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THERMAL STRUCTURE OF WALLS FROM SHORT, ALL-YEAR-ROUND MONITORING

A Novel Statistical Method for Thermophysical Properties Estimation

Virginia Gori (Supervisors: Dr Cliff Elwell, Prof Mike Davies)

LoLo Annual Colloquium 2016

17 November 2016

UCL Loughborough University EPSRC Pioneering research and skills

RESEARCH IN SUMMARY

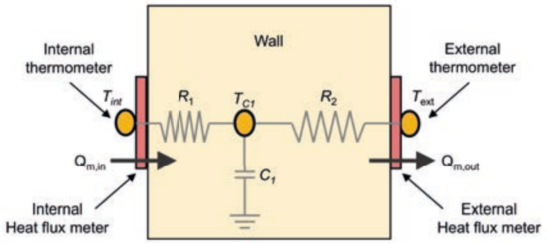
Aim:

Novel statistical-based dynamic method for the estimation of the thermophysical properties of building elements:

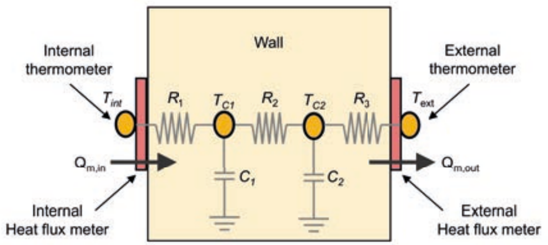
- using **short** & **seasonal-independent in-situ measurements**;
- producing **robust estimates** & **acceptable error ranges**;
- giving useful **insights on the thermal structure** of the element.

Method:

Physical model(s) of heat transfer + **Bayesian optimisation**



1TM (2HF): 4 parameters



2TM: 7 parameters

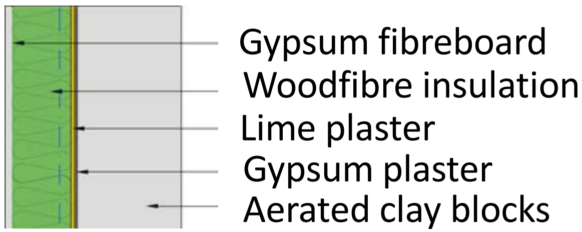
Set of *most probable parameters* that *minimise the prediction error*

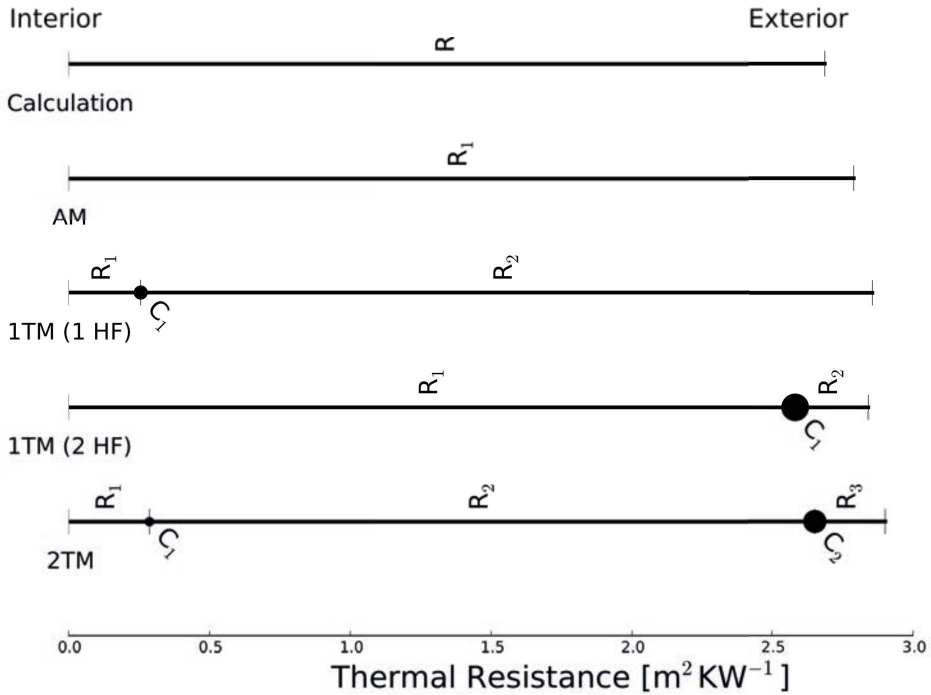
Advantages:

- Model comparison
- Estimation of uncertainties
- Handles changes in heat flux direction & small ΔT → summer

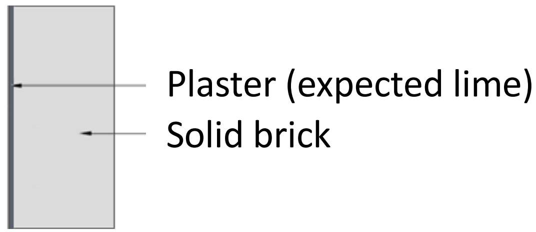
DYNAMIC, AVERAGE METHOD & LITERATURE

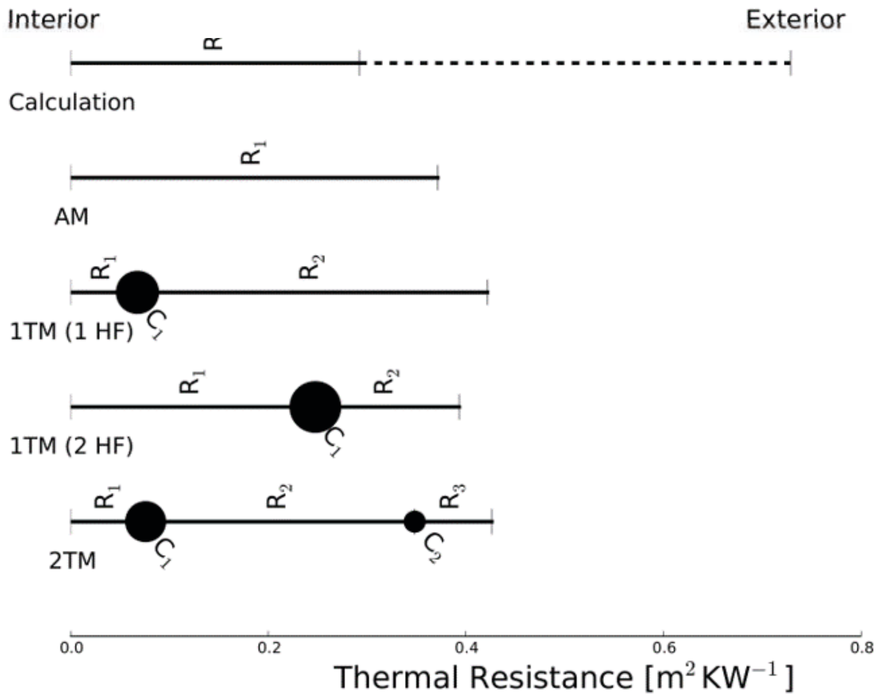
Thermal Chamber:





In-situ:

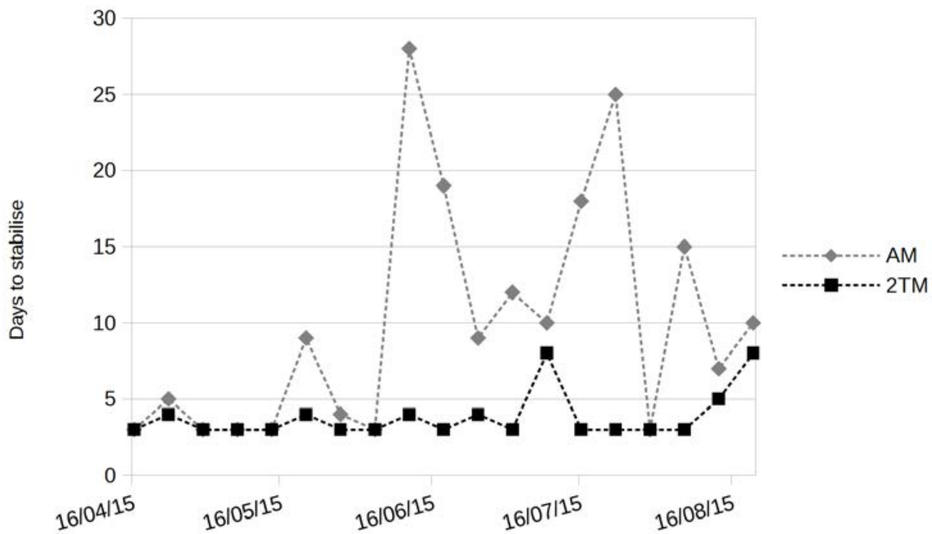


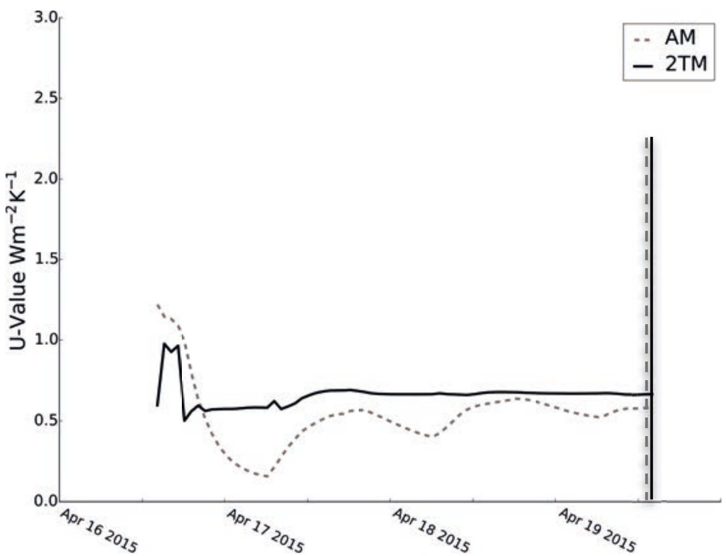


	Thermal Chamber: Literature	Thermal Chamber: 2TM	In-situ: Literature	In-situ: 2TM
C_1 [$kJm^{-2}K^{-1}$]	48.0	46.7 ± 0.5	[107.5, 180.1]	212.9 ± 1.8
C_2 [$kJm^{-2}K^{-1}$]	119.0	119.1 ± 0.8	[100.8, 191.6]	113.1 ± 1.0
U [$Wm^{-2}K^{-1}$]	0.35	0.33 ± 0.03	[1.11, 2.16]	1.71 ± 0.26

