# Characterizing and Structuring Urban Data for Housing Stock Energy Modeling

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**The master thesis defence**

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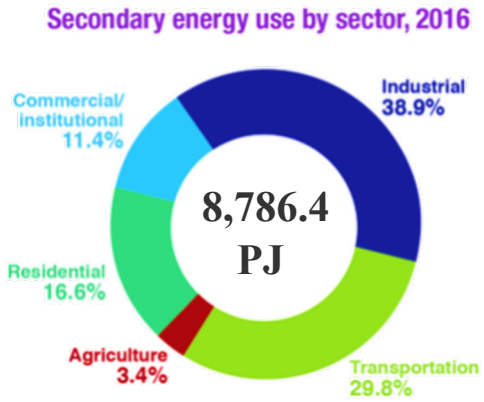
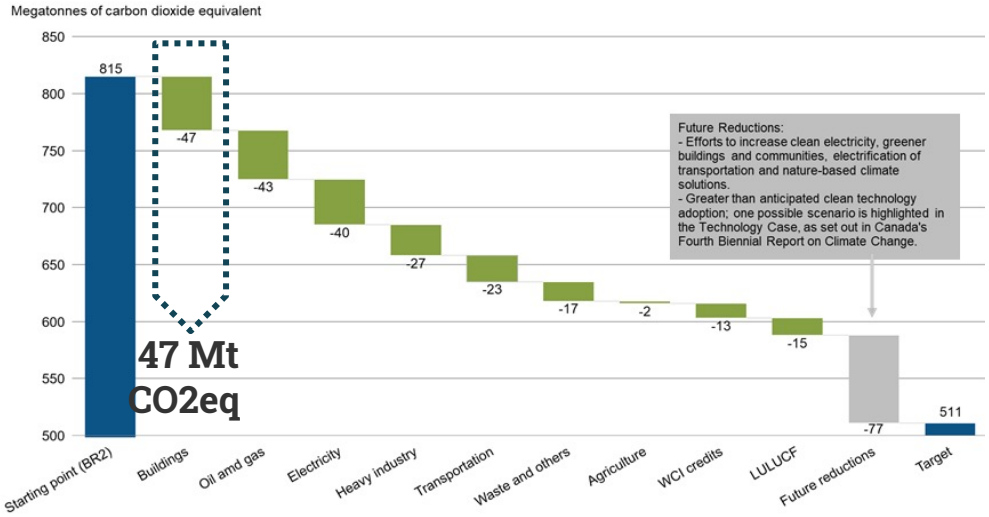
# Introduction

- **Canada priorities to reduce CO2eq (near zero by 2050) [1]**
  - Clean electricity
  - Greener buildings and communities
  - Context/nature-based climate solutions




**Building Section**




**Contribution of different sectors in projected Mt CO2 eq reduction in 2030 relative to 2015 [2]**

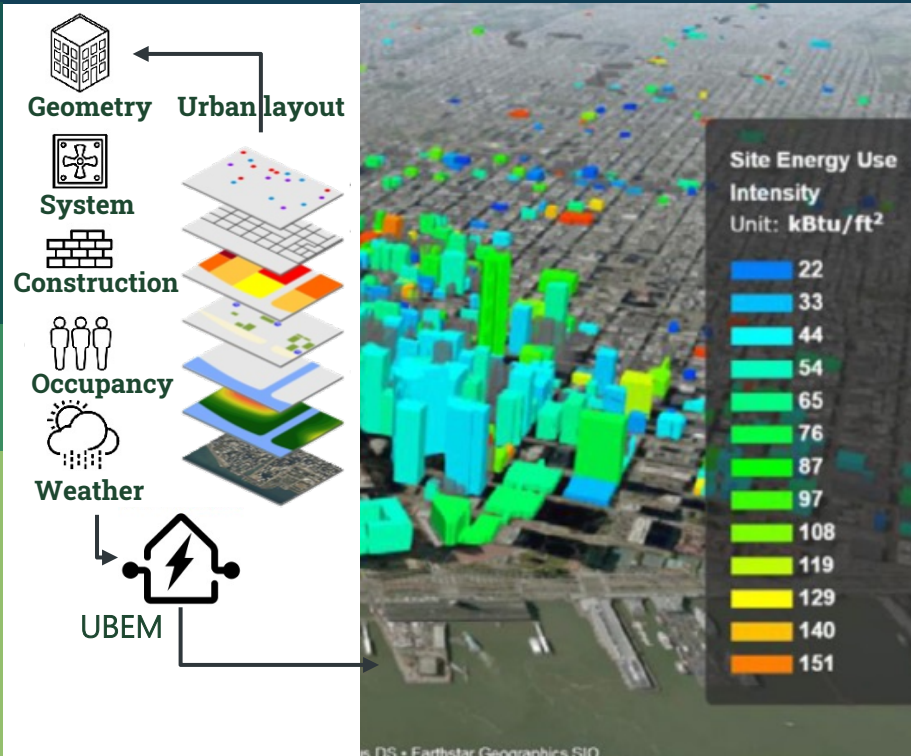
# Introduction

Building-stock energy mapping allows a deep understanding of building energy performance versus social, economic, physical, and environmental characteristics of cities and supports opportunities to enhance energy and environmental policies.

- Canadian Energy End-use Mapping (CEEMap) Project

Identify a harmonized data incorporation, characterization, and energy performance evaluation process, for a consistent online-authorized platform to support stakeholder groups and energy retrofit planning [3].

# Problem statement




- Urban building energy modeling (UBEM) requires multiple datasets
- There is a gap between available data and required parameters for energy performance modeling
- No harmonized urban datasets available to model status quo and future low carbon building retrofits

# Literature review

| Author | City/ Country | scale | Methodology | UBEM/visualization Platform | Energy Metered dataset | Urban dataset | Archetype |
|---|---|---|---|---|---|---|---|
| **Chen et al. 2019 [4]** | San Francisco | City | **Modeling Mapping** | No/GIS | Yes | **Footprint, Land Use, Accessory** | **The U.S. reference building archetype** |
| **Ali et al. 2018 [5]** | Ireland/ Dublin | City | **Modeling Simulation Mapping** | GIS/GIS | Yes | **GIS dataset, Census surveys data** | **TABULA library/ Customized model** |
| **Delmastro et al. 2017 [6]** | Italy | City | **Simulation Mapping** | GIS/GIS | Yes | **Census survey, Footprint outline** | **TABULA library** |
| **Davila et al. 2016 [7]** | The U.S./ Boston | District | **Modeling Simulation** | Rhinoceros/No | No | **Tax Parcels, footprint, Tax Record Lite and Full** | **The U.S. reference building archetype Customized model** |

