Health impact assessment of energy efficiency: A UK Case Study

Beyond energy savings: The multiple benefits of energy efficiency

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Buildings as a modifier of health

- **Buildings act as a modifier for health, exacerbating or protecting against exposure to thermal stresses and air quality.**

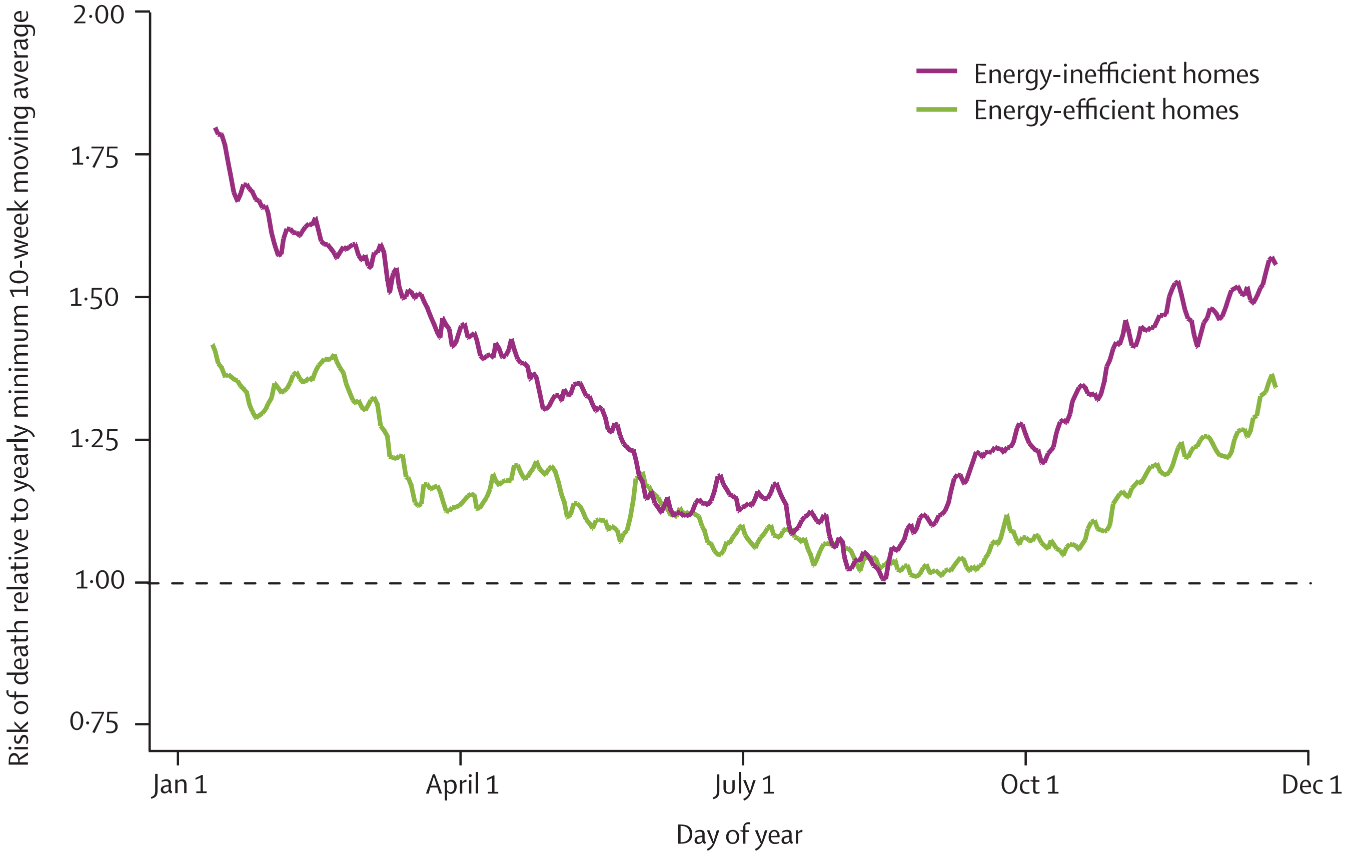
- Indoor environmental quality
  - Indoor air quality and exposure to internal & external pollutant sources
  - Exposure to heat and cold

- Energy use is a strong feature in modifying the indoor environment
  - Energy for maintaining adequate indoor environment (ventilation, heating and cooling)

- **Population exposure to air pollution is typically evaluated using the outdoor concentration of pollutants** and does not account for the fact that people spend a majority of their time indoors.

Buildings as a modifier of health

Building energy performance can **increase the risk of temperature related death from cardiovascular disease.**



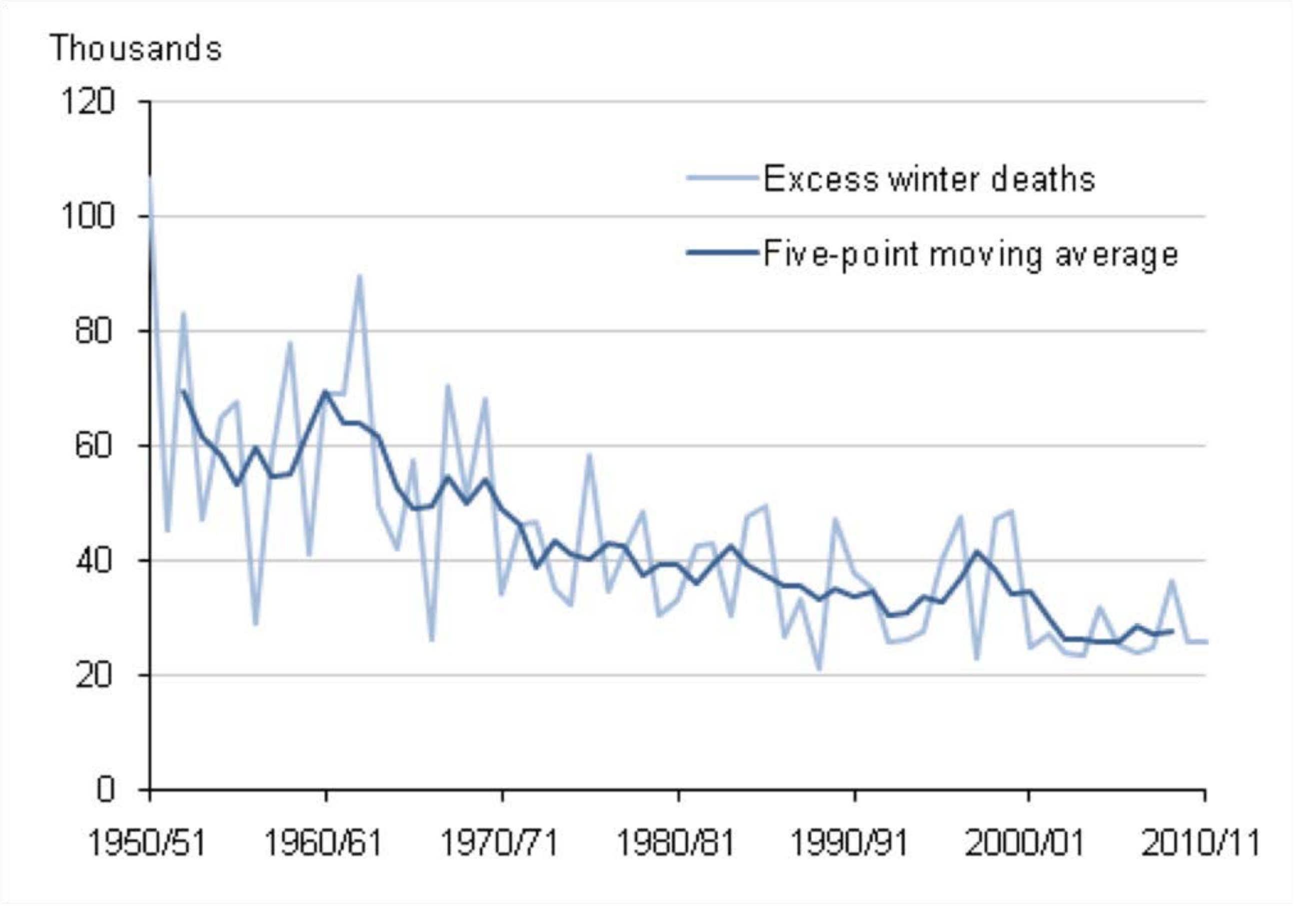
Seasonal average variation in mortality in relation to energy efficiency of English home. Energy-inefficient homes are in the lowest quartile of standardised heating costs and energy-efficient homes are in the highest quartile.

Figure adapted from Wilkinson et 2001.