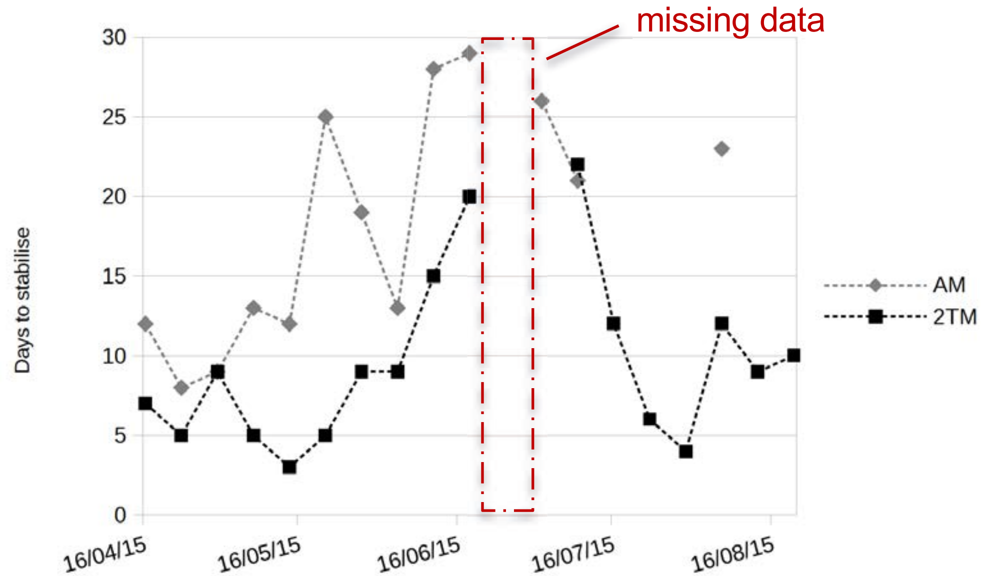
THERMOPHYSICAL ESTIMATIONS OVER TIME

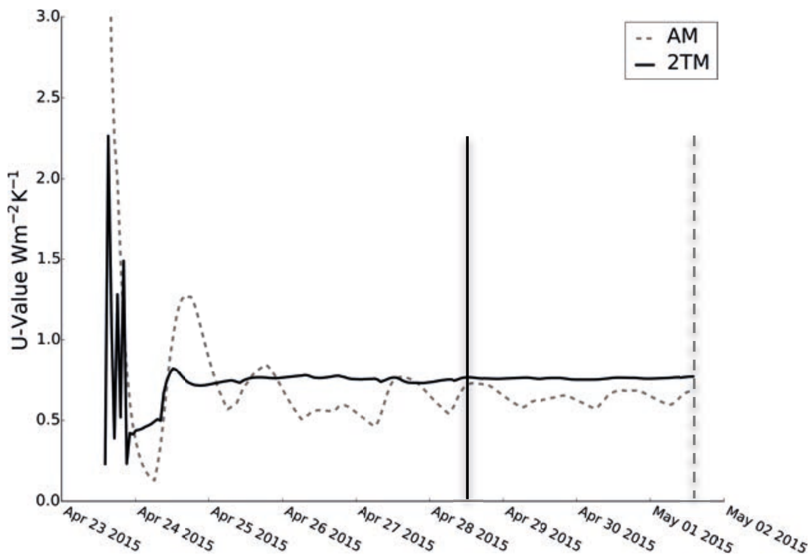
North-facing cavity wall:





East-facing cavity wall:





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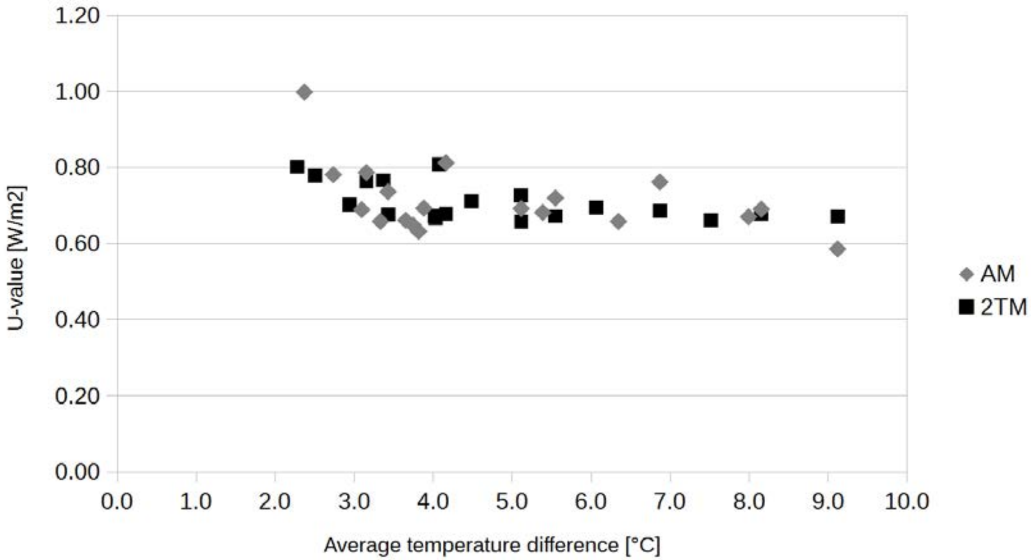
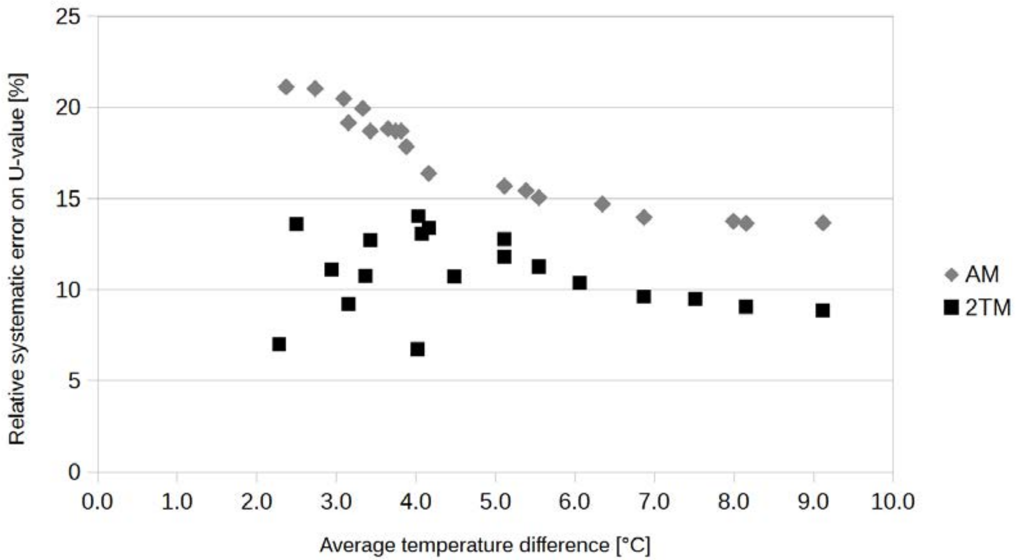
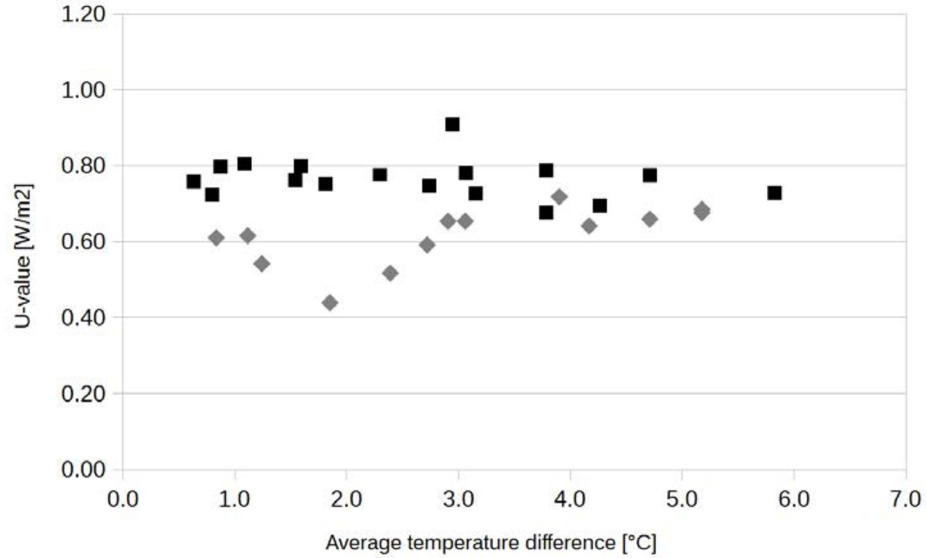
THERMOPHYSICAL ESTIMATIONS OVER TIME

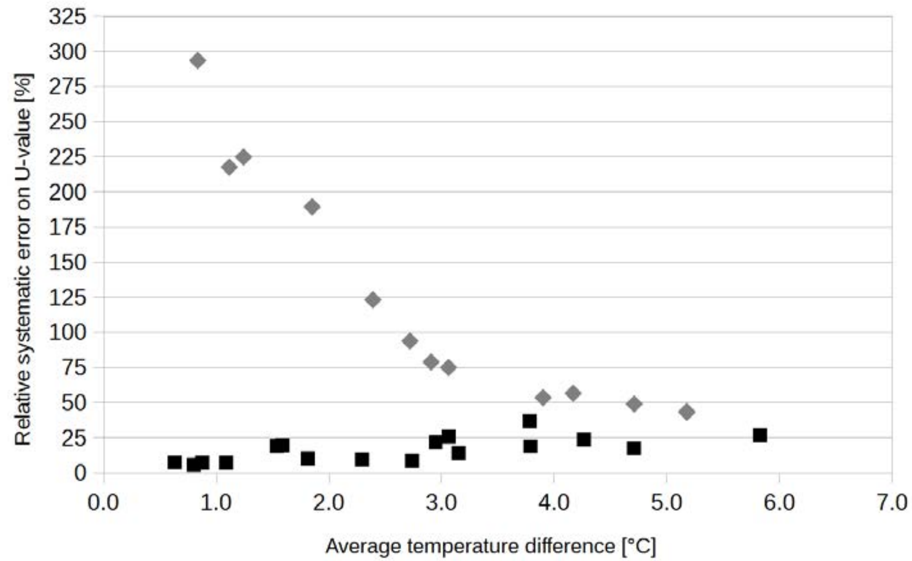
North-facing cavity wall:





East-facing cavity wall:





RELEVANCE TO POLICY MAKING

QUICK → Benchmark characterisation of the building stock.

ROBUST → Actual characterisation of the **thermal performance** of buildings:

- in their **environment** and **state of conservation**;
- from **short** & **seasonal-independent monitoring**.

INSIGTHS → The **reliable characterisation** of the thermal performance of the building stock enables to:

- inform **guidelines and policies** (*e.g.*, on performance gap);
- issue **tailored energy-saving-oriented incentives**;
- evaluate the **cost-effectiveness of different strategies**.

RELEVANCE TO INDUSTRY

QUICK → In-situ tests may be widely performed (*different seasons*) for:

- **quality assurance** of new built;
- characterisation of the **base-case performance** before retrofitting (*even if structure is unknown*).

ROBUST → **Improvement** of the overall **quality of the building process** by **quickly feeding** the **lessons learned back** into the system.

INSIGTHS → Characterisation of the **thermal structure of the building**:

- **improve thermal comfort**;
- inform **tailored retrofitting** & **heating / cooling strategies**;
- evaluate the **cost-effectiveness** of different solutions.

RELEVANCE TO ACADEMIA

NOVEL → **Novel statistical based** (*Bayesian*) **method** to enhance the use of in-situ measurements.

ROBUST → Valid **thermophysical estimates** from data collected over **different seasons** and **temperature ranges**:

- quantification of **errors** & **uncertainties** (*acceptable range*);
- objective comparison of the **probability of different models**.

INSIGTHS →
- Characterisation of **heat transfer at both sides** of elements;
- Inform **high-quality in-situ monitoring** & **data analysis**;
- **Development** of **new concepts** & aspects of heat transfer **modelling** (e.g., *new stabilisation criteria*).

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Gori, V., Marincioni, V., Biddulph, P. Elwell, C. 2016.
Inferring the thermal resistance and effective thermal mass distribution of a wall from in situ measurements to characterise heat transfer at both the interior and exterior surfaces. (Energy and Buildings).

