QUANTIFYING AND MITIGATING DIFFERENCES BETWEEN PREDICTED AND MEASURED ENERGY USE IN BUILDINGS

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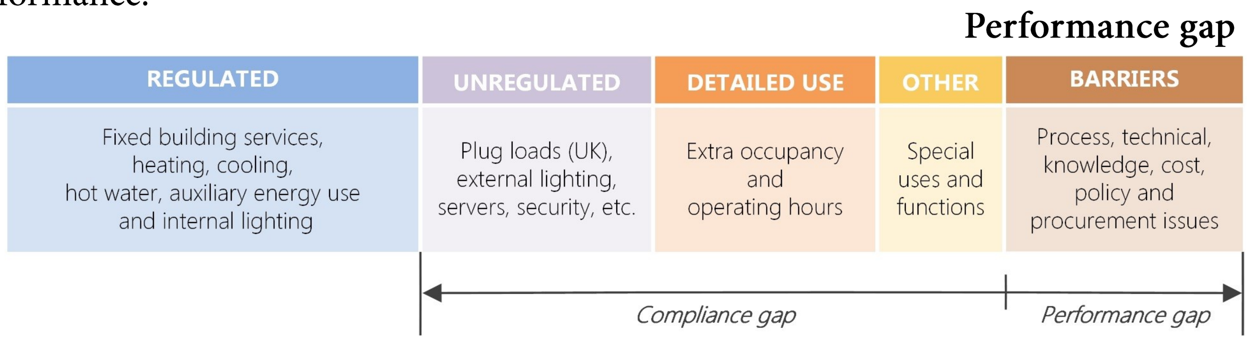
Abstract

To reduce energy use in buildings, investigation in both the prediction and actual in-use building energy performance in thorough detail is required so that discrepancies are identified. An in-depth case research approach is taken to investigating the discrepancy between predicted and measured energy use. A hierarchy is established for comparing data at a high granularity, building energy models are then used to compare predicted and measured energy use utilising automated calibration. Calibrated models are used for quantifying the impact of the underlying causes of the energy performance gap and determining the influence of design assumptions. Prior to the in-depth study, an exploration of industry practices and stakeholder engagement established the meaning of building performance and key factors for delivering such performance.

