EBC

Energy in Buildings and Communities Programme

IEA EBC Annex 71

Building energy performance assessment based on in-situ measurements

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Brussels workshop@A71-meeting

Workshop 'Building energy performance assessment and quality assurance based on in-situ measurements'
Brussels, Belgium__ April 11, 2018


LOCI
Bruxelles
Louvain-la-Neuve
Tournai
Faculté d'architecture
d'ingénierie architecturale
d'urbanisme
KNAUF INSULATION
FEBELCEM
Wallonie énergie SPW
EBC
Energy in Buildings and Communities Programme
DYNASTEE
bruxelles environnement
leefmilieu brussel
.brussels
OWENS CORNING
FOAMGLAS

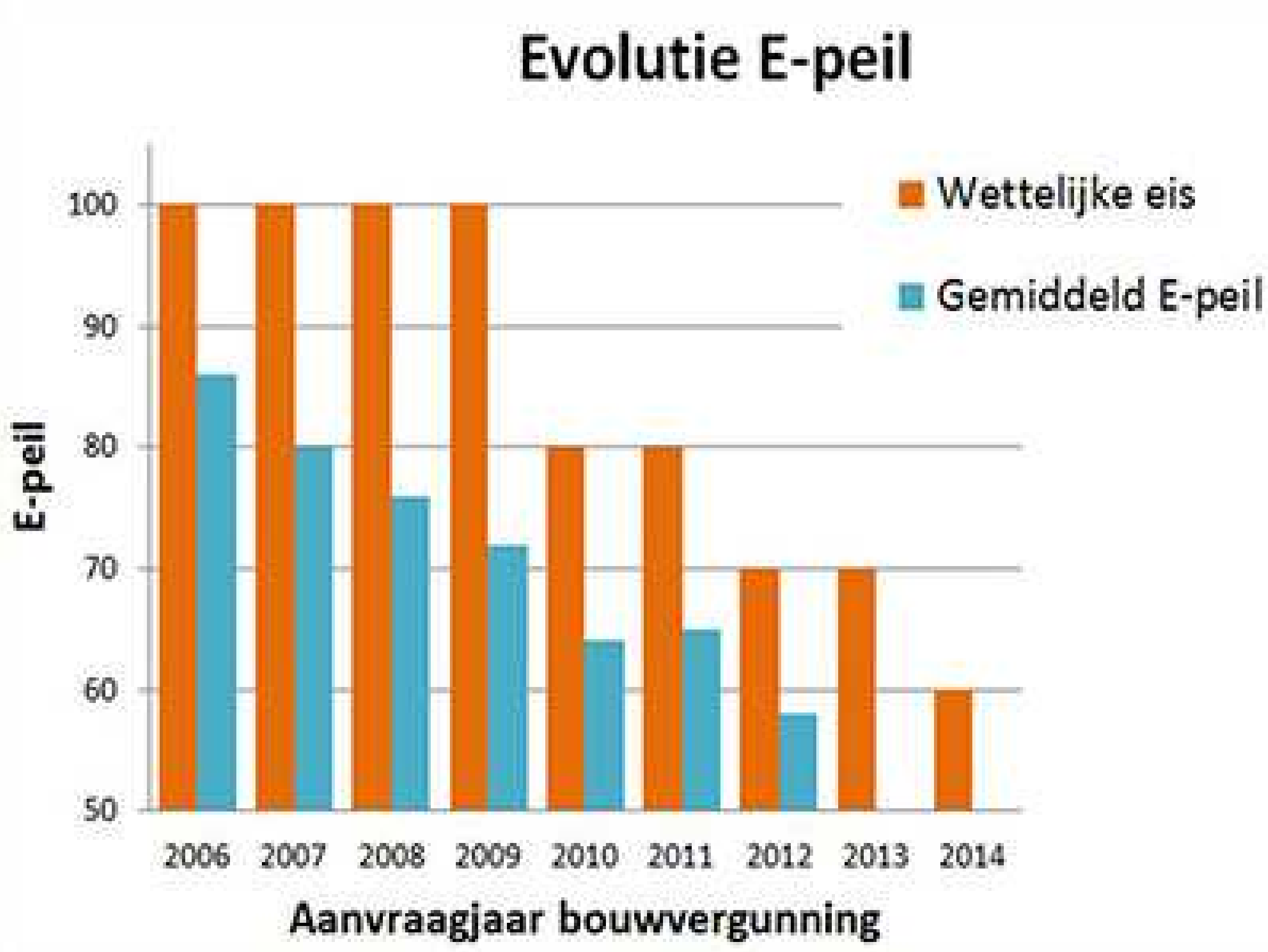
International collaboration

1. Austria University of Innsbruck
2. Belgium BBRI, BCCA, Energyville, INIVE, Knauf Insulation, KU Leuven, UCL, UGhent, University of Liège
3. Denmark Danish Building Research Institute, DTU
4. France Cerema, CSTB, Ecole des Mines de Douai, ENTPE, Groupe Atlantic, Saint Gobain, Univ. de Savoie Mont-Blanc
5. Germany Fraunhofer Institute, FH Rosenheim
6. Netherlands Saxion Hogeschool, Huygen Ingenieurs&Adviseurs
7. Norway NTNU
8. Spain CIEMAT, CIMNE, Univ. of the Basque Country
9. Switzerland ETH
10. UK Knauf Insulation, Leeds Beckett Univ., Loughborough Univ., UCL, Univ. of Lincoln, Univ. of Salford, Univ. of Strathclyde, Univ. of the West of England, The British Blind and Shutter Ass.

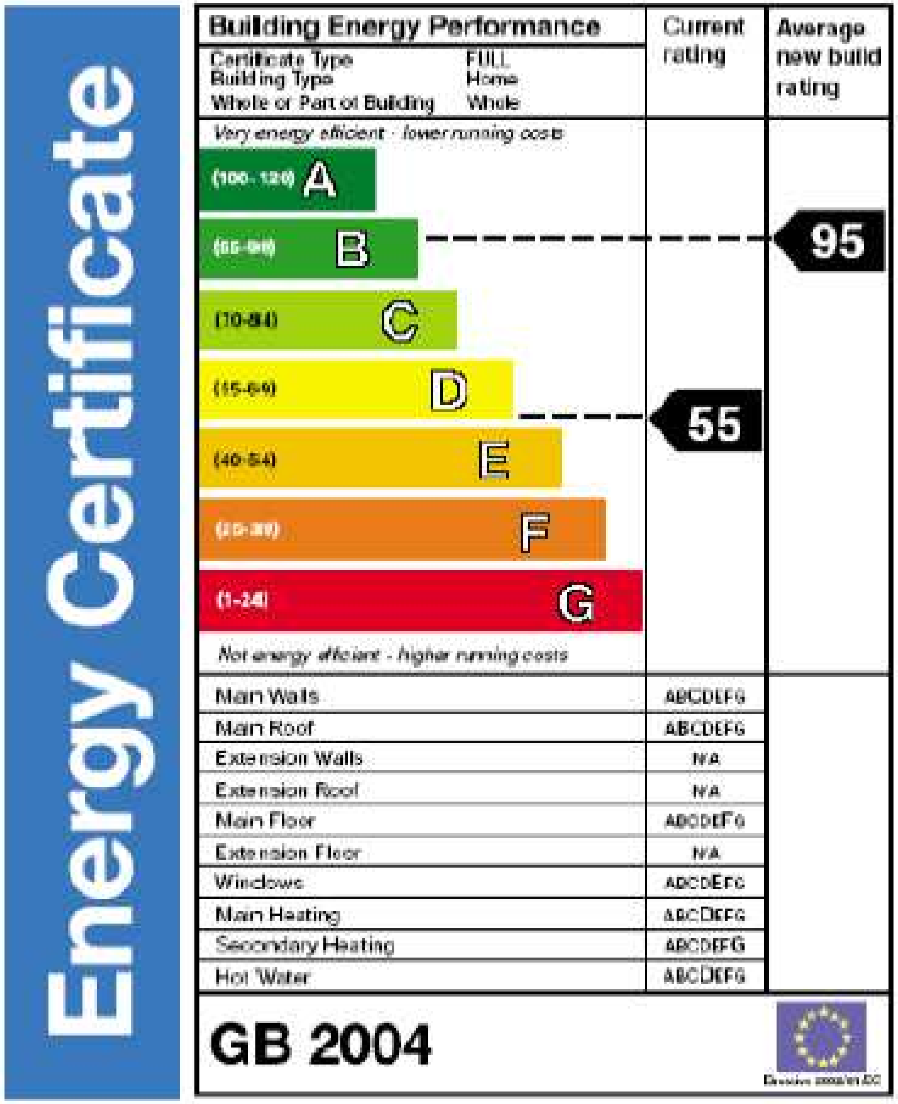
Climate change is a fact…

…though not everybody is convinced.

