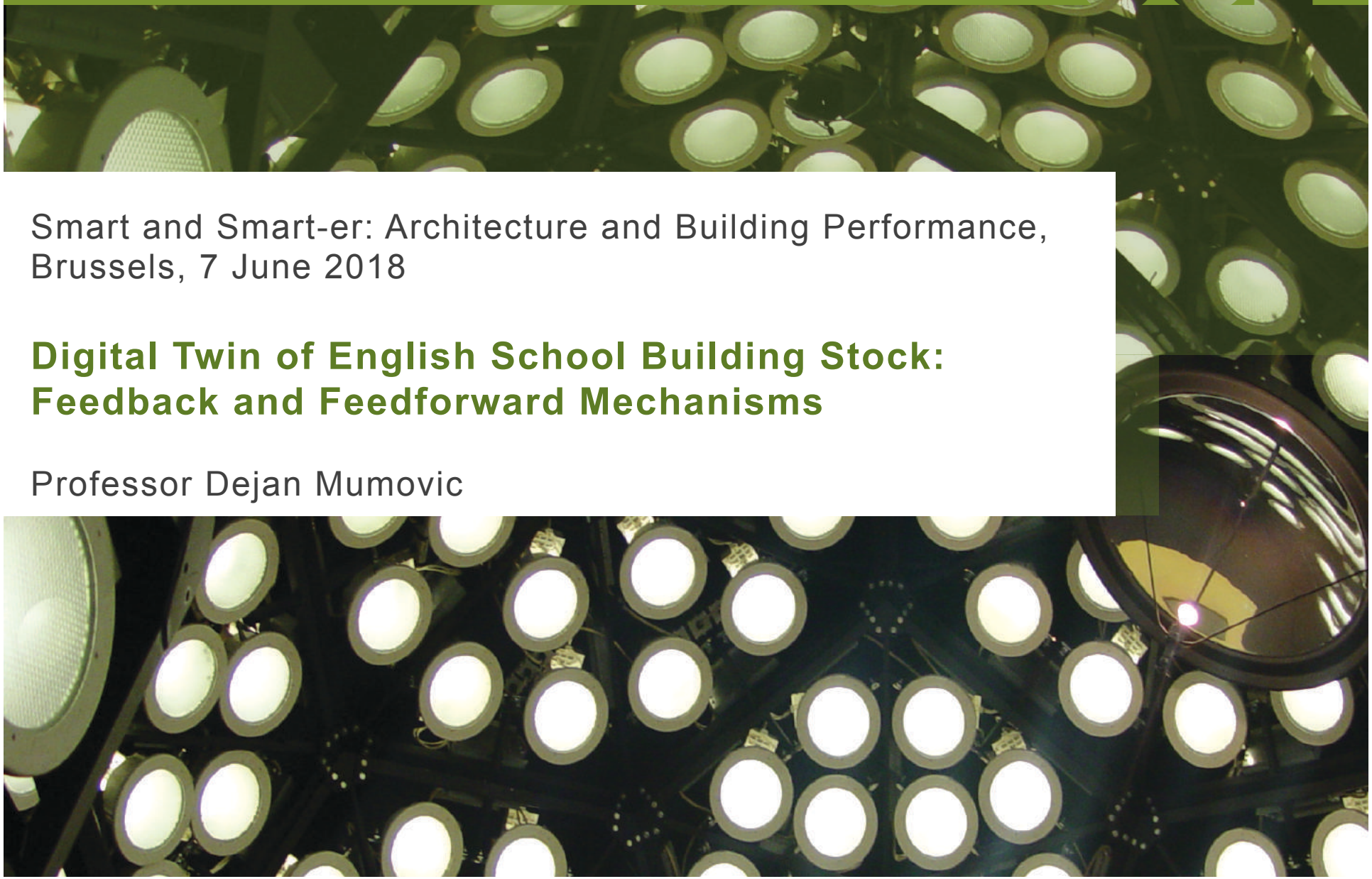
UCL Institute for Environmental Design and Engineering



Smart and Smart-er: Architecture and Building Performance, Brussels, 7 June 2018

Digital Twin of English School Building Stock: Feedback and Feedforward Mechanisms

Professor Dejan Mumovic

REDUCE ENERGY DEMAND
SMART METERING
BUILDING CONTROLS
ON-SITE RENEWABLES
ENERGY STORAGE CAPACITY
DEMAND RESPONSE CAPACITY
DECARBONIZE HEATING & COOLING
SMART CITY INFRASTRUCTURE (E-VEHICLES)

BUILDING LEVEL. CITY LEVEL. ENERGY.

THE ANSWER IS TECHNOLOGY.

THE ANSWER IS TECHNOLOGY.
WHAT WAS THE QUESTION AGAIN?

Why we need digital twins?

23,122 schools

£ 645,743,961 Maintenance (2012)

£ 410,185,246 Energy (2012)

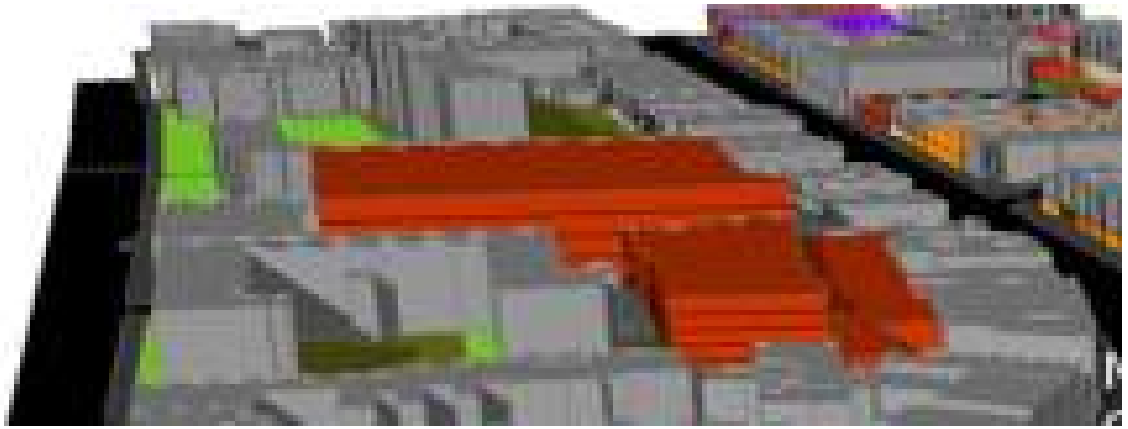
£ 28,650,536,841 Total Expenditure

1.4% spent on energy

2.3% on maintenance and improvement

3DStock

3DStock



- Ordnance Survey (OS) data polygon geometry
- Properties height (LiDAR)
- Surrounding context: Adjacent structures, shading