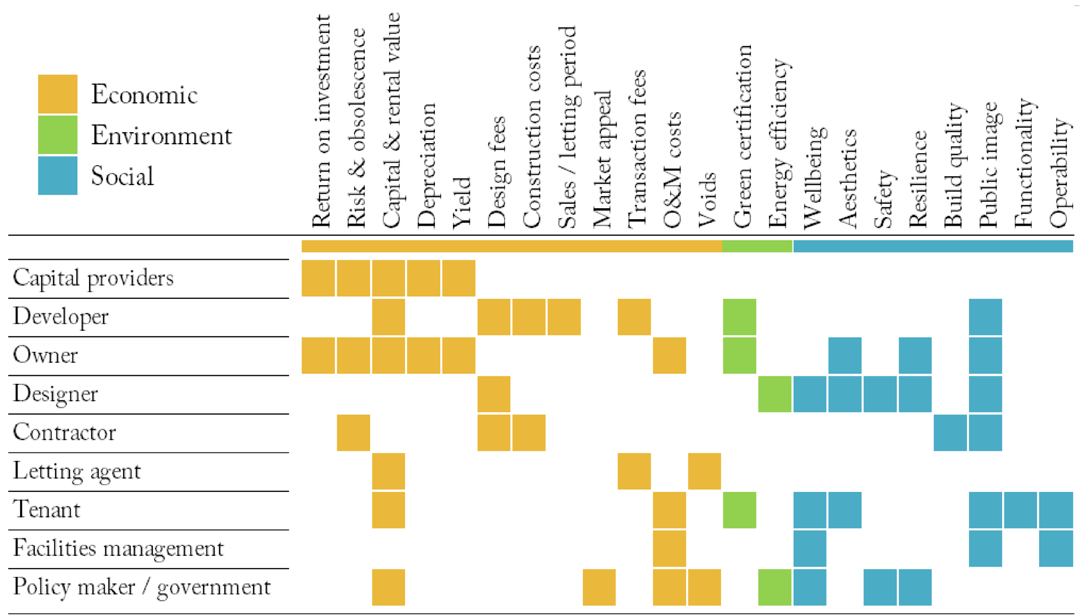


Building Performance

The author in partnership with the UKGBC investigated how the industry currently designs, constructs and operates non-domestic buildings. Examining industry approaches, tools and behaviours, the group will focus on how to maximise building performance, not just in energy terms, but also other aspects of performance that impact both the building user and the wider environment.

Segmentation of the building industry is a key influential factor of building performance. Interrelations between stakeholders are complex and typically not very well integrated in the supply chain and is more apparent in some procurement methods.

Fundamental to this integration are the underlying incentives for procuring a building in the first place. These stakeholder incentives for building procurement can be defined as building performance.

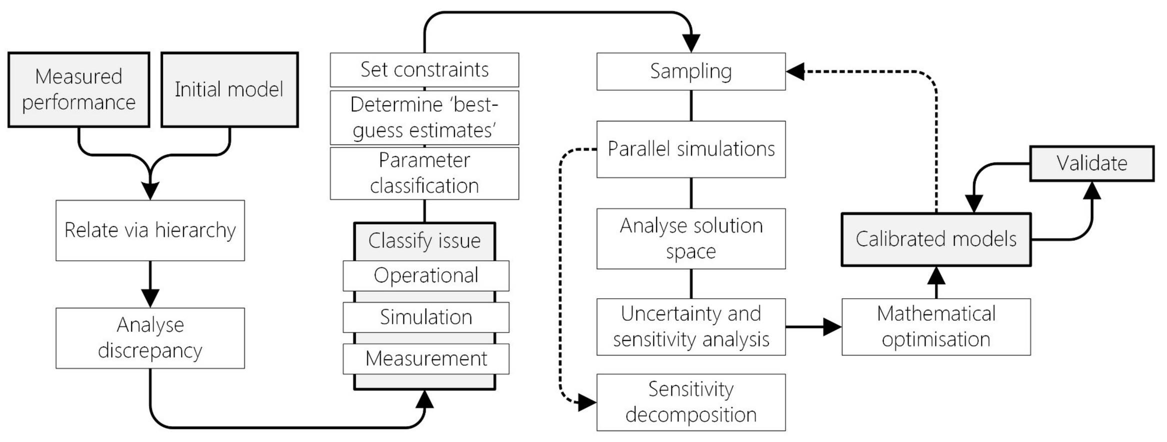


Exploration of industry practices and stakeholder engagement has identified the following five inner-related key factors for delivering building performance:

- **Aspiration** – set target(s) for operational building performance early in the design process.
- **Control** - ensure that the procurement and delivery process is set up to deliver operational performance at every stage.
- **Design for performance** - determine the building's use and operational components as early as possible to reduce inaccurate assumptions.
- **Feedback** - make sure there is a reciprocal link between operational facilities management (FM) and the design team, and between FM and building occupiers
- **Knowledge** - assemble the necessary knowledge and skills so each part of the supply chain can play its part in delivering the building to the performance standard(s). And check that each has done so.

