UCL Institute for Environmental Design and Engineering

Modelling the effects of adaptions to the English housing stock on health

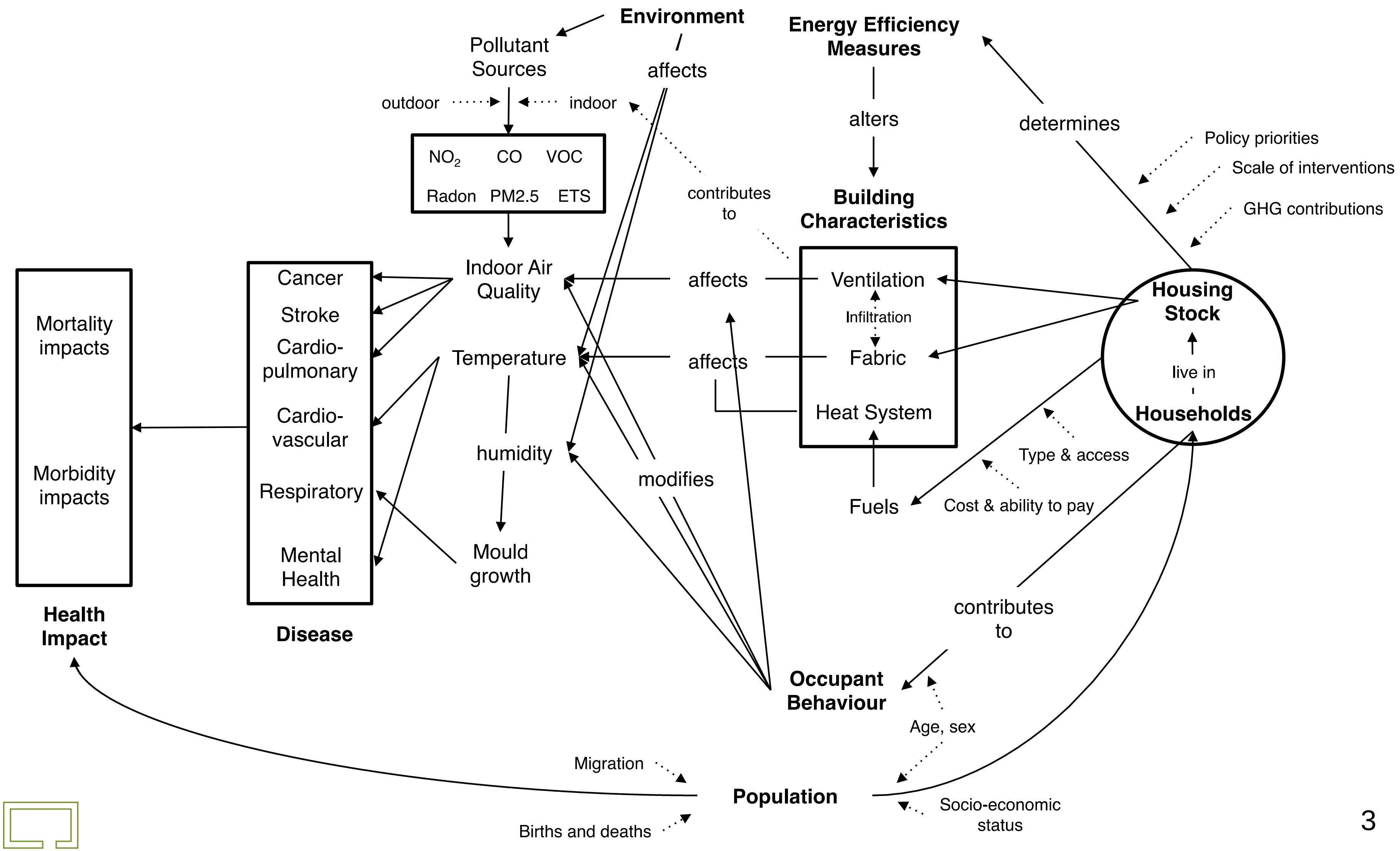
Phil Symonds

Aim: Model the impacts of adaptations to the domestic building stock on health (mortality and morbidity)

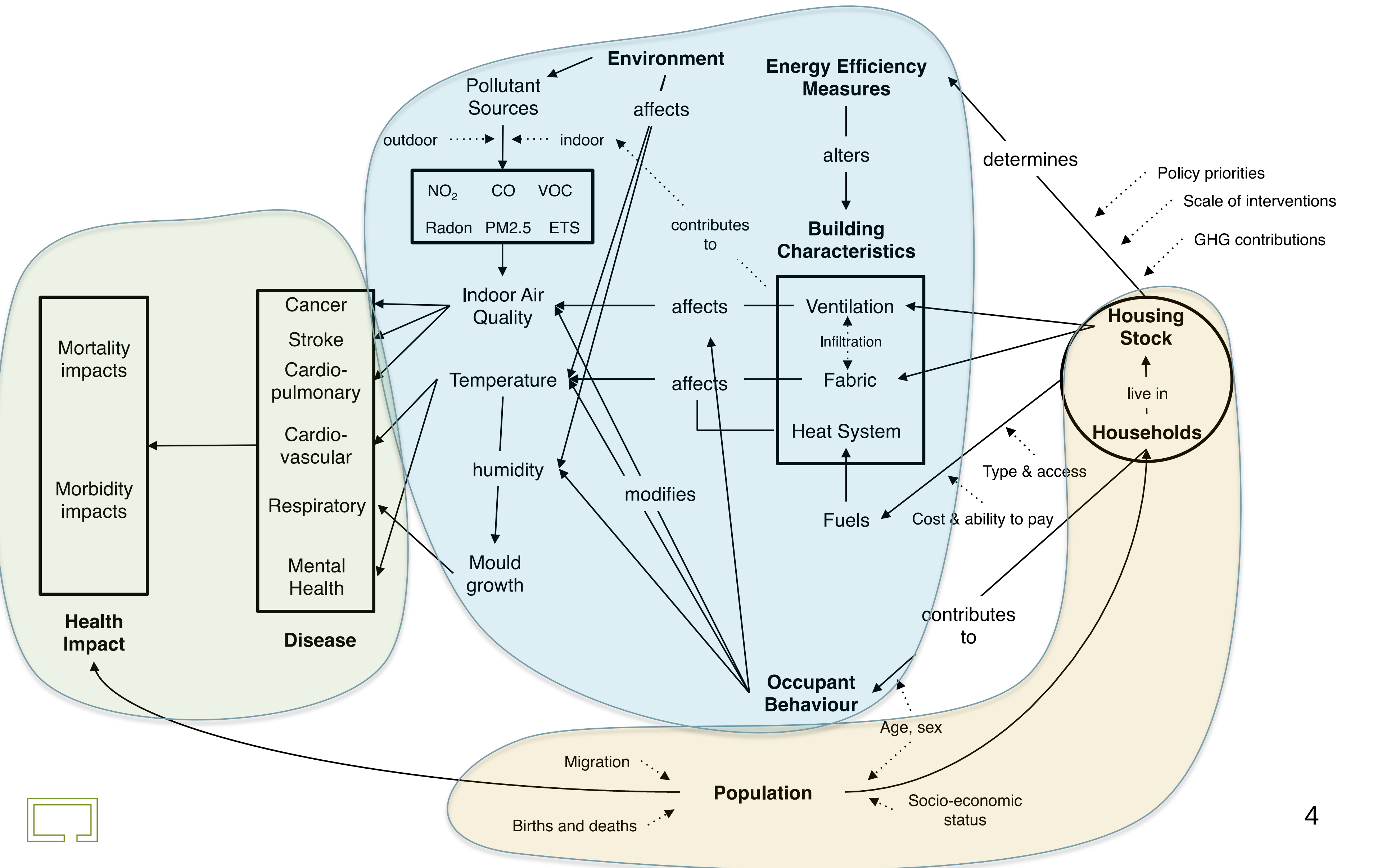
Outline:

- Within the IEDE and EI, we have developed several models in collaboration with LSHTM over recent years
- *HIDEEM - Health Impact of Domestic Energy Efficiency Measures*
- Effect of energy efficient retrofit on indoor/outdoor pollutants and cold on health (life-tables)
- *AWESOME*: Modelling of postcode-level overheating and indoor air pollution exposure
- *Microsimulation* - An alternative to life-table methods

Pathways of energy efficiency and health impact

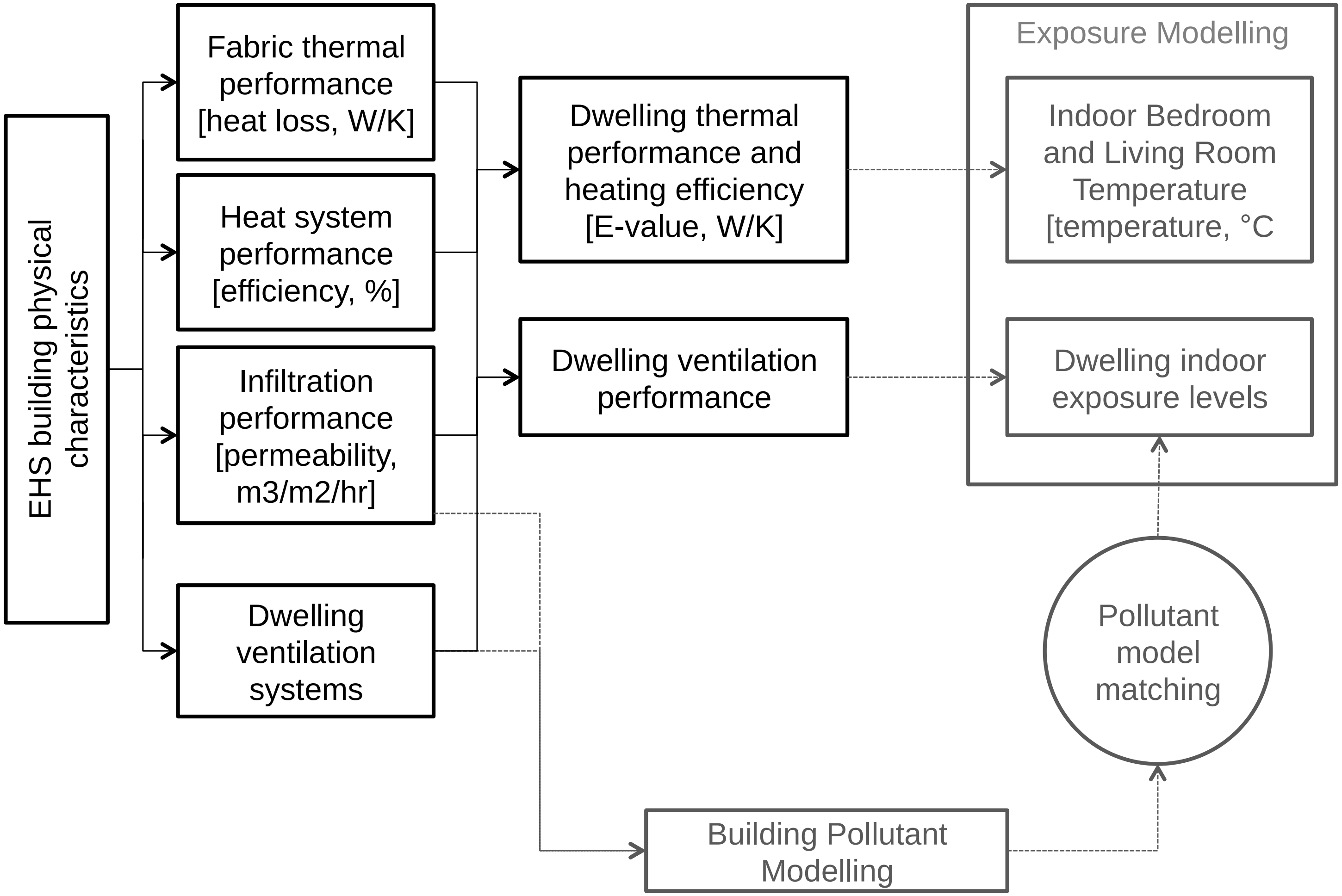


Pathways of energy efficiency and health impact



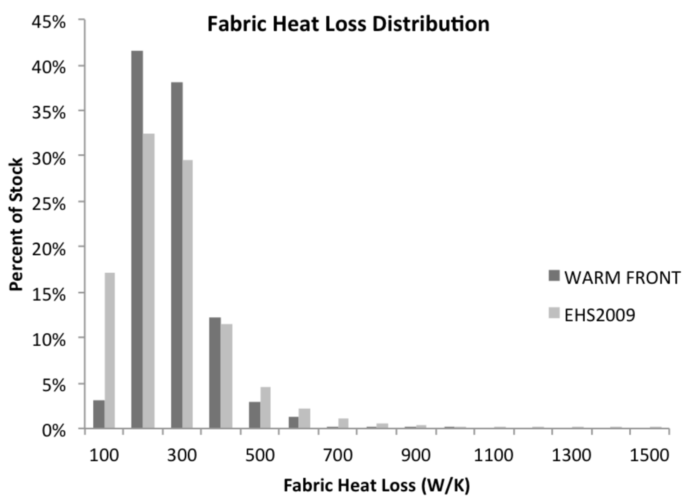
Building efficiency modelling

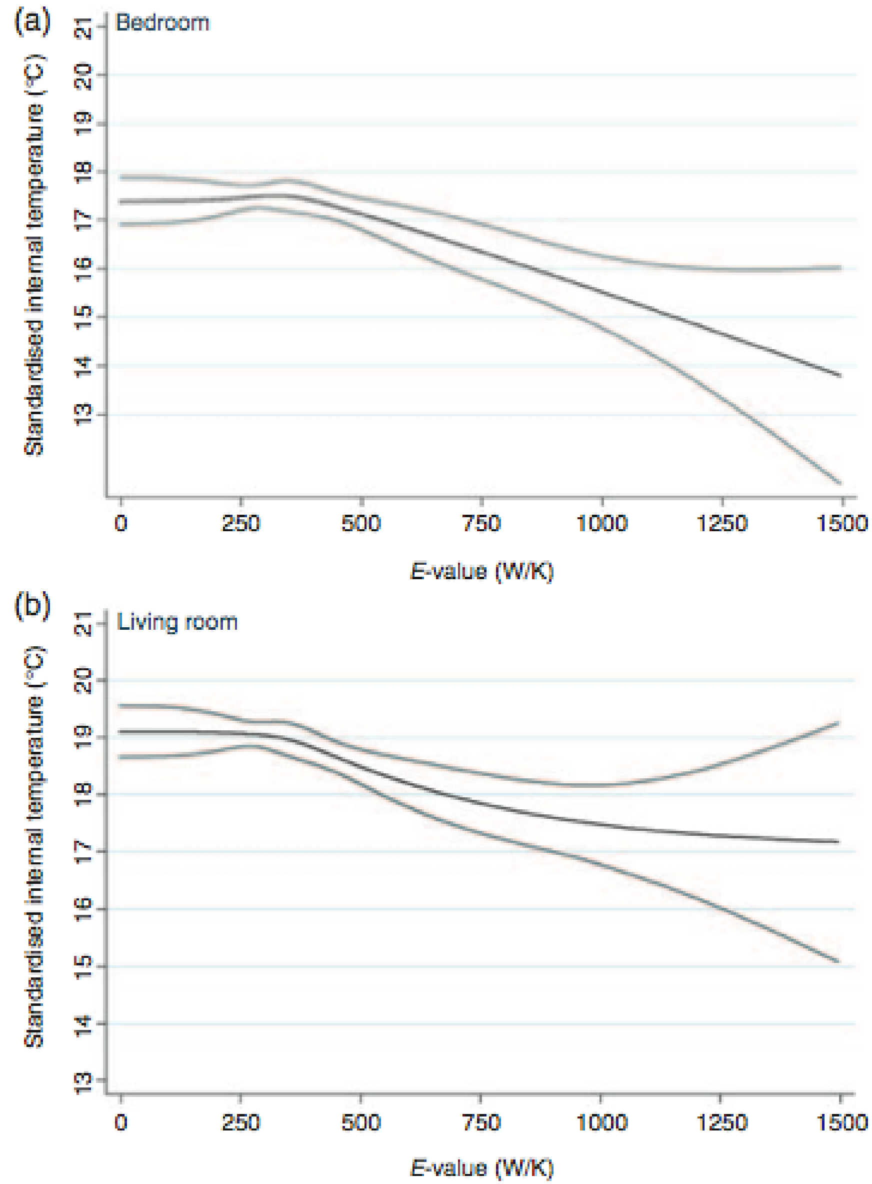
Estimates of fabric heat loss, heating system, ventilation heat loss and overall energy performance are made using a SAP like model.