Buildings as a modifier of health

Health impacts

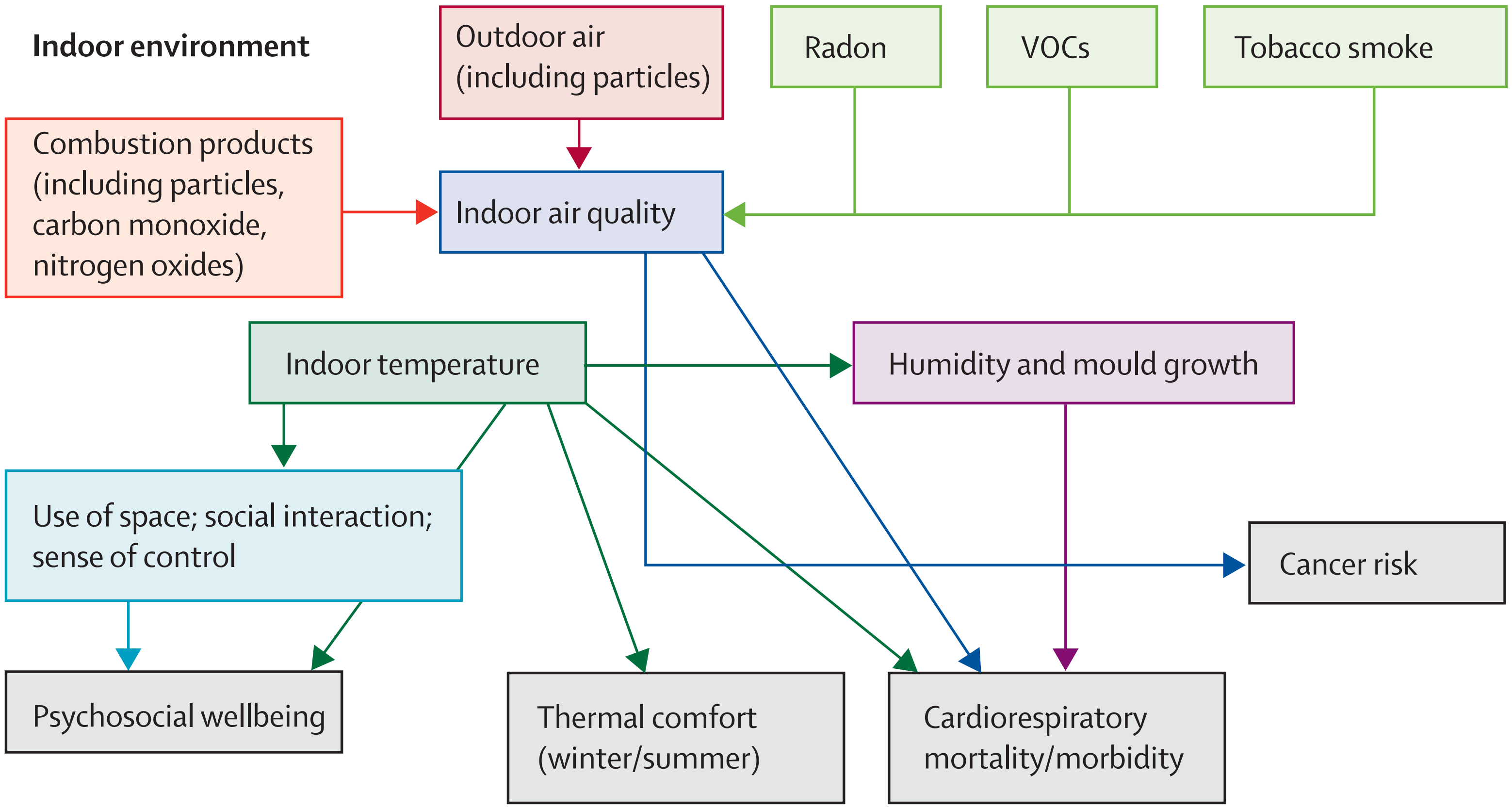
The UK has more **excess winter deaths** and more ill health in winter than colder European countries. England’s EWD ranges from 15,000-30,000 per year.



Source: ONS 2012

Building quality and health

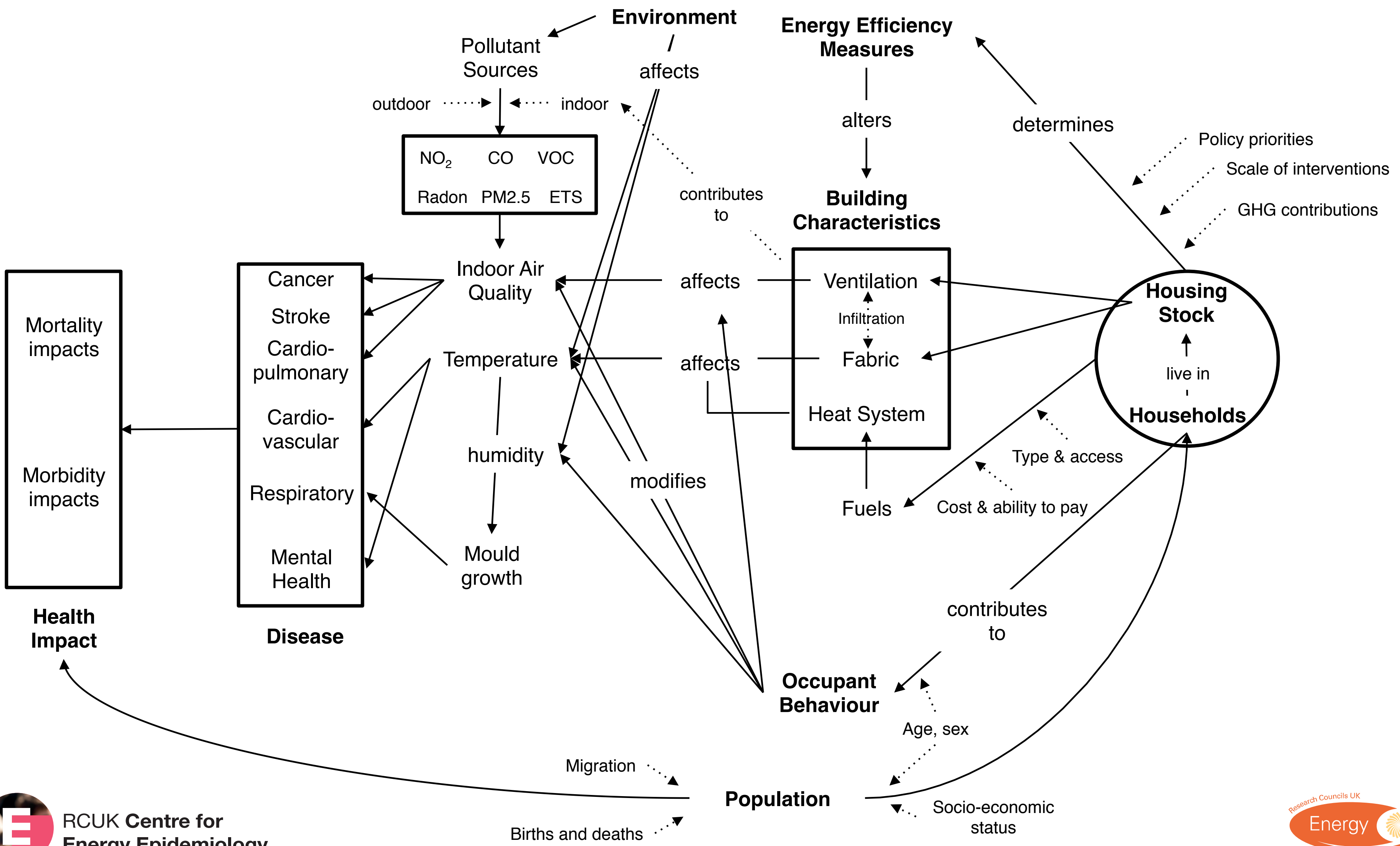
Connections between building quality, energy and health