Regulation rapidly grew more strict



Figuur: www.mijnepb.be/evolutie-e-peil/

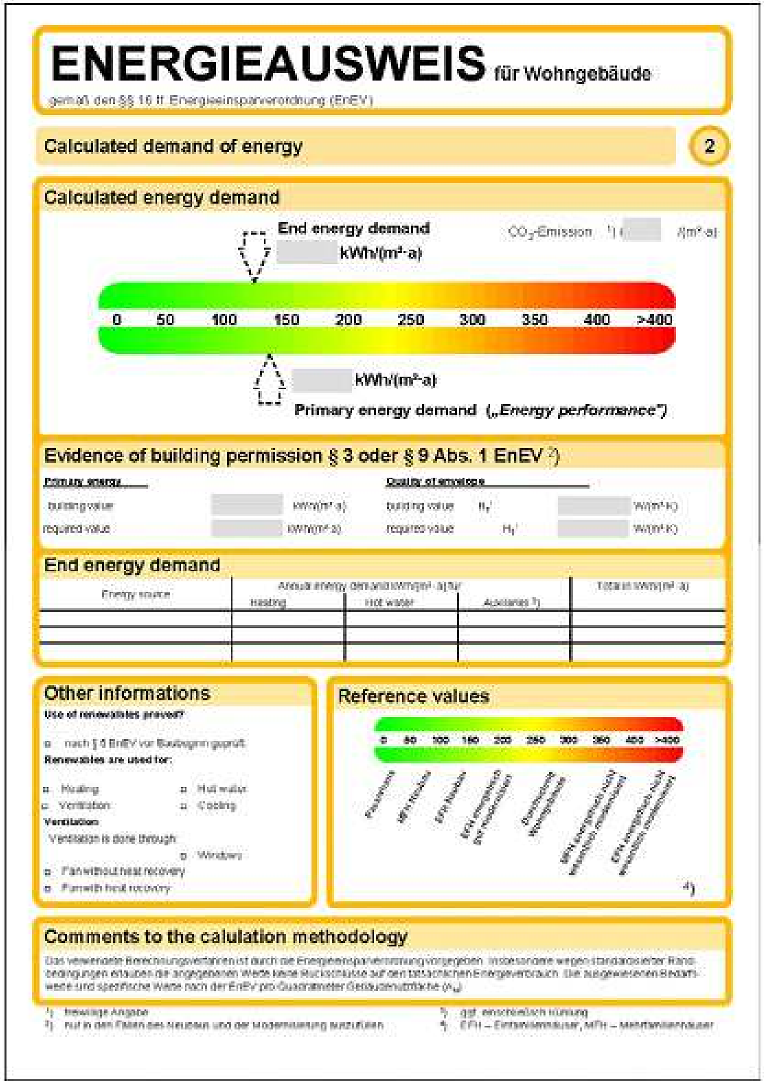


Energy Certificate

Building Energy Performance	Current rating	Average new build rating
Certificate Type: FULL Building Type: Home Whole or Part of Building: Whole		
Very energy efficient - lower running costs (100-120) A (85-99) B (70-84) C (55-69) D (40-54) E (25-39) F (1-24) G *Not energy efficient - higher running costs*	55	95
Main Walls	ABCDEFG	
Main Roof	ABCDEFG	
Extension Walls	N/A	
Extension Roof	N/A	
Main Floor	ABCDEFG	
Extension Floor	N/A	
Windows	ABCDEFG	
Main Heating	ABCDEFG	
Secondary Heating	ABCDEFG	
Hot Water	ABCDEFG	

GB 2004

Directive 2002/91/EC



ENERGIEAUSWEIS für Wohngebäude

gemäß den §§ 16 ff. Energieeinsparverordnung (EnEV)

Calculated demand of energy 2

Calculated energy demand

End energy demand ____ kWh/(m²·a)

CO_2-Emission [1] ____ /(m²·a)

0 50 100 150 200 250 300 350 400 >400

____ kWh/(m²·a)

Primary energy demand („*Energy performance*")

Evidence of building permission § 3 oder § 9 Abs. 1 EnEV [2]

Primary energy			Quality of envelope			
building value		kWh/(m²·a)	building value	H_T'		W/(m²·K)
required value		kWh/(m²·a)	required value	H_T'		W/(m²·K)

End energy demand

Energy source	Annual energy demand in kWh/(m²·a) for: Heating	Hot water	Auxiliaries [3]	Total in kWh/(m²·a)

Other informations

Use of renewables proved?

- nach § 5 EnEV vor Baubeginn geprüft

Renewables are used for:

- Heating
- Hot water
- Ventilation
- Cooling

Ventilation

Ventilation is done through

- Windows
- Fan without heat recovery
- Fan with heat recovery

Reference values

0 50 100 150 200 250 300 350 400 >400

Passivhaus
MFH Neubau
EFH Neubau
EFH energetisch gut modernisiert
Durchschnitt Wohngebäude
MFH energetisch nicht wesentlich modernisiert
EFH energetisch nicht wesentlich modernisiert
[4]

Comments to the calulation methodology

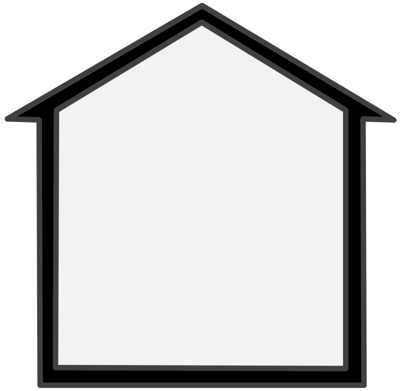
Das verwendete Berechnungsverfahren ist durch die Energieeinsparverordnung vorgegeben. Insbesondere wegen standardisierter Randbedingungen erlauben die angegebenen Werte keine Rückschlüsse auf den tatsächlichen Energieverbrauch. Die ausgewiesenen Bedarfswerte sind spezifische Werte nach der EnEV pro Quadratmeter Gebäudenutzfläche (A_N).

[1] freiwillige Angabe
[2] nur in den Fällen des Neubaus und der Modernisierung auszufüllen
[3] ggf. einschließlich Kühlung
[4] EFH – Einfamilienhäuser, MFH – Mehrfamilienhäuser

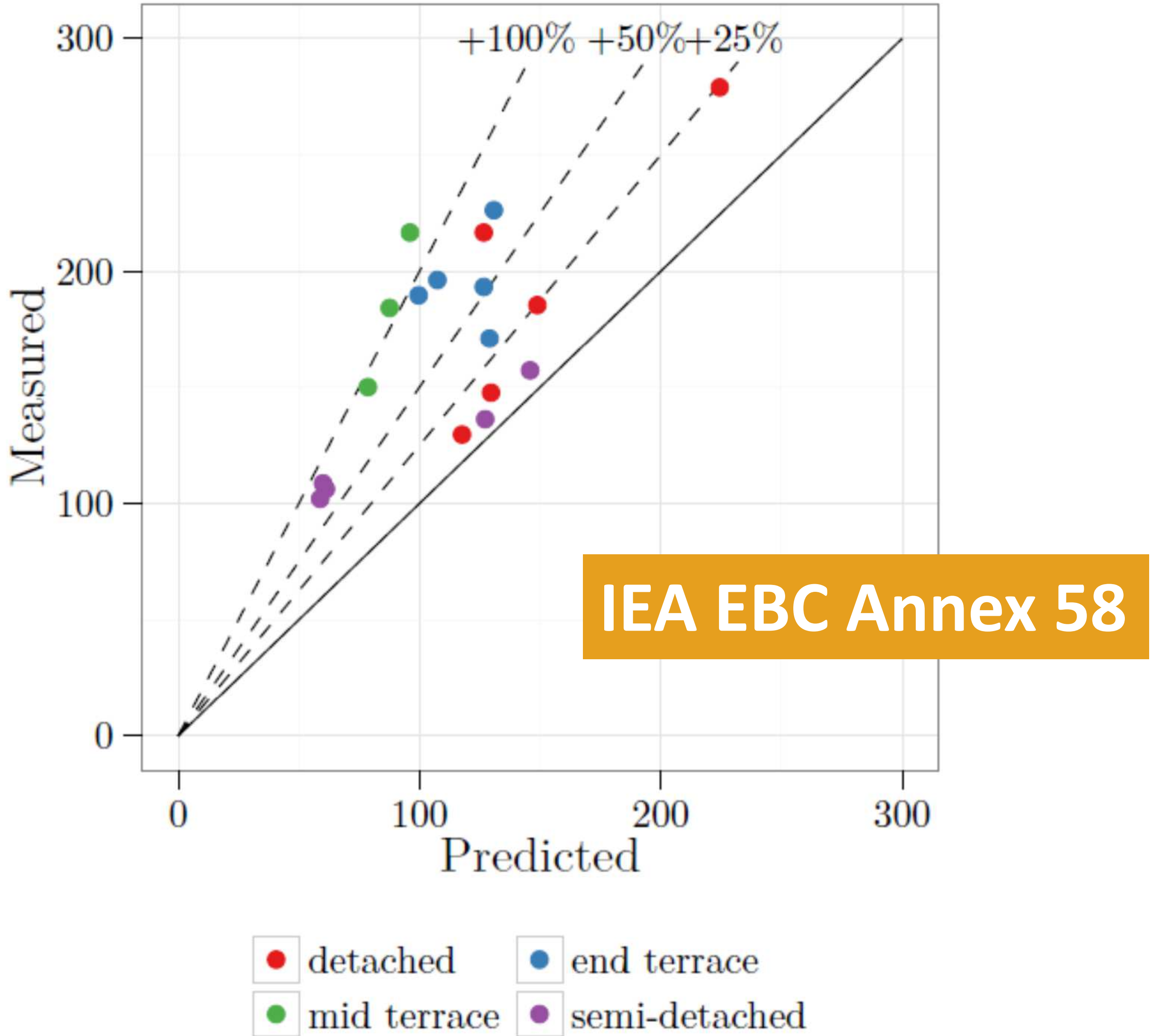
'As an expert in the field of energy efficiency in new building I find it astonishing that countries, states and cities do not pay more attention to the actual energy consumption of new buildings. How can we be sure of the value of the codes if we don't know how well the new buildings are performing under them? So, I guess large savings could be achieved if more attention was paid to the actual energy performance.'