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RETROFITTED INTERNAL WALL INSULATION IN SOLID WALL HOUSES

The effect on energy demand, thermal comfort and overheating

Vicki Tink

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17 November 2016

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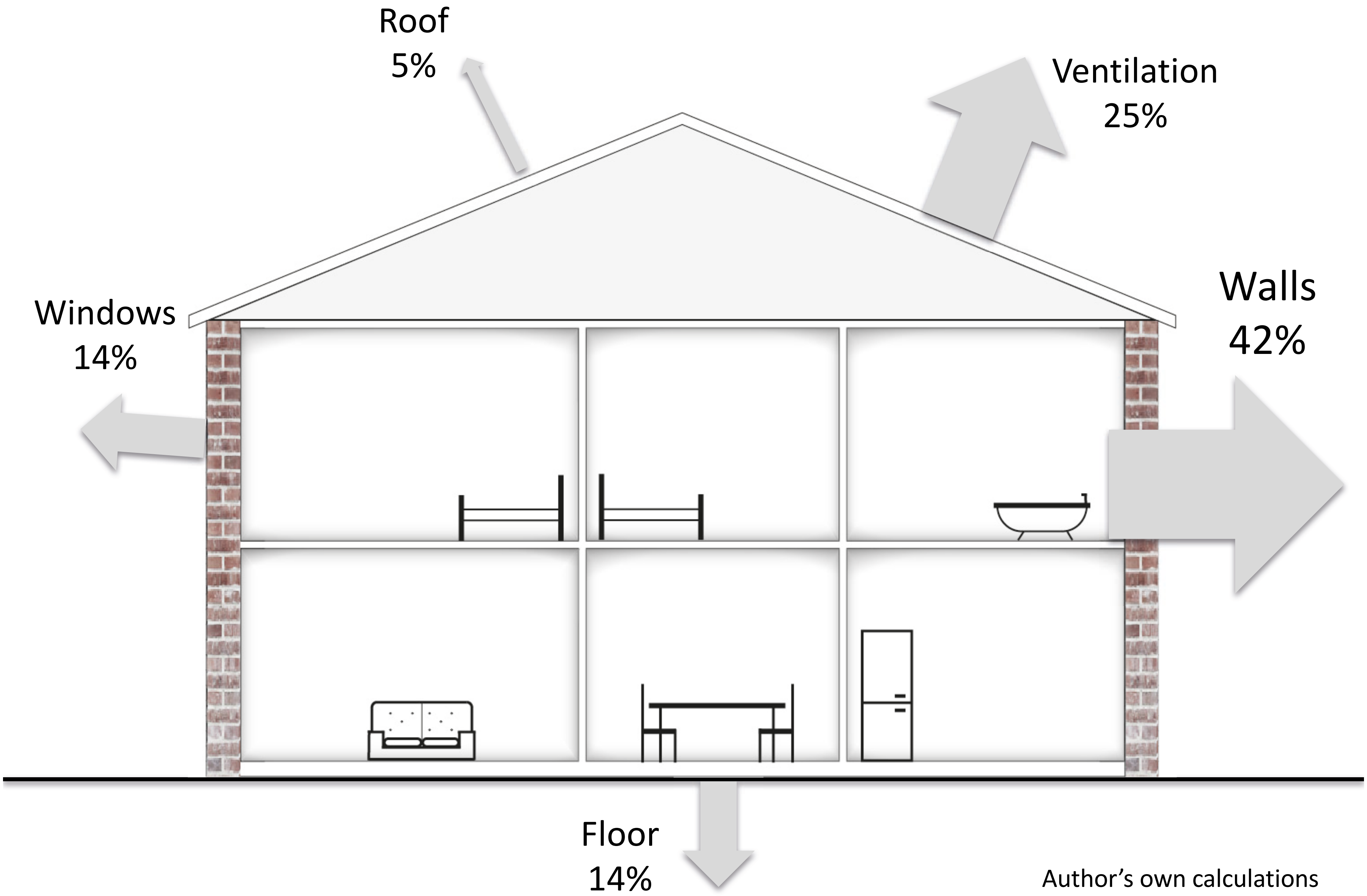
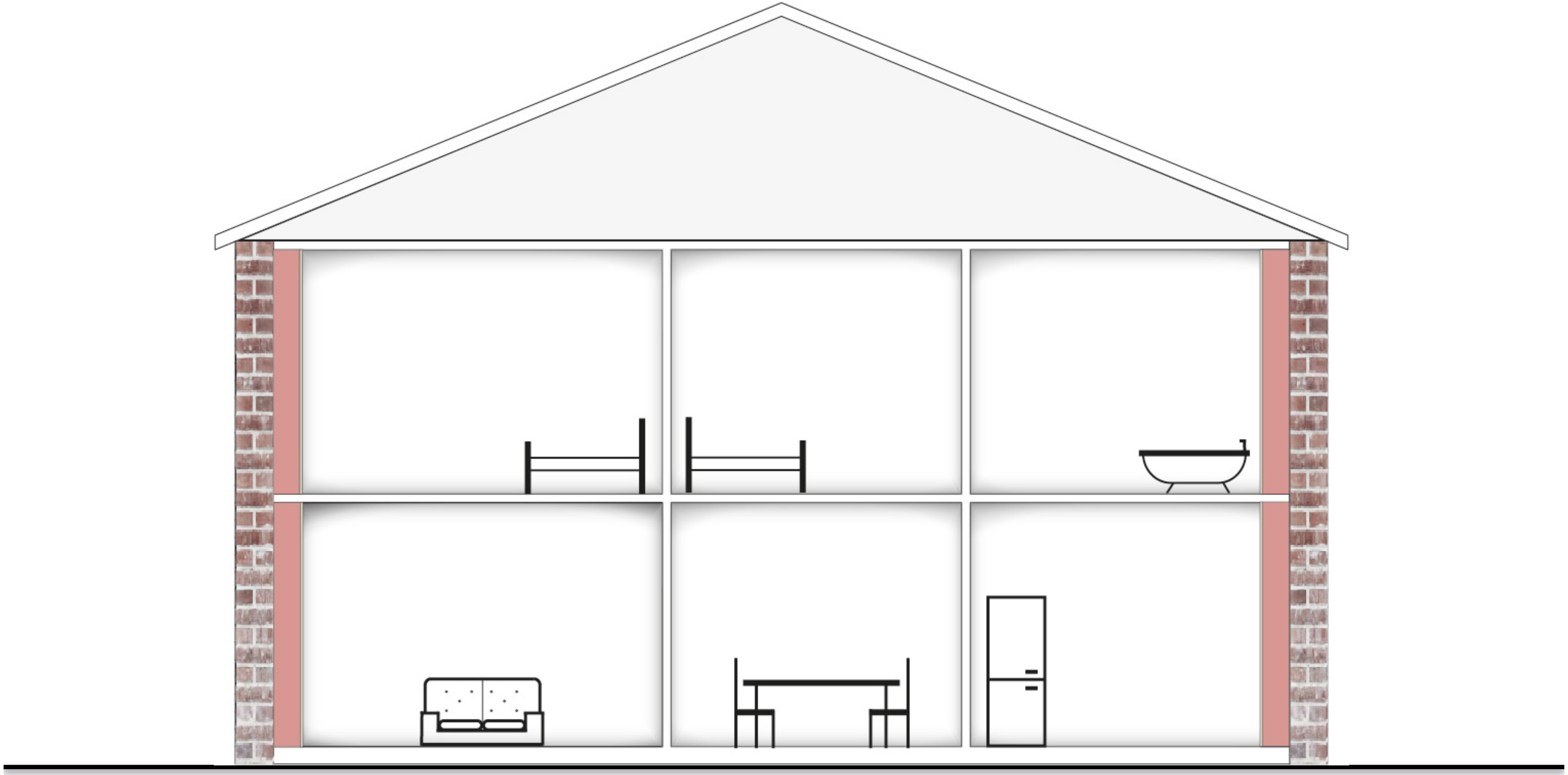
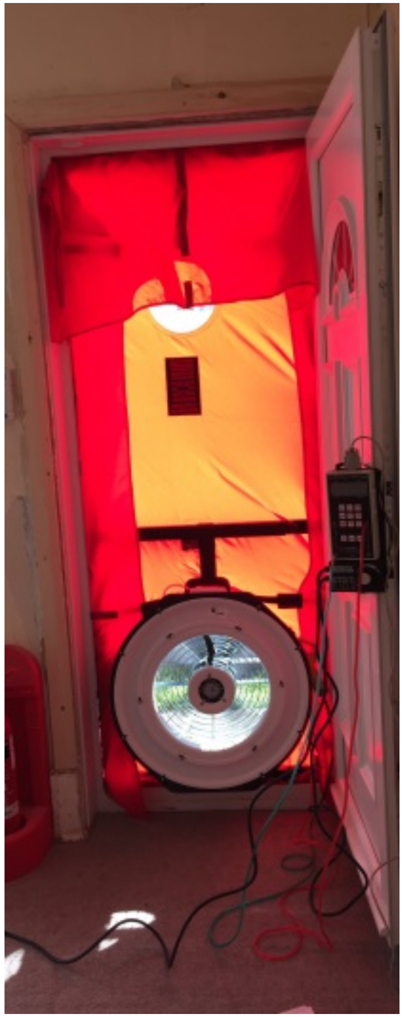


Author's own calculations



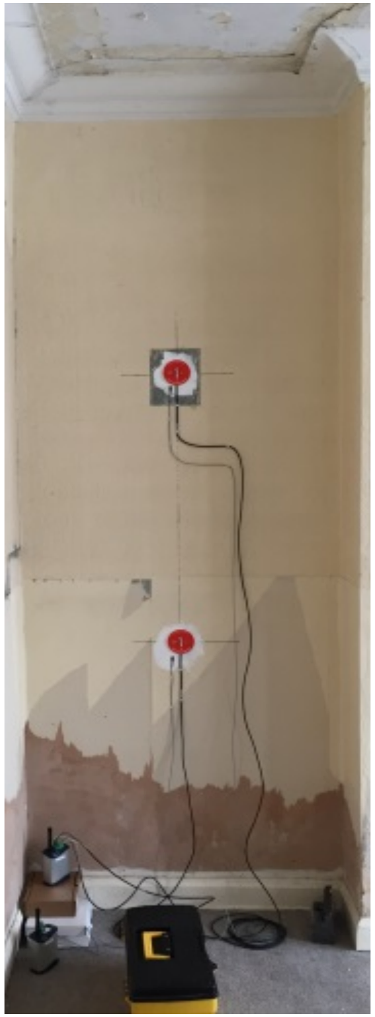
Internal Wall Insulation

Blower Door Test



Co-heating Test

Heat Flux measurements



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Energy Demand

Gas consumption

Electricity consumption

Thermal Comfort

Air temperature
Black globe temperature
Humidity
Air speed

Overheating

Air temperature

Wall surface temperature

Insights

Policy

- Original solid wall performance is better than assumed
- IWI significantly reduces U-values and HLCs
- Improved overheating assessment in SAP is needed

Academia

- New evidence doesn't match previous studies
- Models required to extrapolate findings
- Further field work required to inform models

Industry

- Holistic retrofit needed to mitigate overheating
- Overheating in building regulations needed

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Questions?