Building efficiency modelling ‘WARM FRONT’

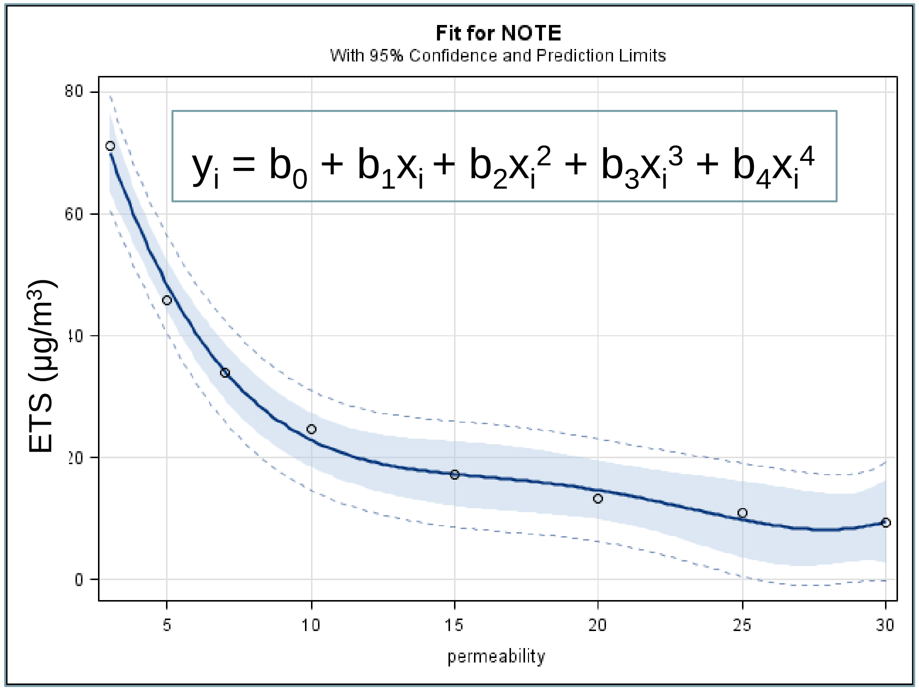
Internal temperatures are predicted using a relationship between the whole house efficiency (fabric, ventilation and heat system) and indoor temperature (Oreszczyn et al, 2006).





Pollutant modelling (in CONTAM)

- Eight dwelling archetypes
- Four occupancy types
- Five ventilation strategies:
  - No trickle vents or extract fans (Window opening)
  - Trickle vents and extract fans
  - Trickle ventilation
  - Extract fans
  - Mechanical ventilation with heat recovery systems (MVHR)



Models were constructed with permeability values of 3, 5, 7, 10, 15, 20, 25 and 30 $m^3/m^2/hr$ at 50 Pa representing an estimate of the UK range (Stephen 2000). MVHR scenarios were run at a permeability of 3 $m^3/m^2/hr$ at 50 Pa.

