Building Energy Retrofits in Social Housing

20th Annual Building Science Camp

August 2nd 2016

Marianne Touchie

Civil Engineering
UNIVERSITY OF TORONTO

Mechanical & Industrial Engineering
UNIVERSITY OF TORONTO

Image Credit: University of Toronto

Outline

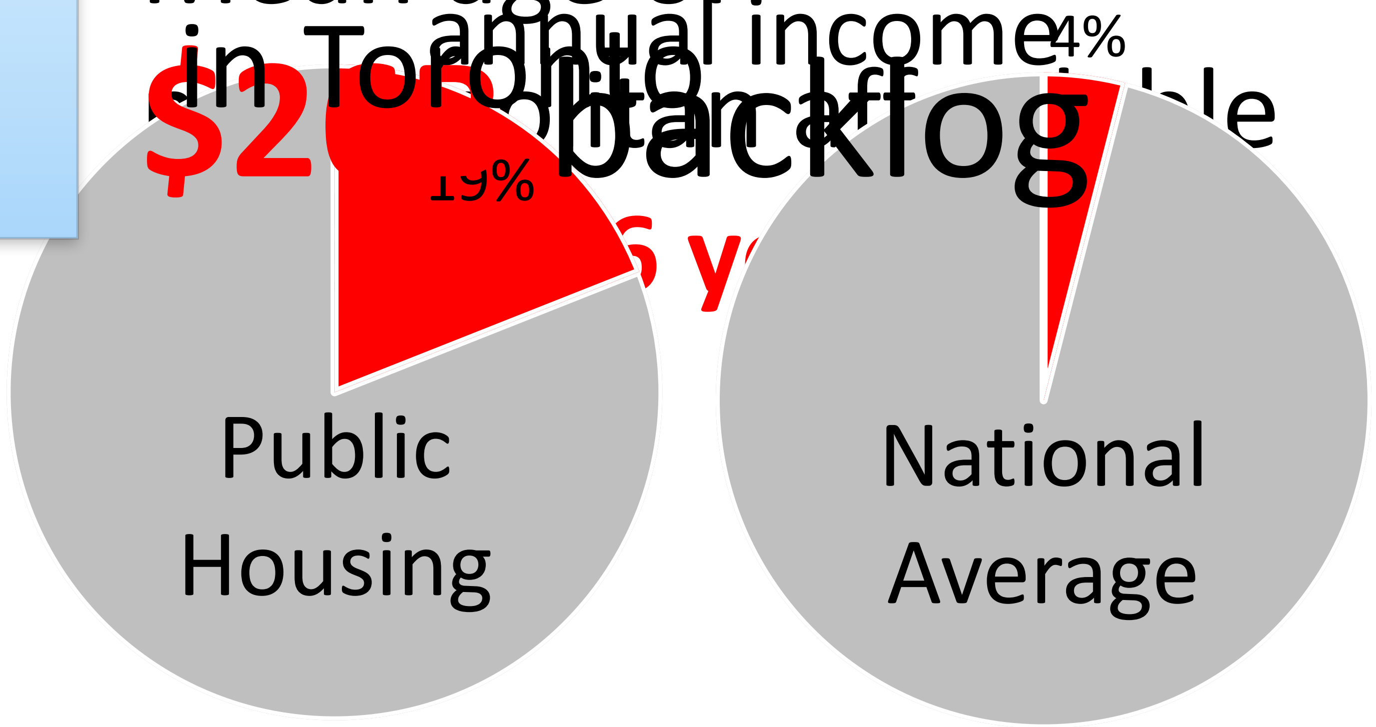
- Characteristics of social housing MURBs
- Drivers of and approach to retrofit
- It’s not all about energy
- Case studies and research

Image Credit: University of Toronto

Characteristics of Social Housing Buildings

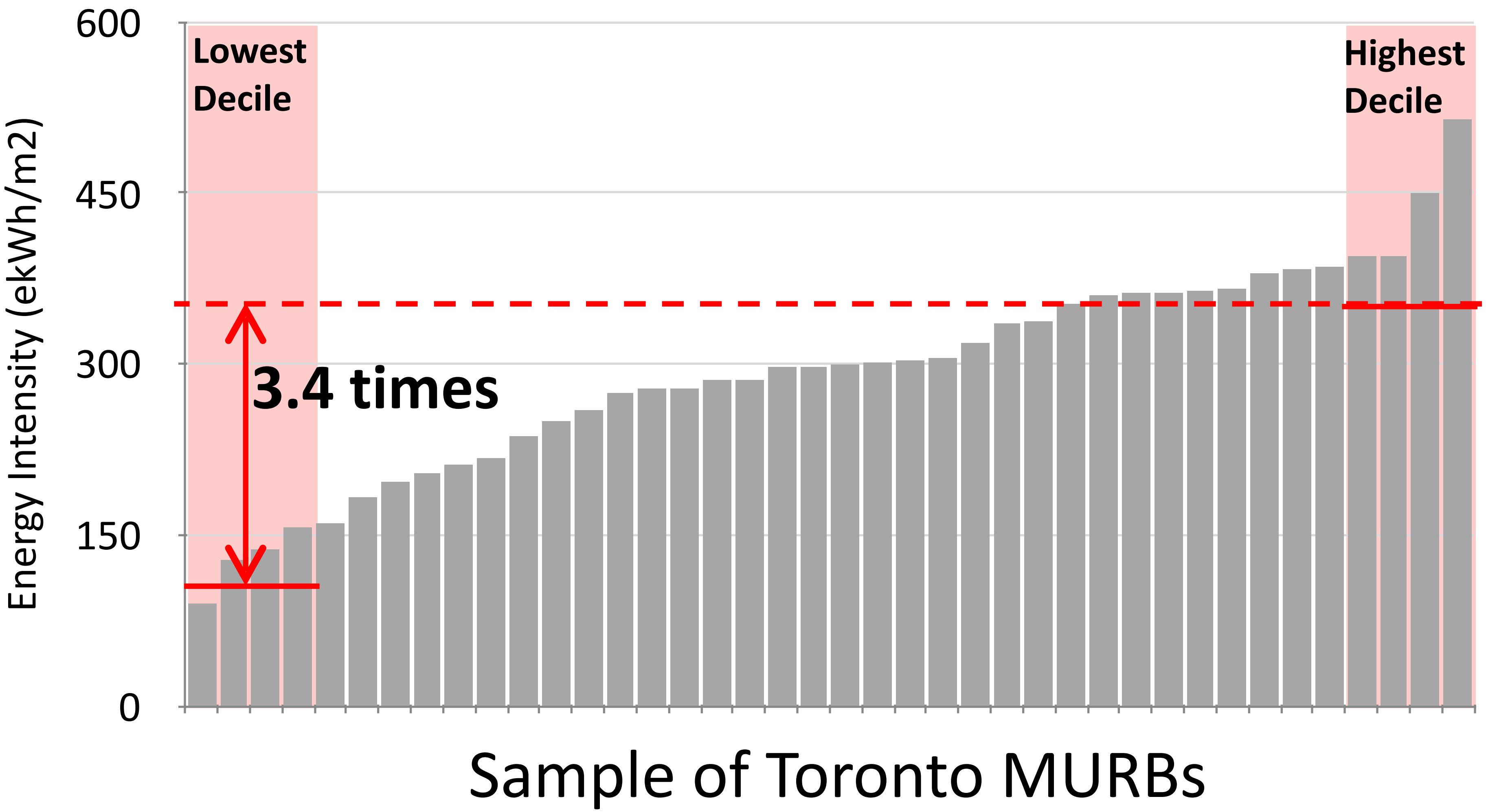
- They are old[1]
- They use l
- They aren’
- They have
- There are a lot of them![5]

Add vintage graph, pie chart with energy, $26B backlog, % of housing provided?



1 Harvard University Graduate School of Design 2003, Somerville & Mayer 2003
2 Department of Energy 2011
3 Abt Associates 2010
4 Jacobs et al., 2007, Northridge 2010
5 https://www.ucalgary.ca/cities/files/cities/toronto-report.pdf

