MULTIVARIATE STATISTICAL ANALYSIS ON BLOWER DOOR TESTING POPULATION

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AGENDA

- Introduction
- Background
- Research Questions
- Method
- Results/Discussion

INTRODUCTION

Importance of airtightness:

1. Human Comfort (IAQ, Draughts, Mold Potential)
2. Energy Inefficiency (Latent & Sensible Heat, HVAC Sizing)
3. Building Durability (Concealed Condensation, Deterioration)
4. Meeting Current and Future Building Standards (EnergyStar, R2000, HERS, EnerGuide, LEED for Homes, Net Zero)

BACKGROUND

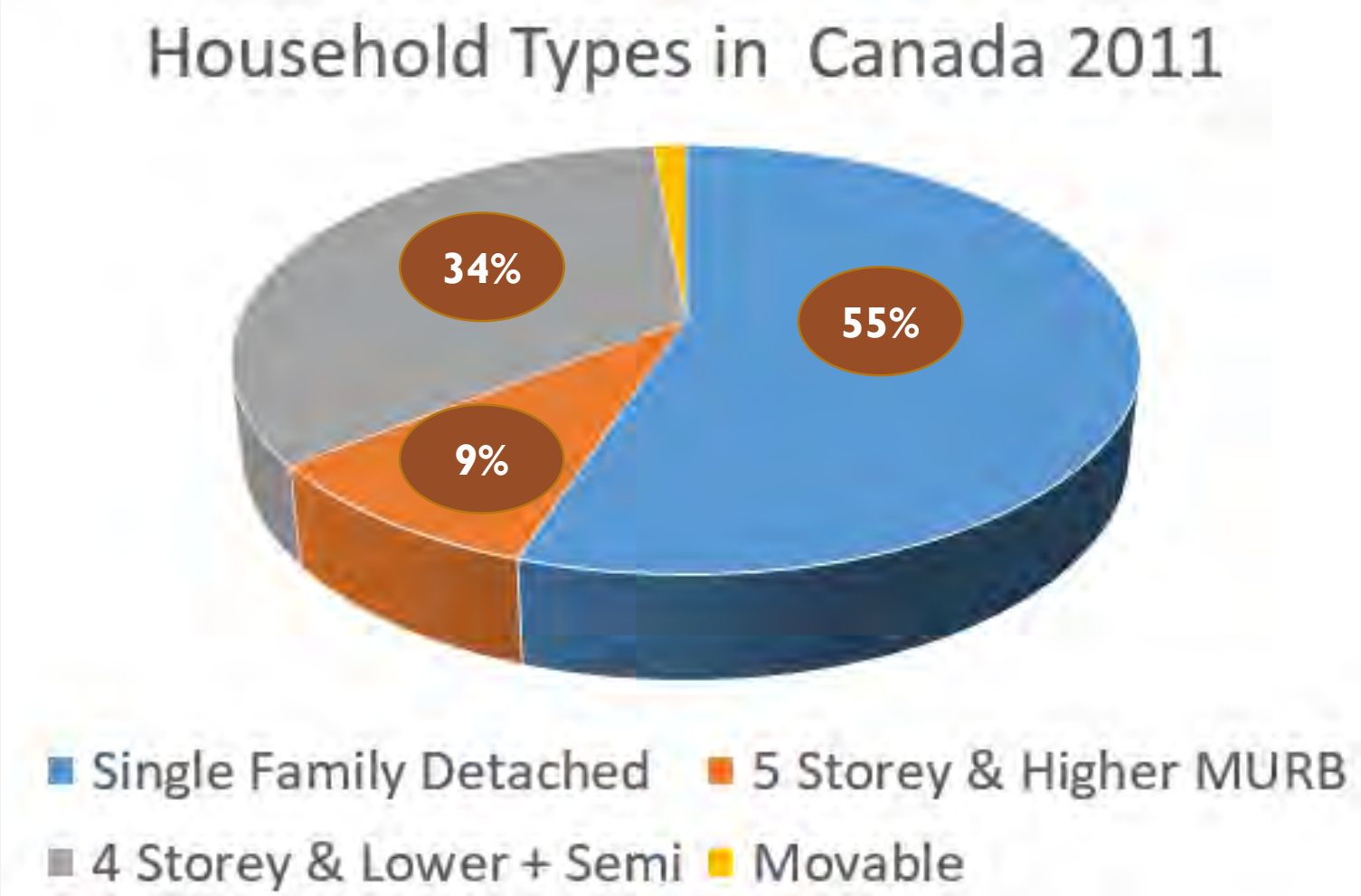


Figure 1: House Hold Types in Canada

DATA ADAPTED FROM: www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/famil55c-eng.htm

