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USING MACHINE LEARNING AND MATHEMATICAL PROGRAMMING TO BENCHMARK ENERGY EFFICIENCY OF BUILDINGS

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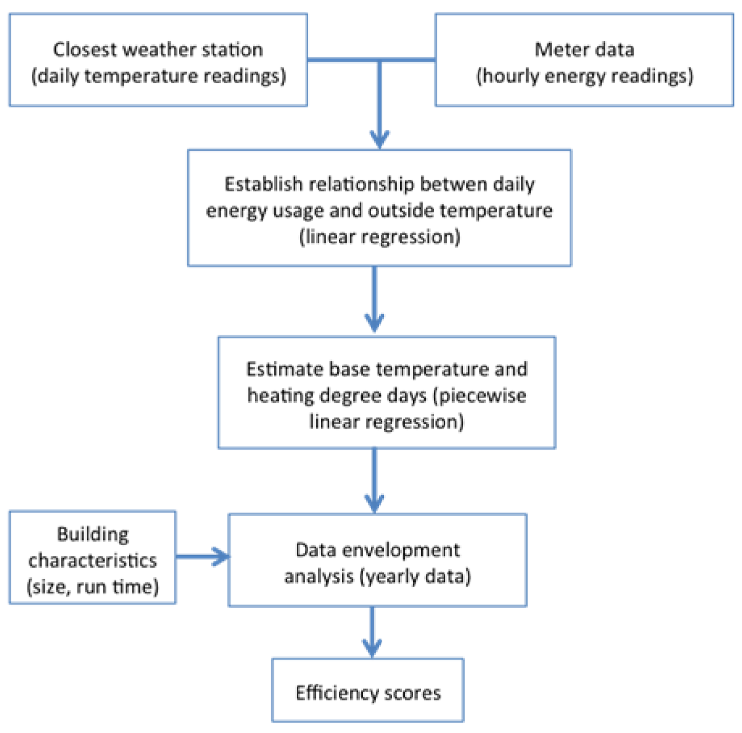
BRIEF SUMMARY

- We demonstrate a novel benchmarking technique to identify buildings with a potential to reduce energy consumption, taking into account both weather effects and building characteristics
- We analyze the relationship between daily average outside temperatures, run-time, size, and daily energy use for 132 Norwegian retail stores
- We have developed a fully automated procedure that collects data from meter data, weather stations, adjusting for weather effects and ranks stores in terms of energy efficiency
- Results suggest that the average store is 28% less efficient than the most efficient stores
- Our analysis show that using our suggested analytical framework will improve the accuracy of the efficiency scores compared to more standard methods

