Ground Heat-Loss Modelling: Neural Networks versus Closed-Form Correlations

Ian Beausoleil-Morrison

CANMET Energy Technology Centre

Natural Resources Canada

Ottawa

ibeausol@nrcan.gc.ca

Background

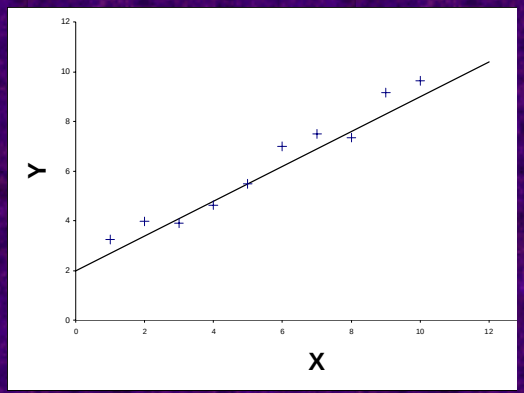
- Numerous detailed models exist for calculating heat transfer from buildings to ground.
- Physics complex $\Rightarrow$ most detailed models too computationally intense for whole-building simulation programs (BSim).
- Pragmatic approach $\Rightarrow$ use “simplified” models in BSim.
- “Simplified” models based on regressions of data generated using detailed models.

BASESIMP model

- Comprehensive foundation heat-loss model for houses, suitable for use in BSim programs.
- 30 000+ parametric runs performed with a detailed FEM-based model.
- Regression analysis $\Rightarrow$ results collapsed to handful of simple algebraic equations.

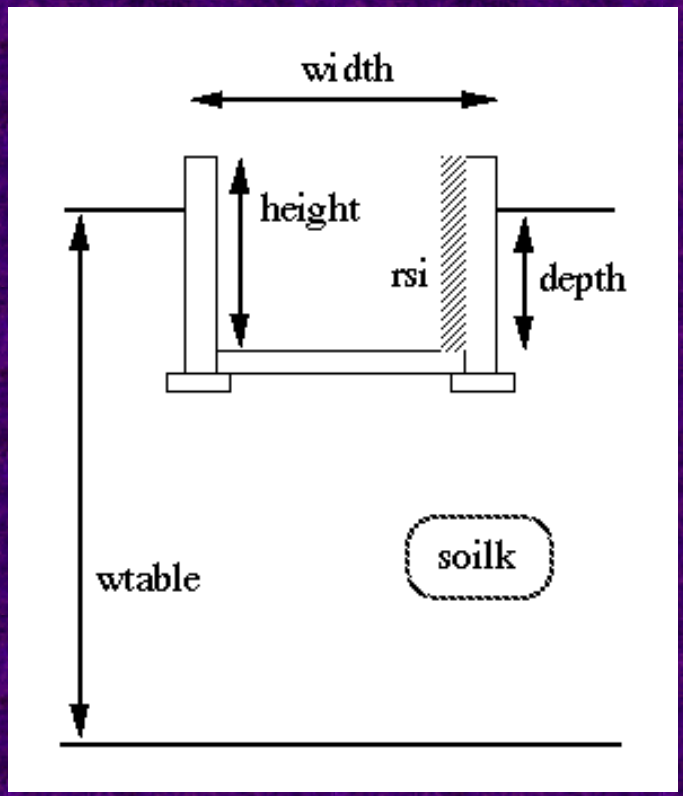
Traditional Approach to Data Regression

- Data regressed using "closed-form" correlations.
  - Physical basis to form of equations.
  - Constants adjusted to optimize fit to data.



$$Y = a + b \cdot X$$

- Effective but can be time consuming.



$$\text{SUMUR} = \left[\frac{\{q_2 + r_2(\text{width})\} \cdot \{u_2 + v_2(\text{soilk})\} \cdot \{w_2 + x_2(\text{depth})\}}{(\text{wtable})^{s_2 + t_2(\text{width}) + y_2(\text{depth})}}\right]$$

$$+ \left[\frac{a_2(\text{depth})^{b_2}(\text{soilk})^{c_2}}{(\text{wtable})^{d_2}(\text{rsi})^{e_2 + f_2(\text{soilk}) + g_2(\text{depth}) + h_2(\text{overlap})}}\right]$$

Neural Networks: an Alternative

- With closed-form regression:
  - Significant time investment to establish form of correlation equations.
  - Typically examine and evaluate many constructs before finalizing form of equations.
- With NNs:
  - User does not define form of correlation between inputs and outputs.
  - Potential for reducing development time without sacrificing accuracy.