3DStock

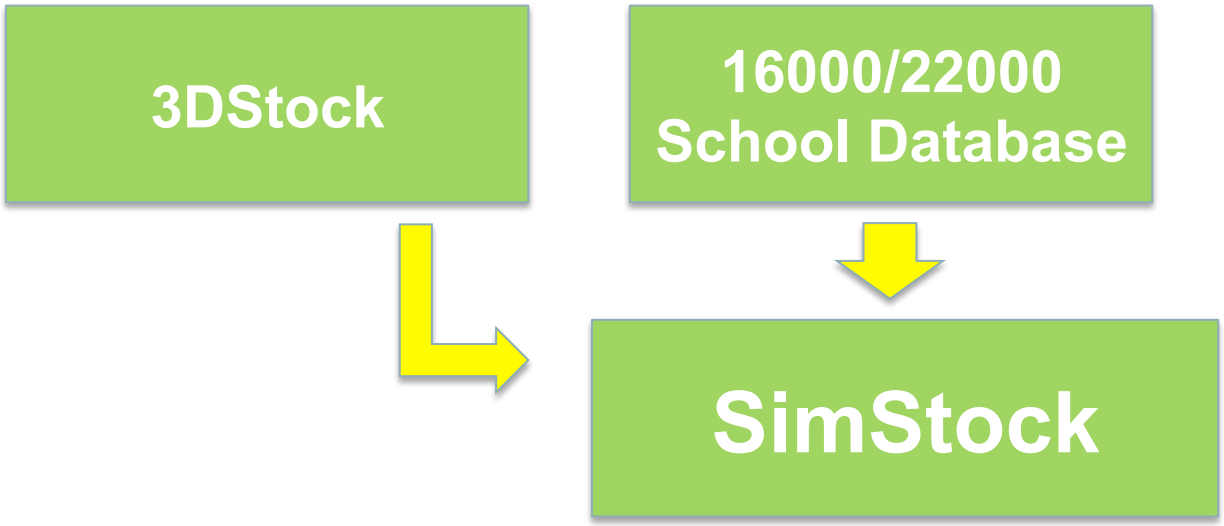
16000/22000 School Database

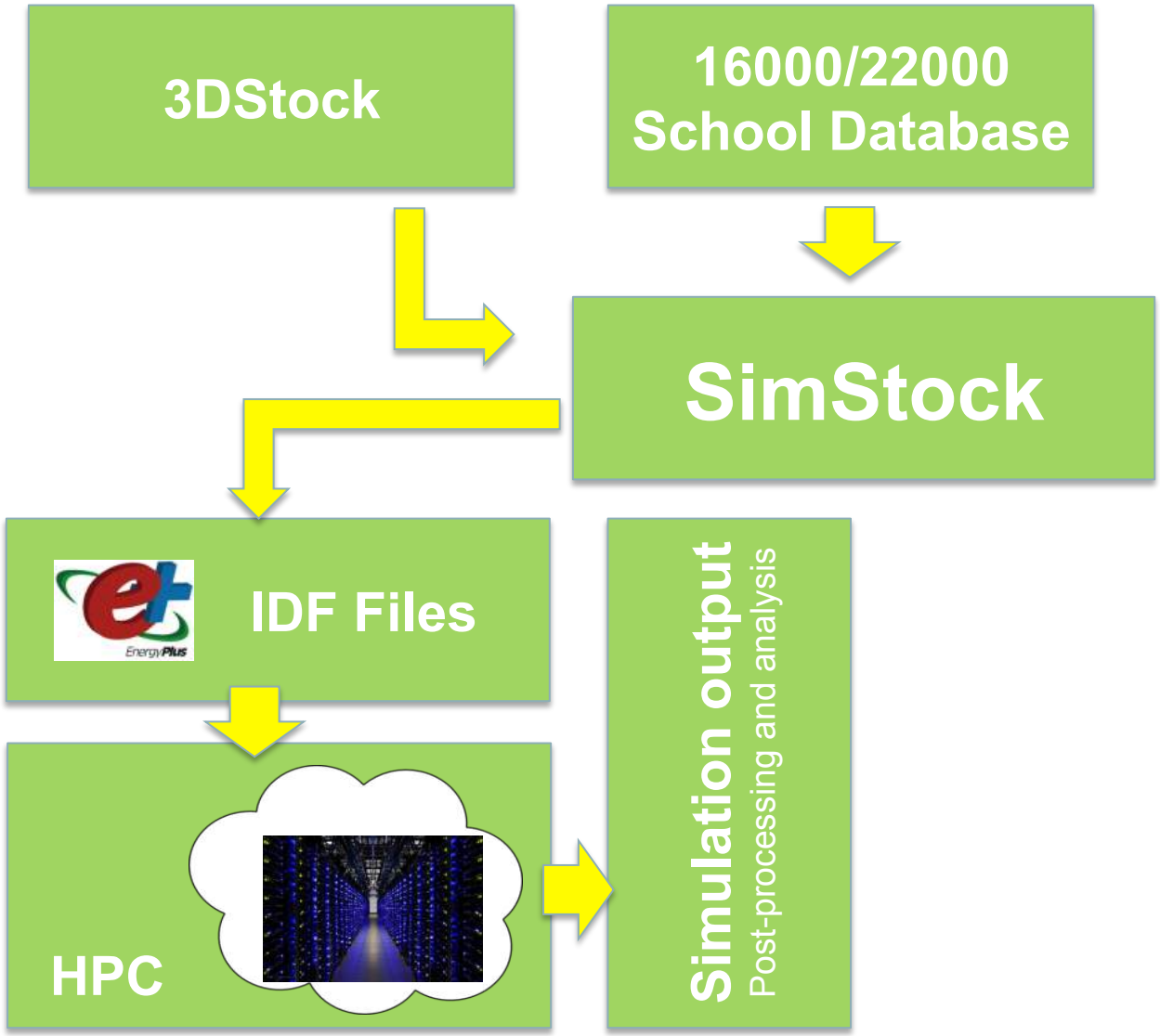
3DStock

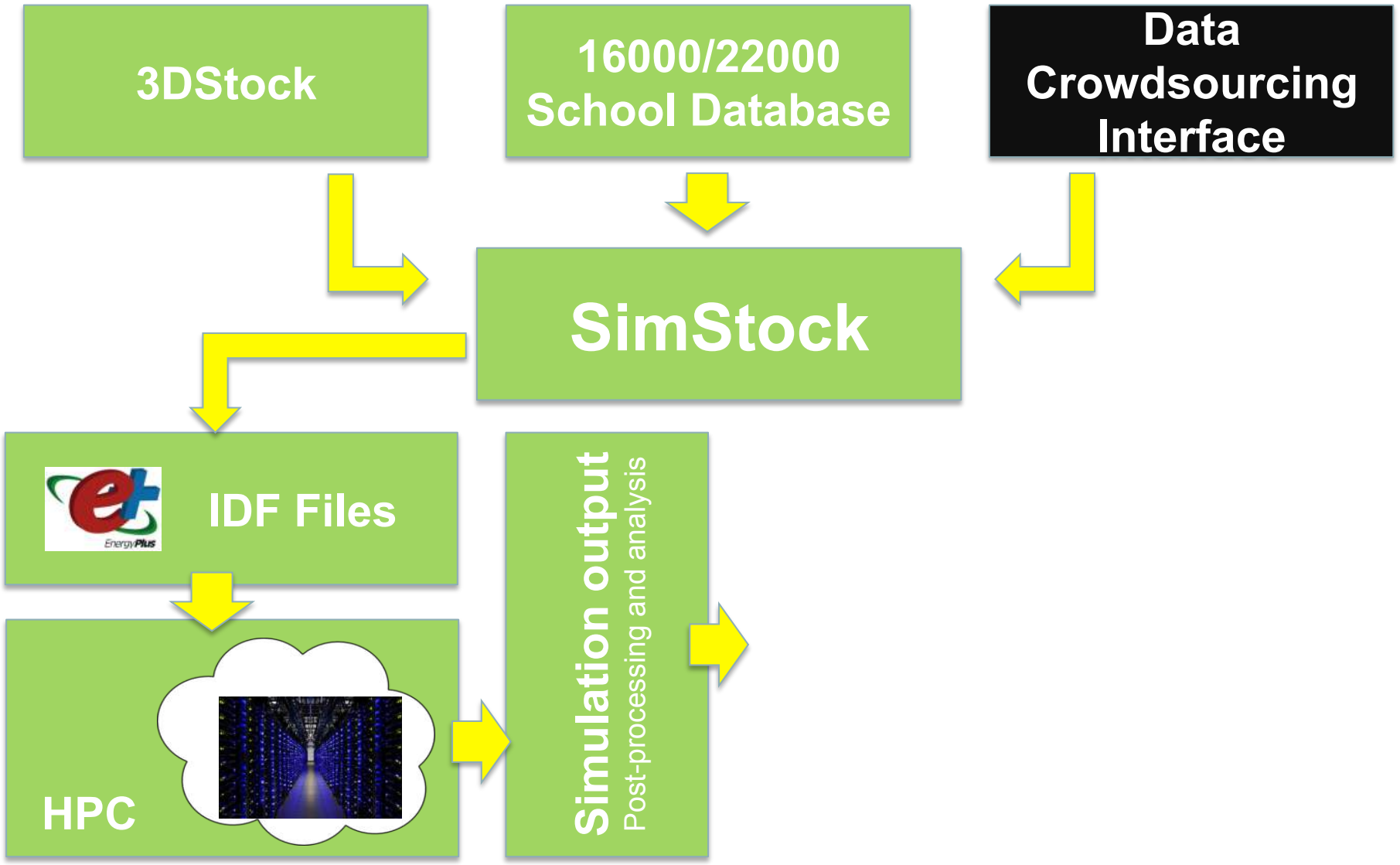
16000/22000 School Database

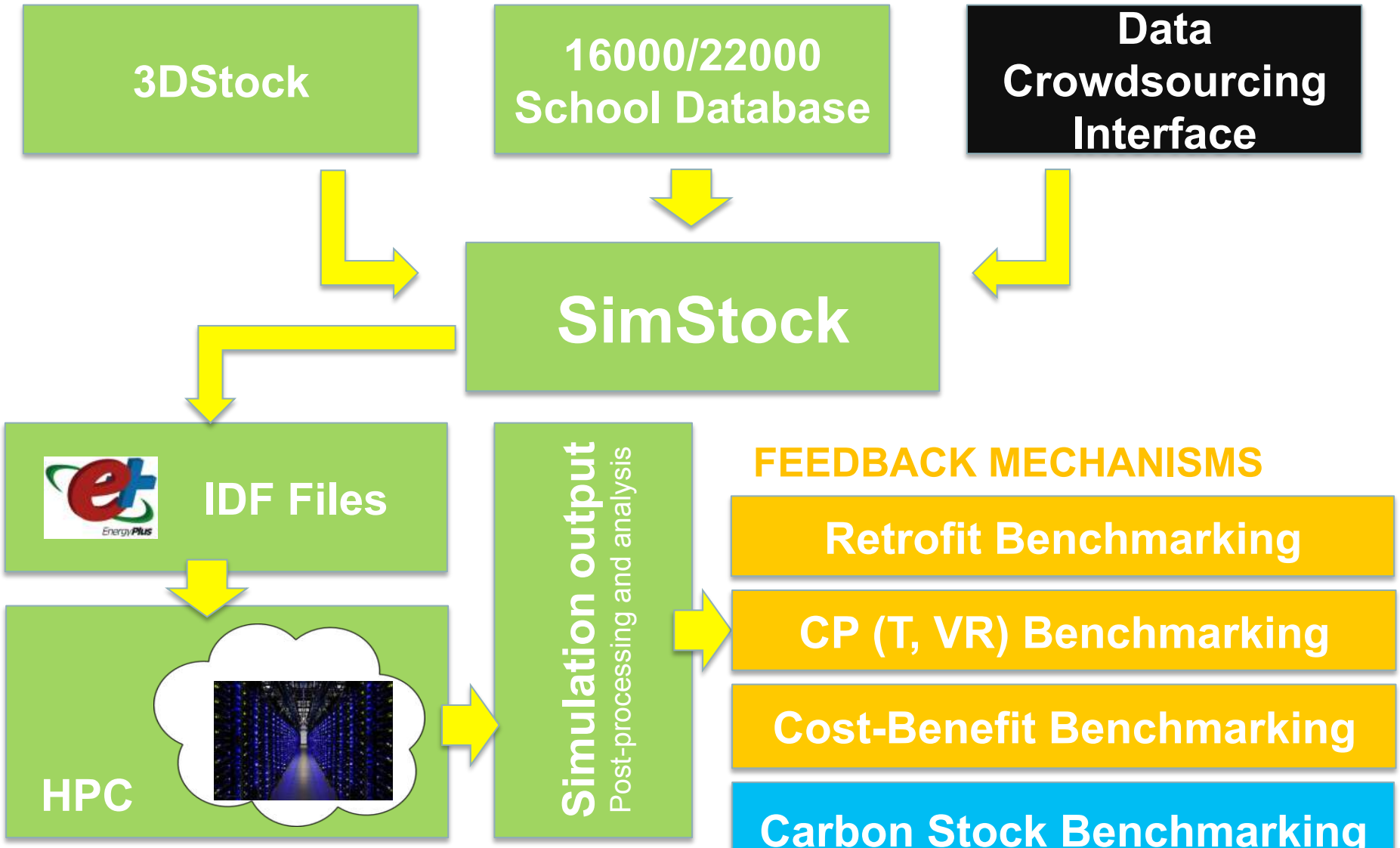
16000/22000 School Database:

- Construction elements specifications (walls, roofs, glazing, etc.)
- Glazing (type of glazing and window-to-wall ratio (WWR))
- Building airtightness and ventilation strategies (natural, mechanical)
- Occupancy schedules
- Appliances power intensity and schedules
- HVAC system types and control (temperature setpoints, part load efficiency, time of operation)

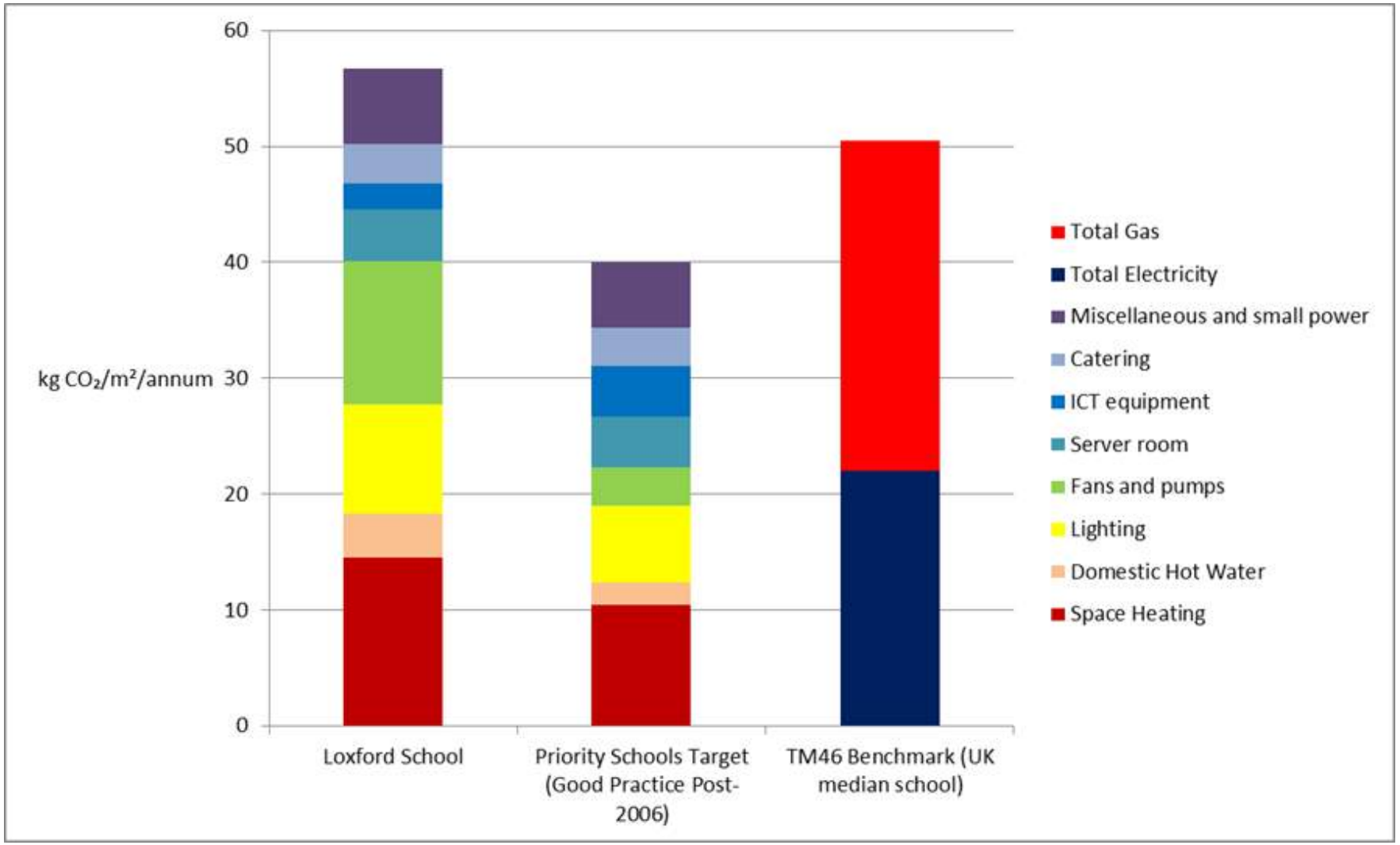

3DStock
16000/22000
School Database
SimStock


3DStock
16000/22000
School Database
SimStock
IDF Files
HPC
Simulation output
Post-processing and analysis