# Literature and research gap

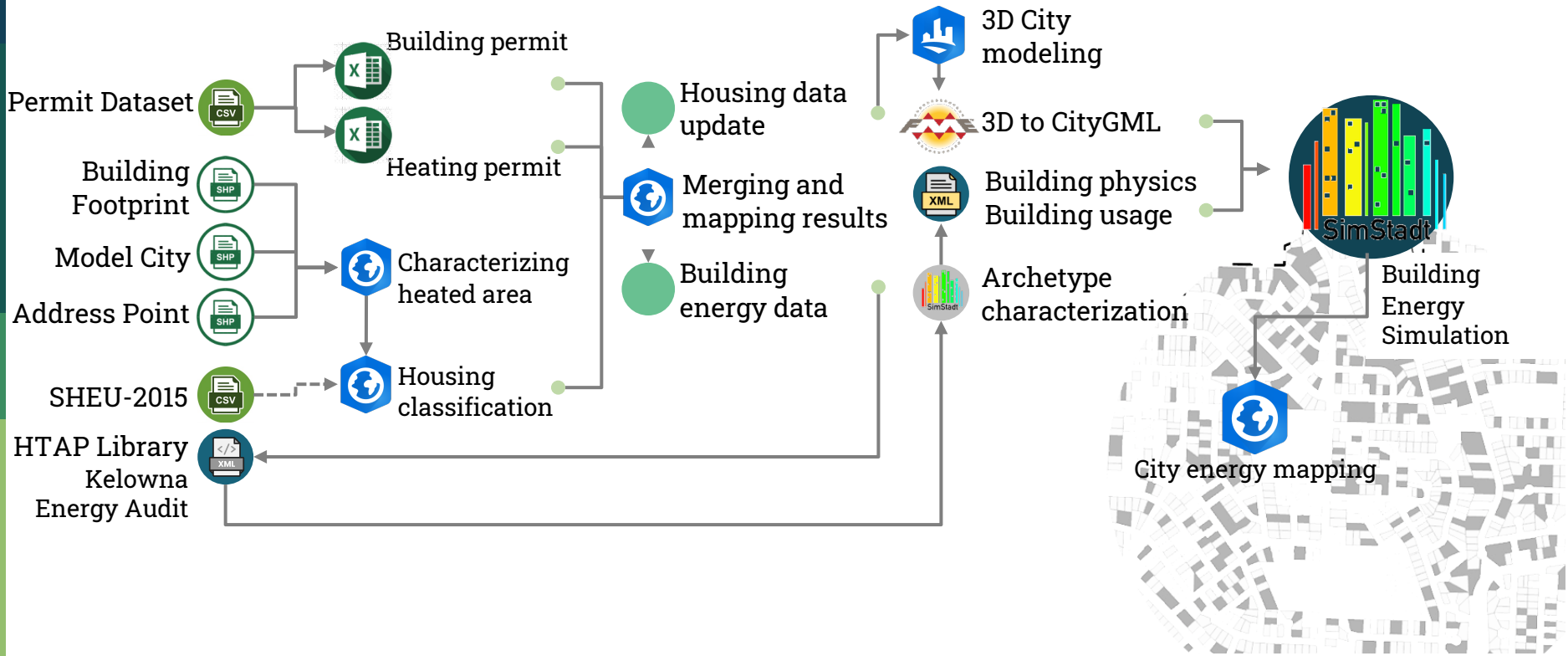
- No harmonized methodology for urban data preparation for urban building energy modeling
- Little use of supplementary datasets (such as building permits) to enrich the urban building dataset and aid decision making
- Lack of a methodology for actively maintaining a GIS dataset usable for energy mapping

# Objectives

- Assess the urban datasets challenges for data extraction regarding the urban building energy model (UBEM) requirements
- Present an urban data-based methodology to develop the building datasets for a data-driven UBEM application
- Map urban building energy demand and future scenarios for a case study neighborhood

# Methodology

Data description | Data processing | Data consolidation | Data modeling | Simulation and mapping

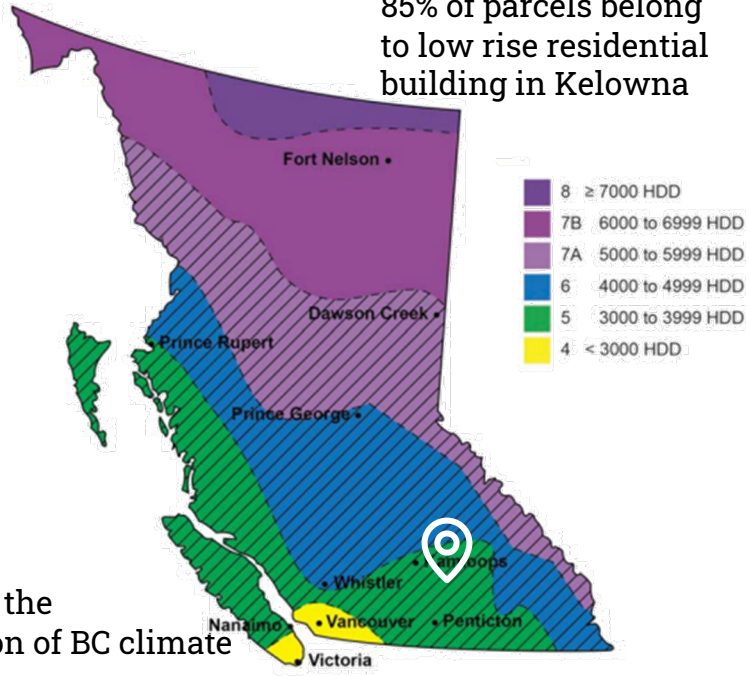


# Case Study

City of Kelowna

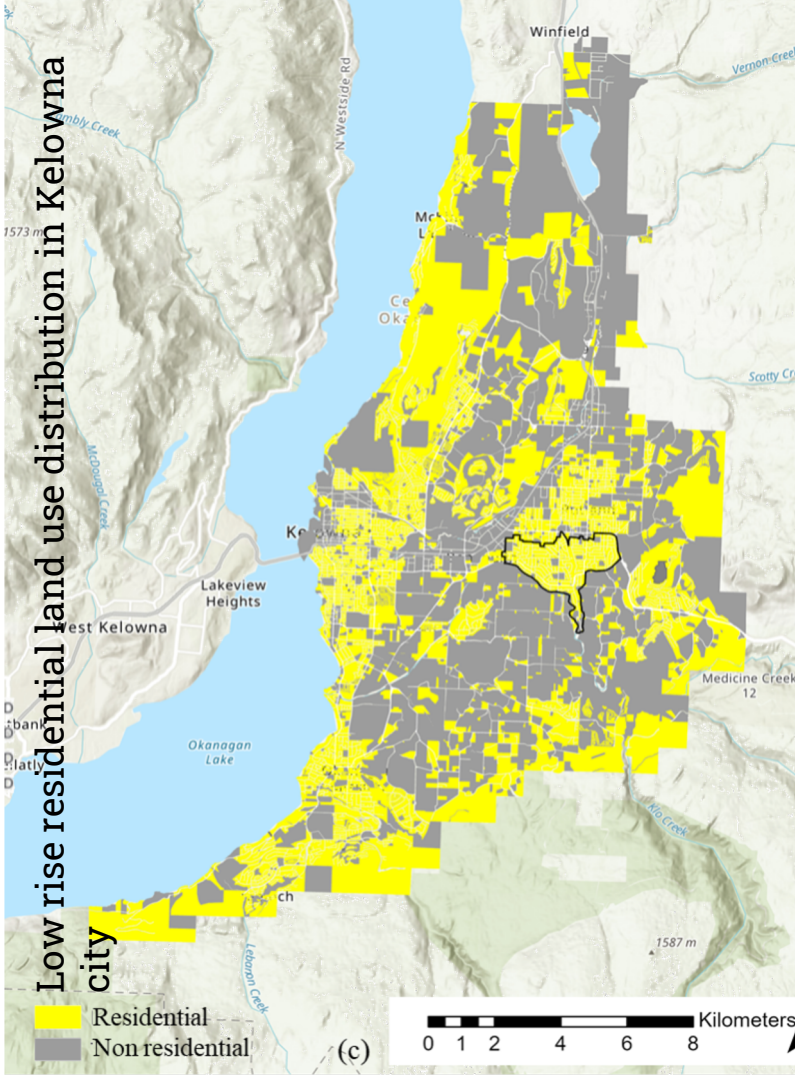
# Case study

85% of parcels belong to low rise residential building in Kelowna

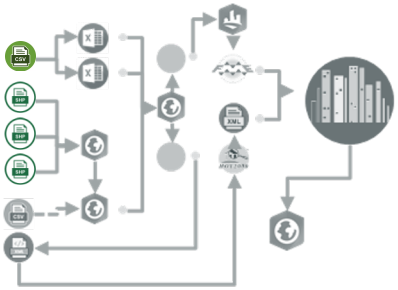



Kelowna in the classification of BC climate zone

Low rise residential land use distribution in Kelowna city



# Data potentials and challenges



## Model City


Critical building information (floor area, story number, construction year)

