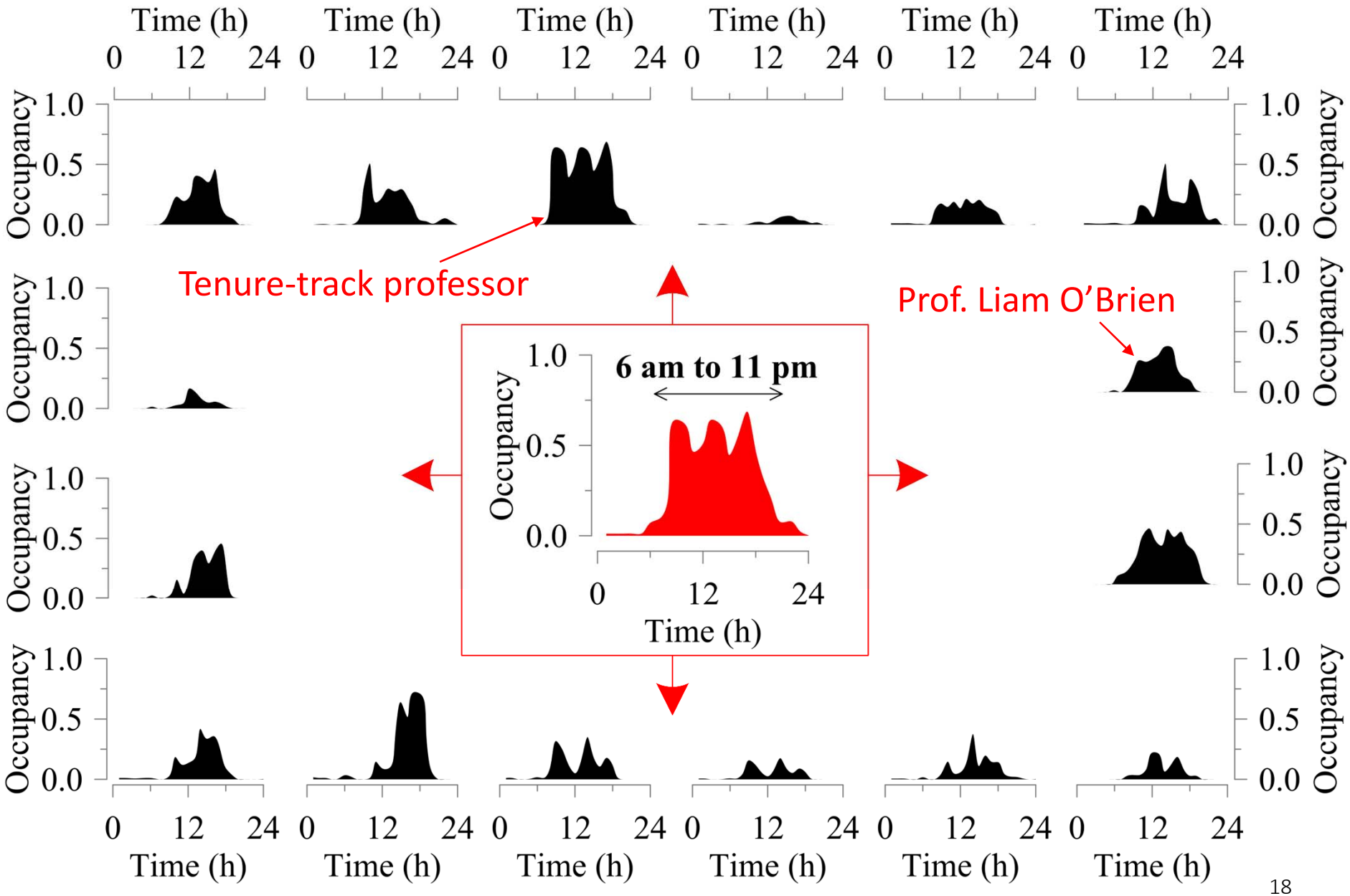




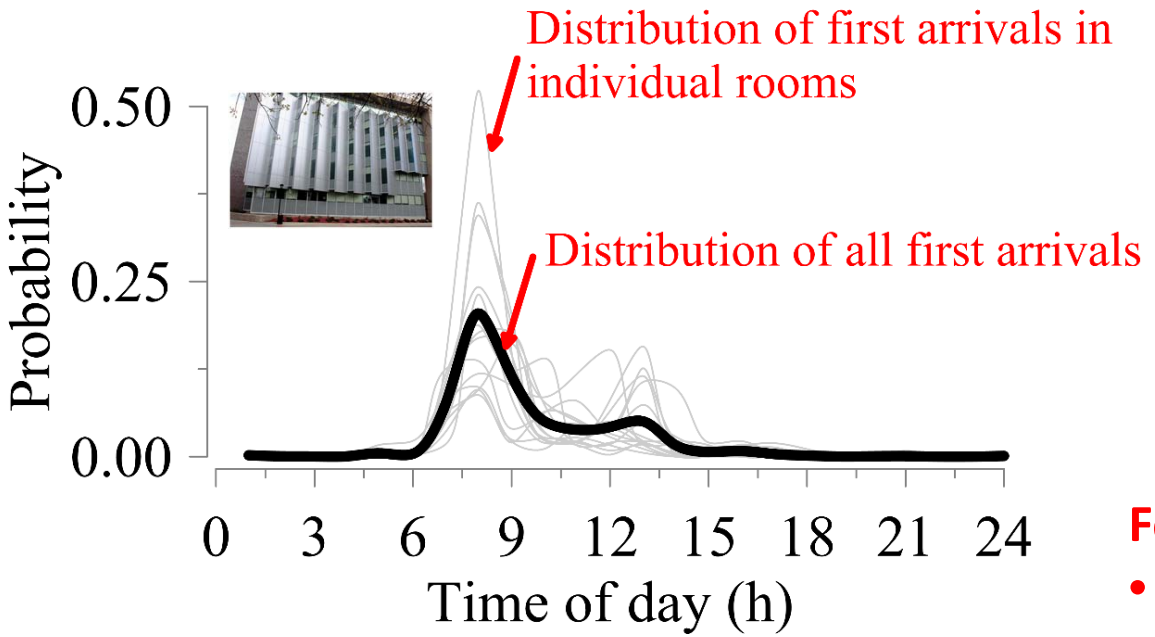


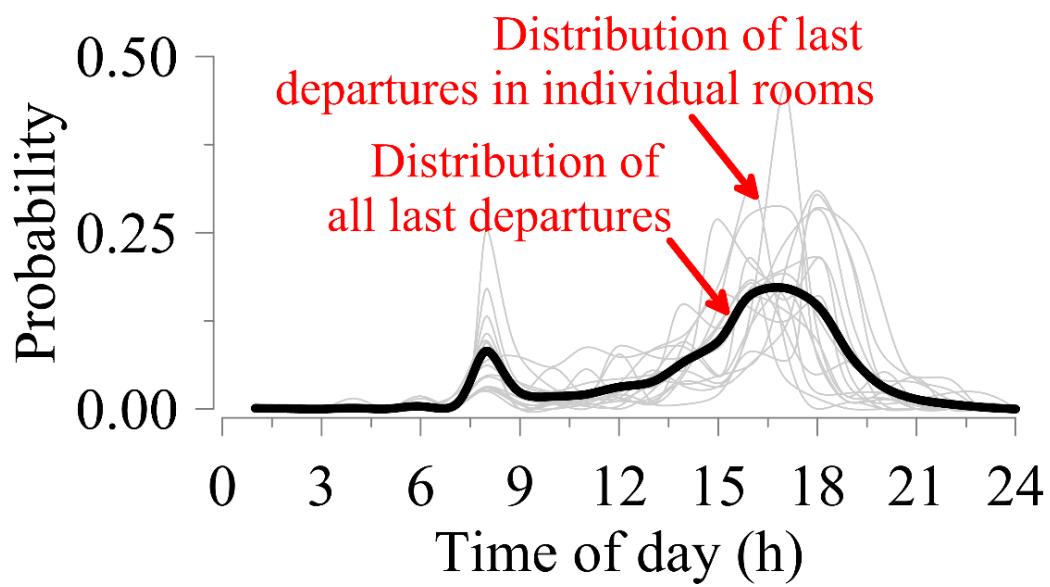


Occupancy in professor offices



Arrival and departure times

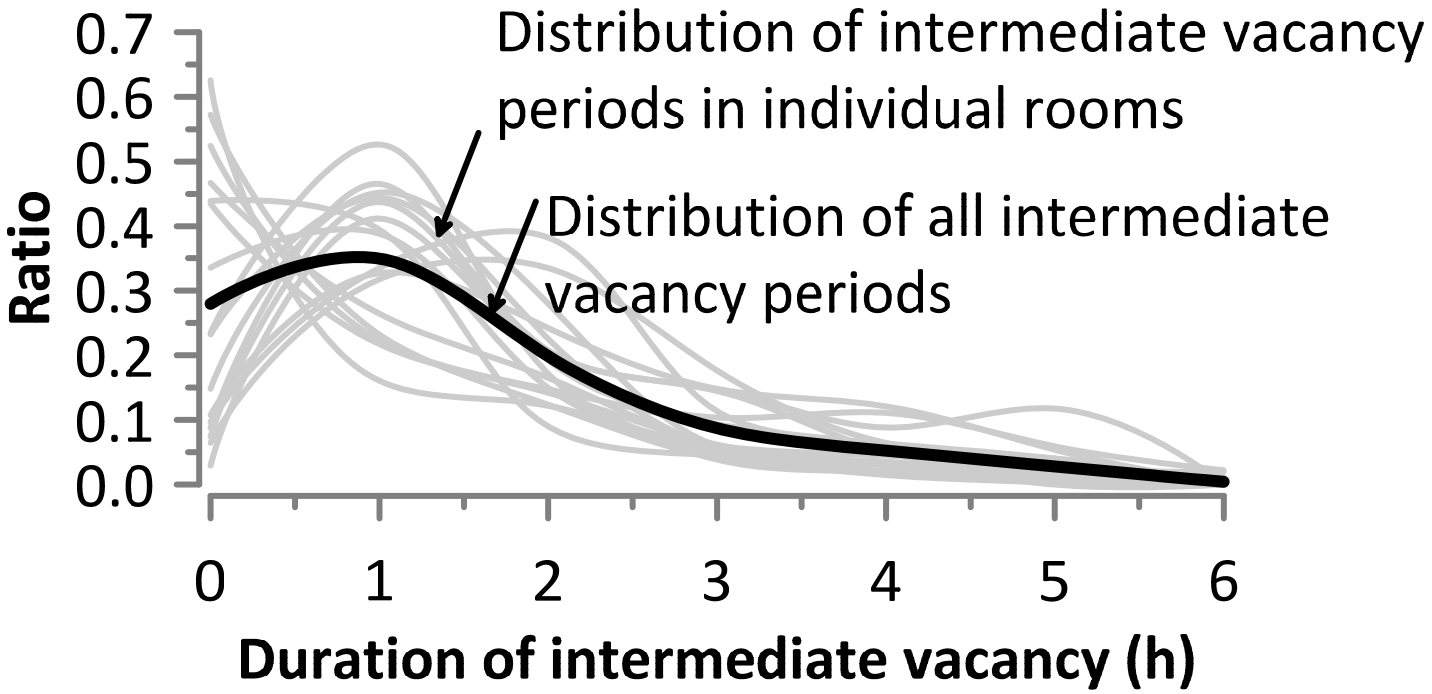




For Prof. O'Brien:

- Earliest expected first arrival time is 8 am.
- Latest expected first arrival time is 1 pm. If it is 1 pm and he has not arrived, his terminal equipment can be setback.
- Latest expected last departure time is 8 pm.

Intermediate vacancy periods



For Prof. O'Brien:

- Longest expected duration of intermediate absence period is 3 h.
- If he takes a break and does not return in 3 h, his room HVAC equipment can be setback.

