Using CIBSE TM54 and TM63 to Accurately Assess In-Use Performance in DesignBuilder

Figure 1: Case study building and its DesignBuilder model

Highlights:

- Using results of building regulation compliance models as a projection of actual energy use is not appropriate as it generally leads to significant underestimates.
- In school buildings, some of the root causes of design stage projected energy use underestimation are diverse operations, system use and occupant behaviour, which are typically very different from those used in the design stage model inputs.
- The study used DesignBuilder software for the building simulation model which made it easy to model its unique pre-fabricated facade and shading design.
- Subsequent iterative fine tuning was also carried out in DesignBuilder to develop a calibrated model, in line with CIBSE TM63 measurement and verification procedures.
- To assist in the model tuning, a pre-release version of DesignBuilder Climate Analytics tool was used to obtain real weather data in .epw file format for the period under performance review.
- DesignBuilder scripting tools were used to speed up the model tuning process.

Study Details

Objective: To assess the design stage projections and in-use performance, and subsequently identify various causes of the performance gap through a calibrated energy performance model.

Case study: A new teaching building in a secondary school buildings complex, finished in 2014. Floor area of ~5000 m^2, 4 floors and external envelope made of prefabricated concrete panels.

Location: London, United Kingdom.

Systems: Heating is provided by a centralised plant for the entire campus via a pressurised LTHW system. Annual DHW demand is provided by a biomass boiler and two gas fired boilers provide backup for heating and DHW. Cooling is only provided to ICT and server rooms by a VRF system. The mechanical ventilation system includes heat recovery, and all systems are controlled and managed via a Building Management System (BMS).

Building Performance and Modelling

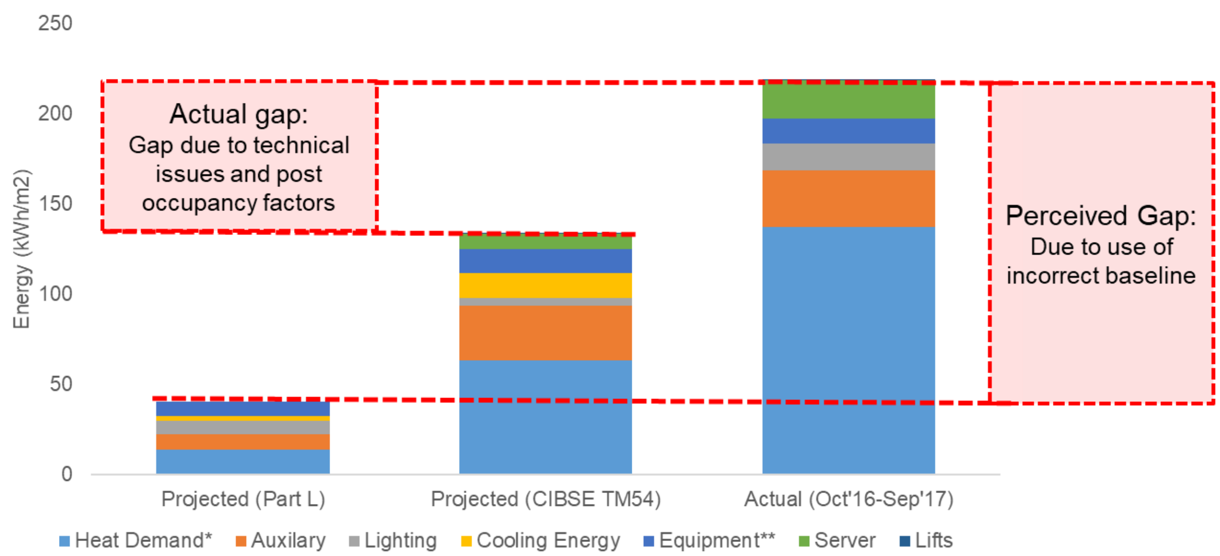
The design stage projection of energy performance was undertaken as part of a UK Part L Building regulations compliance assessment at RIBA Stage 3. However, there is a significant underestimation of energy use in the design stage Part L calculations when compared with actual energy use (Figure 2). The *perceived gap* between predicted results (for "certification" purposes) and actual energy use is to be expected, as the predicted results were calculated using the UK National Calculation Methodology (NCM). The NCM's purpose is for benchmarking, not for accurate prediction, and for that reason it makes some significant simplifications.

The main reasons for the discrepancy were identified as:

- The compliance calculations are primarily aimed at benchmarking use NCM default power densities for pumps.
- Some of the key energy use areas such as equipment, server and lift were not included in the total projections.
- The occupancy and operational profile of the building was also calculated based on NCM defaults which, in real scenarios, can be significantly different.

The CIBSE TM54 modelling approach for design projection requires all end uses to be accounted for and is based on realistic operating patterns and behaviours. Therefore, to retrospectively project energy use based on design stage knowledge and assumptions, a detailed simulation model was developed in DesignBuilder, using the CIBSE TM54 methodology. The flexible modelling tools in DesignBuilder allowed the building with its complex shading and façade system to be modelled easily and accurately.