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Project details: lolo.ac.uk/people/vicki-tink/
Twitter: @Vicki_Tink
LinkedIn: Vicki Tink

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MAPPING THE CURRENT AND FUTURE RISK OF OVERHEATING IN UK HOMES

From Cradle to Grave

Data – Method – Results – Impact

Argyris Oraiopoulos

LoLo Annual Colloquium 2016
17 November 2016

Supervisors:
Dr Steven Firth
Dr Tom Kane
Prof Kevin Lomas

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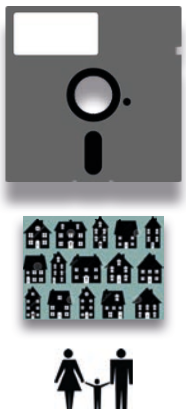
DATA



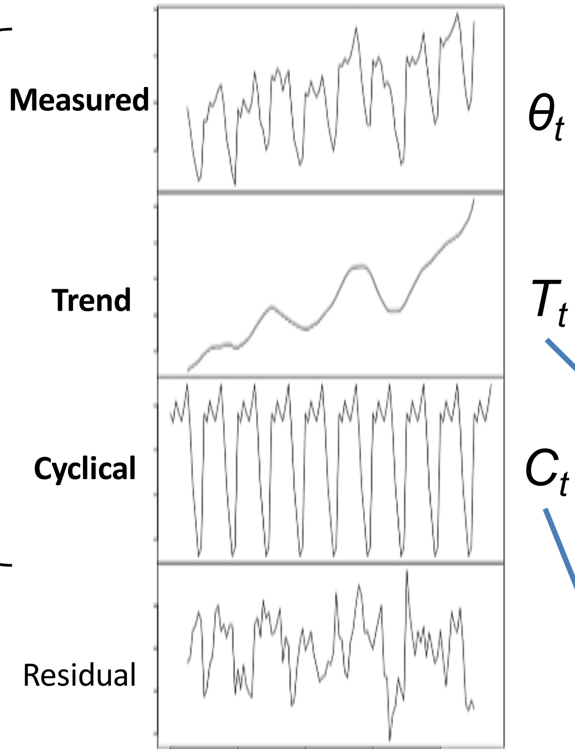
- Hourly recorded internal air temperatures
- Living rooms and main Bedrooms
- 228 homes in Leicester, UK (201 Bedrooms, 210 Living rooms)
- 411 Free-floating spaces (No heating, No mechanical cooling)
- 62 Days, 1st July - 31st August 2009

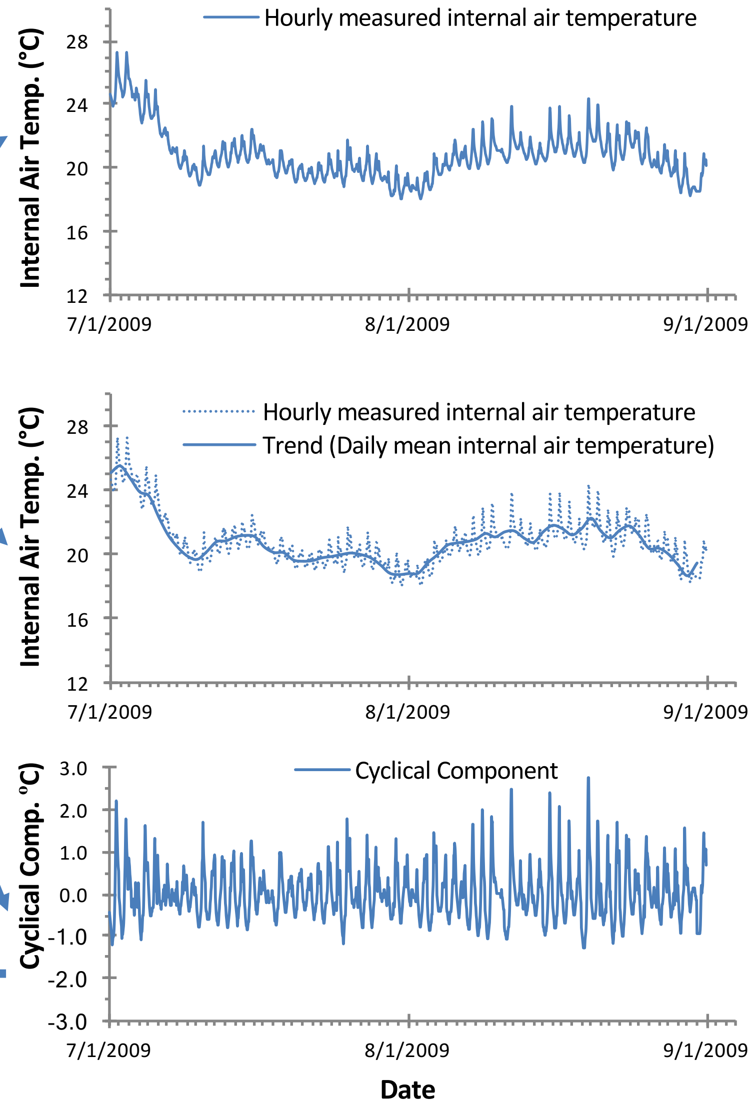
Can we use empirical data to predict internal temperatures in buildings during summer conditions?

- Analyse data
- Understand internal room temperature formation
- Construct statistical models
- Forecast future temperatures

Time Series Analysis – Descriptive *(Box & Jenkins, 1976)*

- Initial Data Analysis
- Adjustments
- Identification
- Estimation
- Model Checking
- Forecasting





Additive Model

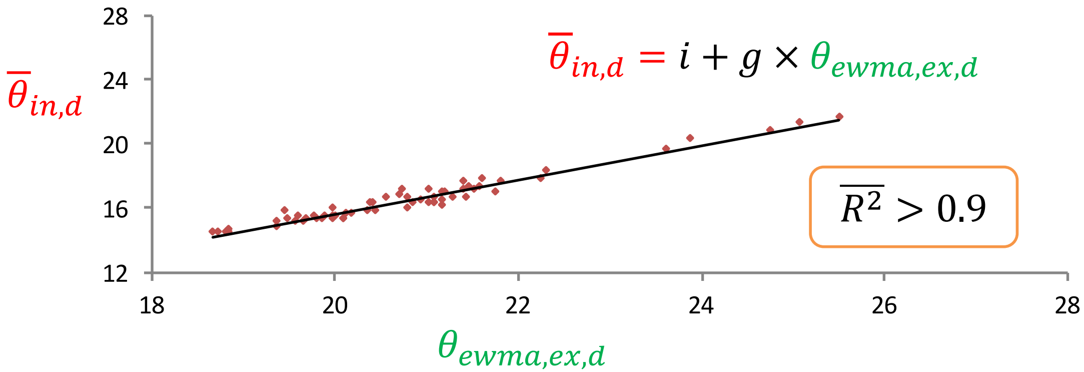
$$\theta_t = T_t + C_t$$

Trend Analysis and Modelling (Day to Day Variation)

- Long-term Trend (T_t) : *Daily Mean Internal Air Temp*
- Influenced by *Present & Past External Daily Mean Air Temp* (*Exponentially Weighted Moving Average*)

$$\theta_{ewma,ex,d} = (1-\alpha)\times(\overline{\theta}_{ex,d} + \alpha\,\overline{\theta}_{ex,d-1} + \alpha^2\,\overline{\theta}_{ex,d-2} + \alpha^3\,\overline{\theta}_{ex,d-3} + \cdots + \alpha^m\,\overline{\theta}_{ex,d-m})$$

- Linear Regression



Cyclical Component Analysis and Modelling (Hour to Hour Variation)

- Short-term Cyclical component (C_t) : *Hourly measured - Daily Mean*
- Influenced by External Temp and Solar Irradiation : $C_{in,t} = f(C_{ex,t}, C_{solar,t})$

Cyclical of Internal ($C_{in,t}$) = A × Cyclical of External (C_{ex,φ_e}) + B × Solar Irradiation (C_{s,φ_s}) + γ

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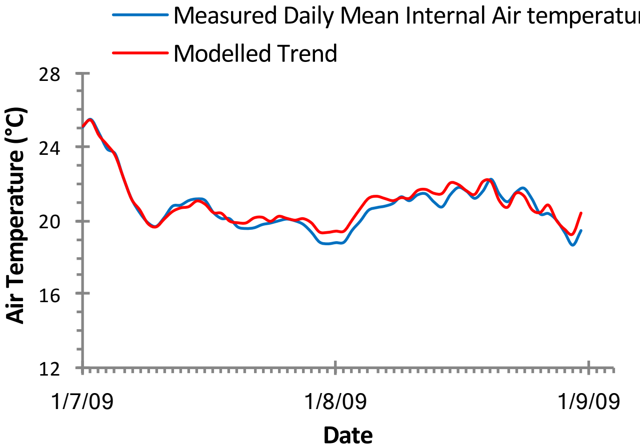
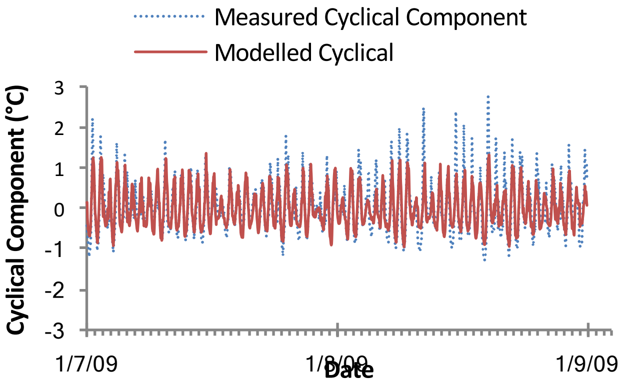
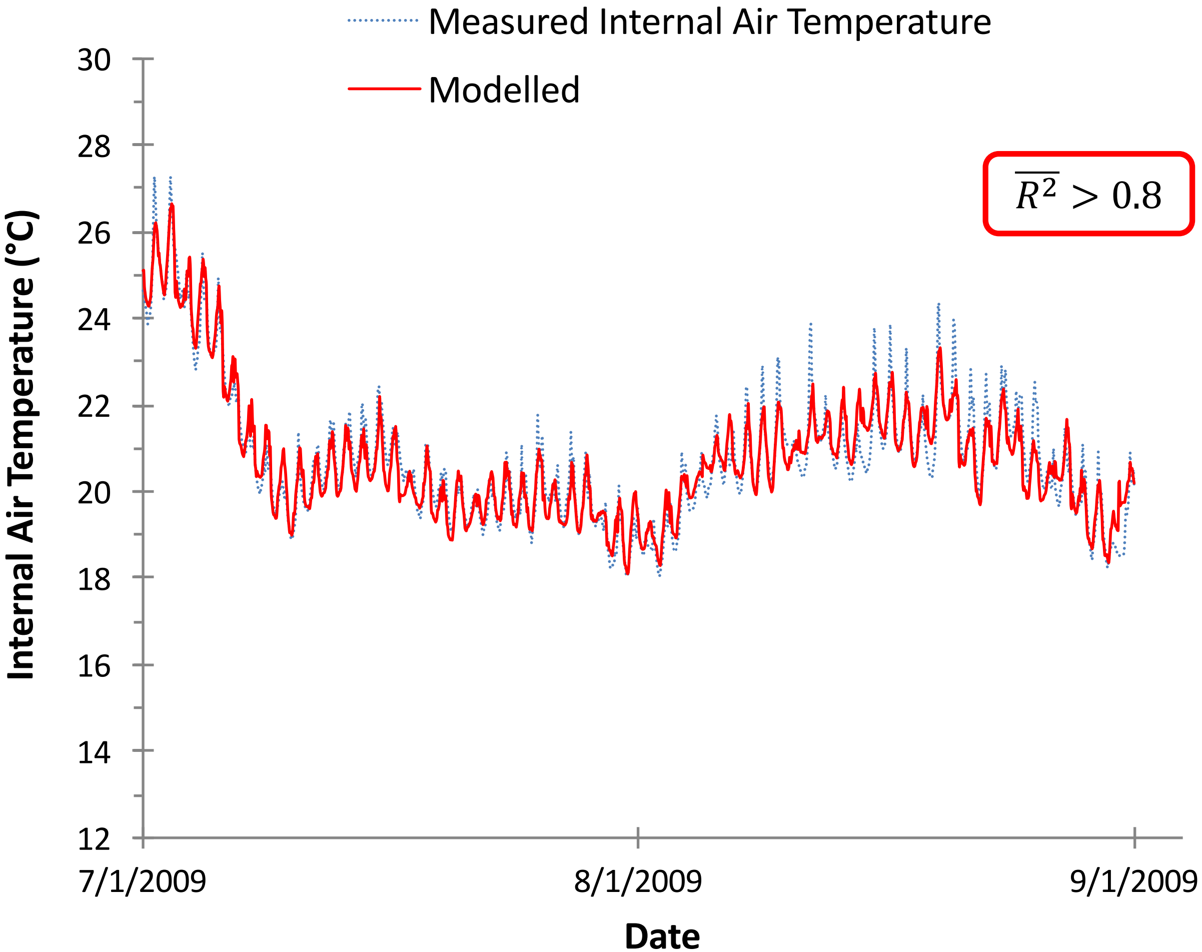
RESULTS: One Living Room – Complete Model

