Linking climate with building energy performance through surrogate models.

OpenMod workshop, 4th of December 2020

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University of Victoria

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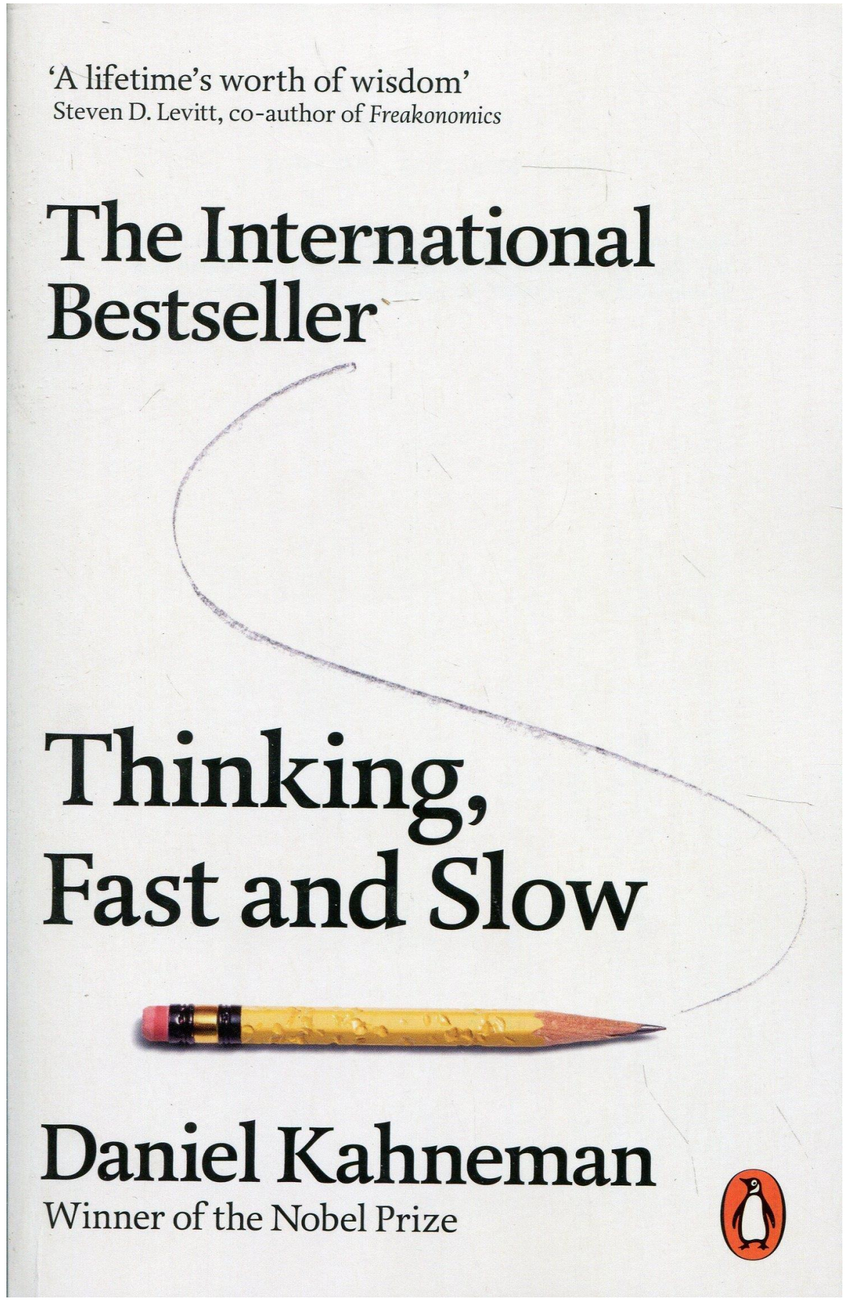
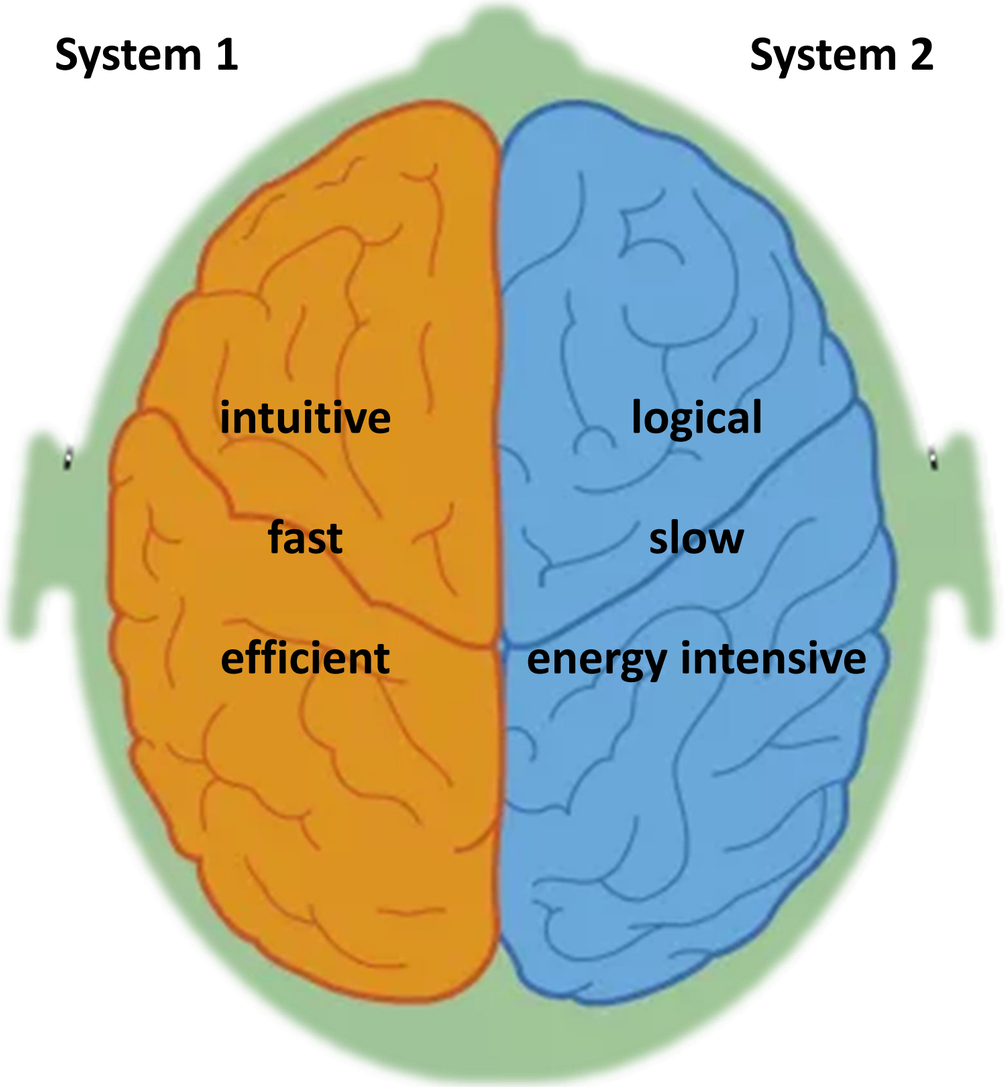
Motivation