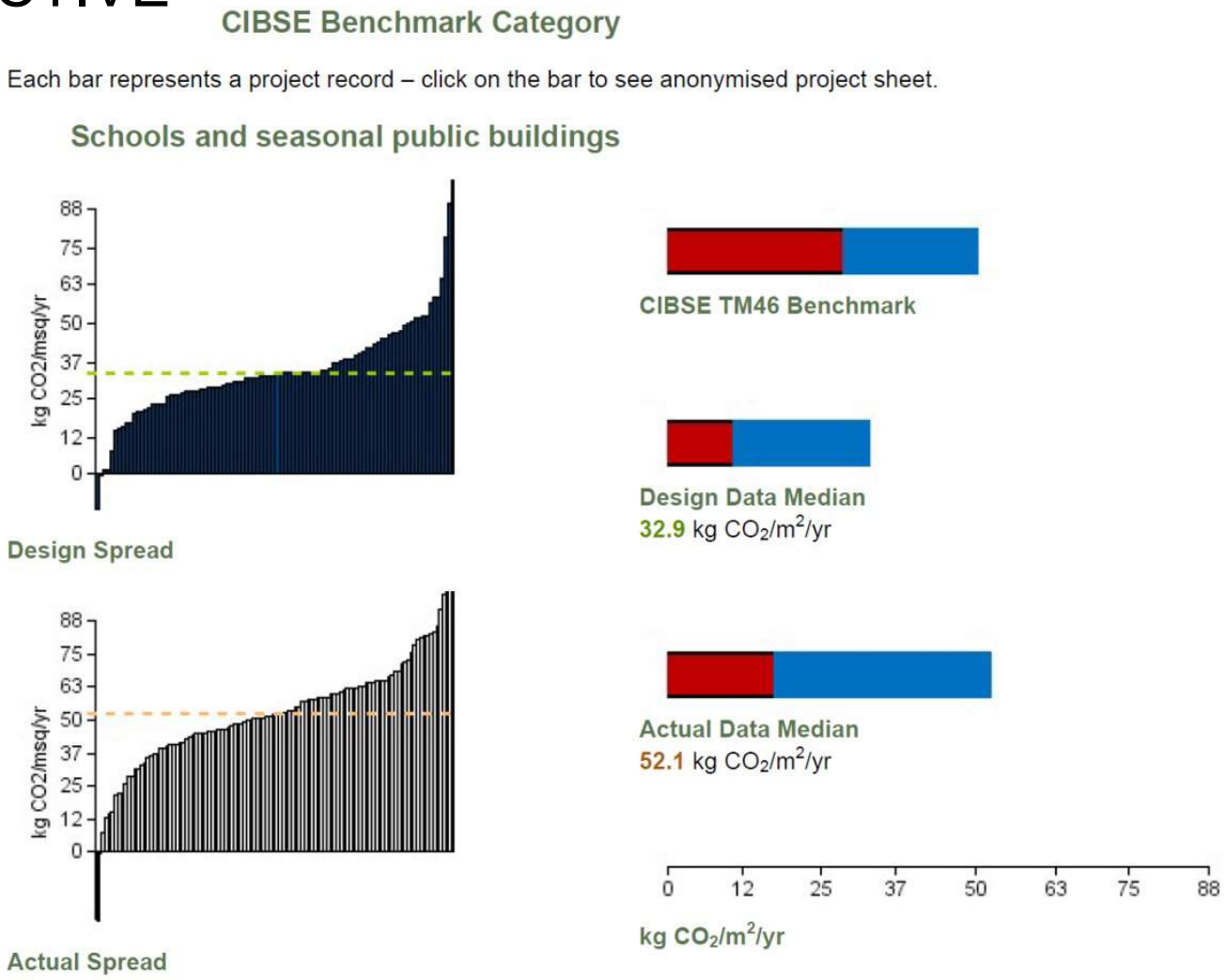

3DStock
16000/22000 School Database
Data Crowdsourcing Interface
SimStock
IDF Files
HPC
Simulation output
Post-processing and analysis


3DStock
16000/22000 School Database
Data Crowdsourcing Interface
SimStock
IDF Files
HPC
Simulation output
Post-processing and analysis
FEEDBACK MECHANISMS
Retrofit Benchmarking
CP (T, VR) Benchmarking
Cost-Benefit Benchmarking
Carbon Stock Benchmarking
FEEDFORWARD MECHANISM

FEEDBACK MECHANISMS: DIGITAL TWIN OF A SCHOOL

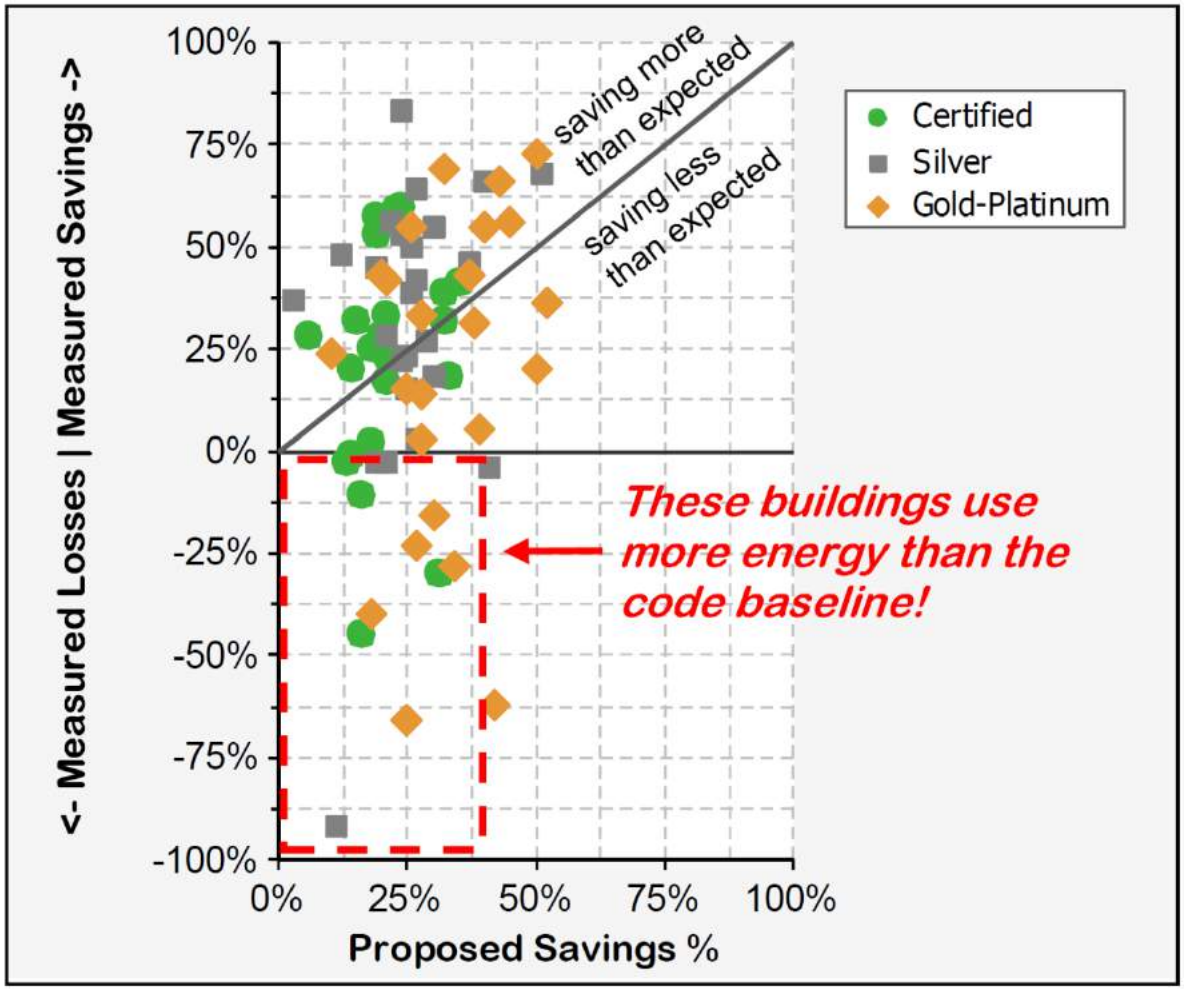

60
50
40
30
20
10
0
kg CO₂/m²/annum
Loxford School
Priority Schools Target (Good Practice Post-2006)
TM46 Benchmark (UK median school)
Total Gas
Total Electricity
Miscellaneous and small power
Catering
ICT equipment
Server room
Fans and pumps
Lighting
Domestic Hot Water
Space Heating

