Guiding Design Teams by Hygrothermal, Energy, and Thermal Comfort Analysis While Managing Uncertainty

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Buildings XIII Conference

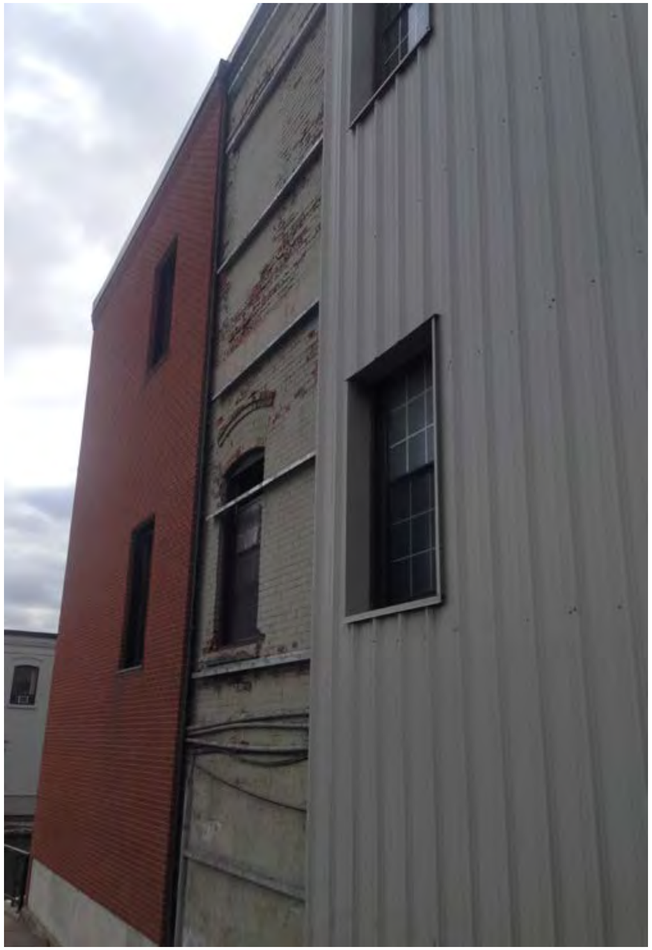
70 Years
MORRISON HERSHFIELD
PEOPLE • CULTURE • CAPABILITIES

Case Study Buildings

- Ottawa and Gatineau, Canada (ASHRAE Zone 6)
- Reuse of four industrial buildings for mix-use (commercial, retail, and office)
- Constructed in the early 1900s

Case Study Buildings

- **Painted brick**
- 3-wythe and 5-wythe load bearing walls
- Single glazed windows
- Uninsulated roofs
- Embedded wood and steel joists
- Spot repairs and overcladding (metal, brick and concrete block)



Developer Interests

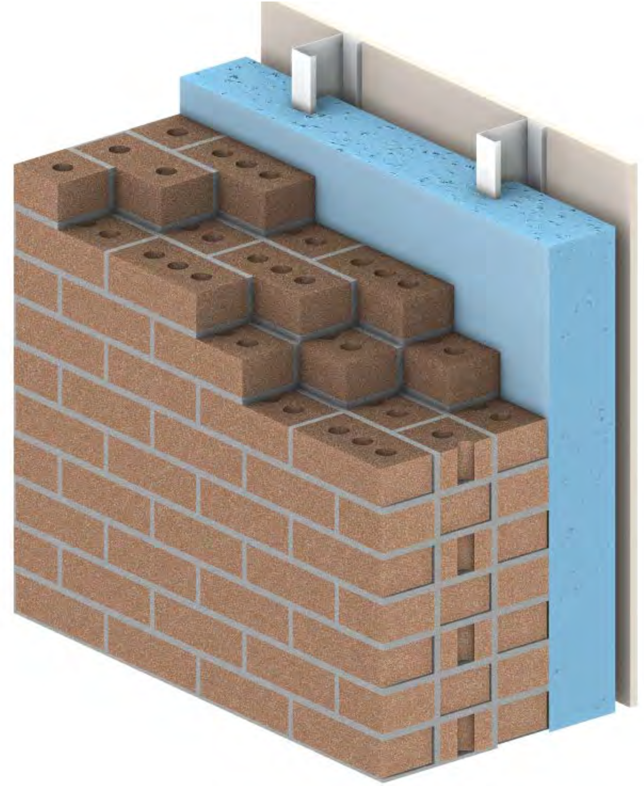
- Industrial exterior appearance of an aged brick facade
- Balance durability concerns with energy-efficiency, occupant comfort, and operation objectives
- Development of a sustainable neighbourhood
- Empower the design team at early stages to avoid introducing unnecessary constraints

Existing Conditions

- Generally in good condition
- Deterioration at localized areas highly exposed to water, snow, salt and poor maintenance

Theory Tells Us

- Adding insulation inboard of existing brick masonry will:
  - Reduce heat flow
  - Reduce drying
  - Increase the risk of freeze-thaw damage in cold climates



Safe Insulation Levels?

Managing Uncertainty

Ideal –

statistical analysis where the probability of failure, loads and design parameters are stochastic variables, similar to limit state design for structural engineering

Gut Feeling and Experience –

relying on your trusted advisor with grey hair to keep you out of trouble and to provide good advice based on what has and hasn't worked in the past

Managing Uncertainty

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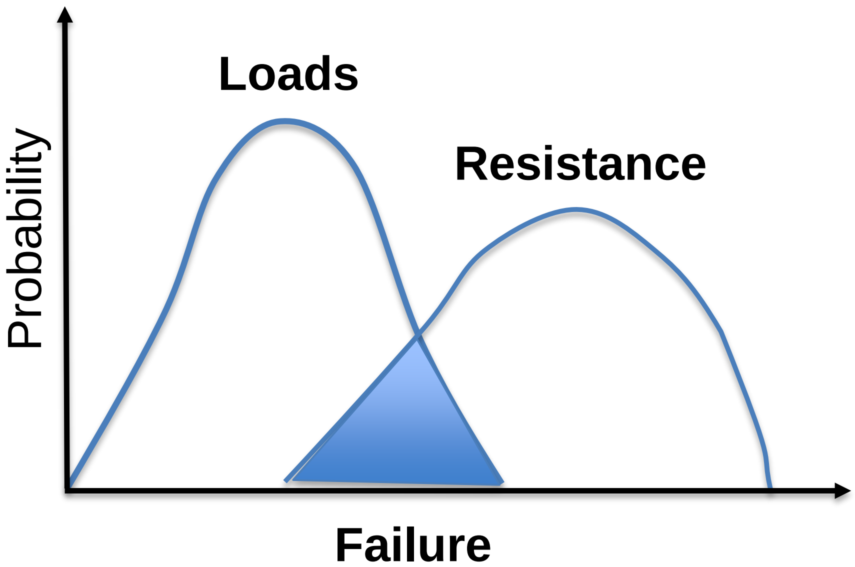
statistical analysis where the probability of failure, loads and design parameters are variables, similar to limit state design for structural engineering

Practical?