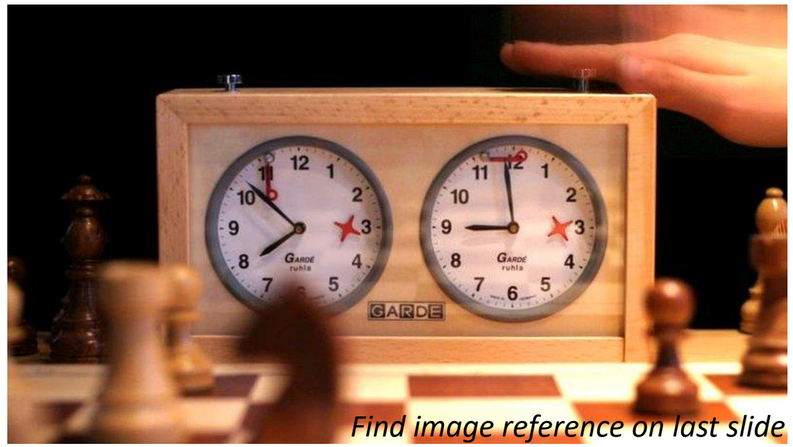
Scalable modelling processes are essential for scaling our impact on sustainable building design

Fast Machine Learning Building Energy Simulation **Surrogate Models**


'A lifetime's worth of wisdom'
Steven D. Levitt, co-author of Freakonomics
The International Bestseller
Thinking, Fast and Slow
Daniel Kahneman
Winner of the Nobel Prize


System 1
System 2
intuitive
fast
efficient
logical
slow
energy intensive

The example of the chess player



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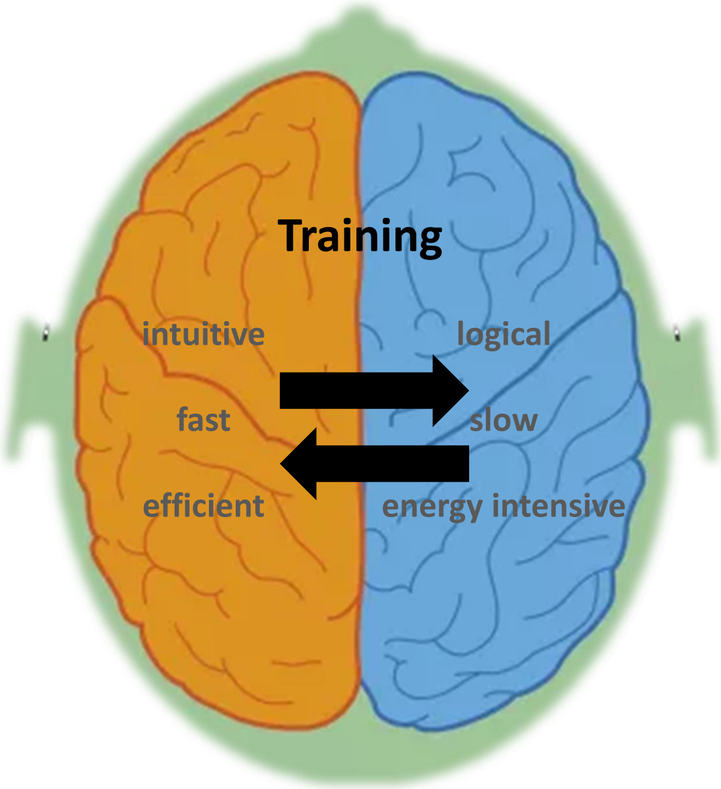

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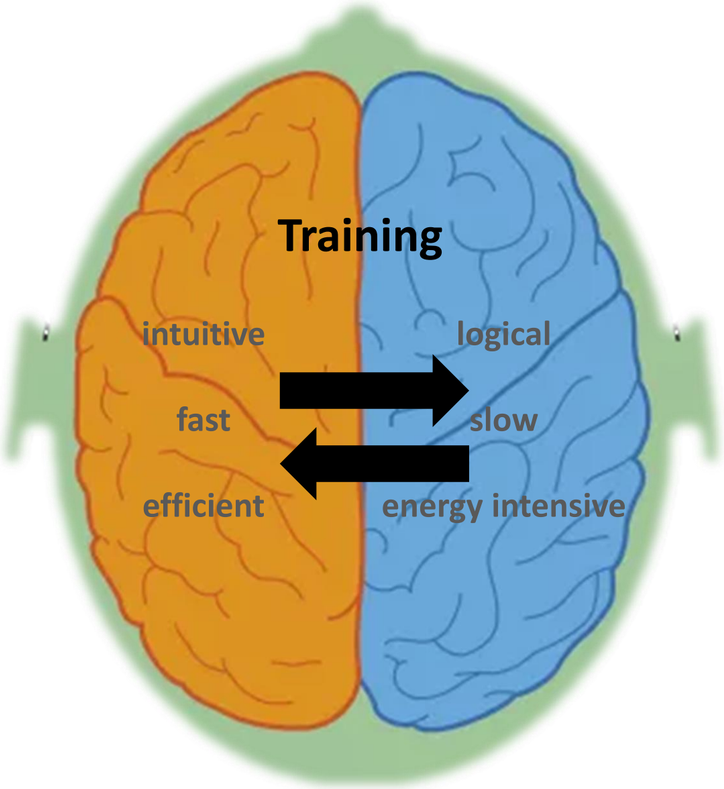
Find next move in seconds