MURB Energy Use is highly variable



MURB Energy use - NYC

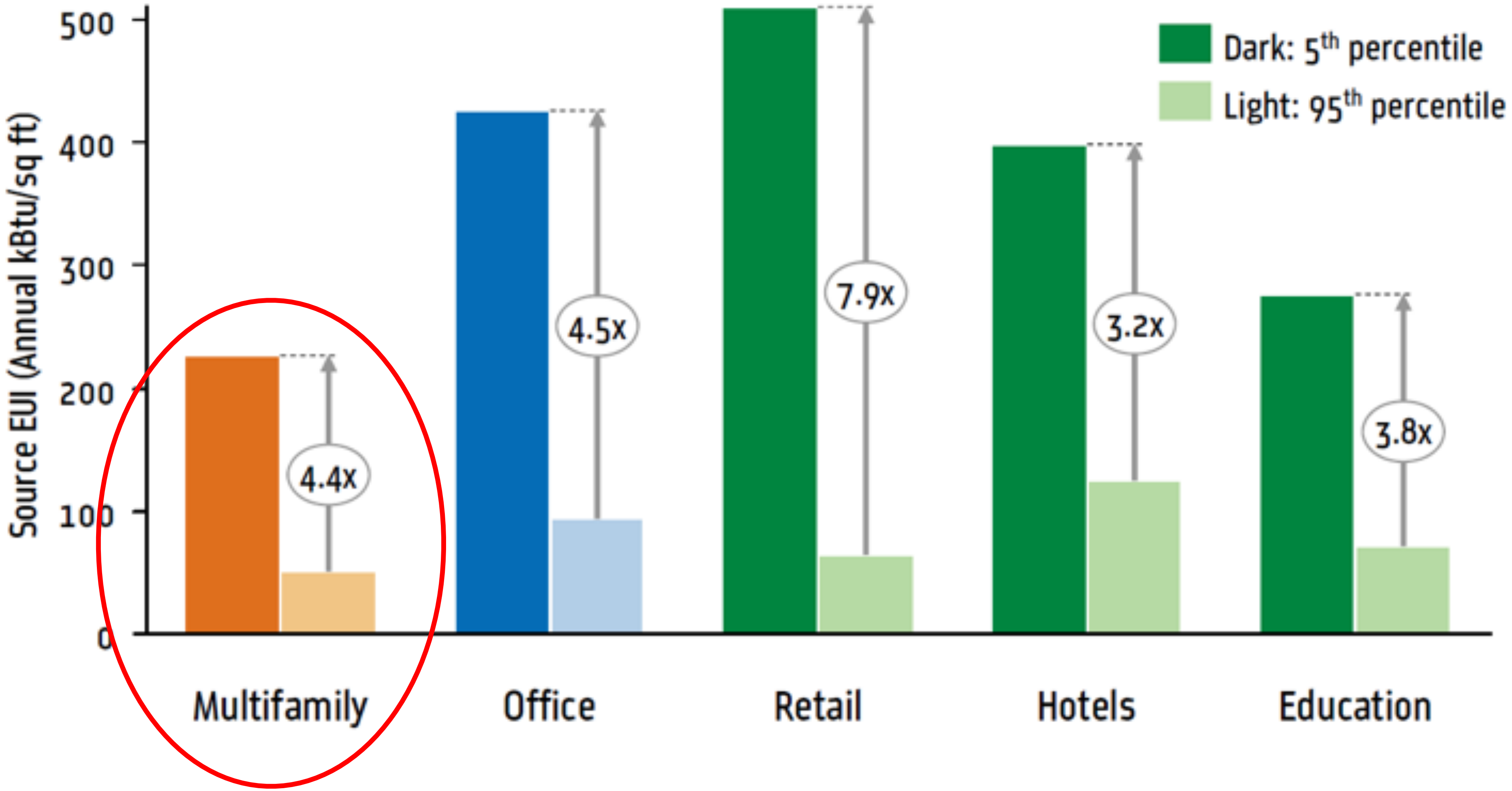
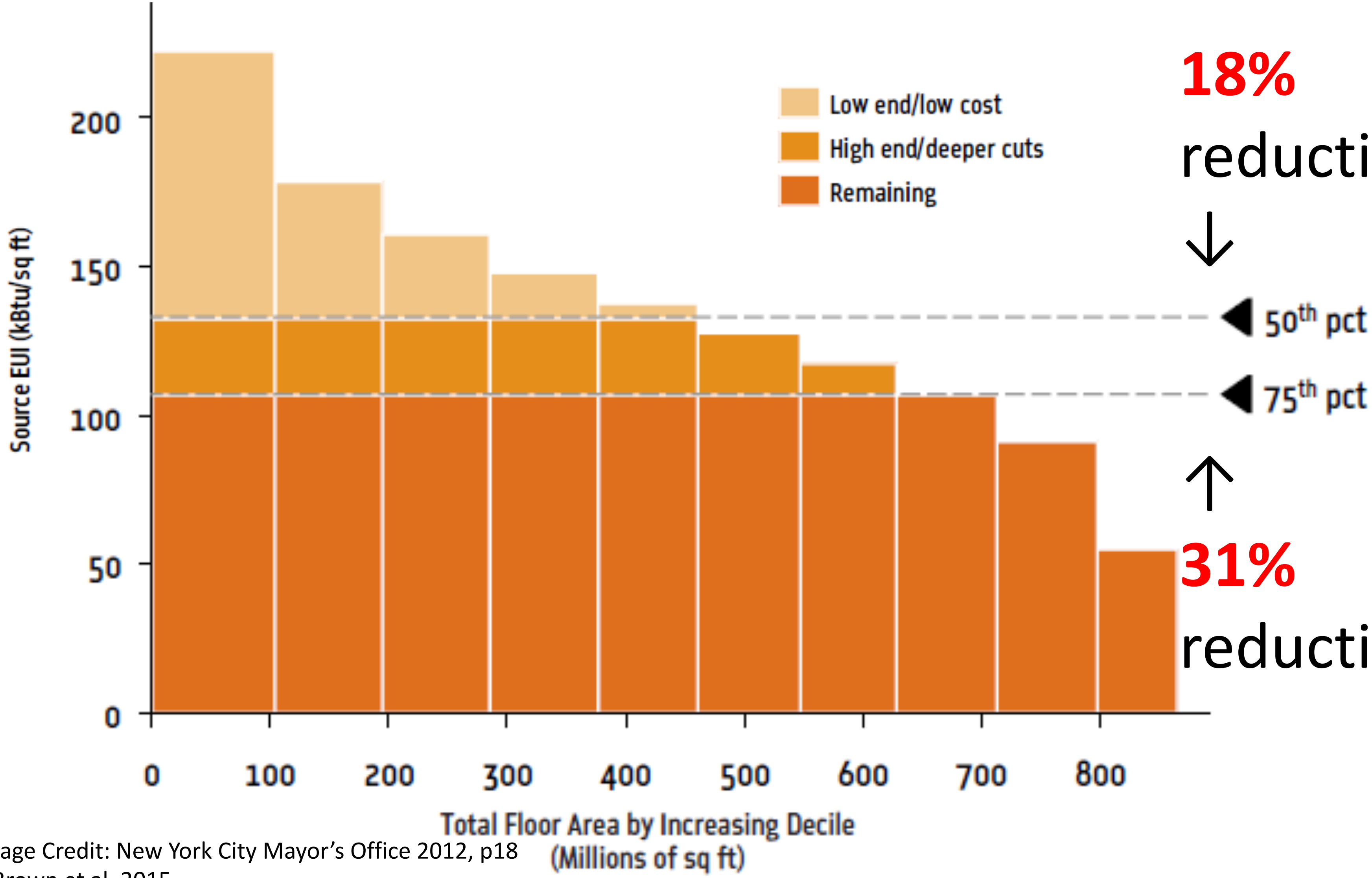


Image Credit: New York City Mayor's Office 2012, p14

Great potential to improve MURB energy performance



18% reduction
↓
↑
31% reduction

Ryerson Study: 57% heating and 84% cooling variability because of occupants[1]

Image Credit: New York City Mayor's Office 2012, p18
1 Brown et al. 2015

What prompts an energy retrofits?

- Emergency replacement of failing equipment
- Anticipating equipment at end-of-life (trying to avoid emergencies!)
- Need to reduce operating expenses
- Incentive programs

Lowest hanging fruit

- Lighting retrofits
- Water fixture replacement (toilets, shower heads)

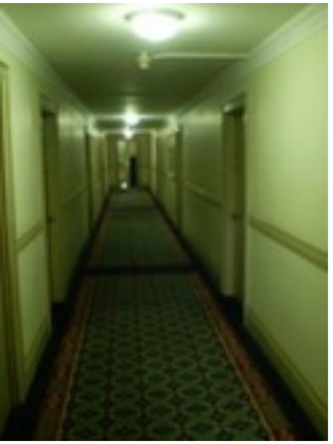
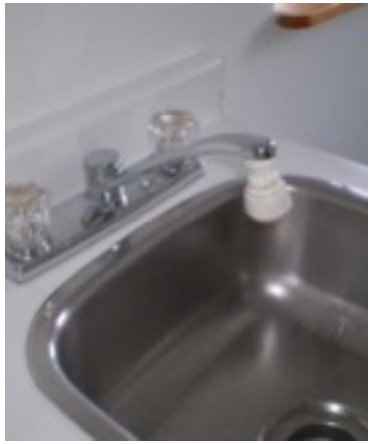
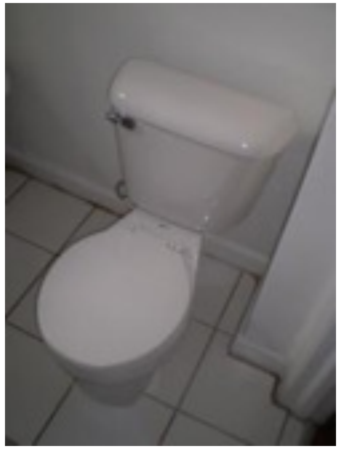





Image credits: Toronto Atmospheric Fund

Case for comprehensive energy retrofits in social housing

- Take advantage of blended payback
- Piecemeal approach takes longer, more expensive, limited ability for improve durability
- Reduce vulnerability to changing utility prices
- Limits on equipment efficiency