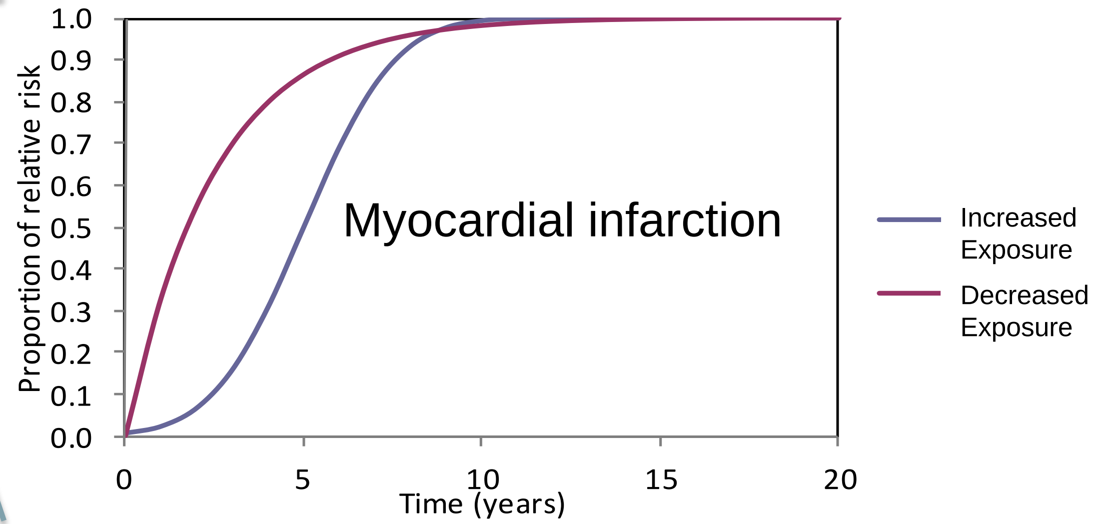
Health modelling

Mortality - Life tables (ONS data):
$p_{survival}(\text{age, sex}) = 1 - N_{deaths}/N_{pop}$

Quality Adjusted Life Years:
$\text{QALYs} = \prod_{t=1..N_{years}} p^{t}_{survival}$

x Time-lagged relative risk

Exposure-response relationship



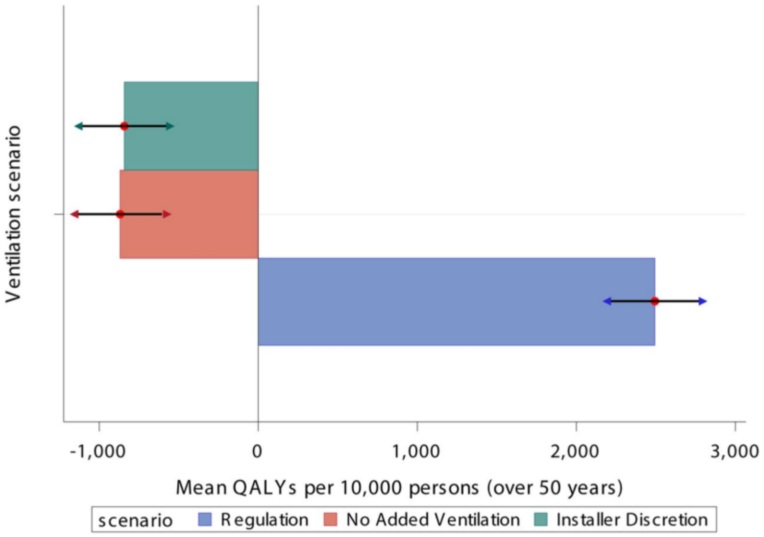
Morbidity:

- determined using a scaling factor : *Years of life with disease/Years of life lived*

Results (published in Hamilton et al. 2015)

- Health impact of 2030 Carbon reduction targets with:
  - Regulation ventilation (trickle vents and extract fans)
  - Installer discretion (trickle vents and extract fans installed ~6%)
  - No purpose provided ventilation

	Baseline	Experiment ventilation scenarios		
	Intervention stock	Regulation	Installer discretion	No added ventilation
Sample		N		
Dwellings (1000s)		18 990	17 350	17 320
People (1000s)		44 740	41 130	41 060
Building characteristics		Mean (SD*)		
Fabric heat loss (W/K)	294 (167)	219 (120)	213 (115)	213 (116)
Ventilation heat loss (W/K)	75 (45)	70 (42)	51 (35)	50 (33)
Heat system efficiency (%)	76 (12)	88 (11)	89 (10)	89 (10)
Permeability ($m^3/m^2/h$)	16 (5)	11 (5)	11 (5)	11 (5)
Exposure†		Mean (95% credibility intervals)		
Standardised indoor temperature‡ (°C)	17.8 (0.7)	18.1 (18.1, 18)	18.1 (18.1, 18.1)	18.1 (18.1, 18.1)
STS§	0.5 (0.4)	0.5 (0.5, 0.4)	0.7 (0.7, 0.6)	0.7 (0.7, 0.7)
Indoor¶ $PM_{2.5}$ ($\mu g/m^3$)	9.4 (5.4)	4.6 (4.4, 4.2)	10.6 (10.1, 9.6)	11 (10.5, 9.9)
Outdoor $PM_{2.5}$ ($\mu g/m^3$)	6.2 (1.7)	6.8 (6.5, 6.2)	5.9 (5.6, 5.3)	5.8 (5.5, 5.2)
Radon (Bq/m^3)	22.9 (14.1)	22.4 (20.3, 20.1)	34.2 (30.7, 30)	35 (31.3, 30.7)
Mould (% with MSI >1)	14.9 (7.5)	12.3 (11.6, 11)	18.5 (17.8, 16.2)	18.8 (18.3, 16.5)
Heating energy (MWh/year)	22.9 (10.4)	16.6 (16.4, 16.3)	15.7 (15.6, 15.4)	15.6 (15.5, 15.4)



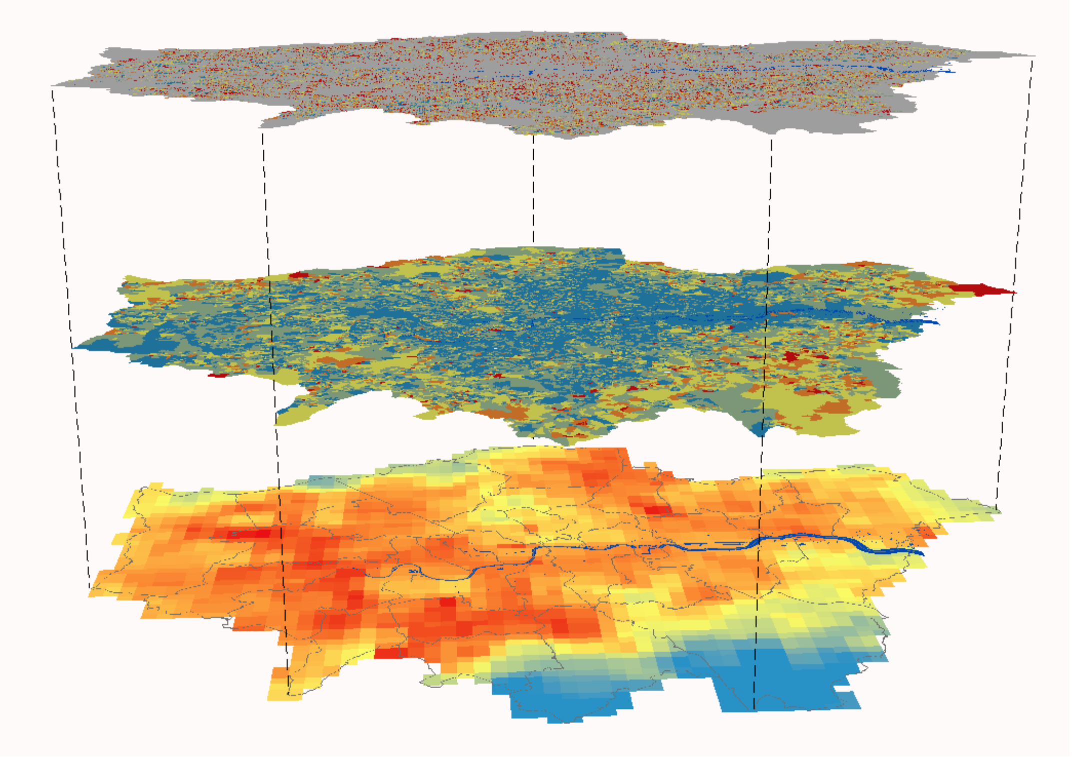
See also Shrubsole et al. 2015: *A tale of two cities: Comparison of impacts on CO2 emissions, the indoor environment and health of home energy efficiency strategies in London and Milton Keynes*