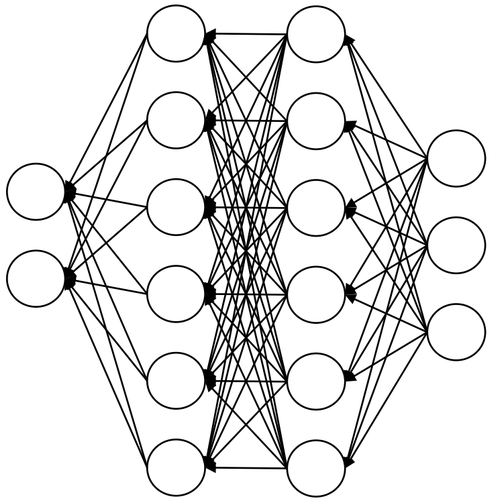
Building performance design
Fast and Slow

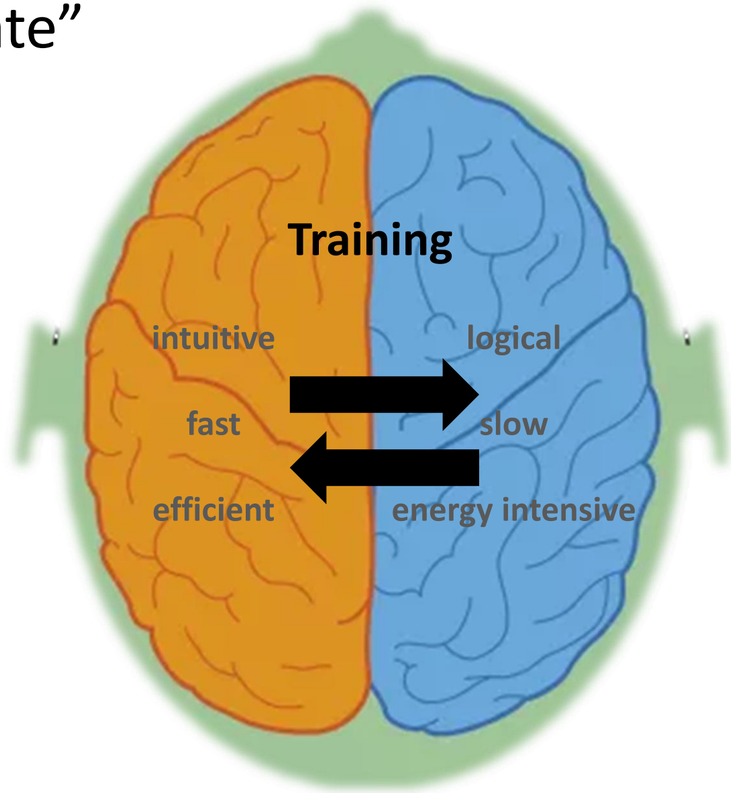


Find building energy performance in seconds

Building performance design
Fast and Slow

Machine learning model - “Surrogate”
as System 1





Physics-based model
as System 2

IES INTEGRATED ENVIRONMENTAL SOLUTIONS

EnergyPlus

Find building energy performance in seconds

Surrogate modelling

WWR	SHGC	AEC [kWh]
.50	.4	1500
.65	.5	2000
⋮	⋮	

Building description file
(.idf)

Annual hourly climate
(.epw)

Building simulation software

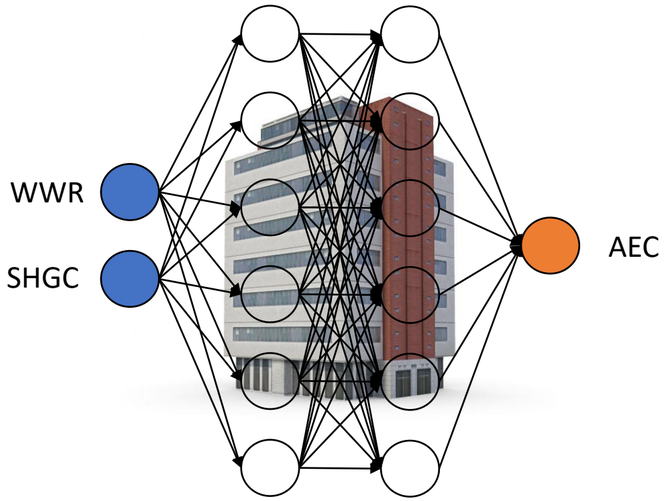
Simulation outputs
(e.g. heating demand)

$\overrightarrow{X_P}$

Surrogate model
(feed-forward neural net)