Thermal and optical properties of offices

Outdoor temperature

Indoor temperature

Daylight sensor

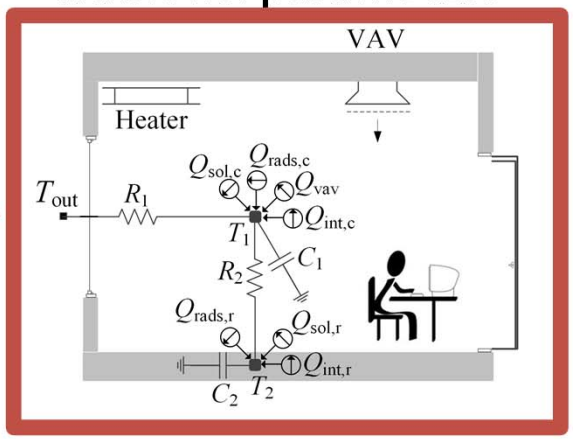
Occupancy state

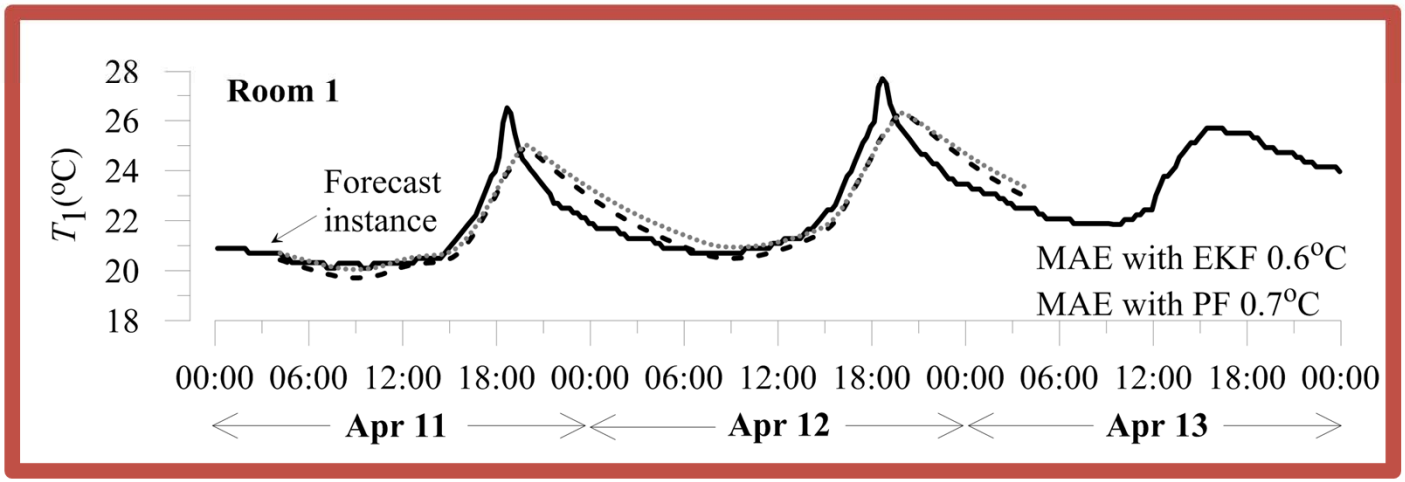
Radiant panel state

VAV pressure sensor

VAV supply air temperature

Generic graybox model with unknown parameters



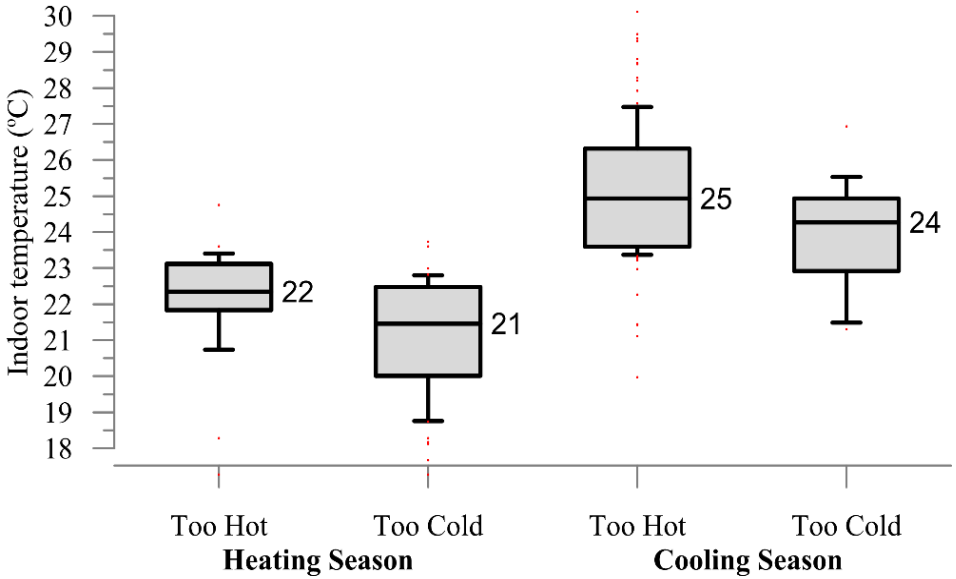


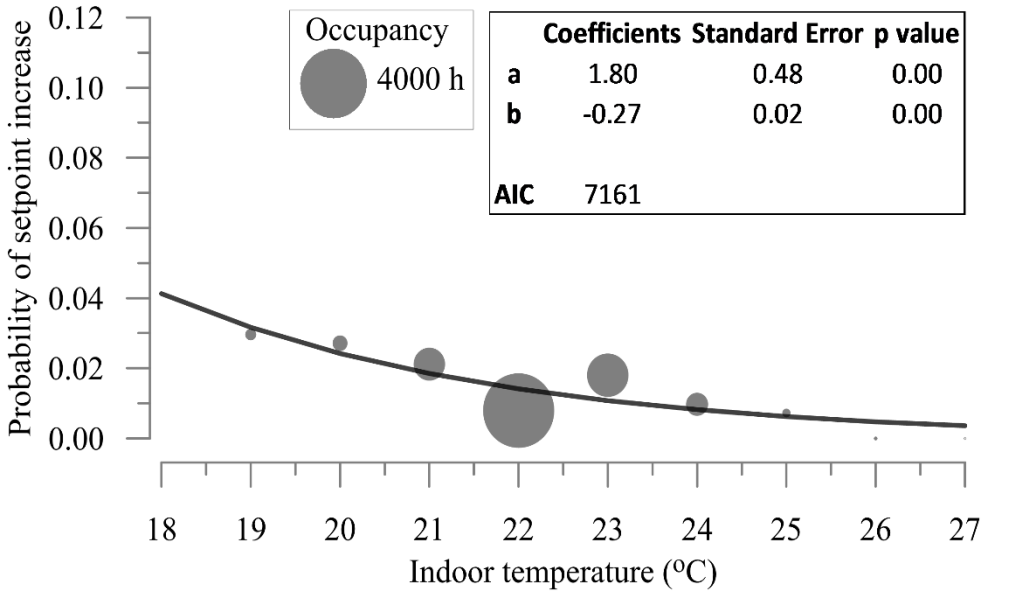
Gunay, H. Burak, William O'Brien, and Ian Beausoleil-Morrison. "Control-oriented inverse modeling of the thermal characteristics in an office." *Science and Technology for the Built Environment* (2016): 1-20.

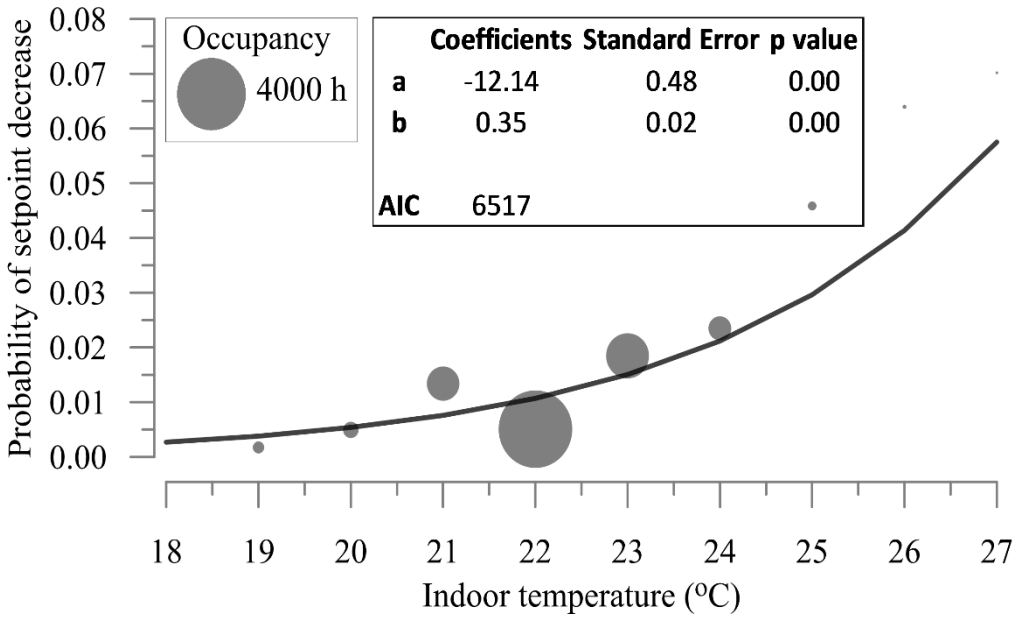
Julia Day

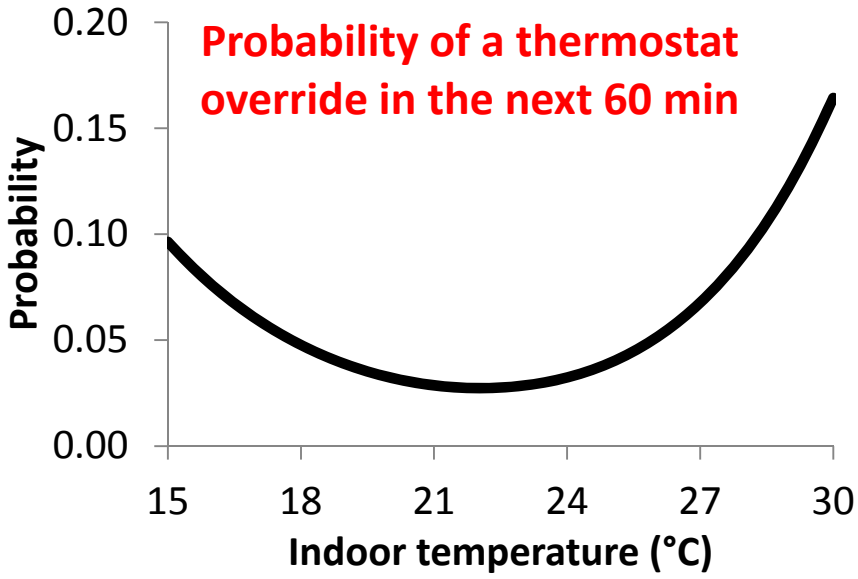
Temperature learning

- Original controls heated and cooled to 22°C with minimal occupant *overrideability*
- But 1/3 of overrides in winter were to <u>decrease</u> temperature
- But 1/3 of overrides in summer were to <u>increase</u> temperature





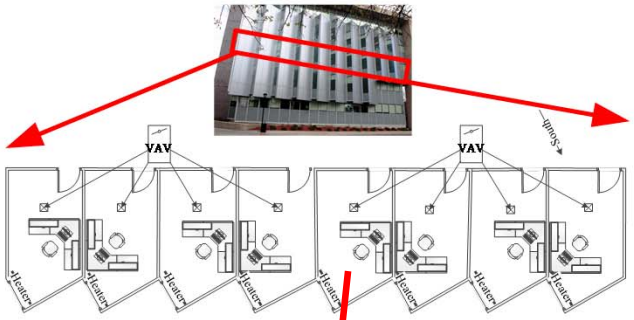




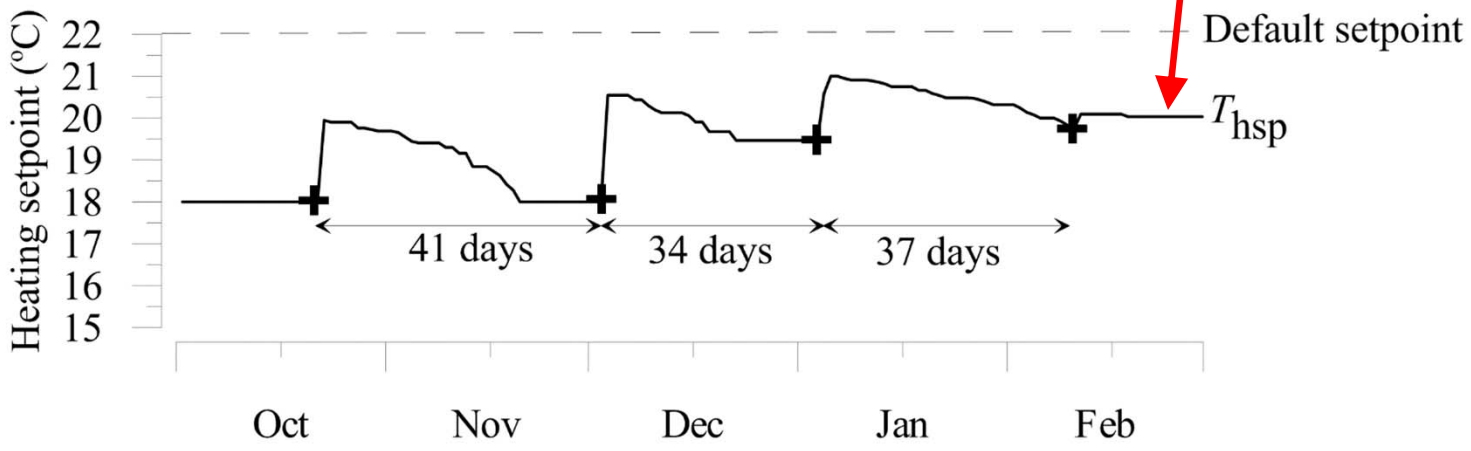
Frequency of thermostat override actions is a proxy for user comfort

Always lower than 22°C

Always higher than 22°C

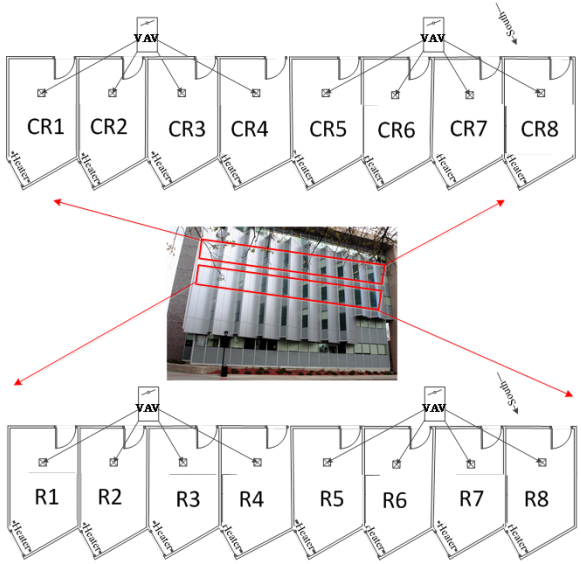


Heating setpoint (°C)	19	19	19	19	20	—	21	21
Cooling setpoint (°C)	24	24	24	24	25	—	24	24



Default algorithm – between Mar 2015 and Mar 2016

- 1400 h radiant panel operation
- 8.6 ac/h chilled air purchased in summer
- 8% of the occupied duration below 20 or above 25°C
- 2 complaints

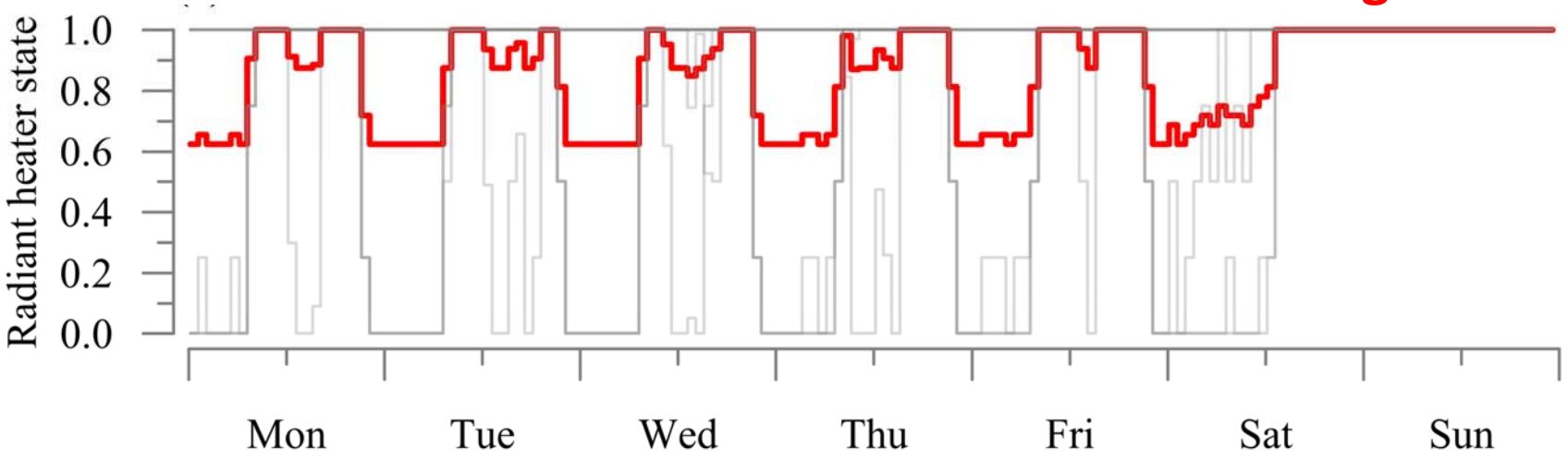


Adaptive algorithm – between Mar 2015 and Mar 2016

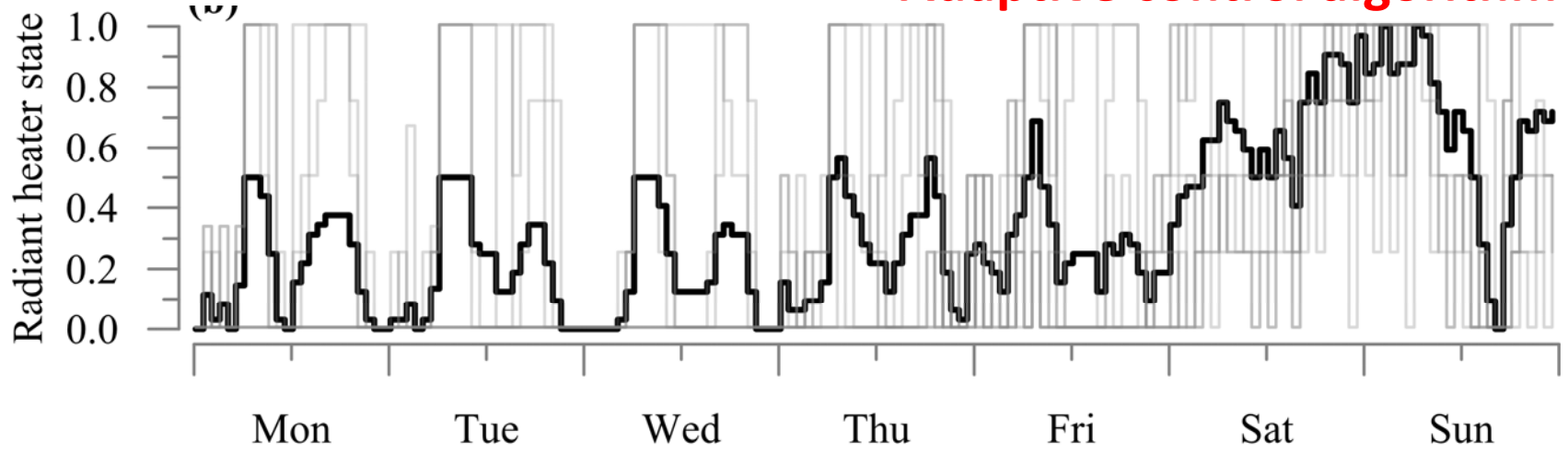
- 400 h radiant panel operation
- 2.1 ac/h chilled air purchased in summer
- 4% of the occupied duration below 20 or above 25°C
- 0 complaints
- 1% of the occupied duration above 1000 ppm CO_2