HIDEEM is now included as a module within the NHM

Overheating in homes

- Method developed under the AWESOME and HPRU projects
- Overheating risks are associated to:

1. Dwelling overheating risk
2. Population age
3. The Urban Heat Island (UHI)



Overlaid maps from Taylor et, 2015

Methods

1) Calculate the mean maximum temperature for a ward, *j*:

$$T^*_{max\ ,j} = \left(T_{max\ ,\ out} + \frac{\sum_k \left(T_{UHI\quad anomly\ ,k} + T_{IndoorTemp\quad anomly\ ,k} \right)}{n_j} \right)$$

Mean max daily outdoor temperature from weather data

Modelled UHI temperature for a dwelling – London average

Modelled indoor temperature - Stock average

- Models run using EnergyPlus for eight archetypes
- Premeabilities and U-values calculated using SAP
- Two occupancy types (Family and Pensioners)
- Pre-2002 10% with vents, post 2002 100% (as per regulations)
- Results averaged over eight orientations
- Geoinformation Group Build Class dataset used for building info

2) Mortality summed over all individuals, *i*, in ward, *j*, is calculated:

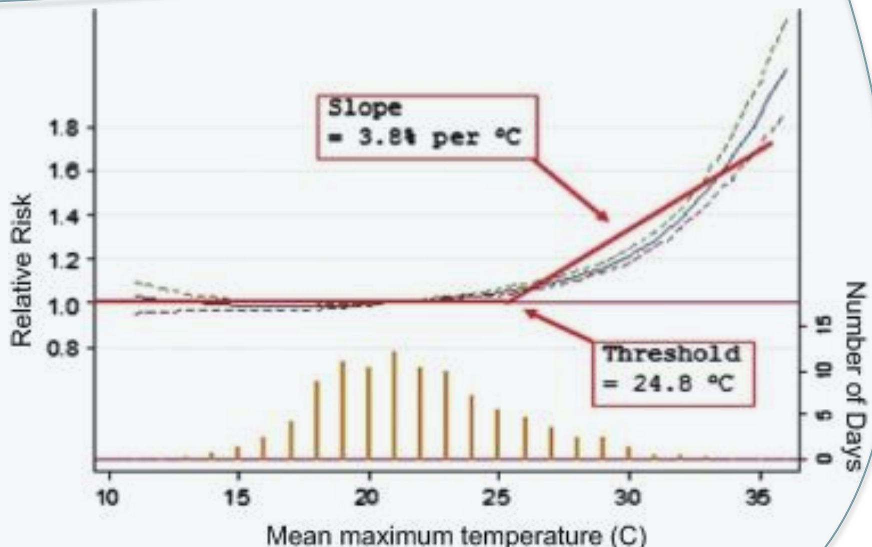
$$D_j = \sum_i \left[population_{i,j} \times deathrate_i \times \left(RR_{heat,i} - 1\right)\right]$$

Population in age bracket, *i*, in ward, *j*

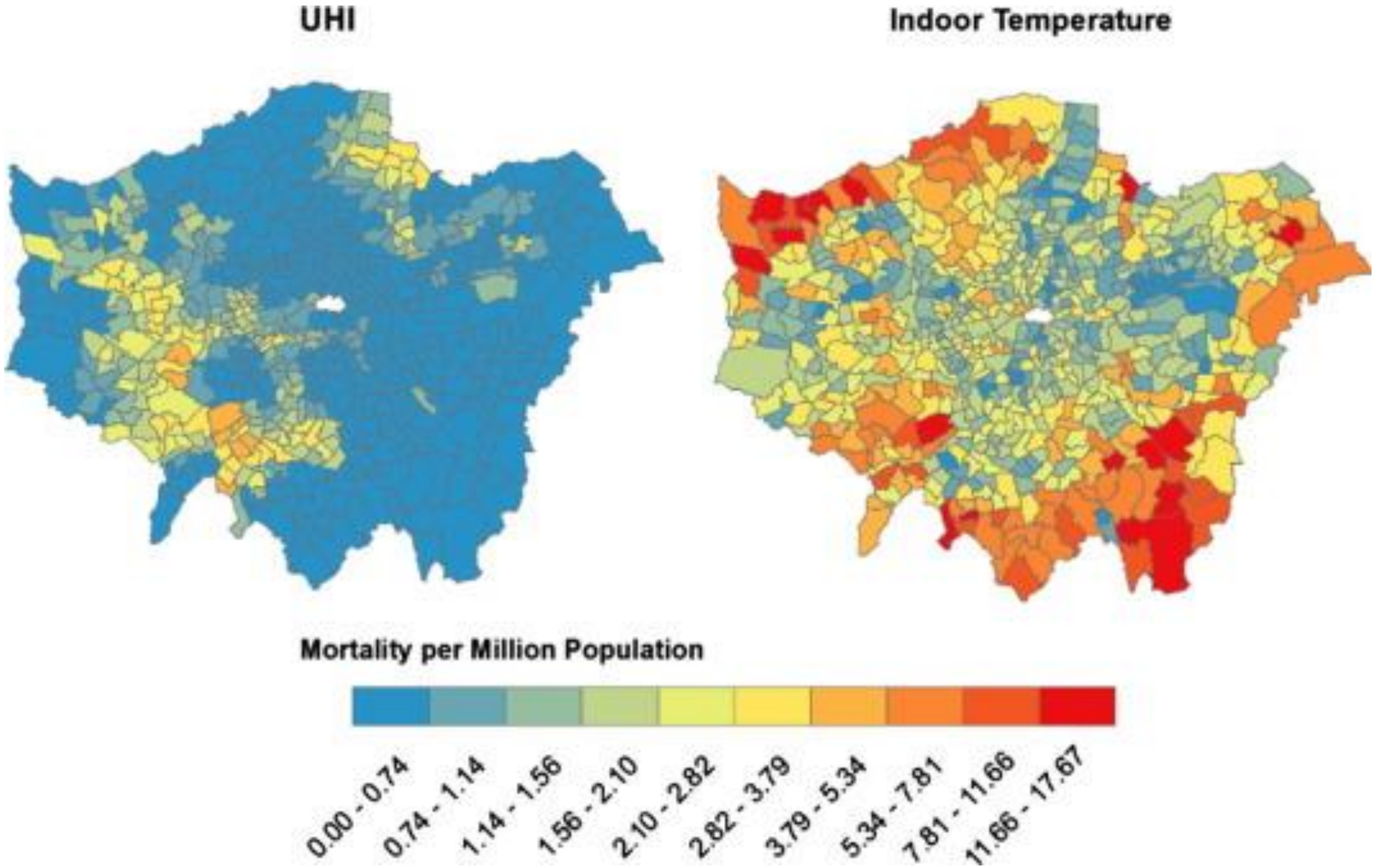
summertime background death rate in age bracket, *i*