Case research

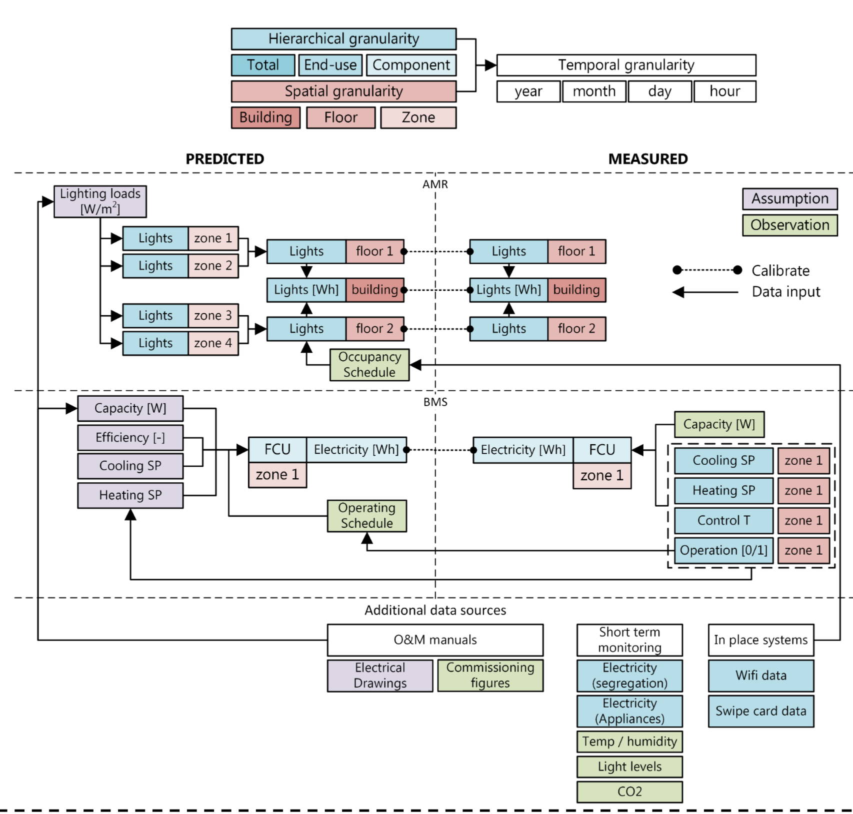
An in-depth case research approach was taken to investigate the discrepancy between predicted and measured energy use for four different case study buildings. A high level of data granularity is established in order to investigate its effect on building model calibration accuracy. Analysis of operational data informed initial model assumptions and supports understanding of typical energy use in the buildings. Sensitivity and uncertainty analysis were used to quantify the uncertainty in model outputs given the uncertainty in inputs and to identify which parameters are significantly affect the model outputs. Due to computational limitations, meta-models were established for efficient analysis, for both meta-model based sensitivity analysis and optimisation.



Data granularity

Hierarchical, Spatial, Temporal

Data needs to be organised in order to systematically compare measurements with predictions and assumptions from energy modelling. Representing all this data therefore requires a hierarchy. That can be analysed at a different spatial and temporal levels.

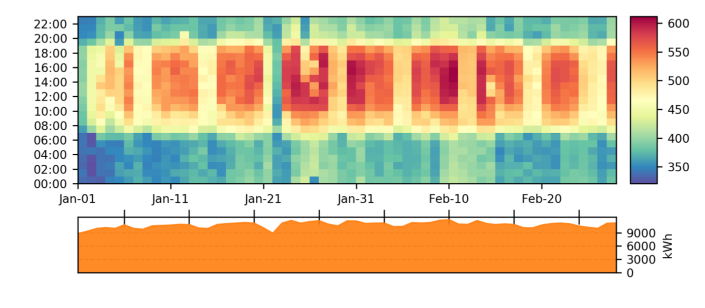


Predicted versus measured performance

Operational data is used for the calibration of building energy models, both for directly comparing the models to measured energy use and indirectly for informing the model by identifying typical patterns of use and analysing the performance of systems.