PERFORMANCE GAP IN THE UK: REGULATORY PERSPECTIVE



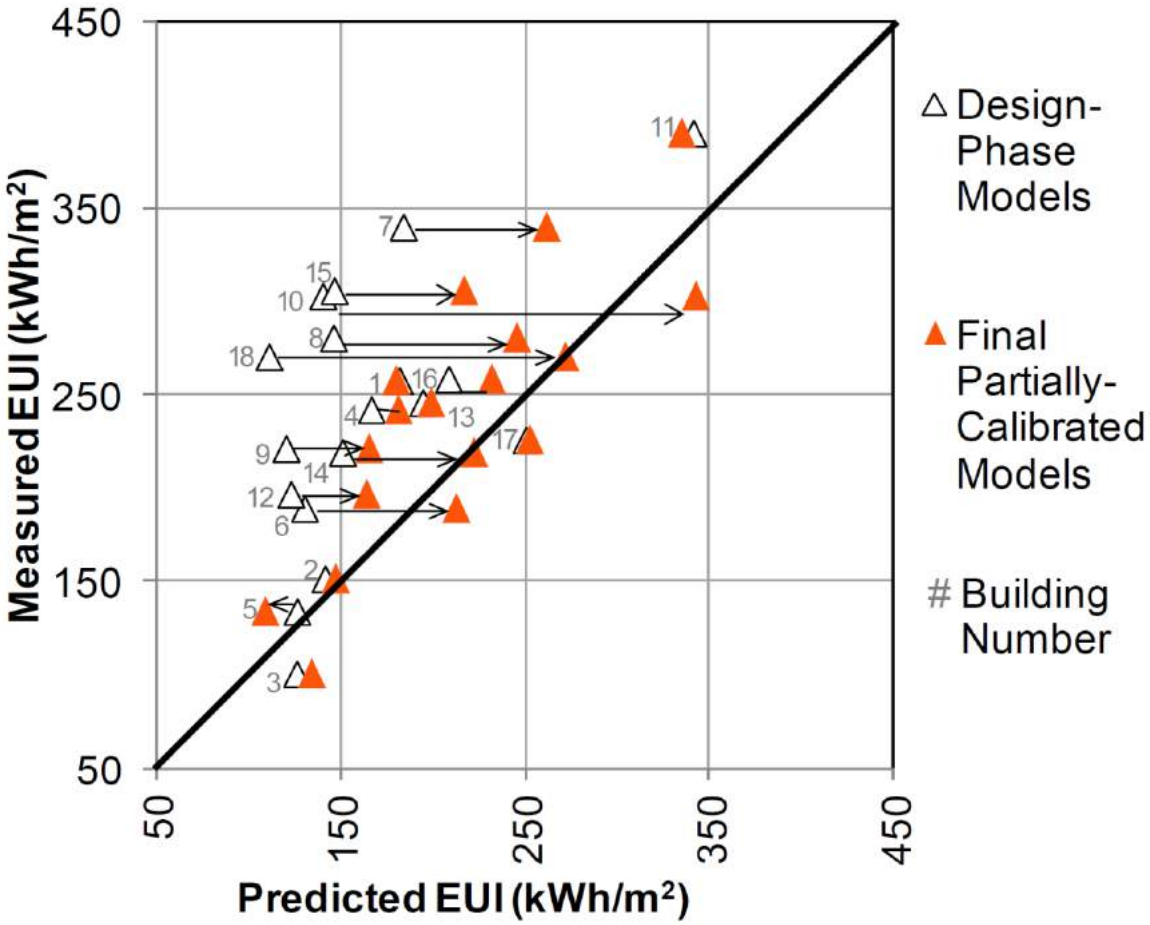
Source: http://www.carbonbuzz.org

STATIC NOTION OF PERFORMANCE GAP: DESIGN VS. ACTUAL OPERATION



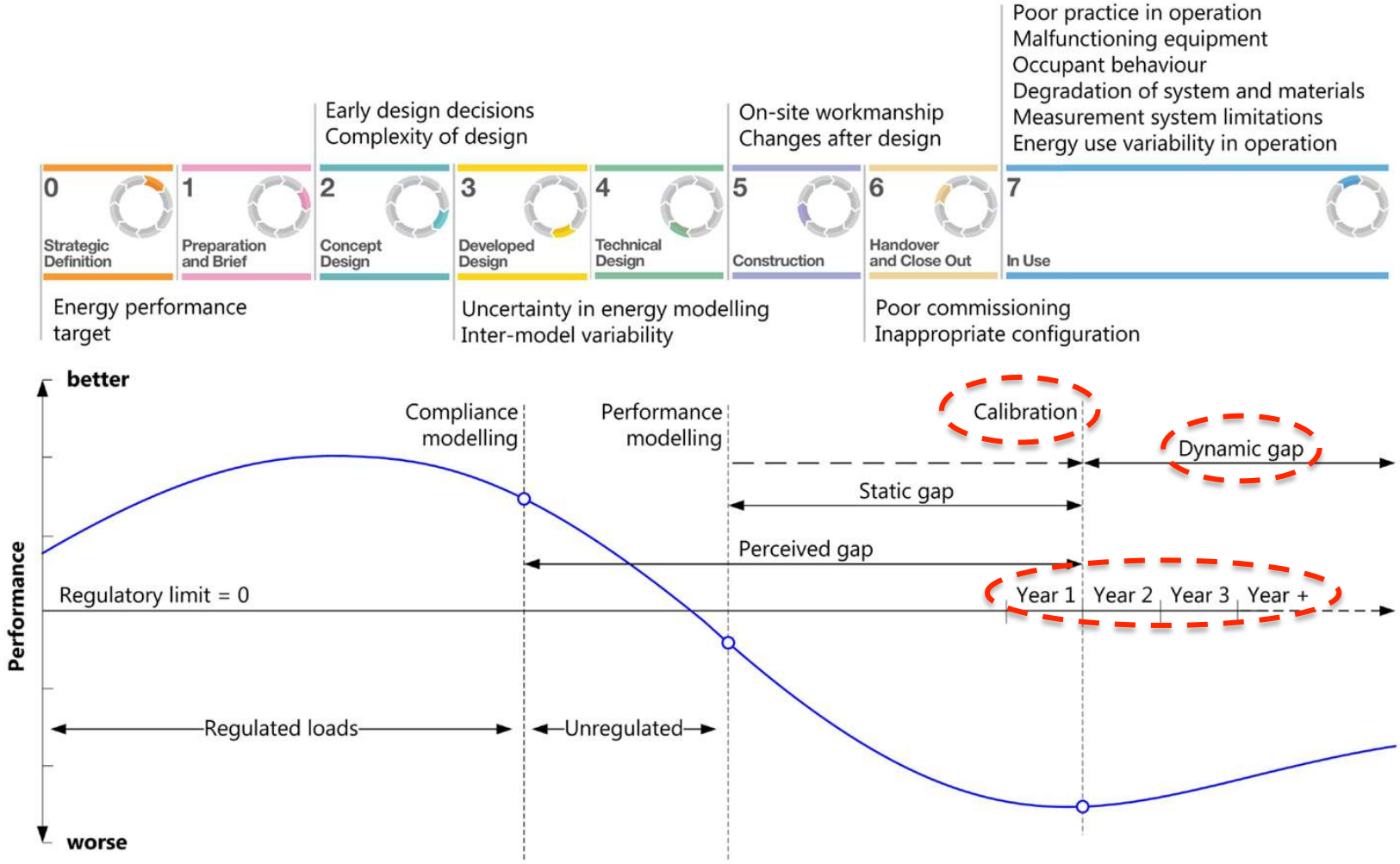
Source: Turner and Frankel, 2008. Energy Performance of LEED for New Construction Buildings.

TOWARDS A DYNAMIC UNDERSTANDING OF THE PERFORMANCE GAP



Source: Samuelson et al., 2014. Post-Occupancy Evaluation and Partial-Calibration of 18 Design-phase
Energy Models, ASHRAE/IBPSA-USA Building Simulation Conference.

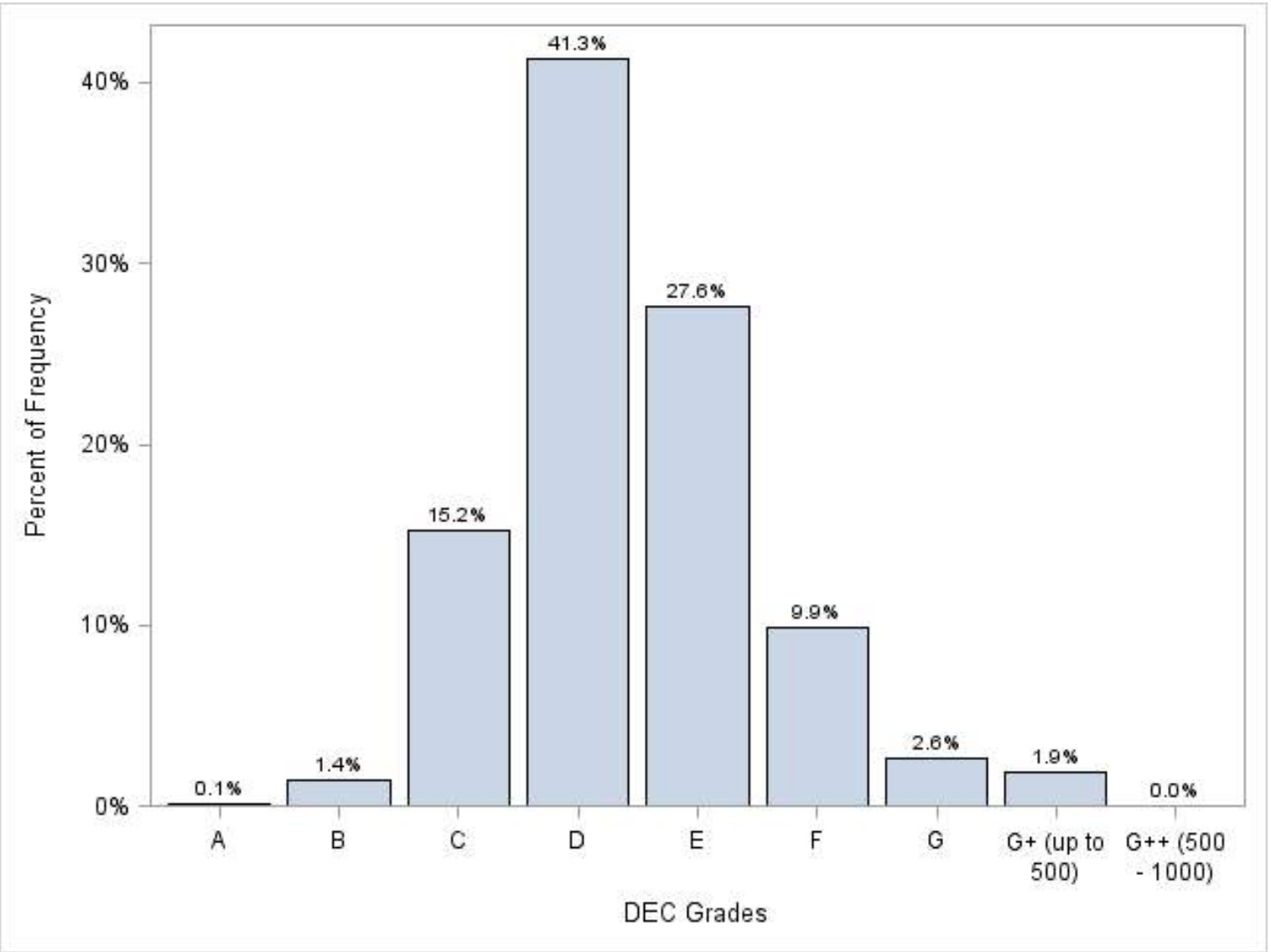
LONGITUDINAL VIEW OF THE PERFORMANCE GAP



Source: Dronkelaar, C., Dowson, M., Burman, E., Spataru, C., and Mumovic. D., 2016. *A review of the energy performance gap and its underlying causes in non-domestic buildings*, Frontiers in Mechanical Engineering – Indoor Environment.