Jens Laustsen,
former Senior Policy Analysist for Efficiency in Buildings, IEA

designed energy performance < > actual energy performance



designed energy performance < > actual energy performance



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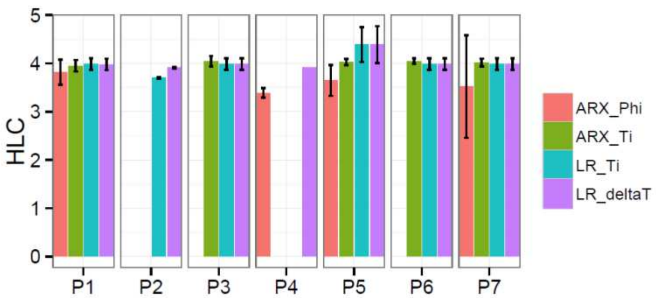
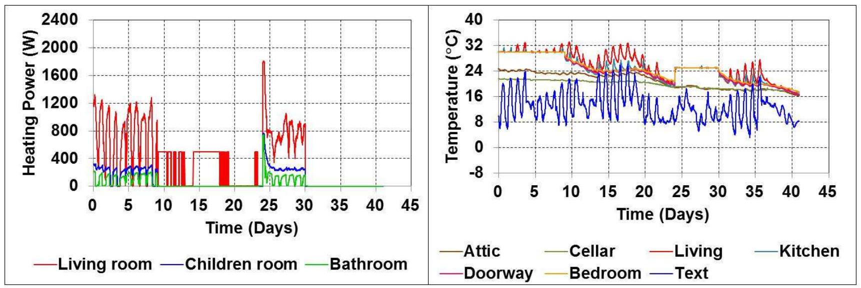
Reliable building energy performance characterisation based on full scale dynamic measurements

CE3-CE4



CE5



Analysis based on dedicated intrusive tests

renovation step 1

renovation step 2

21/02 01/03 07/03 25/03 04/05 19/05

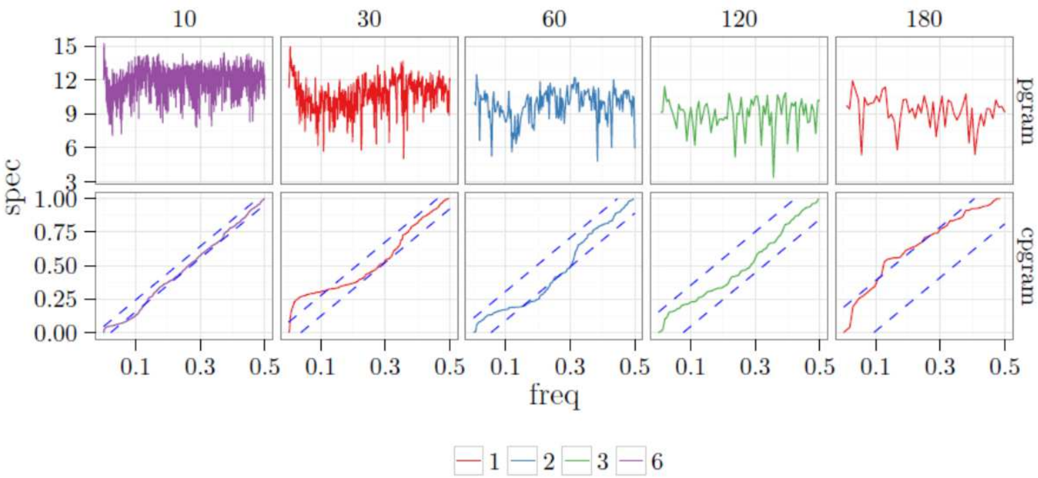
HLC before

HLC after 1

HLC after 2

On site assessment of thermal performance of building fabric

From static co-heating test towards dynamic building performance characterisation



	H_{tr}
Expected	207.2
LR	203.6
ARX	205.2

Today no in-use quality check and little measurement based optimisation of buildings

At the same time, we see following trends

Internet of Things

Home automation

Big Data

To what extent can we use on board monitored data instead of going to dedicated intrusive measurements?

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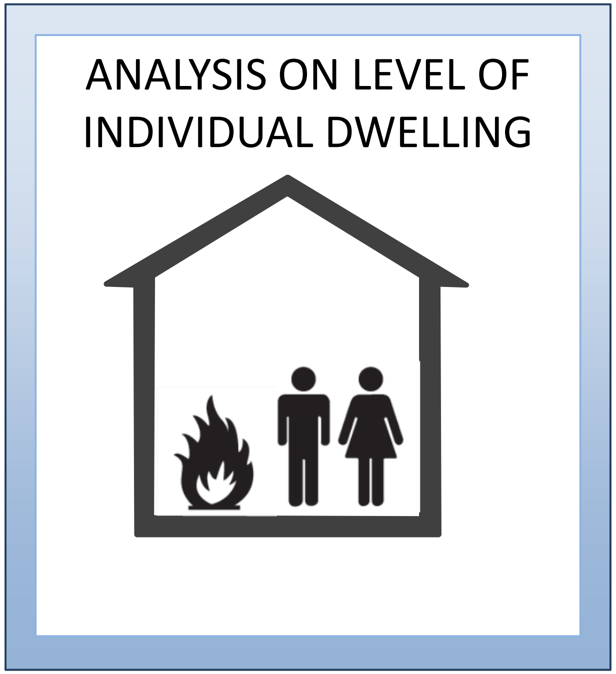
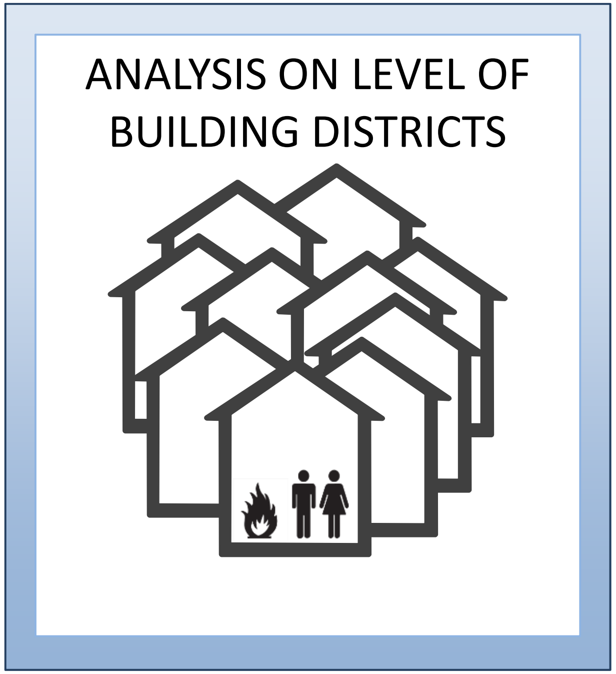
Building energy performance assessment based on in-situ measurements

Main objective:

Support the development of replicable methodologies embedded in a statistical and building physical framework to characterize and assess the actual energy performance of buildings starting from on board monitored data of in-use buildings

Focus on residential dwellings, but both individual as aggregate scale





At both levels the development of characterization methods as well as of quality assurance methods will be explored

CHARACTERIZATION METHODS

- Translate the (dynamic) behaviour of a building into a simplified model
- Simplified model can be used in model predictive control, fault detection, optimisation of district energy systems,...

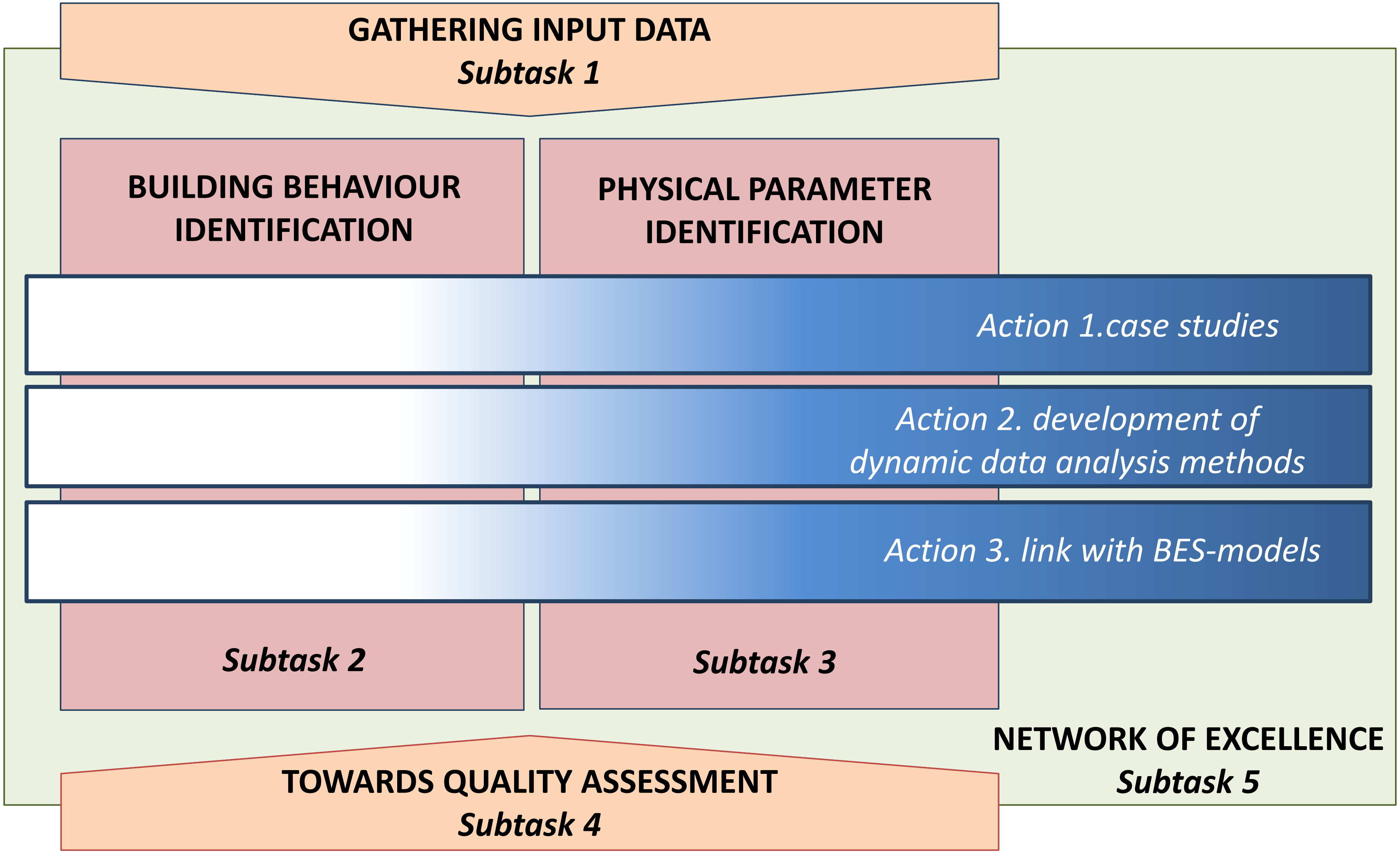
building behaviour identification

QUALITY ASSURANCE METHODS

- Pinpoint some of the most relevant actual building performances
- For instance: the overall heat loss coefficient of a building, the energy efficiency of the heating (cooling) system, air tightness, solar absorption,...