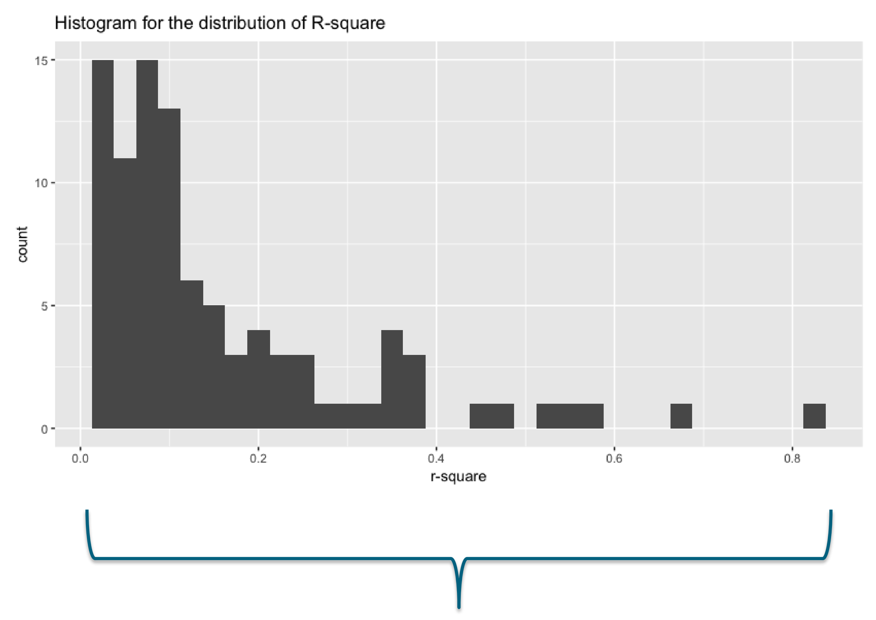
MOTIVATION

- Somewhere between 30 and 40% of the global energy consumption occurs in buildings (United Nations Environment Programme, 2007).
- Buildings represent an important opportunity to reduce energy consumption, and further help mitigate global warming, one of the world's most important problems
- Researchers have proposed a number of methods to analyze and improve energy efficiency in buildings, both data driven approaches (Wang et al. (2012), Chung (2011), Lee and Kung (2011)), and simulation approaches with high accuracy
- The data driven approaches have the advantage of being able to analyze a large number of buildings, and at the same time consider multiple parameters; both weather conditions and buildings characteristics (Lee and Kung, 2011).
- Historically, lack of data has made it a challenge to use data driven approaches, both detailed meter readings and weather data has often been on an aggregated level