DIGITAL TWIN OF ENGLISH SCHOOL BUILDING STOCK: FEEDFORWARD MECHANISMS

DEC Grade Distribution

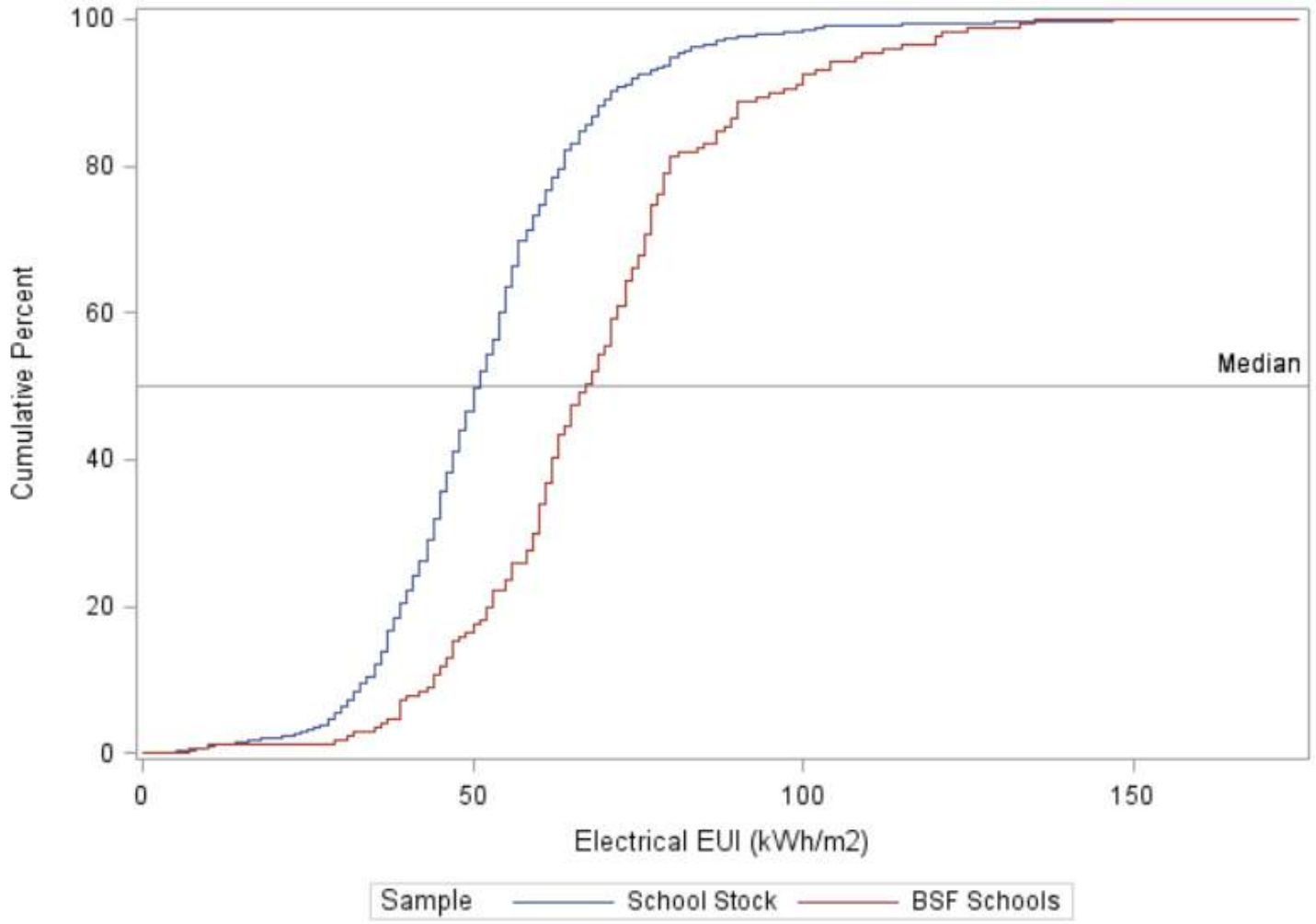


Energy Performance

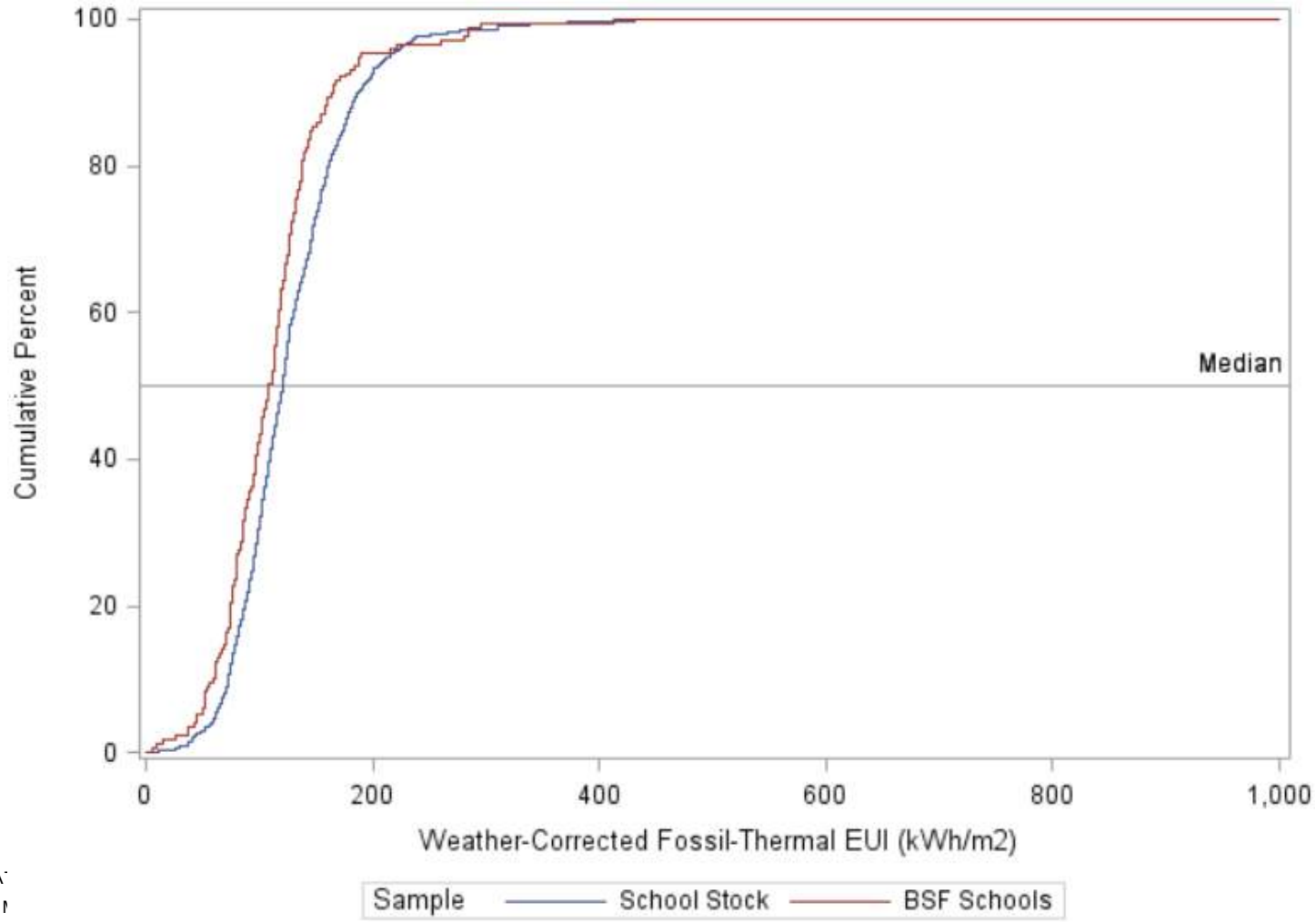
Electrical EUI	
Level	Quantile
100% Max	441
99%	107
95%	80
90%	70
75% Q3	57
50% Median	46
25% Q1	38
10%	30
5%	26
1%	15
0% Min	1

Fossil-thermal EUI	
Level	Quantile
100% Max	1549
99%	313
95%	224
90%	192
75% Q3	152
50% Median	119
25% Q1	91
10%	70
5%	58
1%	31
0% Min	1

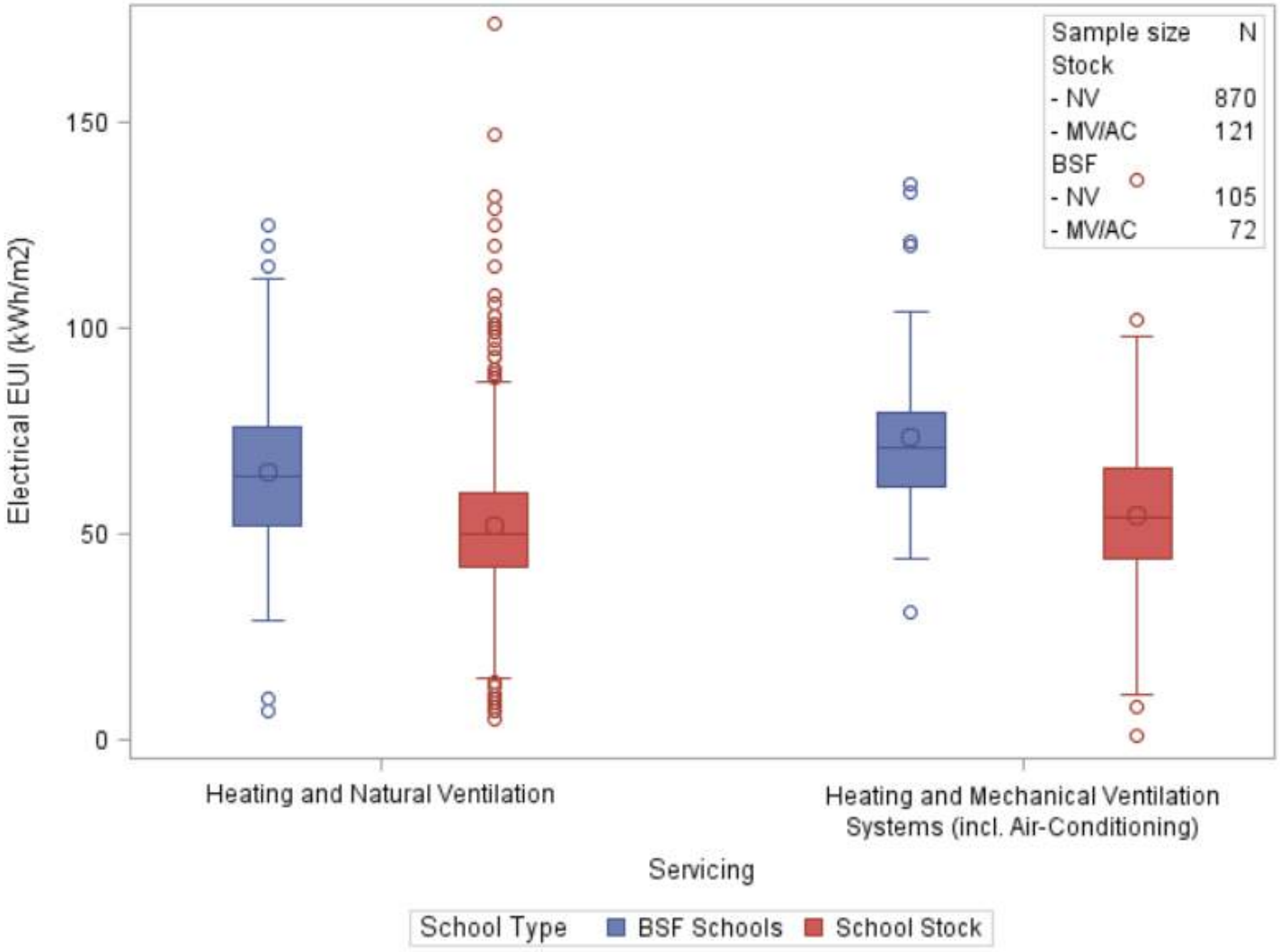
Cumulative frequency distribution of **electrical EUI** of the **school stock** and **BSF Schools**



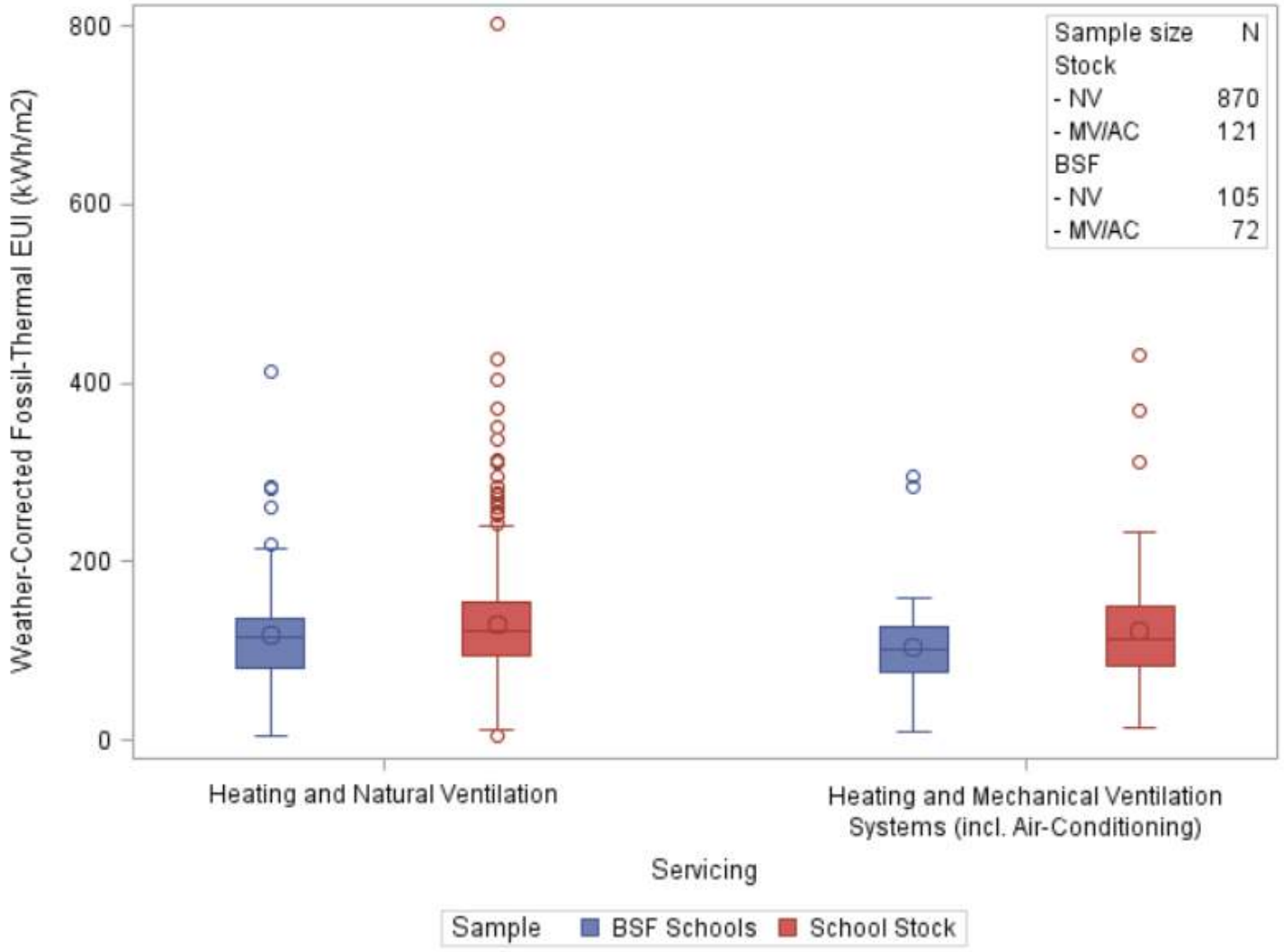
Cumulative frequency distribution of **fossil-thermal EUI** of the **school stock** and **BSF Schools**