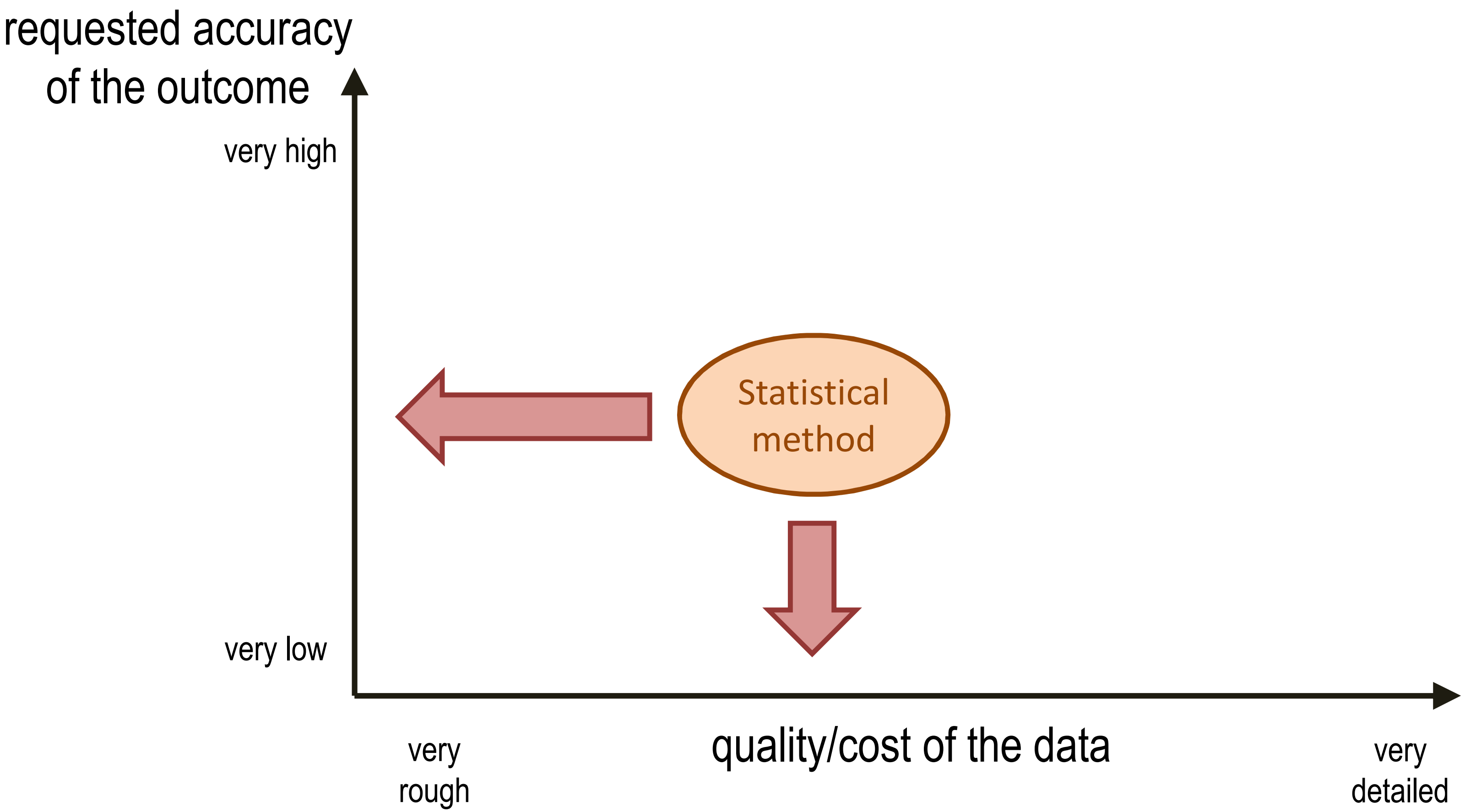
physical parameter identification

Overall structure



Major outcome

Evaluate methods regarding the requested input and expected outcome



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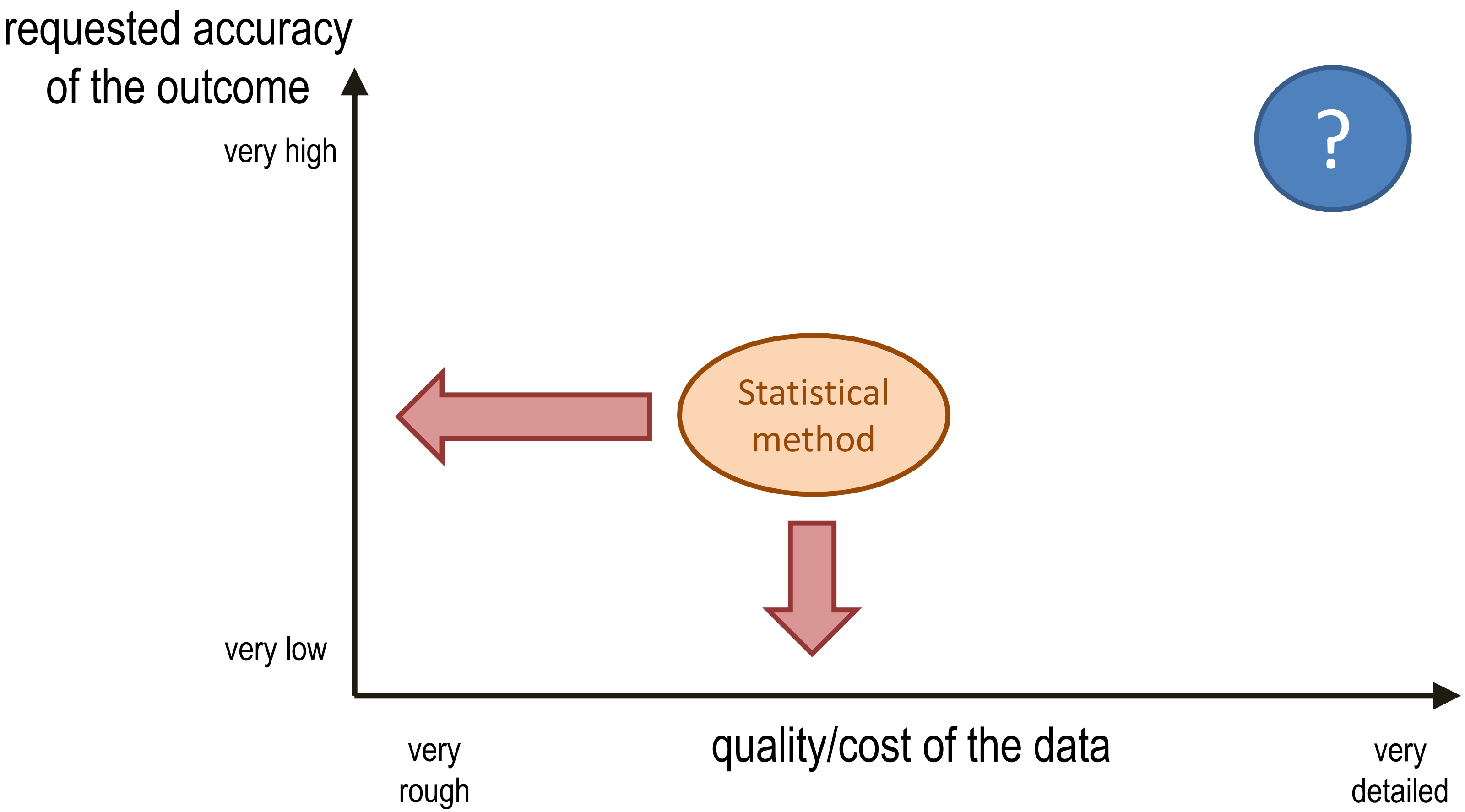

Major outcome

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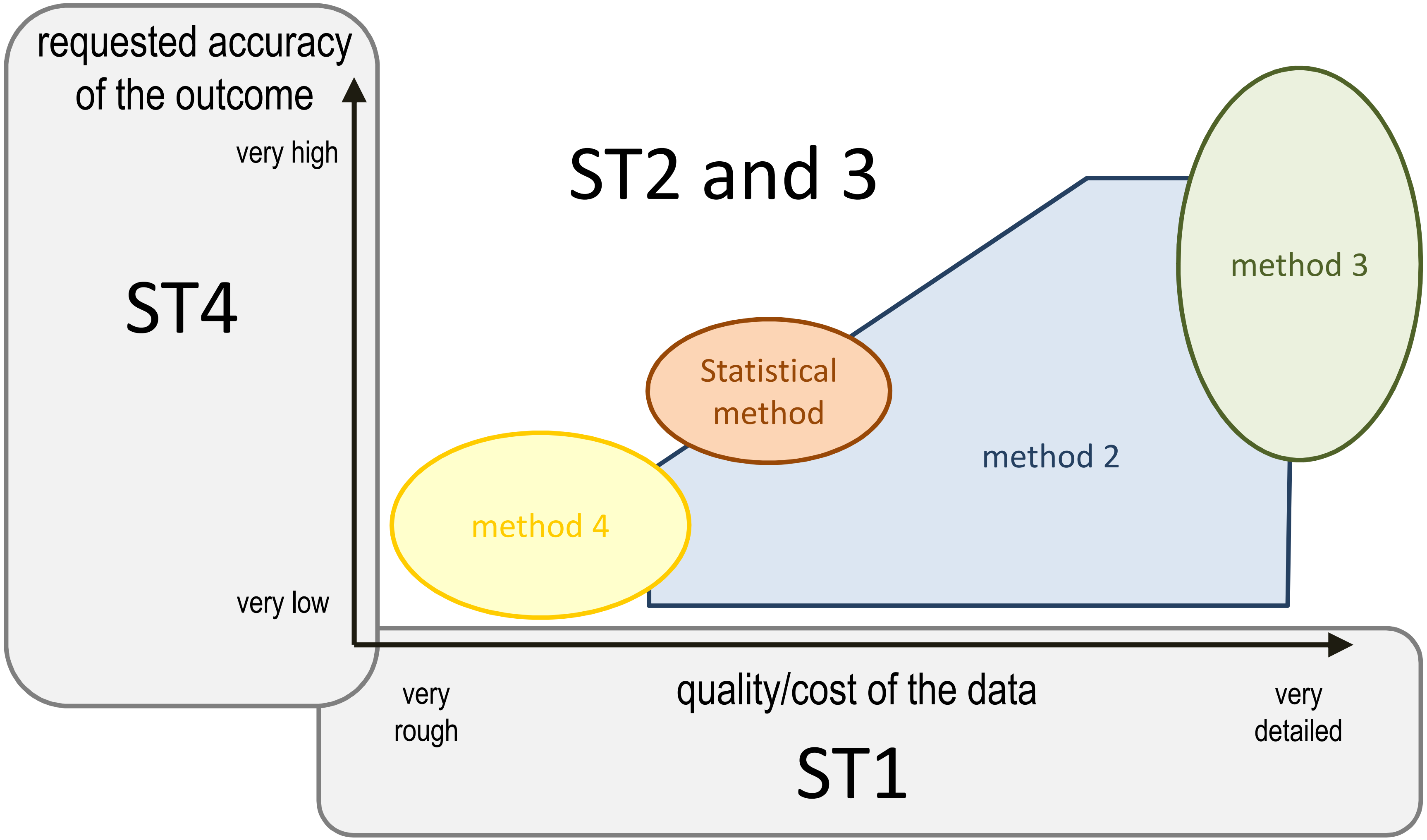