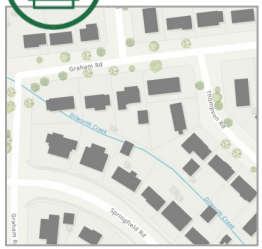
Aggregated values for floor area

Missing values

Aggregated dataset

No coding for dwellings

## Footprint

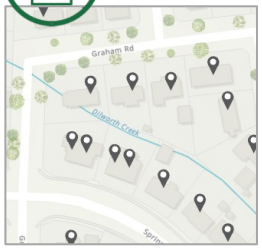



Approximate boundary of buildings

No clarification between accessory structure and living area

Error in measured footprint and building height

## Address Point




Determination of living area

Human error in point placing

## Building Permit

| al Abbreviation | NlmID |
|---|---|
| AIDS Behav | 9712133 |
| AIDS Care | 8915313 |
| AIDS Educ Prev | 9002873 |
| AIDS Patient Care STDS | 9607225 |
| AJNR Am J Neuroradiol | 8003708 |
| ASAIO J | 9204109 |
| Acad Emerg Med | 9418450 |
| Acad Radiol | 9440159 |
| Accid Anal Prev | 1254476 |
| Acta Chir Iugosl | 0372631 |
| Acta Clin Croat | 9423483 |
| Acta Diabetol | 9200299 |
| Acta Med Croatica | 9208249 |
| Acta Med Iran | 14540950R |
| Acta Neurochir (Wien) | 0151000 |
| Acta Neurol Scand | 0370336 |
| Acta Odontol Scand | 0370344 |
| Acta Psychol (Amst) | 0370366 |
| Acta Trop | 0370374 |
| Adv Ther | 8611864 |
| Ageing Res Rev | 101128963 |
| Aging Clin Exp Res | 101132995 |
| Aliment Pharmacol Ther | 8707234 |
| Am J Addict | 9208821 |
| Am J Sports Med | 7609541 |

Critical building information (floor area, story number, construction year)

Aggregated values for floor area

Missing values

Aggregated dataset

No coding for dwellings

25 history of registered building and heating permit

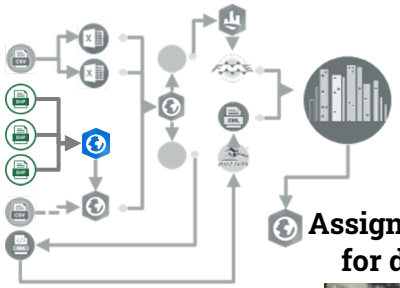
Covering construction and heating system retrofit

No standard for data classification

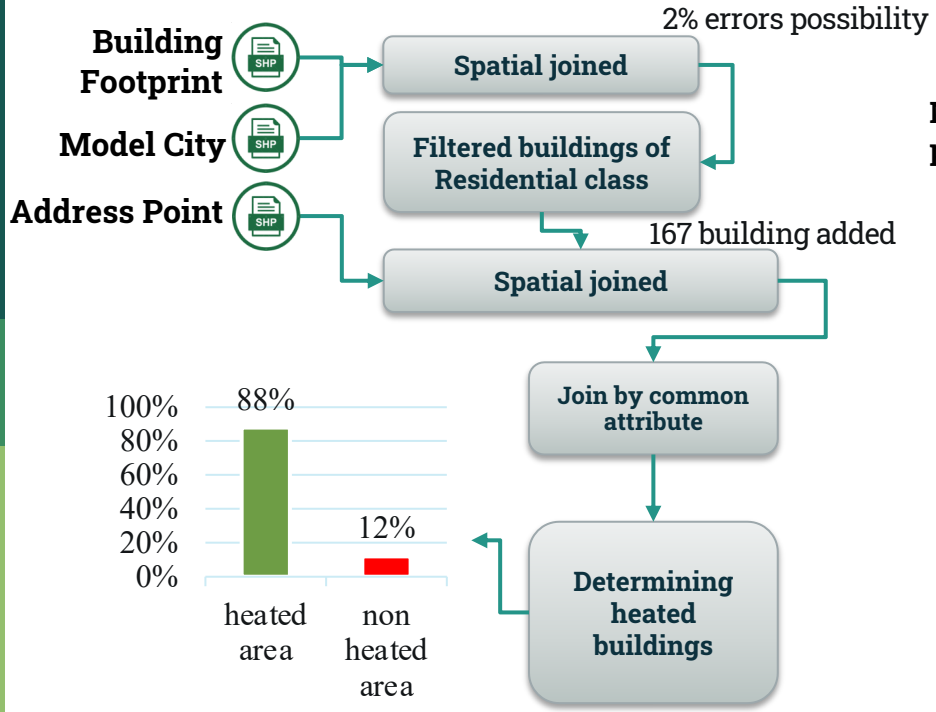
No supporting documents for abbreviation

Large number of missing values and word description

# Data processing
## Characterizing heated area

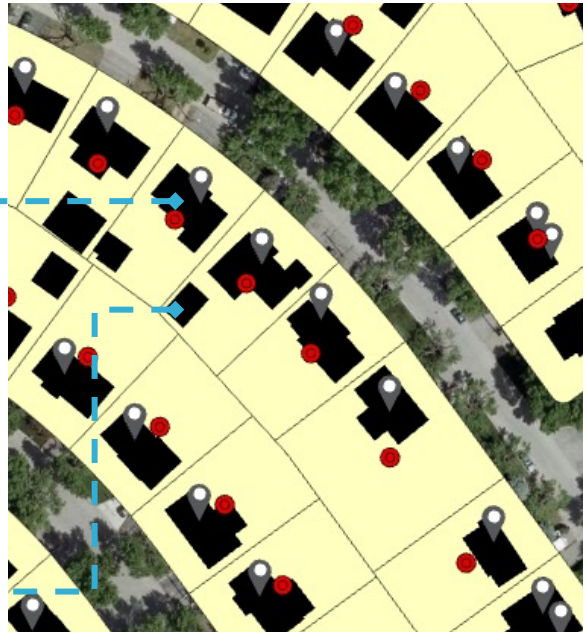


Assigning building information to footprint for developing master building dataset




Main building of the parcel (heated area)

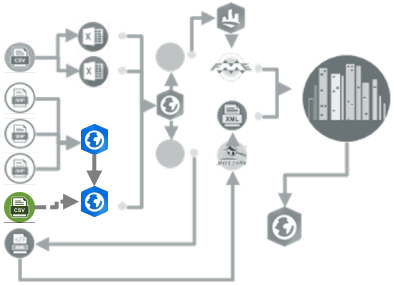
Accessory building of the parcel (non heated area)