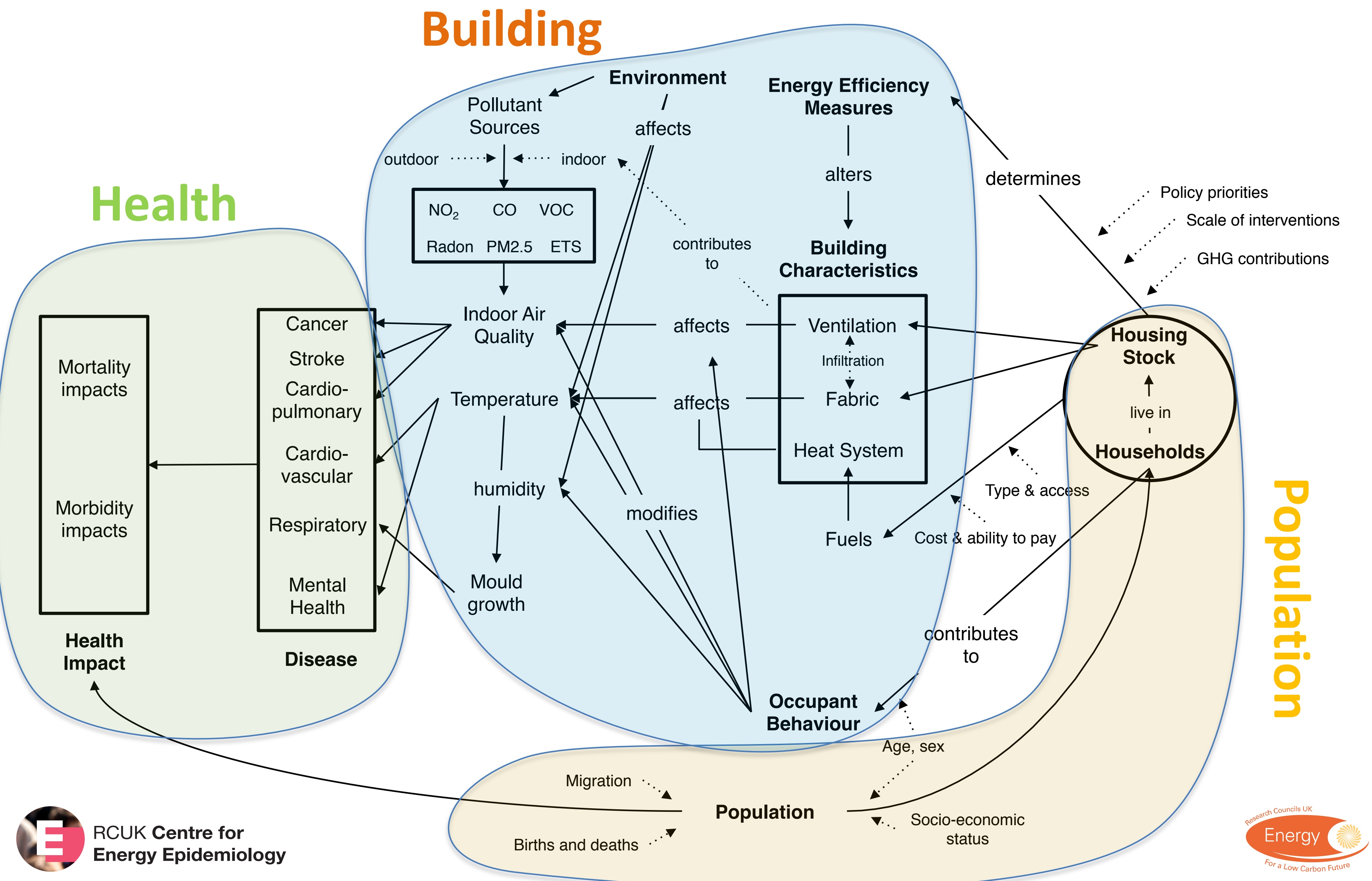
Source: Wilkinson, Lancet, 2009

Pathways of energy efficiency and health impact

http://dx.doi.org/10.1136/bmjopen-2014-007298



Pathways of energy efficiency and health impact

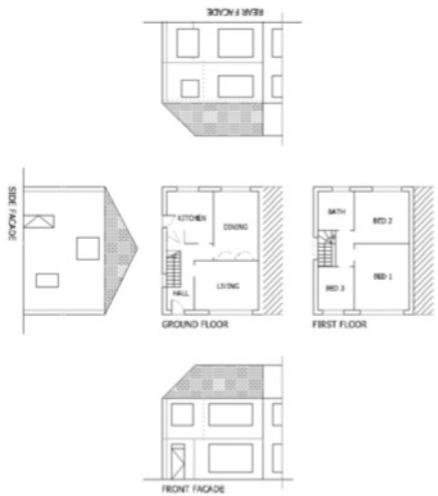


The English housing stock

- **22.8 million homes** in England
- **8** typical dwelling types
- **4** main occupancy types; owned, private rented, local authority, housing association (RSL)

Detached archetype

Semi-detached archetype



Terrace (end and mid)

Bungalow

Highrise, lowrise and converted flats

Energy Efficiency Retrofits include…

Insulation of walls, loft and floor

Double glazing

Draught proofing

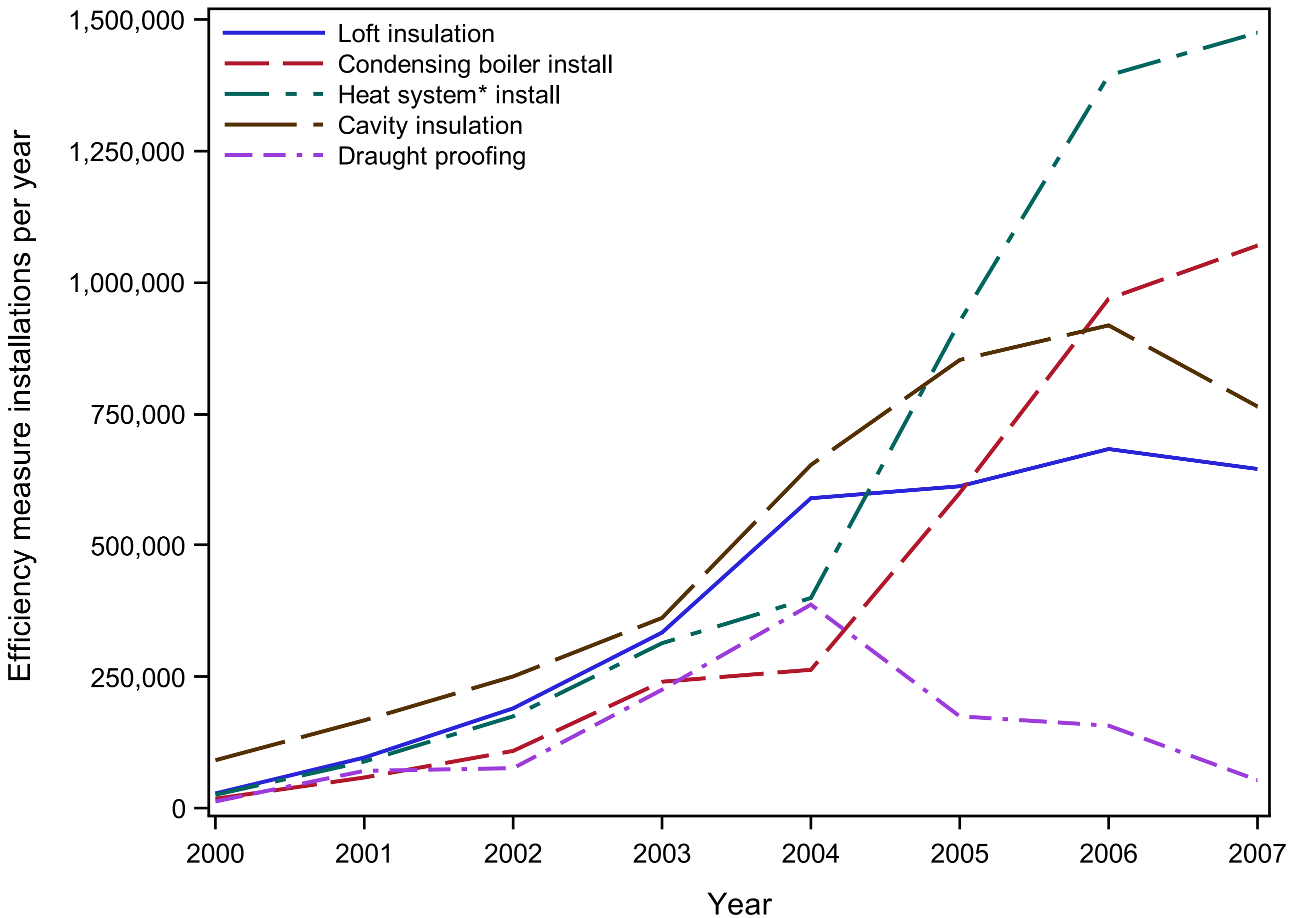
Boiler upgrade

Trickle vents and extract fans

'one home retrofit per minute will need to be carried out between now and 2050 if the UK is to meet its legally binding climate change target' – UK Green Building council (2013)

Energy Efficiency in England

Uptake from Homes Energy Efficiency Database 2000 to 2007



*Heat system includes: Condensing and standard boiler, and hot water cylinder replacement and solar hot water