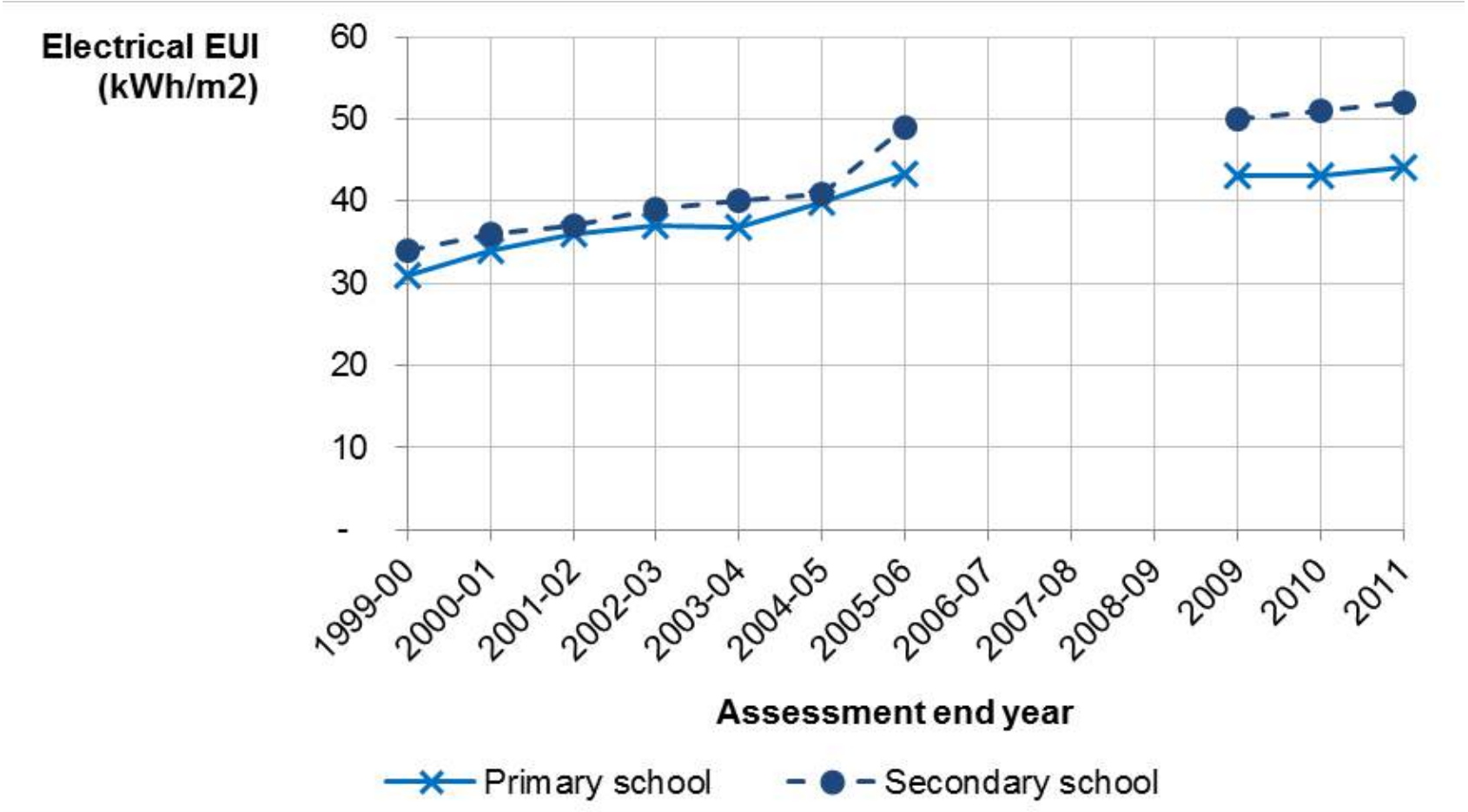


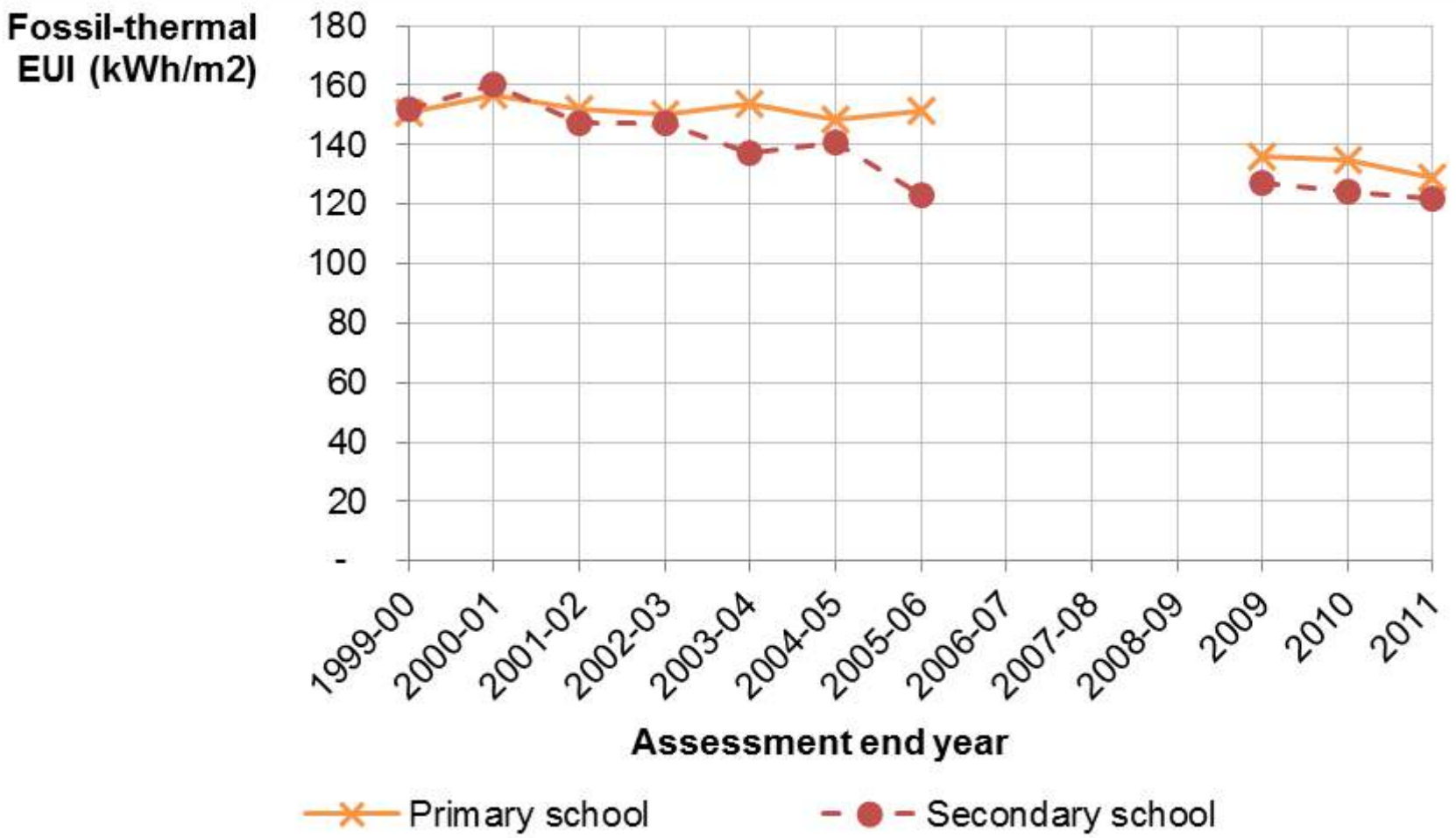
Comparison of **electrical EUI** of schools by **servicing strategies**



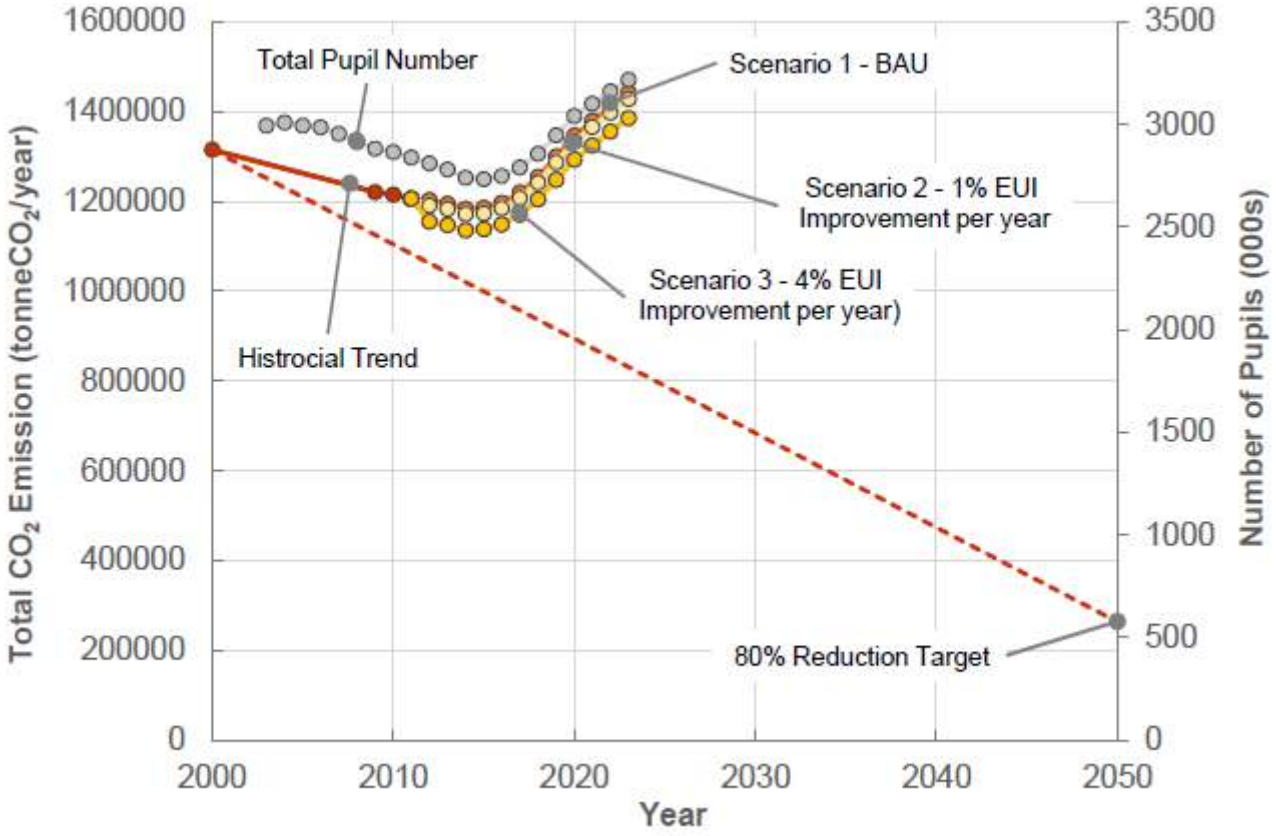
Comparison of **fossil-thermal EUI** of schools by **servicing strategies**