BACKGROUND

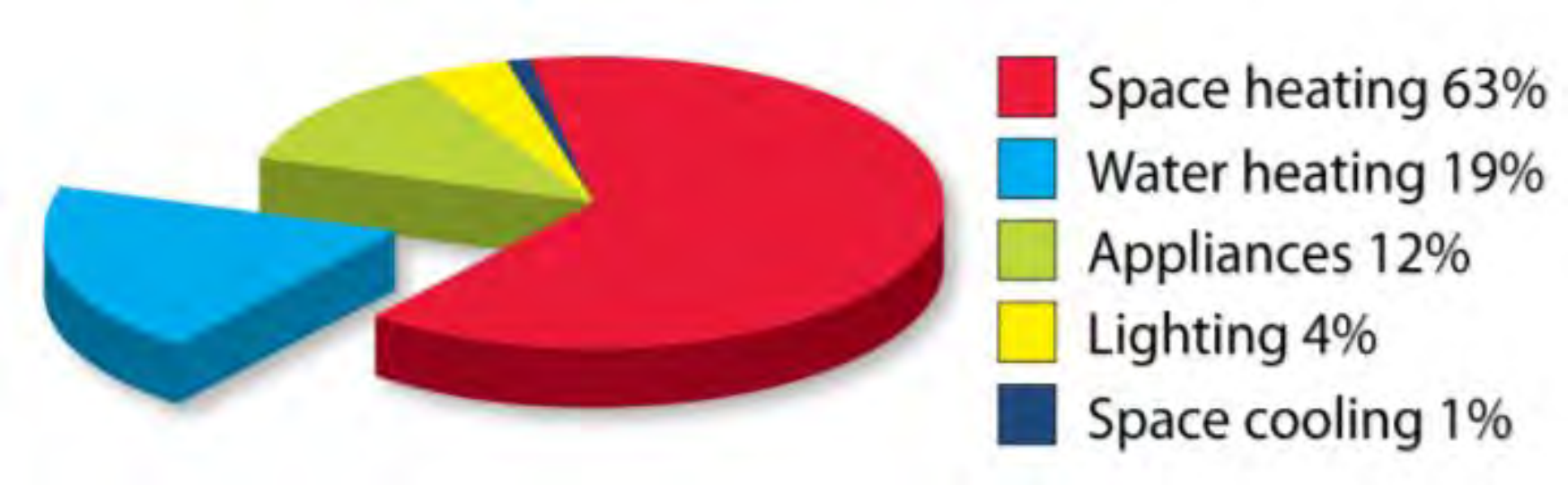


Figure 2: Residential Energy Use in Canada 2013

Image Source: www.nrcan.gc.ca/energy/products/categories/water-heaters/13735

BACKGROUND

Residential Whole Building Air Leakage

- Wall Details (18 to 50%) **35%**
- Ceiling Details (3 to 30%) **18%**
- Forced Air HVAC (3 to 28%)**18%**
- Fenestration (6 to 22%)**15%**
- Fireplaces (0 to 30%)**12%**
- Vents Conditioned Spaces (2 to 12%) **5%**
- Diffusion through walls **<1%**