Relative risk

- Calculated using relationship derived for external temperatures (Armstrong et al. 2011)



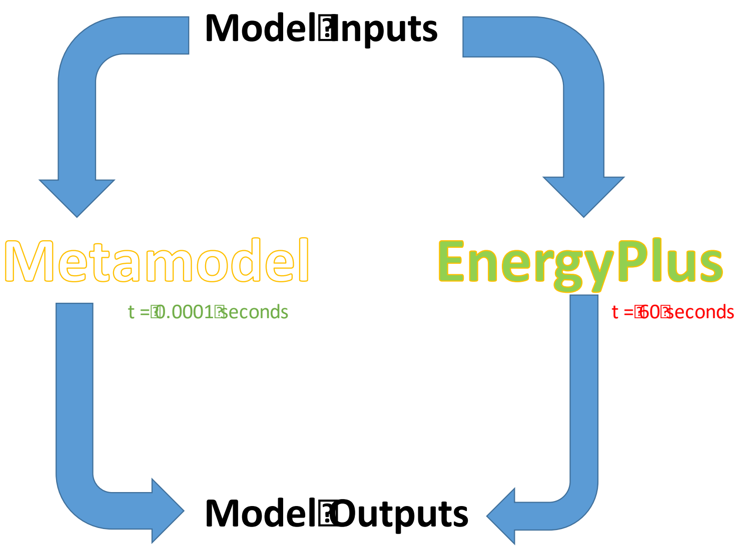
Results

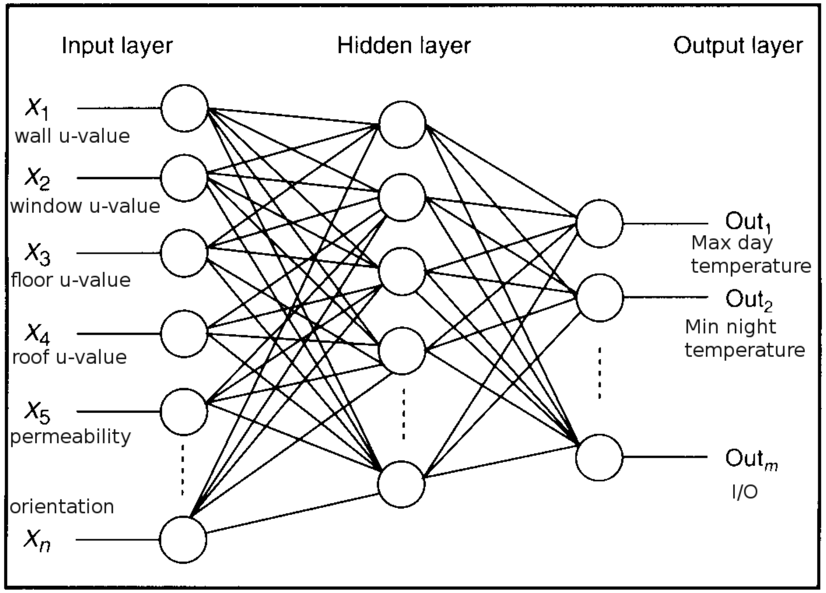

UHI
Indoor Temperature
Mortality per Million Population
0.00 - 0.74
0.74 - 1.14
1.14 - 1.56
1.56 - 2.10
2.10 - 2.82
2.82 - 3.79
3.79 - 5.34
5.34 - 7.81
7.81 - 11.66
11.66 - 17.67

Further work is currently underway to extend and improve these models…

Metamodelling

- A ***metamodelling framework*** is used to replicate the EnergyPlus models (Symonds et al. 2016)
- ...this allows a large number of dwellings to be modelled (e.g. we can calculate overheating metrics for all entries in the English Housing Survey (EHS) ~16,000 entries within a few minutes)