Sufficient information is rarely available

Managing Uncertainty

Memory like an Elephant

Take the risk?

Gut Feeling and Experience –

relying on your trusted advisor with grey hair to keep you out of trouble and to provide good advice based on what has and hasn't worked in the past

Finding Balance

Informed Design Decisions

Ideal –

statistical analysis where the probability of failure, loads and design parameters are stochastic variables, similar to limit state design for structural engineering

- *Best available information*
- *Professional judgement*
- *Assumptions that closely parallel reality*
- *Not too stringent or optimistic*
- *Experience*

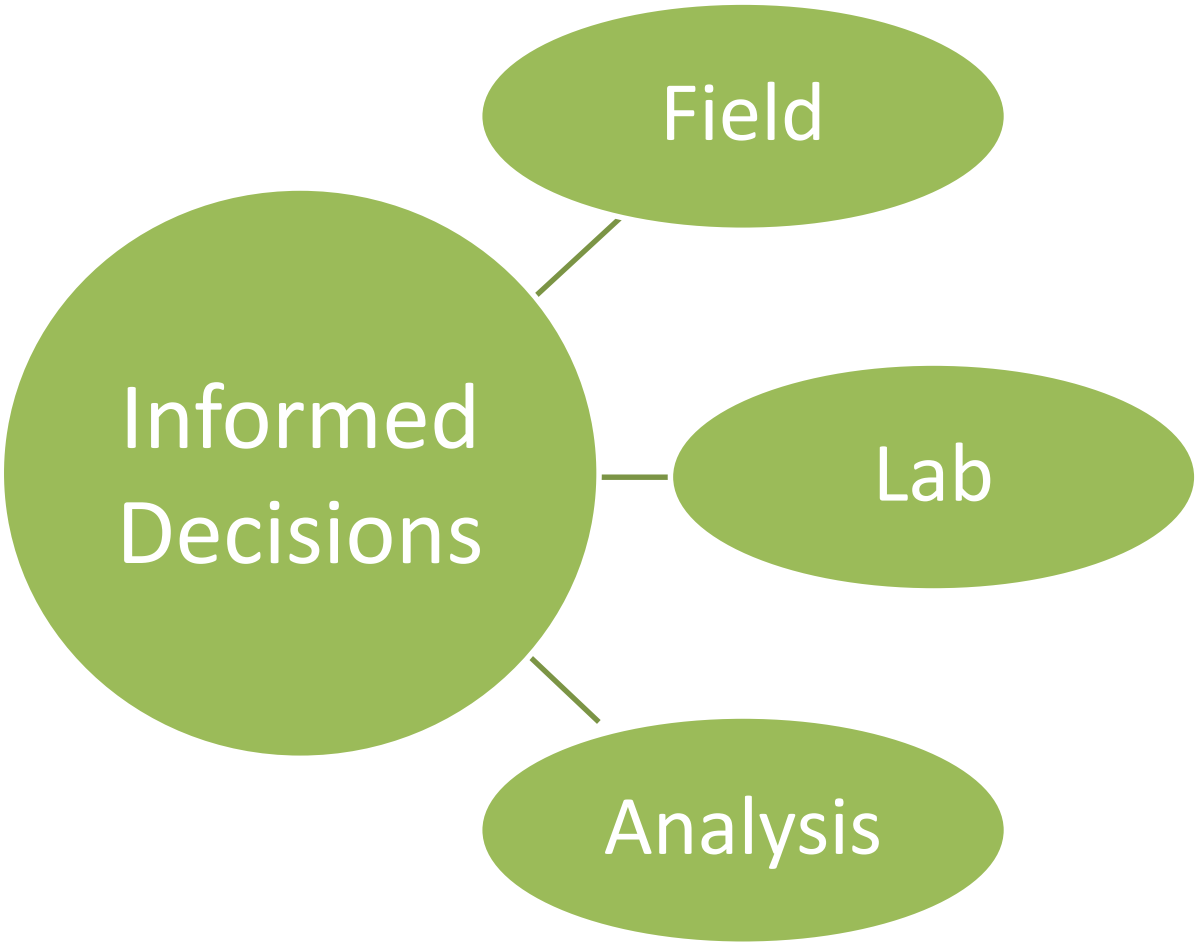
Gut Feeling and Experience –

Requirements

relying on your trusted advisor with grey hair to keep you out of trouble and to provide good advice based on what has and hasn't worked in the past

- ✓ **Durability**
- ✓ **Energy-Efficiency**
- ✓ **Occupant Comfort**
- ✓ **Architectural**