First explorative results

Based on the on-site measured data, participants are requested to:

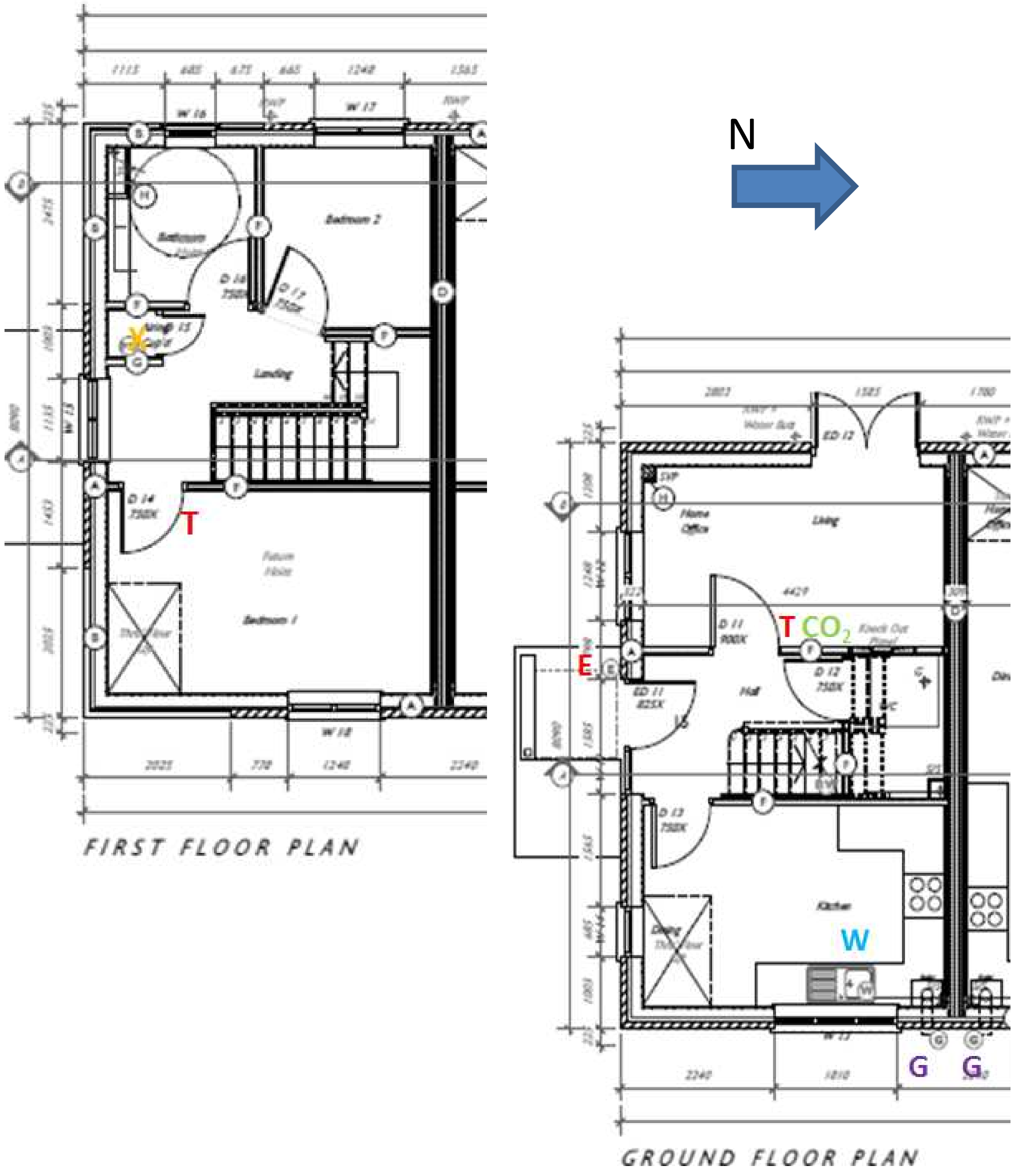
- develop a model to predict indoor temperature (ST2)
- calculate the overall heat transfer coefficient (ST3)

CE1 – Gainsborough case

- South-facing end-terrace of 4 single family housing block
- Gainsborough, UK
- Social housing
- Occupied by 1 adult + 2 children
- Code for sustainable homes level 5

[1] Sodagar B and Starkey D, 2016. The monitored performance of four social houses certified to the Code for Sustainable Homes Level 5. Energy and Buildings 110: 245-256’

CE1 – Gainsborough case



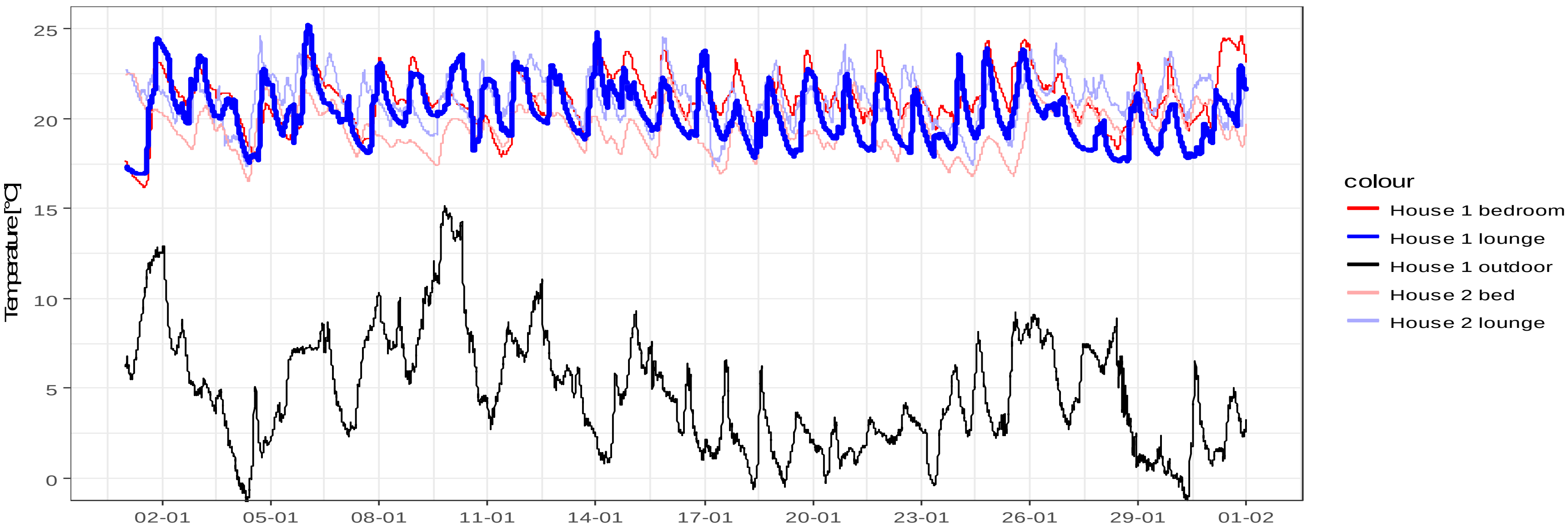
- 2-storey house
- Total floor area 67m²
- Well-insulated and air-tight envelope
    - U_{avg} ~ 0.12 W/(m².K)
    - v_{50} ~ 3.65 m³/(h.m²)