Neural-Network Model

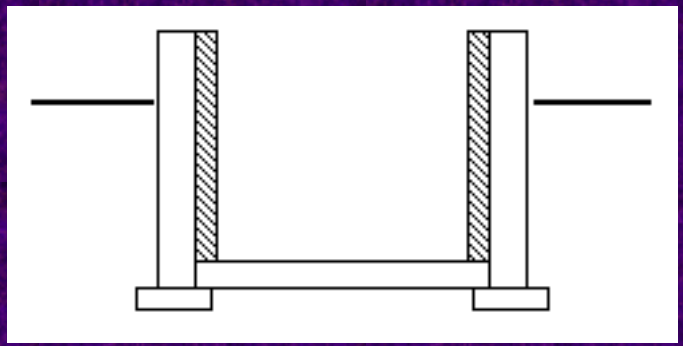
- User does not define form of correlation between inputs and outputs.
- NN model essentially applies an error-minimization routine to adjust weights until the model has "learned" the mapping between the input and output variables.
- A multi-layer feedforward NN model with back-propagation learning algorithm was used here.

NNs vs. Closed-Form Correlations: the Challenge

- Could the BASESIMP model have been developed more quickly with NNs?
- Could NNs represent the data as (or more) accurately than the closed-form correlations?

Approach

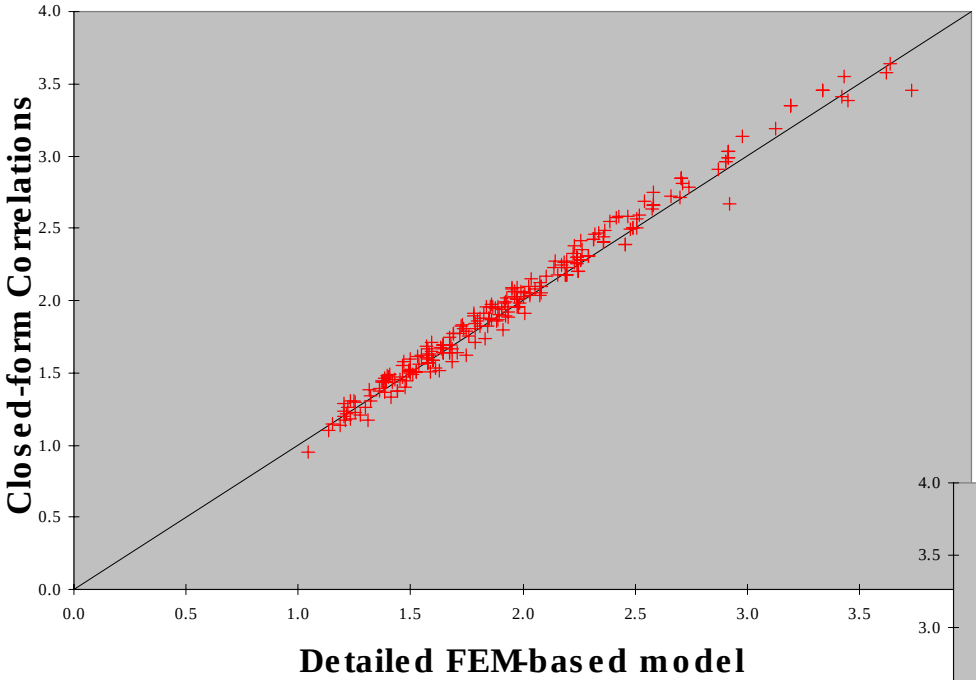
- One of BASESIMP's 67 insulation configurations selected for test.