Conseptual model

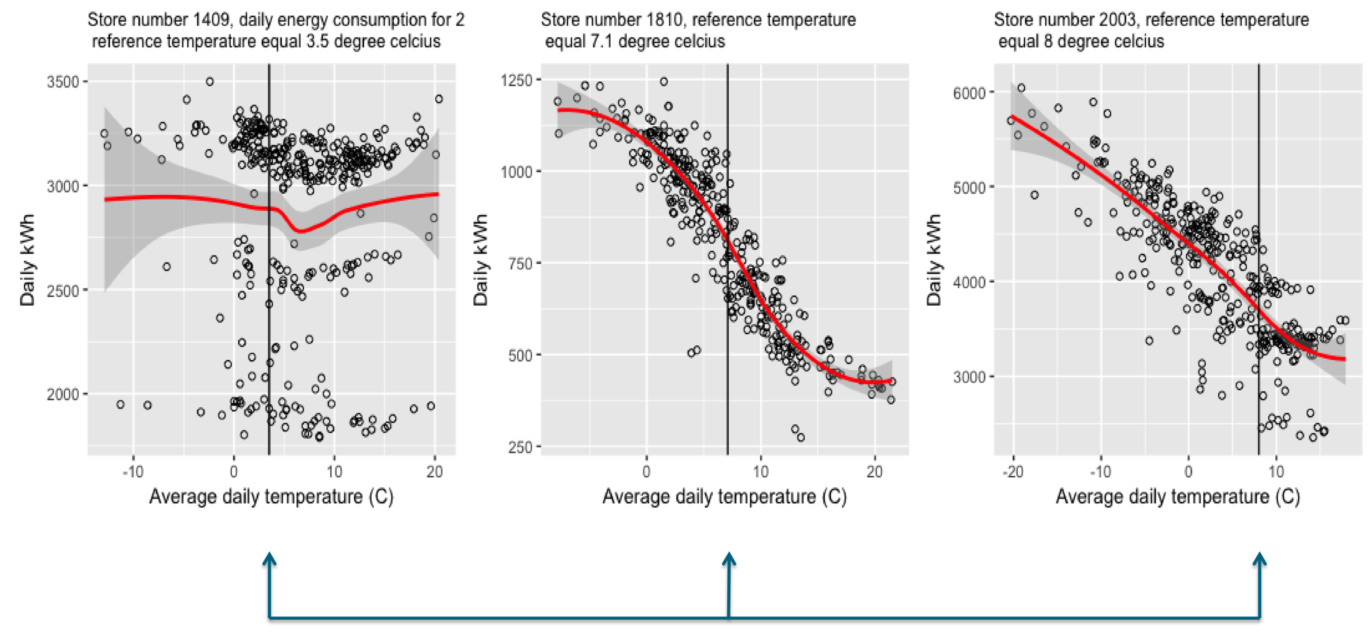


Histogram of R^2 from 132 regression models



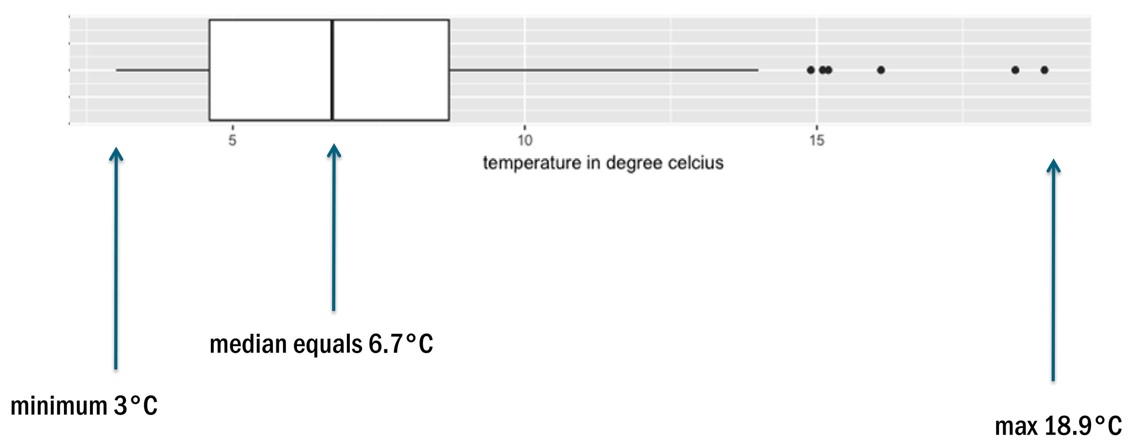
The relationship between individual stores energy consumption and outside temperature has large variation, from zero dependency to more than 60%

Finding the changing point temperature (CPT) – when heating is required



Example from three of the 132 stores, vertical line from PLR indicating the estimated changing point temperature (CPT)

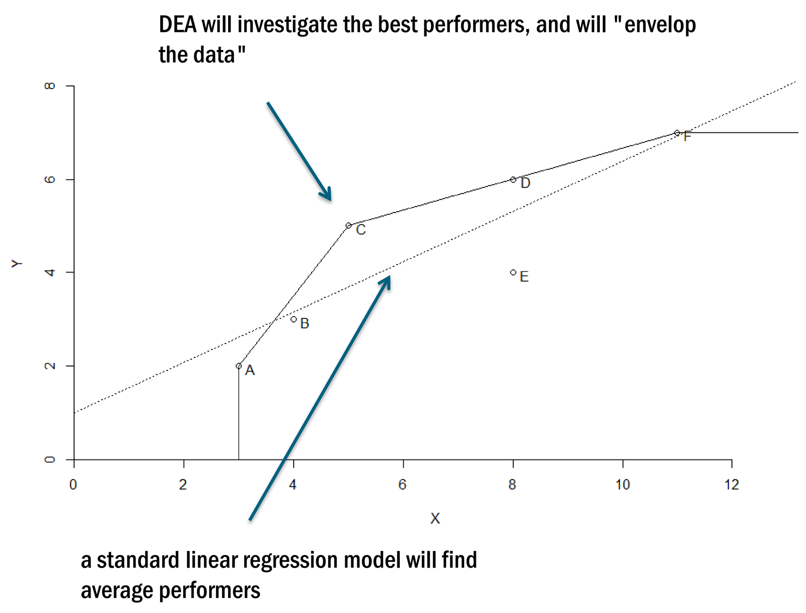
95 stores and the corresponding CPT – that is a lot of variation!