Energy End uses in typical U.S. MURB

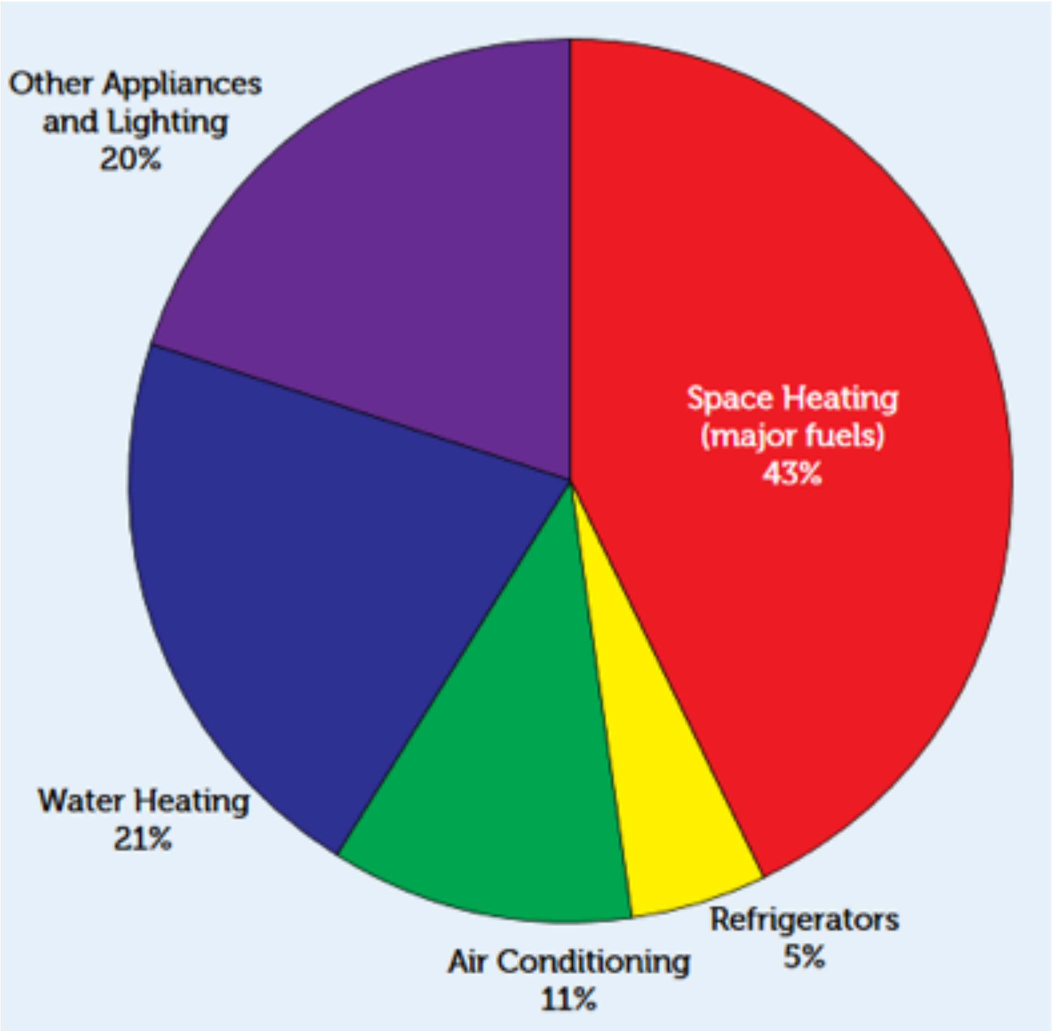


Image credit: US EIA 2008

Heating energy use

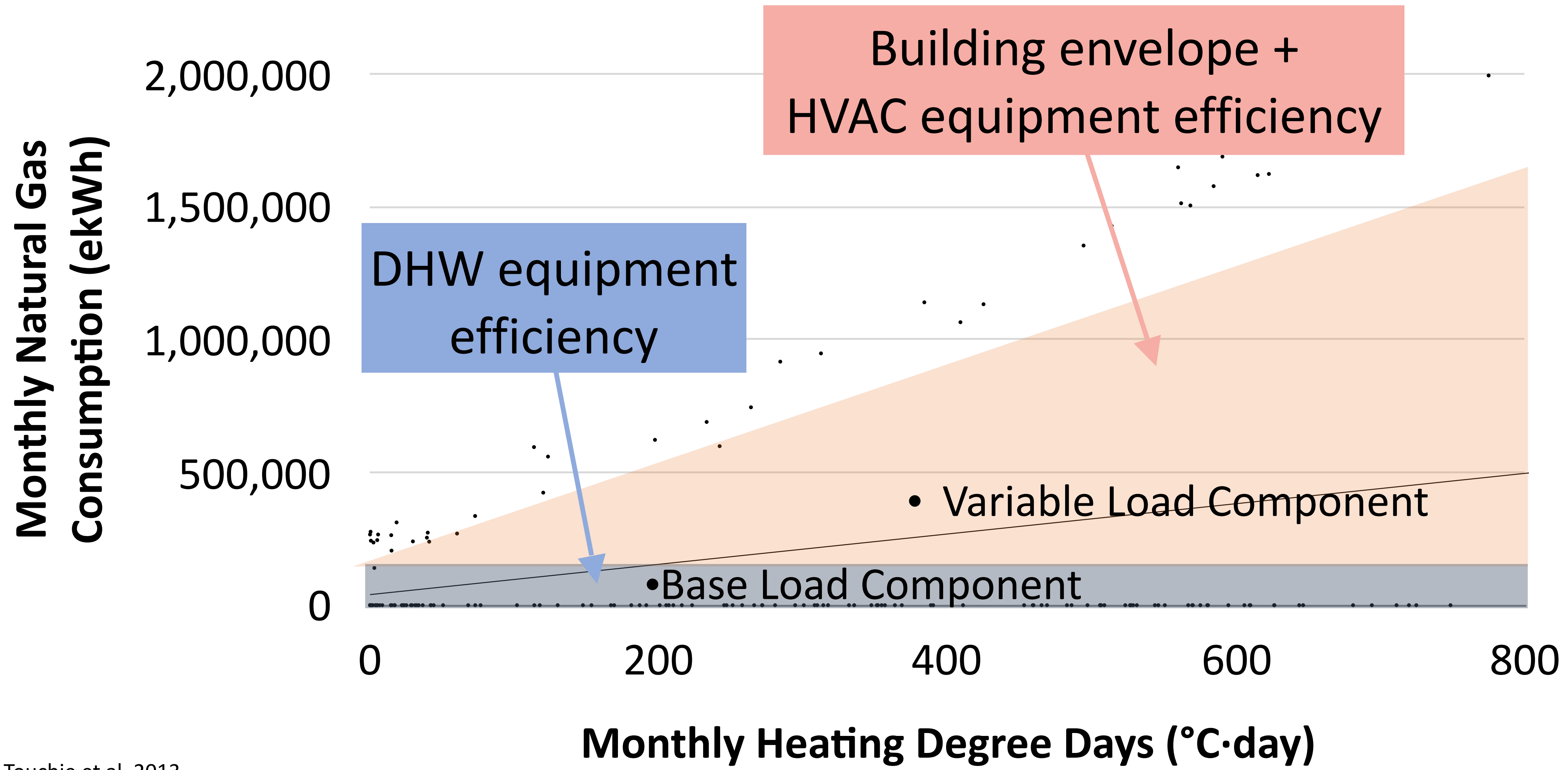
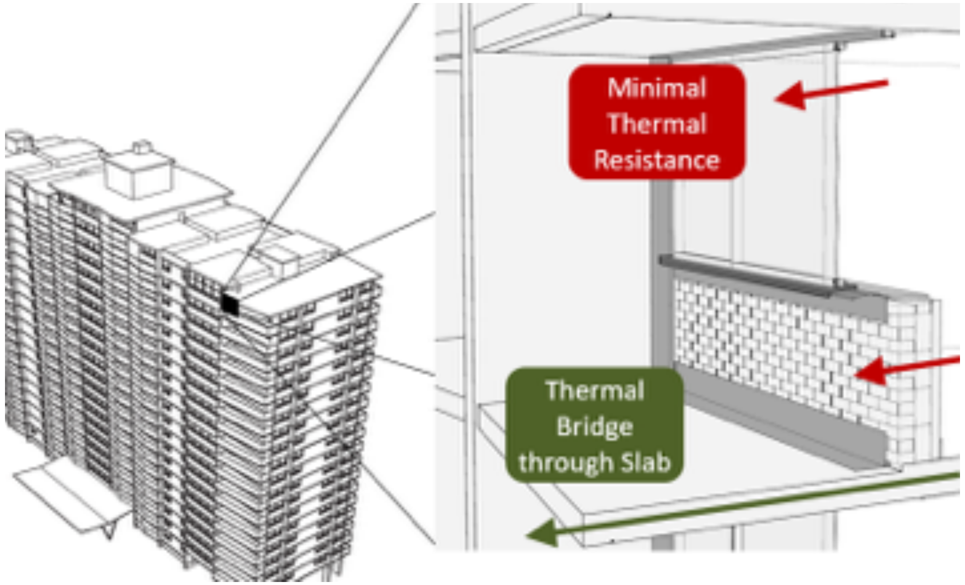


Image credit: Touchie et al. 2013

Envelope Thermal Resistance

- Often little to no insulation
- Thermal bridging through balcony slabs
- Single-glazed windows, sliders