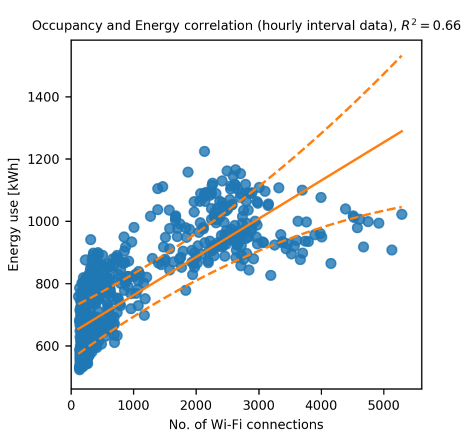
Energy use

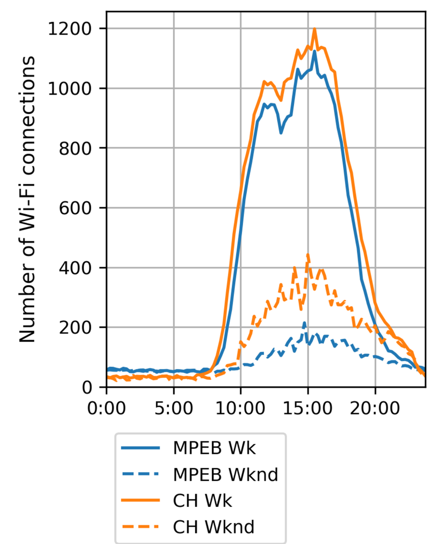
How is energy being used in the building? Disaggregate according to available metering data and replicate with predictions.



Occupancy

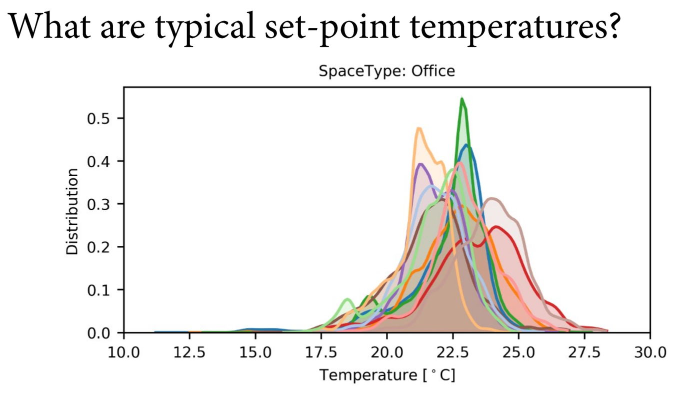
When are people present and how do they influence energy use?



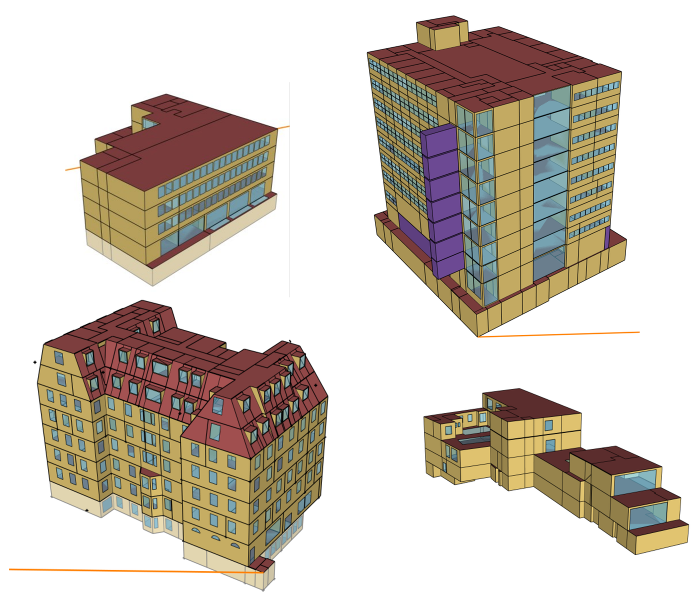


Space temperatures

What are typical set-point temperatures?