Example of a typical neural network architecture

Greater detail is being modelled in terms of building and occupancy parameters

Permeability: Normal(μ = 20, σ =10) $m^3/h/m^2$

Roof U-value: 0.10-2.25 $W/m^2/K$

Rural/Urban/Country wind exposure

Glazing fraction: 0.1-0.6

Window U-value: 0.85-4.80 $W/m^2/K$

Wall U-value: 0.15-2.55 $W/m^2/K$

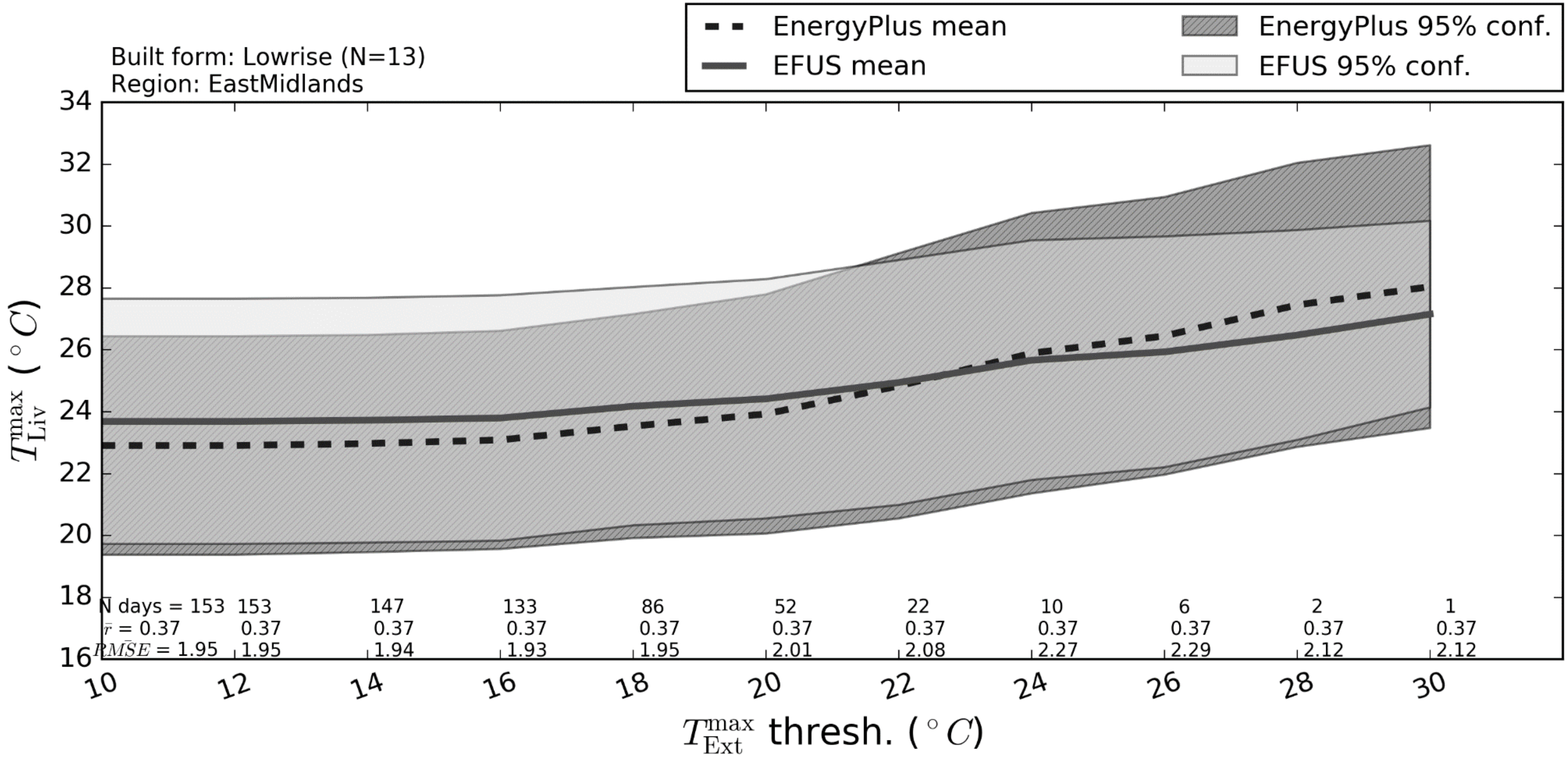
ceiling height: 2-3m

Ground floor area: (0.5-3) x Dwelling average

Orientation: 0-360°

Floor U-value: 0.15-1.30 $W/m^2/K$

Future work will aim to calibrate models using a large scale dataset (Energy Follow-Up Survey)



EnergyPlus models are being run in parallel using High Performance Computing (HPC) facilities at UCL

This allows several thousand simulations to be run per hour

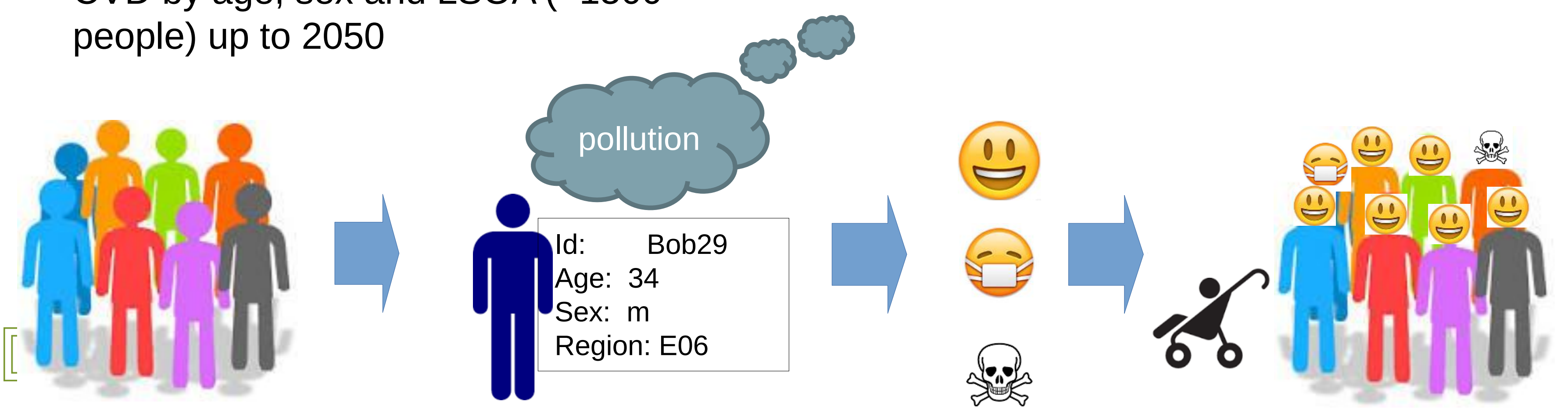
A microsimulation health model is being developed to improve morbidity predictions and resolution

Microsimulation is a computational modelling technique that works at the level of the micro-units (e.g. individuals within a population)

- **Inputs:**
- Census: to set up initial population
- Office for National Statistics (ONS): mortality, migration and birth projections
- Ricardo AEA: air pollution data
- British Heart Foundation (BHF): cardiovascular disease (CVD) data

$$M = \begin{bmatrix} p_{11} & p_{12} & p_{13} & p_{14} \\ p_{21} & p_{22} & p_{23} & p_{24} \\ p_{31} & p_{32} & p_{33} & p_{34} \\ p_{41} & p_{42} & p_{43} & p_{44} \end{bmatrix} = \begin{bmatrix} p_{11} & p_{12} & p_{13} & p_{14} \\ 0 & p_{22} & p_{23} & p_{24} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

- **Outputs:**
- Mortality, incidence and prevalence for CVD by age, sex and LSOA (~1500 people) up to 2050



Health, Wellbeing and Sustainable Buildings

A New Master's Degree

Are You Interested in Making our Buildings and Cities Better Places to Live?

Would you like to be one of a new generation of professionals, driving innovation by building sustainably for health and wellbeing?

The MSc ‘Health, Wellbeing and Sustainable Buildings’ is an exciting new Master’s degree forming a new generation of professionals to drive innovation for health, wellbeing and human performance in the design, assessment, retrofit and operation of residential and non-domestic buildings.

The MSc is taught at the world-leading UCL Institute for Environmental Design and Engineering.

We are part of The Bartlett: UCL’s Global Faculty of the Built Environment

Course Structure

Six compulsory core modules, plus two optional modules, and a dissertation. Modular/flexible options available. The taught modules are:

- Health, Comfort and Wellbeing in the Built Environment (Core)
- Wellbeing in Buildings: Theory and Practice (Core)
- Integrated Building Design for Health, Comfort and Wellbeing (Core)
- Methods of Environmental Analysis (Core)
- Health and Wellbeing in Cities: Theory and Practice (Core)
- Indoor Air Quality in Buildings (Core)
- Light, Lighting and Wellbeing in Buildings (Optional)
- Building Acoustics (Optional)
- Designing Inclusive Places (Optional)

Health, Wellbeing and Sustainable Buildings

A New Master's Degree

Are You Interested in Making our Buildings and Cities Better Places to Live?