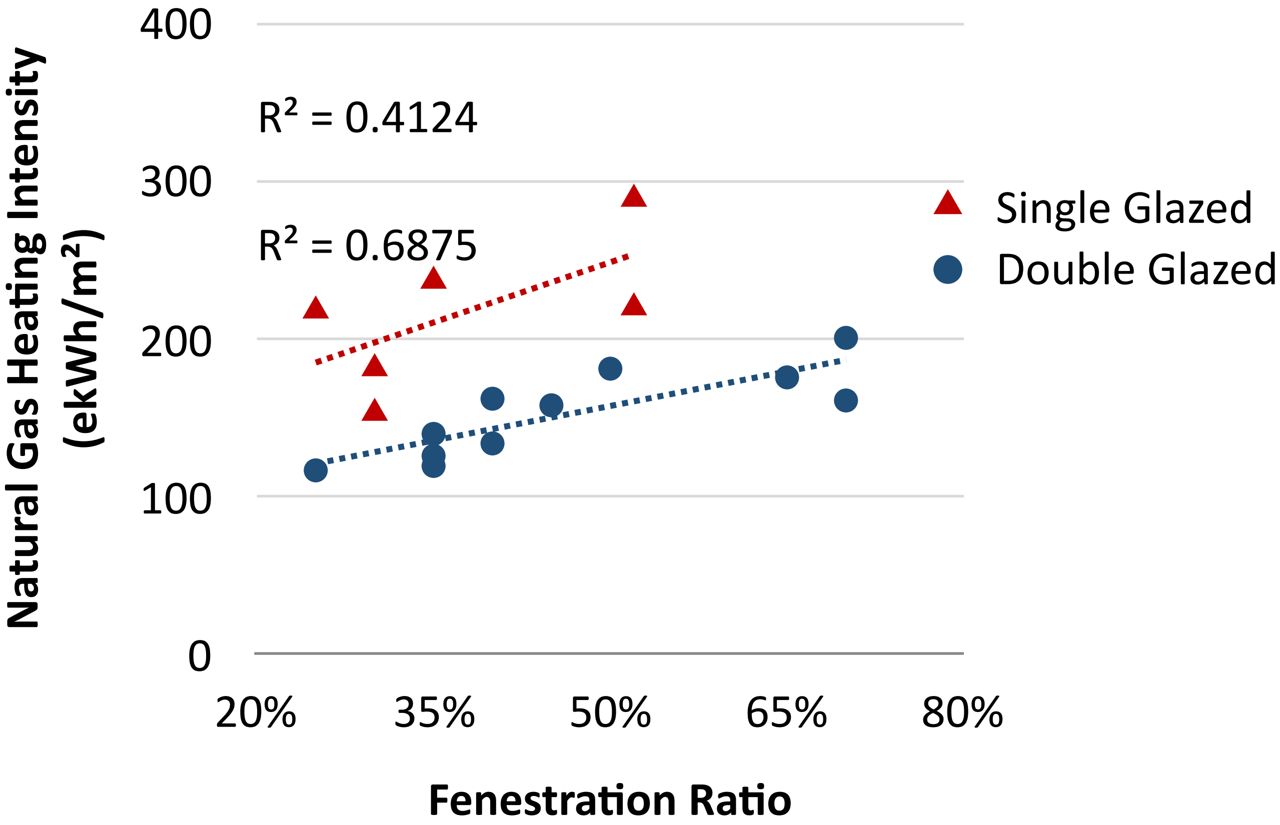


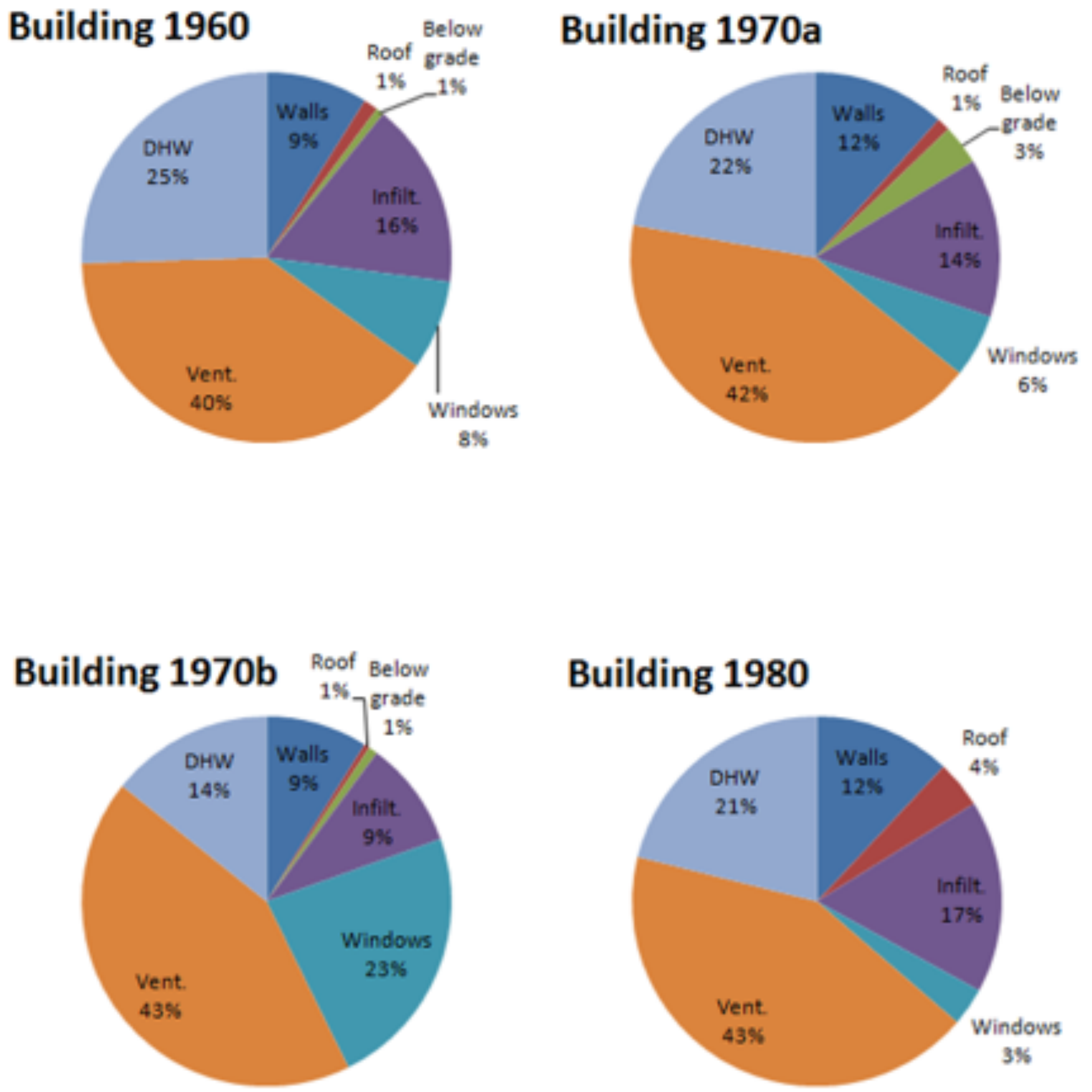
Image credit: Touchie et al. 2013, Tower Renewal Guidelines

Air leakage

Wi

- Highly uncertain, complex, negative impacts
- Corridor pressurization ineffective
  - Canadian apartment study: Measured 31% to 81% of design ventilation rates[1]
- Significant impact on energy use
  - In Ontario, 25-40% of peak heating demand[1]
  - Vancouver study: 69% of space heating energy to condition ventilation air but as little as 13% of that air got to the suites. Large pressure differences across interior partitions.[2]

N



1 Edwards 1999
2 RDH 2012
Image Credit: Touchie

HVAC equipment

- Many factors influence efficiency
- Toronto study: Poor correlation between efficiency and energy use
- Can't rely on estimated efficiencies (TAF study to the rescue)

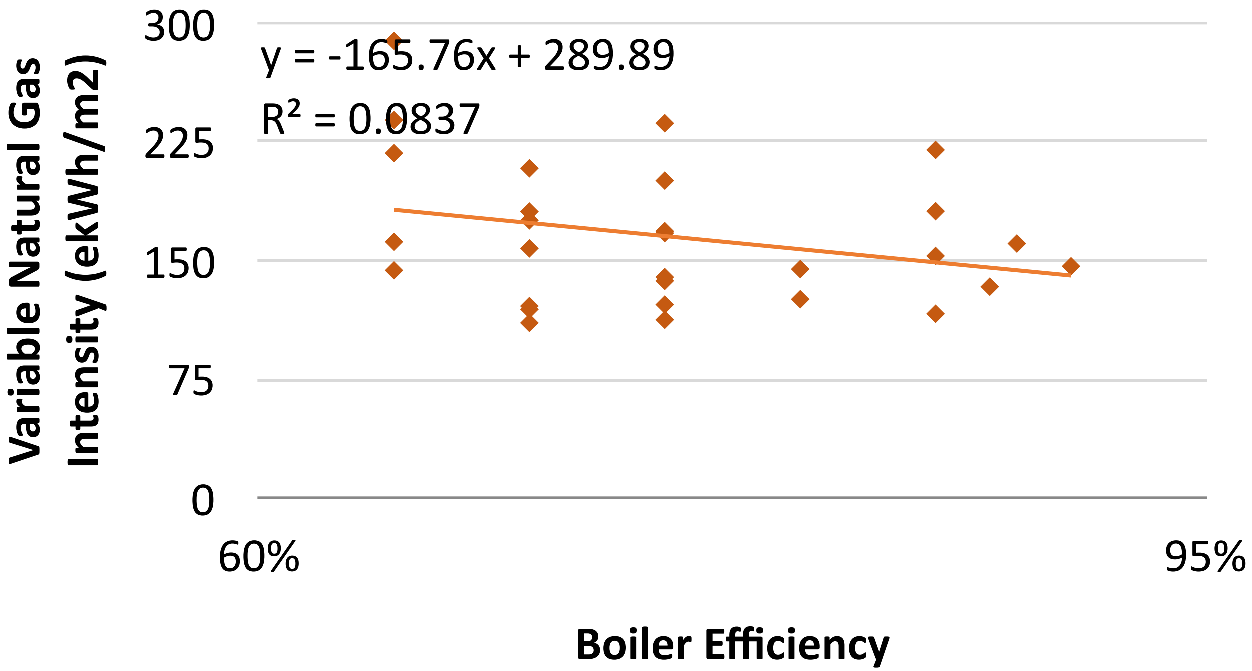


Image credit: Toronto Atmospheric Fund; Touchie et al. 2013

Steps to designing an energy retrofit strategy

- Establish baseline performance
- Develop a calibrated model
- Determine potential savings and set targets
- Evaluate retrofit options
- Select a strategy that meets targets and budget constraints

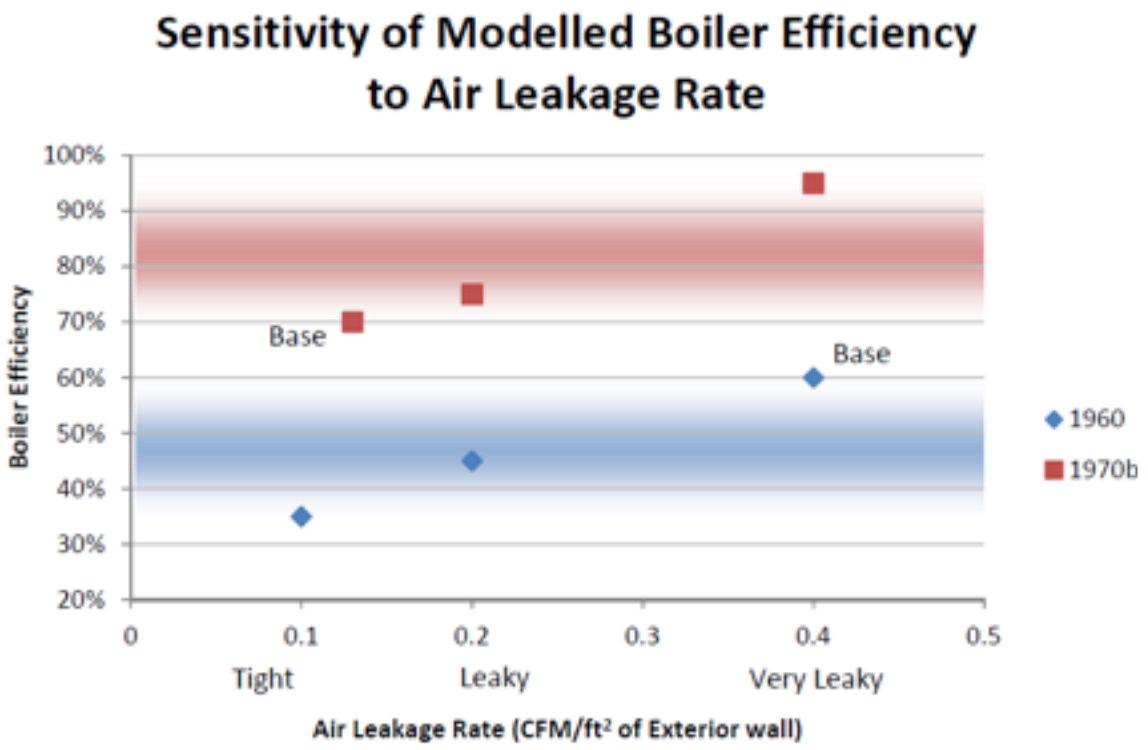
Establish your baseline performance

- Building condition assessment and historical energy bills
- Targeted assessment of major factors influencing energy performance:
  - Assess envelope performance through air leakage testing, infrared imaging
  - Performance monitoring of boilers, chillers, make-up air units, pumps
  - Electricity sub-metering
- Look for recommissioning opportunities
  - LBNL study: retro-commissioning costs approx. $0.30/ft^2$, reduced energy consumption by 16%, payback of 1.1 years[1]

1 Rocky Mountain Institute 2013

Develop a calibrated energy model

- Be aware of model uncertainties



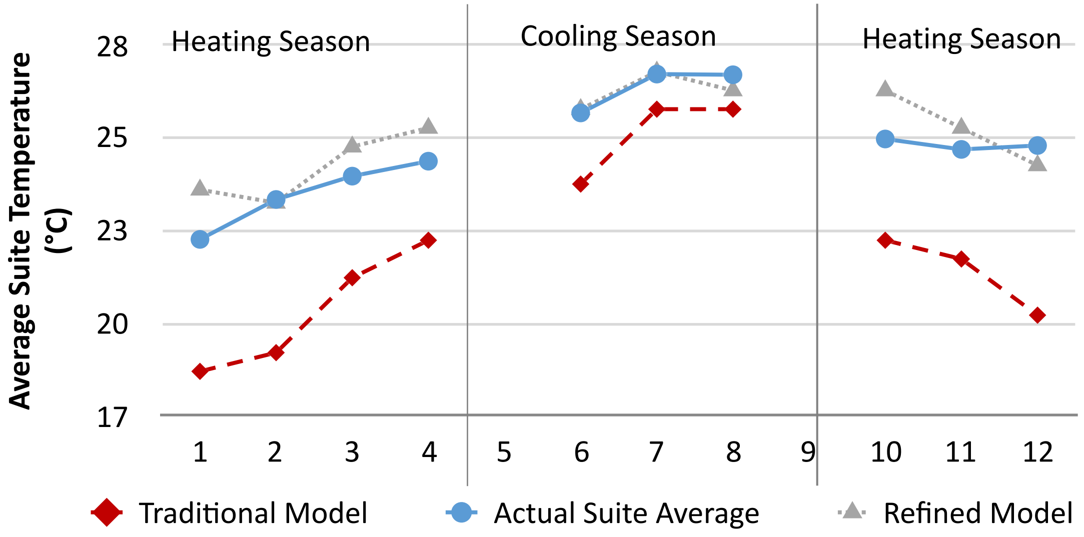


Image credits: Touchie 2014

Determine potential and set targets

Rocky Mountain Institute: How much could you save if there were no economic or non-technical constraints?