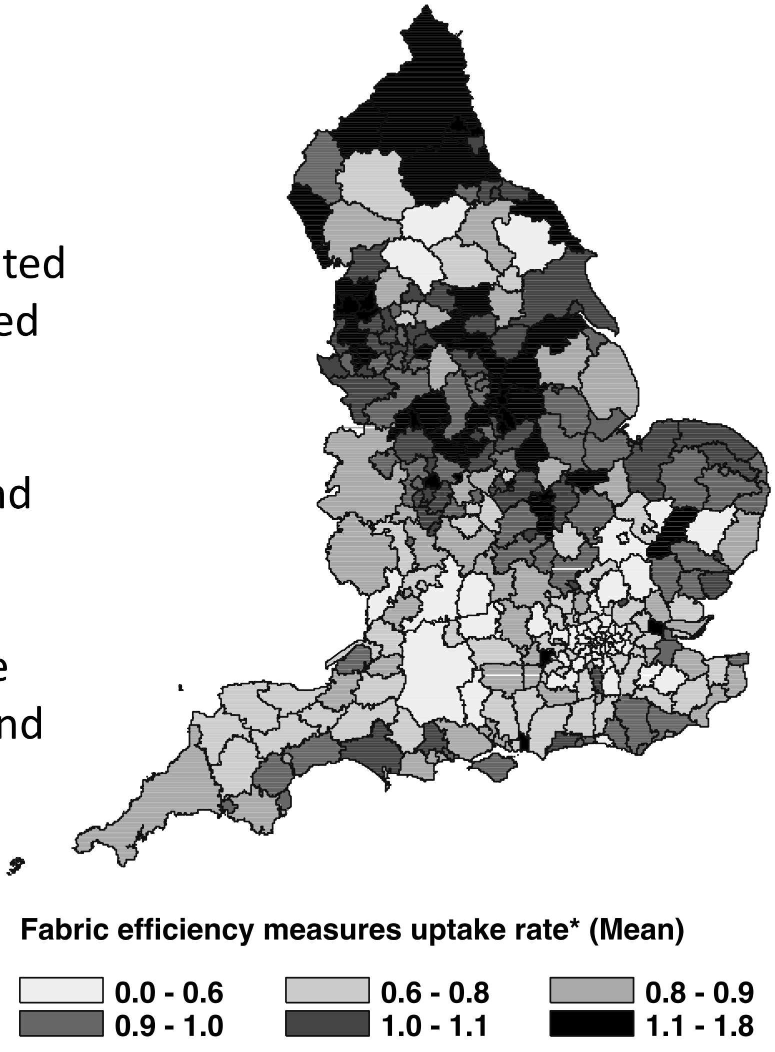
Energy Efficiency in England

Uptake distribution

High uptake rate (vs a low rate) is associated with lower incomes, more owner-occupied dwellings and fewer flats

Retrofits are concentrated in northern and urban areas.

Programmes targeting lower-incomes are associated with higher benefits receipt and household age.



*Average of cumulative number of measures 2000 to 2007 over total number of houses in 2007 at LSOA (n=500 dwellings) level

https://doi.org/10.1080/09613218.2014.867643

The Challenge

UK's **ventilation guidance** for retrofits is very **unclear**.

The approved documentation used for compliance with the building regulation offer only limited guidance on **determining adequate ventilation** during works.

No guidance for determining the ventilation characteristics or **air quality in advance of, or following**, a retrofit.

The provision of ventilation measures is ultimately left to the **discretion of the installer or household**.

If **outdoor pollution is minimized** with mitigation measures, exposure to **indoor pollutants** will comprise the **majority of occupant exposure**.

Health Impact Assessment modelling

The modelling comprised Three main sub-components:

A **building physics** and **air flow model** of the indoor environment of English houses that quantifies:

indoor temperature,
particle pollution,
Environmental tobacco smoke (ETS),
radon, and
mould growth;

A model of **indoor exposure-related health impacts** based on a combination of life table methods and,

(for adults) common mental disorder and childhood asthma, directly modelled changes in disease prevalence;

A **health and healthcare cost model** to evaluate economic impacts

Method

Model development timeline

HiDEEM v1

- Two dwelling archetypes
- Limited exposures
- Population level lifetables

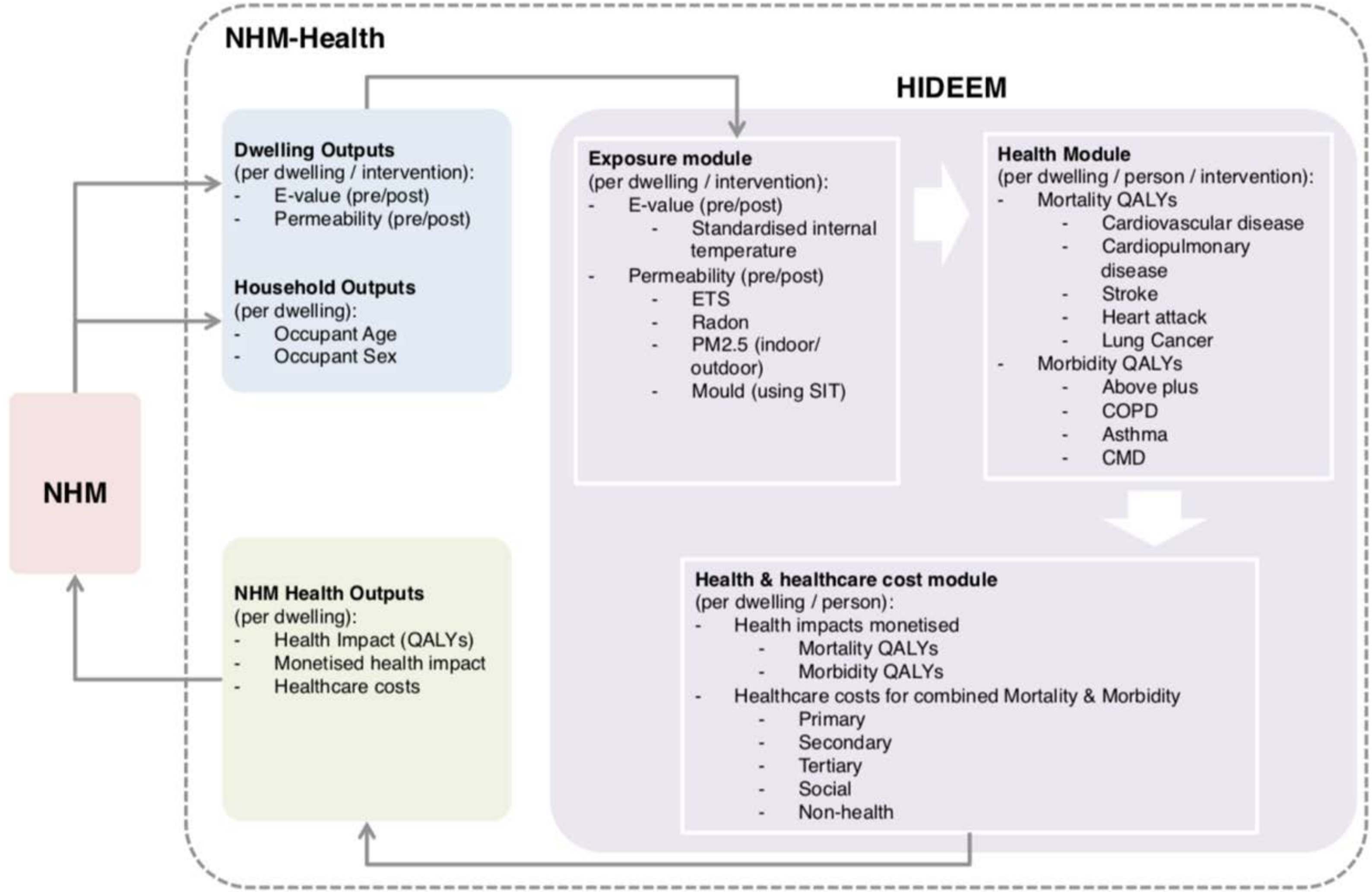
HiDEEM v2

- Housing Survey base (dwellings + people)
- Extended exposures with interactions
- People specific lifetables

NHM Health (HiDEEM v3)