Internal Air Temperature = Trend + Cyclical Component : $\theta_{in,t} = T_{in,t} + C_{in,t}$

$$\theta_{in,t} = i + g\times\left[(1-\alpha)\times\left(\overline{\theta}_{ex,d} + \alpha\,\overline{\theta}_{ex,d-1} + \cdots + \alpha^m\,\overline{\theta}_{ex,d-m}\right)\right] + A\times C_{ex,\varphi_e} + B\times C_{s,\varphi_s} + \gamma$$



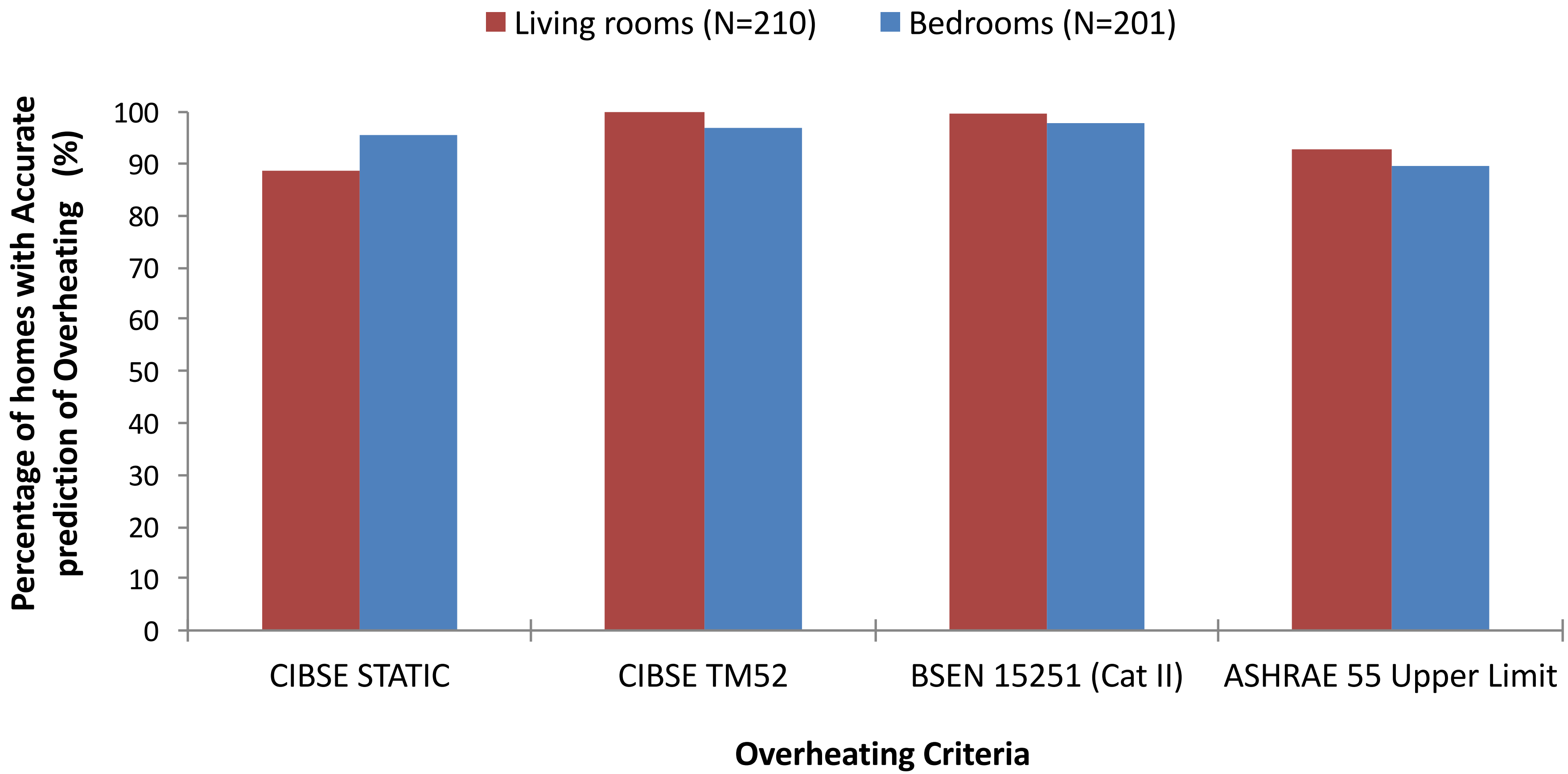




RESULTS: Summary for 411 rooms – OVERHEATING

Overheating

Accurate prediction in >95% of the 411 spaces (*CIBSE TM52 & BSEN15251*)



Policy

- Impact on Retrofitting
- Timely information to Elderly
- Future Scenarios, 2030s, 2050s, 2080s

Industry

- Risk Alert Home Device
- SAP improvement
- Smart Homes, ICT

Academia

- International application
- Passivhaus Zero Carbon
- Naturally Vent. Health Care

Questions / Discussion

Thank you

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Developing a Household Appliance Usage Model to quantify the demand response potential of domestic appliances in UK homes

Selin Yilmaz
Supervisors: Dr. Steven Firth, Dr. David Allinson

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Proposed Research

→ Many energy system models on a national or international scale often have a lack of granularity on the demand side
→ The standardized/fixed electrical load profiles employed in many of these models are not appropriate.

Aim: Investigate new approaches to household appliance behaviour modelling to generate realistic electricity demand profiles for domestic appliance use that are based on measured data.

Methodology

Nationally representative household sample:
English Housing Survey 2013-2014

Appliance ownership model:
The number and the type of appliances are modelled.
EFUS 2011 dataset is

Cooker
Oven
Fridges
Freezers
TVs
Electric shower
Washing machine
Dishwasher

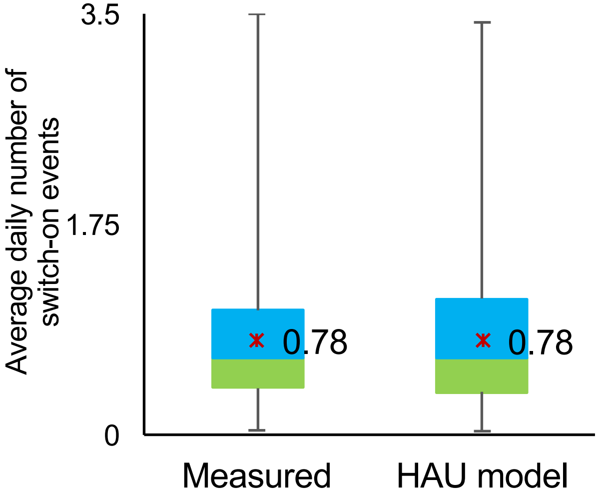
Appliance behaviour model and converting to power demand profiles:
Appliance behaviour metrics and power demand profiles are generated for the individual appliances.
HES 2011 is used to generates the profiles of:

- Number of switch-on events
- Switch-on times
- Duration and power demand profiles

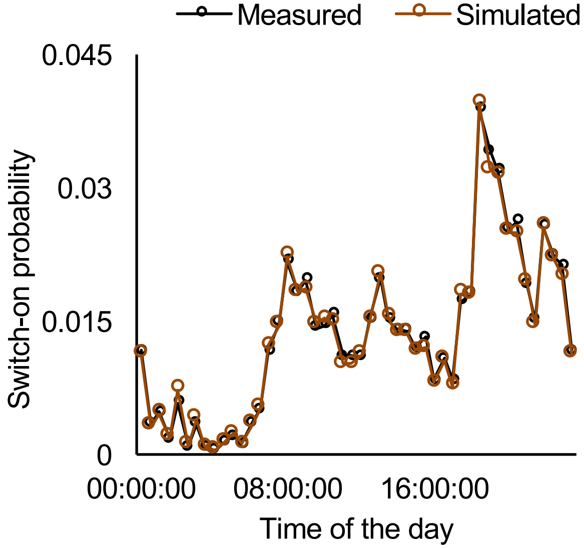
Output: Daily electricity demand vs. time of the day