Effect of adaptive controls in heating load diversification

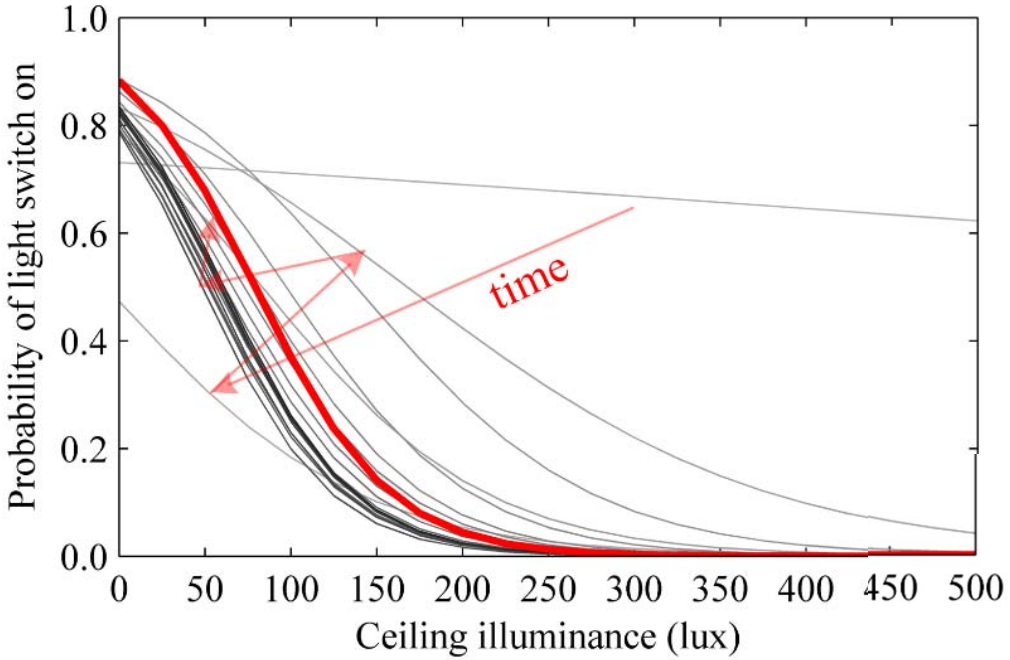
Default control algorithm



Adaptive control algorithm

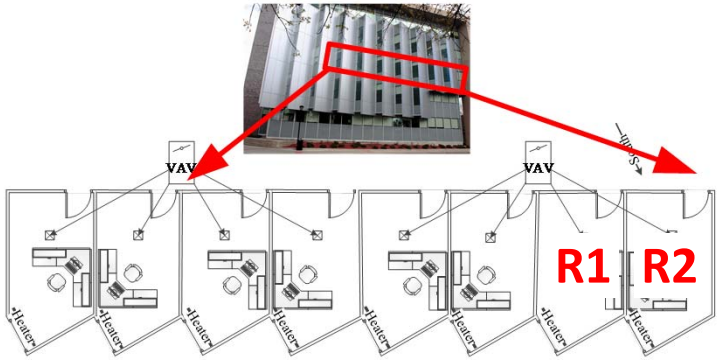


Recursive learning from users' light switch on behaviour inside Delta Lab



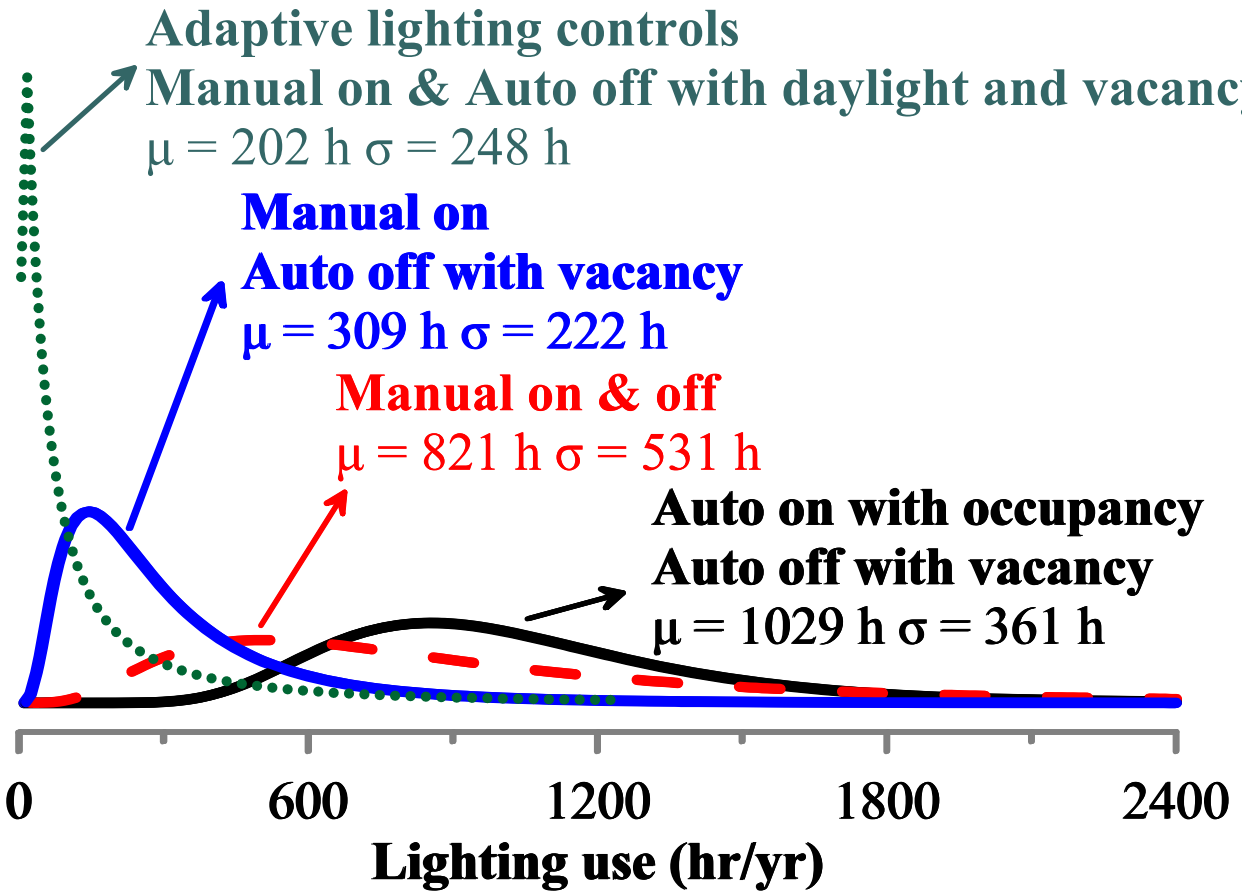
93% of the light switch off decisions were accepted

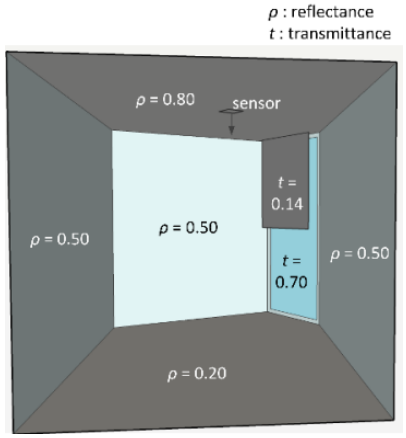
R1 prefers brighter conditions than R2



Light switch off setpoint (lux)	430	108	108	–	398	269

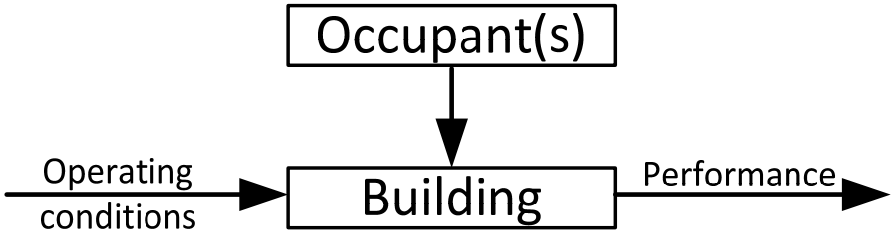
Integrated energy, daylight, and occupant simulation 30