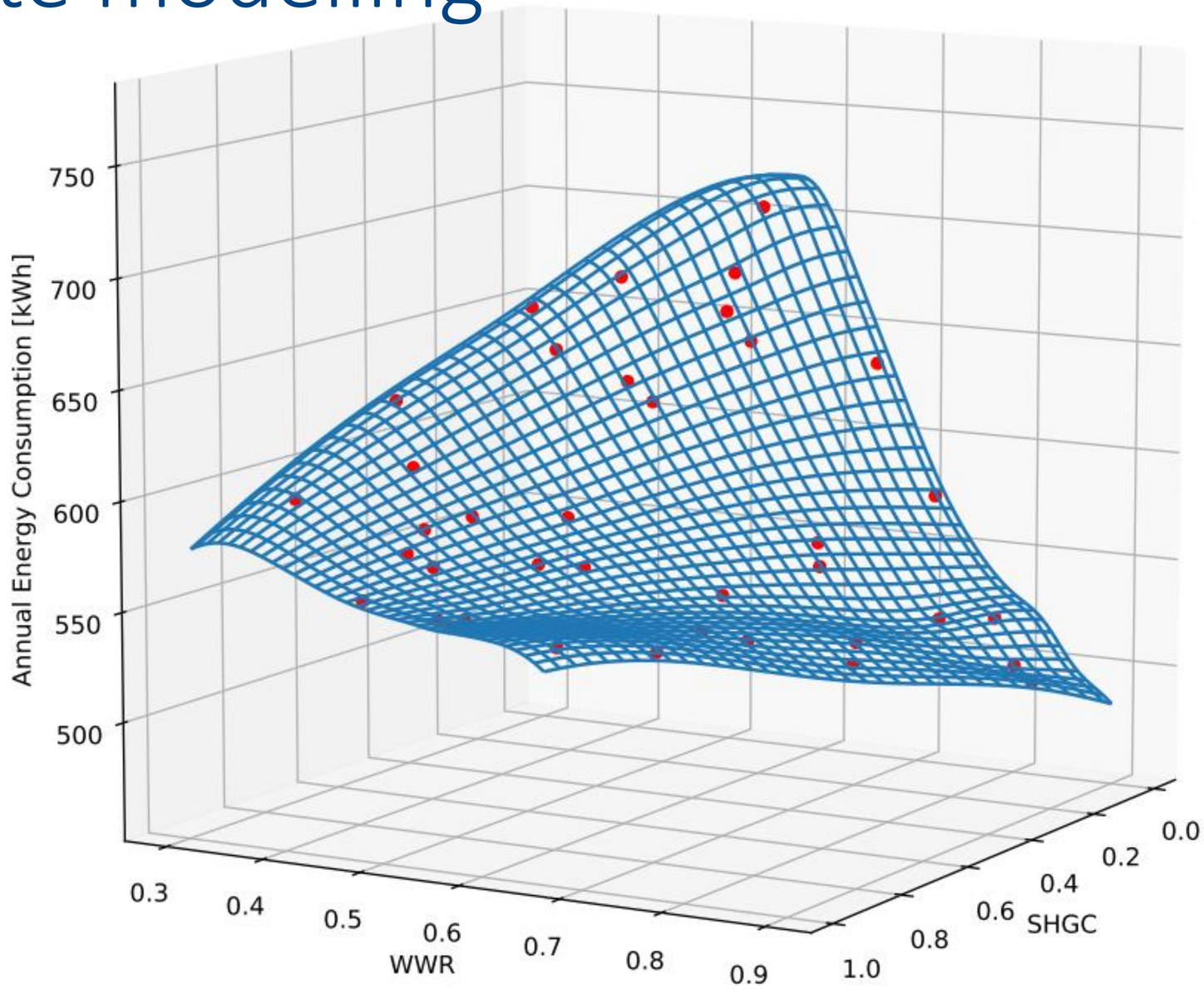
Training/ validation labels

Estimates



Westermann, P., and Evins, R.. "Surrogate modelling for sustainable building design-A review." Energy and Buildings (2019).

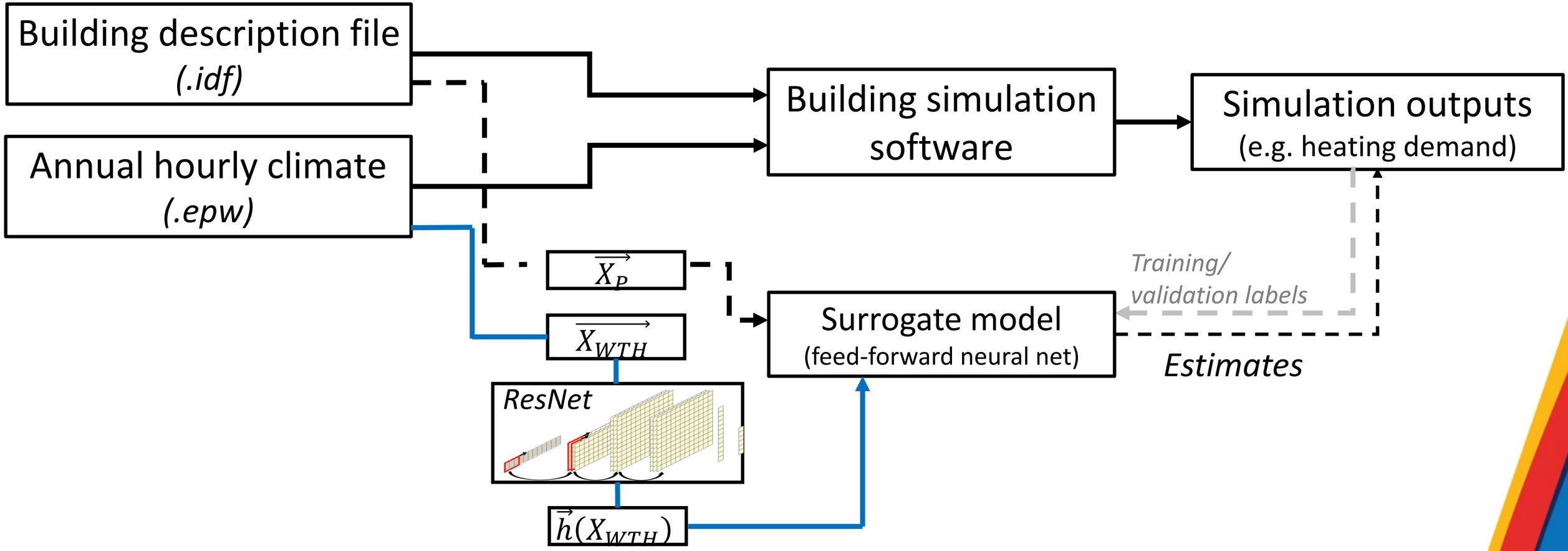
Surrogate modelling



Westermann, P., and Evins, R.. "Surrogate modelling for sustainable building design-A review." Energy and Buildings (2019).