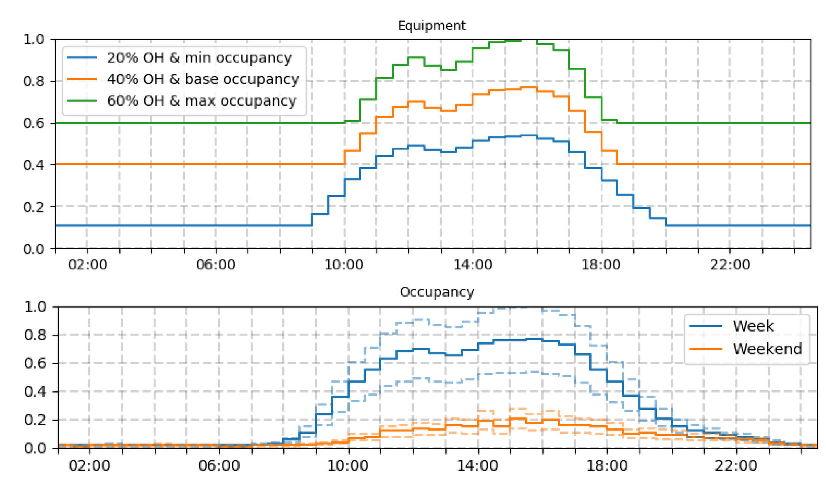


Virtual models

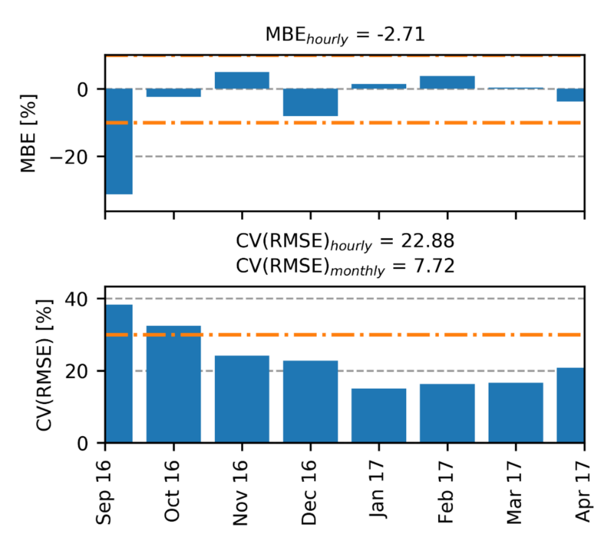


Modelling and parallel simulation

Virtual models of the existing buildings are created, assumptions are based on gathered operational data, existing design information from O&M manuals and building audits. Initially a base case is created where input variables are validated and an initial comparison is made, several iterations are necessary to replicate system behaviour (manual calibration). Parallel simulation create a solution space based on the uncertainty in input variables, which are then used to build meta-models for further analysis.

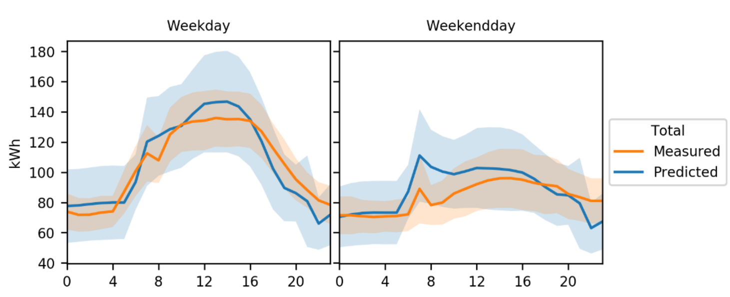


Predicted vs. measured



Meta-model calibration and sensitivity analysis

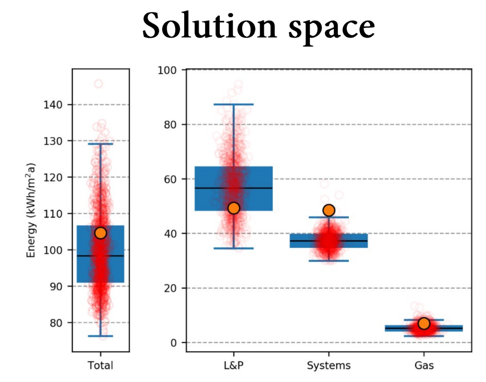
Meta-models are automatically calibrated or optimised towards possible solutions based on criteria that deem a model to be calibrated, and are used for sensitivity analysis.