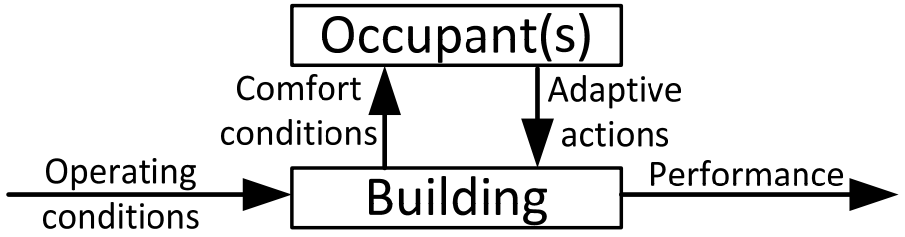


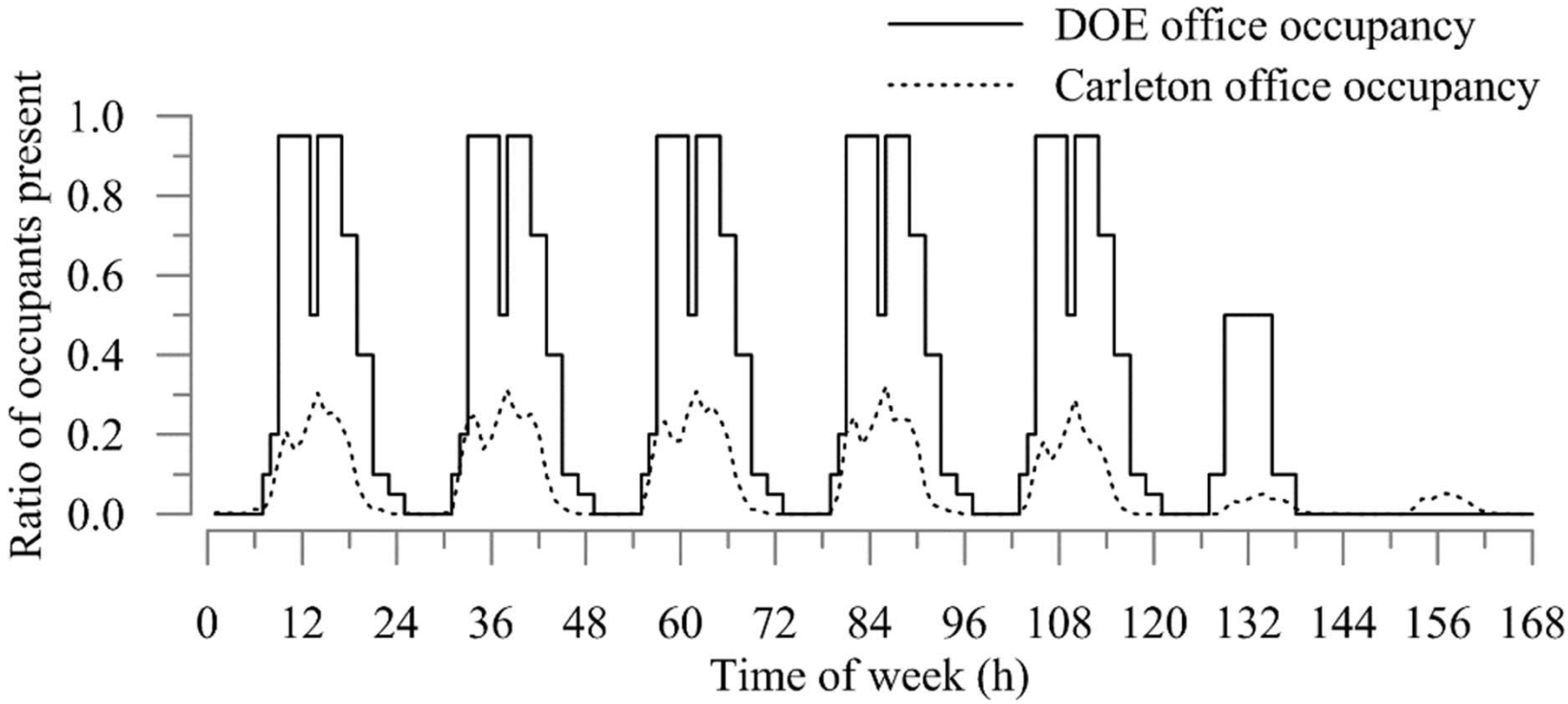


DAYSIM

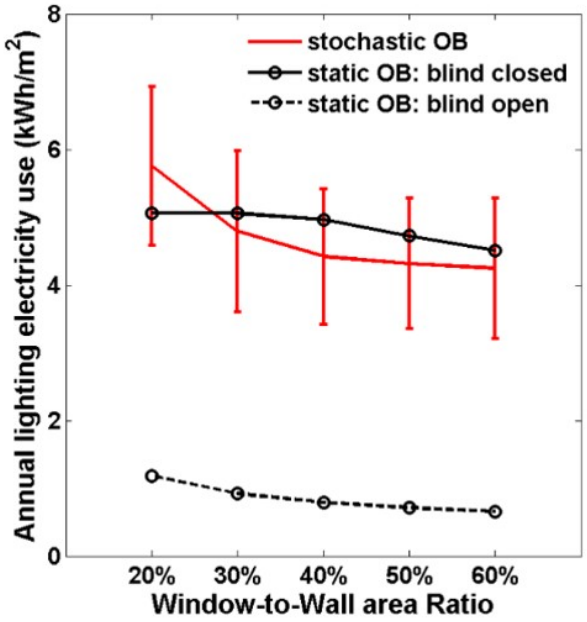
Occupant model development

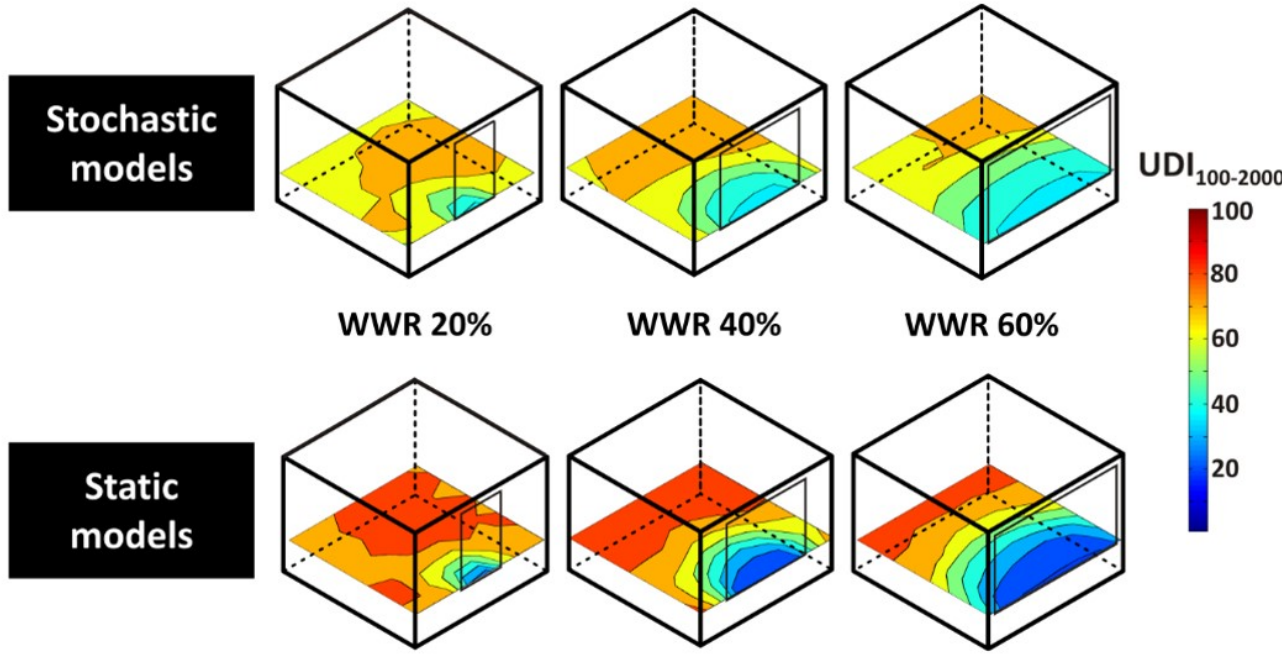






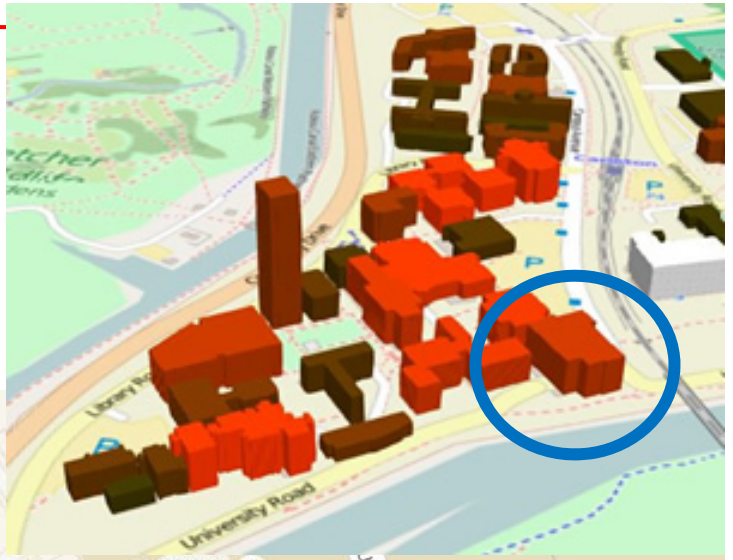
Occupant modelling in the design process

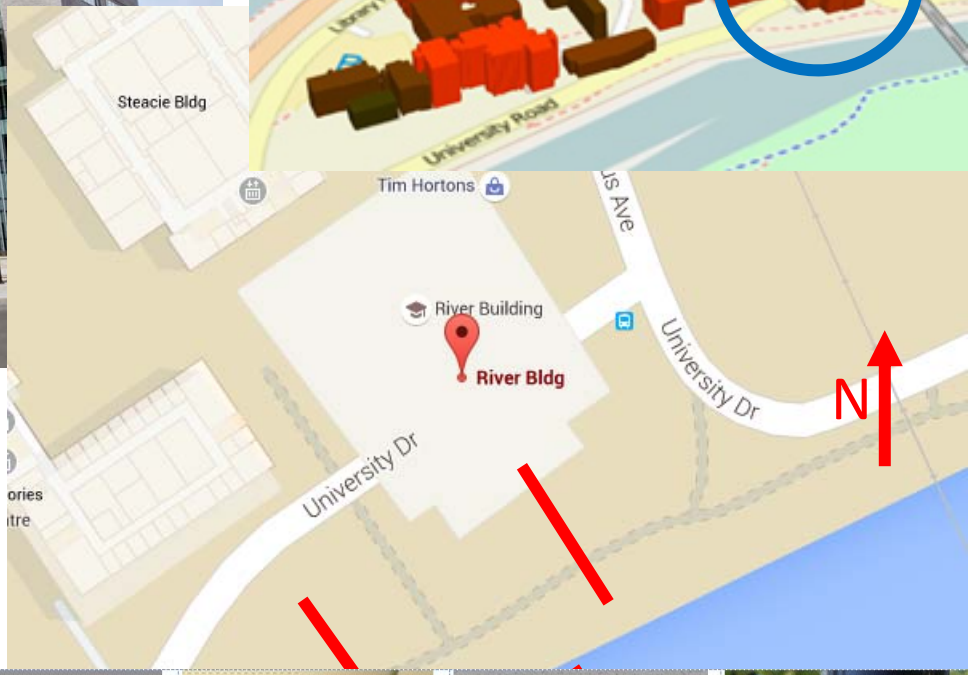


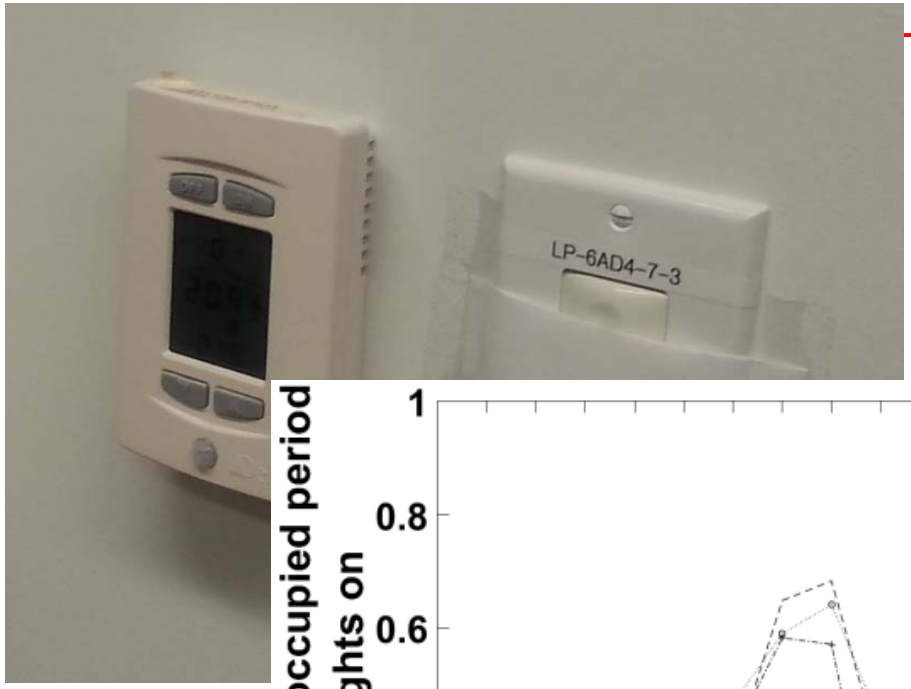


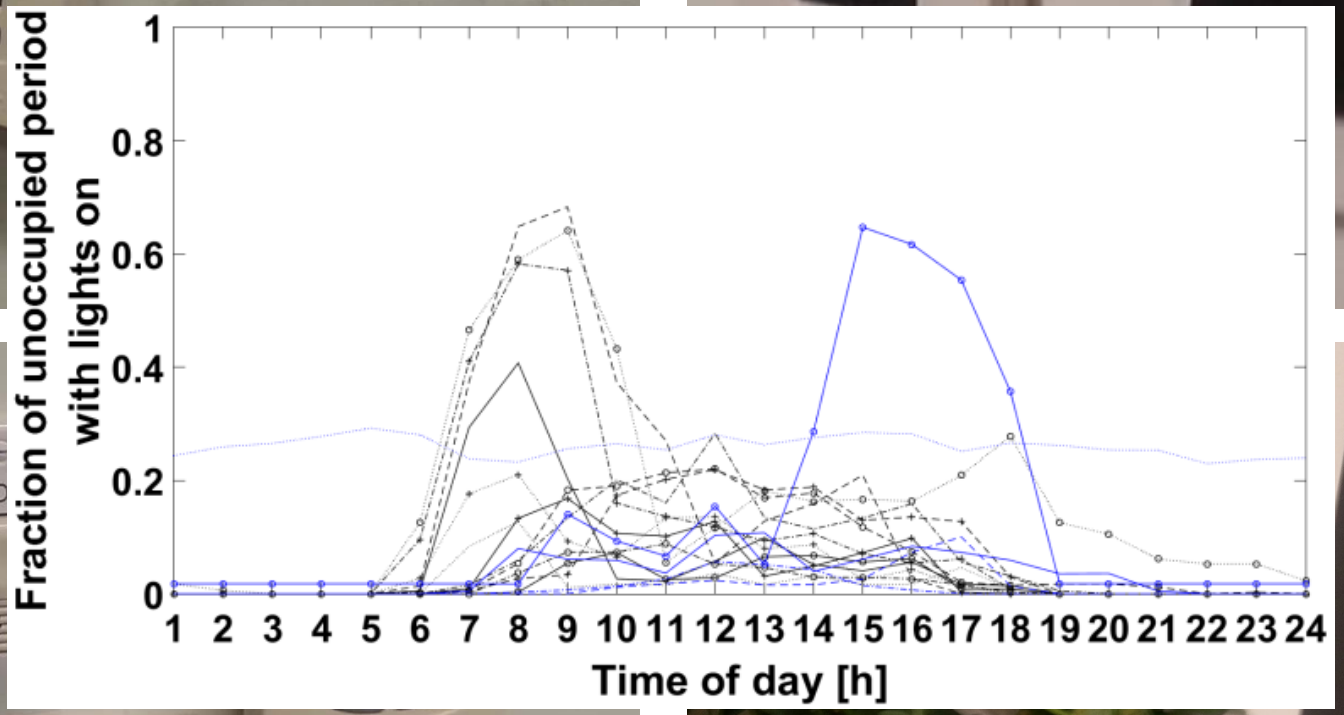
(Gilani et al., 2015)