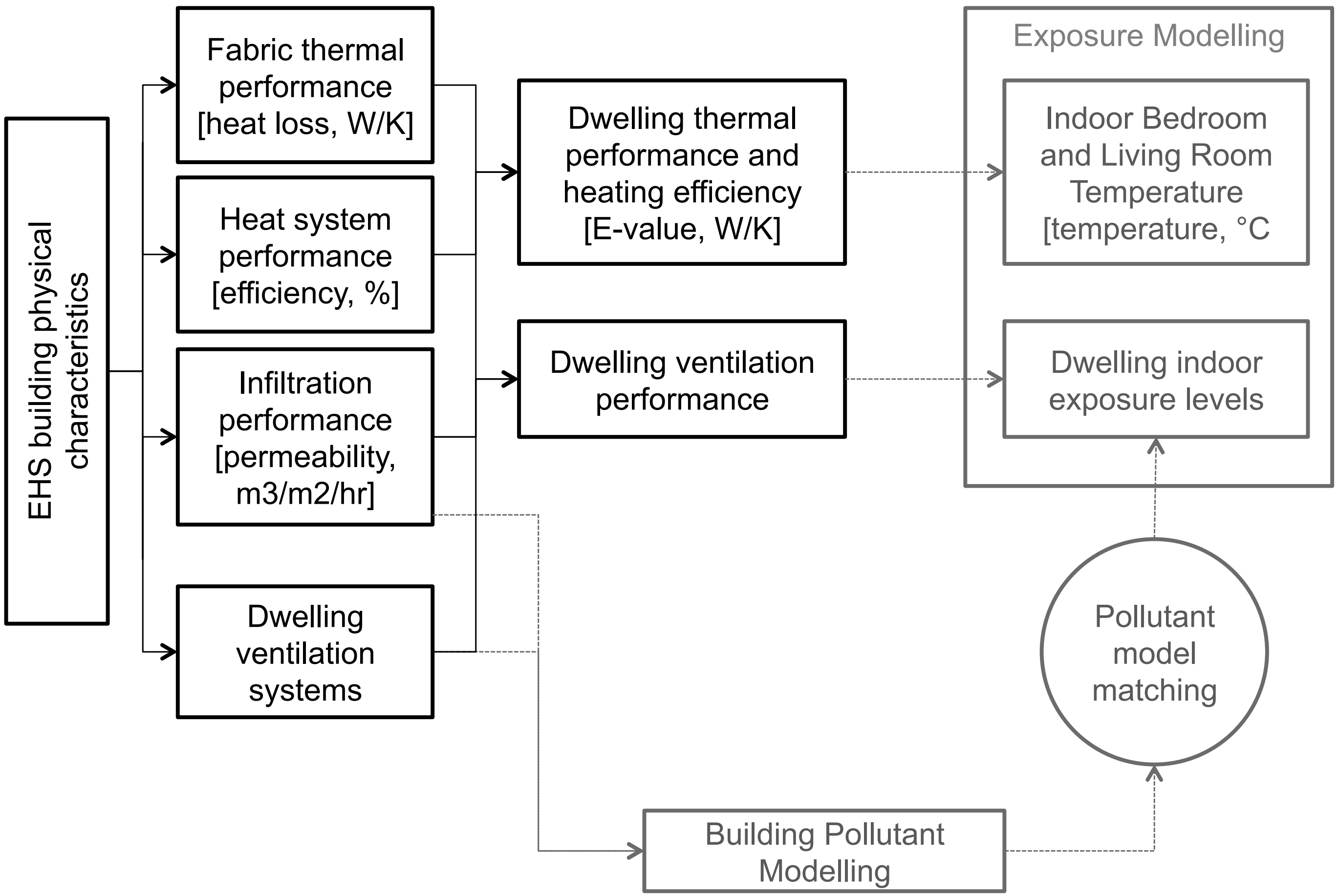
- Micro-simulation model
- Language based scenarios
- Probabilistic projections
- Healthcare costs

Method: National Housing Model – Health Module



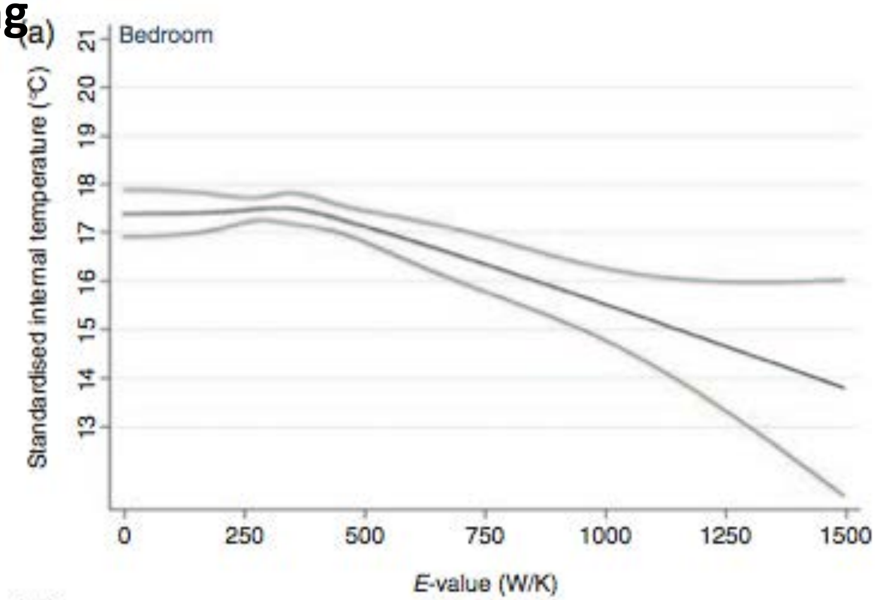
Method: Building efficiency modelling

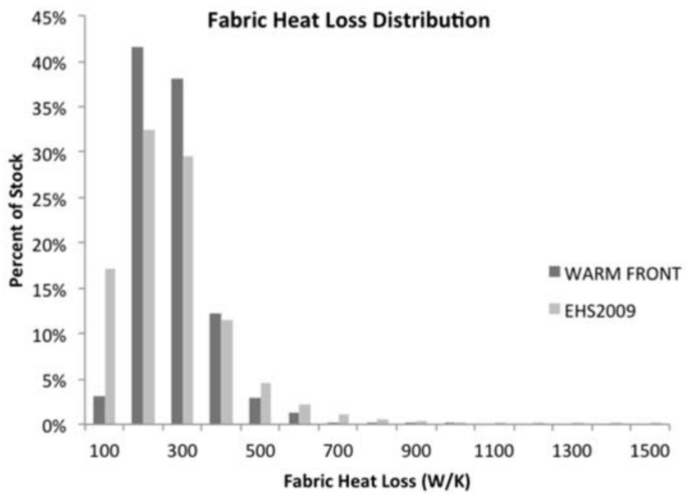
Estimates of fabric heat loss, heating system, ventilation heat loss and overall energy performance are made using a SAP like model.

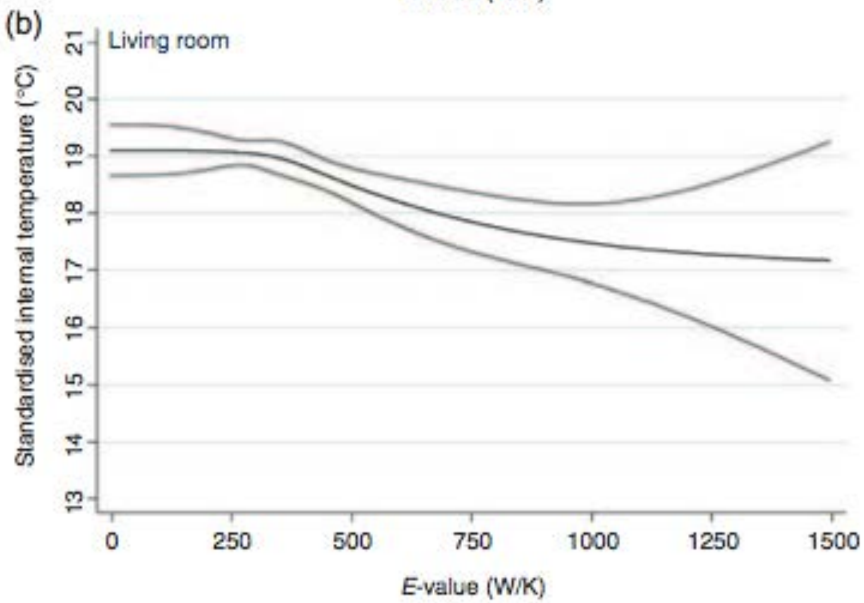


Method: Building efficiency modelling

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

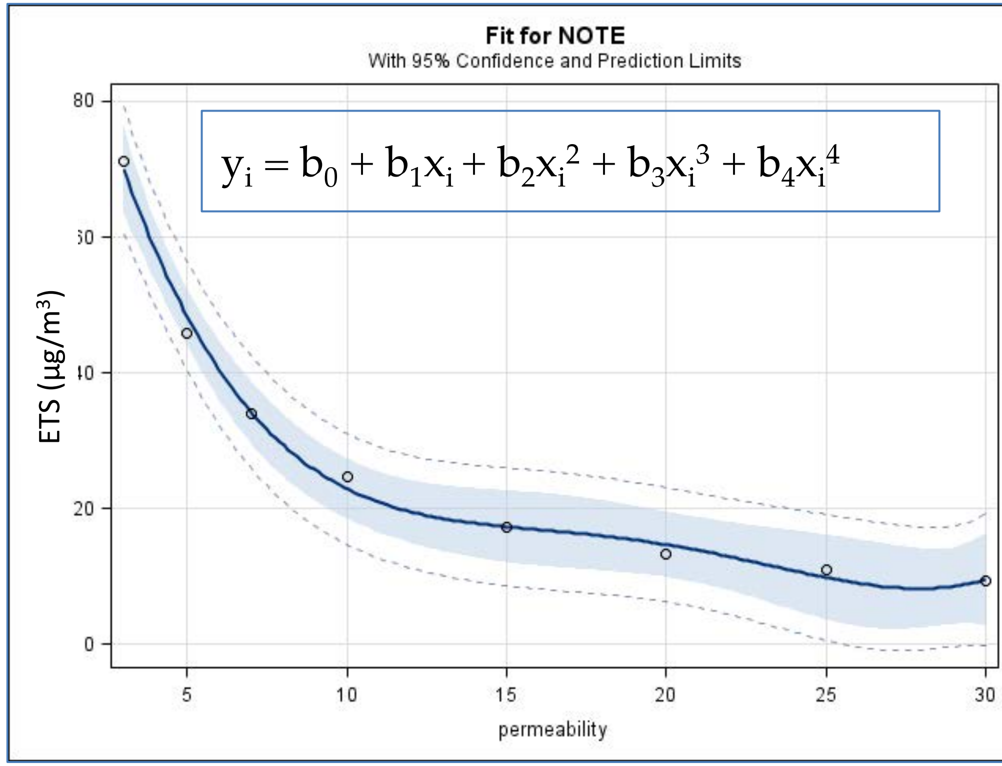






Method: Pollutant modelling (in CONTAM)

- 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)



Method: Building performance and exposure 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.