Best Available Information



Investigate

- Existing conditions
- Construction
- Correlation to exposure

Test Samples

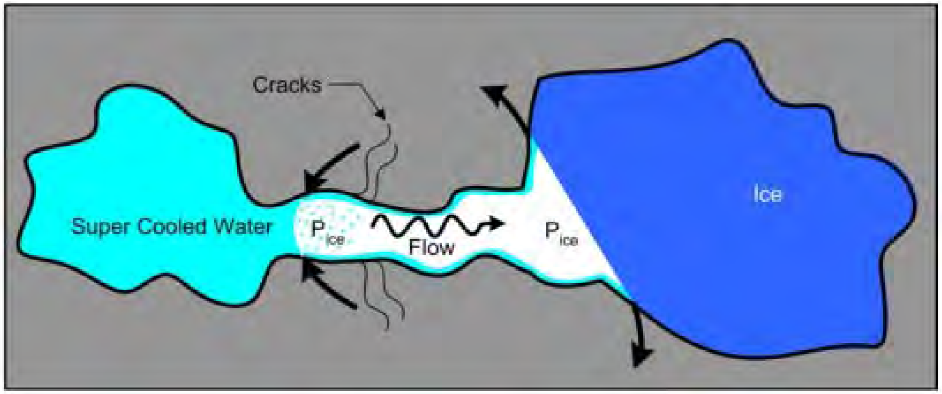
- Hygrothermal Properties
- Freeze thaw

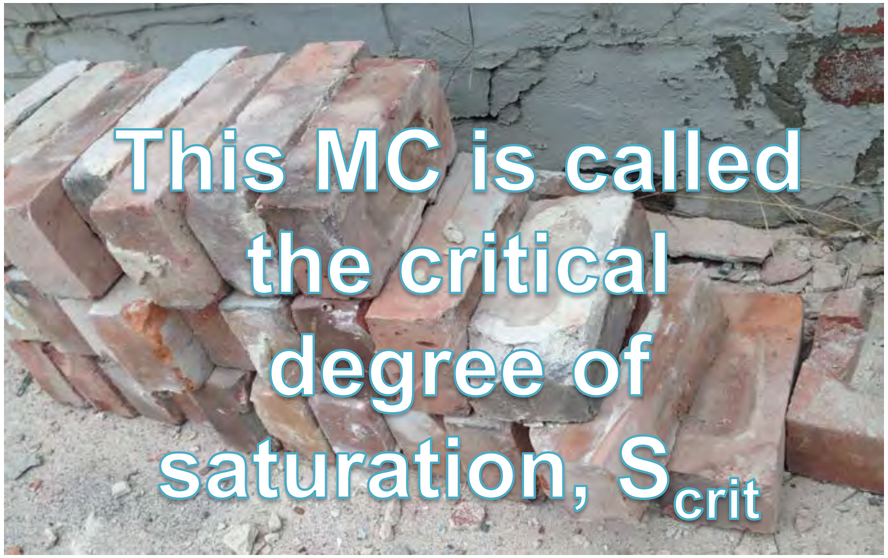
Simulations

- Hygrothermal
- 3D Thermal
- Whole Building Energy

Durability Concerns

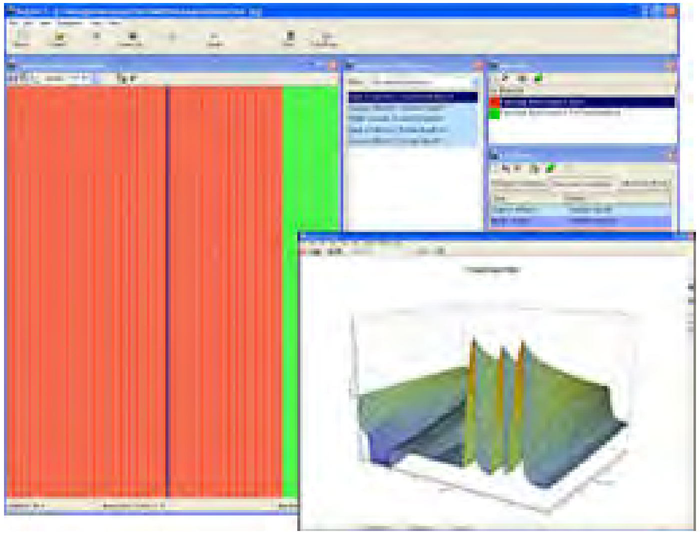
- Freeze-thaw occurs when bricks are saturated beyond a critical point upon freezing and subsequent thawing
- Bricks can be sampled and tested to determine the moisture content (MC) where damage will likely occur





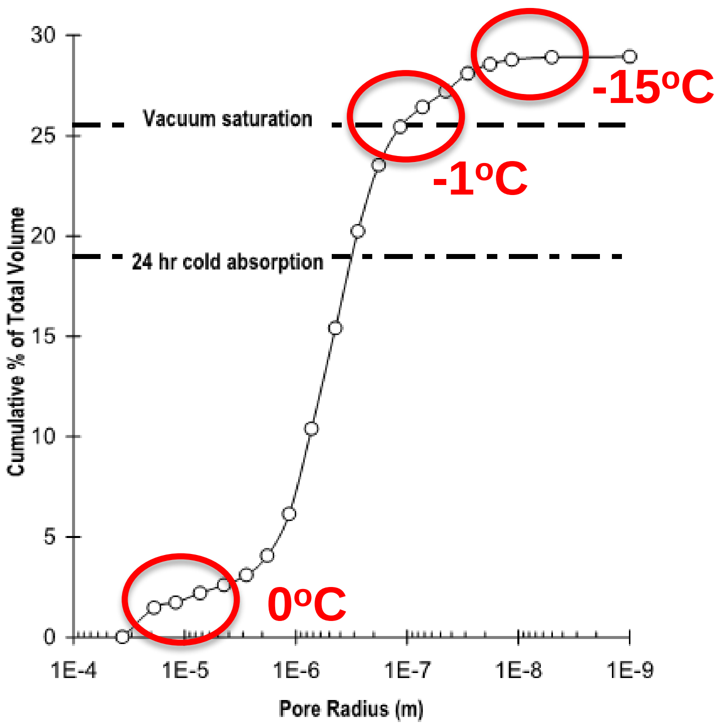
Durability Concerns

- High order screening
  - S_{crit} < Free Water Saturation
- Hygrothermal simulations
  - Compare simulated T and MC to S_{crit}
  - Natural weather for location and exposure
- Higher level of due diligence does not eliminate the uncertainty embedded within this approach