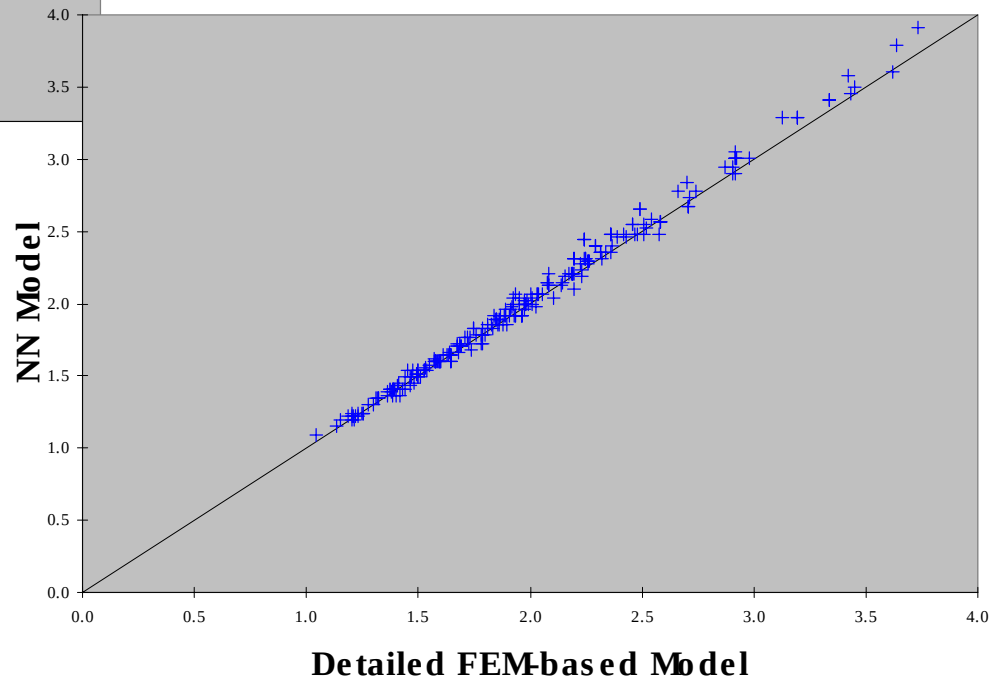


- 1 080 parametric simulations were performed performed with detailed FEM-based model to to generate the closed-form correlations $\Rightarrow$ the the *training* data set.

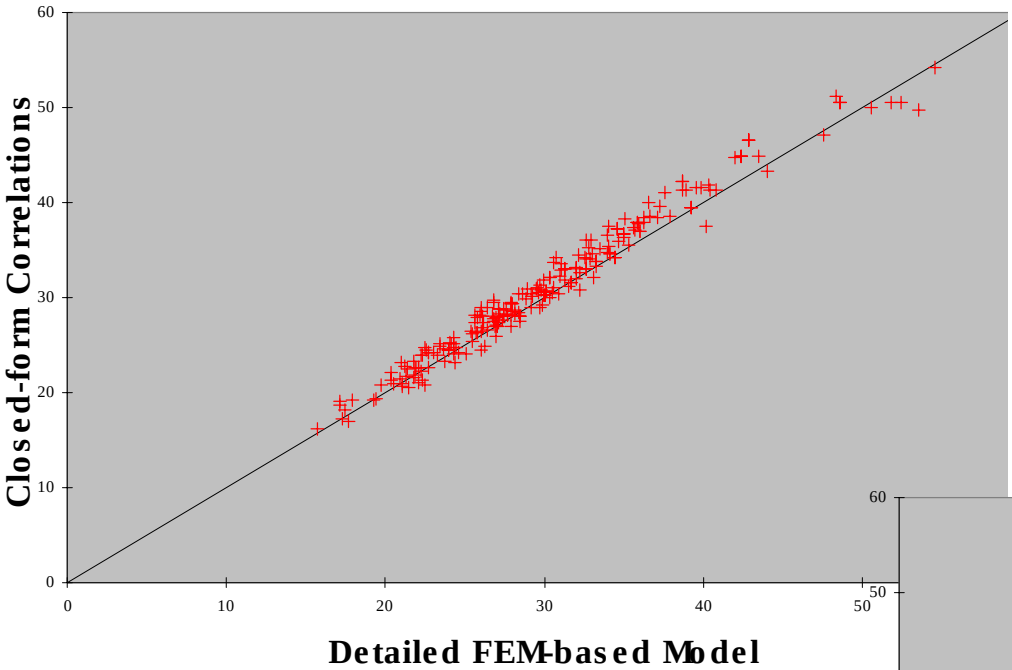
- NN model *trained* with training data set.
- Additional 228 simulations performed with detailed FEM-based model:
  - inputs randomly generated.
  - input combinations neither closed-form correlations nor NN model had seen.
  - the *test* data set.
- Tests performed to determine how accurately closed-form correlations and NN model could represent *test* data set.
- *Blind* test for both models.