Website:
www.bartlett.ucl.ac.uk/iede

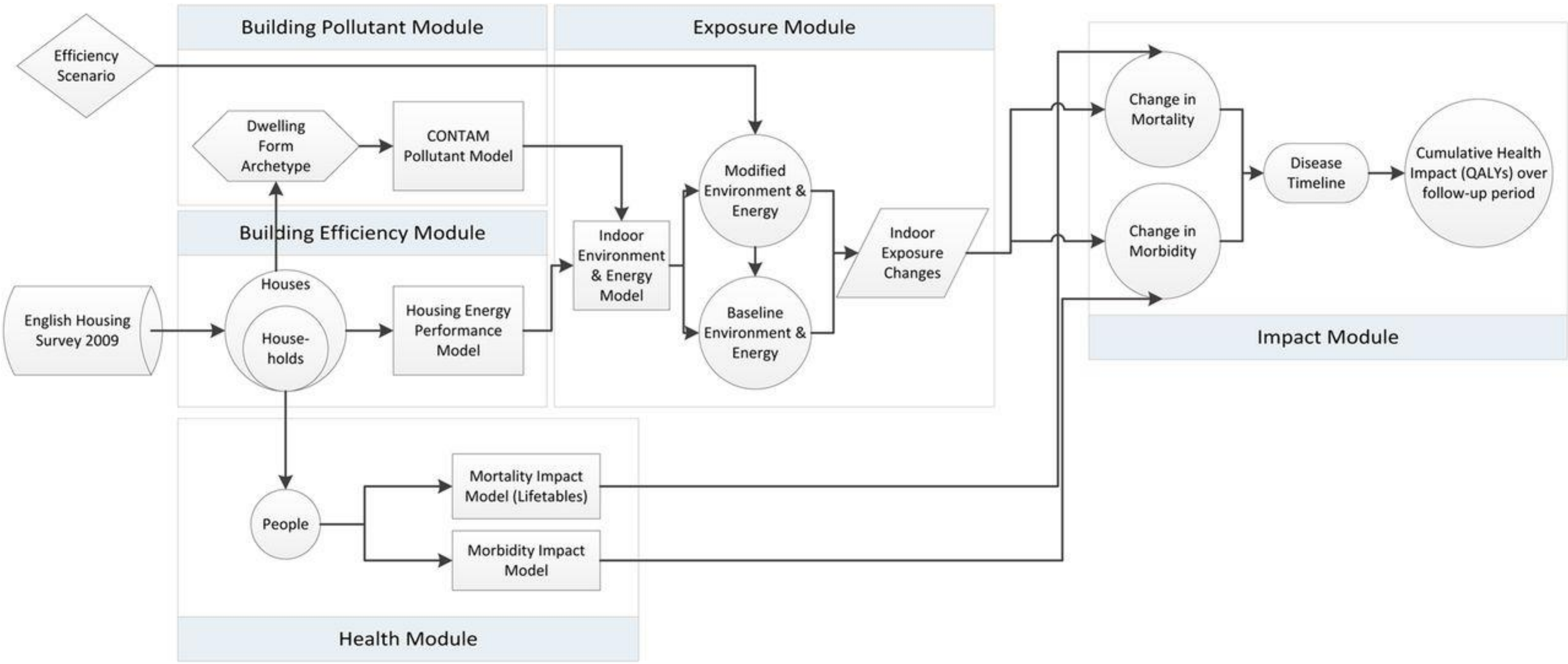
Course Director:
m.ucci@ucl.ac.uk

Admin. Enquires:
l.tufekci@ucl.ac.uk

We are part of The Bartlett: UCL's Global Faculty of the Built Environment

Backup Slides

Model structure



Model validation

Building performance and exposure model outputs are validated against national measurements and monitoring (where available).

Energy performance

Building Performance	Modelled Mean	Warm Front Study Mean	Warm Front Study Source	National Mean	National Source
Fabric heat loss (W/K)	274	224	Oreszczyn et al, 2006	203.8	DECC, 2012
Heat system efficiency (%)	76%	67%	Hong et al, 2009	74%	DECC, 2008
Permeability (m3/m2/hr)	13.8	17.2	Hong et al, 2006	13.9	Stephen, 1998

Environmental exposures

Exposures	Modelled	Comparison	Source
Temperature - living room (° C)	18.6	17.9 - 19.1	Hong et al. 2006, OPDM 1998
Temperature - bedroom (° C)	17.1	15.9 - 18.5	Hong et al. 2006, OPDM 1998
Indoor PM 2.5a (ug /m2)	17	17 - 25	Hanninan et al. 2004, Dimitroupolou et al. 2006
Indoor PM 2.5 b	10.9	9.3*	Shrubsole et al. 2012
Outdoor PM 2.5	6.1	6.1*	Shrubsole et al. 2012
Radon (Bq/m3)	26.2	21	Gray et al. 2009
Mould (% with MSI >1)	11.5	14.6 - 21.2	OPDM 1998, Oreszczyn et al. 2006
% of houses with smoker	21.2	21	ONS 2008

Note: a) Weighted average values of kitchen (10%), lounge (45%) and bedroom (45%); b) Indoor sources of PM2.5 relate to cooking only with an emission rate of 1.6 ug/min; * Indicates modelled estimate.

Exposure response health outcomes

Mortality

Exposure	Health outcome	Exposure-response relationship	Reference
Standardised internal temperature	Winter excess cardiovascular mortality	0.98 per ° C standardised indoor temperature	Warm Front analysis (unpublished)
Environmental tobacco smoke (ETS)	Cerebrovascular accident mortality	1.25 (if living with smoker)	Lee and Forey (2006)
	Myocardial infarction mortality	1.30 (if living with smoker)	Law et al. (1997)
PM2.5	Cardiopulmonary mortality	1.082 per 10 µg/m3	Pope et al. (2002; 2004)
	Lung cancer mortality	1.059 per 10 µg/m3	Pope et al. (2002; 2004)
Radon	Lung cancer mortality	1.16 per 100 Bq/m3	Darby et al. (2005)

Morbidity

Exposure	Health outcome	QALY weighting	Exposure-response function	
			Relative Risk	Reference
	Mental health:			
Standardised internal temperature	Common mental disorder (GHQ-12 score 4+)	0.9	0.90 per ° C	Based on Warm Front (e.g. Gilbertson et al., 2012)
Mould	*Respiratory illness:*			
	Harm class II (hospital admission)	0.75	1.53	Based on Fisk et al. (2007)
	Harm class III (GP consultation)	0.9	1.53	As above
	Harm class IV (minor symptoms)	0.9	1.83	As above