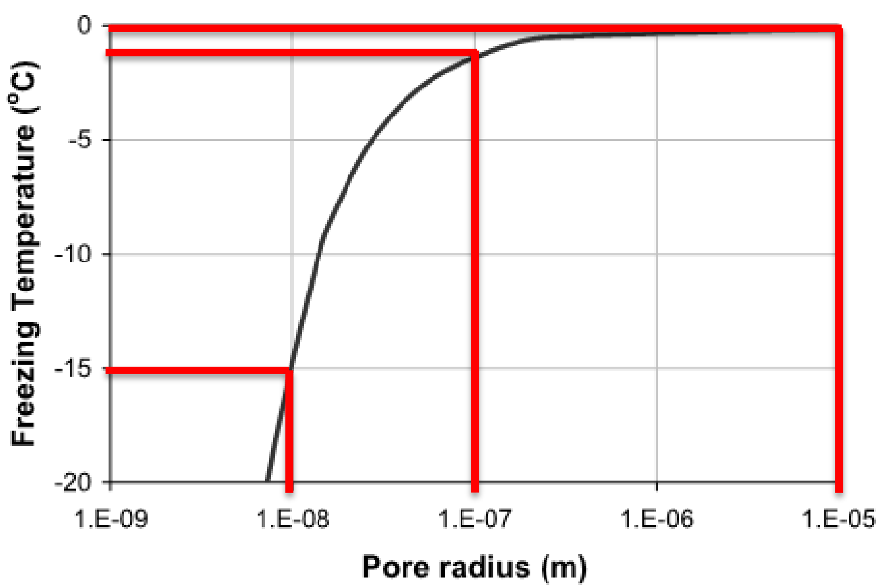


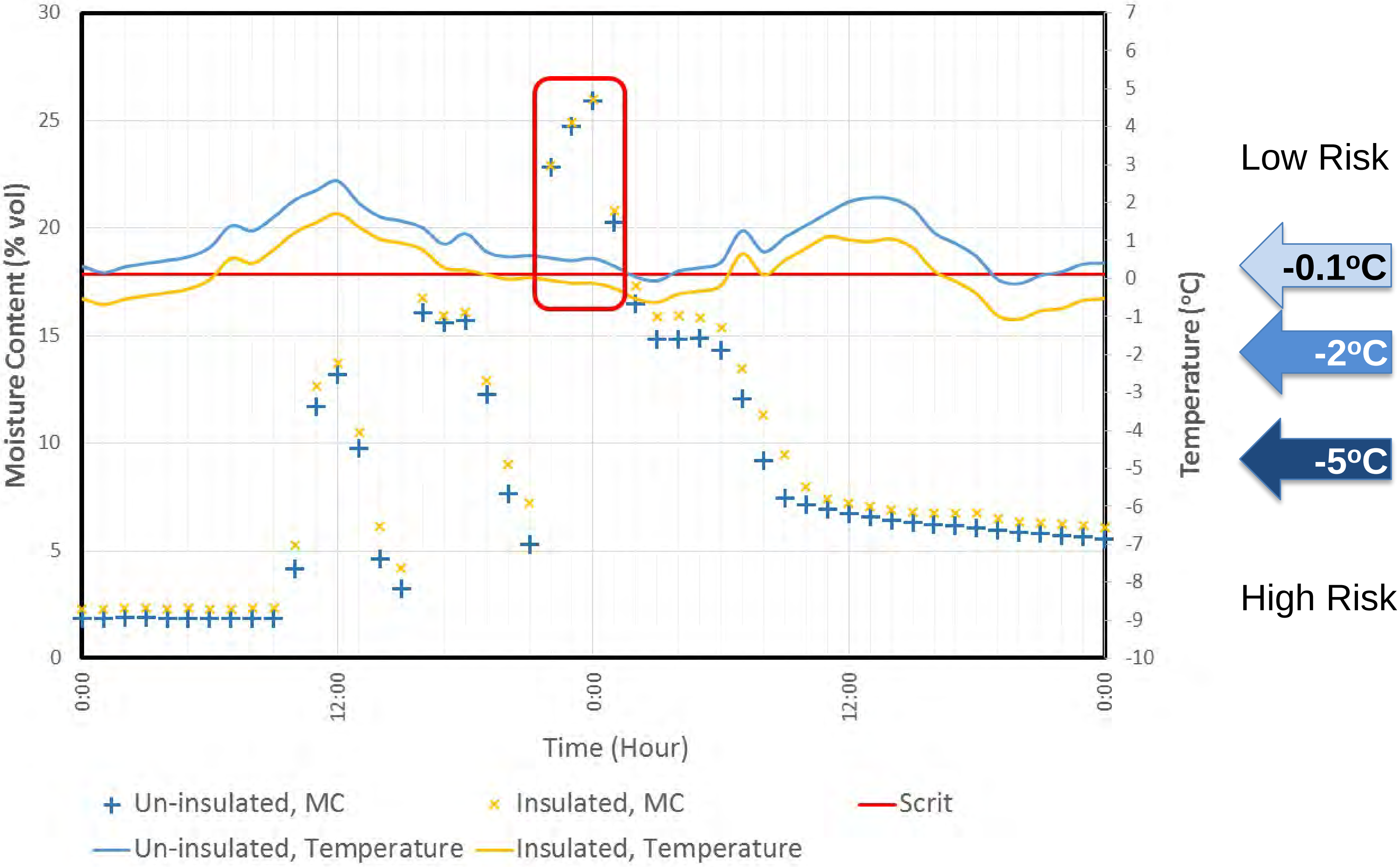
Freeze-Thaw Criteria

Testing cycled at one temperature 5 F (-15 ^{o}C) and freezing rate



Freezing temperature is a function of pore size and clay brick has a broad pore size distribution




Moisture Content (% vol)
Temperature (°C)
Time (Hour)
Un-insulated, MC
Insulated, MC
Scrit
Un-insulated, Temperature
Insulated, Temperature
Low Risk
-0.1ºC
-2ºC
-5ºC
High Risk

Additional Uncertainties

- Salt
  - Impact on moisture transport
  - Crystallization
- Multi-directional freezing for testing versus un-directional freezing for natural conditions
- Water from snowmelt at locations such as window sills and parapets

Brick Testing

- A-value testing on large sample size (50)
  - Several locations
  - Interior, mid, and exterior wythes
  - Face versus common
  - Painted versus non-painted
- Detailed properties measured on small sample size of eight

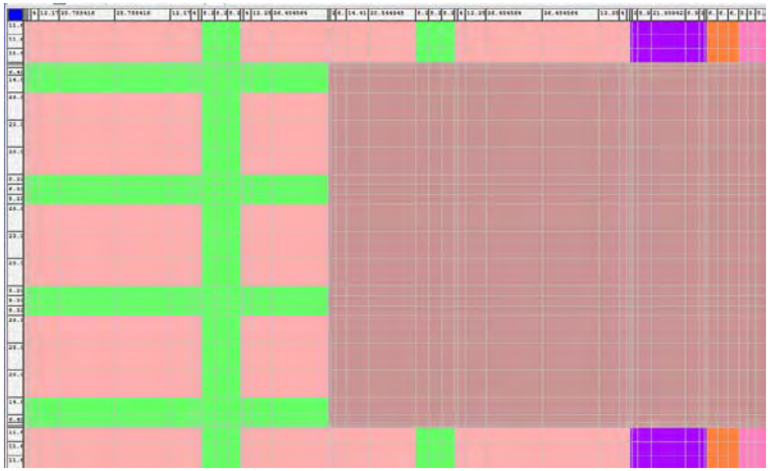
Brick Testing

Sample ID	Dry Bulk Density (kg/m3)	Thermal Conductivity (W/m K)	Heat Capacity (kJ/kgK)	A-value ($kg/m^2s^{0.5}$)	Wf (Moisture Content by weight)	Vapour Permeability (ng/s.Pa.m)	Scrit (Moistue Content by weight)
1	1822	0.82	0.79	0.187	18.2%	16.0	18%
2	**1785**	**0.79**	**0.79**	**0.264**	**15.9%**	**13.7**	**10%**
3	**1864**	**0.85**	**0.79**	**0.128**	**15.8%**	**10.0**	**14%**
4	1810	0.81	0.79	0.221	17.3%	15.2	14%
5	1781	0.79	0.79	0.179	16.9%	17.7	14%
6	1809	0.81	0.79	0.166	18.7%	16.8	17%
7	1867	0.85	0.79	0.125	16.7%	13.7	16%
8	1806	0.81	0.79	0.134	17.1%	13.1	15%