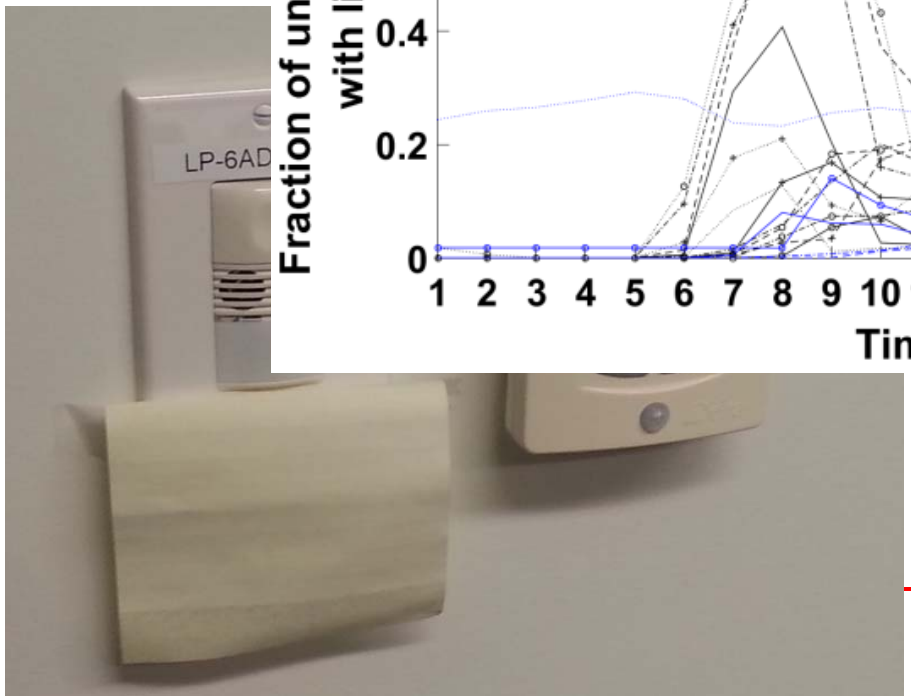
River Building

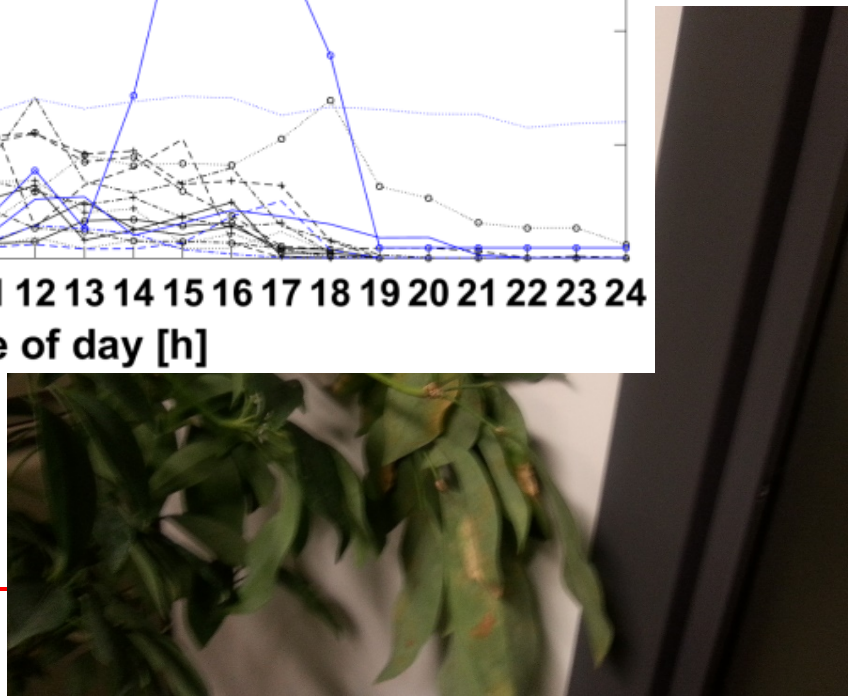





LP-6AD4-7-3

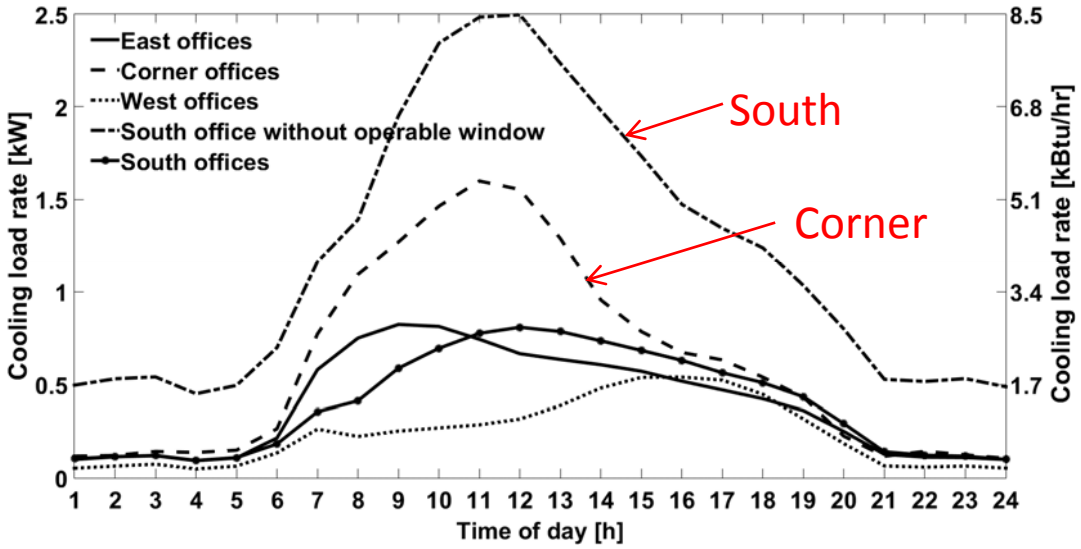

Fraction of unoccupied period with lights on
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time of day [h]

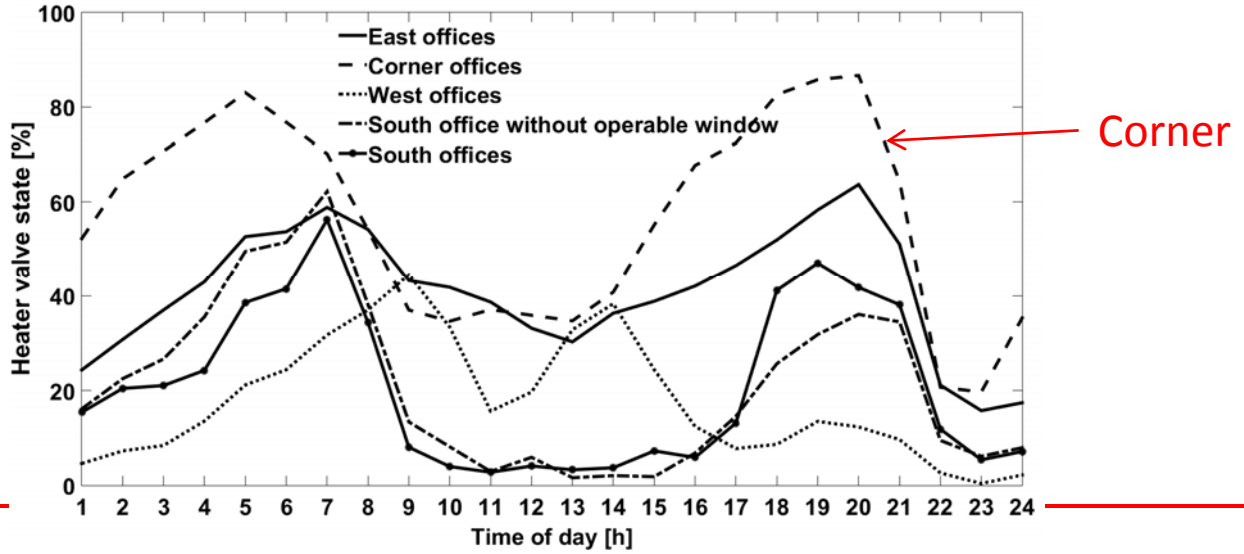

LP-6AD

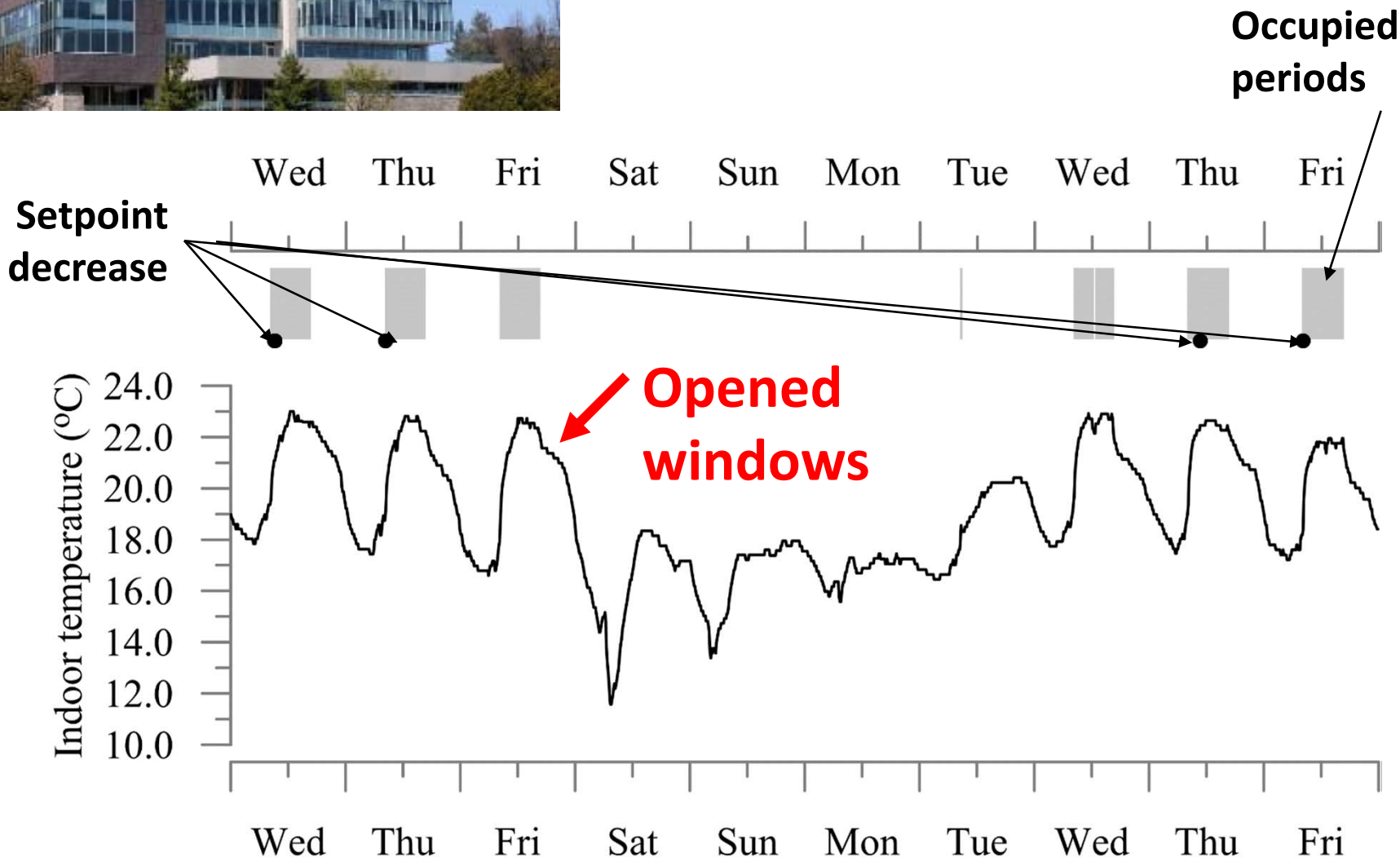


WINGSCAPES
30 MINUTES
CANALB
FEB.20,14
11:29 AM

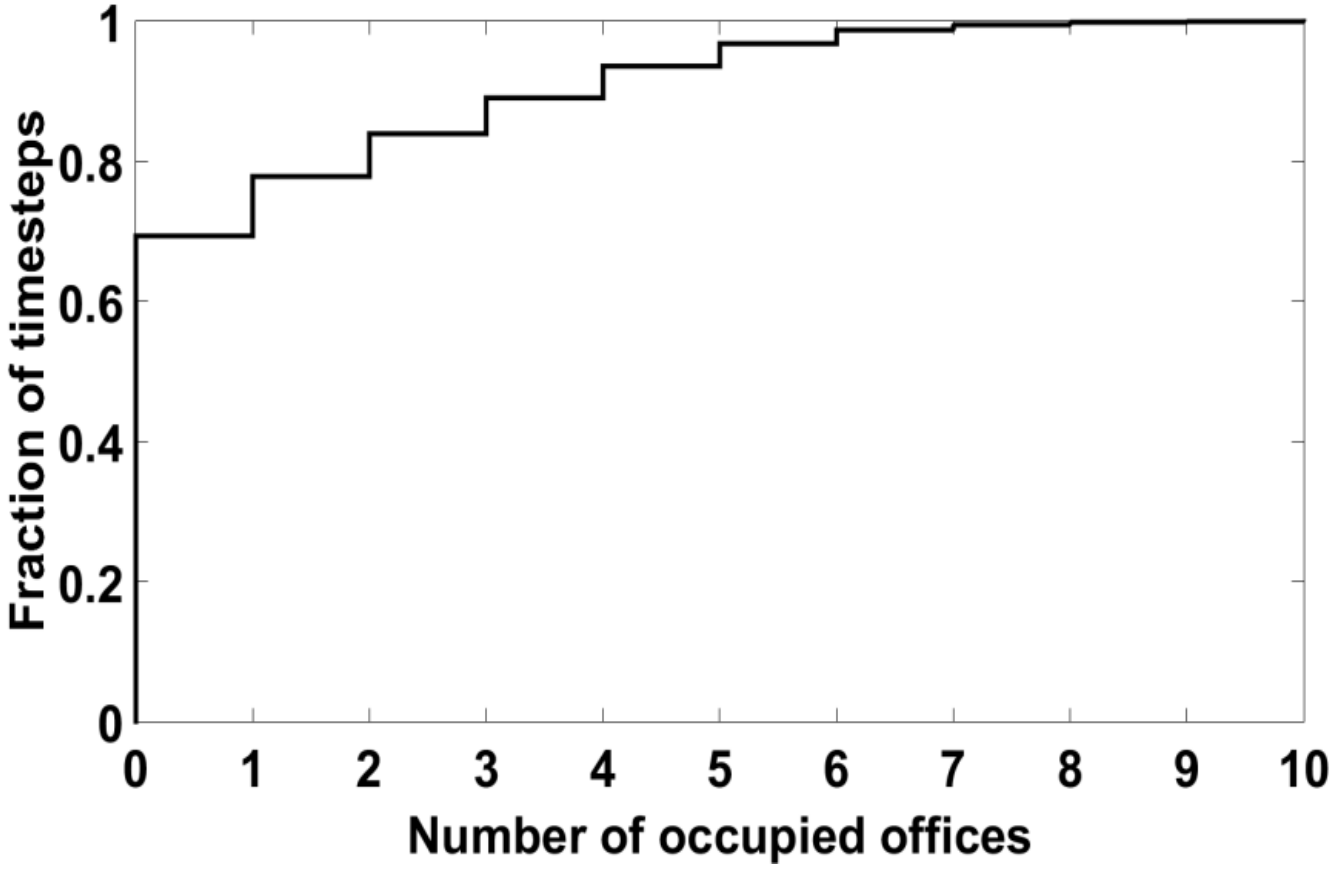
Zone level heating and cooling





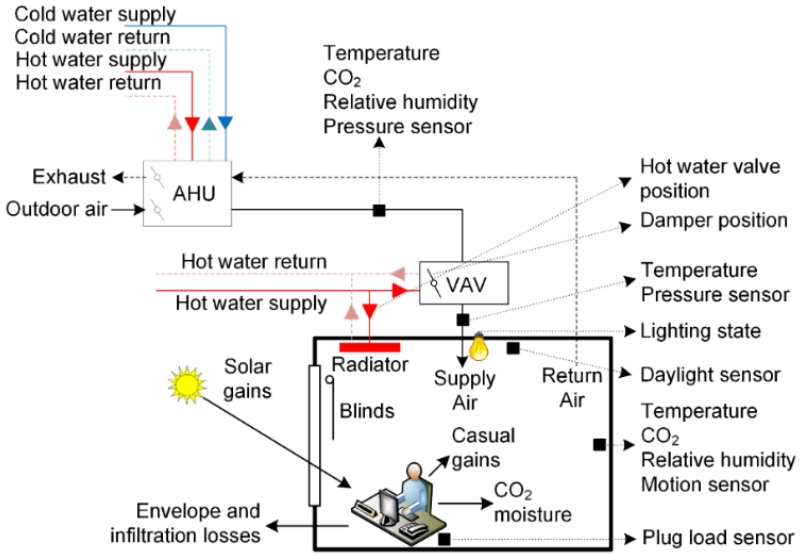

Occupied periods
Setpoint decrease
Wed Thu Fri Sat Sun Mon Tue Wed Thu Fri
Opened windows
Indoor temperature (°C)
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
Wed Thu Fri Sat Sun Mon Tue Wed Thu Fri