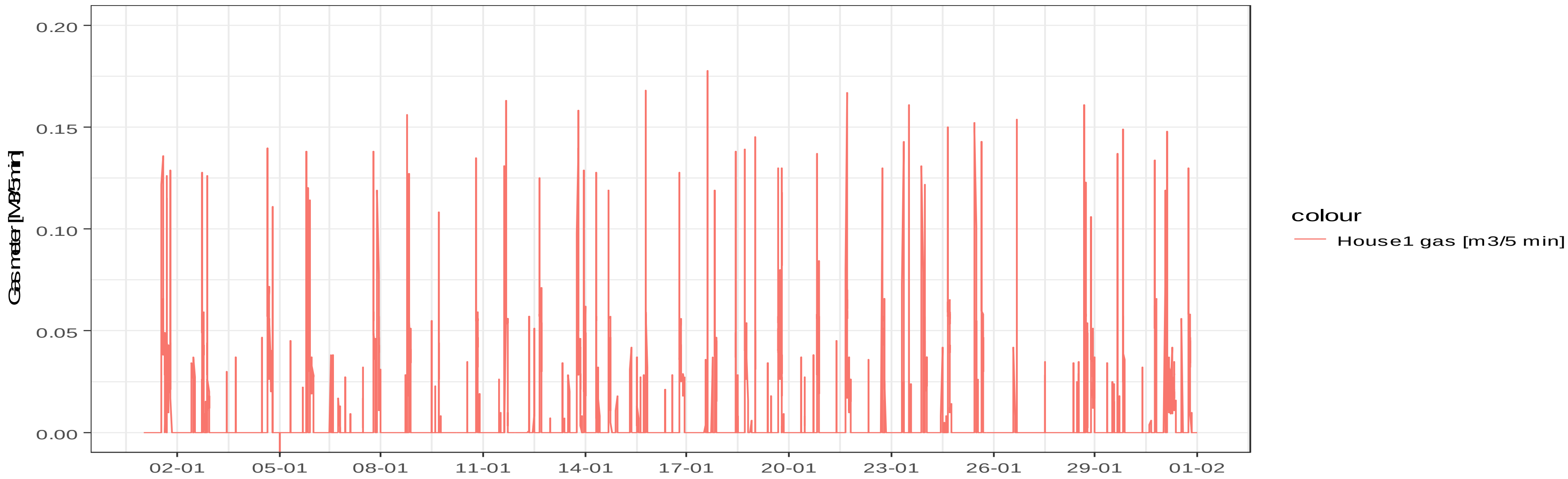
- Gas-boiler for space heating & domestic hot water
- Mechanical ventilation with heat recovery
- Roof-mounted PV-system

CE1 – Gainsborough Data

- Data collected between October ‘12 and November ‘15
- Data set contains
  - On site (5 min sampling time)
    - Indoor temperature & RH (living room and bedroom)
    - Outdoor temperature & RH
    - Neighbour temperature & RH
    - CO_2 (living room)
    - Supply and return temperature & RH (ventilation)
    - Gas consumption
    - Mains water consumption
    - Electricity consumption (mains, MVHR & PV)
  - Off site (Weather station Waddington; hourly)
    - Outdoor temperature
    - Wind speed, direction
    - Global horizontal irradiance

CE1 – Gainsborough Data





CE1 – Identified challenges

Challenges data

- Missing data
- No sub-metering (gas & electricity)
- Room temperatures representative?
- Occupancy unknown (at high resolution)
- Low heat demand -> intermittency
- Temperature control
- …

First explorative results

Based on the on-site measured data, participants are requested to:

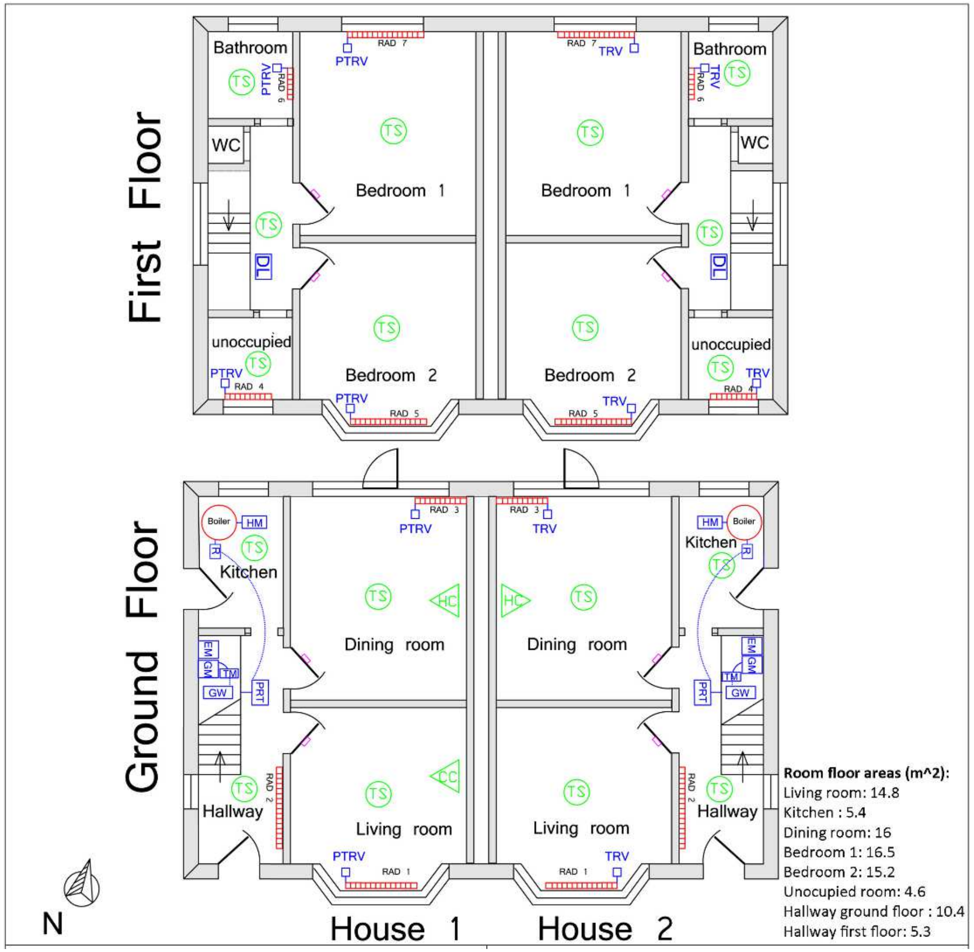
- develop a model to predict indoor temperature (ST2)
- calculate the overall heat transfer coefficient (ST3)

CE1bis – Loughborough case

- West-facing house of 2 identical semi-detached dwellings
- Loughborough, UK
- Un-renovated 1930s
- Synthetic occupants

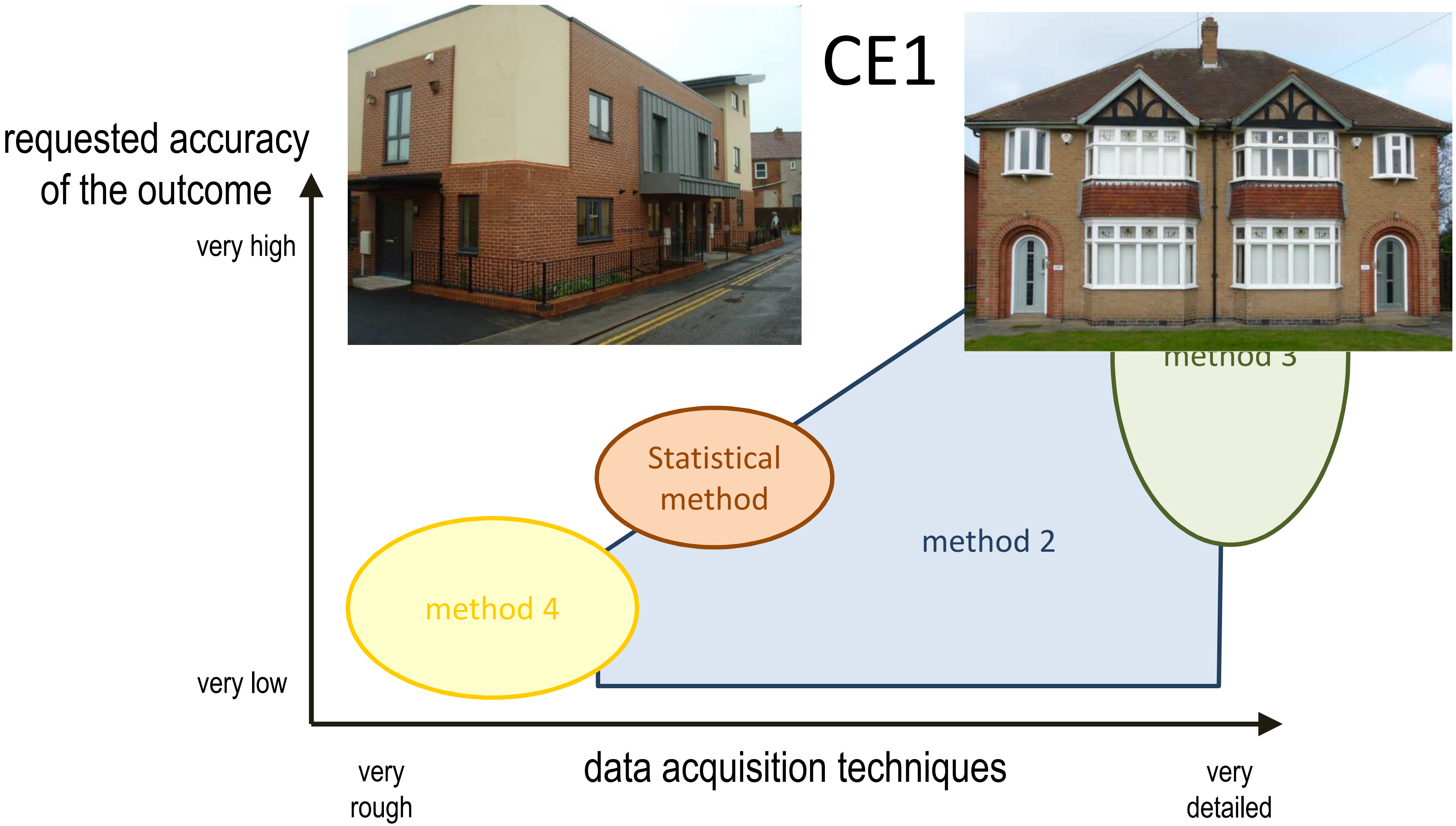
[2] Beizaee A et. al., 2015. Measuring the potential of zonal space heating controls to reduce energy use in UK homes: The case of un-furbished 1930s dwellings. Energy and Buildings 95: 20-44

CE1 – Loughborough case



- 2-storey house
- Total floor area 92m²
- Un-insulated envelope
  - U_{wall} ~ 1.6 W/(m².K)
  - U_{roof} ~ 2.3 W/(m².K)
  - U_{win} ~ 4.8 W/(m².K)
  - $HLC_{theoretic}$ ~ 382 W/K
- Gas-boiler for space heating only (no DHW)
- No mechanical ventilation, but n_{50} of 21.5 ACH