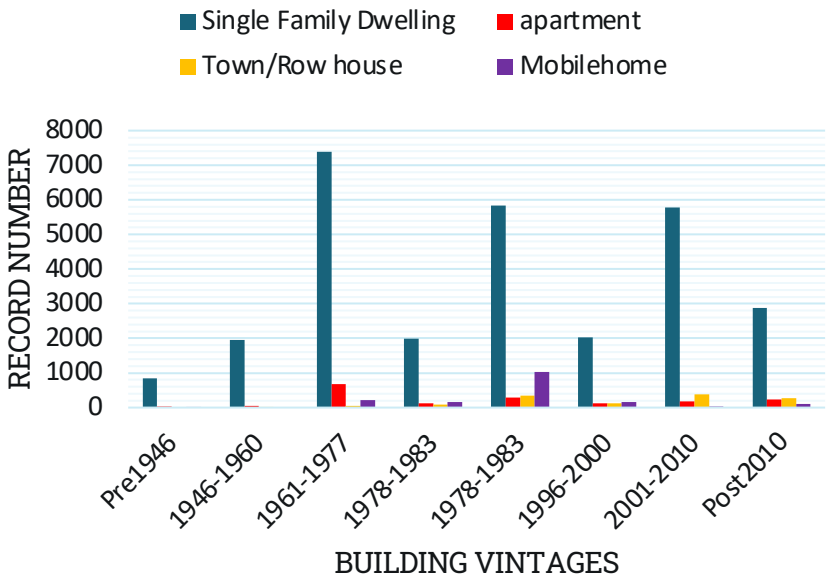
Building footprint
Address Point
Lot (Parcel)
Applied for Permit

# Data processing

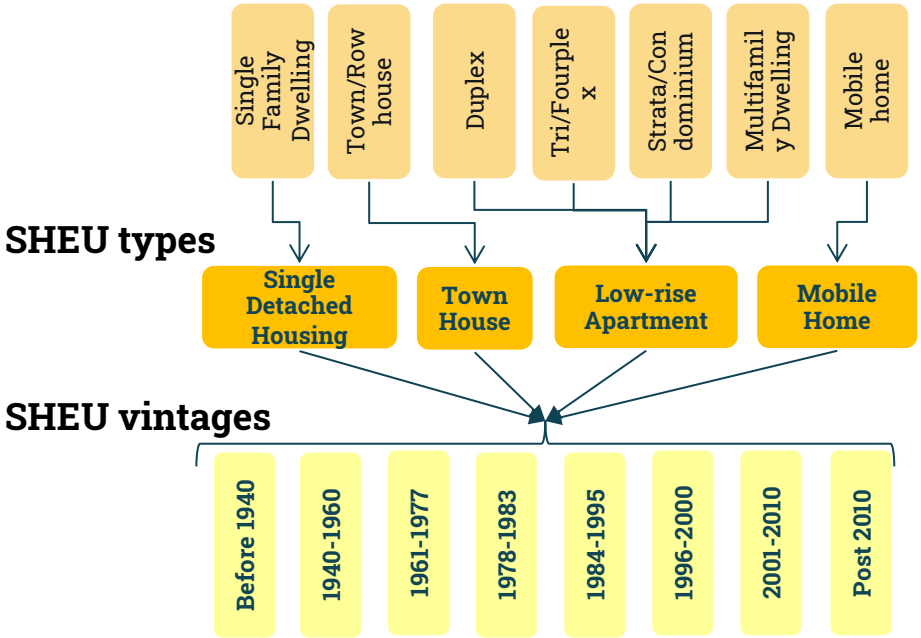
## Housing classification and archetype development



**Distribution of housing types per principle Canadian housing vintage**

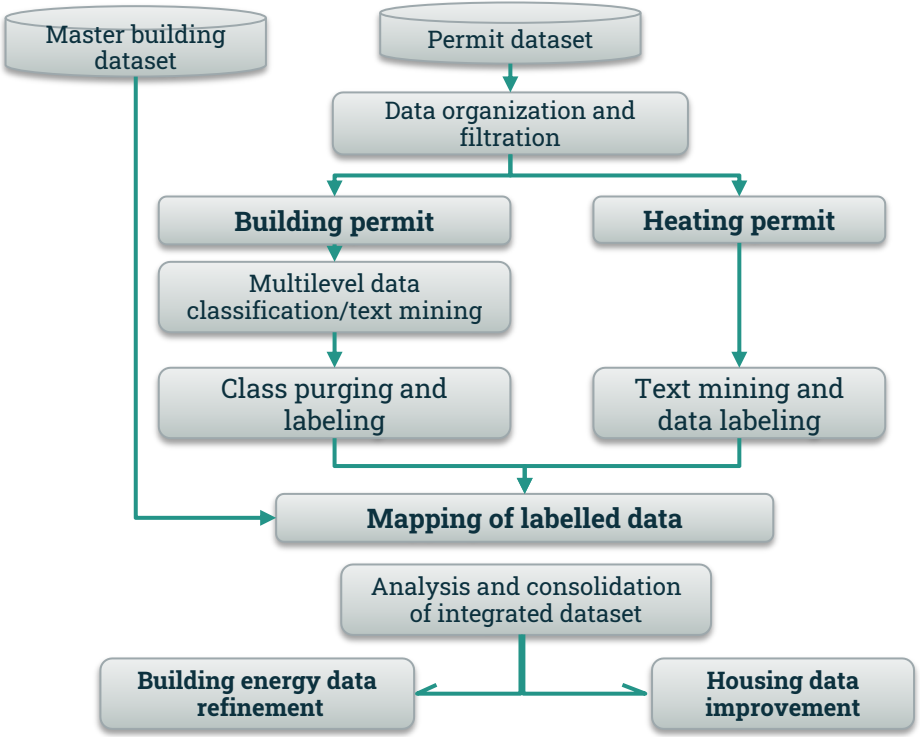


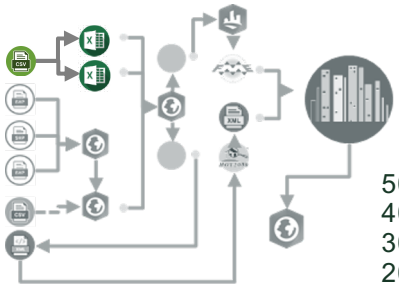

**Reclassifying the building types based on the SHEU-2015 dataset**



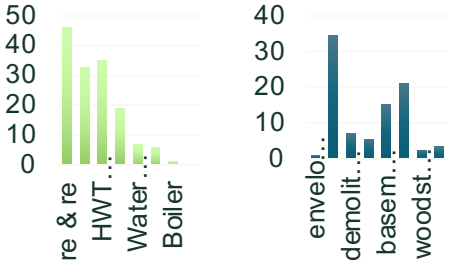
# Data processing

## Permit data analysis

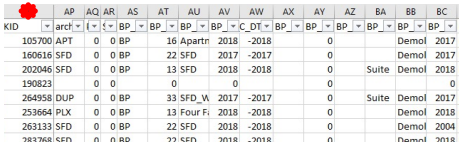


**Data mining output**




**Harmonized dataset with clarified terminology**



| KID | AP | AQ | AR | AS | AT | AU | AV | AW | AX | AY | AZ | BA | BB | BC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 105700 | APT | 0 | 0 | BP | 16 | Apartn | 2018 | -2018 | | 0 | | | Demol | 2017 |
| 160616 | SFD | 0 | 0 | BP | 22 | SFD | 2017 | -2017 | | 0 | | | Demol | 2017 |
| 202046 | SFD | 0 | 0 | BP | 13 | SFD | 2018 | -2018 | | 0 | | Suite | Demol | 2018 |
| 190823 | | 0 | 0 | | 0 | | 0 | | | 0 | | | | 0 |
| 264958 | DUP | 0 | 0 | BP | 33 | SFD_W | 2017 | -2017 | | 0 | | Suite | Demol | 2017 |
| 253664 | PLX | 0 | 0 | BP | 13 | Four Fa | 2018 | -2018 | | 0 | | | Demol | 2018 |
| 263133 | SFD | 0 | 0 | BP | 22 | SFD | 2018 | -2018 | | 0 | | | Demol | 2004 |