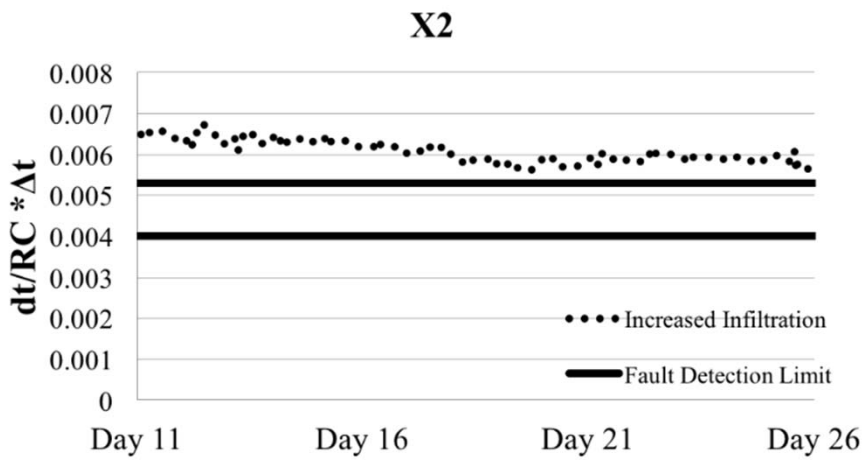
Hotelling potential

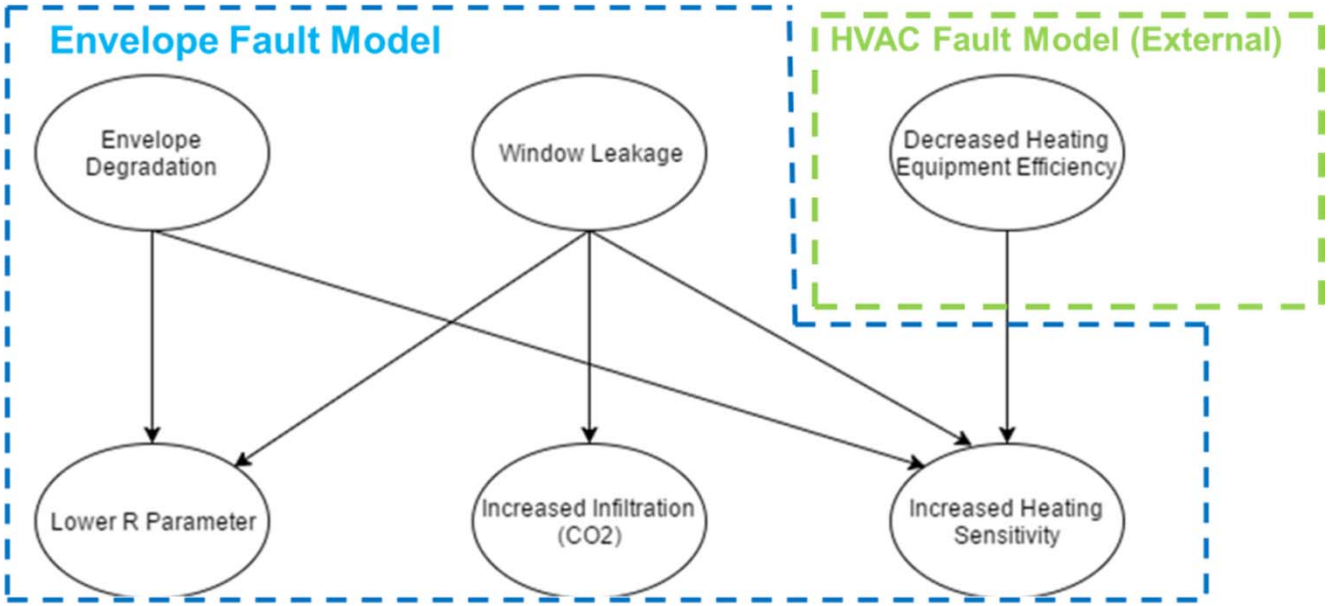


(out of 15 employees)

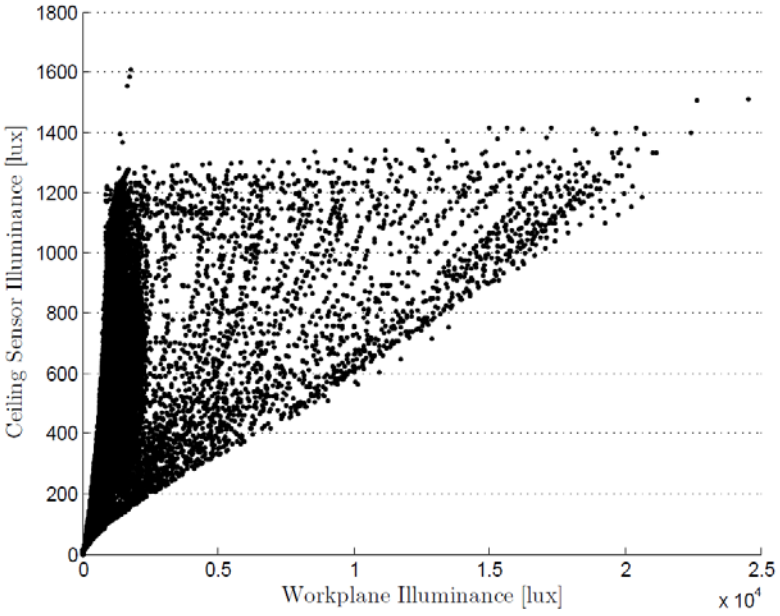
Fault Detection and Diagnostics (FDD)