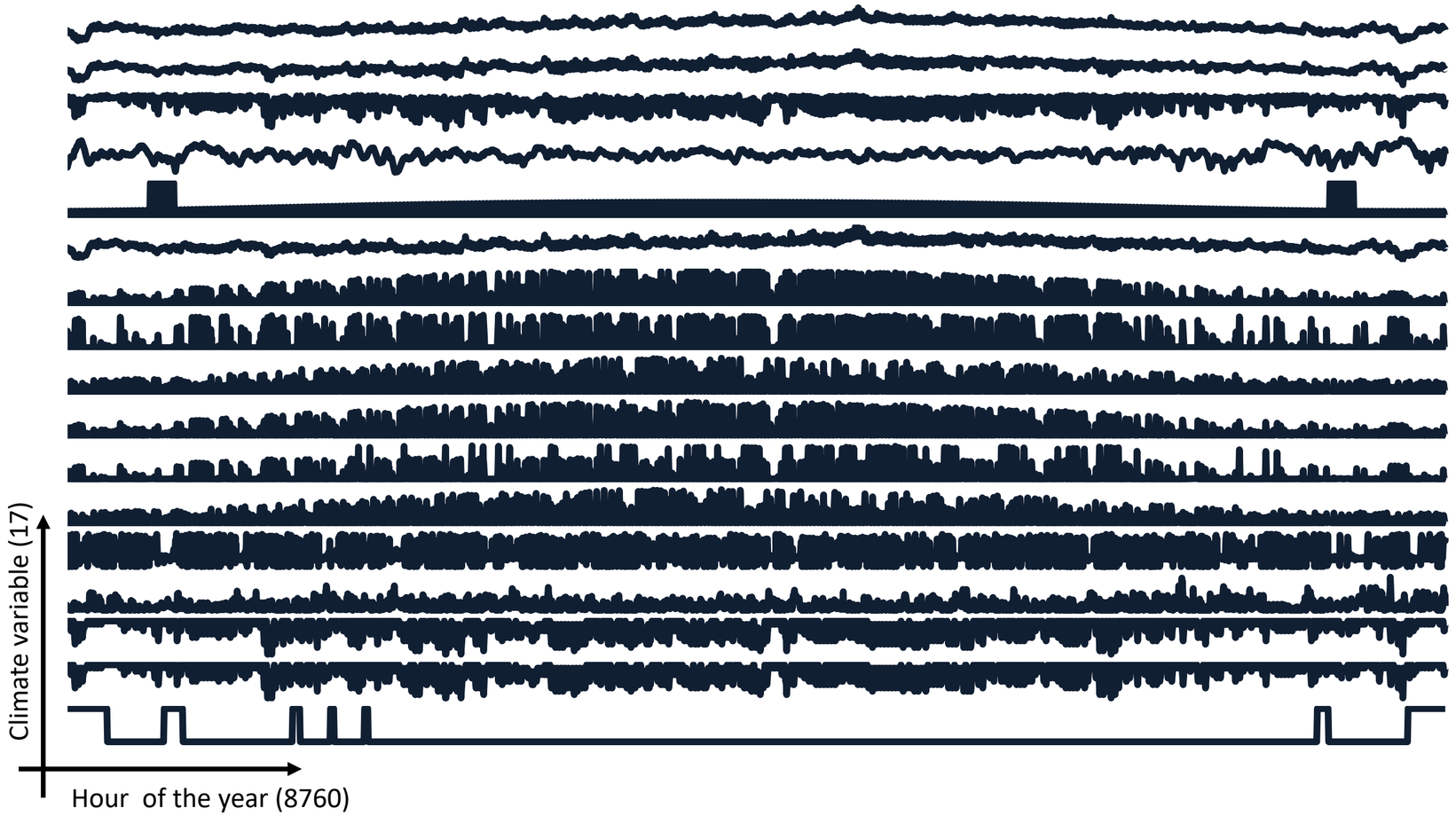
Use of climate data

Generalization of surrogate models: Weather file as surrogate model input



Westermann, P., Welzel, M., and Evins, R.. "Using a deep temporal convolutional network as a building energy surrogate model that spans multiple climate zones." Applied Energy (2020).

The climate file

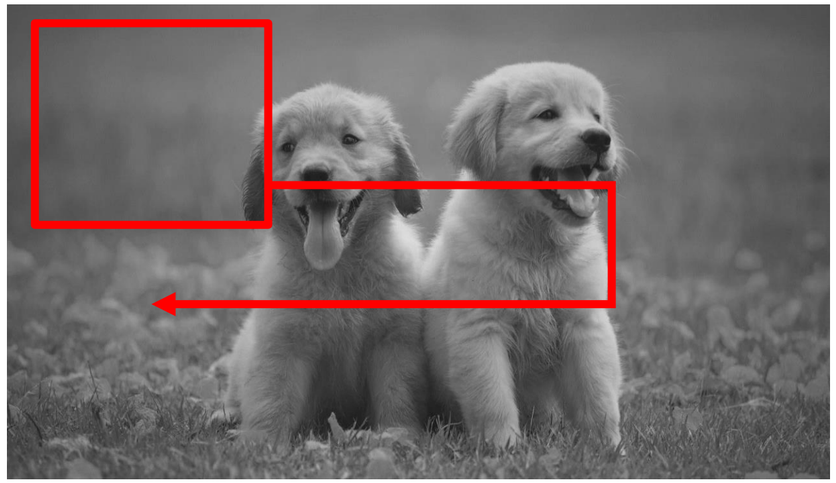


~150’000 values

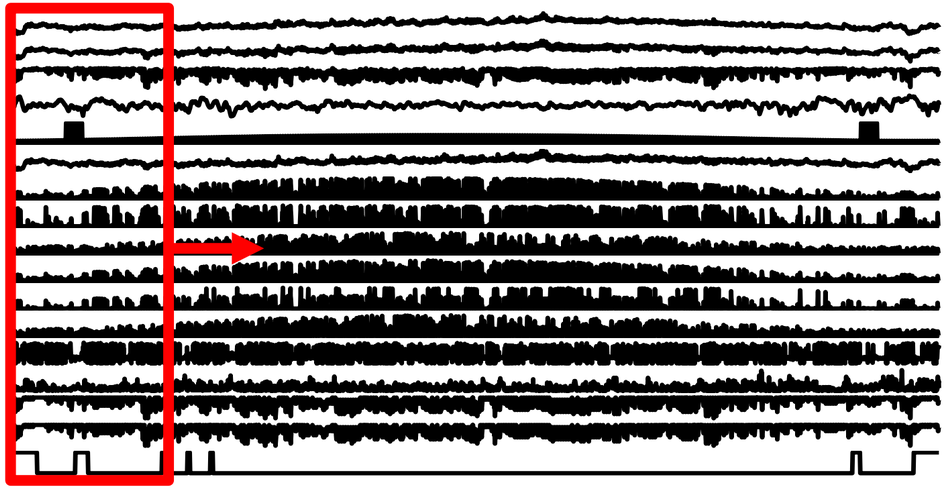
Westermann, P., Welzel, M., and Evins, R.. "Using a deep temporal convolutional network as a building energy surrogate model that spans multiple climate zones." Applied Energy (2020).