- Samples 2 and 3 were a focus of the hygrothermal analysis

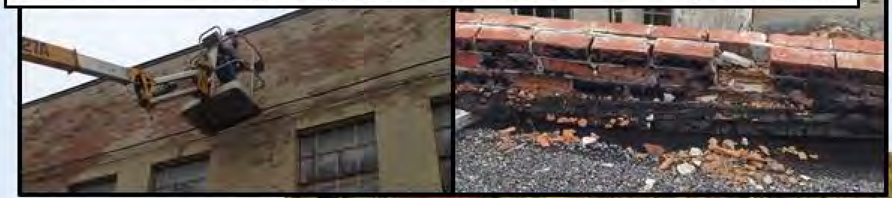
Hygrothermal Analysis

- DELPHIN 1D and 2D models
- Weather data from Ottawa/Gatineau Region for 20-year period
- Interior conditions set to 20^{o}C and ΔVP 540 Pa, simulated average winter RH of 30-40%
- Varying orientation and rain exposure
- Insulation retrofit scenarios
- **With and without paint**
- A total of 564 scenarios

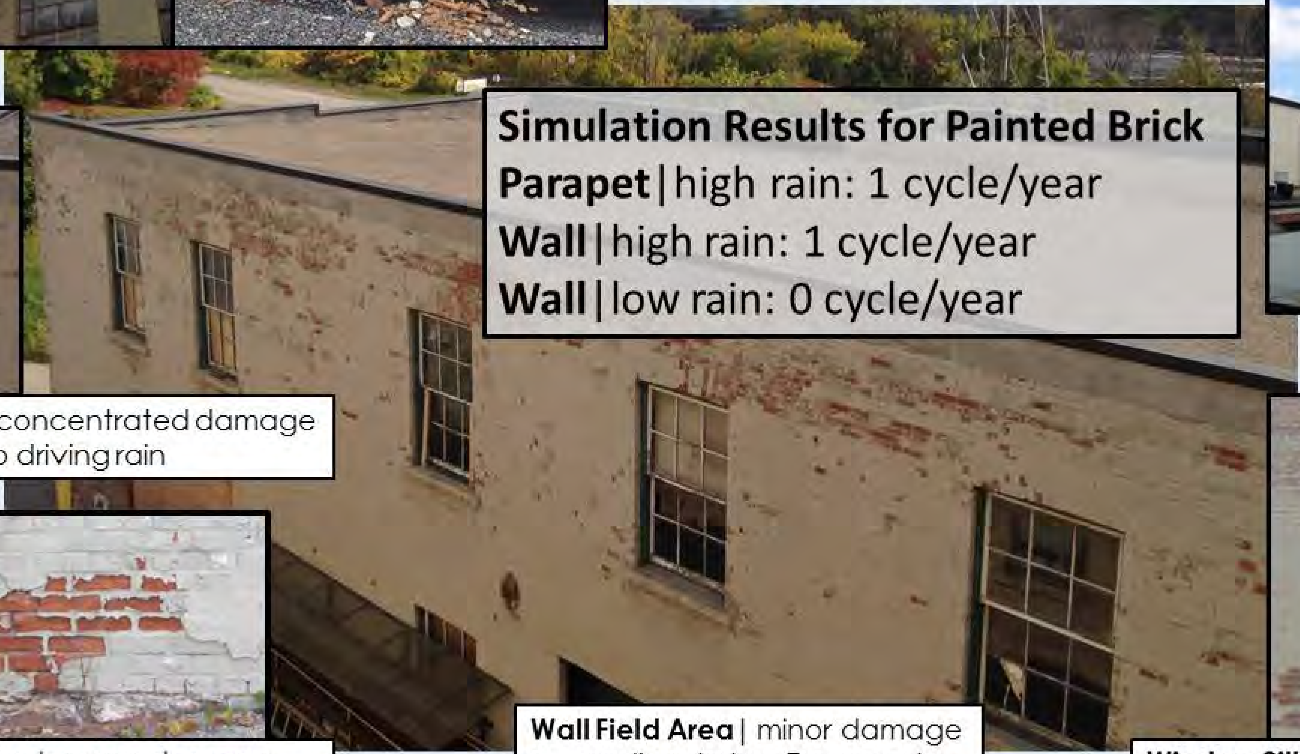


Reality Check

Parapet | extenstive severe damage
- Un-heated, high exposure to snow Melt, driving rain, solar



Un-heated Wall | localized severe damage
- high exposure to rain and run-off



Simulation Results for Painted Brick
Parapet | high rain: 1 cycle/year
Wall | high rain: 1 cycle/year
Wall | low rain: 0 cycle/year