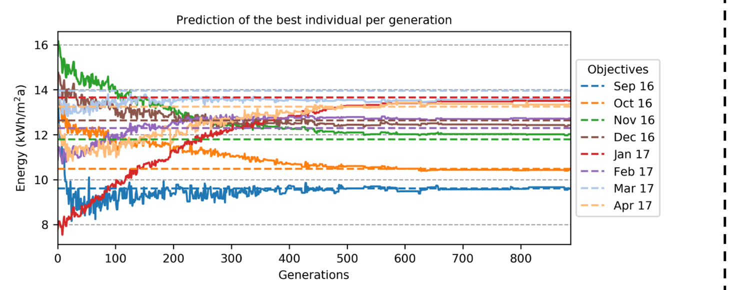
Discussion

Analysing the available operational data supported in determining input parameters and typical schedules, which were found to be essential for effectively calibrating the energy models. Concurrently however, the availability and quality of sub-metering data is sparse, meters are not commissioned properly, are malfunctioning and not correctly labelled, as such it was sometimes impossible to establish a high level of hierarchical and spatial data granularity. Furthermore, the high level of detail established in the models is not pragmatic in an industry context, some simplification in larger buildings will be necessary, and their implications on model accuracy will have to be further investigated.

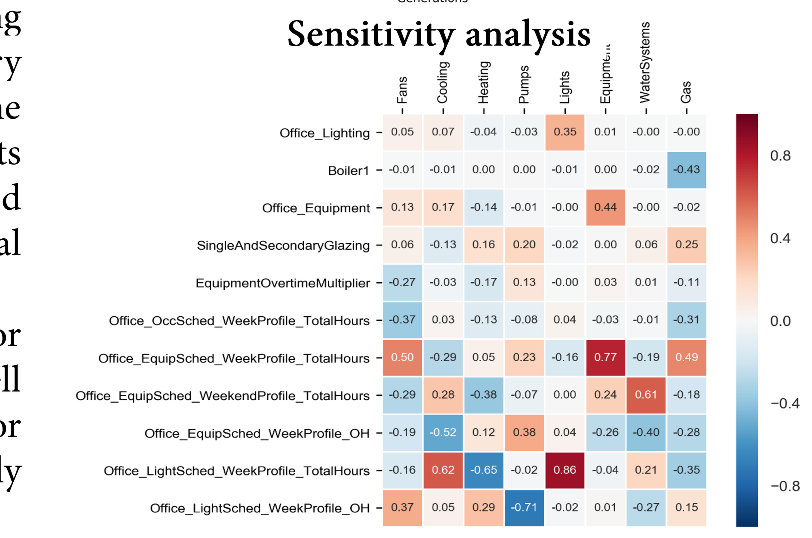
Solution space



Automated calibration



Sensitivity analysis



- The qualitative research into building performance through exploration of industry practices, highlights the importance of the segmentation in the construction industry and its effect on performance. Key factors were identified for improvement, where some of the typical barriers were also identified in the case research.
- The introduction of uncertainty in scheduling for set-points, occupancy and loads has not been well investigated, and proved to be a major contributor to energy use, as such schedules are strongly correlated.
- As such, schedules were found to be the major influencers on energy use in addition to lighting and equipment loads as these are typically the major contributors in non-domestic buildings.
- The use of meta-models proved beneficial for detailed sensitivity analysis and automated calibration. Building retrofit scenarios could be quickly analysed, but are limited the initial inputs and outputs on which the meta-model is based.
- A higher level of data granularity for building calibration was established than what has been typically investigated, this identified some major limitation in previous studies where energy use has been calibrated solely on total energy use, evidently masking the break down into other energy end-uses and interrelation between input parameters.