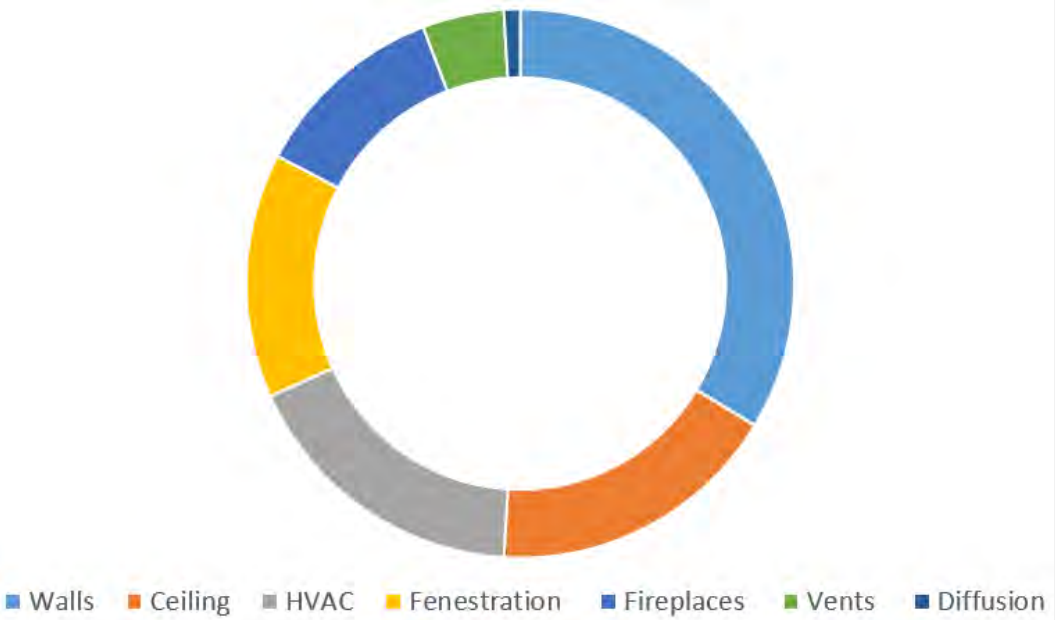


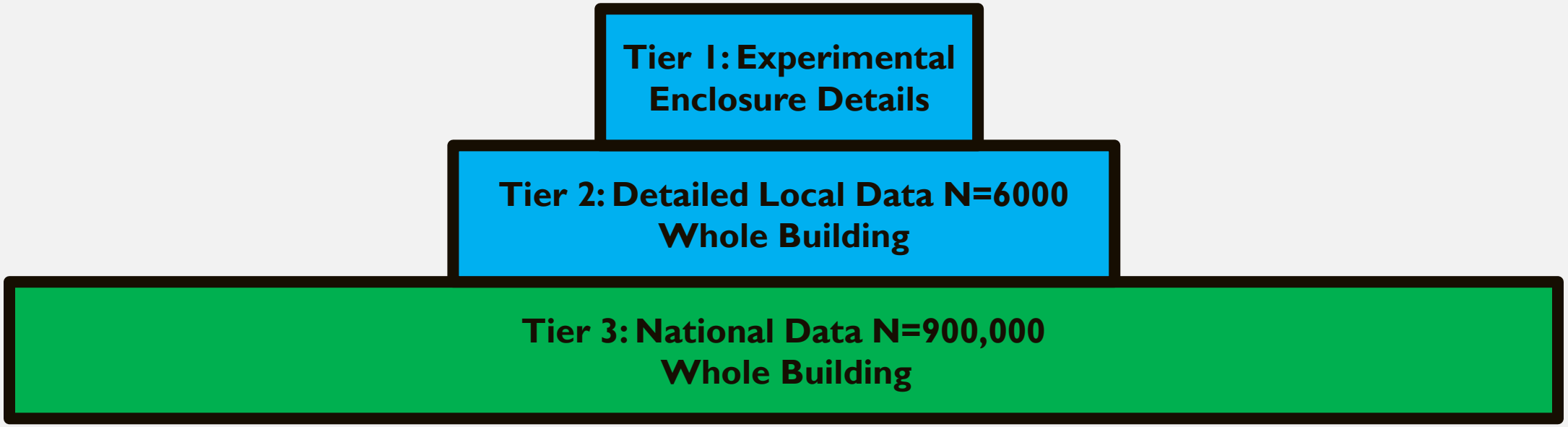
Figure 3: Residential Air Leakage Sources
Adapted from *2009 ASHRAE Handbook: Fundamentals*

RESEARCH QUESTIONS

1. Can a **linear regression model** estimate building airtightness in single family, low rise, residential buildings for a Canadian cold climate?

2. Which of the model variables have the most influence, and the least **influence on airtightness** in single family, low rise, residential Canadian dwellings?