1D - Convolutional kernels

(i) 2D convolutional kernel on image data



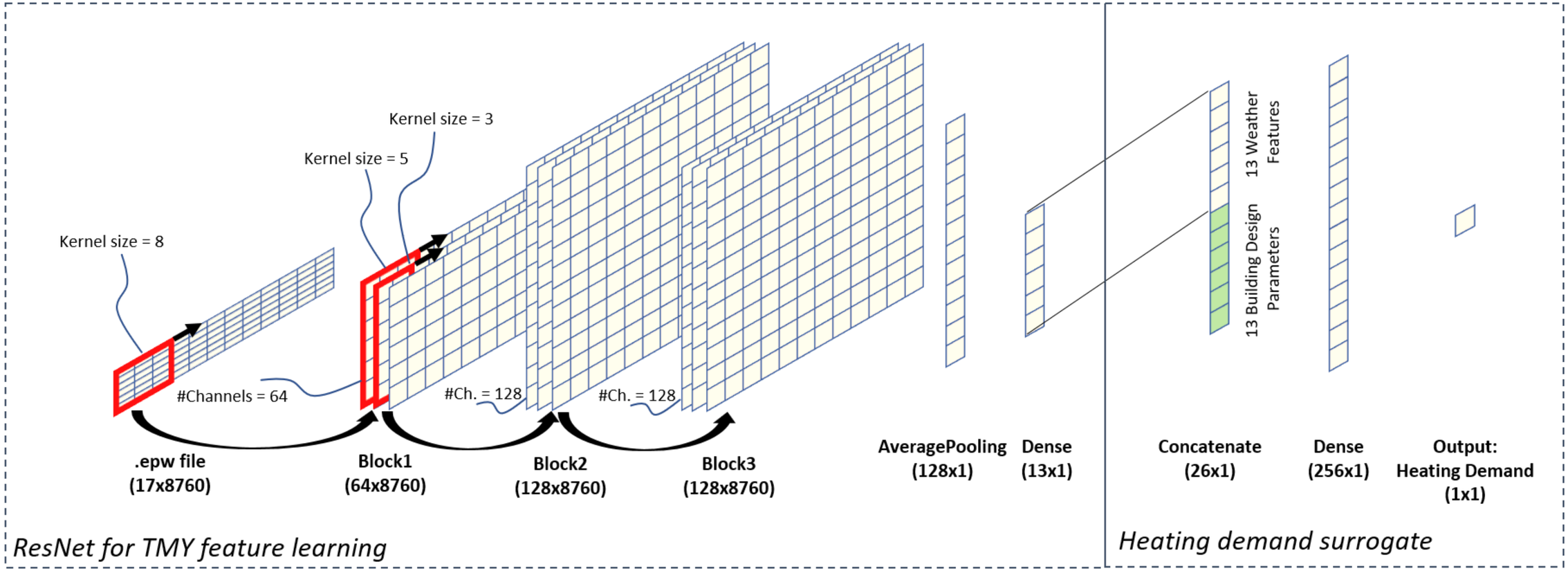
(ii) 1D convolutional kernel on time series data



$$e_{t=0} = b + \sum_{i=0}^{16} x_{i,t=0}\omega_i$$

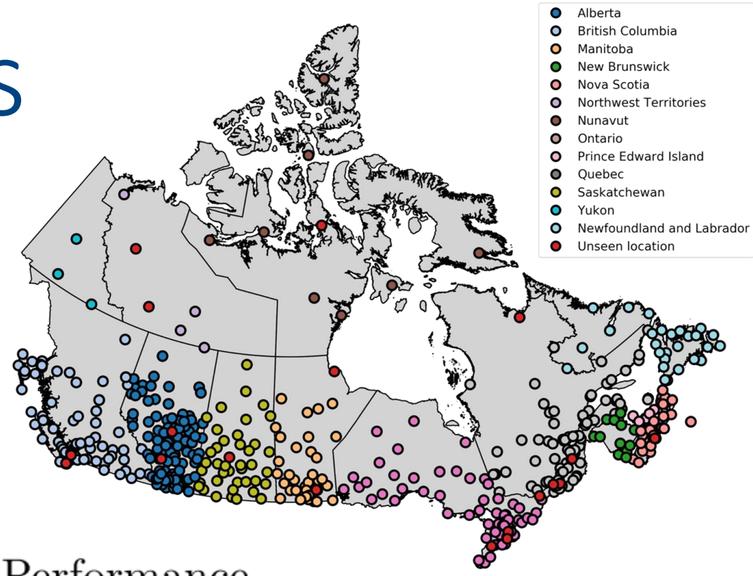
Westermann, P., Welzel, M., and Evins, R.. "Using a deep temporal convolutional network as a building energy surrogate model that spans multiple climate zones." Applied Energy (2020).

The convolutional neural network (CNN)



Z. Wang, W. Yan, T. Oates, Time series classification from scratch with deep neural networks: A strong baseline, in: 2017 international joint conference on neural networks (IJCNN), IEEE, 2017, pp. 1578–1585.