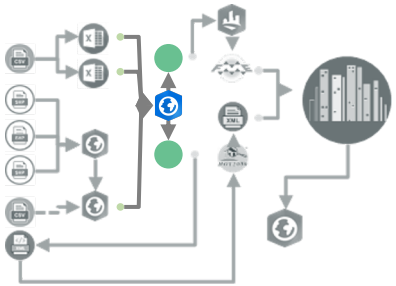
**Mapping identified attribute with building info.**

**Navigating results to improve building dataset**

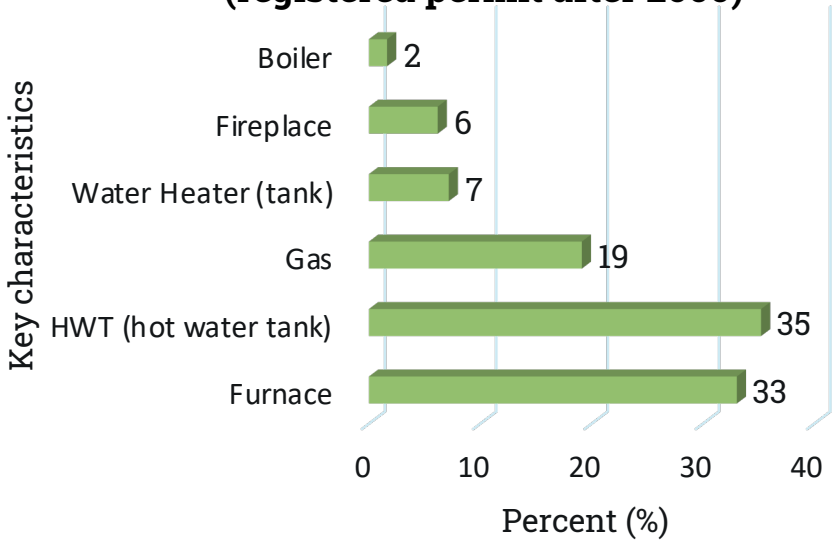
- Occupant density
- Heating system type