First explorative results

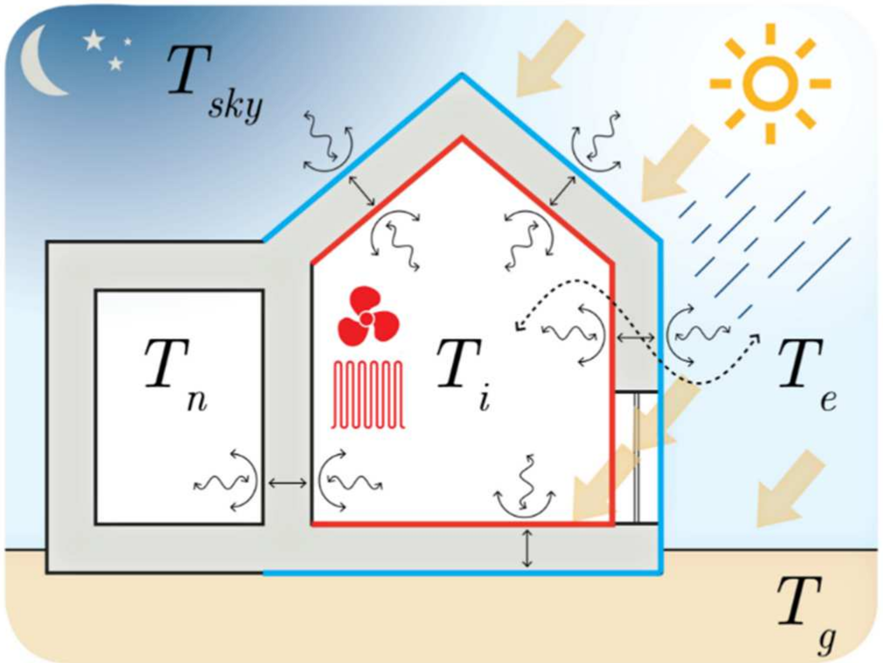


First common exercise to explore the matrix

First explorative results ST3

Estimate global as-built heat transfer coefficient HTC,
based on measured data during normal operating conditions

$$C_i \frac{\partial \theta_i}{\partial t} = \Phi_h + \Phi_{int} + \Phi_{sol} + \Phi_l + \Phi_{tr} + \Phi_v + \Phi_m$$



HTC ?

$$C_i \frac{\partial \theta_i}{\partial t} = \Phi_h + \Phi_{int} + \Phi_{sol} + \Phi_l + \Phi_{tr} + \Phi_v + \Phi_m$$

$$\Phi_{tr} = \Phi_{tr}^{e} + \Phi_{tr}^{n} + \Phi_{tr}^{adj} + \Phi_{tr}^{g}$$

$$\Phi_{tr}^{e} + \Phi_{tr}^{g} \sim HTC$$

A needle in a haystack?

$$C_i \frac{\partial \theta_i}{\partial t} = \Phi_h + \Phi_{int} + \Phi_{sol} + \Phi_l + \Phi_{tr} + \Phi_v + \Phi_m$$

HTC

Exploration of different methods:

- Averaging method
- Energy signature model
- AR(MA)X-models
- grey box models
- ...

$$C_i \frac{\partial \theta_i}{\partial t} = \Phi_h + \Phi_{int} + \Phi_{sol} + \Phi_l + \Phi_{tr} + \Phi_v + \Phi_m$$

AVERAGING METHOD

$$0 = \Phi_h + \Phi_{int} + \Phi_{sol} + \boldsymbol{\tilde{\Phi}_{tr}} = \Phi_h + \Phi_{int} + \Phi_{sol} + HTC.(\theta_e - \theta_i)$$

Averaging all data points:

$$\sum(\Phi_h + \Phi_{sol}) = HTC.\sum(\theta_i - \theta_e)$$

ENERGY SIGNATURE MODEL

$$0 = \Phi_h + \Phi_{int} + \Phi_{sol} + \boldsymbol{\tilde{\Phi}_{tr}} = \Phi_h + \Phi_{int} + \Phi_{sol} + HTC.(\theta_e - \theta_i)$$

Definition of a base temperature:

$$\Phi_{int} + \Phi_{sol} = HTC.(\theta_i - \theta_b)$$

$\Phi_h = HTC.(\theta_b - \theta_e)\ \delta_h$ with δ_h=1 if θ_e< θ_b
δ_h=0 if $\theta_e \geq \theta_b$

Linear regression of time interval integrated data yields HTC and base temperature.

AR(MA)X-models

Auto-regressive models with eXogeneous inputs:

$$\omega_i(B)T_{i,t} = \omega_e(B)T_{e,t} + \omega_h(B)\Phi_{h,t}^{h} + \omega_{sol}(B)I_{sol,t} + \mu + \epsilon_t$$

Dynamic model that links current output at time *t* with previous inputs and outputs

Black box model; direct link with physics is lost, but stationary properties of the model can be deduced

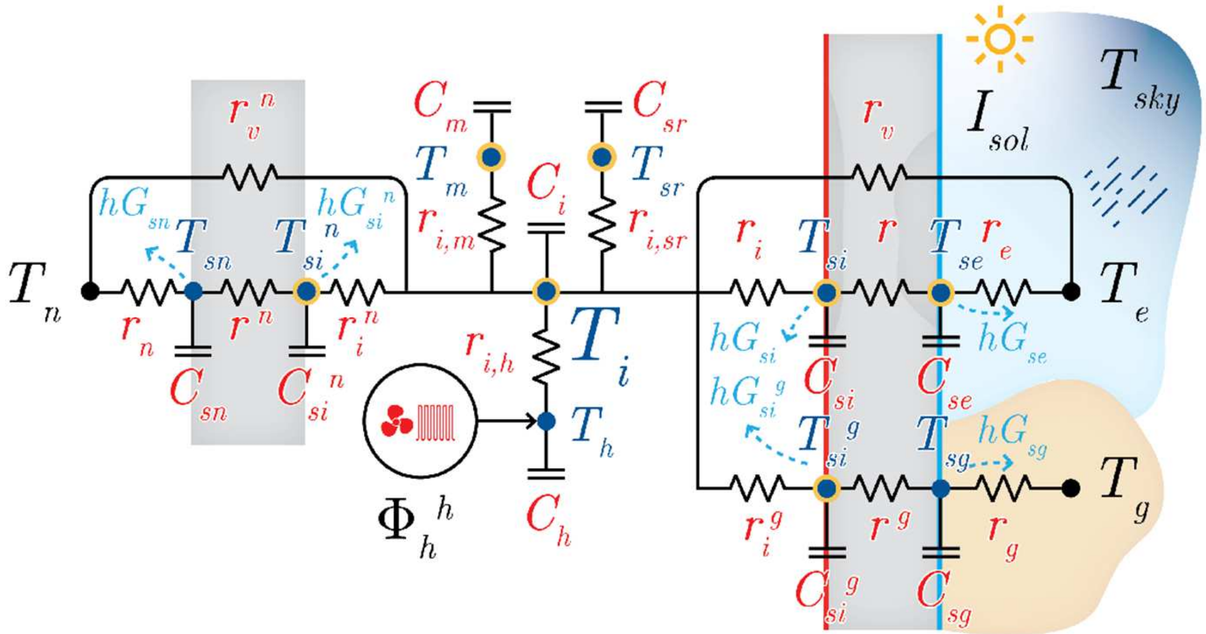
STATE SPACE MODELS

Continuous time stochastic state space models:

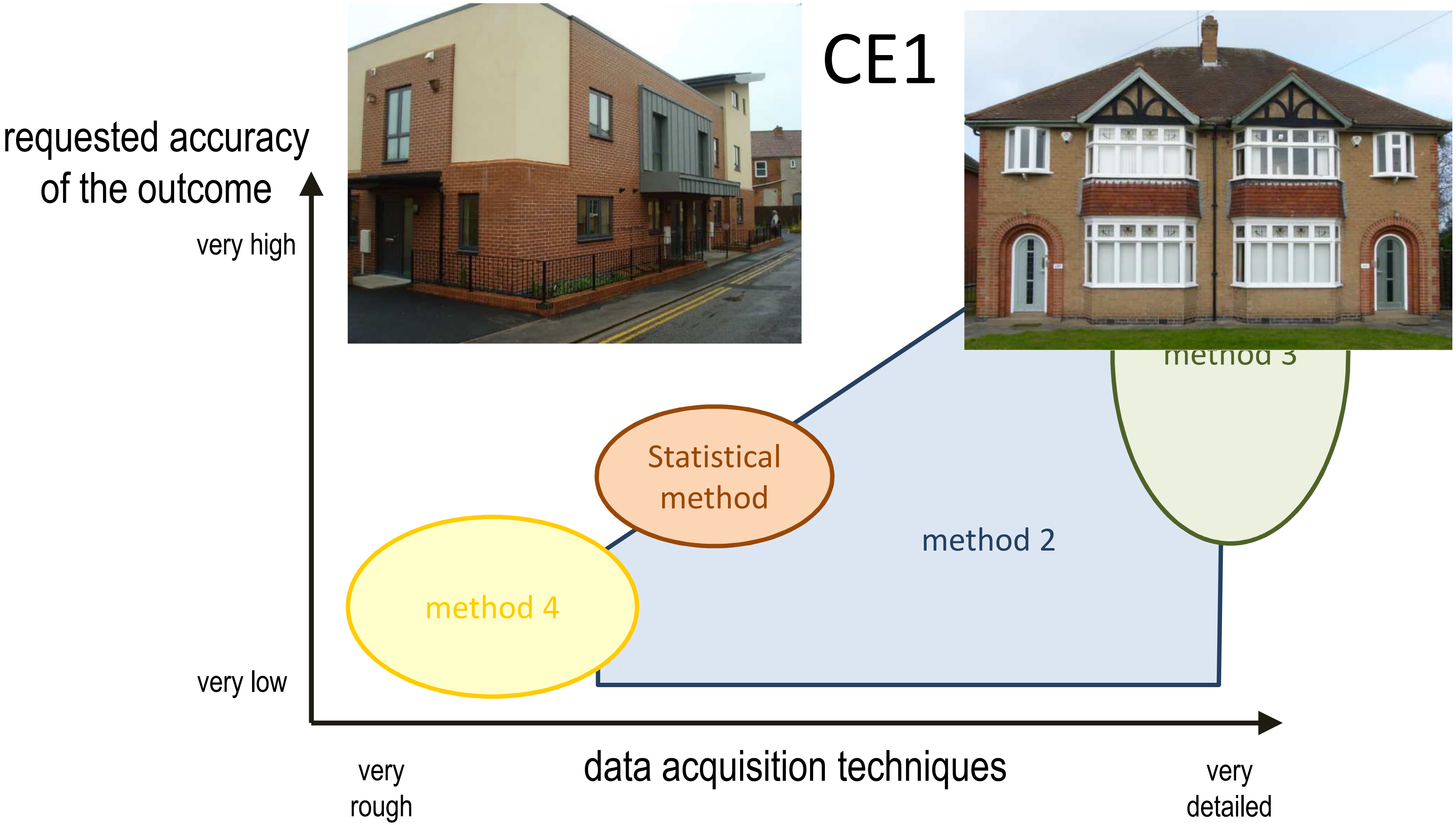
$$d\mathbf{T}(t) = \mathbf{A_c}\mathbf{T}(t)dt + \mathbf{B_c}\mathbf{U}(t)dt + \mathbf{W}(t)$$