Results

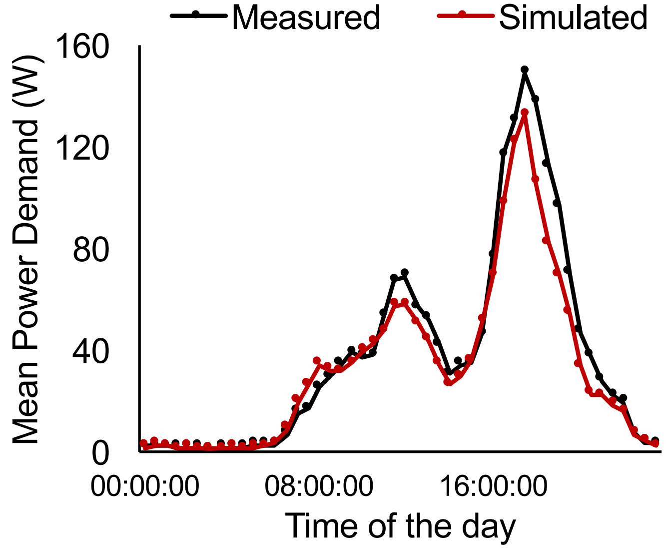
Washing machines

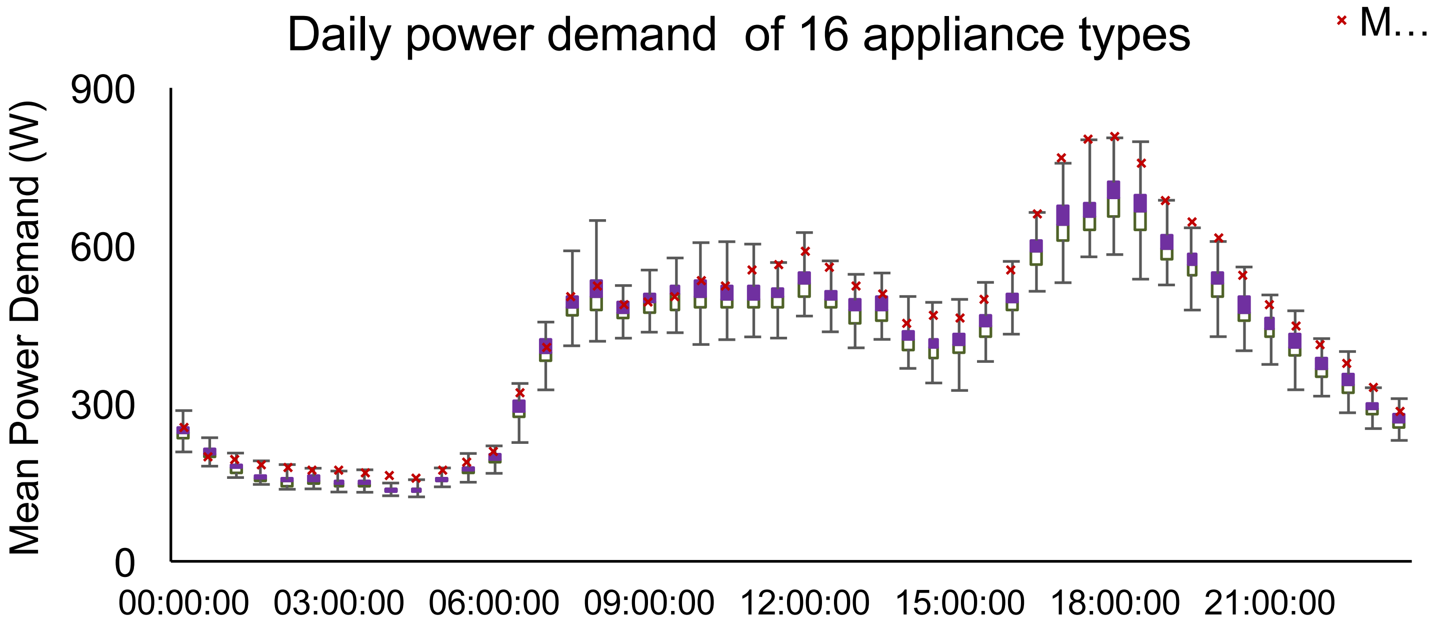


Dishwashers



Ovens





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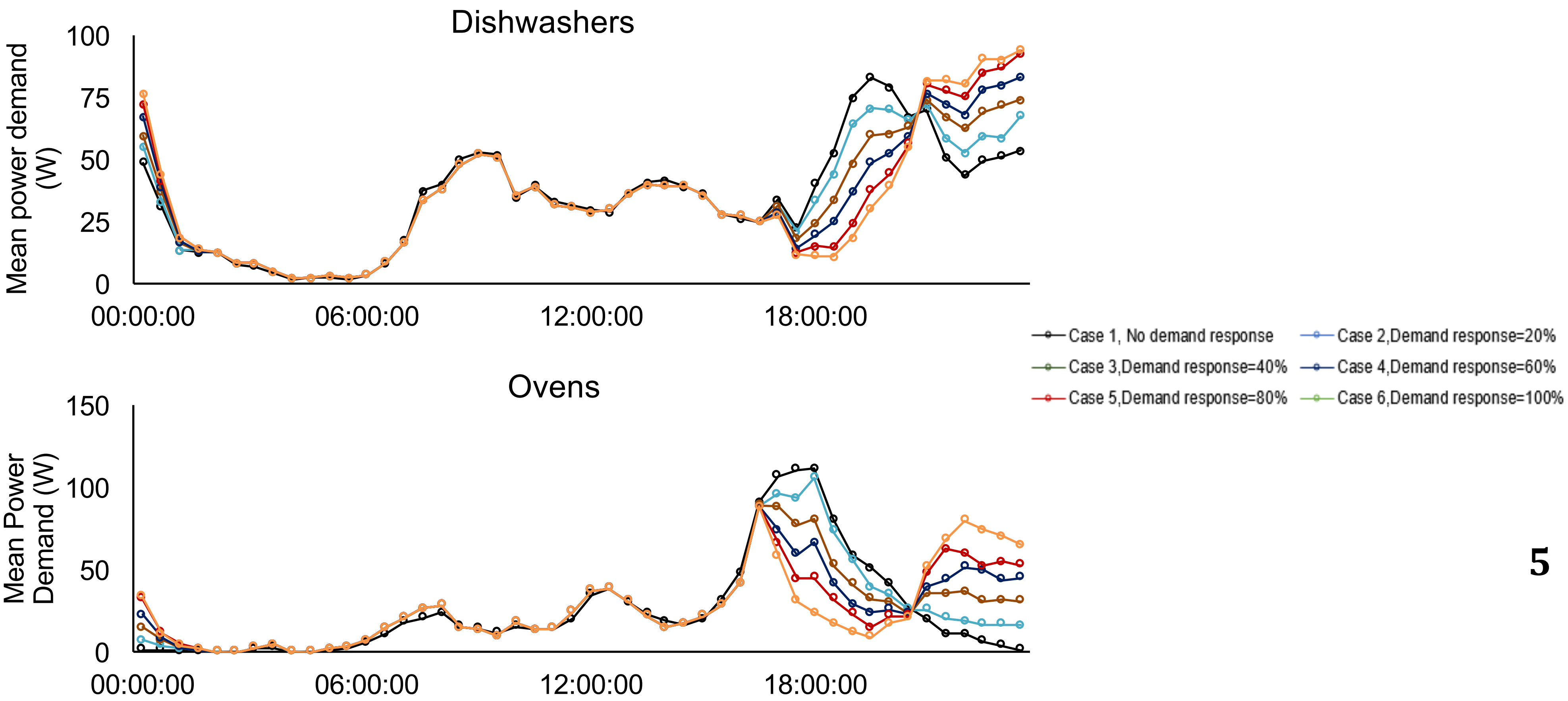
Modelling demand response

	Percentage of the households agreeing to shift to a lower power demand	
	Dishwasher	Ovens
Case 1 (no change)	0%	0%
Case 2	20%	20%
Case 3	40%	40%
Case 4	60%	60%
Case 5	80%	80%
Case 6 (every household shifts)	100%	100%



Insights for academia

- An improved understanding of the occupant appliance behaviour of household appliance use in UK homes:

  E.g: Number of switch-on events, seasonality, duration of usage, programme of choice

- Modelling the use of appliances is a challenging task.
- New modelling approach is shown to have advantages than previous efforts in modelling the variations in appliance occupant behaviours.

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Insights for industry

- The amount of flexible demand available is of interest for utility companies:

  E.g: Ovens have the highest absolute decrease of the electricity consumption from the peak period followed by tumble dryers and dishwashers.
- Risk of additional peak demands.

Insights for policy

- Bottom-up modelling identifies the contribution of each appliance to total consumption or peak load.
- Target groups or appliances for demand response can be identified.

  E.g.: Convincing only 40 % of the households to shift their dishwashers or tumble dryer can lead to same decrease for households with ovens where 20 % of the households agrees to shift their ovens.

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ASSESSING LONG-TERM ACTUAL DAYLIGHTING PERFORMANCE OF CLASSROOMS IN-USE

Nafsika Drosou

Supervisors:
Prof J. Mardaljevic
Dr V. Haines

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Would you spend
90% of your life
in windowless spaces
?

Aim

Explore the extent to which UK government daylight directives result in classrooms which satisfy the daylighting needs of the occupants.

Key Objectives

- Characterise daylighting performance based on:
  - a **physical** quantity of light
  - **objective** criteria
  - **subjective** criteria
- Establish the compatibility between these three assessments.

Case studies

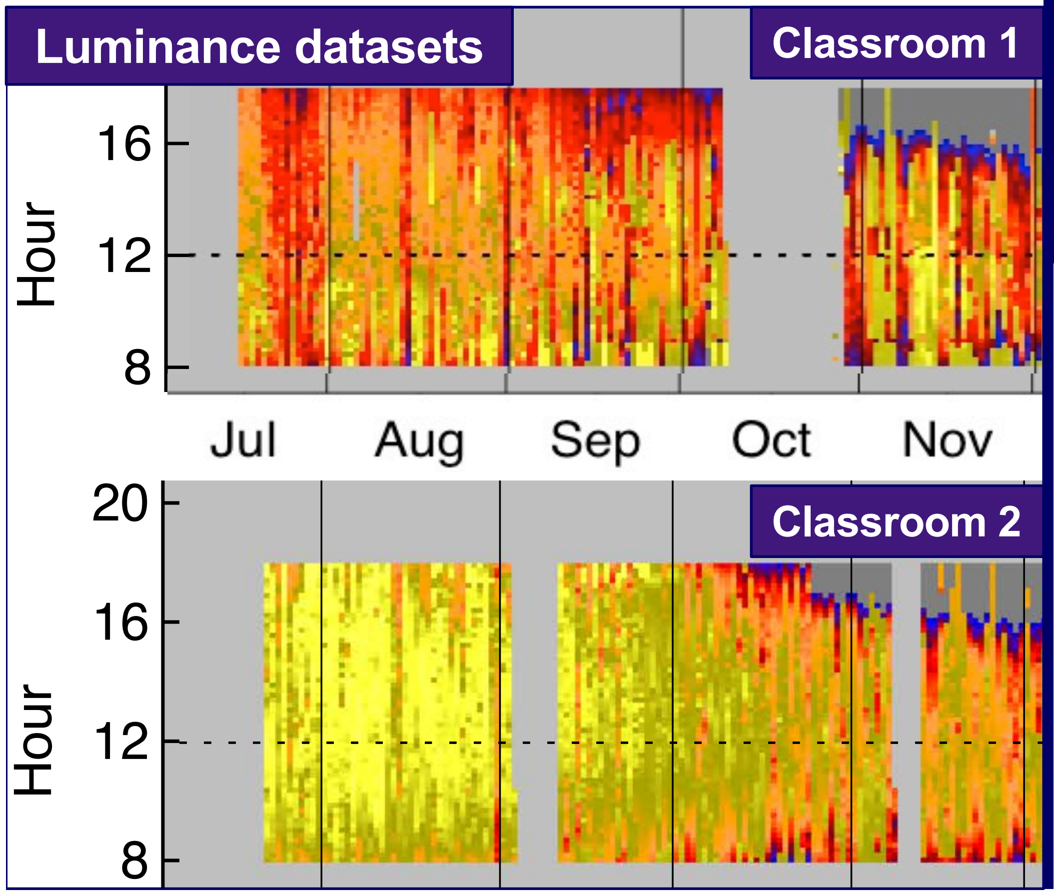
Methodology

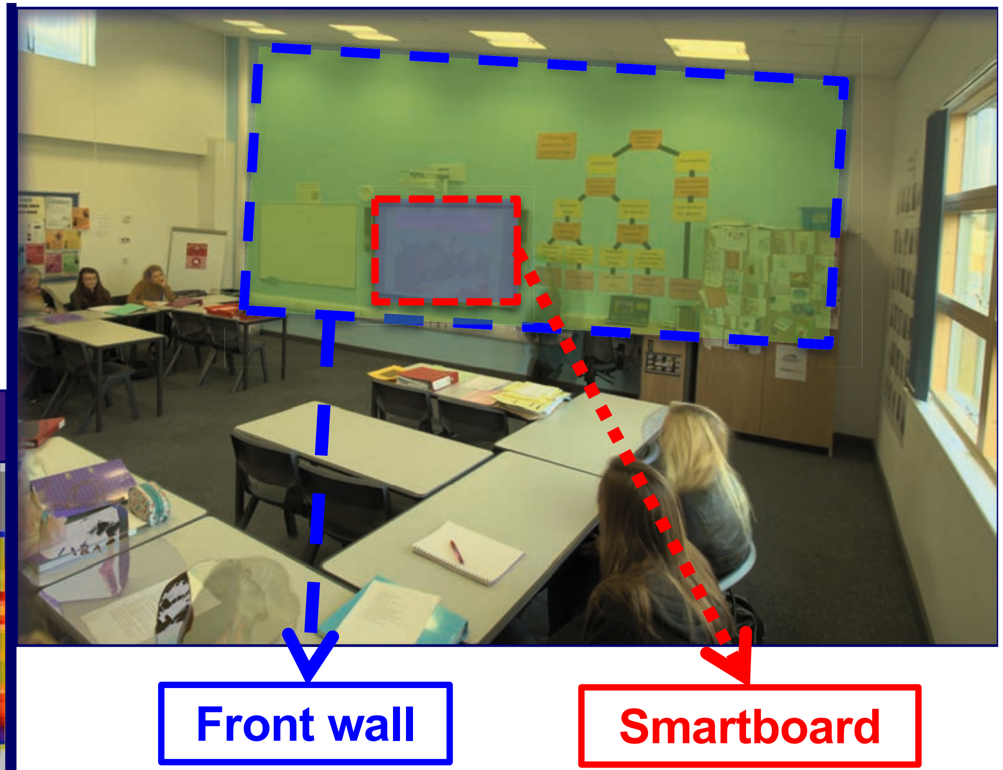
	Physical	Objective	Subjective
Methods	Measurement	Observation	Self-reporting (students)
Quantities	luminance	elec. lights blinds VDTs	brightness visual comfort
Sources	HDR images	standard images	questionnaire focus groups
Data	~ 10^{12} luminance values	~ 62,000 images	412 completed questionnaires
	10-minute interval for 7-12 months	10-minute interval for 7-12 months	Oct - Dec