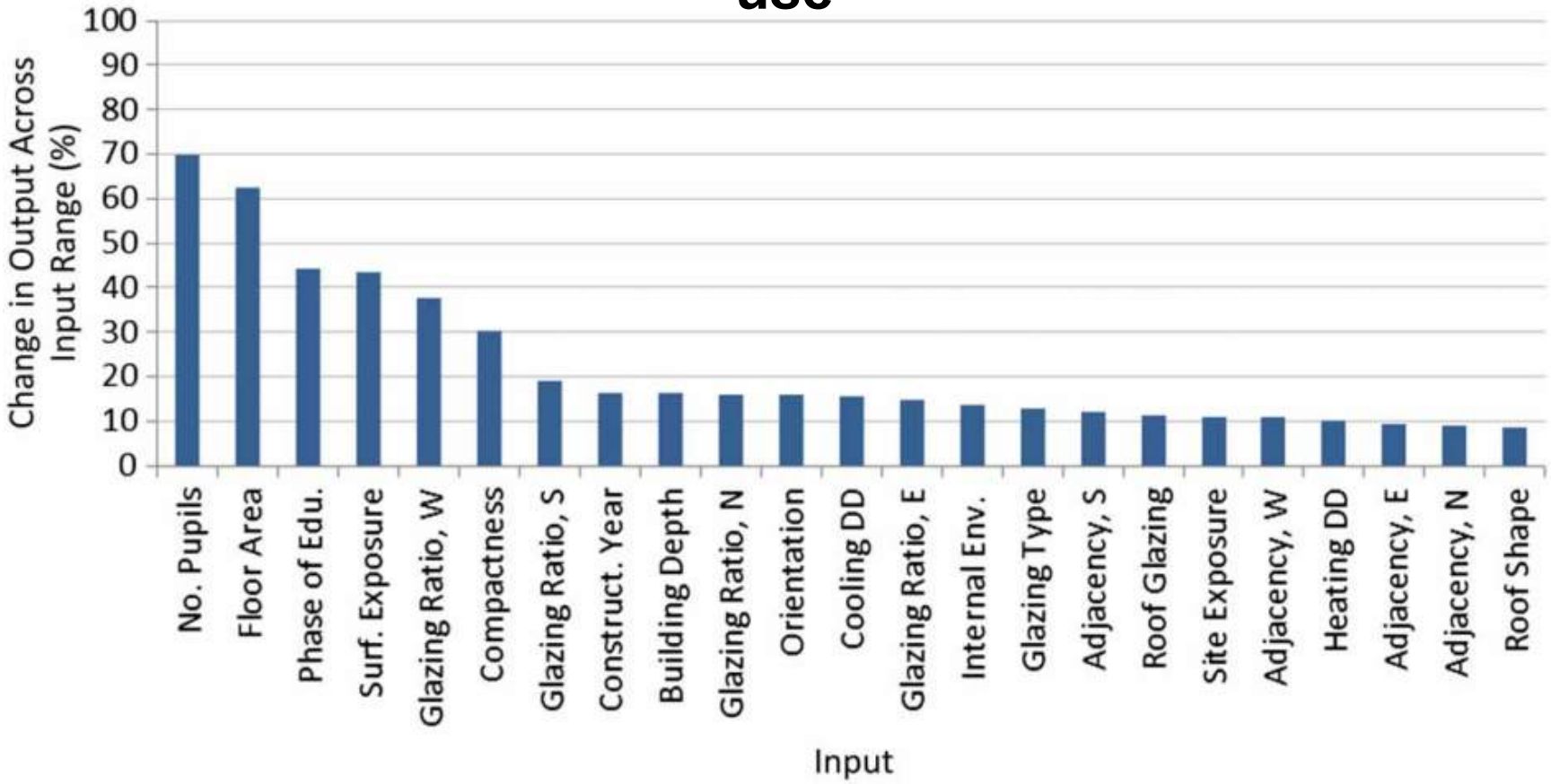

Electrical EUI
(kWh/m2)
60
50
40
30
20
10
-
1999-00
2000-01
2001-02
2002-03
2003-04
2004-05
2005-06
2006-07
2007-08
2008-09
2009
2010
2011
Assessment end year
Primary school
Secondary school


Fossil-thermal EUI (kWh/m2)
180
160
140
120
100
80
60
40
20
-
1999-00
2000-01
2001-02
2002-03
2003-04
2004-05
2005-06
2006-07
2007-08
2008-09
2009
2010
2011
Assessment end year
Primary school
Secondary school

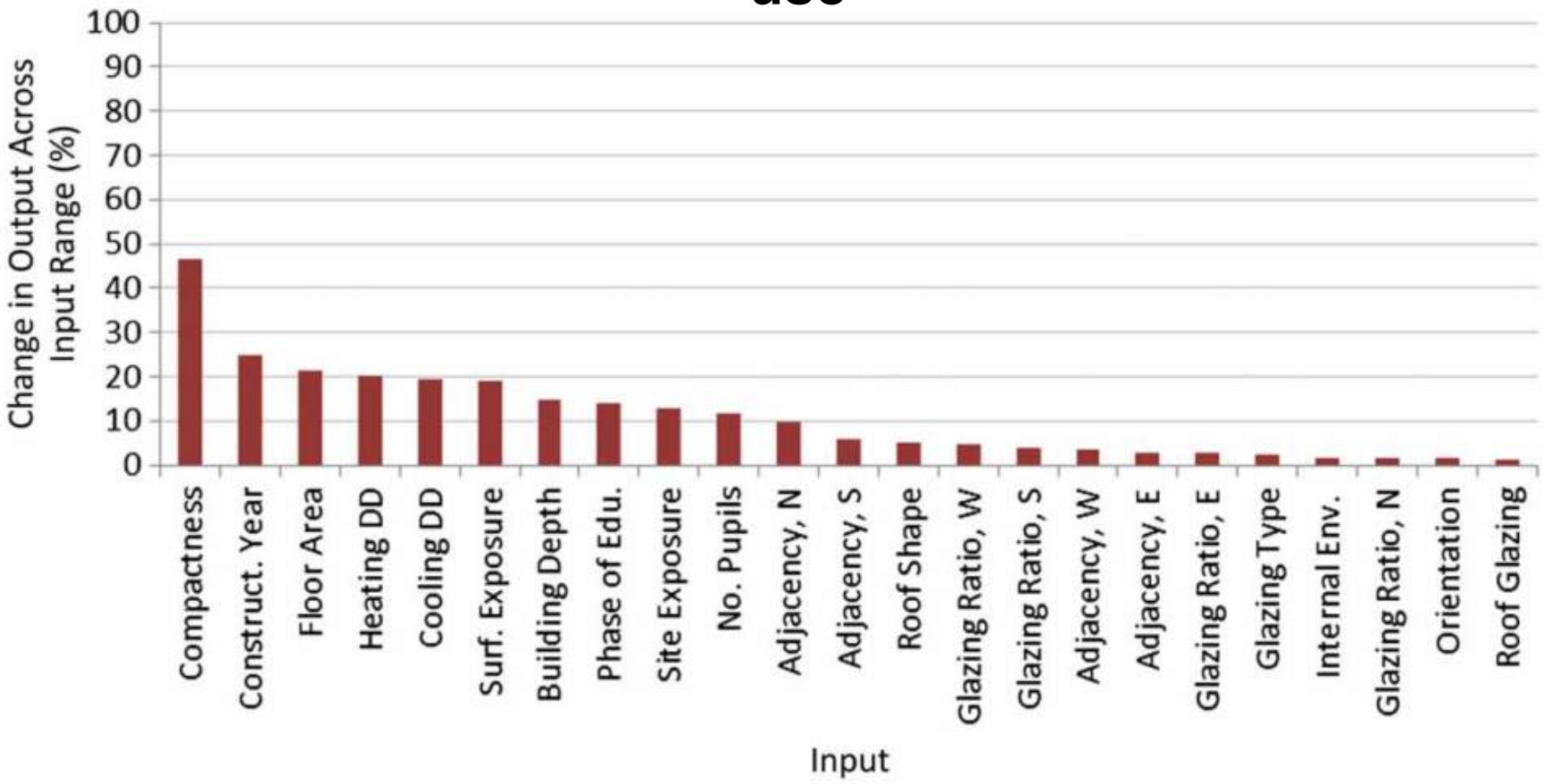
Smart Building Stocks: Long-term trends in EUI required to achieve 80% reduction from 1999 levels



Releasing potential of passive design: Change in output across the input range for **electricity use**



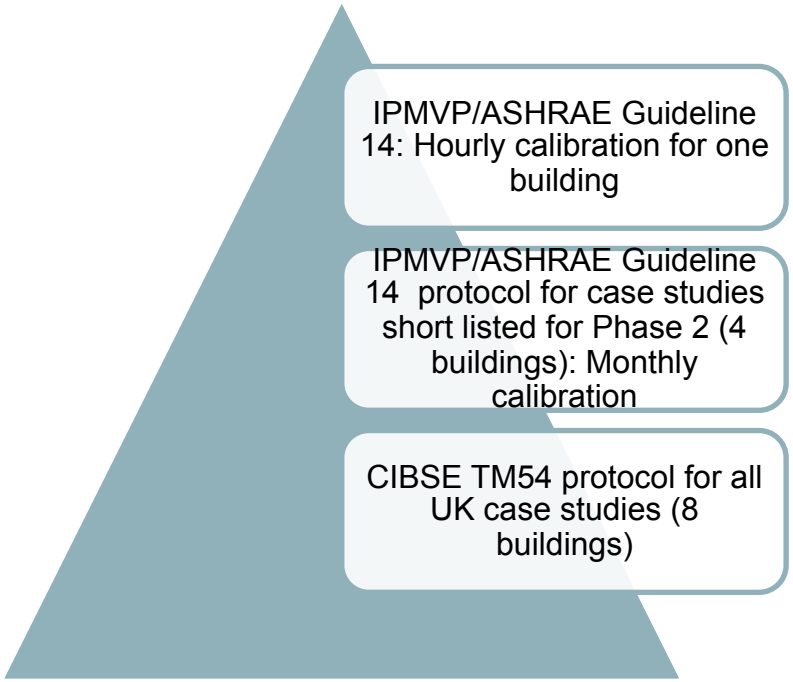
Releasing potential of passive design: Change in output across input range for **fossil-thermal energy use**



DATA CROWDSOURCING: WHAT? WHY? HOW?

NOTES ON DESIGN 'BASELINES'

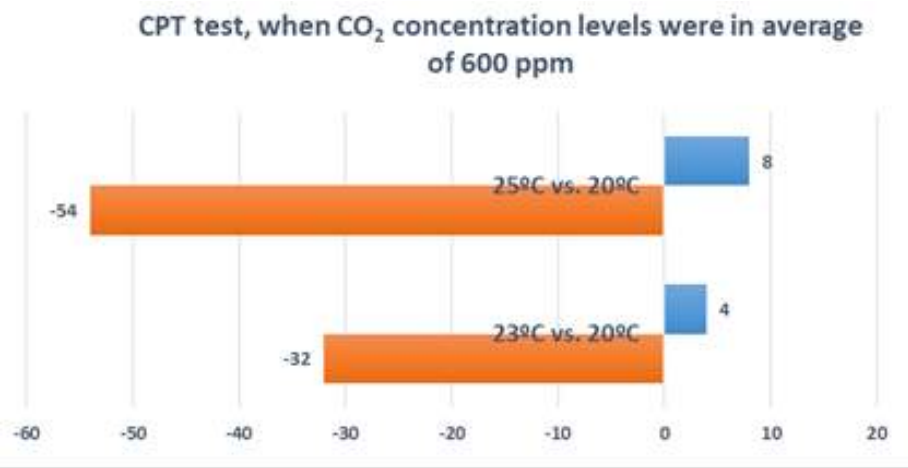
- The available design calculations have been sourced for all case studies.
- However, uncalibrated modelling is not necessarily reliable and is prone to errors.
- It is therefore necessary to develop robust baselines derived from calibrated computer models (link between modelling & monitoring).

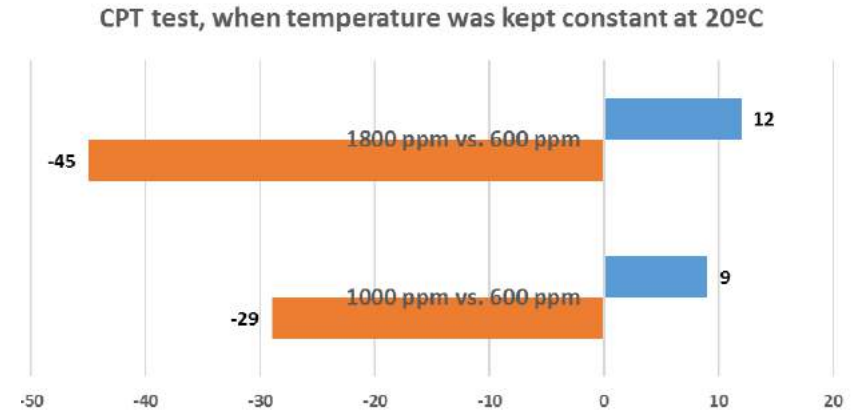


Suggested method to develop robust computer models and baseline performances for TOP case studies in the UK

(Single software: DesignBuilder/EnergyPlus, single first user)