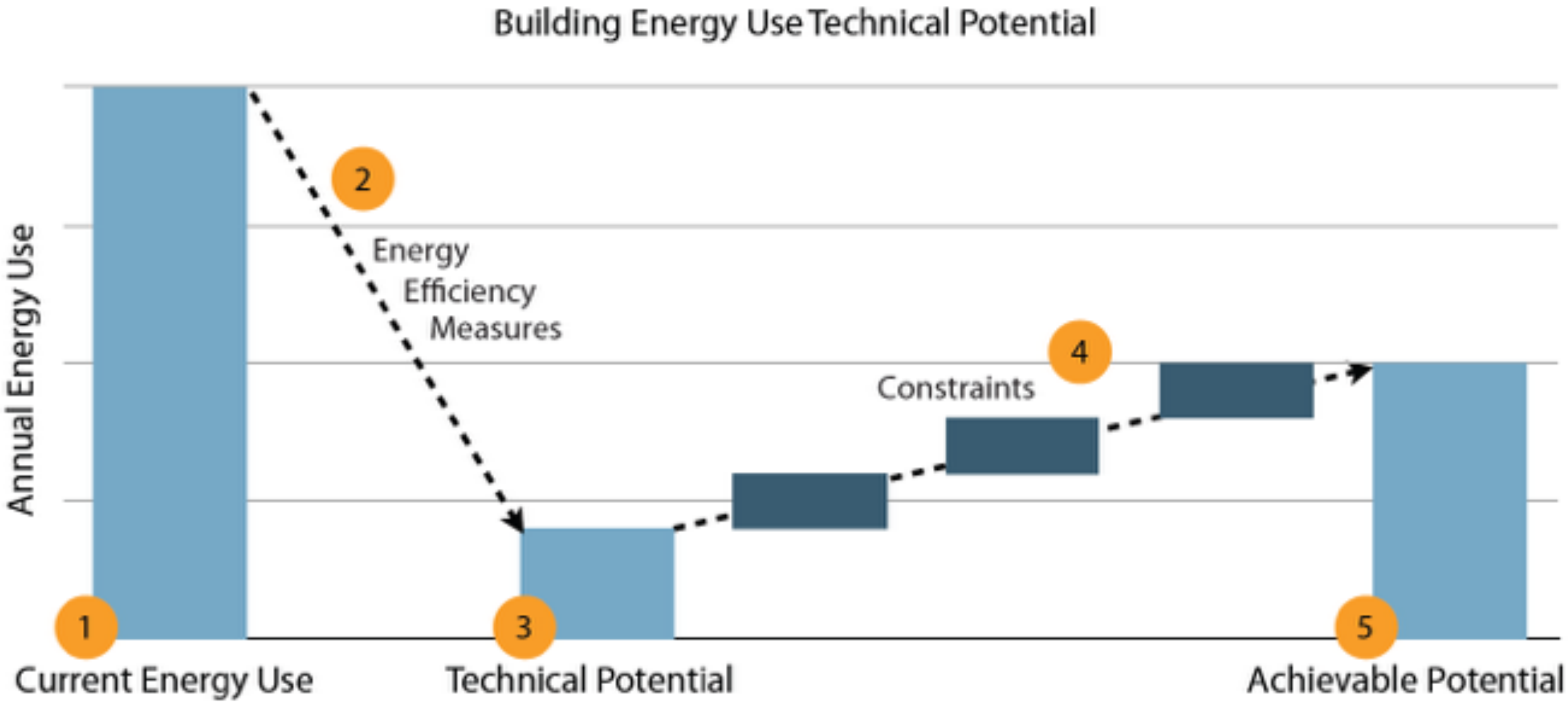


Image credit: http://www.rmi.org/retrofit_depot_the_blueprint_enacting_a_deep_energy_retrofit

Model and select energy retrofit strategies

- Passive: Window replacement/over cladding, Air sealing measures
- Active: Equipment replacement/refurbishment
- Synergies?

- Consider incremental cost of higher performance components and potential energy savings
- Consider the capital cost savings of downsizing equipment if load is reduced

And you’re done!

- Contracting, Construction, Commissioning and start saving energy!

Saving energy is good, right?

- It is! But it should not be at the expense of the indoor environmental quality (IEQ)

- Buildings are for people: comfort and health of residents should be paramount

- Energy retrofits can have a positive, neutral or negative influence on IEQ: should consider these influences early in the design stage

Occupant health

- Spend 90% of time indoors and more than 65% time in residential buildings[1,2]
- Movement of odors (cooking, tobacco smoke) is a common complaint in MURBs[3]
- Environmental exposure depends on many factors

1 Klepeis et al. 2001
2 Leech et al. 2002
3 CMHC 2003

Occupant exposure in social housing

- Prevalence of asthma 2-4 times higher in vulnerable populations, than the general population[1]
- Reduction in asthma morbidity among children when comparing new social housing units to older buildings[1]
- Boston Housing Authority: concentration of multiple indoor pollutants are higher in low-socioeconomic households, compared to general population[2]

1 Colton et al. 2015
2 Adamkiewicz et al. 2011

Occupant exposure in social housing

TABLE 1—Representative Housing Variables Associated With Indoor Environmental Exposures, by Household Income: American Housing Survey, United States, 1999

	Income Category				
Housing Variable	<$30 K/Year (n=25647)	$30<$60 K/Year (n=25840)	$60<$100 K/Year (n=24000)	≥$100 K/Year (n=22842)	Associated Exposures and Hazards
Built before 1980, %	71.56	65.82	57.77	48.63	Lead paint; structural integrity
Area of peeling paint larger than 8 × 11 in, %	3.11	2.04	1.41	0.99	Lead paint
Any inside water leaks in past 12 mo, %	9.14	8.67	8.24	7.98	Mold and moisture; structural integrity
Neighborhood with heavy street noise or traffic, %	28.19	25.42	21.95	16.69	Outdoor air sources–mobile
Industry or factory within half block, %	6.90	5.50	3.54	1.74	Outdoor air sources–stationary
Unit uncomfortably cold for ≥24 h, %	10.70	9.67	7.33	6.71	Supplemental heating; comfort
Evidence of rodents in unit, %	17.77	16.81	16.98	16.26	Allergen exposure; pesticide exposure
Mean floor area of unit, ft^2	1524	1762	2098	2853	Exposure to indoor air pollutants
Mean occupant density, no./1000 ft^2	2.78	2.59	2.31	1.82	Indoor source strength–various
Homes with cracks in floor, wall, or ceiling, %	7.13	5.10	3.88	3.31	Allergen exposure (pests)
Homes with holes in floor, %	1.85	1.03	0.58	0.37	Allergen exposure (pests)

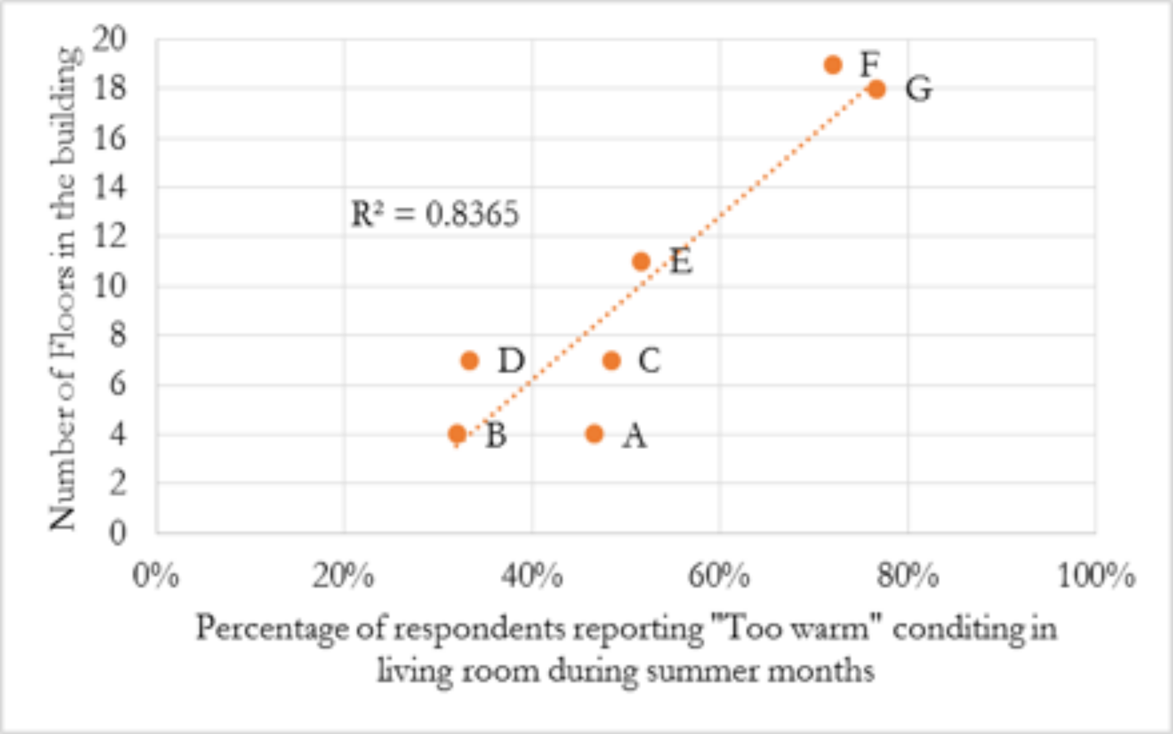
Occupant comfort

- Lots of attention in the commercial sector (Productivity = $$$)
- Under-heating in some areas
  - Fuel poverty and poor envelope performance can lead to under-heating[1]
- Chronic overheating even in cold climates
  - Serious health implications of overheating
  - NYC: 46 heat stroke deaths in 2006, most did not have working A/C, and more than 80% were exposed at home[2]

1 A. Powers, personal communication
2 Extreme heat awareness and protective behaviors in NYC, 2013

Study of overheating in Toronto's social housing

- Over 50% of residents reported feeling "Too Warm" during summer
- Average summer air temperature indoors 27.7°C (82°F)
- Thermal dissatisfaction and building height: Stack effect?
- Mechanical solutions may not be the only/best approach



Increasing threat of overheating

- Heat-related deaths expected to double over next 30 years[1]
- Lower income housing is at higher risk:
  - Poor quality housing
  - No central cooling
  - Higher likelihood of pre-existing illness
- Without cooling measures, buildings accumulate heat[1]
  - Montreal study: average apartment temp 4°C higher than outside
  - NYC study: average indoor temp 2.8°C higher than outside

1 City of Toronto Staff Report 2015

Consider Energy and IEQ from the start…

Co-benefits

- Better IAQ
- Better thermal comfort
- Better durability

Revised steps to designing E+IEQ Retrofit

- Determine residents needs (surveys, focus groups) and capabilities of on-site staff
- Establish comprehensive baseline performance (including temperature and IAQ assessments)
- Develop a calibrated model
- Establish energy savings targets and goals for IEQ improvement
- Models retrofit strategies to determine potential for E+IEQ improvements
- Select strategies that either improve or have no impact on IEQ
- Construction, commissioning, testing, monitoring, surveys…

Resident engagement

- Community meetings
- Surveys, Focus groups
- Design charrettes
- Provide status updates
- Move vulnerable residents off site
- Consider how information is presented

Establish comprehensive performance baseline

- Consider
  - short term temperature monitoring during summer/winter
  - Indoor air quality monitoring
  - Air tightness testing
  - Air flow measurements

Establish targets

- Energy reduction target
- Reduction in air leakage?
- Better temperature control?
- Lower pollutant levels?