Range of output

✔ **Zooming OUT**

comparison across:
- spaces
- design elements
- seasons





✔ **Zooming IN**

critical:
- moments in time
- areas

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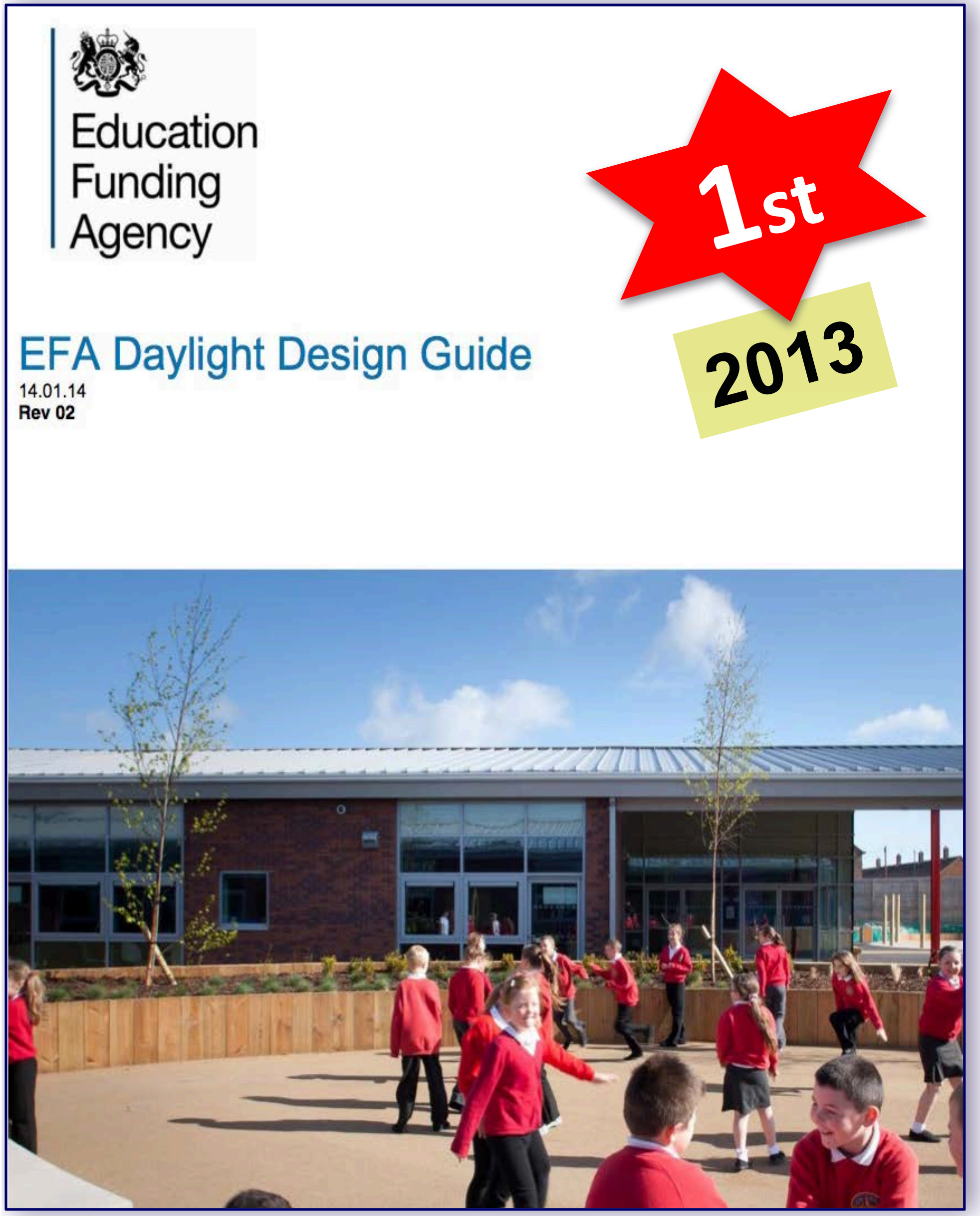
Implications for policy



✔ **Encourage evidence-based benchmarking, so that approved designs will result in classrooms that are well daylit in practice too.**

Implications for industry

✔ **Reduce the gap between reality and daylight simulation outputs, by helping designers make evidence-based daylight modelling assumptions.**

Implications for academia

- ✔ A **robust methodology** for monitoring long-term daylighting performance of complex spaces
- ✔ A **novel dataset** of how users shape daylighting performance (fine-grained & spans 1 year)

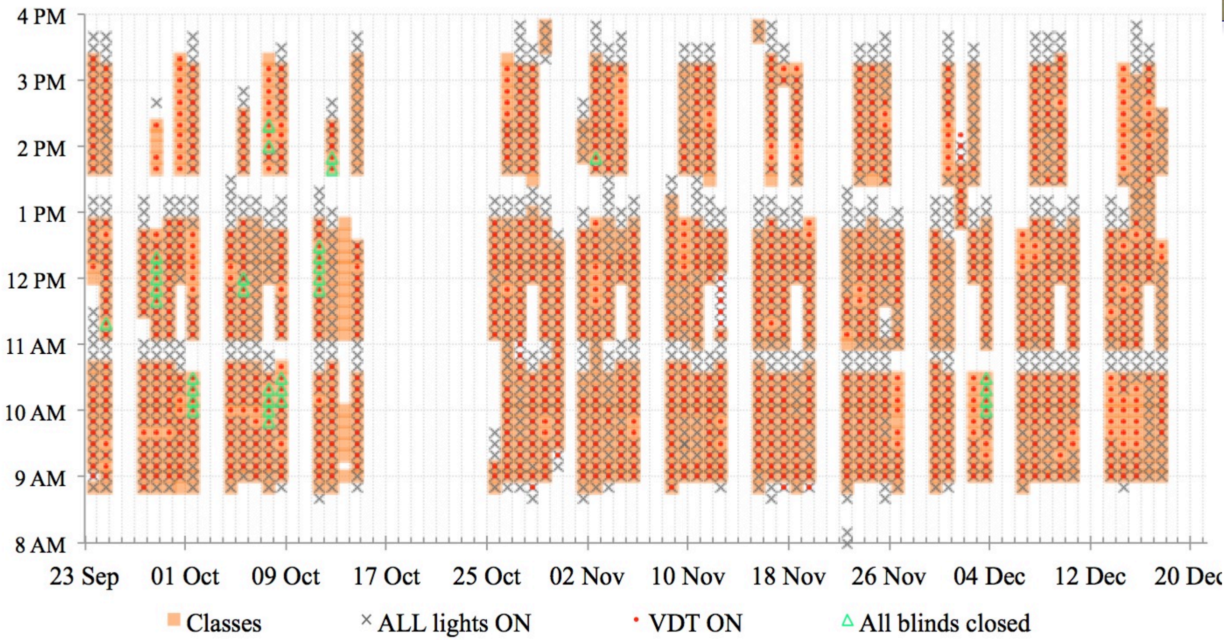


Figure 5: Temporal map of occupancy, VDT, blinds and light use

- ✔ The association of daylight measurements with **human factors** (behaviour & opinions) that affect daylighting performance

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THANK YOU!

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EVALUATION OF RETROFIT STRATEGIES FOR POST-WAR OFFICE BUILDINGS

Part L vs EnerPHit, 2015 vs 2050, Passive vs Active Cooling
Energy vs Comfort vs Costs

ÖZLEM DURAN **Supervisors: Simon Taylor, Kevin Lomas**

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INTRODUCTION

Evaluation of the retrofit

decision making process of

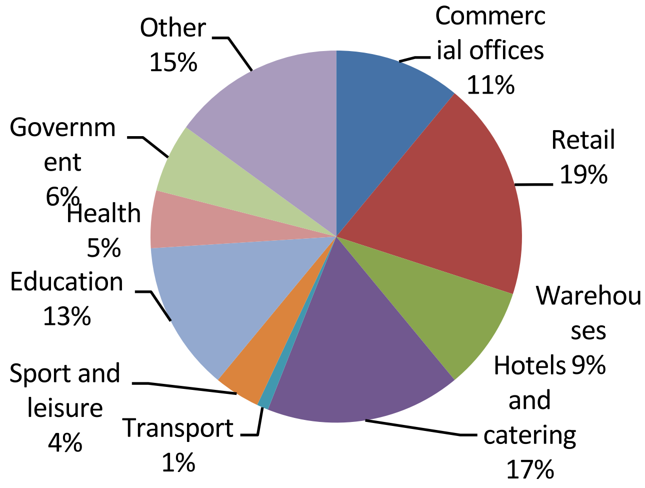
post-war office buildings (1945-1980)

by applying dynamic energy simulations to

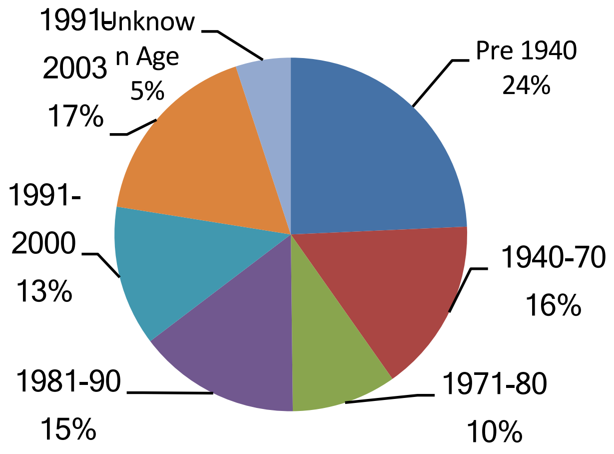
representative building models

in order to create a guidance optimising;

- Energy reduction
- Thermal comfort
- Costs



UK commercial and public sector energy consumption by sub-sector (Pout et al. 2002)



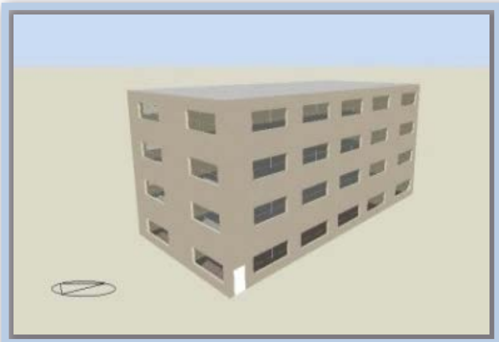
Total floor area percentage of age profiles of office buildings in UK (DCLG, 2005b)

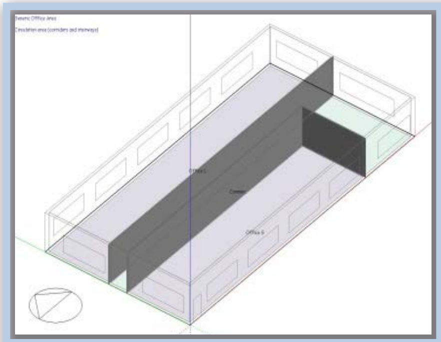
EXEMPLAR

Corridor type plan
Natural ventilation
Daylighting

- High energy consumption
- Unregulated toxic materials
- Thermal discomfort
- Aesthetical problems