Corner | moderate concentrated damage
- high exposure to driving rain

Base of Wall | localized severe damage
- high exposure to snow melt

Wall Field Area | minor damage
- medium to low Exposure to driving rain

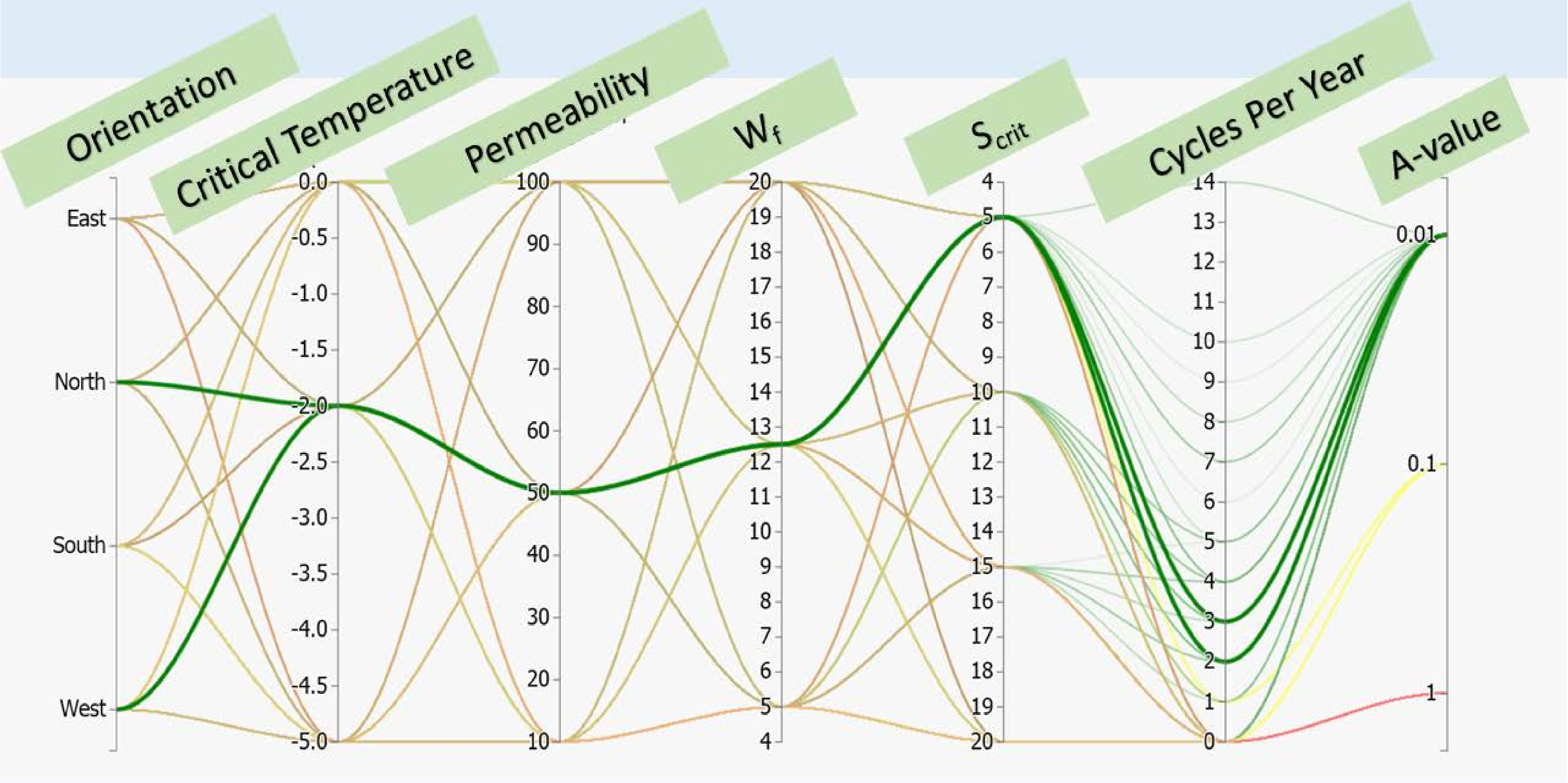
Window Sill | locatized damage
- water/snow run-off

Findings

- Insulation presents a marginal impact on freeze-thaw risk
- Paint is a more significant factor
- Properties affecting liquid transport is a significant factor
- No increased risk in the inner-wythe
- Most of the damage is likely already done

Sample ID	Scrit (Moisture Content by weight)	Paint	Insulation Level	Orientation	Freeze-Thaw Cycles/ Year Criterion 1 (0°C)	Criterion 2 (-2°C)	Criterion 3 (-5°C)
2	10%	Painted	None	North and West	1	0	0
			R-6	North and West	1	0	0
			R-12	North and West	1	0	0
			All other cases had no simulated freeze-thaw cycles				
		Un-painted	None R-6 R-12	All cases had no freeze-thaw cycles			
3	14%	All cases had no simulated freeze-thaw cycles					

Freeze-Thaw Risk



- 2592 Simulations

Mortar Joints and Wythes

Impact of Mortar Joints

- Unsatisfactory mortar joints can introduce additional moisture. However, depending on the type of mortar, the mortar can also help dry out the bricks quicker
- Mortar joints appear to have a net reduction in the risk of freeze-thaw damage and the relative number of freeze-thaw cycles can be determined by the 1D hygrothermal analysis

Number of Wythes

- Adding insulation has even less impact on freeze-thaw risk for the thicker wythe walls because the relative change in the brick temperatures is small due to the extra thermal resistance of the thicker wythes