Figure 2 below shows that while CIBSE TM54 calculation results are still not very close to actual energy use, they are significantly better than Part L calculations. The remaining gap, i.e., the *actual gap* is predominantly caused by technical issues. Note that *perceived gap* and *actual gap* are technical terms defined in CIBSE TM61 and TM63.



*Heat demand used instead of heating energy; **Equipment includes cooling and heating energy use of VRF system in some zones.

Figure 2: Comparison of projected (Part L), projected (CIBSE TM54) and actual energy use of Building 4

Reasons for the performance gap

Post occupancy site visit observations, interviews with the facility managers and analysis of metered and monitored data revealed many deviations from the design stage intent which are probable causes of the performance gap. Most of the 'actual' performance gap, was due to suboptimal operation and irregular maintenance of building systems. This was partly due to a centralised system design and lack of user-friendly BMS controls to manage it. Besides this, procurement/handover stage issues such as using less efficient fans, more small power equipment, and not using biomass boilers also contributed to the gap.

Many of the technical issues regarding building systems are specific to this case study, however the wider issue of optimal operation and maintenance of building systems for better energy and IEQ will apply equally to other schools.

Use of modelling to ascertain the main causes of the gap

As described in CIBSE TM63, it is not certain that the technical issues uncovered in a building reflect all or most of the key causes of the performance gap. It is likely that one or two key issues are identified during investigations whilst other potential issues are not covered.

Developing a calibrated thermal simulation model with the actual operation ensures that the uncovered issues can explain the actual performance with reasonable accuracy and therefore the deviations from the design model can help identify all the major causes of the gap.

Therefore, to ensure that the performance gap findings can explain most of the deviation between design and actual performance, the DesignBuilder baseline model was calibrated as per ASHRAE Guideline 14 monthly calibration criteria of CV(RMSE) <15% and NMBE<±5%.

To calibrate the simulation model, changes were made to occupancy patterns, equipment load, lighting load, set-point temperatures and suboptimal out of hours operation of lighting equipment and ventilation systems. Figure 3 shows calibrated electricity use and heat demand respectively. The calibrated model result had a CV(RMSE) and NMBE of 4.6% and 1.9% for electricity use and a CV(RMSE) and NMBE of 5.6% and -2.6% for heat demand.

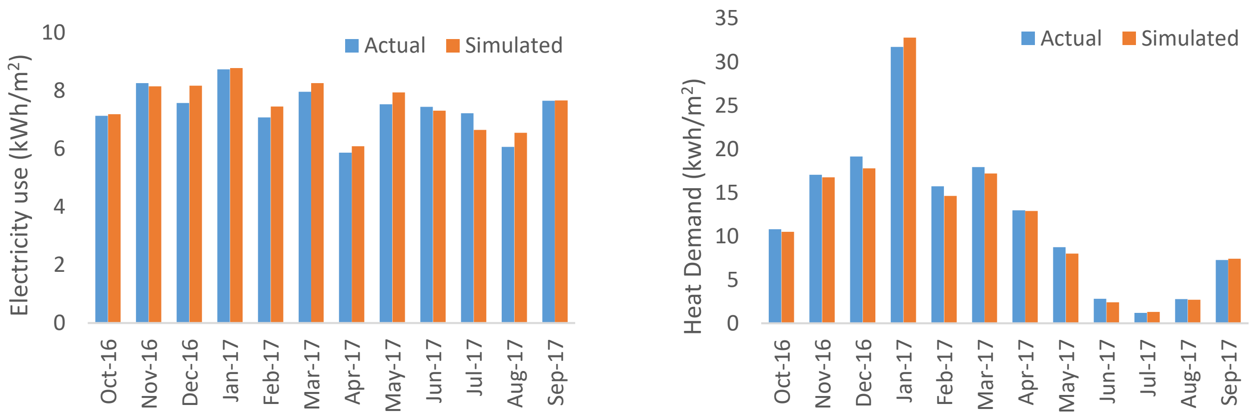


Figure 3: Simulated vs actual monthly electricity use (left) and heat demand (right)

Actual weather as per station and satellite measurements for Kew-in-London (WMO: 37750) for the calibration period was obtained from the pre-release version DesignBuilder Climate Analytics tool and was used in the simulations.