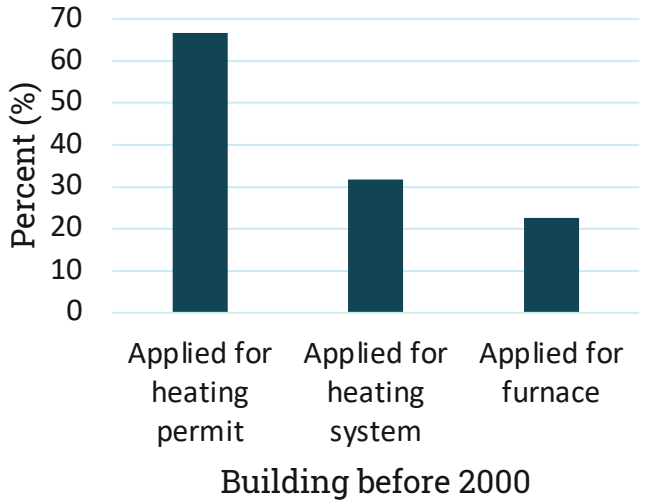
# Data consolidation

## Mapping building permit analysis to building dataset



**The ratio of identified characteristics records to the total candidate records (registered permit after 2000)**

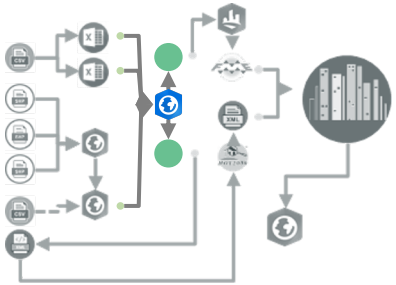


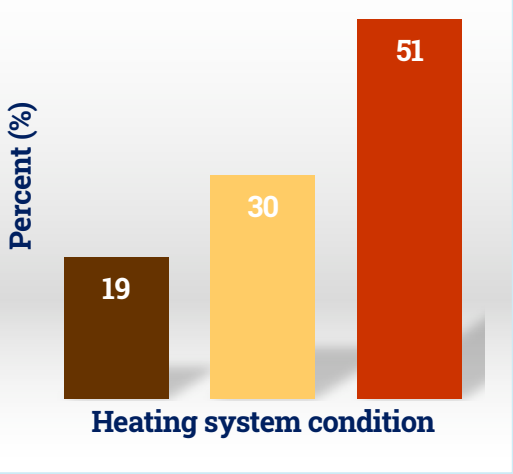

**(%) of buildings constructed before 2000 and applied for heating permit**

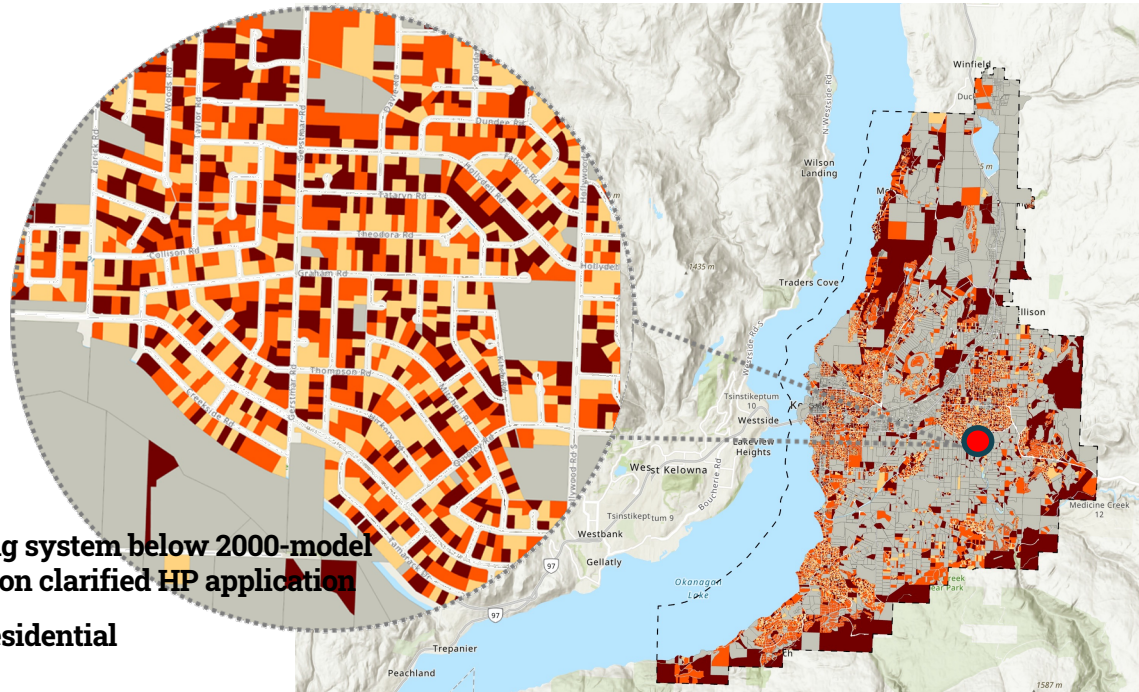
# Data consolidation

## Mapping heating permit analysis to building dataset



### The distribution of dwellings based on their heating system condition

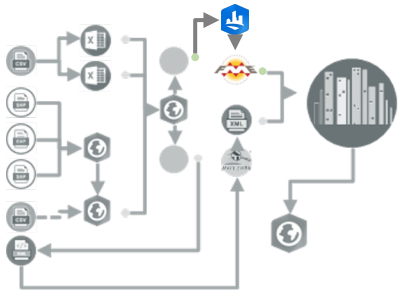


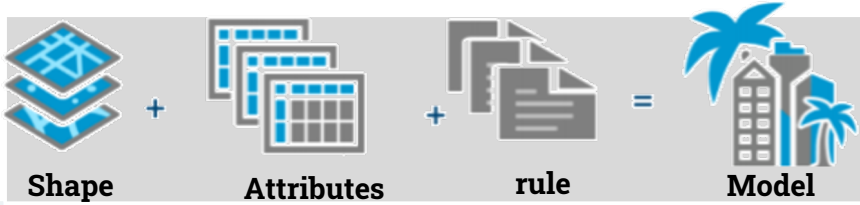




- Heating system below 2000-model without HP application
- Heating system below 2000-model with non clarified HP application
- dwellings with heating system post-2000 model
- Non residential

# Data modeling

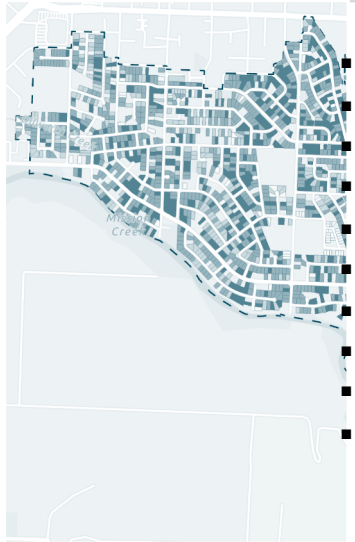
## 3D model generation






CityEngine

GBD



- Building_ID (string)
- Building_function (string)
- Construction year (int)
- Story_number (int)
- Floor_area (float)
- Footprint_area (float)
- Building_height (float)
- Roof_type (string)
- Eave_height (float)
- Roof_rise (float)

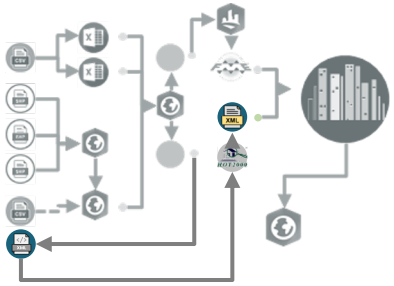
ArcGISPro

SHP Multipatch

FME

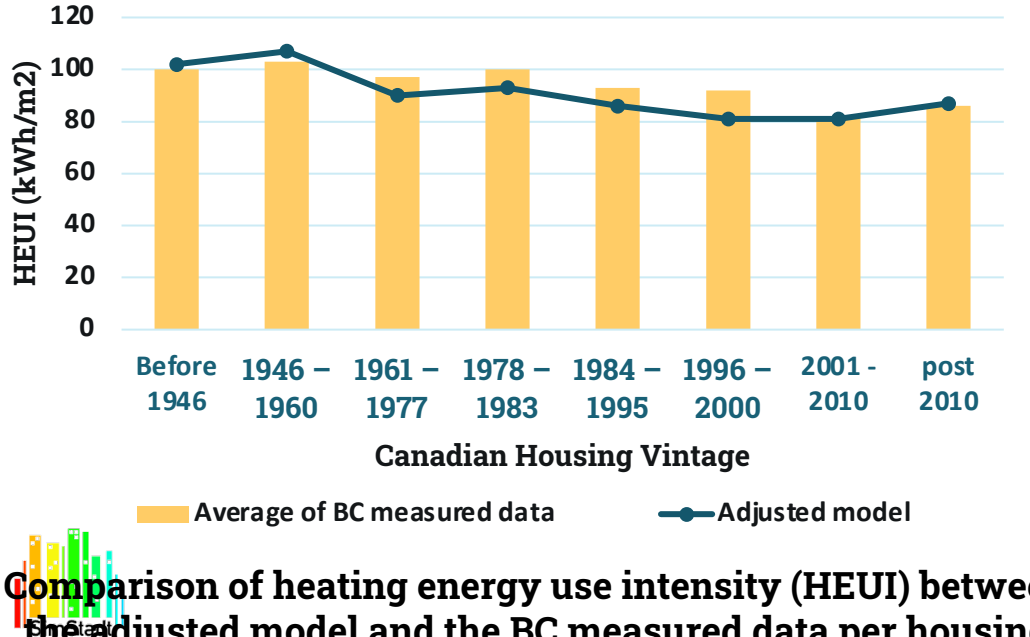
CityGML

# Data modeling
## Archetype characterization



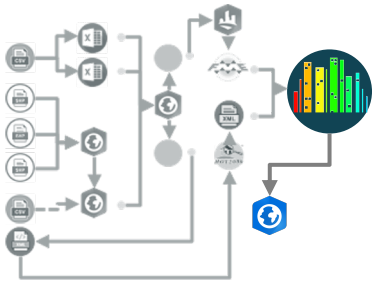
**Data sources used for extracting the building energy data**

- HOT2000 dataset
- Kelowna Energy Audit
- ecobee data analysis on Kelowna housing




**Comparison of heating energy use intensity (HEUI) between the adjusted model and the BC measured data per housing vintage**