Method: Health impacts data

Exposure	Health outcome	Exposure-response relationship	Reference
Mortality			
Standardized internal temperature	Winter excess cardiovascular (including excess cerebrovascular accident and myocardial infarction)	0.98 per °C	Derived from (Wilkinson et al., 2001)
Environmental tobacco smoke	Cerebrovascular accident	1.25 (if in same dwelling as smoker)	(Lee and Forey, 2006)
	Myocardial infarction	1.30 (if in same dwelling as smoker)	(Law et al., 1997)
$PM_{2.5}$	Cardiopulmonary	1.082 per 10 μg/m^3	(Pope et al., 2004, 2002)
	Lung cancer	1.059 per 10 μg/m^3	As above
Radon	Lung cancer	1.16 per 100 Bq/m^3	(Darby et al., 2005)
Morbidity			
Standardized internal temperature (°C)	COPD	0.90 per °C	Estimate based on studies from UK (Osman et al., 2008) and New Zealand (Howden-Chapman et al., 2007)
	Common mental disorder (GHQ-12 score 4+)	0.90 per °C	Based on Warm Front (Gilbertson et al., 2012)
Mould (% MSI > 1)	Asthma:		
	Harm class II (hospital admission)	1.53 per 100%	Based on (Fisk et al., 2007) and used in HHSRS
	Harm class III (GP consultation)	1.53 per 100%	As above
	Harm class IV (minor symptoms)	1.83 per 100%	As above

Method: Health modelling

Mortality - Life tables (ONS data):

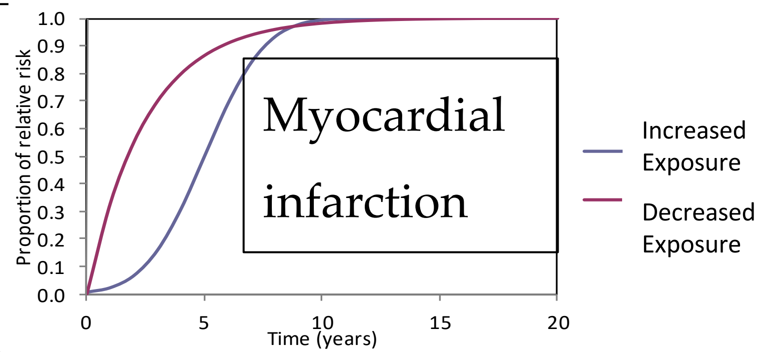
$p_{survival}(\text{age, sex}) = 1 - N_{deaths}/N_{pop}$

Quality Adjusted Life Years:

$\text{QALYs} = \prod_{t=1..N_{years}} p_{survival}^{t}$

x Time-lagged relative risk

Exposure-response relationship



Morbidity:

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

Exposure	Health outcome	Exposure-response relationship	Reference
Mortality			
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Radon	Lung cancer	1.16 per 100 Bq/m³	(Darby et al., 2005)

Method: Health costs data

Disease Outcome	Total Cost (£M)	Prevalence (Crude, all ages, unless stated otherwise, %)	Unit Cost (£/contact)	Sources
Cerebrovascular (Stroke)	819.06	1.70	860.83	NHS Budgeting Tool, QOF
Cardiovascular disease	6,897.22	11.76	1047.09	NHS Budgeting Tool, ERPHO
IHD	1,597.86	4.57*	765.55	NHS Budgeting Tool, HSE
Respiratory	4,693.74	7.3*	1147.93	NHS Budgeting Tool, HSE
Cardio Pulmonary (Respiratory and circulatory problems combined)	11,590.96	17.33*	1194.1	NHS Budgeting Tool, HSE
Asthma	1,048.39	6.00	312.08	NHS Budgeting Tool, QOF
COPD	799.88	1.74	820.39	NHS Budgeting Tool, QOF
Lung Cancer	172.75	0.06	4,951.47	NHS Budgeting Tool, Cancer Research UK
Mental Health Disorders (Other) (Proxy for Common Mental Disorder (CMD))	5,806.85	5.8 **	2248.77	NHS Budgeting Tool, QOF

*All adults >=16 years; ** All adults >18 years;

Scenario: Improving energy efficiency of England's housing

To illustrate NHM-Health, the model is used to evaluate an energy efficiency retrofit scenario in English dwellings.

The scenario included retrofitting all eligible dwellings to an EPC band of B and the effect of A) adding purpose provided ventilation; or B) no added ventilation.

The retrofits include:

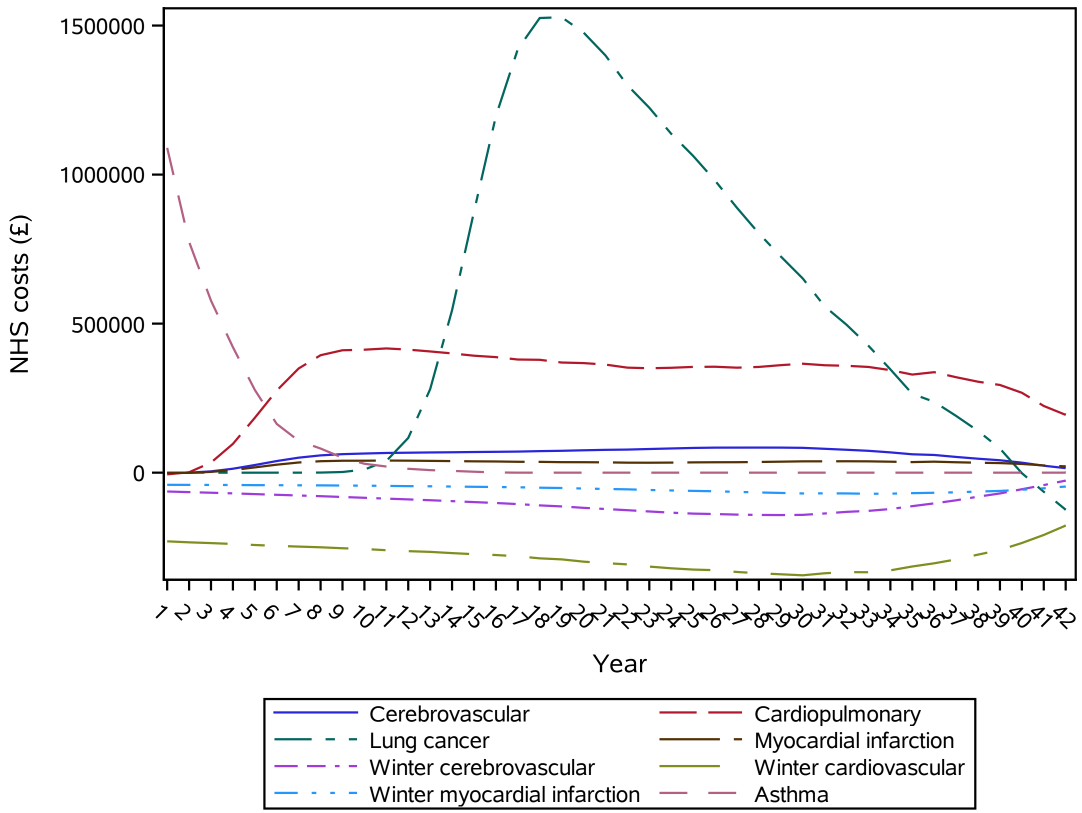
- installation of fabric insulation (cavity, solid wall and lofts),
- replacing single glazing with low-emissivity double glazing,
- replacing non-condensing heating system with condensing systems, and
- adding draught-proofing to reduce air leakage.

Technologies were installed into all eligible dwellings, i.e. those where a less efficiency technology was present or was missing altogether.