$$\mathbf{Y}_t = \mathbf{C}\mathbf{T}_t + \mathbf{D}\mathbf{U}_t + \mathbf{e}_t$$

Parameter estimation based on maximising the likelihood function.

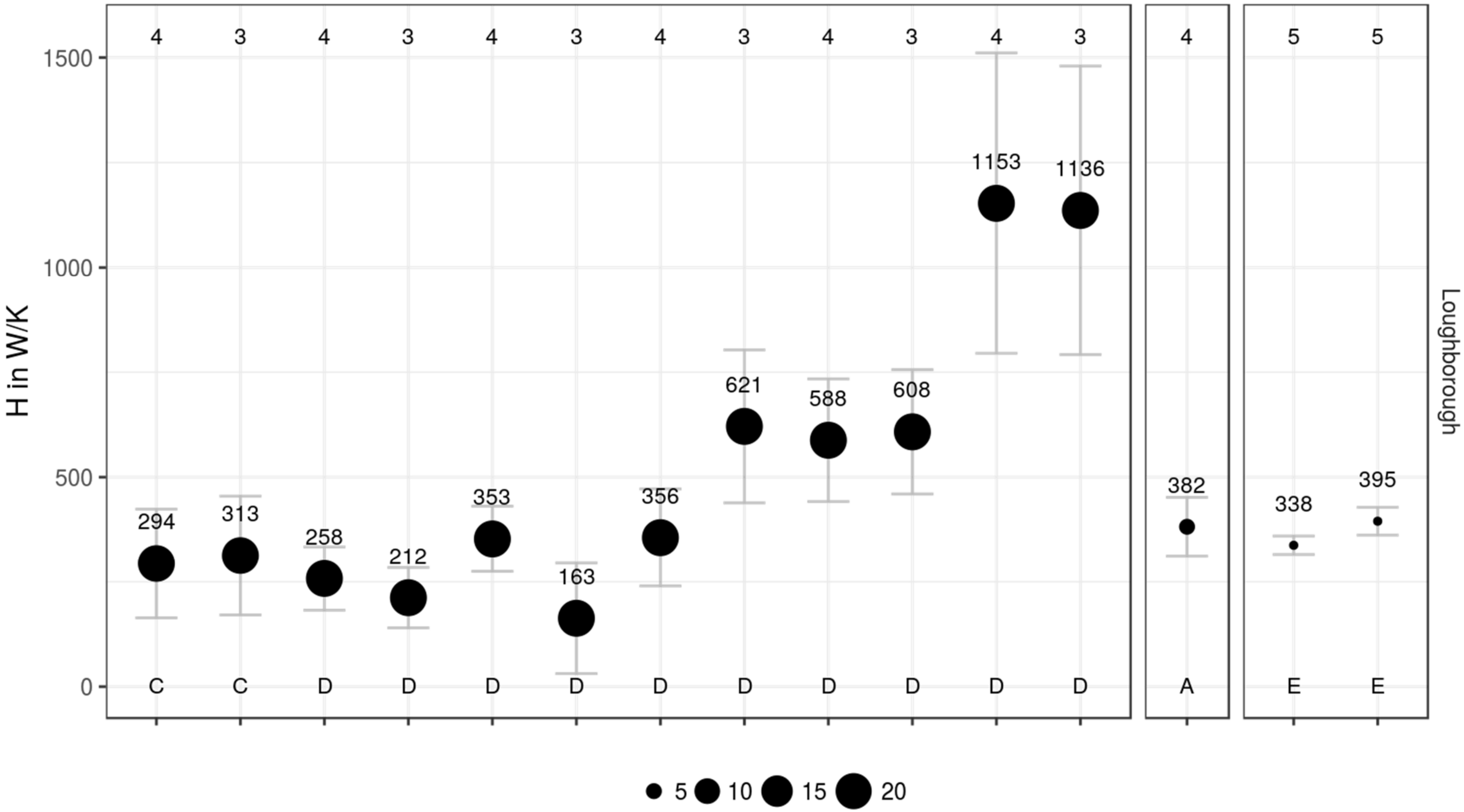


First explorative results



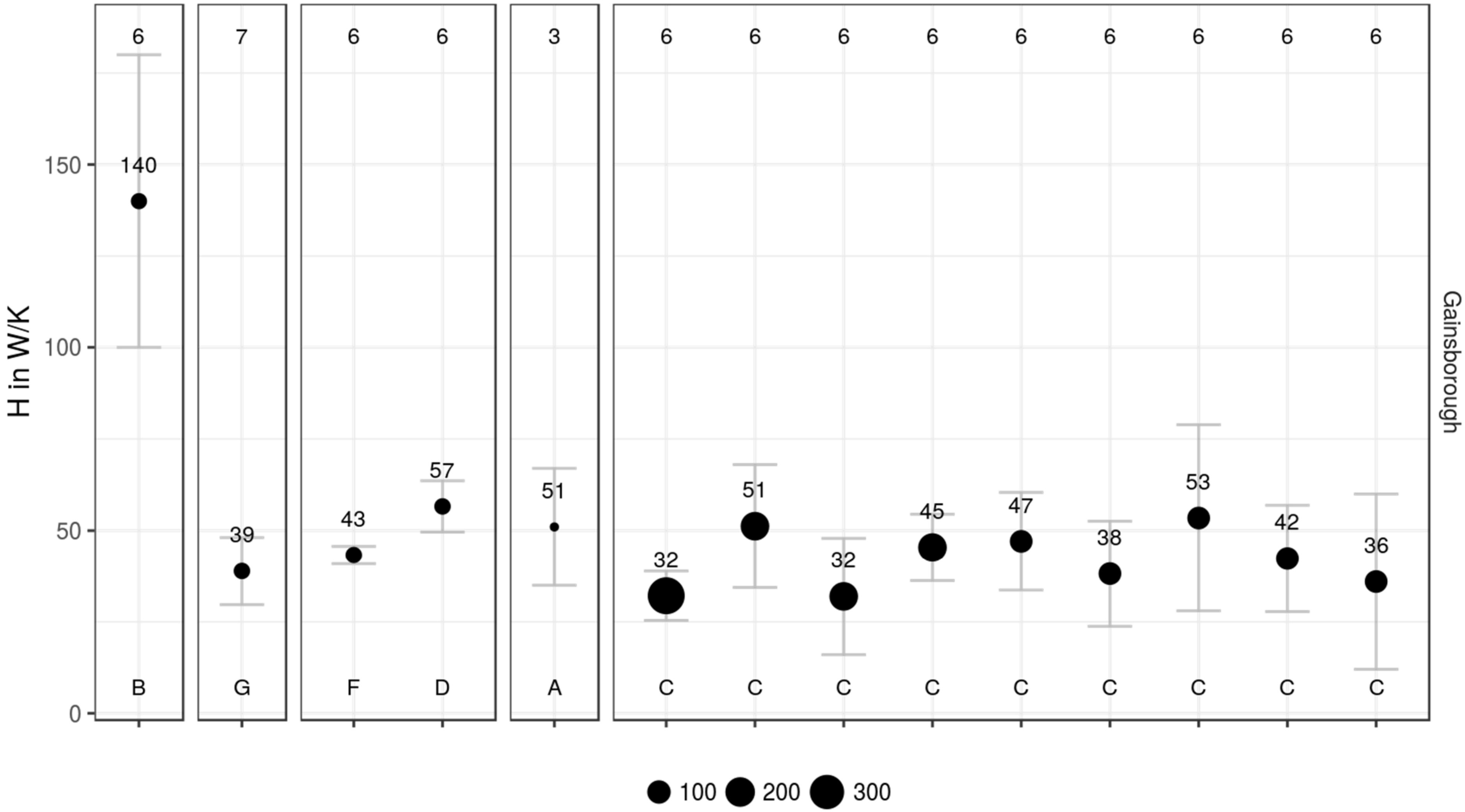
First common exercise to explore the matrix

Loughborough case



A: Bayesian - MCMC, B: BEECHAM, C: Linear regression, D: ARX, E: Average, F: RC (LORD), G: Grey-box (CTSM-R)

Gainsborough case



A: Bayesian - MCMC, B: BEECHAM, C: Linear regression, D: ARX, E: Average, F: RC (LORD), G: Grey-box (CTSM-R)

Preliminary conclusions

- Different techniques can be applied to assess the performance of a building in use
- Methods differ in input data and accuracy of output data
- Several questions remain to be answered:
  - robustness, reliability and accuracy of the methods
  - required accuracy for different use cases
  - acceptable costs for different use cases
  - ….

More results in due time!

Questions?