Cellular daylit 4 storeys





PARAMETERS

Physical conditions

Location

Weather Data

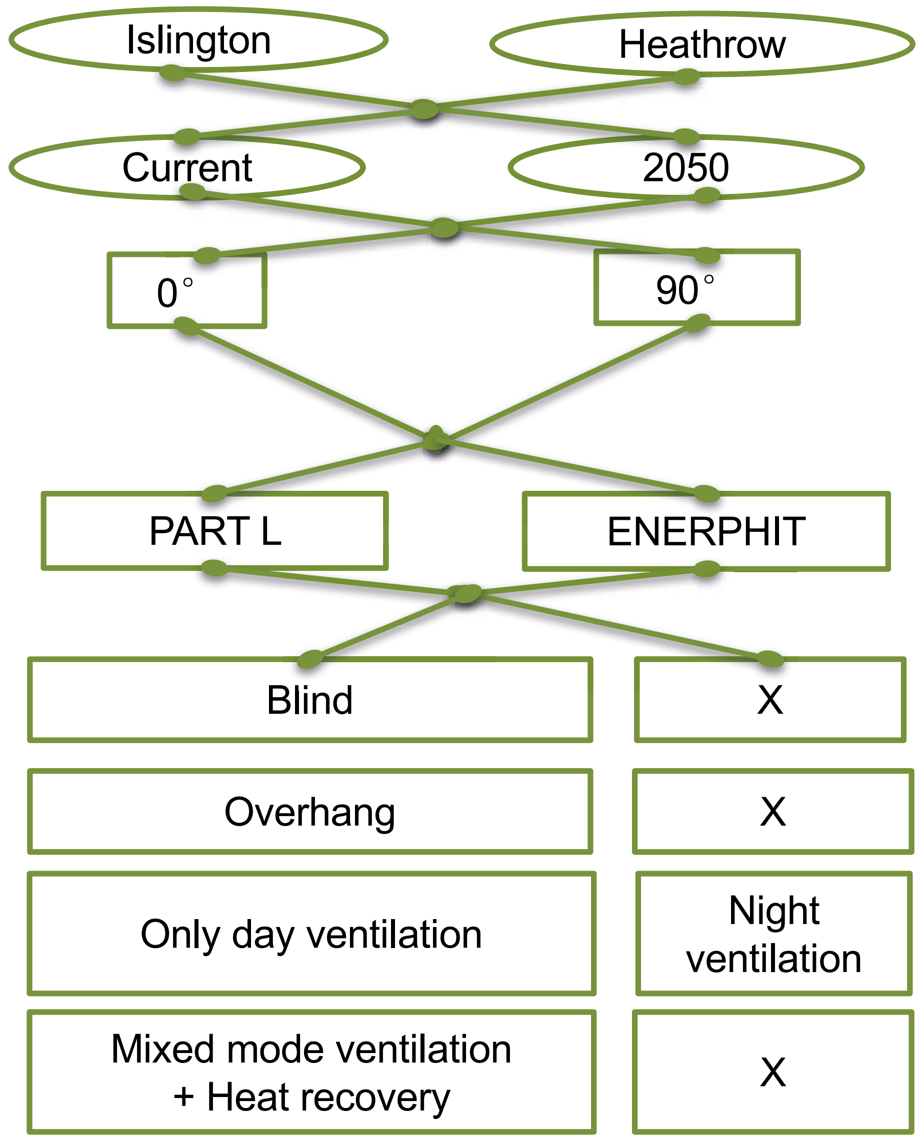
Orientation

Retrofit packages

Heating Energy Reduction

Passive Cooling Energy

Active Cooling Energy



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METHODOLOGY

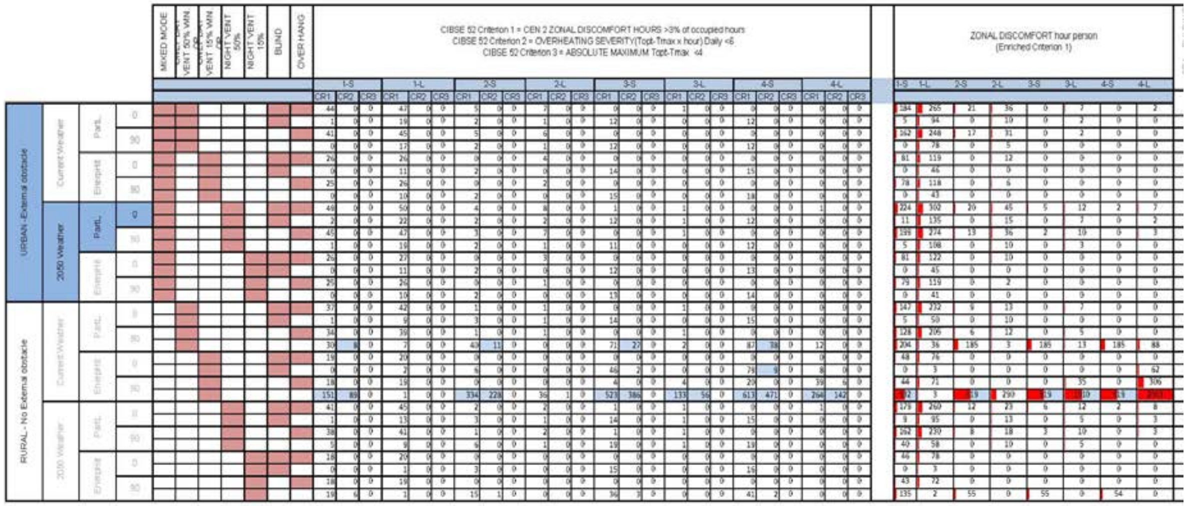
STAGE 1

Forming exemplar; UA / SA

	Min	Base	Max
Occupant density	3.04%		-2%
Lights	-1.45%		1%
Equipment	-3.13%		3%
Infiltration	-6.02%		6%
Heating setpoint	-9.35%		11%
Heating setback	-1.70%		4%
Heating start time	2.41%		-2%
Room depth	3.82%		0%
Storey height	-3.61%		0%
Uncertainty range	**18%**		**19%**
Demand range	**115.9**	**133.9**	**152.9**
Consumption range	**165.6**	**191.3**	**218.4**

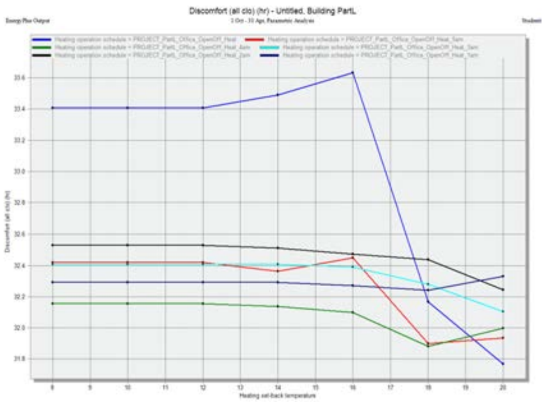
STAGE 3

Detailed analysis



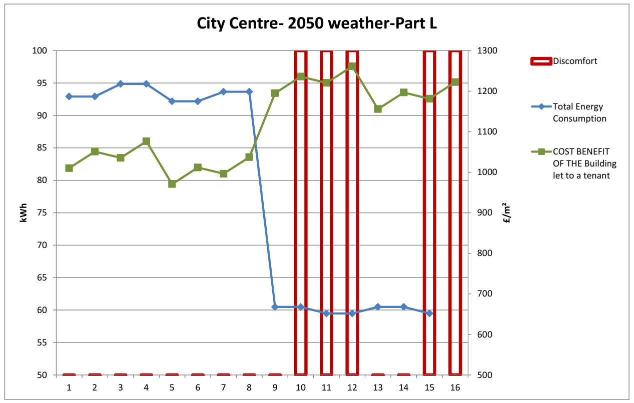
STAGE 2

Parametric study



STAGE 4

Final evaluation



CHALLENGES

Challenge 1; Finding air change rate

By using EMS coding on Air Flow Network, wind speed is limited.

		Day Vent	Night Vent	
City centre	Current Weather	1.4	1	ach
	2050 Weather	1.5	0.7	
Outer city	Current Weather	2.2	1.5	
	2050 Weather	2.7	0.9	

Challenge 2; Building level comfort

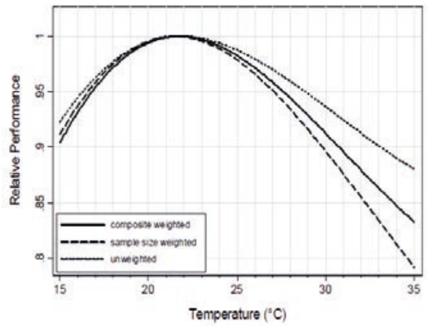
Enriched CIBSE Criterion 1; Building discomfort hour person

$$BDP= \frac{\sum_{t=1}^{T} \sum_{z=1}^{Z} NPxDH}{\sum_{t=1}^{T} \sum_{z=1}^{Z} NPx\,TH}$$

BDP= Building discomfort hour person
NP=Number of people
DH=Discomfort hour
TH=Total occupied hour

Challenge 3; Productivity costs

Loss of performance based on to air temperature difference



Challenge 4; Overall cost calculation

Building used by the owner: benefit from energy cost savings + addition of costs saving as a result of productivity improvement

NPV of energy reduction with fuel price increase - initial investment + productivity improvement

Building let to a tenant: not benefit from energy cost savings but does from rent increase

NPV of rent increase - initial investment

Uncertainties

POLICY

- Rent increase as a result of retrofit

The building sector is driven by profit. Results show cost benefits are high only when the building is let to tenant and if there is a rent increase as a result of retrofit. This increase could be supported by policies.

- Overheating in future weather

Part L applications without a combination of passive cooling interventions or mixed mode ventilation will result in overheating. Standards could be extended requiring passive cooling interventions.

- EnerPHit

EnerPHit reduces the heating demand close to zero but passive cooling alone fails providing the thermal comfort. Addition of active cooling results in higher energy consumption and costs. EnerPHit is advisable when there is a rent increase as a result of certification and for the prestige buildings

- Discomfort hour person

Evaluation of discomfort based on only discomfort hours neglects the severity of the overheating. CIBSE criterion could be enriched in this regard.

INDUSTRY

- The methodology suggests a staged decision making process;

By using this methodology, a tool, implemented to BIM, using a library of exemplar buildings could be created which is beneficial for non-expert decision makers.

- Long term implications of not considering passive cooling by the building sector;

UK is no more a 'cold' country. Retrofit projects which Part L standard is applied has to comprise of night ventilation and shading devices.

- Improvement in retrofit decision making process in building sector;

Conventionally, in practice by applying heating and cooling set-points referring to standards is assumed enough to achieve thermal comfort. Energy efficiency measures are chosen based on experience and most of the time only investment costs driven. Both evaluation could be improved by using suggested methodology.

ACADEMIA

- Similar guidelines for other non-domestic building types could be the subject of further research

- Increment of productivity as a result of retrofit creates savings in the costs.

In this specific case this increment is not significant. However, when only summer time in future weather is evaluated, productivity improved up to 40 %. The measurement of productivity, especially considering operative temperatures needs further research.

- There is no agreed protocol on the evaluation of building level thermal comfort.

- Implementation of sensitivity analysis to retrofit decision making tool;

Assumptions on future conditions inputs are significantly uncertain and there is a potential to get misleading outcomes.

THANK YOU

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