Imbedded Wood and Steel

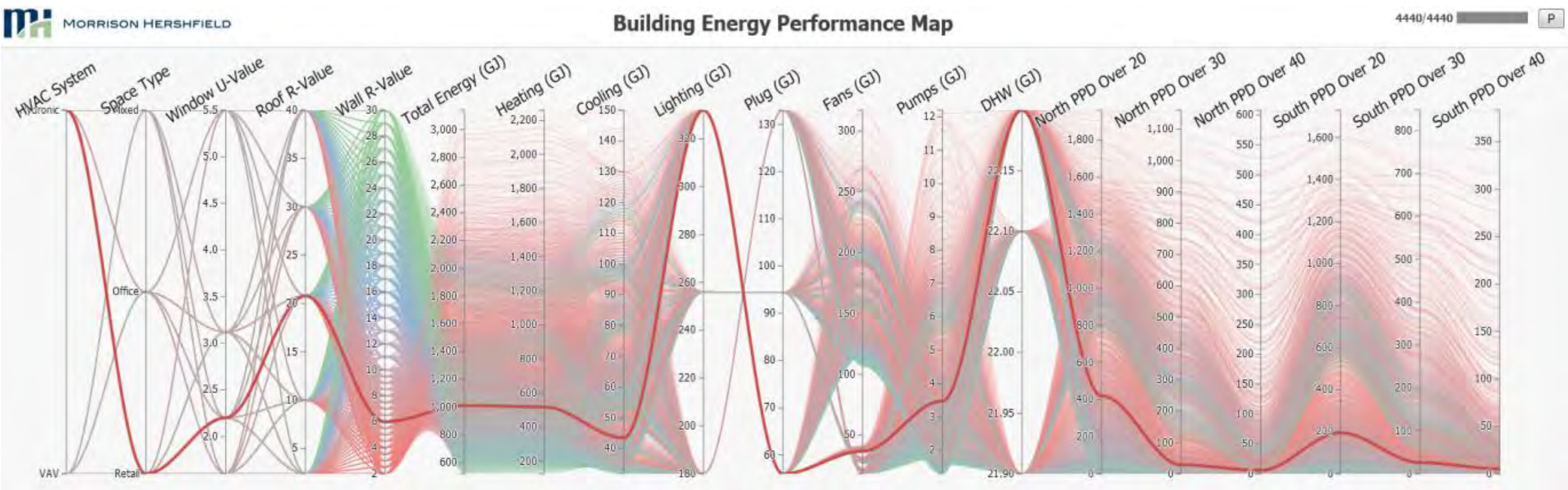
Painted Brick

- Irrespective of insulation, wood beams that are in a pocket where there is only one wythe outboard the beam will likely be exposed to moisture levels greater than 28% MC at the outer fibres, if the beams are in direct contact with the outer wythe
- The difference in hours spent about 28% MC for the beam end is 85 versus 283 hours over a two year period for the un-insulated and insulated scenarios respectively

Natural Brick

- The wood beam spends no hours about 28% MC, with or without insulation.

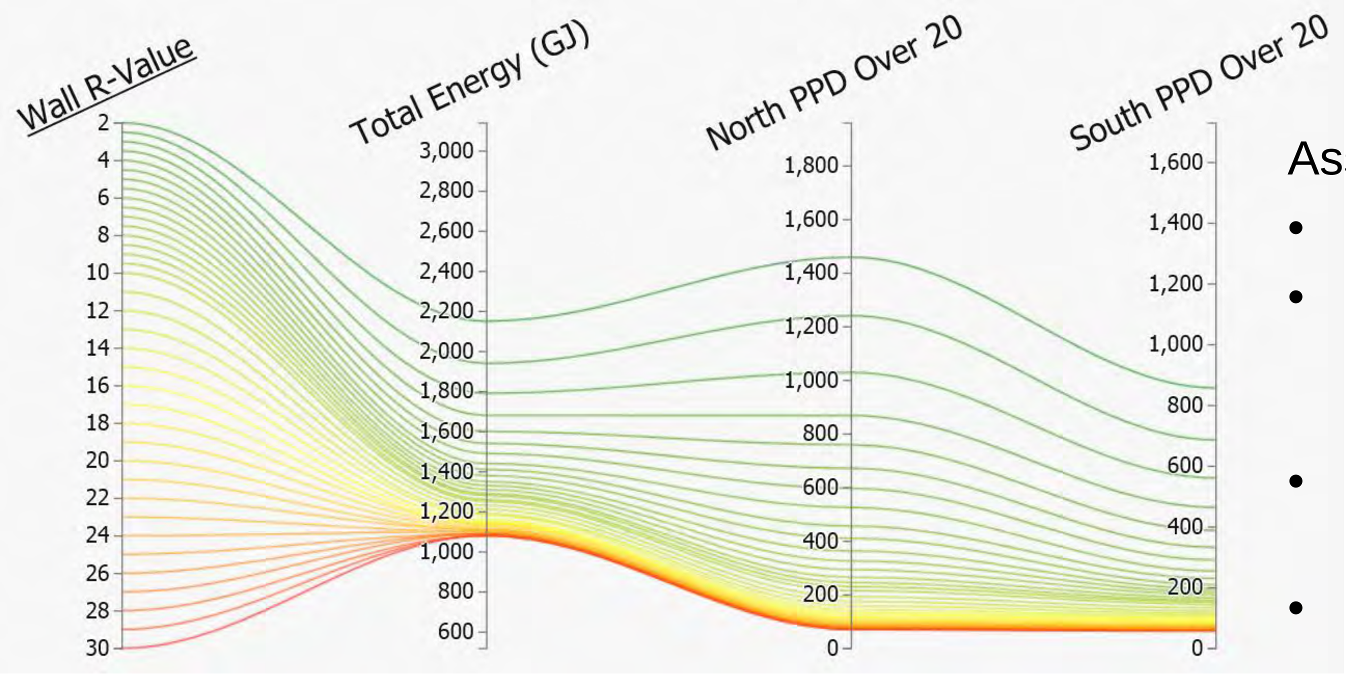
Whole Building Energy and Thermal Comfort



- Impact of adding wall insulation, roof insulation, and glazing improvements
- EnergyPlus model of two-story building
- No change to existing window-to-wall ratio
- **Heating and cooling demand** determined by assuming primary HVAC (heating and cooling plant) as ideal equipment distributing hot water and chilled water at 100% to secondary HVAC equipment
- 4400 Simulations