Choose retrofit strategies for E+IEQ benefits

- EPA: Healthy Indoor Environmental Protocols for Home Energy Upgrades[1]
- EPIQR: Energy performance indoor environmental quality retrofit
- Noris et al. 2013: points-based approach to score potential retrofit measures on energy and IEQ performance per dollar value measure

1 https://www.epa.gov/sites/production/files/2014-12/documents/epa_retrofit_protocols.pdf)

Noris et al. 2013

Table 1
Expected energy and IEQ (IAQ and comfort) impacts of retrofits.

Retrofit	Energy impacts	IEQ impacts
Air seal envelope	Reduces heating and cooling	Reduces pollutant entry from other apartments and common areas Reduces outdoor air ventilation-potentially worsening IAQ
Replace bath fan	More efficient motor decreases electricity use Potentially more use, increases heating and cooling demand	Reduces fan noise Improves moisture and indoor pollutant removal
Replace range hood	More efficient motor decreases electricity use Potentially more use, increasing heating and cooling demand	Reduces fan noise Improves removal of cooking pollutants and moisture (if system is used)
Replace natural draft water heater with forced combustion water heater	Reduces water heater energy use	Reduces risk of combustion pollutant spillage to indoors
Provide portable fan	Reduces cooling demand in air-conditioned apartments	Improves thermal comfort
Replace gas cook stove with standing pilot with electronic ignition stove	Reduces natural gas use Reduces cooling demand, increases heating demand	Eliminates indoor pollutants from pilot light
Replace HVAC ductwork and seal return plenum	Reduces heating and cooling demand	Reduces drawing of pollutants from other apartments, attics, etc. May improve thermal comfort
Replace single-pane sliding glass doors and windows	Reduces heating and cooling demand	Reduces cold drafts and radiant heat losses, improving comfort
Add insulation	Reduces heating and cooling demand	Improves thermal comfort and noise transmission
Install HEPA filter	Increases electricity consumption	Reduces indoor particle levels

Noris et al. 2013

- 16 low-income apartments
- Suite-based retrofits
- Pre- and post-retrofit monitoring
- Occupant surveys
- IEQ parameters appeared to improve with continuous balanced ventilation

F. Noris et al. / Building and Environment 68 (2013) 170–178

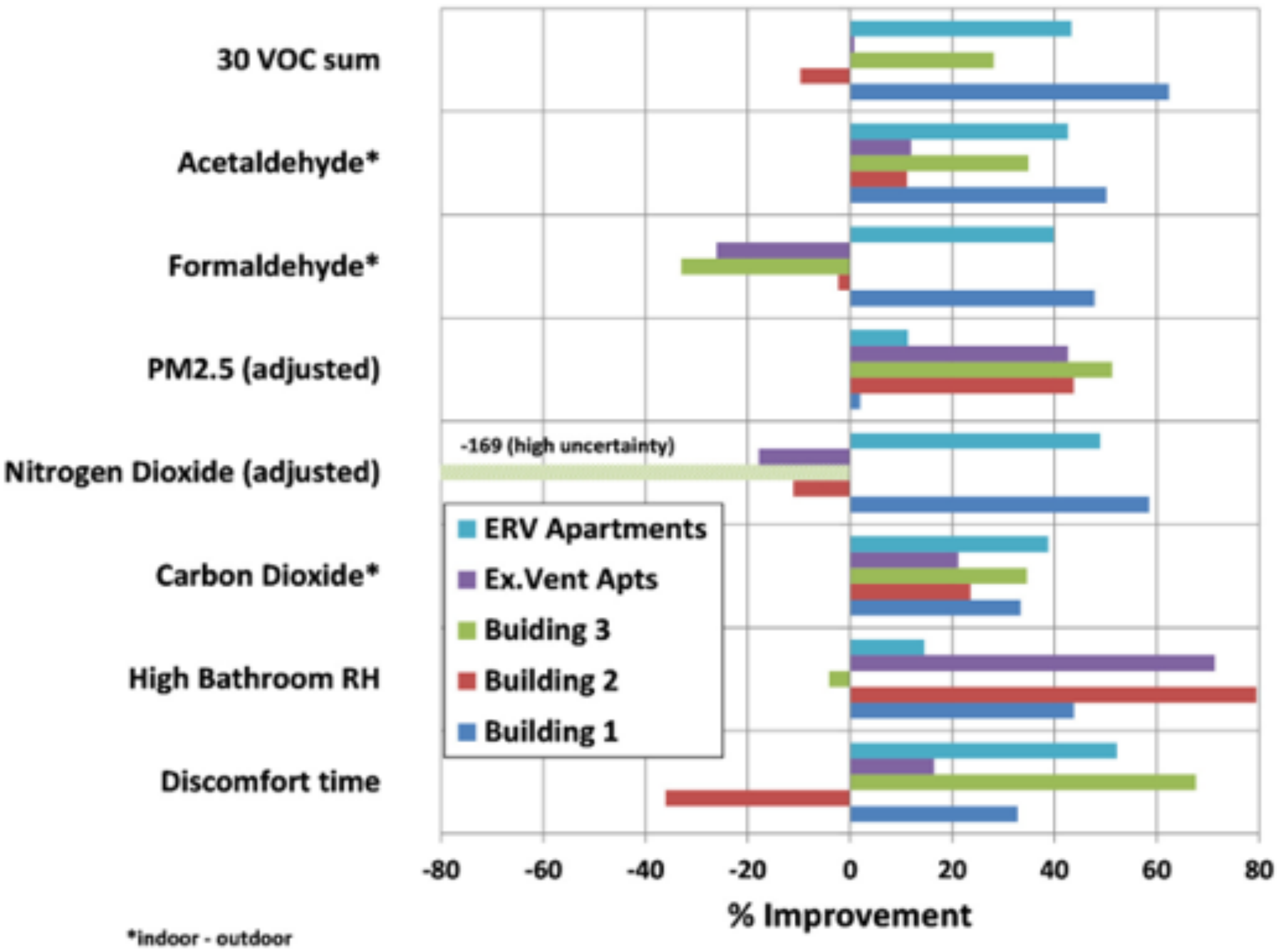


Fig. 11. Summary results.

Swedish Public Housing Retrofit

- Linköping, Sweden (avg annual outdoor temp 6.9°C)
- Six mid-rise 1970's apartment buildings, one retrofitted
  - Overcladding, window replacement
  - in-suite control of heating system
  - Heat recovery

Image credit: Lui et al. 2015

Swedish Public Housing Retrofit

- Monitoring
  - Temp and RH
  - Suite electricity use
  - Heating energy (retrofit only)
- Modeling with IDA ICE
  - Calibrated to temp and space heating
- Surveys