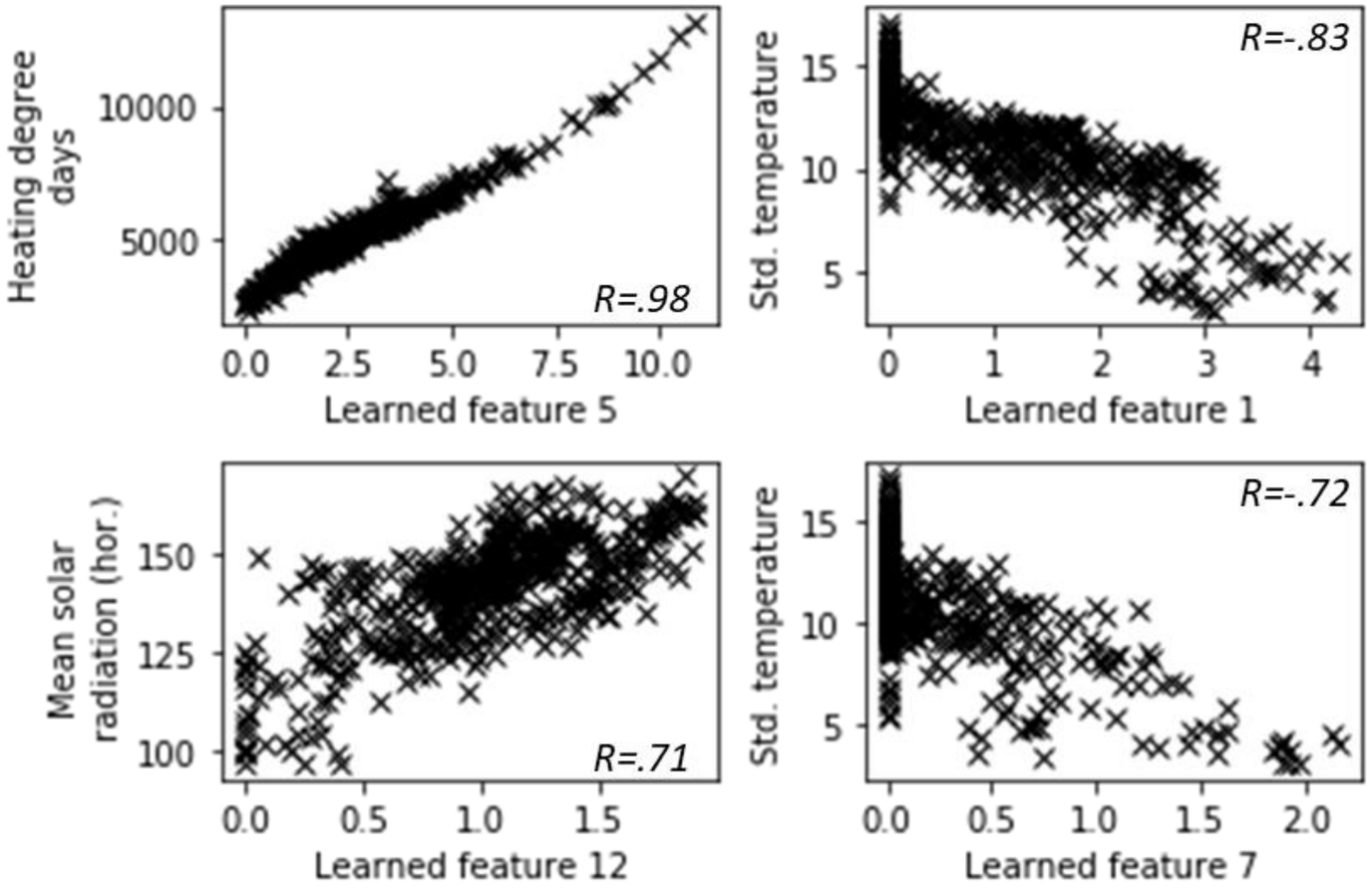
Performance on Canadian Climates



	Training Performance				Testing Performance (unseen designs and locations)			
Feature set	R^2	nMBE	MAPE	RMSPE	R^2	nMBE	MAPE	RMSPE
No Weather Data	0.3223	0.84 %	43.37 %	81.01 %	< 0	-13.83 %	52.26 %	74.95 %
HDD Only	0.9931	0.07 %	2.25 %	3.78 %	0.9852	- 3.82 %	8.33 %	13.62 %
Engineered	0.9966	-0.10 %	3.22 %	8.77 %	0.9951	- 0.96 %	3.76 %	7.10 %
Learned	0.9977	-0.03 %	1.93 %	2.60 %	0.9971	- 0.43 %	2.94 %	3.81 %

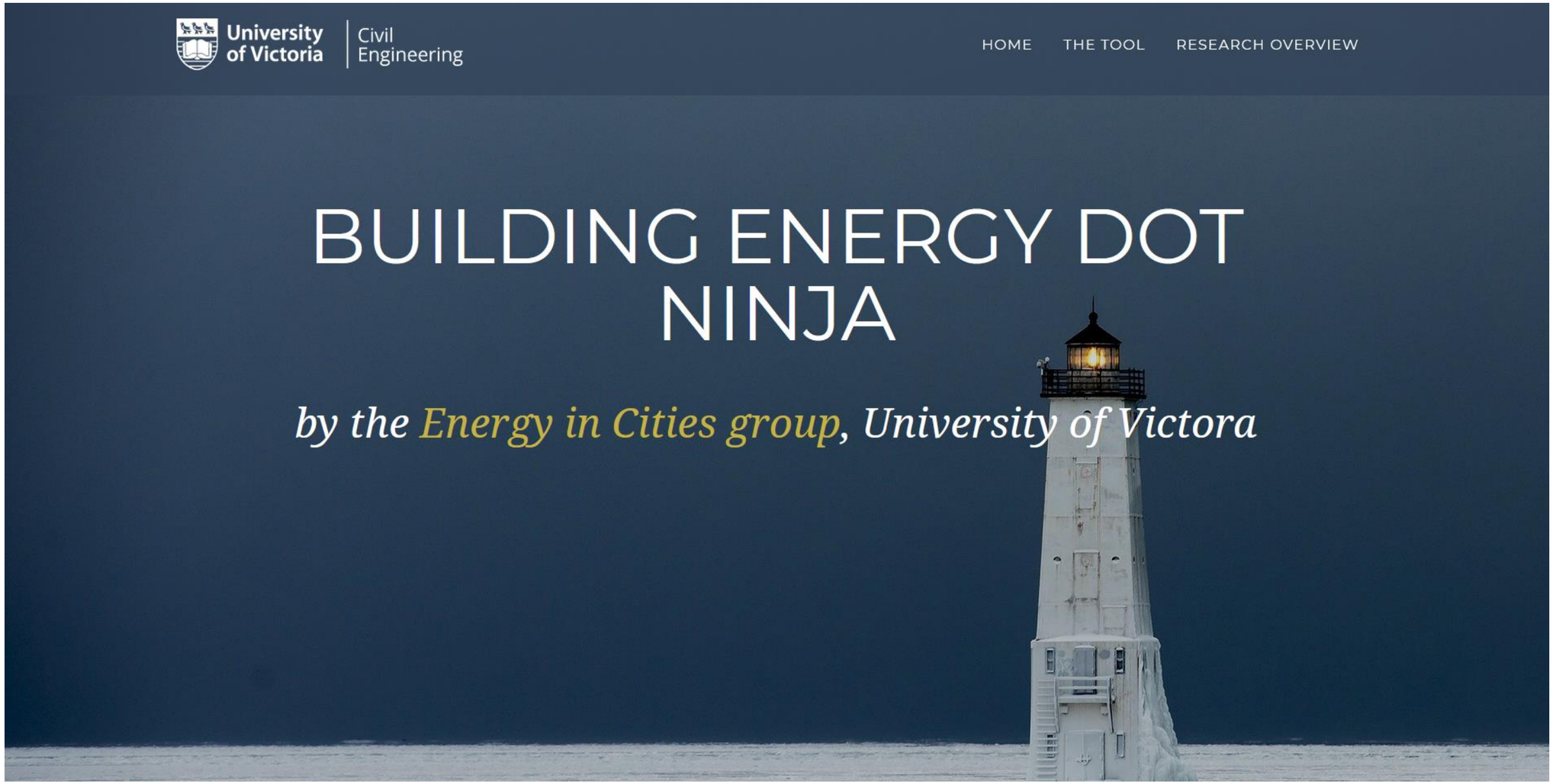
Westermann, P., Welzel, M., and Evins, R.. "Using a deep temporal convolutional network as a building energy surrogate model that spans multiple climate zones." Applied Energy (2020).