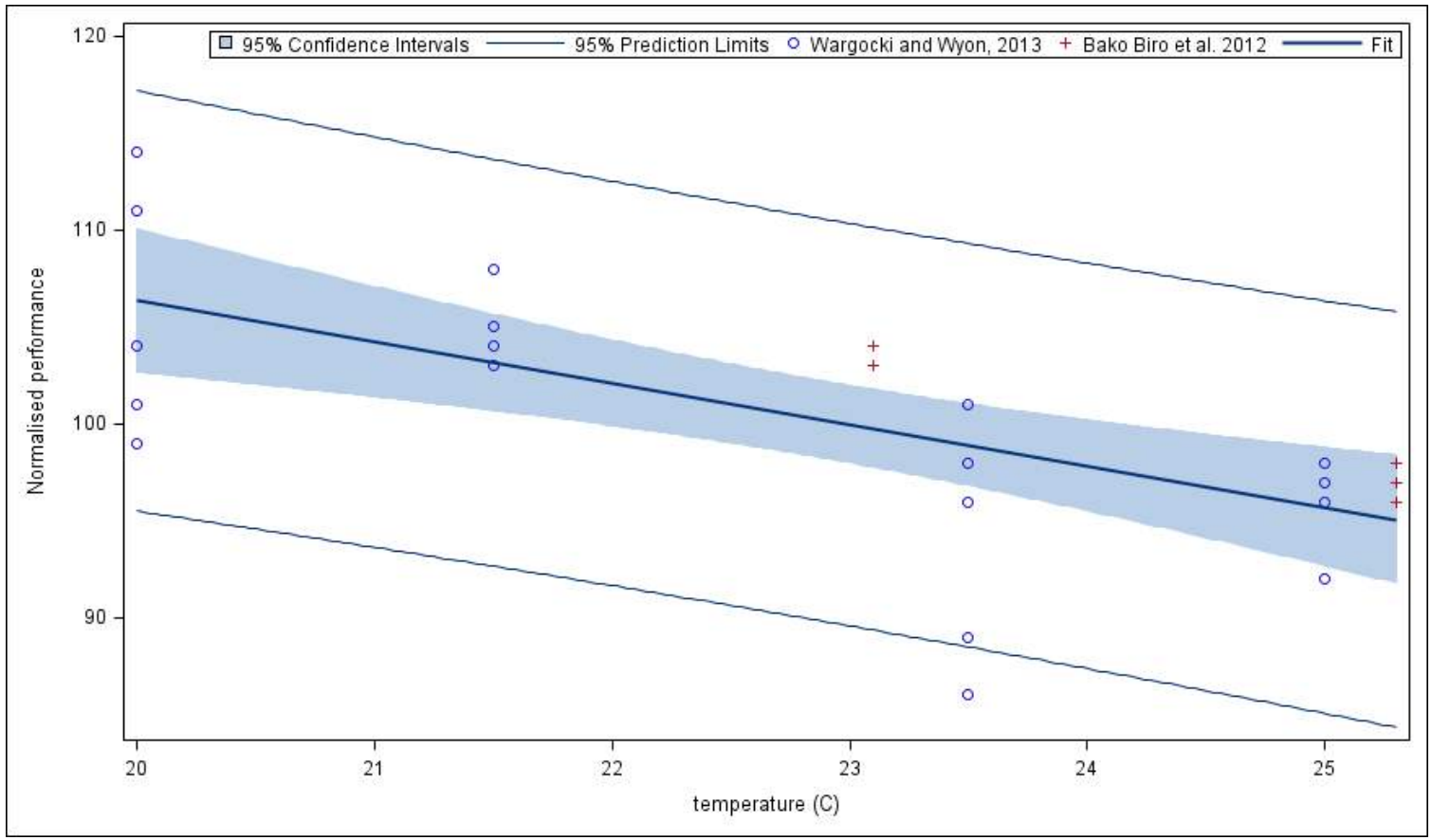
Continuous Performance Test (CPT) Results (compared to the base line condition)





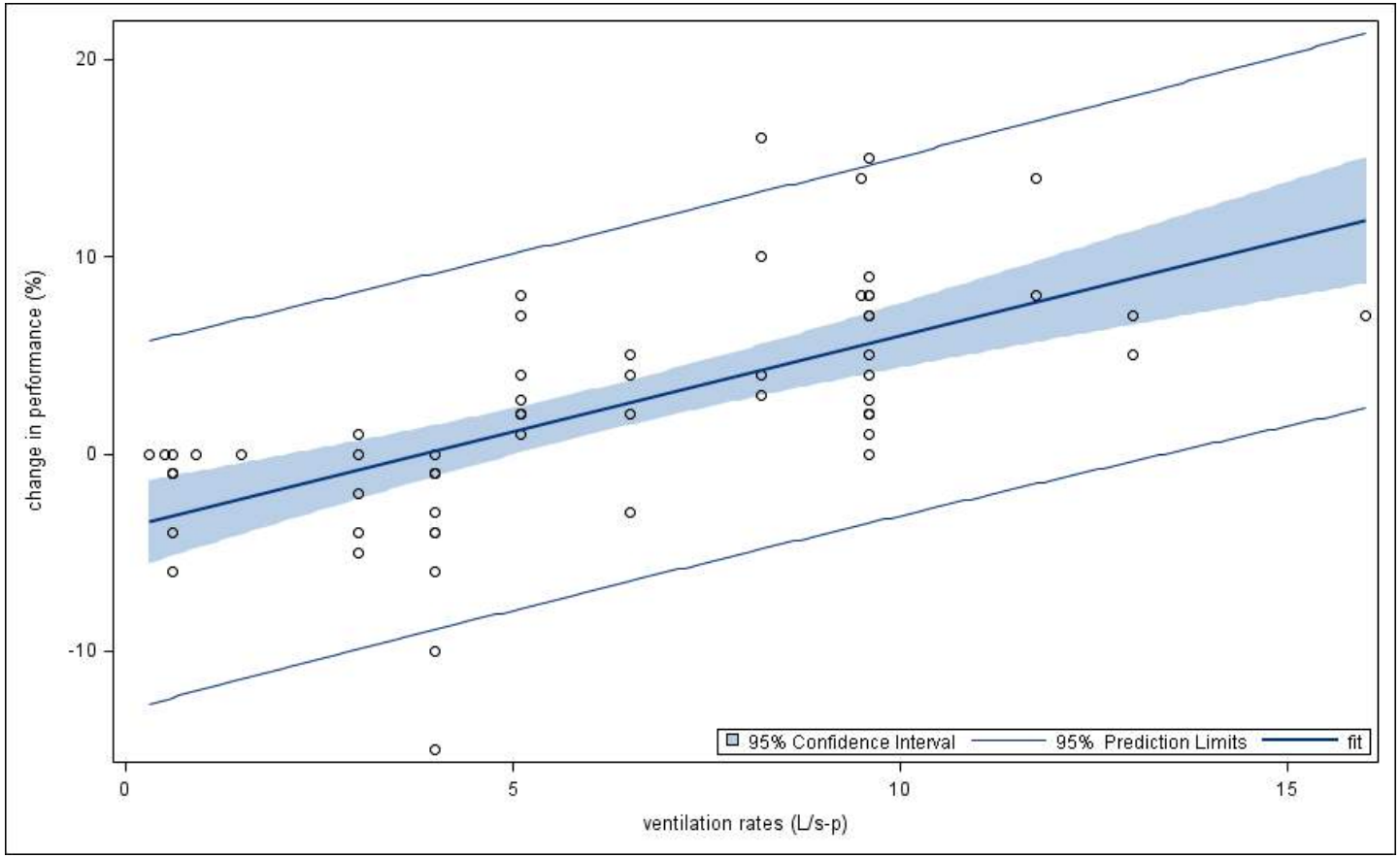
Tornado diagrams showing the trend of change in the % of errors (blue) and speed of response (orange) at the CPT test relative to the baseline conditions.

Normalised performance as a function of classroom temperature. Graph synthesised from two peer-reviewed publications



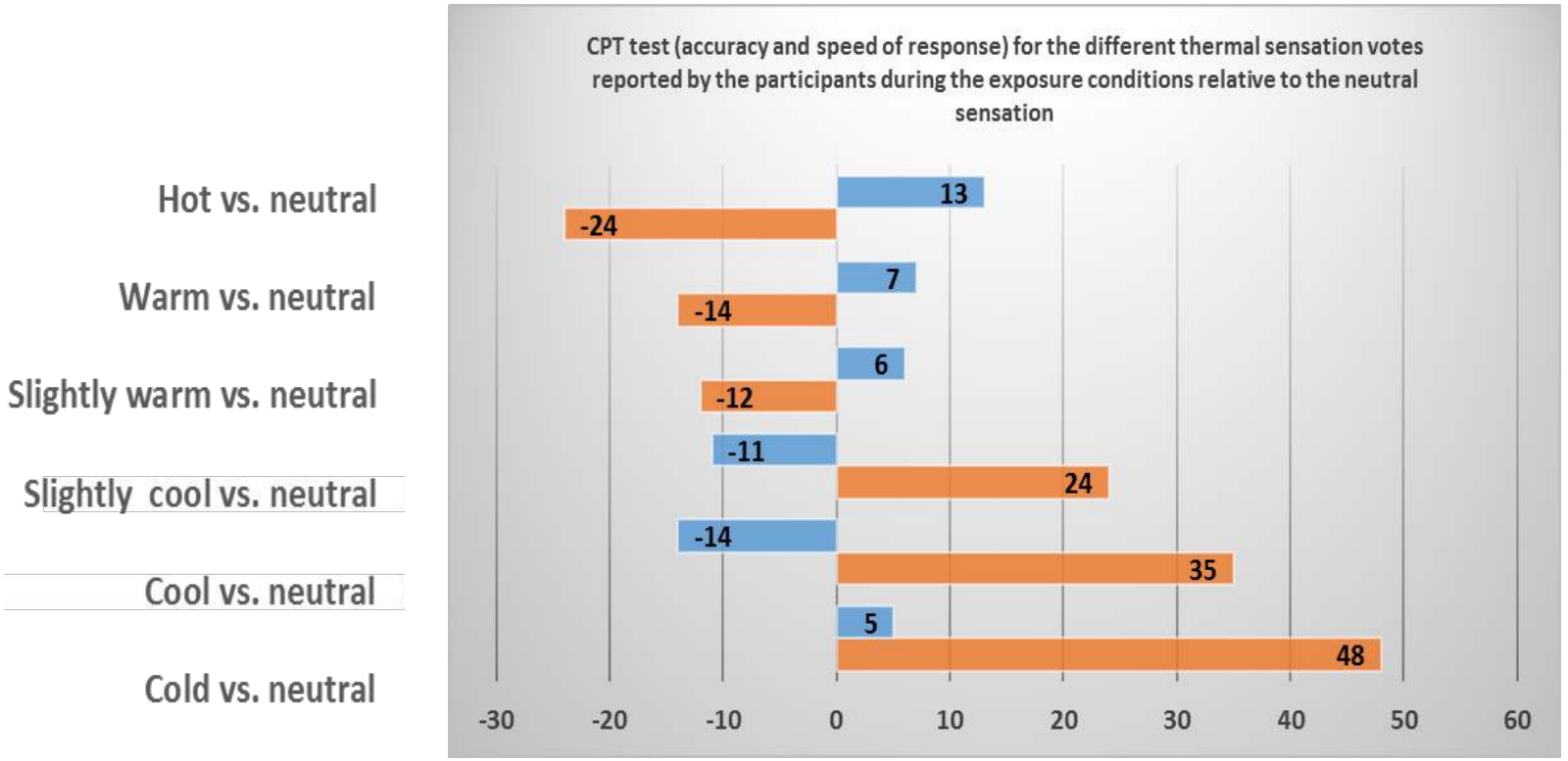
Synthesised relationship shows that an improvement of meta-OR: 11.0 % (95% CI: 10.0 % to 11.2 %) in cognitive performance may be expected when temperature drops from 25 ^{o}C to 20 ^{o}C

Percentage change in performance vs. average ventilation rate, fitted with a linear regression model derived from six studies



This synthesis suggests that an increase of ventilation rates from 5 L/s-p to 15 L/s-p will result in an improvement in performance by 10.8 % (95 % CI: 7.9 to 13.0 %).

Continuous Performance Test (CPT) Results vs. Thermal Sensation



Tornado diagram showing the trend of change in the % of errors (blue) and speed of response (orange) at the CPT test for the thermal sensation votes reported by the participants relative to the neutral sensation conditions

THE ANSWER IS TECHNOLOGY.
WHAT WAS THE QUESTION AGAIN?

READINESS VS PERFORMANCE: WHAT BUILDING IS VS WHAT BUILDING DOES

OWNERSHIP OF PERFORMANCE: FROM A BUILDING LEVEL TO BUILDING STOCK LEVEL

ENFORCEMENT OF PERFORMANCE: DEC & ENERGY REPORTING

SMART: PRIORITY ON HEALTH COGNITIVE PERFORMANCE COMFORT WELLBEING FOLLOWED BY ENERGY USE INTENSITY

INTEGRATION IN EXISTING MANDATORY SCHEMES (DEC & EPC)

THANK YOU