Also, DesignBuilder scripting tools that allow EMS, Python or C# code to be used to process the model were used to help generate custom outputs for easy comparison with sub-meters and to speed up iterative fine tuning of multiple custom input parameters instead of changing them in the main modelling interface (Figure 4).

```
! extra outputs for viewing in the results viewer
<If BuildingAttribute HourlyOutput = 1 Then>
Output:Variable, *, Zone Air CO2 Concentration, hourly;
<Endif>
<If BuildingAttribute TimesteplyOutput = 1 Then>
Output:Variable, *, Zone Air CO2 Concentration, timestep;
<Endif>


EnergyManagementSystem:ProgramCallingManager,
   DCV Mec Vent,
   BeginTimestepBeforePredictor,
   MyComputedHeatingSetpointProg,
   BSLightEnergy,
   BSPowerEnergy,
   BSLiftEnergy,
   BSServerEnergy,
   DCVMecVent;

EnergyManagementSystem:Program,
    DCVMecVent,
   ! add program code
<ForAllOccupiedHeatedZones>
   If Zone_Air_CO2_Concentration_<LoopZoneVariableName> > 1500 || Zone_Air
      Set Schedule_Value_<LoopZoneVariableName>_MV = 1,
   Else,
      If Month == 10 && (DayOfWeek >= 2) && (Hour > 7) && (Hour < 18),
         Set Schedule_Value_<LoopZoneVariableName>_MV = 1,
      Elseif Month == 11 && (DayOfWeek >= 2) && (Hour > 7) && (Hour < 17),
         Set Schedule_Value_<LoopZoneVariableName>_MV = 1,
      Elseif Month == 12 && (DayOfWeek >= 2) && (Hour > 7) && (Hour < 17),
         Set Schedule_Value_<LoopZoneVariableName>_MV = 1,
      Elseif Month == 1 && (Hour > 5) && (Hour < 18),
         Set Schedule_Value_<LoopZoneVariableName>_MV = 1,
      Elseif Month == 2 && (DayOfWeek >= 2) && (Hour > 7) && (Hour < 18),
         Set Schedule_Value_<LoopZoneVariableName>_MV = 1,
      Elseif Month == 3 && (DayOfWeek >= 2) && (Hour > 7) && (Hour < 18),
         Set Schedule_Value_<LoopZoneVariableName>_MV = 1,
      Elseif Month == 4 && (DayOfWeek >= 2) && (Hour > 7) && (Hour < 15),
```

```
EnergyManagementSystem:Actu
   Schedule_Value_BS_CIRCUL
   BS_CIRCULATION_LIGHT,
   Schedule:Compact,
   Schedule Value;

EnergyManagementSystem:Actu
   Schedule_Value_BS_SERV_LI
   BS_SERV_LIGHT,
   Schedule:Compact,
   Schedule Value;

EnergyManagementSystem:Actuator,
   Schedule_Value_BS_STORE_LIGHT,
   BS_STORE_LIGHT,
   Schedule:Compact,
   Schedule Value;

EnergyManagementSystem:Actuator,
   Schedule_Value_BS_TOILET_LIGHT,
   BS_TOILET_LIGHT,
   Schedule:Compact,
   Schedule Value;

<ForAllOccupiedHeatedZones>
EnergyManagementSystem:Sensor,
   Zone_Air_CO2_Concentration_<LoopZoneVariableName>,
   <LoopZoneIDFName>,
   Zone Air CO2 Concentration;
```

```
EnergyManagementSystem:Program,
   MyComputedHeatingSetpointProg,

   IF Month == 10,
      IF (Hour > 5) && (Hour < 18),
      <ForAllOccupiedHeatedZones>
            Set Schedule_Value_<LoopZoneVariableName>_HSP = 22.0,
      <LoopNextZone>
      Else,
      <ForAllOccupiedHeatedZones>
            Set Schedule_Value_<LoopZoneVariableName>_HSP = 21.0,
      <LoopNextZone>
      Endif,
   Elseif Month == 11,
      IF (DayOfWeek >= 2) && (Hour > 5) && (Hour < 18),
      <ForAllOccupiedHeatedZones>
            Set Schedule_Value_<LoopZoneVariableName>_HSP = 22.0,
      <LoopNextZone>
      Else,
      <ForAllOccupiedHeatedZones>
            Set Schedule_Value_<LoopZoneVariableName>_HSP = 21.0,
      <LoopNextZone>
      Endif,
   Elseif Month == 12,
      IF (Hour > 5) && (Hour < 18),
      <ForAllOccupiedHeatedZones>
            Set Schedule_Value_<LoopZoneVariableName>_HSP = 23.0,
      <LoopNextZone>
```

Figure 4: DesignBuilder scripting tools screenshots enabled custom variables and outputs for faster iterative fine tuning.

Lessons Learnt

The work presented here provides a useful demonstration of modelling and calibration based operational performance assessment in accordance with CIBSE TM63. Some lessons arising from the work can potentially be used to project energy simulation results at the design stage, with applicability to other schools and building types:

- Design projections of energy performance should use CIBSE TM54 guidelines to account for all end uses in the building alongside realistic operating patterns and occupant behaviour.
- The changing trend of schools' occupancy patterns, beyond regular school hours and term times, needs to be considered when estimating performance.

More detailed operational performance analysis of this case study for energy and IEQ along with discussions on the role of data granularity and validation of these calibrated models can be found in some academic papers here and here.