Performance



Westermann, P., Welzel, M., and Evins, R.. "Using a deep temporal convolutional network as a building energy surrogate model that spans multiple climate zones." Applied Energy (2020).

Buildingenergy.ninja

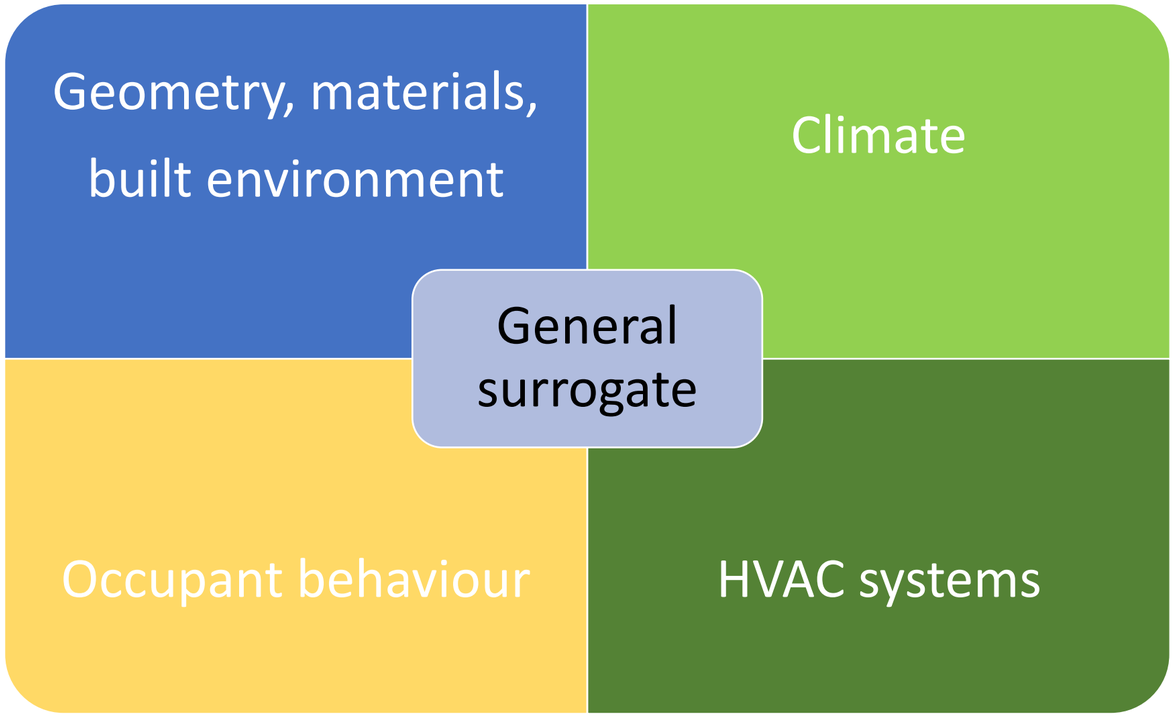


http://206.12.93.86/

Conclusion and future research

Conclusion

- Concept of **reusable surrogate models** as **building simulation 2.0**
  - Showcased large scale generalization potential



Ongoing and future research

- One “universal surrogate” to replace simulations
  - Span the entire globe and more types of outputs (hourly!)

- Retrofit analysis of existing buildings
    - Building model calibration

- Urban building energy modelling (UBEM)
    - Urban retrofit analysis

References

- **Introduction:**

IEA (2020), Tracking Buildings 2020, IEA, Paris https://www.iea.org/reports/tracking-buildings-2020

Hawken, Paul, ed. Drawdown: The most comprehensive plan ever proposed to reverse global warming. Penguin, 2017.

Østergård, Torben, et al. "Building simulations supporting decision making in early design–A review." Renewable and Sustainable Energy Reviews 61 (2016): 187-201.

Petersen, Steffen. Simulation-based support for integrated design of new low-energy office buildings. DTU Civil Engineering (2011).

- **Research study I:**

Z. Wang, W. Yan, T. Oates, Time series classification from scratch with deep neural networks: A strong baseline, in: 2017 international joint conference on neural networks (IJCNN), IEEE, 2017, pp. 1578–1585.

Fawaz, Hassan Ismail, et al. "Deep learning for time series classification: a review." Data Mining and Knowledge Discovery 33.4 (2019): 917-963.

Rackes, Adams, Ana Paula Melo, and Roberto Lamberts. "Naturally comfortable and sustainable: Informed design guidance and performance labeling for passive commercial buildings in hot climates." Applied Energy 174 (2016): 256-274.

- **Images:**

Blitz chess: https://www.zeit.de/sport/2015-10/live-schach-wm-berlin; https://www.chess-site.com/articles/chess-books/

Books: https://www.springer.com/de/book/9783319208305?gclid=EAIaIQobChMItb3l0_i96wIVj9eyCh1YZwDFEAQYBSABEgJLWfD_BwE; https://www.exlibris.ch/de/buecher-buch/english-books/daniel-kahneman/thinking-fast-and-slow/id/9780141033570;

ID3-factory: https://www.sueddeutsche.de/auto/bmw-daimler-vw-software-id3-1.4856930

Construction site: https://www.letsbuild.com/de/blog/bauprojektmanagement-eine-checkliste-der-grundlagen

Image of office CAD model: https://evermotion.org/shop/show_product/building-45-am62-archmodels/5029

All other images were made available for free use.

Thank you!!

Energy in Cities group

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