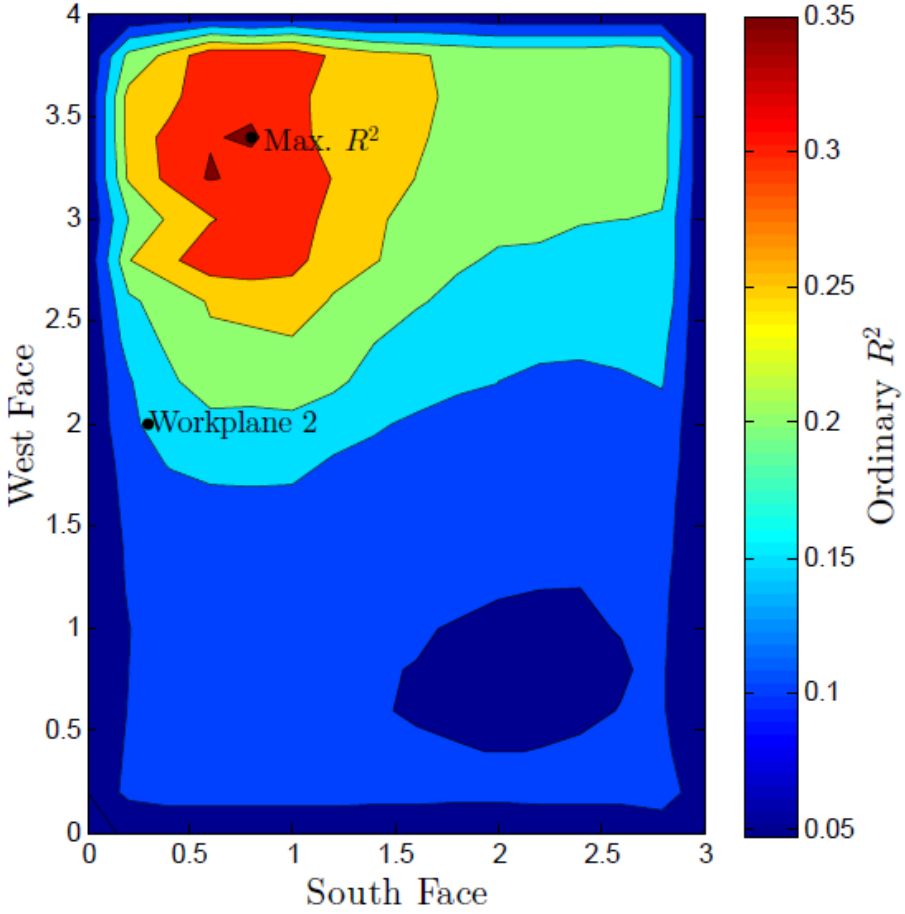




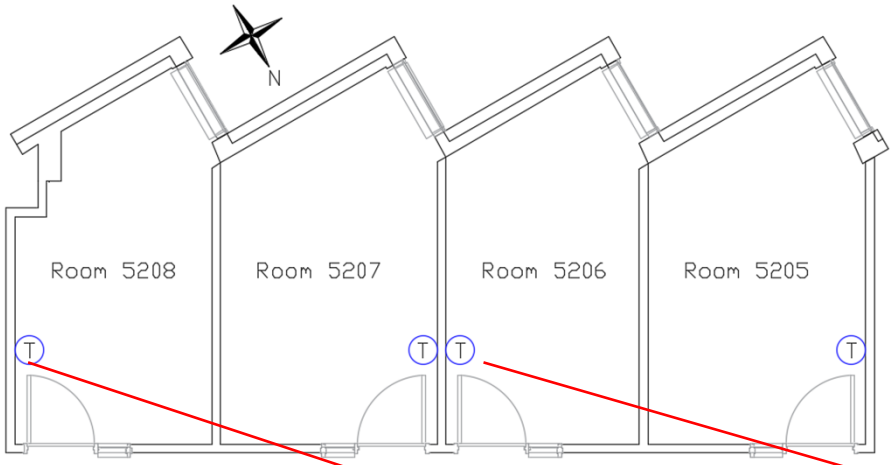


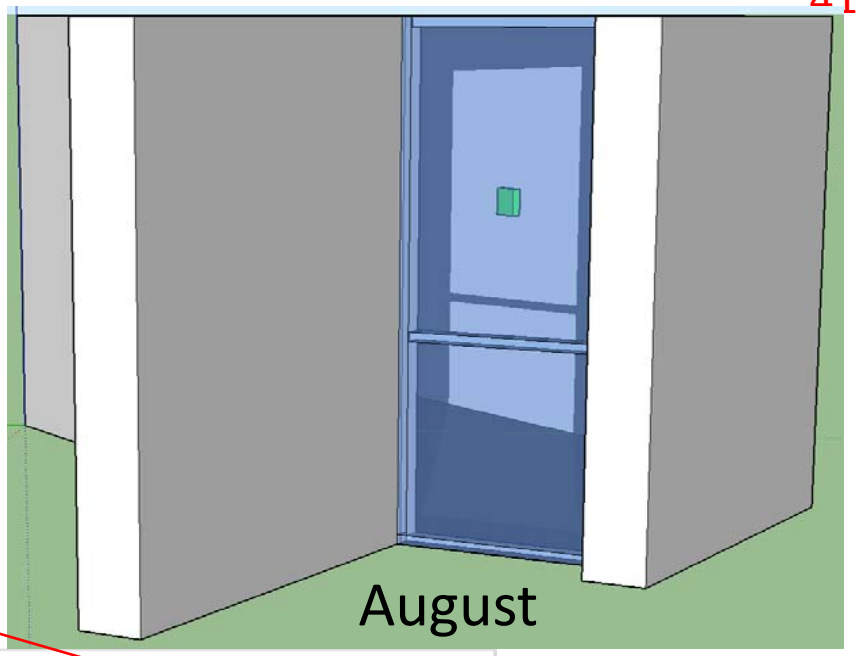
Sensor placement optimization

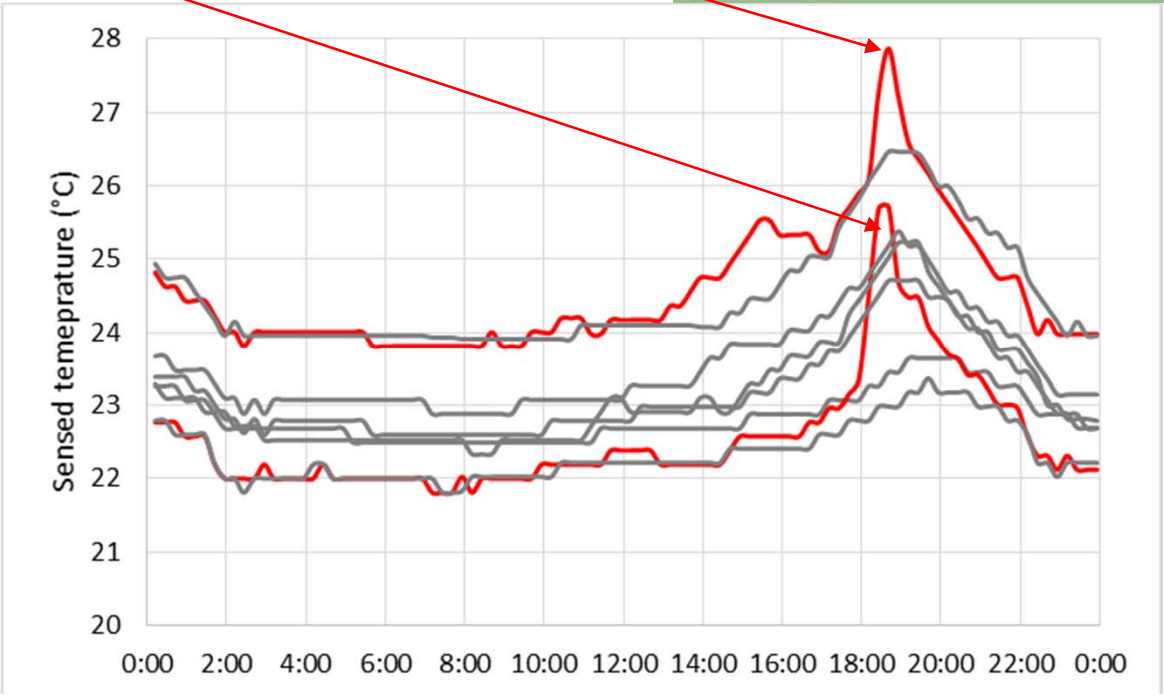


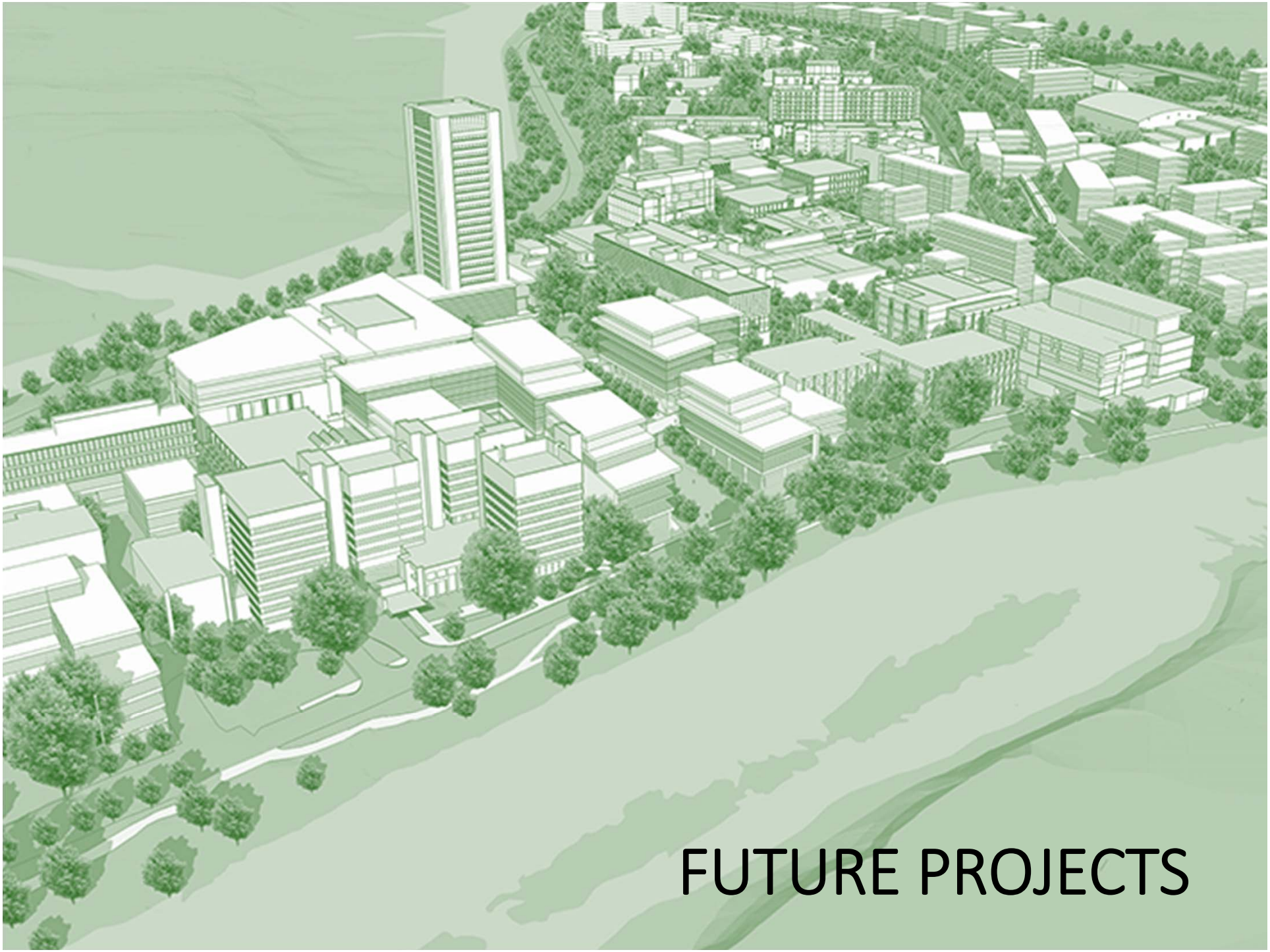


Sensor positioning



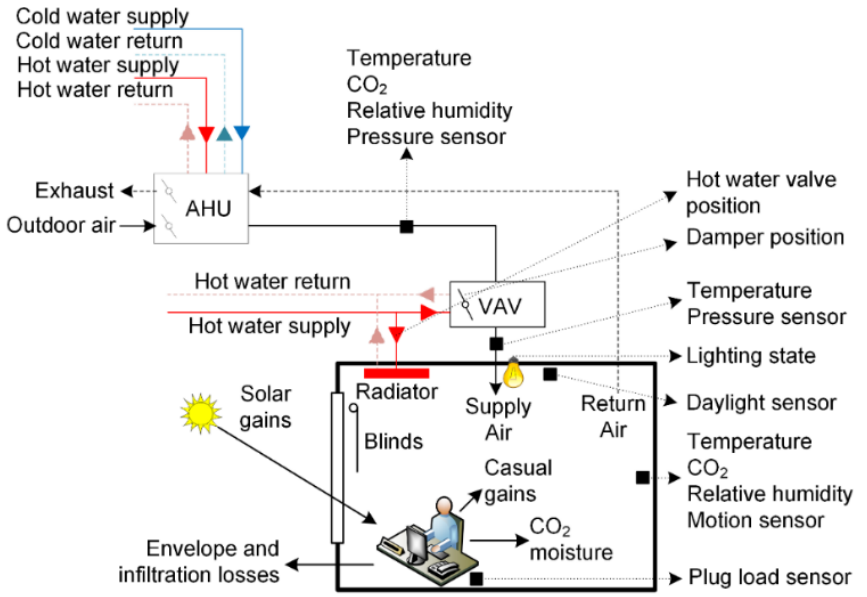


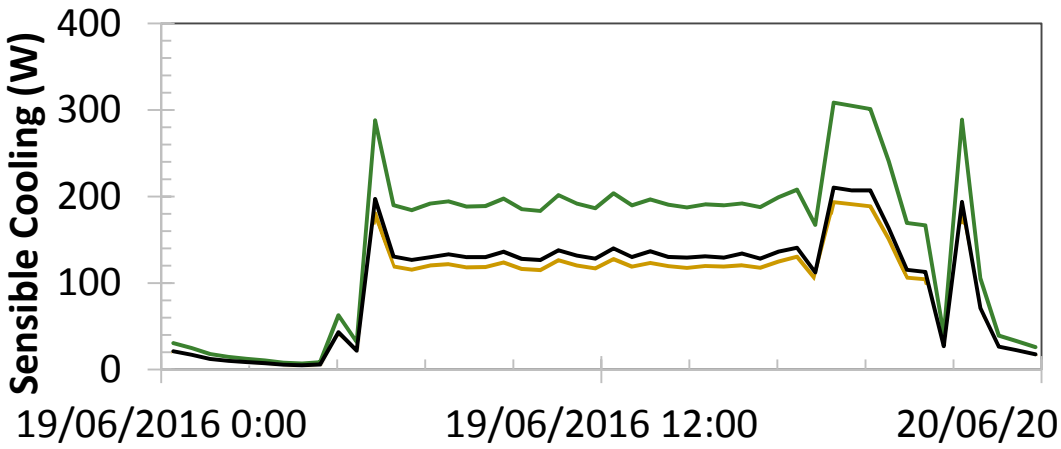



FUTURE PROJECTS

Zone-level virtual sensing

- It is expensive and impractical to measure everything at the zone level
- But virtual sensors can be developed to combine multiple sensors, inferences, and mathematical modelling
- Domains
  - Heating and cooling rate/energy
  - Lighting power
  - Number of occupants
  - Solar gains
  - Internal heat gains





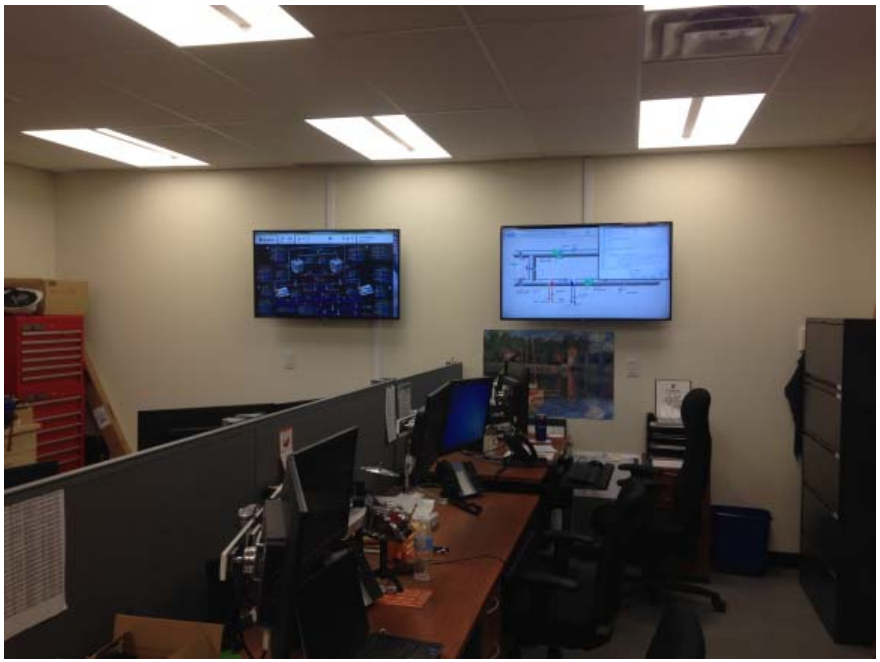
Auto-commissioning

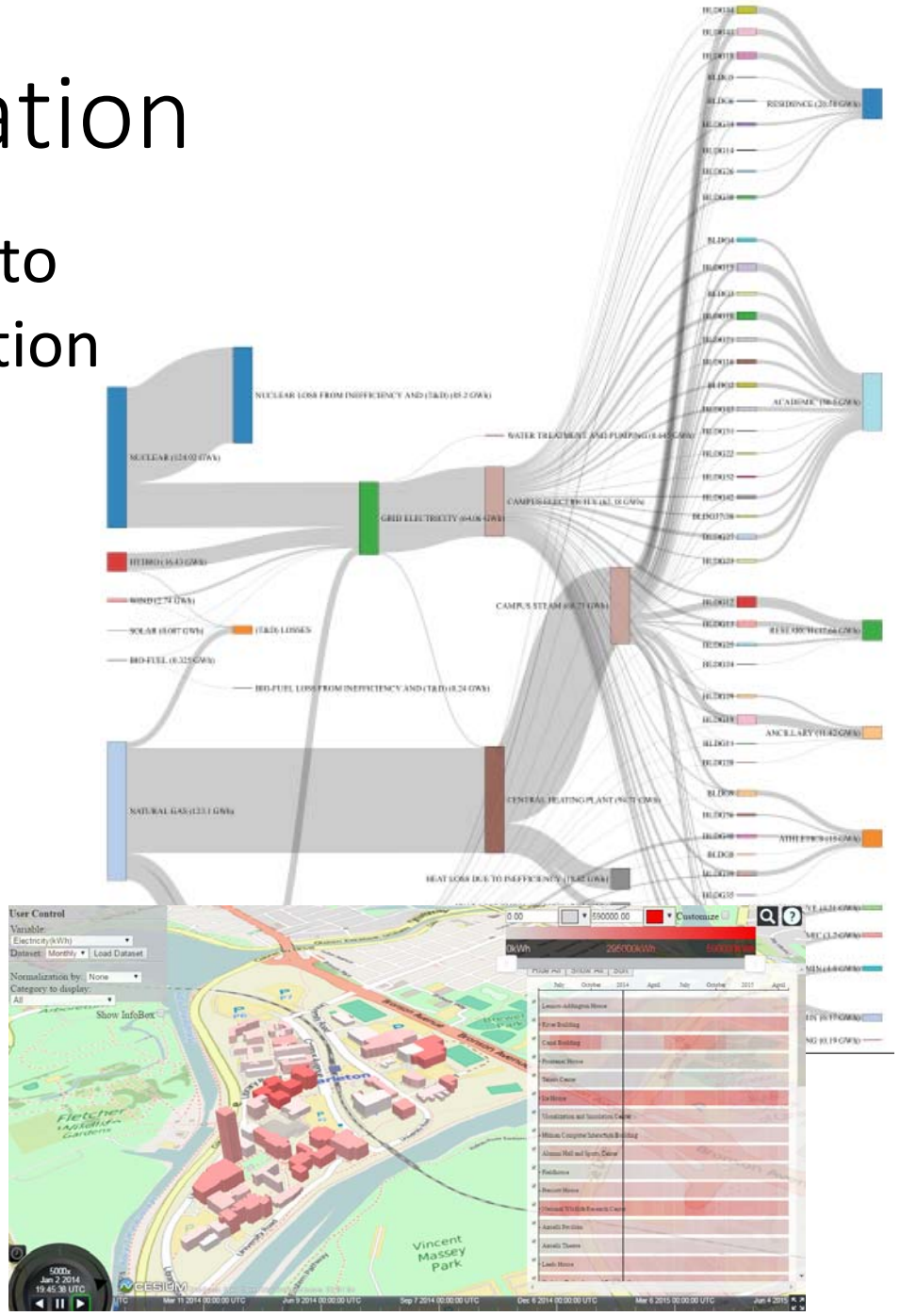
- Many opportunities to characterize spaces before occupancy using reduced order models and systematic system identification. Examples:
  - Estimate lighting power at room level by turning lights one at a time,
  - Estimate thermal resistance to outside in a room and compare to as designed.
  - Air-balancing by estimating OA supply rate using CO_2 mass balance models.
  - Use of BIM to obtain basic building information.

Integrate BIM into operations

Real-time visualization

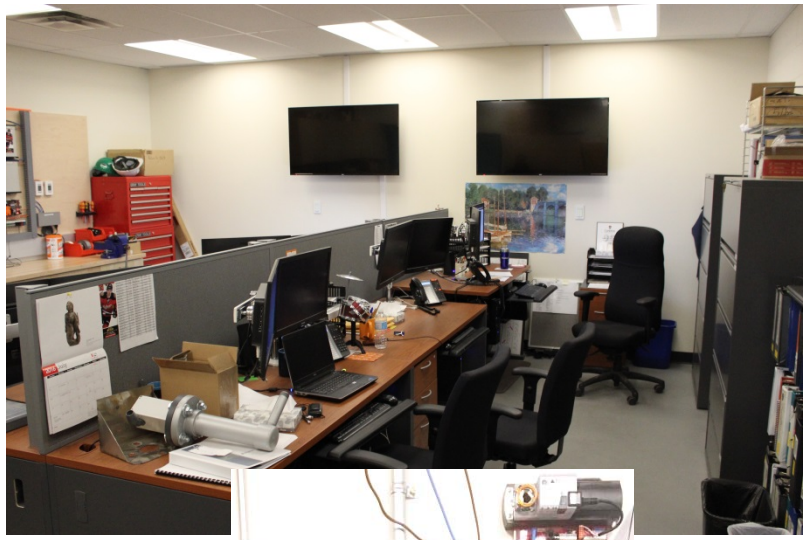
- Build up data infrastructure to provide interactive visualization for operators and other stakeholders

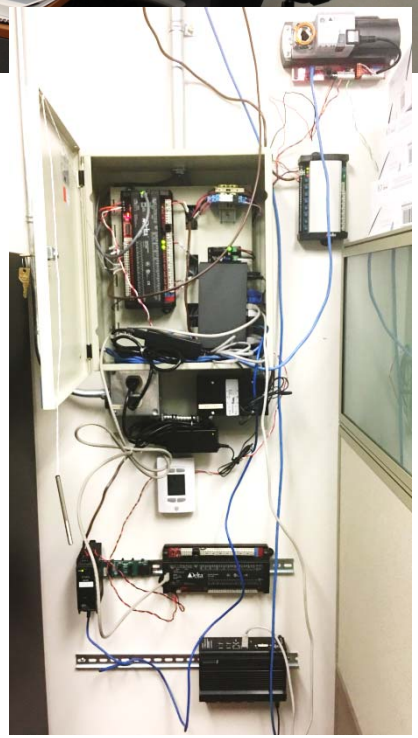




Immerse graduate students in operations

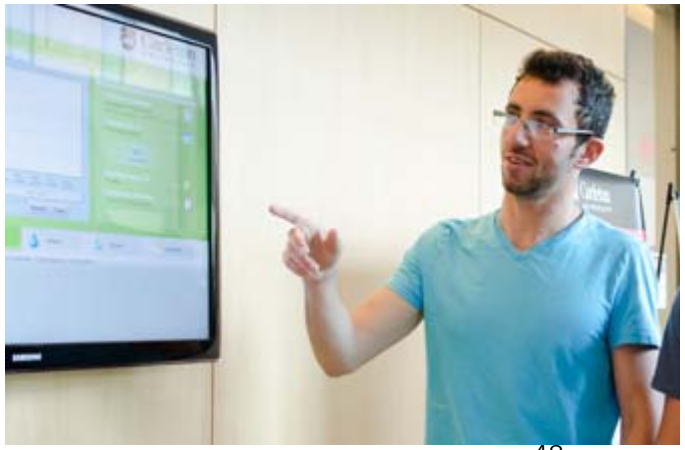
- Most of our research has been inspired by observations, training from Regulvar, etc.
- This hands on experience provides unparalleled learning and research opportunities





Occupant Engagement

- Current occupant feedback is limited to LCD screens (temperature) and building-level display.
- New eZNS thermostats will enable better engagement and answer:
  - Is system working and responding to user input?
  - Is office operating efficiently?
  - How could occupant reduce energy?
    - Windows, blinds, thermostat, etc.
  - How does occupant/space rank?