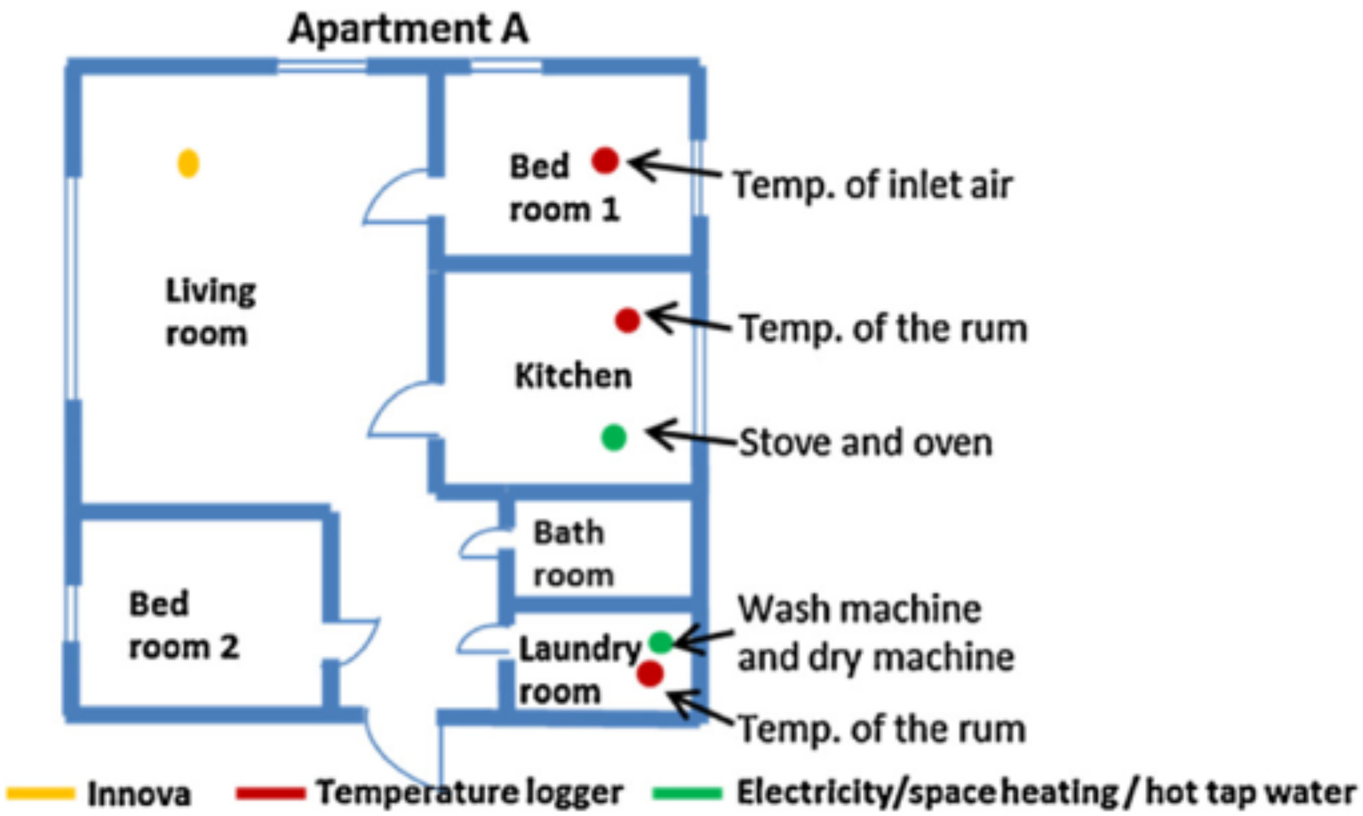


Image credit: Lui et al. 2015

Swedish Public Housing Retrofit

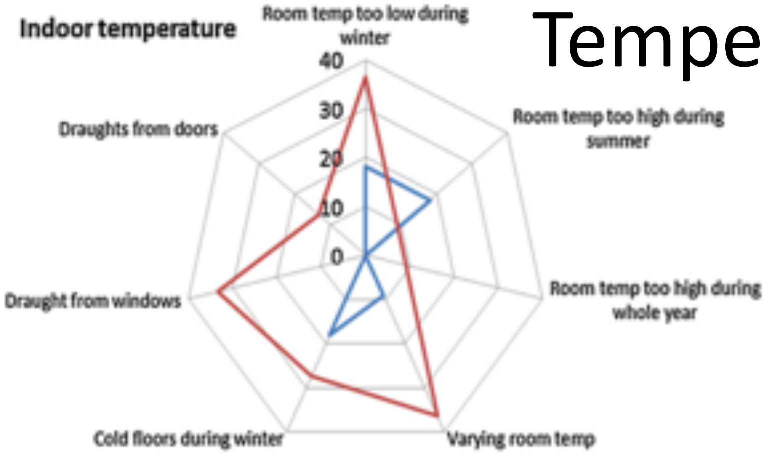
Non-retrofitted

Retrofitted

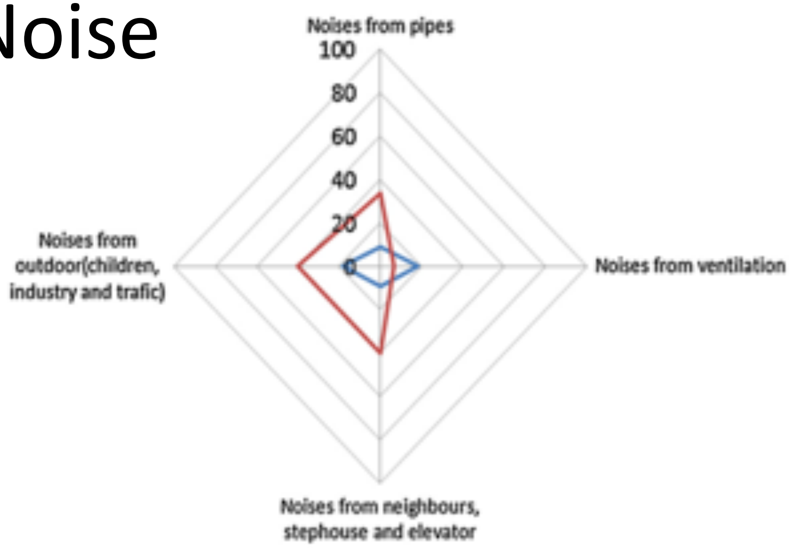
More satisfied with IEQ and 39% reduction in space heating energy

Air Quality

Indoor Temperature



Noise



Health Issues

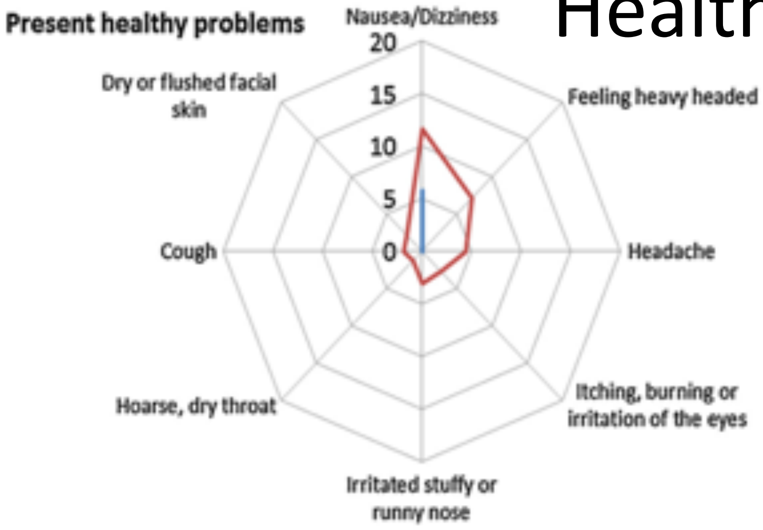


Image credit: Lui et al. 2015

Wilmcote House Retrofit

- 1968 Council Housing, Portsmouth UK
- 100 homes, mostly 3 bedroom units
- Concrete panels, 25mm insulation,
- Electric heat
- Widespread fuel poverty
- Thermal comfort issues

Image credit: http://www.building.co.uk/wilmcote-house-thermal-vision/5077130.article

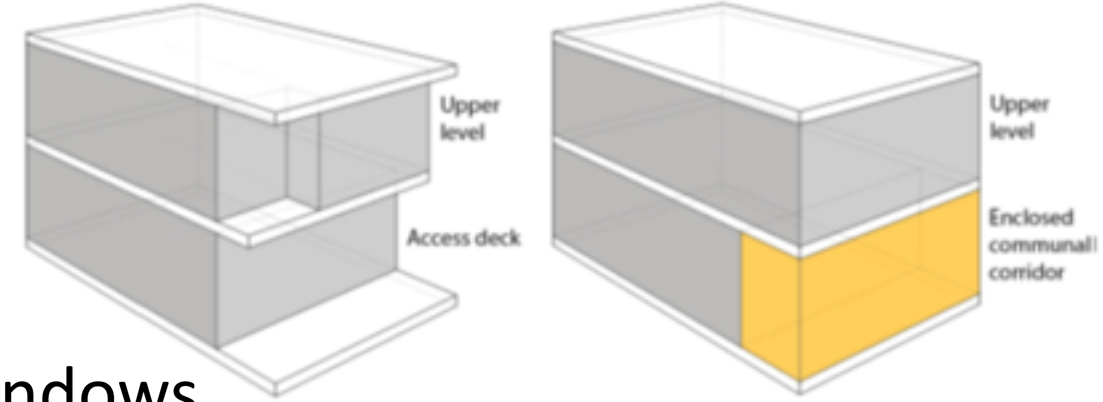
Wilmcote House Retrofit

- Semi-structured questionnaires, interviews before, during and after
- Meter readings
- What the residents' say:
  - *"the windows are rubbish."*
  - *"the heaters are rubbish"*
  - *"I had like little mushrooms growing on the window…in the inside"*
  - *"The rent is ₤430 a month…so the energy cost is half the rent"*

A. Belotti, Personal Communication

Image credit: http://www.building.co.uk/wilmcote-house-thermal-vision/5077130.article

Wilmcote House Retrofit



- R43 Over cladding, new triple glazed windows
- Measures to improve airtightness
- Heat recovery ventilators in each apartment

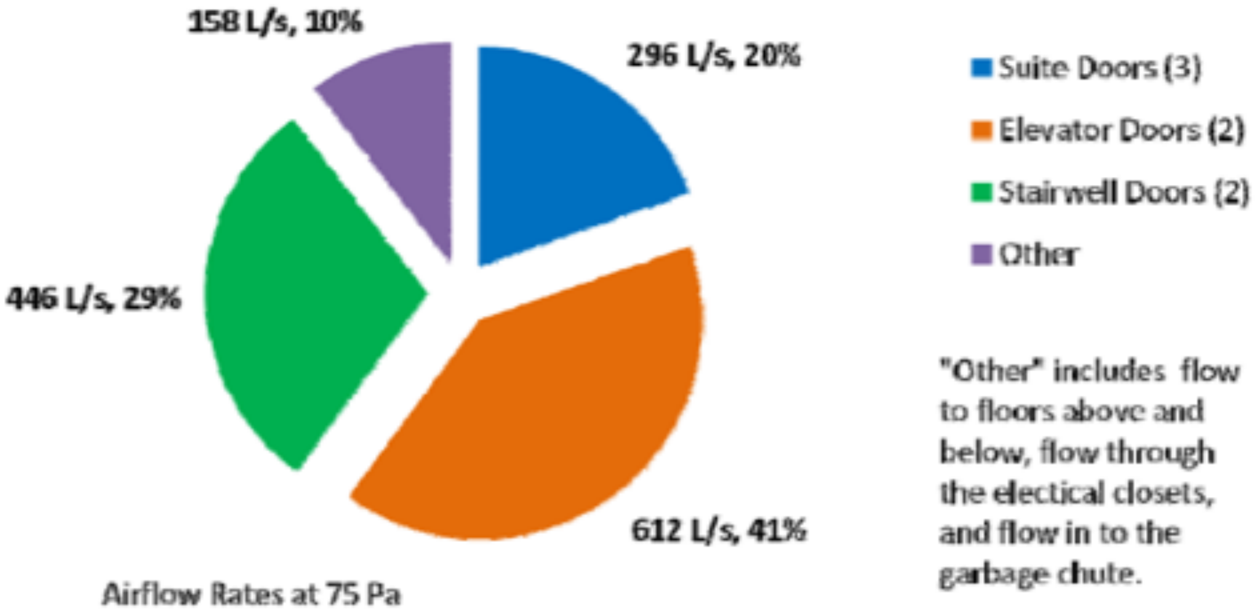
Image credit: http://www.building.co.uk/wilmcote-house-thermal-vision/5077130.article

Belmont Retrofit

- Belmont Condominium (Not social housing)
- 13-storey, 37 suites
- Impact of over-cladding and window replacement on air tightness
- Comprehensive assessment of air flow
  - PFT gas testing for interzone air flow
  - Air flow measurements at MAU and corridor
  - Air tightness of enclosure and between suites

Belmont Retrofit

- Over and under ventilation
- HRVs? Compartmentalization?