METHOD


Tier 1: Experimental Enclosure Details
Tier 2: Detailed Local Data N=6000 Whole Building
Tier 3: National Data N=900,000 Whole Building

METHOD

Governing Equation: The Power Law

$$Q = C\Delta P^n$$

Multivariate Linear Regression Model

$$Y_i = \beta_{0,i} + \beta_{1,i}X_1 + \beta_{2,i}X_2 + \beta_{3,i}X_3 + \beta_{4,i}X_4 \ldots\ldots \beta_{24,i}X_{24}$$

RESULTS

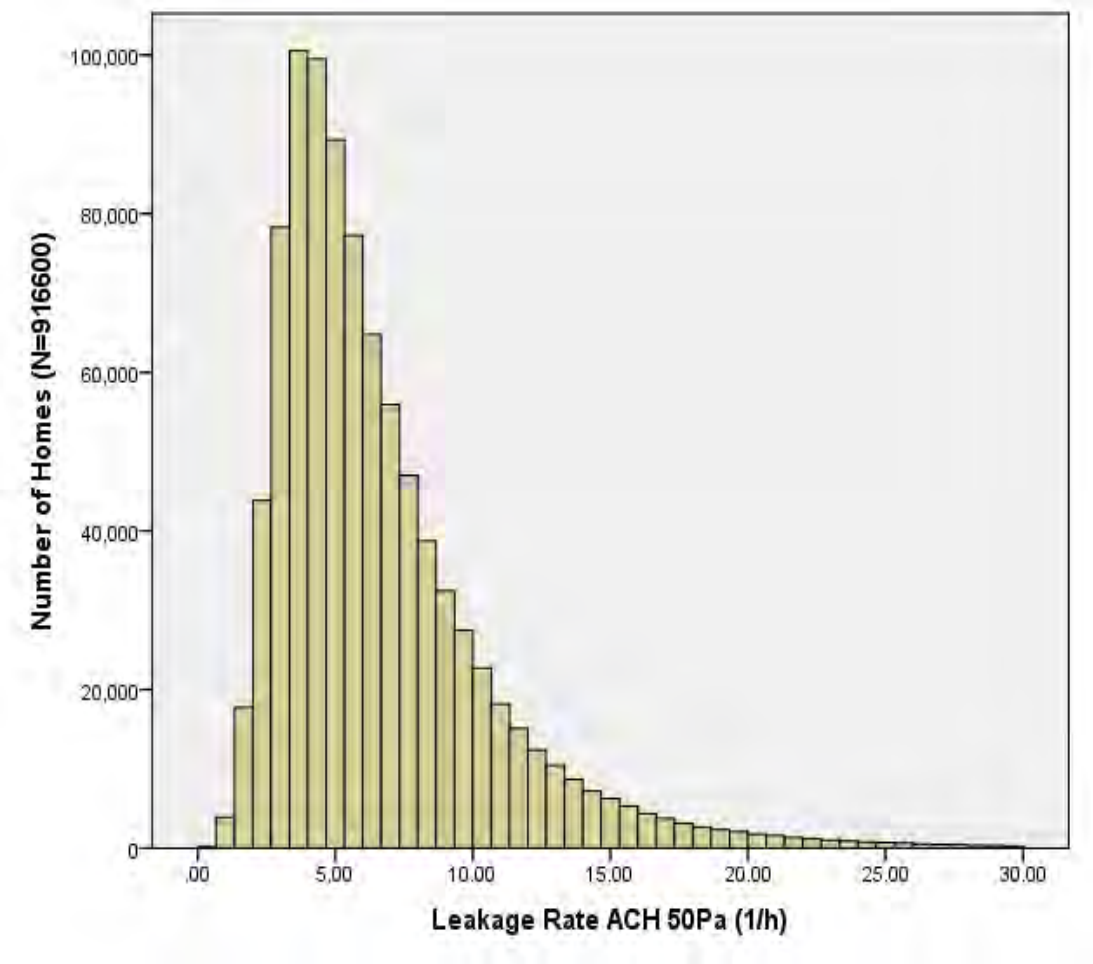


Figure 4: Distribution of Leakage Rate ACH50

	ACH 50		
	A. mean	G. mean	Std. Dev
Alberta	5.6	4.8	3.6
British Columbia	7.9	7.0	4.2
Manitoba	5.2	4.3	3.6
New Brunswick	6.3	5.2	4.4
Nova Scotia	8.5	7.1	5.5
NWT	6.3	5.3	4.1
Nunavut	3.9	3.4	2.3
Ontario	6.8	5.9	4.2
PEI	6.4	6.4	4.2
Quebec	5.9	5.0	3.9
Saskatchewan	5.1	4.4	3.4