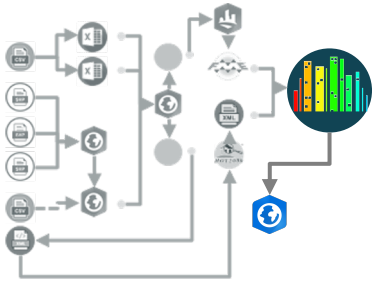
# Simulation and energy mapping

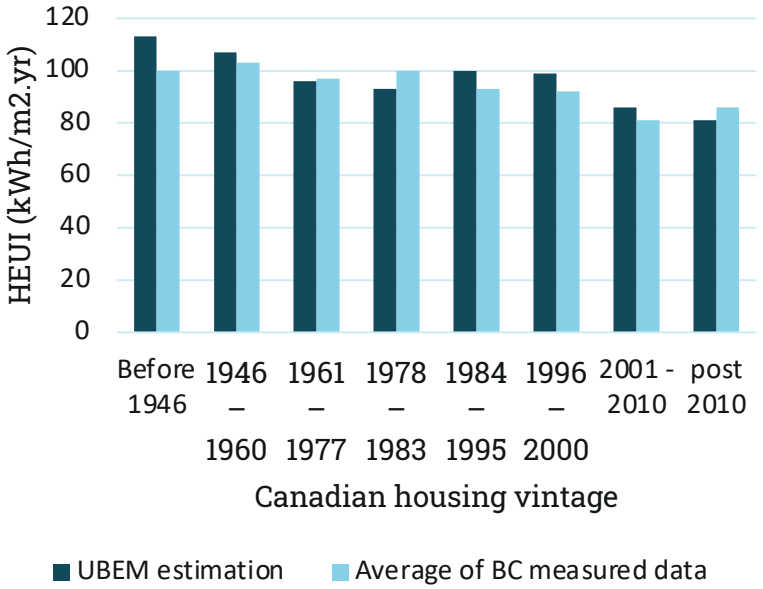


| Data acquisition | Data pre-processing | Model definition | Simulation |
|---|---|---|---|
| CityGML(LOD2) | Define thermal zone, process geometrical feature, analyze segmentation data for assigning building physics | INSEL file; mapping geometry to relevant physics and usage to model thermal characteristics of buildings individually | Thermal energy demand calculation |
| Building Physics | | | |
| Building Usage | Internal load for monthly time series based on building use type | | |
| Weather data | Ambient temperature, Sky temperature Global and diffuse radiation | | |

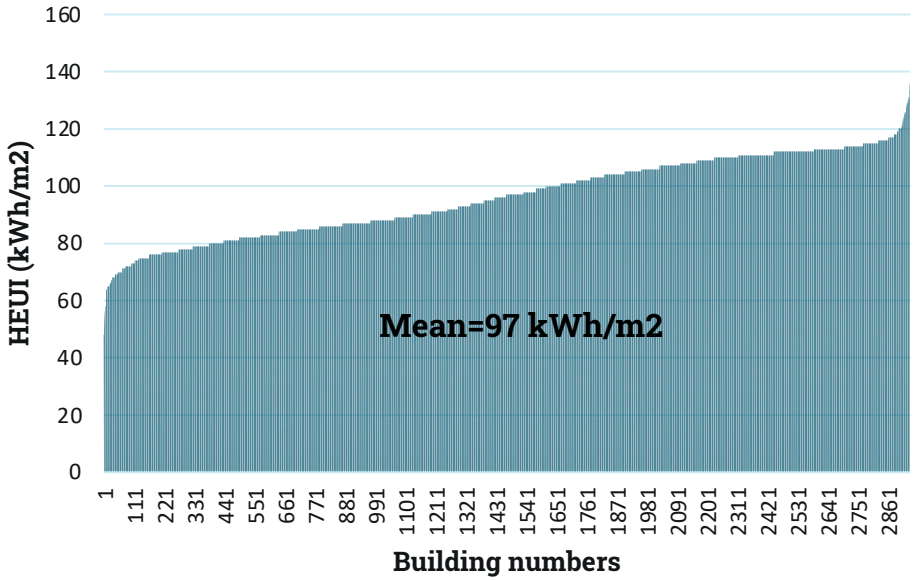
**German standard DIN V 18599-2 for monthly balance calculation (ISO3790)**