Results: Health costs over 42 years

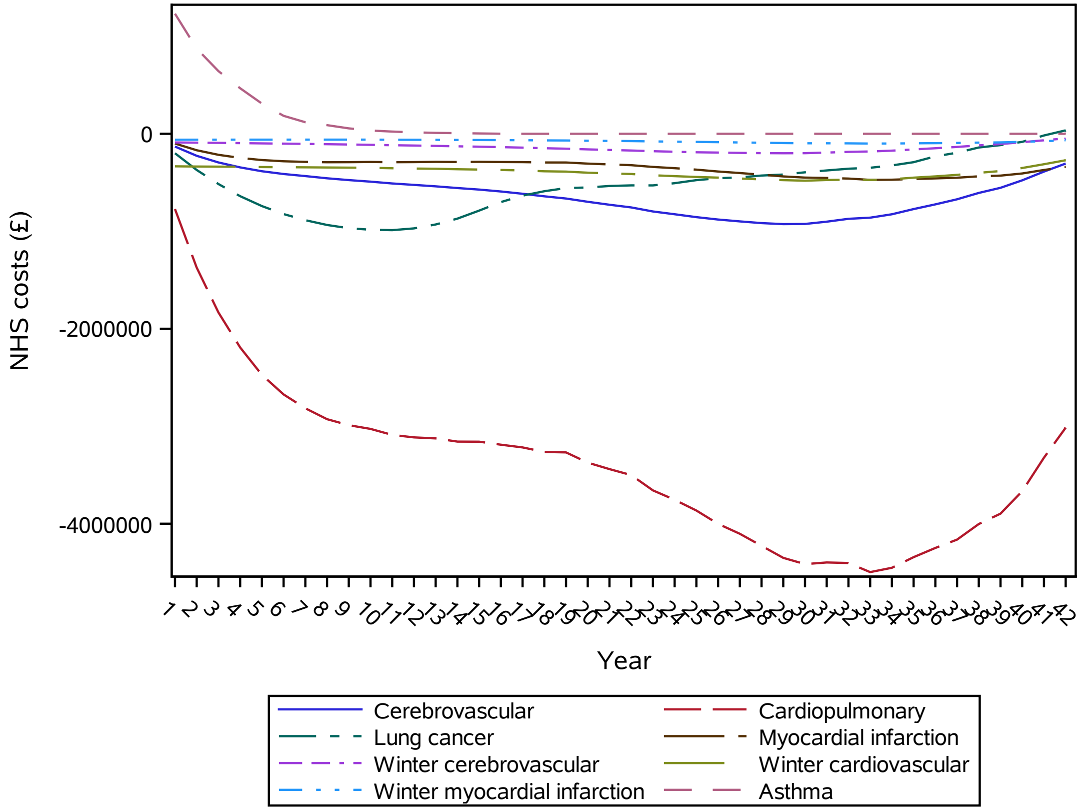
	Fabric & heating improvements	
Intervention	No added ventilation	Added ventilation
Total intervention cost (£)	102,970,000,000	123,545,000,000
Mean intervention cost (£)	5433	6525
Max intervention cost (£)	31417	32781
Energy Savings		
Mean energy savings (kWh)	2,690	2,436
Mean energy savings (£)	156	142
Total energy savings (£)	3,077,271,447	2,783,932,967
Health Impacts After 42 years		
NHS Costs (£)	24,134,214	-226,409,211
Morbidity Costs (£)	111,818,516	-11,288,773,057
Mortality Costs (£)	3,423,034,652	-123,804,894,465
Health Impact Costs (£)	3,558,987,381	-135,320,076,733
Per capita Health Impacts After 42 years		
NHS Costs (£/person)	0.52	-4.91
Morbidity Costs (£/person)	2.4	-244
Total Mortality Costs (£/person)	74.3	-2686
Health Impact Costs (£/person)	77.2	-2936

Results: Health costs over 42 years after full energy efficiency intervention



NHS costs without (first) and with (second) extract fans and trickle vents

Results: Health costs over 42 years after full energy efficiency intervention



NHS costs without (first) and with (second) extract fans and trickle vents

Implications

The built environment has **significant impact on health** via, for example, **indoor environmental** quality (a function of both the quality of a building and its immediate urban environment)

Appropriate **interventions to improve health** can coincide with responses to **climate change** (adaptation and mitigation) and the desire for energy security

The complex nature of the impact of such interventions means that the possibility of **negative unintended consequences** exists

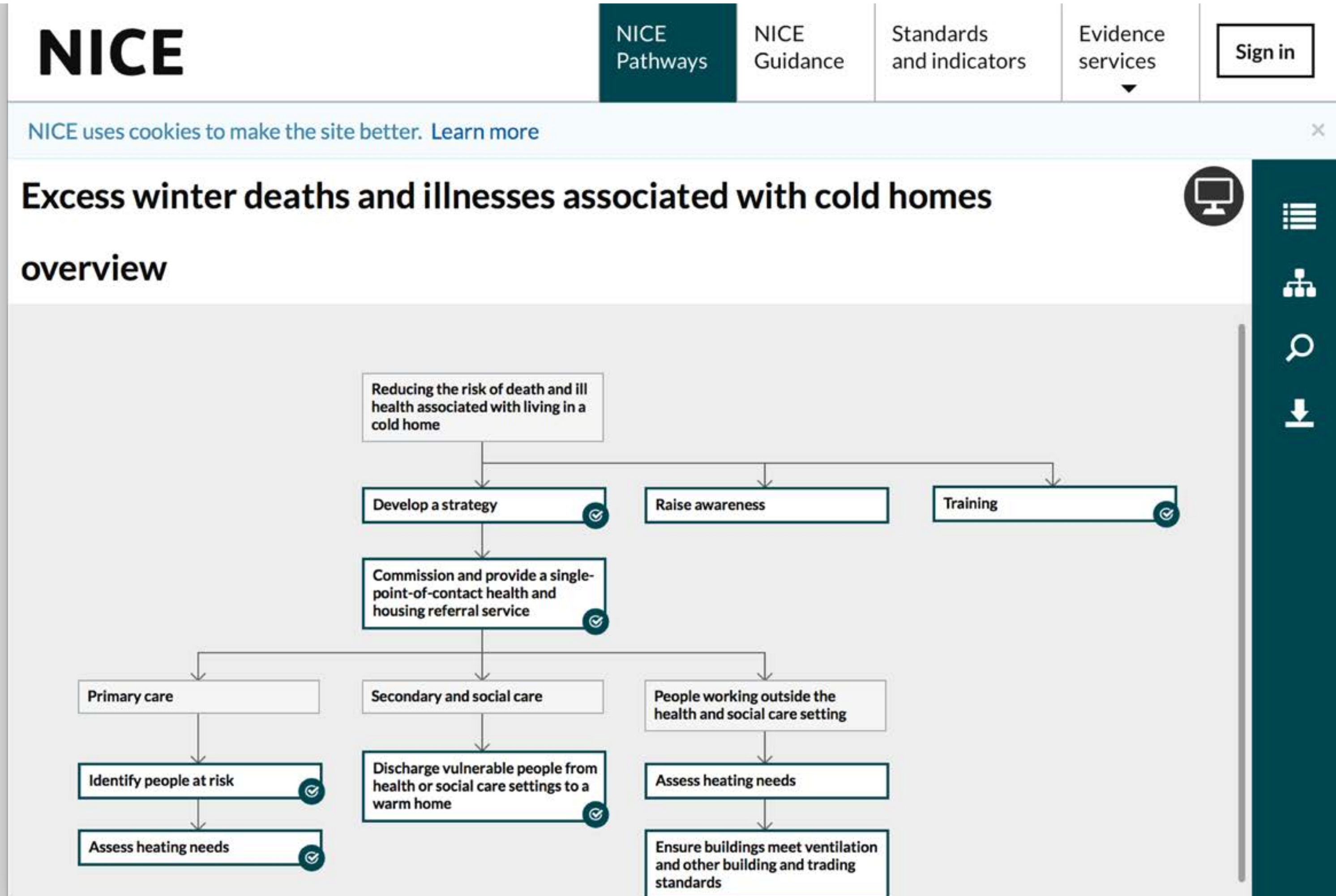
However, there is increasing **acknowledgement and understanding of this complexity**. The success of relevant policies is not dependant on a capricious and unpredictable reality – rather that the reality is amenable to study, of which we must do more.

Summary

- Health impact assessment model provides a means for decision makers to evaluate the costs and benefits of energy efficiency programmes
- The UK, which is dominated by heating needs, health impacts of energy efficiency may still largely be indoor air quality related
- Exposure to indoor or outdoor pollution is a key concern when changing the building fabric and its air-tightness
- For hot and humid countries, focus on heat exposure indoors and modifying effect of buildings and cooling technologies likely most important
- The balance of outdoor to indoor air pollutant exposure is a key driver for choosing appropriate ventilation strategies for health

Using HIA for Policy & Guidance

Using the model for Policy



https://www.nice.org.uk/guidance/ng6

Using the model for Policy: NICE EWD Review

- The aim of the project was to model the cost-effectiveness of interventions to reduce the health risks associated with cold homes.

- The specific objectives were:
  - To develop a model of cold-related health impacts based primarily on life table methods.
  - To develop a model of the cost-effectiveness of home energy efficiency interventions and fuel subsidies, concentrating on the effects of low temperature but including adverse effects on indoor air quality.
  - To assess costs and health and non-health benefits relevant to the interventions.