Table 1: Mean Leakage per Province ACH50

RESULTS

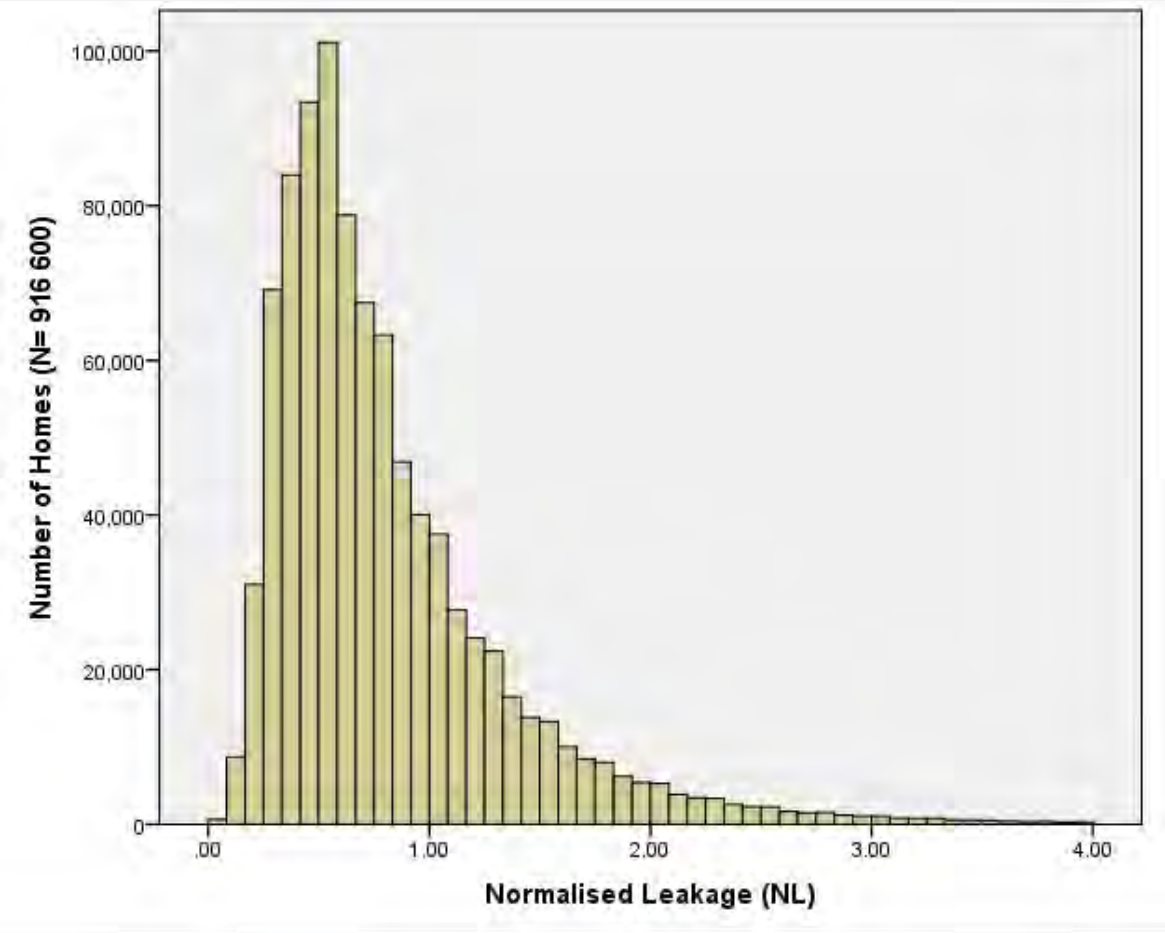


Figure 5: Distribution of Leakage Rate, NL

	Normalised Leakage		
	A. mean	G. mean	Std. Dev
Alberta	0.65	0.54	0.47
British Columbia	0.96	0.83	0.55
Manitoba	0.60	0.48	0.47
New Brunswick	0.75	0.59	0.59
Nova Scotia	1.07	0.85	0.78
NWT	0.75	0.63	0.49
Nunavut	0.46	0.40	0.26
Ontario	0.84	0.71	0.56
PEI	0.80	0.64	0.60
Quebec	0.70	0.57	0.52
Saskatchewan	0.57	0.47	0.44