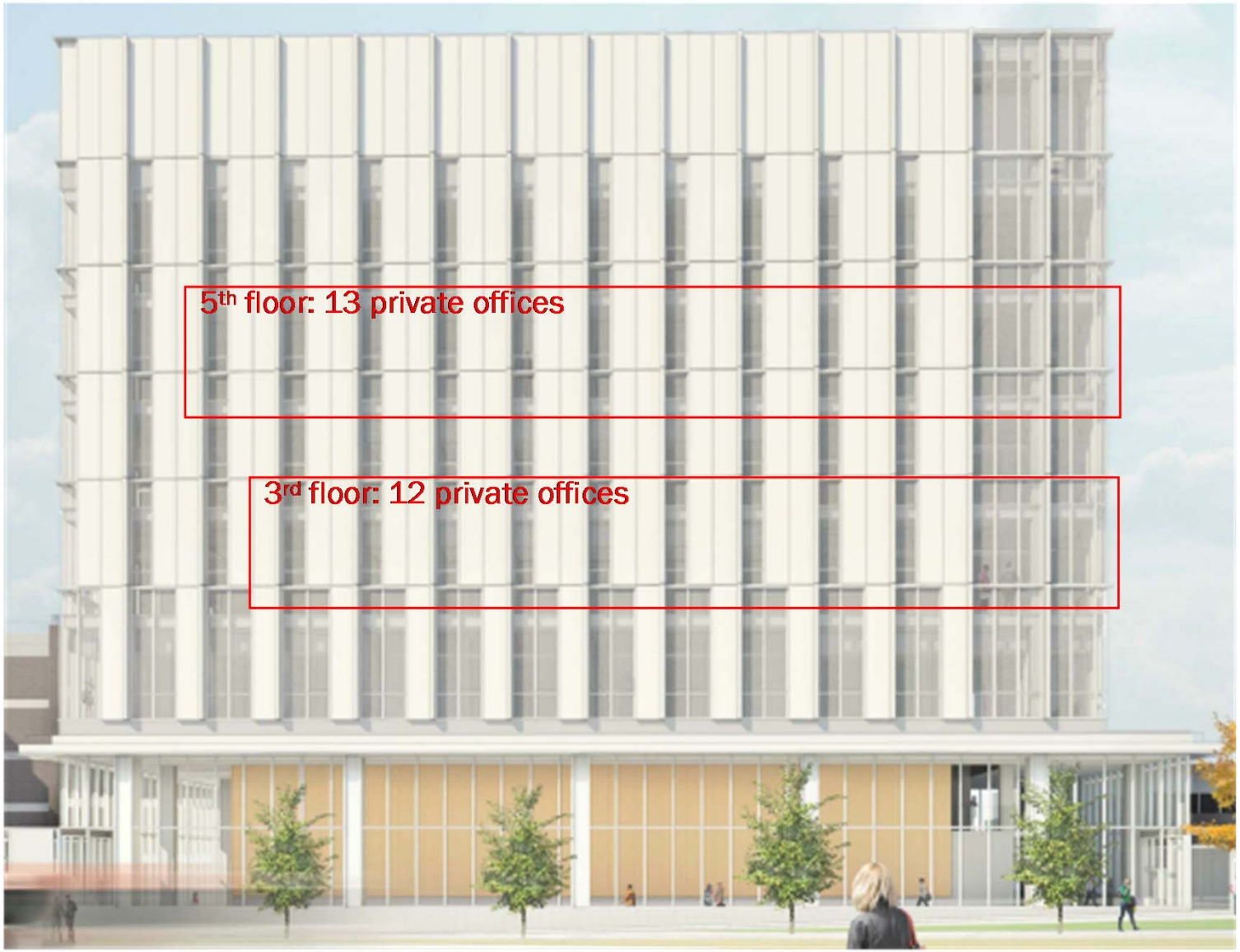


Training the next generation of engineers

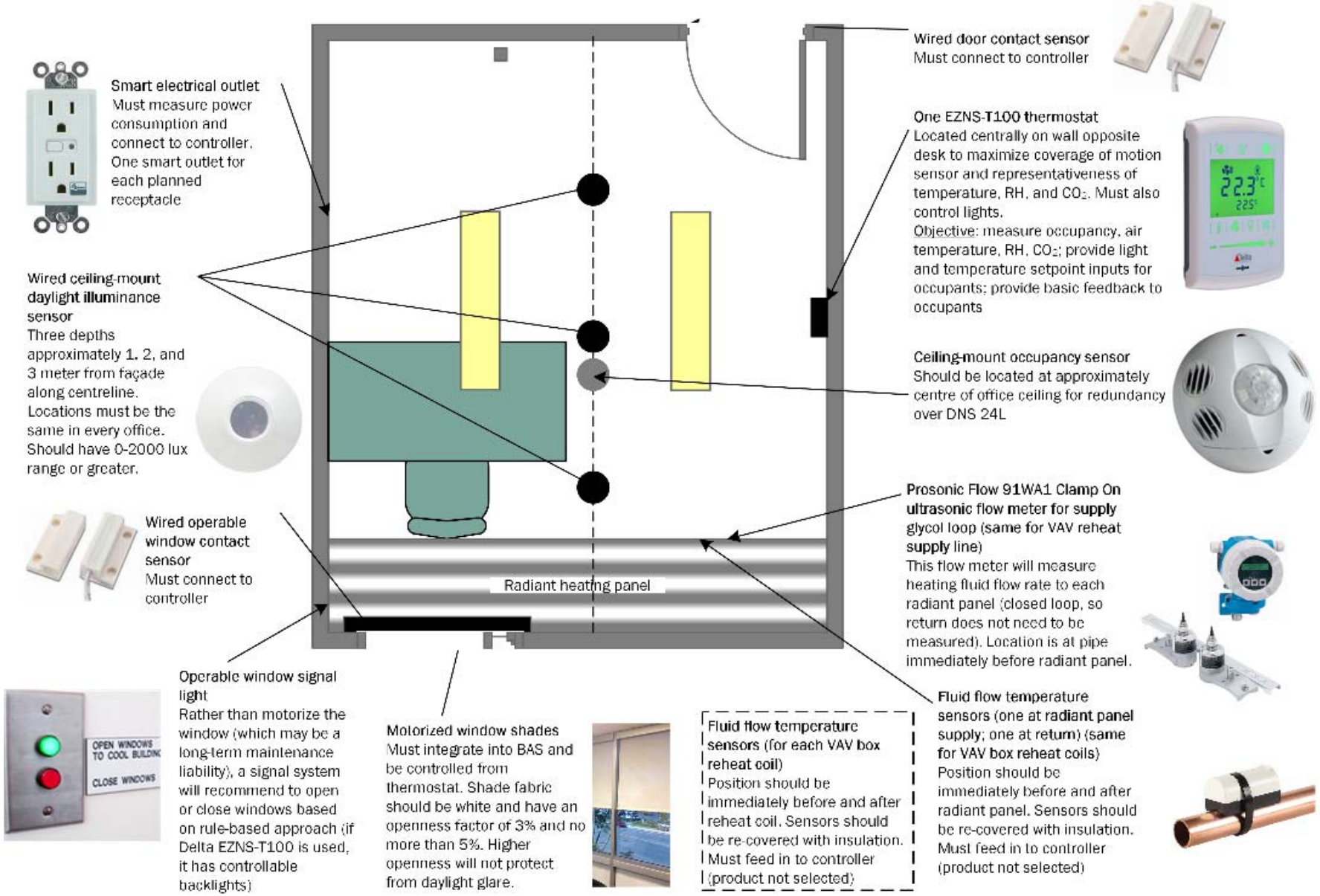
- We are developing a course around the design, construction, and operation of the new Health Sciences Building.
- Resources provided to students will provide the ultimate training experience:
  - Recorded lectures and technical tours
  - Access to drawings and BIM
  - Raw data repository
  - Time-lapse construction video

ATCO

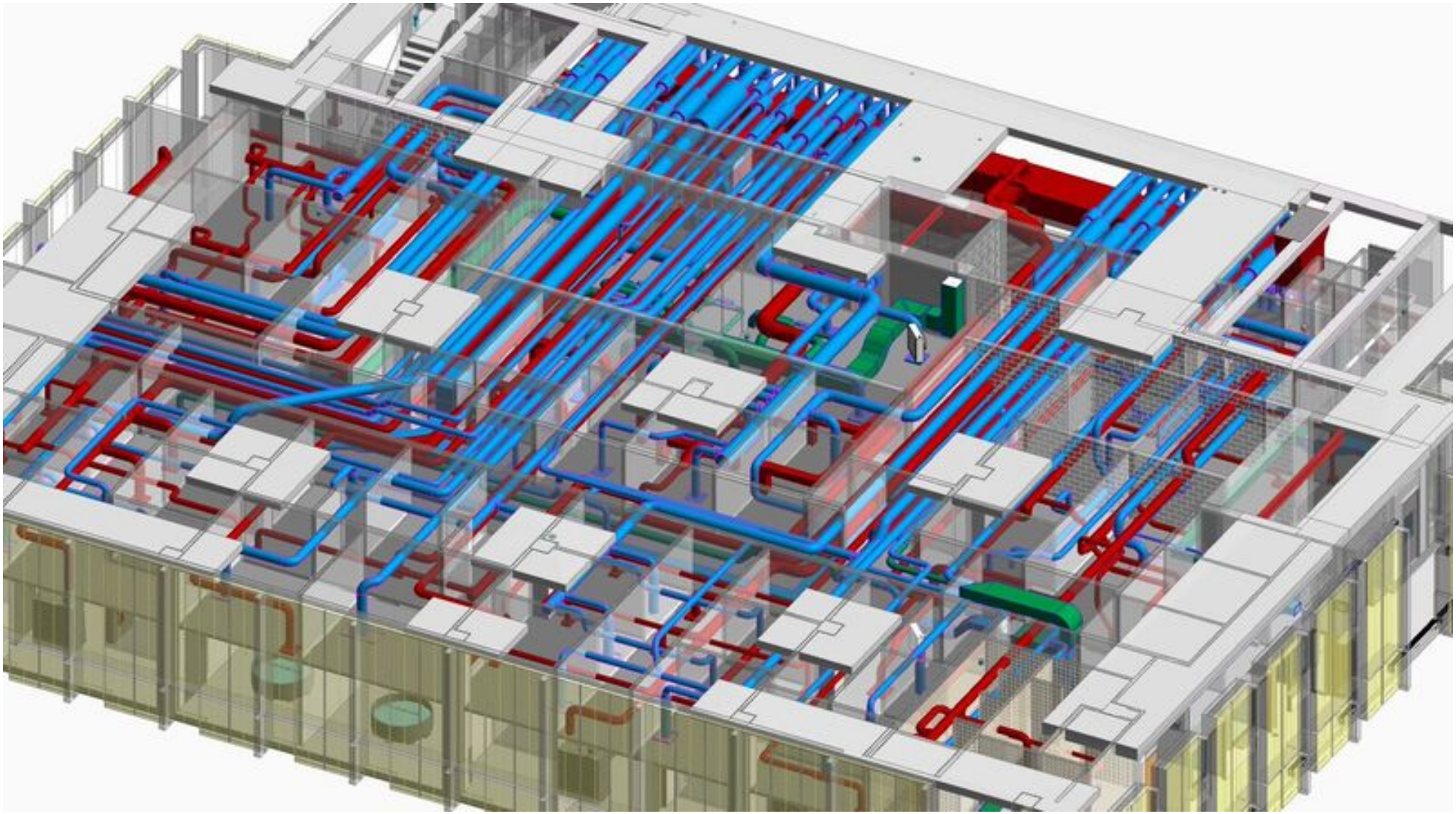
Health Sciences Building

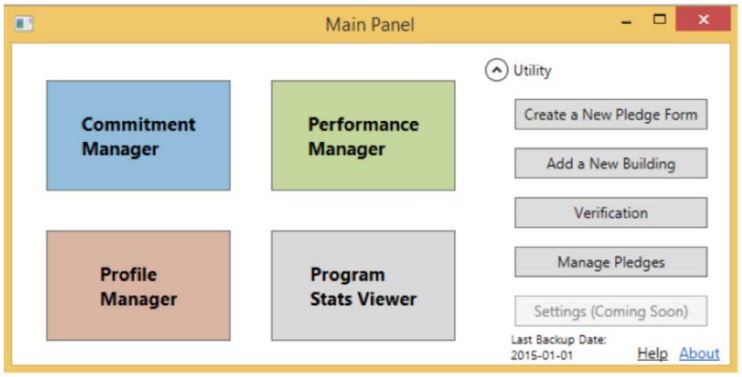


Health Sciences Building / SIF Grant



R.E. HEIN
Construction





Watch the Kilowatts Fall

October 18, 2016

In its second week 45 people pledged to reduce energy and Watch the Kilowatts Fall.

Urbandale Centre for
Home Energy Research
47
Carleton

Acknowledgements

Dr. Burak Gunay
Alumni
Civil Engineering

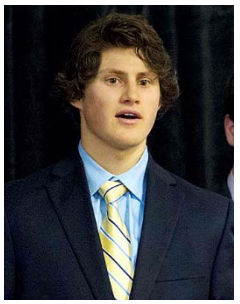
Brent Huchuk, MASc
Research Assistant
Civil Engineering

Ruth Tamas
Undergrad,
Environmental
Engineering

Zach Burgoyne
MASc Candidate
Sustainable and Renewable Energy Engineering

Mihai Mateescu
MASc Candidate
Mechanical Engineering

Jayson Bursill
PhD Student
Mechanical Engineering



Andrew Hicks
MASc Candidate
Sustainable and Renewable Energy Engineering

Aly Abdelalim
PhD Candidate
Environmental
Engineering

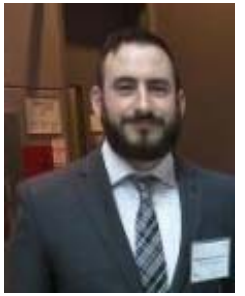
Sara Gilani, PhD
PhD Candidate
Civil Engineering

Isis Bennet
MASc Candidate
Civil Engineering

Shawn Shi
PhD Candidate
Civil Engineering

Justin Berquist
MASc Candidate
Mechanical Engineering

Anthony Fuller
MASc Candidate
Systems and Computer Engineering



Max St-Jacques
MASc Candidate
Sustainable and Renewable Energy Engineering

Carleton colleagues: Profs. Beausoleil-Morrison, Cruickshank, Bucking, Gunay, Santana, Fai

Partners and Sponsors

ASHRAE funding: 4 UG Project Grants; 2 Grant-in-Aid scholarships to Burak Gunay and Sara Gilani ($10k each)

Hbi
Human-Building Interaction Laboratory

Thank you – Questions?

Liam O'Brien – liam.obrien@carleton.ca

carleton.ca/HBILab

Carleton UNIVERSITY

Hbi Human-Building Interaction Laboratory