Economic Modelling: https://www.nice.org.uk/guidance/ng6/history

Using the model for Policy: NICE EWD Review

- Evaluate the impact of different retrofit or fuel subsidies on health and healthcare costs for reducing Excess Winter Death

Target group	Composition of target group				
	COPD	Heart disease	CMD	Age 65 or above	Low income
COPD	895,280	404,765	203,062	634,040	243,106
Heart disease	301,603	1,699,129	136,089	912,681	262,102
CMD	76,931	58,412	2,965,131	151,274	170,015
Age 65 or above	803,995	1,539,344	600,850	6,099,082	1,370,010
Low income	434,813	555,983	1,052,403	1,651,199	4,545,404

Using the model for Policy: NICE EWD Review

- Costs experienced under different perspectives for home energy efficiency intervention

Home energy efficiency	Perspective				
	NHS	Local authority	Government (including NHS and LA)	Householder	Combined (Government + householder)
Taxation (for intervention)			(-)		-
Taxation (for transfer/administration)			(-)		-
Government expenditure (transfer)		(+)	+		+
Government expenditure (intervention)		(+)	+		+
Household expenditure (intervention)				(+)	
Health care costs	-		-		-
Social care costs	-/+	-/+	-/+		-/+
Carer costs				-	-
Work absence costs			-		-
School absence costs				(-)	-
Household expenditure (fuel)				-	-
CO_2 equivalent cost			(-)		-

Legend: + cost incurred, - cost saving, -/ + potential for cost incurred or cost saving, () possible cost

Using the model for Policy: NICE EWD Review

Intervention	All energy efficiency measures installed in eligible homes				
Description					
Time frame	5 years	5 years	5 years	5 years	5 years
Population	Households containing at least one person with:				
Target group	COPD	heart disease	CMD	age 65 or above	low income
Number of affected households	1,003,853	1,789,366	3,641,674	4,869,389	3,409,304
Size of affected population	2,211,431	2,741,572	3,965,976	7,258,132	6,168,686
Mean changes in environmental exposures					
Standardised internal temperature (°C)	+0.29 °c	+0.35 °c	+0.26 °c	+0.39 °c	+0.23 °c
Mould (% MSI > 1)	-0.46%	-0.54%	-0.38%	-0.64%	-0.33%
Intervention cost					
Number of interventions	1,778,439	3,185,491	6,713,955	8,677,392	6,126,532
Total cost of intervention (M£)	£1,382	£2,624	£5,466	£7,338	£4,893
Energy cost					
Total change in stock energy demand (GWh/ yr)	-6,199	-11,448	-23,105	-33,551	-19,502
Total incremental energy cost (M£)	-£1,192	-£2,278	-£4,344	-£6,643	-£3,860
NHS healthcare cost					
Change in healthcare contacts					
- GP consultations	-187,711	-166,243	-32,772	-675,854	-179,535
- Hospital admissions	-8,362	-7,405	-1,460	-30,107	-7,998
Cost of healthcare contacts					
- GP consultations (M£)	-£8	-£7	-£1	-£30	-£8
- Hospital admissions (M£)	-£11	-£10	-£2	-£39	-£10
Total incremental NHS health care cost (M£)	-£19	-£17	-£3	-£69	-£18
QALYs gained					
Cardiovascular	1,148	2,179	394	9,903	2,594
Stroke	182	341	61	1,495	365
Heart attack	177	341	60	1,620	442
Common mental disorders	3,735	1,637	10,732	7,485	6,618
COPD	42,751	12,071	2,479	25,513	7,402
Asthma (children)	135	19	119	84	246
Total QALYs gained	48,129	16,588	13,845	46,100	17,668

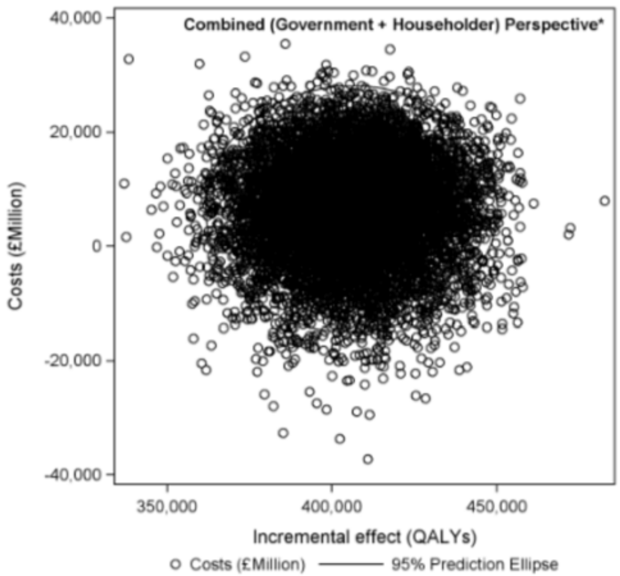
Using the model for Policy: NICE EWD Review

Intervention					
Description	All energy efficiency measures installed in eligible homes				
Time frame	42 years	42 years	42 years	42 years	42 years
Population	Households containing at least one person with:				
Target group	COPD	heart disease	CMD	age 65 or above	low income
Number of affected households	1,003,853	1,789,366	3,641,674	4,869,389	3,409,304
Size of affected population	2,211,431	2,741,572	3,965,976	7,258,132	6,168,686
Mean changes in environmental exposures					
Standardised internal temperature (°C)	+0.29 °C	+0.35 °C	+0.26 °C	+0.39 °C	+0.23 °C
Mould (% MSI > 1)	-0.46%	-0.54%	-0.38%	-0.64%	-0.33%
Intervention cost					
Number of interventions	1,778,439	3,185,491	6,713,955	8,677,392	6,126,532
Total cost of intervention (M£)	£11,611	£22,038	£45,913	£61,635	£41,099
Energy cost					
Total change in stock energy demand (GWh/ yr)	-6,199	-11,448	-23,105	-33,551	-19,502
Total incremental energy cost (M£)	-£9,252	-£17,680	-£33,718	-£51,558	-£29,959
NHS healthcare cost					
Change in healthcare contacts					
- GP consultations	-2,325,402	-1,998,586	-861,991	-9,363,649	-2,688,512
- Hospital admissions	-103,587	-89,029	-38,398	-417,113	-119,762
Cost of healthcare contacts					
- GP consultations (M£)	-£105	-£90	-£39	-£421	-£121
- Hospital admissions (M£)	-£132	-£115	-£50	-£535	-£154
Total incremental NHS health care cost (M£)	-£237	-£205	-£89	-£957	-£275
QALYs gained					
Cardiovascular	25,626	29,187	13,304	146,198	41,919
Stroke	3,883	4,387	2,108	20,699	6,131
Heart attack	4,136	4,811	2,004	24,818	6,803
Common mental disorders	24,208	10,607	43,032	48,504	42,887
COPD	277,051	78,229	16,062	165,340	47,970
Asthma (children)	873	126	771	544	1,597
Total QALYs gained	335,776	127,346	77,281	406,104	147,308

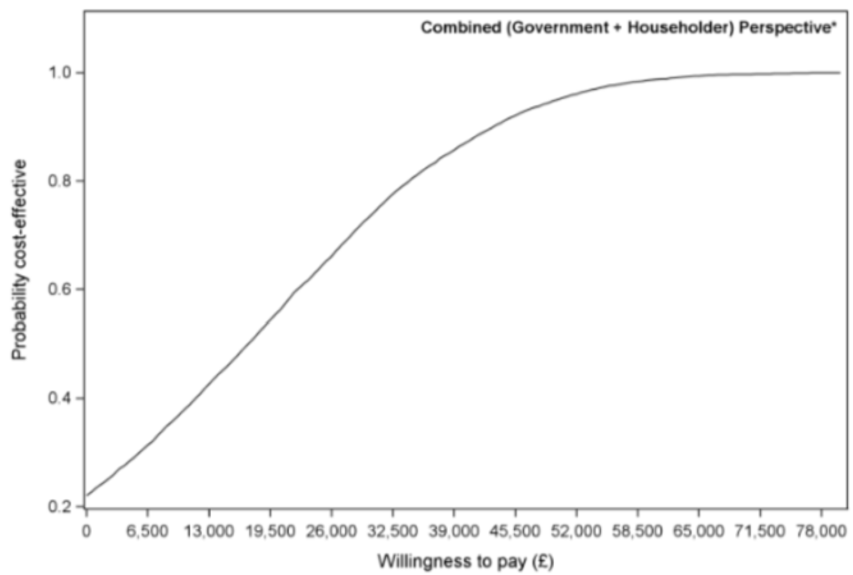
Using the model for Policy: NICE EWD Review

Combined (Government + householder) perspective

A willingness to pay of £15,000 offers a 50% probability of being cost-effective, with a tight range of +/ - £15,000 within 5% and 95% probability of being cost-effective.



*Includes intervention, healthcare and change in energy costs
Target group: Elderly households; Interventions: All efficiency measures



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Target group: Elderly households; Interventions: All efficiency measures

THANK YOU

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