Table 2: Mean Leakage per Province ACH50

RESULTS

	ACH		Build Year		
ACH Range	G. Mean	Std. Dev	G. Mean	Std. Dev	Number of Houses
0 < ACH < 1	0.8	0.1	1997	16	1071
1 < ACH < 2	1.6	0.3	1991	16	20267
2 < ACH < 4	3.1	0.5	1981	16	220987
4 < ACH < 8	6.0	1.1	1968	23	433123
8 < ACH <16	10.4	2.1	1945	31	204947
16 < ACH < 32	19.9	3.7	1932	34	31289

Table 3: Mean Leakage Compared to Mean Building Year

RESULTS

Regression & Leakage Metric		
	r	R^2
ACH	0.565	0.319
NL	0.592	0.350

Table 4: Comparison of Pearson Correlation and Coefficient of Determination

RESULTS

Regression Analysis				
Range Year Built	**r**	**R^2**	**N**	**p value**
1950 > T	0.375	0.141	174000	0.000
1950 < T < 1970	0.322	0.104	212000	0.000
1970 < T < 1990	0.336	0.113	346000	0.000
1990 < T < 2015	0.351	0.123	108000	0.000
All Years	0.565	0.319	916000	0.000

Table 5: Comparison of Pearson Correlation and Coefficient of Determination Between Years

RESULTS

Regression Analysis				
Province	r	R^2	N	p value
Alberta	0.523	0.274	49000	0.000
British Columbia	0.539	0.291	111000	0.000
Manitoba	0.676	0.457	26000	0.000
New Brunswick	0.592	0.350	45000	0.000
Nova Scotia	0.623	0.388	51000	0.000
North West T.	0.589	0.347	950	0.000
Nunavut	0.658	0.433	70	0.000
Ontario	0.604	0.365	460000	0.000
Prince Edward Island	0.690	0.476	4000	0.000
Quebec	0.540	0.292	114000	0.000
Saskatchewan	0.649	0.421	55000	0.000

Table 6: Linear Regression Model Strength, *r* and R^2 per Province

SUMMARY

- A regression equation predicting pressurised air leakage was constructed based on Canadian homes at the pre-retrofit stage
- Air leakage was examined by building jurisdiction, overall building height, building volume, and build date
- It was found that "Building Year" was the most important predictor variable tied to building air leakage
- Pearson's correlation coefficient, $0.565 < r < 0.592$ ($p < 0.000$), showed a moderate relationship between air leakage and the selected predictor variables
- The coefficient of determination was found that predictor variables can explain between 35-32% of the air leakage ($0.350 > R^2 > 0.319$)

FUTURE WORK

- Consider climate zone in the form of Heating Degree Days as a fourth predictor variable
- Consider number of builders per jurisdiction in the form of Builders/100,000 or Builders per SFH population
- Non-linear regression models to add explanatory power to the air leakage model

ACKNOWLEDGMENTS

- **Lio & Associates** (Toronto, ON)
- **Office of Energy Efficiency - Natural Resources Canada** (Ottawa, ON)

CITATIONS

1. *2009 Ashrae Handbook: Fundamentals*. Atlanta, GA: American Society of Heating, Refrigeration and Air-Conditioning Engineers, 2009
2. Statistic Canada, **"Summary Table: Private households by structural type of dwelling, by province and territory (2011 Census) (Manitoba, Saskatchewan, Alberta, British Columbia)" Weblink:** www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/famil55c-eng.htm
3. **Natural Resources Canada, "Residential energy use in Canada by activity" Weblink: www.nrcan.gc.ca/energy/products/categories/water-heaters/13735**