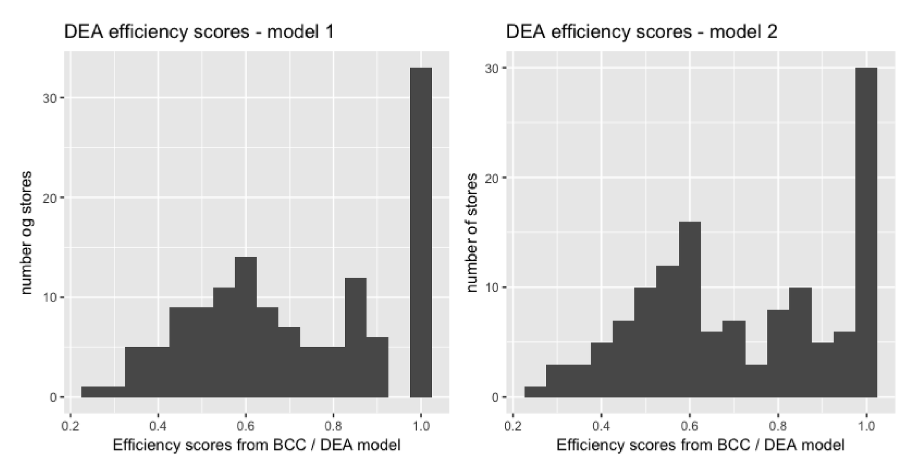


The DEA methodology – finding best performers

The efficiency scores are calculated based on data envelopment analysis (DEA). DEA is a non-parametric method first introduced by Charnes, Cooper and Rhodes (CCR), (1978). DEA measures the relative efficiency between homogeneous units and estimates a composite score for each unit under consideration. Efficient units will obtain a score of 1 (100%), while inefficient units will receive a score less than one but greater than zero. The objective is to minimize input (maximize output) holding output (input) fixed

Conceptual visualization of DEA methodology





Model 1: Modeling with run-time and size as output variables and degree-days as exogenous variables *without* taking into consideration if temperature is statistically significant.

Model 2: Modeling with run-time and size as output variables and degree-days as exogenous variable *taking* into account if temperature is statistically significant. In particular we set yearly degree-days = 0 for all the stores where we find no climate effect.

Brief summary DEA results
- The average efficiency from model 1 is 72%.
- We can potentially reduce the electricity consumption with a considerable 28% (on average).
- Of the 132 stores in model 1 we find that 32 of them are 100% efficient.
- We get the same *average* efficiency score for model 2

Brief summary DEA results changes:

- Only 30 stores are now 100% efficient
- The efficiency scores changes between many of the stores
- Looking at the 37 stores where we found no climate effect and comparing the efficiency scores between model 1 and model 2 we find an average change in efficiency scores of 7%, ranging from a reduction of 34% to an increase of 53%.

DISCUSSION AND OUTLOOK

- The stores with the lowest efficiency scores will be visited and analyzed carefully to better understand the factors behind the low efficiency score
- Developing predictive models to be used to indicate stores in need of maintenance (typically service request and maintenance are very expensive for the store owners)
- A sample of the stores with efficiency scores of 1 will also be visited to better understand the underlying factors
- Future work will also consider more detailed estimation of the CPT, as the changing point could vary between weekdays and weekends
- In future work more detailed information about the stores will be included in the DEA model, for example more details about building materials, lightning, building age, heat recovery system, and amount of cooling/freezing equipment

CONCLUSIONS

- **Our modeling framework seems a good approach to rank energy performance between retail stores**
- **If data is available it is important to find a building's individual changing point temperature (CPT)**
- **DEA is an appropriate technique to benchmark energy efficiency**
- **Not taking into account climate will affect the efficiency scores and changes them by, on average, 7%.**
- **Our methods to rank a large portfolio gives quick insights into the least and most efficient buildings**
- **The average store is 28% less efficient than the most efficient stores**

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