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Quantifying importance of residential building features to electric heating and cooling loads

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Abstract: Understanding the relative importance of residential building features with respect to the heating and cooling energy consumption provides a basis for designing energy-efficient buildings and reducing greenhouse gas emissions. This study analysed dataset of detached or semi-detached residential construction around Brisbane, Sydney, and Melbourne, collected through the certificates of the NatHERS (Nationwide House Energy Rating Scheme) accredited house energy star rating tools (AccuRate, BERS Pro, and FirstRate5) from 2016 to 2022. The certification requires many input fields including dwelling location, construction materials, layout (floors, walls, roofs, windows, insulation, etc) and ventilation, which require inputs with numerical and categorical data as well as descriptive texts. Data tidying and feature engineering were performed in Tableau Software. The target variables available are cooling and heating loads (in MJ/m^2/year, adjusted for the effects of house size), and energy efficiency star rating (from 0.0 to 10.0), with a total of 119 dwelling features extracted from the certificates. The numbers of dwellings in the dataset for Brisbane, Sydney, and Melbourne are 47,000, 42,700, and 120,000, respectively.

The climatic conditions vary across the three cities, so do the construction materials and design of dwellings. To capture the roles of each feature on energy requirements of dwellings across the cities, an extreme gradient boosting model (XGBoost, Chen et al. 2023) was fitted to each of the targets for each of the cities, resulting in a total of nine computational models. The model outputs were used for variance-based sensitivity analyses, which apportions the target variance to the sources of uncertainty (i.e. contribution from every feature). The Sobol' total-effects sensitivity indices based on variance decomposition (Saltelli et al. 2008) were computed to rank the features' relative contribution to the target variance. The derived Sobol' sensitivity indices indicate that, in each model, most of the target variance can be attributed to around a dozen features, with virtually each of the other features contributing less than 5% of the target variance. Note that the total-effects index of a feature represents the sum of the first- and all higher-order contributions made by the feature, hence the direct contribution (i.e. the first order) of the feature would be even lower.

The top-5 most influential features for heating/cooling energy use of detached or semi-detached houses are:

- Brisbane: (1) external wall insulation, (2) ceiling fan count, (3) ratio of window total to conditioned floor areas, (4) ratio of concrete-slab-on-ground to total floor areas, and (5) site exposure.
- Sydney: (1) ratio of window total to conditioned floor areas, (2) external wall insulation, (3) certificate year, (4) area of external wall of construction type cavity masonry as proportion of total external wall area, and (5) proportion of north-facing window to the total external wall areas.
- Melbourne: (1) project type (new, existing, or renovation), (2) ceiling insulation, (3) ratio of window total to conditioned floor areas, (4) external wall insulation, and (5) proportion of suspended timber floor to the total floor areas.

It reveals that external wall insulation is among the most influential for all three cities, whereas ceiling fan count is influential for Brisbane (cooling-dominant) and ceiling insulation for Melbourne (heating-dominant). Project type appears prominent in Melbourne maybe due to Melbourne having significantly more existing and renovated dwellings data. By quantifying the feature contribution to the variance of energy requirements, the outcomes of this research may serve as a useful guide for the design of detached/semi-detached houses to achieve improved energy efficiency and aid in the net zero-carbon initiative of the construction industry.

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