Whole Building Energy and Thermal Comfort

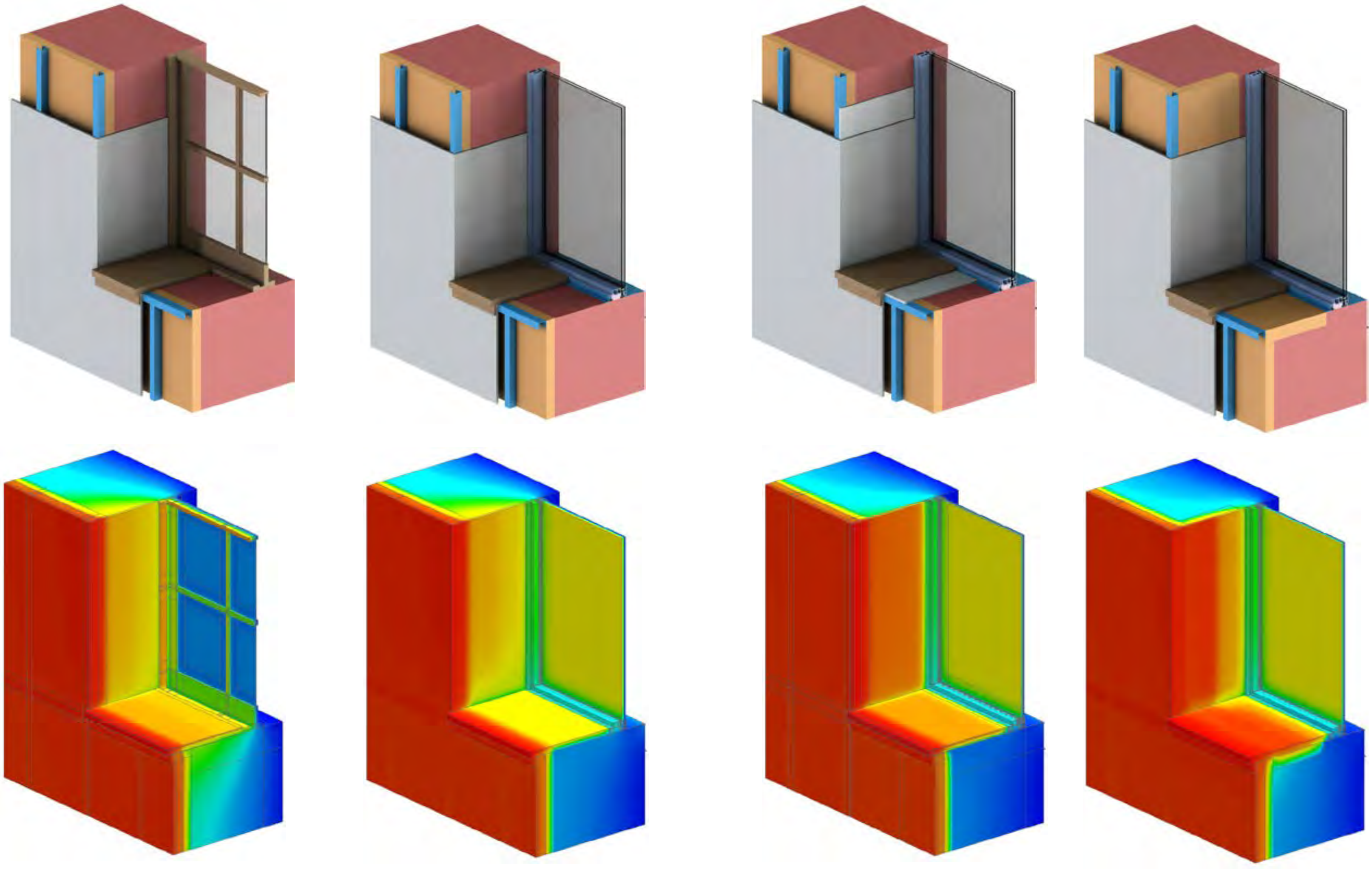
- Occupant thermal comfort was evaluated by Fanger static thermal comfort model



Assumptions

- Sedentary occupants
- Indoor air speed at 0.15 m/s (good HVAC and placement of diffusers)
- Clothing per ASHRAE 55
- Percent people dissatisfied lower than 20%

Realistic Thermal Expectations



Bang for your Buck

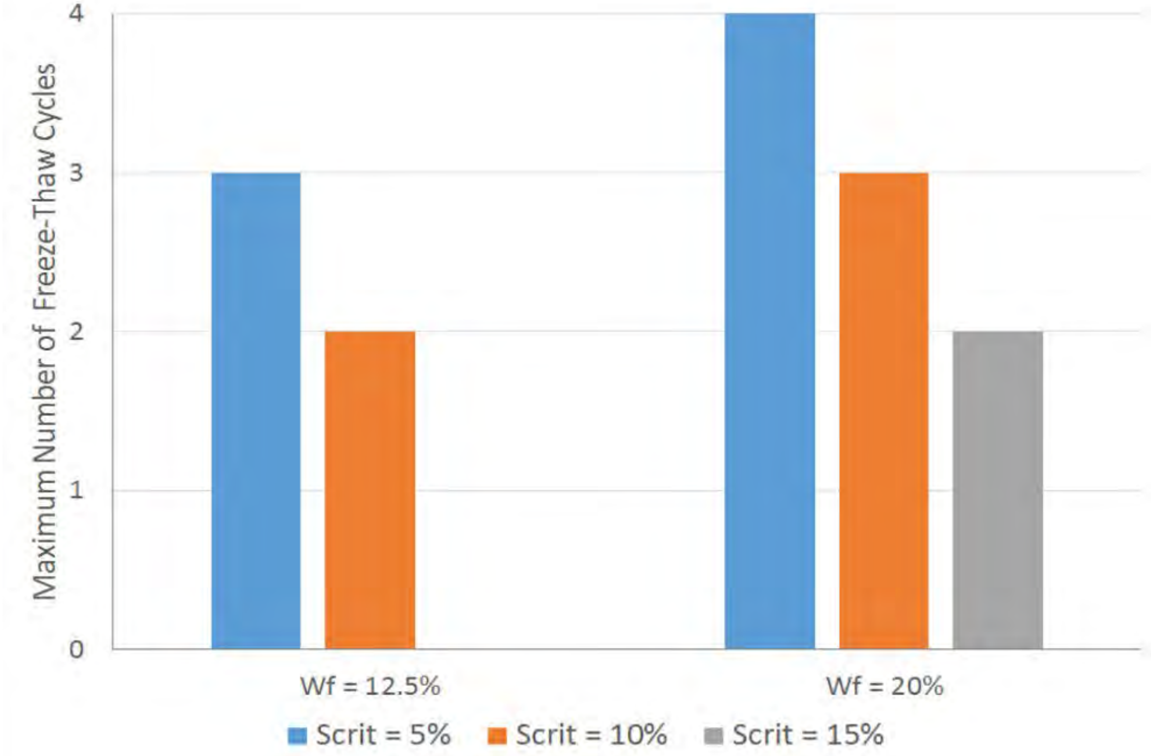
- Multiple ways to decrease energy demand
  - Insulate roof to R-20 for 36% energy savings; only 2% more savings for R-40
  - Insulate walls to “effective” R-10 for 41% energy savings
  - Window U-value had relative lower impact because of the glazing ratio; 8 to 14% savings
- PPD reduced to 200 hours for R-10, double glazing windows, and R-20 roof; which is significantly better Further reductions possible with HVAC controls for night set backs or oversizing

Closing Remarks

- Possible research to support performance based assessments is considerable
  - Better defining freeze-thaw criterion damage functions (rate of cooling, coldest temperature, number of cycles)
  - Better definitions of desorption curves
  - Impact of salts and how to assess in hygrothermal models
  - Loss in compressive strength for successive cycles
- Is increased statiscial analysis and standardization for hygrothermal analysis a goal worth pursuing to help industry make better decisions?

Thank You

Freeze-Thaw Risk



- Freeze-Thaw Cycles at S_{crit} for Un-insulated Wall Assembly with Low Rain Exposure and Critical Freeze-Thaw Temperature of -2^{o}C.