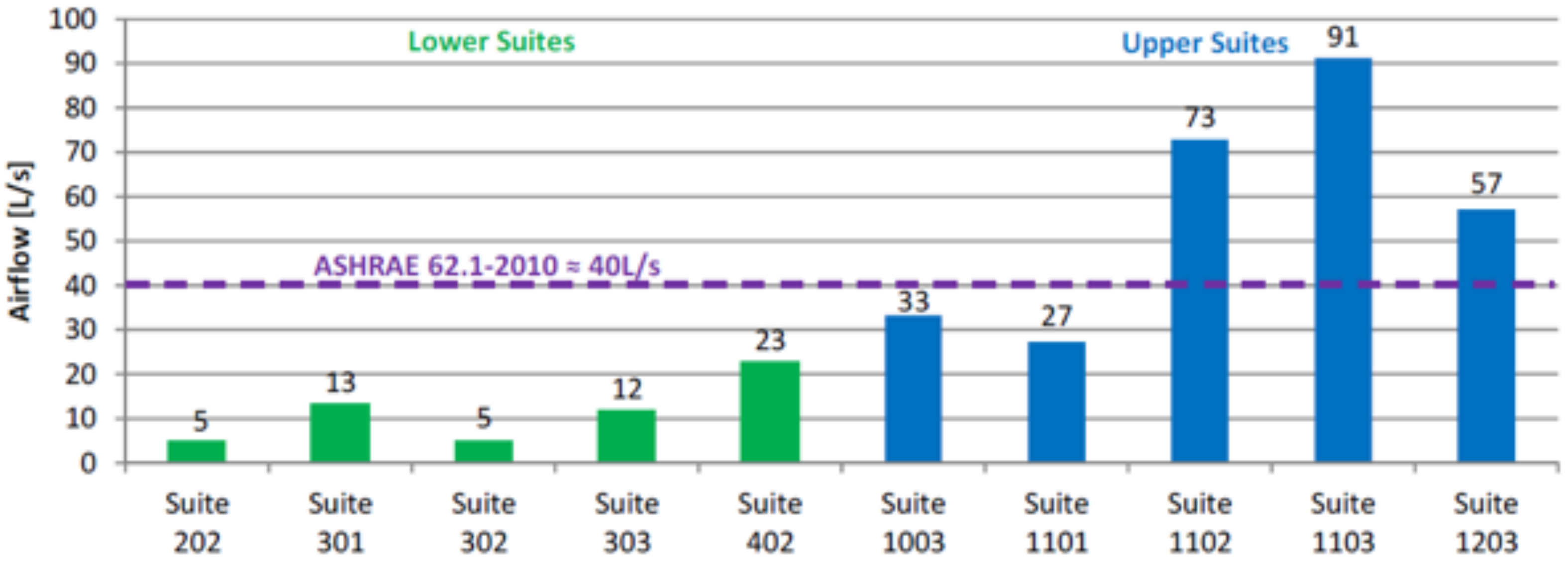


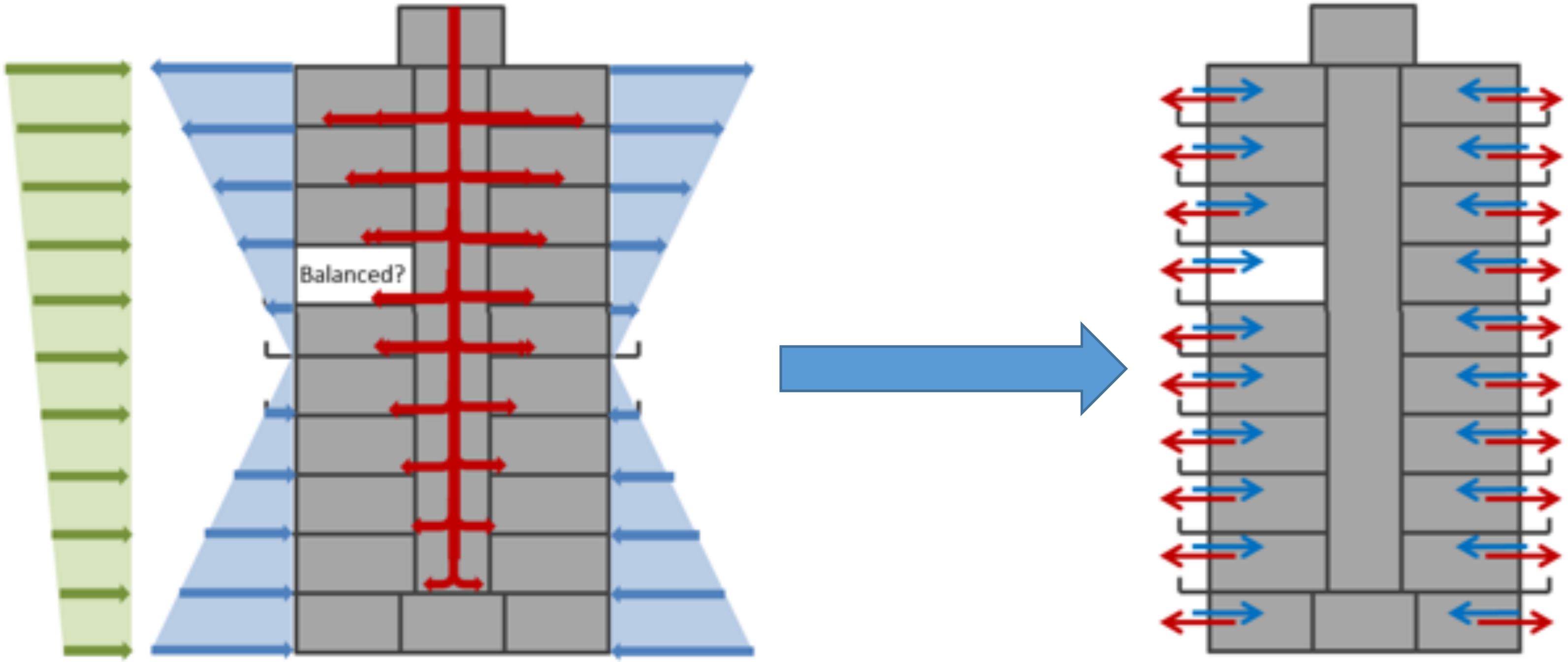
Image Credit: Ricketts and Finch

Compartmentalization Study

- Modeling Belmont in EnergyPlus to explore the energy impact of compartmentalization
- Preliminary results are an 80% reduction in MAU natural gas consumption

RYERSON UNIVERSITY

UNIVERSITY OF TORONTO



Toronto Social Housing Retrofit Study

- 3 sites, 7 buildings, 74 suites
- Pre- and post-retrofit
  - in-suite monitoring:
    - Long-term continuous monitoring of temp, RH, MRT, CO_2
    - Short-term monitoring of Radon, Formaldehyde and PM sampling
  - Boiler efficiency monitoring
  - Resident surveys

TORONTO ATMOSPHERIC FUND

UNIVERSITY OF TORONTO

Measures to improve E+IEQ

- Passive → Reduce demand
  - Over-cladding, window replacement, air sealing
- Active → mechanical ventilation
  - Balanced, heat recovery
  - Improve efficiency
- Control strategies
  - Demand-based

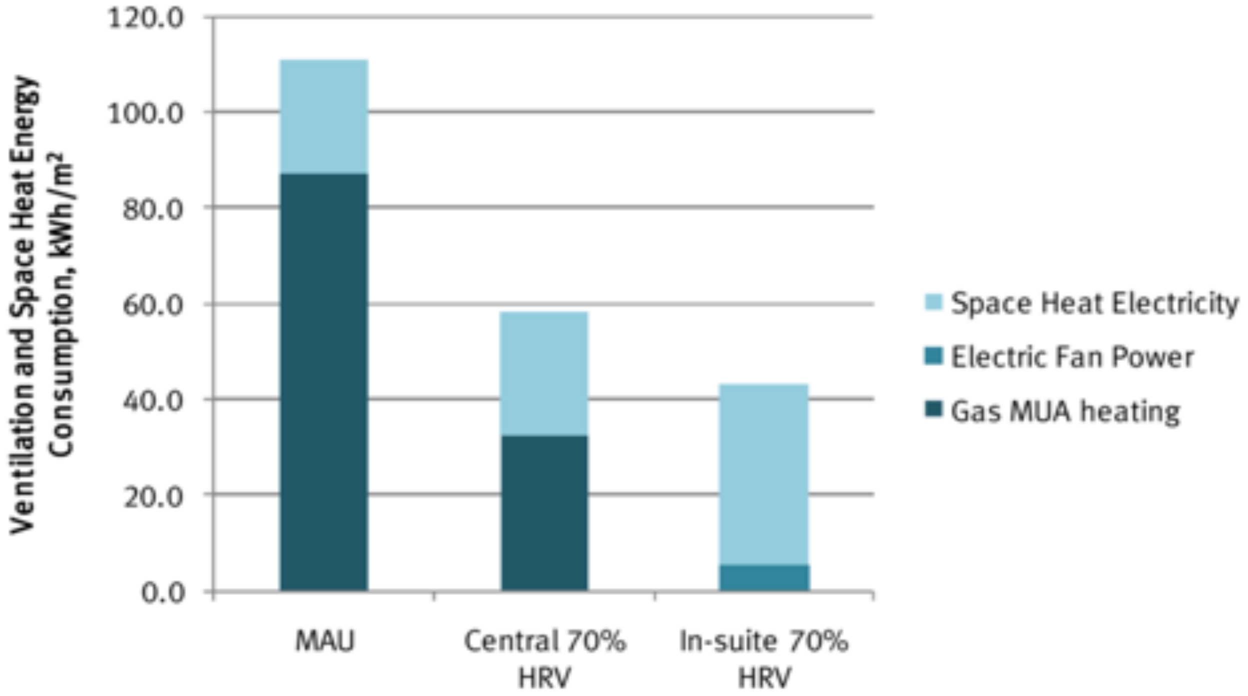


Image Credit: RDH 2012

Why don't we just do it?

- Need a goal to work towards
- Split/no incentive
- Capacity constraints at the public housing authority
- Funding:
  - Other priorities for available funding
  - Separate capital and operating budgets
  - Lack of awareness about funding programs
- Inappropriate use of energy modeling
- Previous bad experience

dles

On the horizon

- Effects of climate change over the service life of the building
- Energy and carbon pricing
- Energy reporting
- Valuing health and comfort impacts of building retrofits

Thank you Joe!

marianne.touchie@utoronto.ca

TORONTO ATMOSPHERIC FUND

Hutcheon Bequest

UNIVERSITY OF TORONTO

NSERC CRSNG

References

http://blog.rmi.org/blog_2013_08_19_affordable_housing_with_unaffordable_energy_bills

Rocky Mountain Institute – Solutions to Hurdles report

Harvard University Graduate School of Design 2003

Somerville & Mayer 2003

Department of Energy (2011). "Building Energy Data Book“; U.S. HUD’s Public Housing Program. Available: http://www.hud.gov/renting/phprog.cfm. Accessed 12/28/2007.)

Abt Associates 2010.

Jacobs DE, Kelly T, Sobolewski J. Linking public health, housing, and indoor environmental policy: successes and challenges at local and federal agencies in the United States. Environ Health Perspect 2007;115:976e82.
[3] Northridge J, Ramirez OF, Stingone JA, Claudio L. The role of housing type and housing quality in urban children with asthma. J Urban Health 2010;87: 211e24.

https://www.ucalgary.ca/cities/files/cities/toronto-report.pdf

New York City Mayor’s Office, New York City Local Law 84 Bench-marking Report, 2012, http://www.nyc.gov/html/gbee/downloads/pdf/nycll84 benchmarking report 2012.pdf – pg 14

Touchie, M.F., Binkley, C, Pressnail, K.D. “Correlating Energy Consumption with Multi-Unit Residential Building Characteristics in the City of Toronto,” *Energy and Buildings* 66 (2013) pp. 648-656.

Edwards, C. (1999). *Modelling of Ventilation and Infiltration Energy Impacts in Mid and High-Rise Apartment Buildings*.

A - Rocky Mountain Institute, Superefficient Affordable Housing: Solutions to Hurdles, 2013

http://www.rmi.org/retrofit_depot_the_blueprint_enacting_a_deep_energy_retrofit