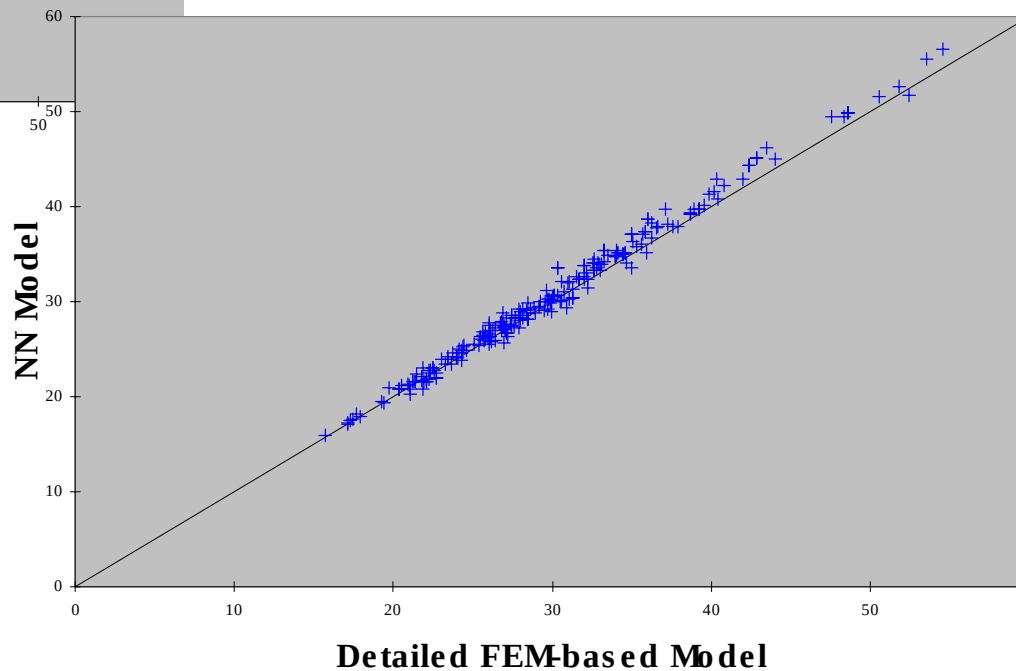
Test A: 2D response factors



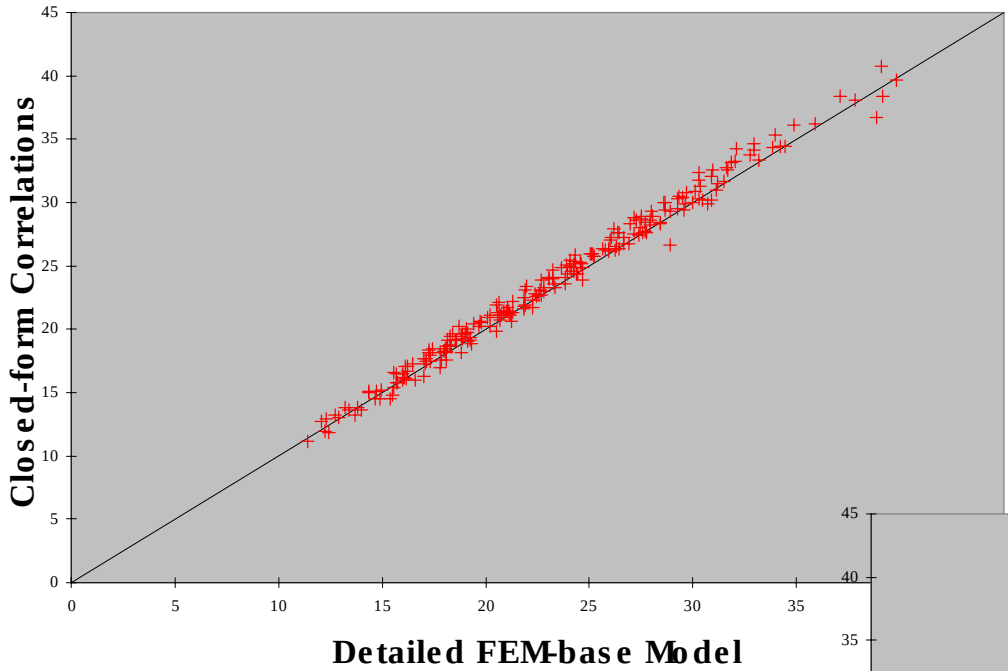


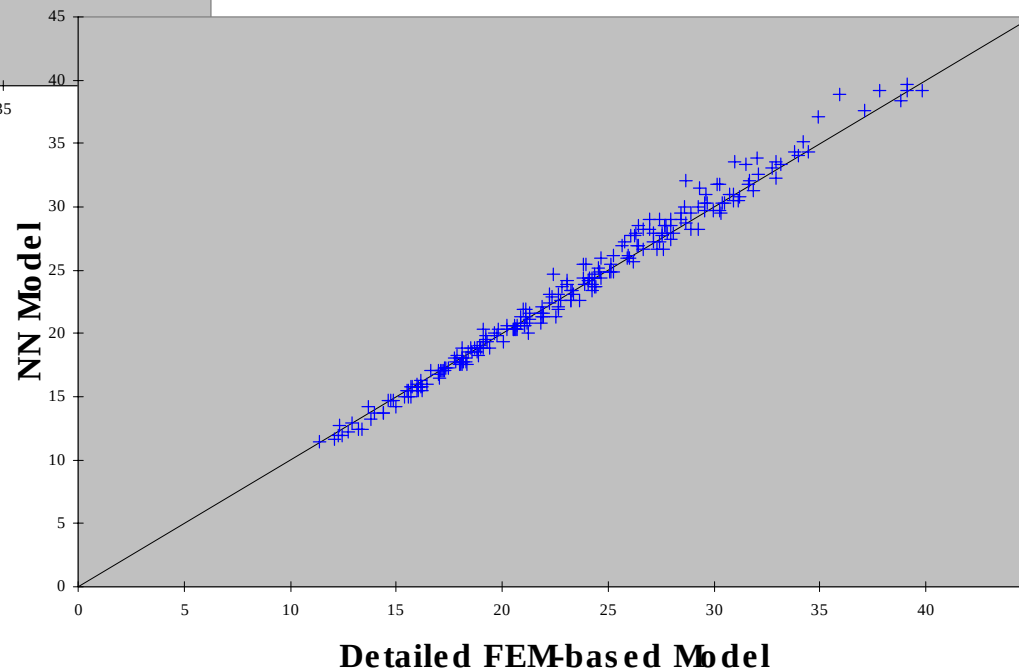
Test B: 2D heat loss





Test C: 3D seasonal load





Conclusions

- Both closed-form correlations and NN model accurately represented *test* data.
- With few exceptions, NN model outperformed closed-form correlations.
- Many constructs examined before finalizing form of closed-form correlations. Substantially less time required to develop NN model.

Conclusions (continued)

- Despite "black-box" nature, NN models offer attractive alternative to closed-form correlation models for development of regression-based algorithms.
- NN approaches should be considered when developing regression-based algorithms for building-simulation programs.