# Simulation and energy mapping



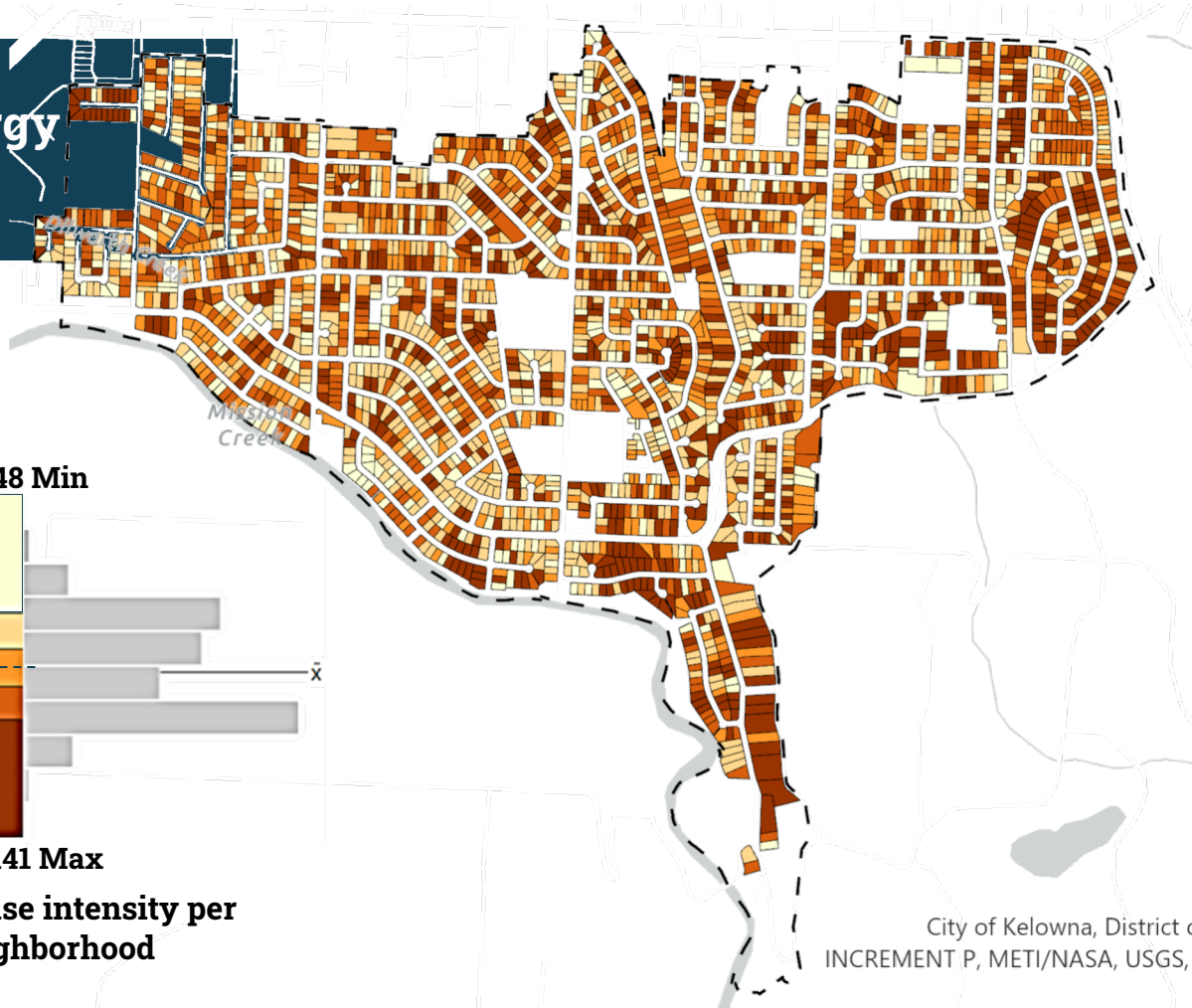



**Comparison of average HEUI of the estimated dwellings and the BC measured data per housing vintage**




**Distribution of the heating energy use intensity (HEUI) per individual buildings**

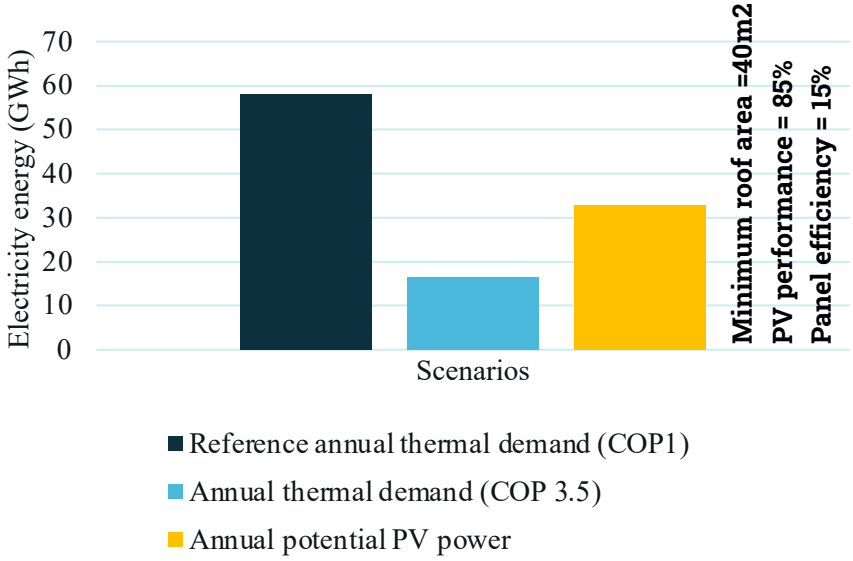
# Simulation and energy mapping

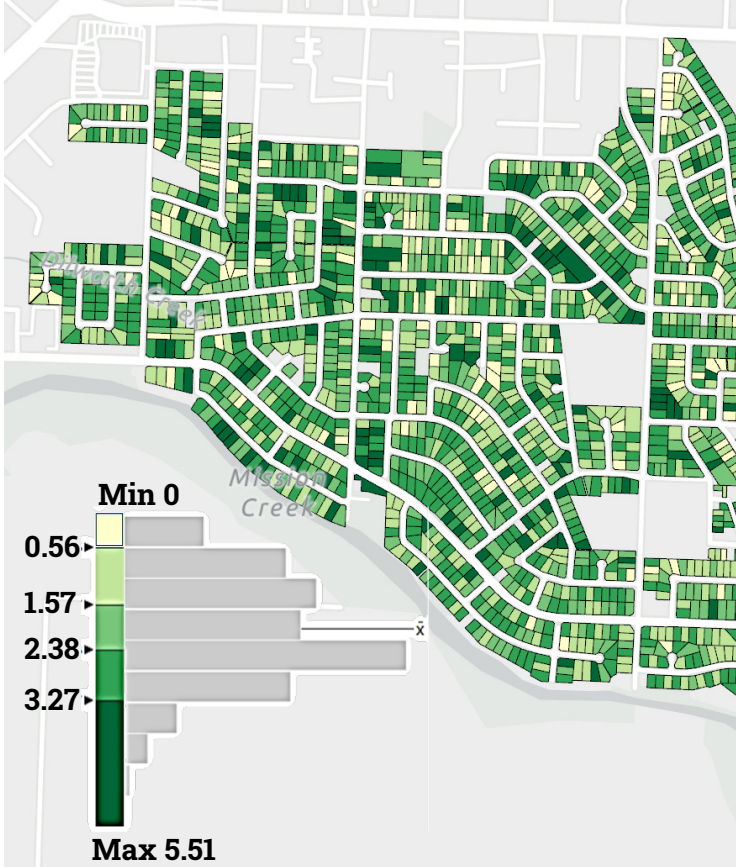



**The distribution of heating energy use intensity per individual buildings in the neighborhood**

# Comparing electricity need for heating and solar potential

**Annual thermal load for heat pump systems with COP 3.5 vs. reference demand and potential PV power from rooftops**




**The fraction of potential PV power to the total heating demand generated with heat pump with (COP 3.5) for individual buildings in the neighborhood**

# Conclusion

# Conclusion

- The provided multiscale workflow successfully resolved urban datasets' challenges and filled in the recognized inconsistencies of datasets, and generated an urban building energy model based on actively maintainable GIS datasets.

- Improve the compatibility between different urban datasets using a georeferenced building identifier

- Providing access to the local utility bills and broader energy audits to fill in the simulated and real consumption gaps in the archetype development and UBEM performance evaluation in terms of more effective bottom-up retrofit planning.

# Contribution

## Under preparation papers

- **HosseiniHaghighi SeyedehRabeeh, Panchabikesan Karthik, Dabirian Sanam, Webster Jessica, Ouf Mohammed, Eicker Ursula, 2021, Discovering, Processing and Consolidating of Building Stock and Smart Thermostat Data in Support of Energy End-use Mapping and Housing,**

- **HosseiniHaghighi SeyedehRabeeh, Padsala Rushikesh, Monsalvet Pilar, Eicker Ursula, 2021, "Characterizing and Structuring Urban Data for Housing Stock Energy Modeling"**


- Developing interactive energy mapping, aiding retrofit planning and decision making
- Developing retrofit scenarios based on local renewable energy sources
- Improving building geometry model using LiDAR or high accurate 3D-GIS data sources
- Developing archetype model with variety of occupant and energy system profiles

# Future work

# Reference


[1] “Energy Use in Canada: Trends Publications | Natural Resources Canada.” [Online]. Available: https://oee.nrcan.gc.ca/publications/statistics/trends/2016/totalsectors.cfm. [Accessed: 19-Dec-2020].

[2] “Progress towards Canada’s greenhouse gas emissions reduction target - Canada.ca.” [Online]. Available: https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/progress-towards-canada-greenhouse-gas-emissions-reduction-target.html. [Accessed: 19-Dec-2020].

[3] “Building Energy Mapping and Analytics CDS | OGC.” [Online]. Available: https://www.ogc.org/projects/initiatives/bdgenergycds. [Accessed: 19-Dec-2020].

[4] Y. Chen, T. Hong, X. Luo, and B. Hooper, “Development of city buildings dataset for urban building energy modeling,” *Energy Build.*, vol. 183, pp. 252–265, 2019, doi: 10.1016/j.enbuild.2018.11.008.

[5] O. Conference, “GIS-Based Residential Building Energy Modeling at District Scale Usman Ali , Mohammad Haris Shamsi , Cathal Hoare , James ODonnell School of Mechanical and Materials Engineering , Energy Institute University College Dublin ( UCD ), Belfield , Dublin 4 , I,” no. September, pp. 11–12, 2018.

[6] C. Delmastro, G. Mutani, and S. P. Corgnati, “A supporting method for selecting cost-optimal energy retrofit policies for residential buildings at the urban scale,” *Energy Policy*, vol. 99, pp. 42–56, 2016, doi: 10.1016/j.enpol.2016.09.051.

[7] C. Cerezo Davila, C. F. Reinhart, and J. L. Bemis, “Modeling Boston: A workflow for the efficient generation and maintenance of urban building energy models from existing geospatial datasets,” *Energy*, vol. 117, pp. 237–250, 2016, doi: 10.1016/j.energy.2016.10.057.

[8] M. Gangolells, M. Casals, N. Forcada, M. MacArulla, and E. Cuerva, “Energy mapping of existing building stock in Spain,” *J. Clean. Prod.*, vol. 112, no. June 2013, pp. 3895–3904, 2016, doi: 10.1016/j.jclepro.2015.05.105.

# THANKS!